Sustainability Transition in China: Policy Instruments and Outcomes from Multi-level and Geographical Perspectives

Dissertation

zur Erlangung des akademischen Grades Dr. rer. pol.

im Fach Politikwissenschaft

an der

Fakultät für Wirtschafts- und Sozialwissenschaften

der Ruprecht-Karls-Universität Heidelberg

vorgelegt von

Jian Shao

im

November 2023

Erstgutachterin: Prof. Dr. Jale Tosun

Zweitgutachter: Prof. Dr. Rahul Mukherji

Heidelberg

Jian Shao

Institute of Political Science

Bergheimer Straße 58

69115 Heidelberg, Germany

First printed in November 2023

Acknowledgements

As I completed this doctoral dissertation and began to write here, a myriad of emotions welled within me. I've traversed a substantial journey, faced challenges, and received considerable help. Looking back now, all that remains is gratitude.

First and foremost, I would like to express my gratitude to my supervisor, Jale Tosun. I believe that there are a few moments that change the course of one's life, and meeting you was one of those moments. I will always remember our first meeting, the nervousness I felt before meeting you, your welcoming demeanor that eased my anxiety, and the excitement I felt after joining your team. When I reflect on it now, it feels as vivid as if it were just yesterday. Studying and living abroad has been a big challenge for me, and it's your constant support, affirmation, and encouragement that have kept me going and allowed me to maintain physical and mental well-being. What touched me is that I remember several times when I reached out to you regarding my papers, even late at night, and you responded to my emails promptly. Your guidance was always practical and invaluable whenever I needed it. When I was feeling lost, you connected me with other researchers for research ideas. More importantly, I have learned a lot from you. Your academic enthusiasm and rigor have earned my respect. This is reflected not only in your dedication to your own research but also in the guidance and requirements you made for my dissertation. In the process of completing this doctoral dissertation, your advice greatly improved the logic and innovation of the articles. Your guidance has not only enriched my doctoral career but also continues to benefit me in my future work and life.

Furthermore, I am thankful to Professor Rahul Mukherji for your willingness and your time to co-supervise this dissertation. Your specialist on climate governance and guidance is invaluable to this dissertation.

I would also like to express my gratitude to Mile Mišić for your valuable contribution to our article on the uneven development of the EV sector. It was exciting to work with you, and I have learned a lot from our collaboration. I still remember the many meetings and passionate debates we had, which significantly improved our article. You are not just a colleague, but also a friend to me. Thank you for your support as a friend over the years. In addition, I would like to thank Dr. Ping Huang for your contribution to our paper on green finance policy. Working with you has been a pleasant experience. Although this article went through some twists and turns before being published, your steady and resolute character has been of great benefit to me.

I am also thankful for having nice colleagues and friends in our team. During the colloquiums, your collective wisdom and fantastic suggestions have continuously improved this dissertation. Especially to Charlene, you are a good friend to me. Talking to you and sharing our feelings always gives me the courage to face life's challenges and academic difficulties. We will continue to support each other. Furthermore, I would like to express my gratitude to the reviewers from the journals. I must say that the continuous process of revising and polishing the articles was a challenging journey, but I still enjoyed this process, especially the exchange of ideas and arguments with different anonymous reviewers. It not only significantly improved the quality of the articles but also enhanced my academic thinking, writing skills, and rigor. All of these will continue to benefit me in my future work and life.

Furthermore, I want to express my gratitude to my parents, Shao Chunbo and Shao Meixia. You are the best parents I could ever hope for. In my life, you have provided me with the greatest and most enduring support, no matter what decisions I made. You have been my constant refuge, allowing me to pursue what I love and achieve my dreams without worry or fear. Despite the physical distance that separates us, especially during these years of the COVID-19 pandemic when international travel became more challenging, you have continued to support and care for my studies and life in your own way. Your love has given me endless courage to move forward in my own life. I would also like to thank my brother, Shao Kang. You have always steadfastly supported me, especially during some difficult moments. Whenever we chat, you can always understand and comfort me. I always feel fortunate to have you as my family. In our future lives, we will continue to support each other.

Finally, I sincerely thank my husband, Fritz Müller, and my daughter, Olivia Shao Müller. Fritz, thank you for your care in our daily life and your unwavering support. We have spent many years together, with many joyful moments and some challenging ones. Fortunately, we have always firmly chosen each other. It is because of your care and support that I was able to complete this dissertation. You have played a significant role in shaping who I am today. You are not just my spouse but also my best friend. I appreciate your dedication to me and our family, and in our future lives, we will continue to support each other. Olivia, having you is the best thing that has happened to me. You make me feel so important. Because of you, I feel that my life is more meaningful. Because of you, I love life even more. Because of you, I strive to become a better version of myself. I hope that as you grow up, I can make you proud. I will love you forever.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

MLP	Multilevel perspective
MLG	Multilevel governance
FYP	Five-year plan (China)
EV	Electric vehicle
CTG	Coal-to-gas clean heating program
ESG	Environmental, social and governance
ETS	Emissions Trading System
CBI	Climate Bonds Initiative
GD Fund	Green Development Fund
CDM Fund	Clean Development Mechanism Fund
RED Fund	Renewable Energy Development Fund
PPP	Public-Private Partnership
PBOC	People's Bank of China
CBRC	China Banking Regulatory Commission
NDRC	National Development and Reform Commission
SEPA	State Environmental Protection Administration
EPB	Environmental Protection Bureau
MEP	Ministry of Environment Protection
BEV	Battery electric vehicle
FCM	Fuzzy c-means clustering method
DID	Difference-in-Differences estimation method
EVMS	EV market share
TPS	Total purchase subsidy
PB	Parking benefits
DP	Driving privilege
CI	Charging Infrastructure
PCDI	Per capita disposable income
AYE	Average years of education

1 Introduction

The concept of a sustainable transition is multifaceted and encapsulates fundamental objectives such as meeting human needs, alleviating hunger and poverty, and curbing emissions and pollutants (Parris & Kates, 2003). Within this diverse landscape, this thesis focuses on sustainability transitions in the environmental and energy sectors. In an era characterized by escalating global environmental concerns, a concerted effort toward sustainability is required to combat challenges related to climate change, public health, social equity, and energy security (Markard et al., 2012, 2020; Williams & Doyon, 2019; Lindberg et al., 2019). The adoption of the Paris Agreement in 2015 stands as a testament to the international commitment to limit the rise in global temperatures to within 2 °C above pre-industrial levels throughout the 21st century; this calls for nations to continually update their nationally determined contributions (Li & Taeihagh, 2020). Given its status as the world's largest GHG emitter and a significant driver of global resource consumption, China's journey toward sustainability holds profound implications for the entire planet.

In 2021, following a reduction the previous year resulting from measures enforced to contain the COVID-19 pandemic, global emissions rebounded sharply to their highest ever level. China's CO2 emissions rose above 11.9 billion tons, accounting for 33% of the global total and largely attributable to China's reliance on coal, which highlights the country's substantial global footprint (IEA, 2022). Alarmingly, China exhibits relatively high-unit GDP energy consumption and carbon dioxide emissions comparing to the global average (Zhang & Chen, 2022). It is evident that a reduction in China's CO2 emissions carries unparalleled significance in the context of climate change mitigation. Concurrently, China grapples with severe air pollution, a pressing environmental issue that poses grave threats to human health and the natural environment (Fan et al., 2020). Therefore, China's shift toward sustainable development is pivotal not just for its own well-being but also for the collective ability of the world to address climate change and safeguard our shared environment.

China strengthened its commitment to climate action in 2020, pledging to peak CO2 emissions by 2030 and aiming for carbon neutrality by 2060 (Su & Tan, 2023). It has since implemented a series of stringent air quality standards, rolled out a nationwide air quality monitoring network, and initiated the Clean Heating Program to combat pollution (Kuerban et al., 2020). These efforts show China's long-term ambitions and priorities on sustainability transition. The current policy supports for a sustainable transition in China focus on a few aspects, as described in China's 14th Five-Year Plan; in particular, these are the energy transition, sustainable urban development, and sustainable investment priorities (Hepburn et al., 2021).

The academic domain of sustainability transitions investigates the intricate interplay between technology, policy, institutions, markets, and society, all while embedding these within the national political economy (Bhamidipati et al., 2019). One of the core themes in sustainability transitions research is the role of public policies in transition processes (Rogge & Reichardt, 2016; Alkemade et al., 2011; Haley, 2017). Previous studies argue that sustainability transition policies are vital for addressing the multifaceted challenges of climate change, because the traditional market-failure perspective falls short of grasping the complexity of the climate crisis and the need for comprehensive systemic change (Rosenbloom et al., 2020). Sustainability transition policies recognize that a low-carbon future requires various levers, from nurturing innovations to phasing out carbon-intensive technologies and reshaping regulations. It isn't about a single policy but a sequence of decisions driving change in technologies, business models, and practices.

In the realm of transition studies, there is a burgeoning research agenda focused on attaining a more profound comprehension of policies and their political dimensions (Markard et al., 2012). Much of the theoretical framework in this field underscores the impact of policies in shaping the trajectories of transitions by formulating long-term sustainability targets (Reichardt & Rogge, 2016), defining environmental standards (Girod, 2016), providing R&D funding (Alkemade et al., 2011) or granting market support for new technologies (Lindberg et al., 2019). Scholars have also elaborated on analytical conceptualizations concerning 'policy mixes' within the domains of innovation studies and sustainability transitions, emphasizing the importance of employing a combination of policy objectives and instruments rather than relying on single instruments (Rogge & Reichardt, 2016; Rogge et al., 2017; Kern & Rogge, 2018). Building upon the findings of previous studies, this dissertation seeks to address a fundamental research question: How are sustainability transition policies formulated and executed, and what impact do they have on the transition process within the Chinese context?

This cumulative dissertation comprises four interlinked papers, each addressing a unique aspect of sustainability transition within the Chinese context. It explores the fertile landscape of sustainability transition in China, providing a comprehensive analysis of policy instruments and their practical implications. The central theme of this work revolves around the examination of policy support for sustainability transition at various levels and across diverse geographic contexts in China. This research represents an in-depth exploration of the interactions between policies, stakeholders, and geographic disparities, enhancing our understanding of the intricacies involved in policy design and implementation and of how these are crucial to achieving sustainability objectives. It offers valuable insights for policymakers, researchers, and stakeholders, with the aim of advancing China and other nations toward a more sustainable future.

The papers in this dissertation are categorized into two parts. The first part, comprising Paper One and Paper Two, delves into the examination of policy instruments and policy implementation in the context of sustainability transitions within China, taking a multilevel approach. This part aims to dissect the interplay between various actors and factors across distinct governance levels and their impact on the processes of policy formulation and implementation. This analysis provides insights into the evolution of sustainability transition policies and into changes in China’s environmental governance. The second part, encompassing Paper Three and Paper Four, shifts the focus to policy outcomes, adopting a geographical perspective. The aim here is to illustrate the spatial disparities and heterogeneity within sustainability transitions and to explore the role of policies in contributing to these geographical variations. Additionally, it delves into the vital concepts of a just transition and social equality, emphasizing the significance of policies in ensuring the equitable distribution of sustainability benefits and in strengthening communities and ecosystems to withstand environmental changes.

The rest of this dissertation's introduction commences with a presentation of the key concepts employed in the subsequent chapters. Subsequently, it delineates the principal theoretical underpinnings. This is followed by a condensed summation of the findings from the four papers. Finally, the conclusion highlights the contributions made and identifies potential avenues for future research.

1.1 Central concepts

Sustainability transition encompasses various dimensions, and in the past decade, extensive research has contributed to understanding the complex shifts required for sustainable modes of production and consumption in sectors like transport, energy, housing, agriculture, and food (Geels, 2005; Jacobsson & Bergek, 2004, Markard et al., 2012). China's Five-Year Plans (FYPs) play a crucial role in guiding the country's economic and social development while outlining sustainability transition goals. The 14th FYP emphasizes three key areas: energy transition, sustainable urban development, and investment priorities. This thesis focuses on two of these areas, specifically energy transition and investment priorities, offering insights into China's sustainability journey and delving into the challenges and opportunities within these domains. The thesis examines various policy processes, including policy design, implementation, and outcome evaluation, to provide a comprehensive analysis.

The first paper focuses on *green finance policy*, which involves channeling public and private green investment through a green financial system supported by green finance policies (Welling, 2017). This is particularly important for sustainability transitions because insufficient investment has been a major concern for green projects around the world (Hafner et al., 2020). The primary objective of the first paper is to examine the evolution of the green finance *policy mix* in China. The concept of policy mixes, which encompasses multiple policy goals and instruments, processes of policy formulation, and the evolution of instrument selection, has gained prominence in policy science research over time (Howlett & Rayner, 2007). *Time* and *scale* are two crucial dimensions of a policy mix, as policy strategies and instruments change over time, and policies are designed and implemented at different scales (Flanagan et al., 2011; Milhorance et al., 2020).

The temporal changes in policy mixes follow different paradigms and are often discerned through the analysis of shifts in policy focus and instruments (Capano & Howlett, 2020). *Policy patching* and *policy stretching* are common mechanisms in the development of policy mixes (Rayner et al., 2017). Both "patching" and "stretching" policies are prevalent in China and can be identified in the evolution of green finance policy. Vertical interactions between instruments and actions at different *levels of governance* are also significant in policy mix analysis (Flanagan et al., 2011). Policy instruments enacted at one level of governance can influence policymaking at other levels. In China, policymaking and implementation involve a *two-way interaction* across governance levels. Subnational governments, instead of passively receiving policies, also adapt policies to suit local contexts and initiate innovative policies that may influence policymaking at higher levels.

The second paper focuses on the *energy transition* of China's heating system, particularly examining its *policy implementation*. It's widely recognized that not all policy implementations are successful. In fact, the *implementation gap* presents a significant challenge to environmental governance (Schreifels et al., 2012). Existing literature predominantly centers on explaining weak and inefficient policy enforcement, often referred to as under-implementation (van Rooij, 2006). Interestingly, under China's authoritarian regime, *policy over-implementation* is a well-known phenomenon and is manifest, for instance, in its anti-corruption measures and its response to the COVID-19 crisis (Cai et al., 2021). However, this phenomenon has only emerged over the last decade in the field of environmental governance. To address this research gap, the second paper explores how China's environmental policy implementation, specifically through the *coal-to-gas clean heating program* (CTG), has tackled long-standing challenges within the environmental governance system and resulted in over-implementation.

Policy over-implementation in China is often linked to its authoritarian approach. Scholars have categorized China's environmental governance as *authoritarian environmentalism*, emphasizing the significant role of a strong central authority in ensuring the swift and effective implementation of environmental policies (Eaton & Kostka, 2014). In recent years, the centralized reform of China's environmental governance system has been propelled by the *recentralization* of power within the central government and by its strong commitment to environmental issues since 2012 (Kostka & Nahm, 2017). These changes have resulted in notable improvements in the local implementation of central environmental policies and occasional instances of over-implementation in environmental policy. However, an authoritarian approach may involve a trade-off between rapid environmental response and the safeguarding of individual freedoms and rights, potentially leading to *social injustice* (Jia & Chen, 2019).

The third and fourth papers of this thesis focus on the *energy transition* in the automotive sector, with a specific emphasis on *electric vehicles (EVs)*. In the third paper, I demonstrate that the *distribution* of the EV sector in China is uneven, and explore how factors such as *policy, economics, and socio-demographics* can account for this *spatial variation*. The fourth paper investigates how EV policies generally promote EV adoption but also reveals that their impact varies across different *local contexts*, which can exacerbate the existing *disparities* in EV adoption.

Energy transitions occur within specific *socio-economic contexts* that are characterized by unique institutions, historical backgrounds, infrastructures, and energy compositions. Consequently, the outcomes of these transitions are often distributed unevenly across different regions (Balta-Ozkan et al., 2015). Given the vast size and complexity of China, it is reasonable to expect that the energy transition will exhibit *regional disparities* at the *provincial level*. Despite the significant growth of EVs in China, it is essential to acknowledge that EV adoption varies widely among the country's diverse regions (Yao et al., 2022). Furthermore, existing research in this area has predominantly focused on two aspects: EV sales and the performance of the EV industry. However, the lack of a comprehensive *framework* inhibits an assessment of the overall development of EVs. Therefore, the third paper of this thesis serves as a valuable starting point for the development of a comprehensive framework that takes into account different geographical areas.

In the third paper, I examine various factors influencing the EV sector. These encompass *economic* and *socio-demographic* elements such as GDP per capita, income per capita, degree of urbanization, and population density. Furthermore, given the disruptive nature of EVs within the automotive industry, the study also explores the role of *existing automotive industries* in the development of EVs. Additionally, considering the significance of *policy mixes* in the EV sector, the third paper delves into the specific details of policy instruments and their external influence on the development of the EV sector. Building on this exploration of policy instruments, the fourth paper shifts its focus to EV policies. It provides a deeper understanding of how policies function, particularly in diverse geographical contexts, and underlines their varying impacts.

The fourth paper aims to address two key questions: First, it examines the *effectiveness* of EV policies; and second, it investigates whether the impact of these policies varies across different *local contexts*. This study acknowledges two dimensions of *heterogeneity* in policy implementation: the variations in the policies themselves, which encompass different policy instruments and the extent of their implementation, and the heterogeneity in policy effectiveness as influenced by other factors, especially the characteristics of the local context. It's important to note that *geographical factors* have the potential to amplify the impact of EV policies in specific areas. The research findings highlight a strong association between the uneven distribution of EVs and the *alignment* (or *misalignment*) between EV policies and the diverse local contexts in which they are implemented.

Understanding the varying patterns of EV adoption across regions and reevaluating existing policy frameworks are essential steps in achieving a *just energy transition*. Such a transition seeks to ensure that safe, affordable, and sustainable energy is accessible to all individuals, irrespective of their income, wealth, gender, or ethnicity (Wang & Lo, 2021). Ideally, well-crafted policies should play a critical role in addressing these disparities. However, current local-level EV policies often fall short of this objective, and in certain cases, they may even worsen existing societal inequalities (Sovacool et al., 2019). An uneven energy transition can lead to problems when new technologies, investments, and job opportunities concentrate in more affluent areas, exacerbating economic disparities and further disadvantaging those in less prosperous regions (Naqvi et al., 2021).

1.2 Theoretical rationale

1.2.1 Sustainability transition policy: Multilevel perspective and multilevel governance

In the realm of sustainability transitions, the multi-level perspective (MLP) stands out as a valuable analytical framework (Grin et al., 2011; Genus & Coles, 2008). The MLP serves as a middle-range theory designed to provide a comprehensive conceptualization of the dynamic patterns within socio-technical transitions (Geels, 2011, 2012). These transitions are intricate, non-linear processes influenced by interactions at three crucial levels: the niche (micro), socio-technical regime (meso), and landscape (macro) (Geels, 2002, 2004, 2005; Verbong & Geels, 2007). The MLP focuses on understanding the evolution of radical innovations in space and time, emphasizing the interplay between processes at different societal scales over time (Sorrell, 2018). The primary focus of this thesis rests on the meso level, where it closely examines the roles of regimes and governance, investigating how actors, policies, and power from diverse levels impact sustainability transitions over time.

While the importance of politics, policies, and power in sustainability transitions is apparent given the complex nature of these transformations (Smith et al., 2005), the MLP has overlooked the distribution of power and politics within landscapes, dominant regimes, and socio-technical niches, along with their varying allocations and mediation, which has resulted in a marked research gap ((Lawhon & Murphy, 2012; Patterson et al., 2017; Geels, 2019). Politics is intricately woven into all three levels of the Multi-Level Perspective. At the landscape level, it influences economic conditions, innovation direction, and technological deployment (Meadowcroft, 2011). The regime level encompasses legal and regulatory aspects that can either support or undermine dominant regimes, while the niche level plays a role in shielding or exposing niches and in influencing innovation (Markard et al., 2016).

Researchers have also taken an interest in understanding how policies, originating from various levels, can propel the shift toward environmental sustainability (Kern & Rogge, 2018). Policies encompassing incentives, regulations, and standards are pivotal in influencing the trajectory of sustainability transitions. Successful sustainability transition policies frequently entail collaborative and harmonized interactions, knowledge exchange, and policy learning across different tiers of government (European Environment Agency, 2018). Recent research has been transitioning toward the diffusion of niche innovations, shifting the focus from individual policy instruments to recognizing the significance of policy mixes (Kivimaa & Kern, 2016; Rogge & Reichardt, 2016; Kern et al., 2019).

A second criticism of MLP is its lack of consideration for scales and agencies (Markard et al., 2012; Geels & Schot, 2010). MLP's primary focus on niches and regimes from a single scale overlooks significant distinctions between different scales (Coenen et al., 2012). Actors operate at various scales, exerting influence and molding transitions. Hence recent studies have endeavored to emphasize agency (Ehnert et al., 2018; Hess, 2014). Government, among the most influential agencies, plays a crucial role in promoting and shaping sustainability transitions (Kemp et al., 2007). To address this concern, I also incorporate multilevel governance (MLG) frameworks into the analysis.

MLG delves into the impact of power on policy development and implementation across various governance levels, often concentrating on national-supranational relationships in existing literature (Di Gregorio et al., 2019). In the study of sustainability transitions, MLG helps to elucidate how institutional structures shape transition governance by examining the dynamic relationships among actors and the distribution of power across multiple territorial levels (Ehnert et al., 2018). Researchers have pursued two primary avenues: One involves authority allocation and highlights the distribution of decision-making power among actors at different levels and of different types (Liesbet & Gary, 2003; Daniell & Kay, 2017);the other concerns governance scales and investigates decision-making and interactions among actors at different scales (Gibson, 2019).

The multilevel and multiscale interactions in this context are particularly relevant given China's multilevel political structure (Huang, 2019). In the realm of sustainability and climate governance, the central government generally sets policy goals, but implementation experiments are often introduced at the regional or local level (Schreurs, 2017). National governments play a crucial role in shaping sustainability policies and regulations by establishing frameworks, setting targets, and allocating resources to promote sustainability across various sectors. Simultaneously, sustainability transition policies may originate at the local level, where communities, municipalities, and regional governments develop and implement initiatives tailored to their specific needs and contexts. Notably, the interaction between different policy levels is not a purely top-down process but involves a two-way influence in which the local level can also impact policies at higher levels (Faller, 2014). This rationale is a significant focus of this thesis.

The incorporation of the MLG approach into the study of sustainability transition policies enables researchers, policymakers, and stakeholders to analyze the interplay of factors and stakeholders across various levels, from the local to the global, and to consider different timeframes. Effective coordination and collaboration among these levels are pivotal for the successful development and execution of sustainability transition policies. Furthermore, ensuring the consistency and coherence of policies across different levels of government stands as a central concern within multilevel governance. MLG mechanisms can assist in reconciling conflicting policy objectives and in ensuring a unified approach to sustainability transitions. This characteristic carries significant importance within this thesis, particularly when investigating sustainability transition policy instruments and their implementation (as presented in the first and second papers).

1.2.2 Unlocking the complexity of sustainability transition: A geographical perspective

How do sustainability transitions manifest in diverse geographical settings, and what is the significance of spatial contexts in these transitions? While MLP theory offers a robust analytical framework for evaluating the potential of more sustainable socio-technical systems, it has faced criticism for its limited consideration of the spatial dimensions where transitions occur and the spatial structures and dynamics of the networks in which transitions evolve (Coenen et al., 2012, Smith et al., 2010; Truffer et al., 2015).

Given the multitude of interconnected factors, contexts, and actors operating at various geographical scales, examining geographic disparities becomes crucial for providing the necessary spatial context to comprehend the institutional mechanisms involved in sustainability transitions (Truffer & Coenen, 2012; Coenen et al., 2012; Raven et al., 2012; Binz et al., 2020).

A geographical perspective offers insights into the scales, spatial aspects, and context-specific variables that influence transitions, aiming to elucidate the reasons and mechanisms behind the similarities and differences in transitions across various locations (Binz et al., 2020; Köhler et al., 2019). The concept of socio-spatial embedding considers the unique conditions of specific places, regions, or cities, which can either facilitate or hinder sustainability transitions. These conditions are shaped by factors such as natural resource availability, distinct cultures, localized institutions, regulatory and transnational environments, policies, networks, and regional industrial specialization (Raven et al., 2012; Bridge et al., 2013; Hansen & Coenen, 2015; Markard et al., 2020). An examination of these contextual elements enriches our comprehension of why particular developments take place in specific locations and not in others. This understanding provides valuable insights for policymaking and the adaptation of successful initiatives to diverse geographic settings (Coenen et al., 2012; Coenen & Truffer, 2012).

Research on the geographical perspective of sustainability transitions emphasizes the importance of sustainability-focused industrial and regional policies (Truffer & Coenen, 2012). Different regions possess unique characteristics that influence their sustainability profiles. Consequently, local actors are crucial in formulating effective policies because they have on-the-ground knowledge, specifically, insights into place-specific conditions and the capacity to tailor policies accordingly (Hansen & Coenen, 2015). When crafting policies, it is essential to consider the innovative potential at the local level and account for regional variations in this potential. The effectiveness of policies is highly dependent on local contexts, and what succeeds in one region may not work as well in another due to variations in local ecosystems, cultures, or economic structures (Bachtrögler et al., 2020; Gagliardi & Percoco, 2017). Additionally, the capabilities and motivations of local governments play a central role in shaping sustainability policies. Local governments differ in their capacity to address climate-related issues and promote sustainability transitions through public policies (Salvador & Sancho, 2021).

As can be gleaned from the above, sustainability transitions often result in spatial differentiation and uneven development, highlighting the need to manage these transitions in a way that reduces inequalities rather than exacerbates them, which poses a significant policy challenge (Balta-Ozkan et al., 2015; Bridge et al., 2013). Incorporating a geographical perspective into transition analyses is crucial for understanding the factors that influence geographically disparate transition processes. Spatial contexts provide valuable insights into the spatial disparities observed in sustainability transition pathways (Strambach & Pflitsch, 2020; Shove & Walker, 2007). Governance structures and policies vary significantly across different levels and play a pivotal role in shaping sustainability transitions. As a result, scholars emphasize the importance of addressing social justice within sustainability transitions (Bennett et al., 2019). The concept of a "just transition" within the energy sector, which focuses on equity and justice issues related to energy and climate challenges, has gained prominence in the past decade (Wang & Lo, 2021). Specific policies need to be designed to make transitions more equal because current low-carbon transitions may inadvertently create new injustices and vulnerabilities instead of addressing existing socio-economic inequalities (Sovacool et al., 2019).

This thesis pays special attention to policies in order to uncover the disparities in the geographical landscape of sustainability transitions. Adopting a geographical perspective allows for the examination of how policies and regulations interact across various regions, particularly within distinct local contexts. This perspective is vital in my thesis for assessing the outcomes of sustainability transition policies in the third and fourth papers. It recognizes the diverse contexts that play a role in sustainability transitions, enabling researchers and policymakers to formulate more comprehensive, context-specific strategies for tackling the multifaceted challenges of sustainability.

Sustainability transition is a complex process that unfolds across multiple levels and geographical contexts and thus requires a thorough understanding of policy drivers. The Multi-Level Perspective offers a robust framework that underscores the significance of politics, policies, and power in shaping transitions. The Multi-Level Governance approach provides insights into how power influences policy development and implementation across various levels of governance, facilitating effective sustainability transitions. Exploring spatial dimensions and geographical disparities enhances transition research by revealing geographic aspects of sustainability transitions, which in turn enables the development of context-specific policies and strategies for promoting fair and equitable transitions. These frameworks provide a solid theoretical foundation for analyzing China's sustainability transition policies.

1.3 Methodological approach

This thesis has used a variety of research methods, including qualitative and quantitative research. Specifically, the first paper used document analysis to trace the development of China’s green finance policy mix. It conducted a systematic review of the national and provincial policy documents to uncover the evolution and characteristics of the green finance policy mix in China. I extracted data from the policy databases, obtaining 418 relevant policy documents including notices, guides, announcements, plans, and government work reports, all published between 2006 and 2020. To code the documents and conduct an in-depth analysis of policy mixes, I used a tri-fold classificatory scheme that includes command and control, market-based, and information instruments.

The second paper conducted a case study focusing on the implementation of the coal-to-gas (CTG) clean heating policies in China. I chose the CTG program as it is a good case to study environmental policy over-implementation in China. In response to the worsening smog problem, China launched the Air Pollution Action Plan during the 12th FYP period (provide DATES in brackets), with the aim of improving air quality within five years. As part of this plan, the CTG program was implemented to phase out the use of bulk coal for heating in rural areas of Northern China. The central government initiated a campaign-style enforcement of CTG in 2017 to achieve the environmental goals set by the 2013 Action Plan. However, the implementation of CTG has also resulted in issues such as over-implementation, gas shortages, and inequality. This paper employed a combination of secondary and primary data. The analysis primarily relied on publicly available secondary data, which I sourced from governmental websites, social media, local newspapers, academic literature, and other public texts. In addition to the secondary data, I collected primary data through semi-structured interviews.

The third paper employed a two-step analysis approach to investigate the spatial distribution of EVs at the subnational level in China and to identify the factors influencing it. In the first step, I used five indicators related to the EV sector as variables and conducted a cluster analysis. The variables included EV production, purchase, patents, charging infrastructure, and electric buses. To this end, I used a fuzzy c-means clustering method (FCM). This approach allowed for a more comprehensive assessment of the development level of the EV sectors by integrating multiple indicators and generating spatial patterns in the distribution of the EV sectors as well as by identifying their characteristics in different regions. Unlike hard-clustering techniques such as k-means clustering, FCM does not assign observations to a single cluster alone. Instead, it provides degrees of membership as an output, expressed in percentages, indicating the extent to which each observation belongs to each cluster.

Subsequently, in the second step, I selected one province from each cluster and examined it as a case study, according to the result of degrees of membership obtained from the cluster analysis. Four provinces from four clusters were identified. The goal of the comparative case study was to understand the reasons behind the differences observed among the clusters of provinces. Several factors including economic and socio-demographic ones, the role of existing automotive industries, and policy instruments were extracted.

The fourth paper employed a three-step analysis. Firstly, I used panel data analysis to evaluate China's EV incentive policies in 80 pilot cities from 2010 to 2022. The panel data model has gained widespread acceptance for analyzing policy effects thanks to its ability to provide more accurate predictions of individual effects by utilizing a larger number of degrees of freedom and sample variability (Qiu et al., 2019). The dependent variable in this study is the EV market share of each city. The independent variables encompass various EV policies and comprise two financial policies – total purchase subsidy and parking benefits – along with two non-financial policies: driving privilege and charging infrastructure. Secondly, cities were stratified based on varying income levels, traffic congestion, population density, and administrative hierarchy, enabling a detailed examination of the heterogeneous impacts of EV policies across diverse local contexts. Additionally, I employed the Difference-in-Differences (DID) estimation method to assess the robustness of the panel model results. While panel data models provide insights into the effects of policies over a substantial period, the DID method allows for an investigation of dynamic changes in policy effects over time.

1.4 Empirical findings

This section briefly summarizes and compares the empirical findings of the four articles in this cumulative dissertation.

1.4.1 The policy mix of green finance in China: An evolutionary and multilevel perspective

The first paper delves into the evolving landscape of green finance policies in China from a multilevel perspective, employing an evolutionary lens that underscores the importance of time and scale as dimensions.

In response to global climate imperatives, green finance has gained significant traction as a policy tool aimed at channeling investments into environmentally sustainable projects. This study conducted comprehensive document analysis to examine the temporal progression of green finance policy mixes in China, shedding light on the nuanced shifts in policy objectives and instruments, both at national and provincial levels. The findings of this study highlight three key points.

To begin, this study demonstrates the significance of considering time and scale as fundamental dimensions in policy mixes. Policies and their associated strategies evolve over time and are implemented at various governance levels. The evolution of green finance policy mixes reveals mechanisms known as 'policy patching' and 'policy stretching,' which, despite some scholars' concerns about suboptimal outcomes, can be cautiously designed to yield effective policy mixes. Furthermore, within China's multilevel political framework, it is important to recognize that policies operate at different governance levels, and the decisions made at one level can significantly influence policymaking at others. This interaction is a two-way process, encompassing both top-down and bottom-up dynamics.

Secondly, the study's results reveal a transitional phase in China's green finance policy mix. Over time, the policy objectives have maintained consistency, progressing from broader environmental protection and energy conservation to more specific targets, such as carbon emission reduction, enhanced energy efficiency, and fostering green development. The policy instruments have also evolved, moving away from traditional command-and-control tools and toward a more intricate mix of instruments. China has progressively shifted its policy strategy away from direct government intervention and investment. Instead, it has embraced a market-oriented approach, focusing on the development of a green finance market that relies on market-based mechanisms and financial products.

Thirdly, the study's results reveal a vertical progression in the evolution of China's green finance policy mix, shifting from primarily top-down processes to multi-level interactions. During the initial stages of green finance policy development, subnational practices significantly lagged behind central-level policy design and implementation. The central government took the lead in policy design and provided guidance to local governments on policy development and implementation. However, as time passed, local experimentation began, with subnational governments becoming more proactive in stimulating local innovation. These innovative practices influenced green finance policy design at the central government level and in other regions. For example, local experiments in green finance policies explored various development models for the local financial system and took into account diverse local contexts. These innovations subsequently impacted the central government's policy design and, in some instances, diffused to other jurisdictions.

In this new stage of China's green finance policy, several changes have emerged. Notably, there is an effort to promote the involvement of non-state actors in green finance activities. Until recently, China's green finance policy was primarily characterized by substantial government intervention in financial activities, with public actors being the driving force behind green finance development. State-owned banks in particular have played a significant role in implementing central policies. However, the influence of the private sector and civil society has been relatively limited, resulting in a highly policy-driven and top-down approach to the development of green finance in China. Nevertheless, the increasing demand for green investments, driven by China's commitment to achieving carbon peaking by 2030 and carbon neutrality by 2060, has necessitated the expansion of participation beyond public actors.

1.4.2 Implementation gap of China's environmental policies: Logic behind the over-implementation of the Coal to Gas transition

The second paper delves into the reasons for the over-implementation of environmental policies in China within the framework of the country's multilevel governance. Using the coal-to-gas clean heating program as a case study, this research constructs a conceptual framework to elucidate how local environmental policies are implemented in the context of China's evolving environmental governance. The findings of this paper posit that the recentralization of environmental governance and a stronger environmental commitment have redefined the interactions between various levels of government. Policy over-implementation can be ascribed to several factors, including political pressures, administrative advantages, and positive economic incentives, all under the backdrop of a high degree of state control in an environmentally authoritarian context.

In China, conflicts of interest between government levels, discretionary power, inadequately designed incentive mechanisms, and institutional fragmentation have frequently led to the under-implementation of environmental policies, as documented in previous research (Schreifels et al., 2012; van Rooij, 2006). However, China has undergone significant changes in its political landscape, including political recentralization and shifts in environmental governance. Steps have been taken to enhance the central government's control over local actors, and the central government has transitioned from prioritizing economic growth to emphasizing sustainable development. Consequently, the central government has exhibited a heightened commitment to environmental protection and adopted more authoritarian and top-down enforcement strategies (Lo, 2021).

These contextual changes have brought about positive shifts in the implementation of environmental policies. First, the central government's strong commitment to environmental protection serves as a motivating factor for subnational governments to diligently carry out environmental policies. Subnational government officials, driven by their career ambitions, often engage in self-reinforcement strategies, displaying behavior characterized by "political awareness" or "high political sensitivity."

Second, the central government formally engages subnational governments through its administrative system. Officials' career advancement relies on recommendations from higher-level authorities, and the recentralization process has bolstered the evaluation of local officials, intensifying competition based on performance. Local officials are encouraged to surpass their competitors by setting higher targets. The central government has amplified the significance of ecological indicators in evaluations, introduced penalty mechanisms, and applied promotion pressure. These measures compel local governments to prioritize environmental protection and meet higher-level targets.

Third, the central government employs various financial strategies. Transfer payments are used to offset the opportunity costs associated with environmental protection, effectively aligning the interests of central and local authorities. Additionally, the central government offers subsidies and rewards for policy implementation, linked to performance, thereby stimulating local competition for larger incentives.

In summary, when the central government demonstrates a strong commitment to environmental protection, establishes ambitious targets, and provides substantial incentives, the conflicts of interest between different government levels can undergo a transformation. Faced with intense top-down pressure, local governments are compelled to prioritize specific policies in accordance with the central government's preferences and to mobilize all possible resources to meet the assigned targets. Moreover, when a higher-level government launches a governance campaign, local governments may incline toward over-implementing certain policies to bolster their political achievements and compete with other governments.

Nonetheless, although recentralization can aid in resolving conflicts between environmental policy designers and re-designers, it may also give rise to new conflicts among local implementers at various levels. The centralized policy-making process, which excludes the participation of local implementers, falls short of addressing conflicts at the grassroots bureaucratic level. Furthermore, the authoritarian enforcement of policies overlooks opposition from policy recipients, which can potentially harm specific social groups and communities, perpetuating social injustice and inequality. It is essential to ensure the meaningful participation of all stakeholders, particularly those impacted by the policy, in the policy-making process.

1.4.3 Why does electric vehicle deployment vary so much within a nation? Comparing Chinese provinces by policy, economics, and socio-demographics

The third paper navigates the multifaceted landscape of EV deployment within China, shining a spotlight on the spatial disparities in the EV sector.

In the initial step, this study employs a cluster analysis technique, specifically the c-means clustering method, utilizing five EV-related indicators. This analysis is conducted to examine the spatial distribution of the EV sector across 25 provinces in Mainland China. The results uncover regional disparities and categorize the provinces into four distinct clusters: Producers, Retailers, Green Transport, and Laggards. The Retailers cluster is characterized by above-average metrics for EV sales, charging infrastructure coverage, and EV patents. The Producers cluster exhibits a high proportion of EVs in its overall vehicle production and a significant share of electric buses in its total bus fleet. The Green Transport cluster is marked by its high proportion of electric buses in the total bus fleet but receives lower scores in other indicators. The Laggards cluster displays low values across all variables, indicating an underdeveloped EV sector.

The cluster analysis brings to light specific geographic trends in China's EV development. Firstly, coastal regions emerge as leaders in terms of production and sales, in line with the overall economic advancement at the provincial level. Conversely, provinces in the northeast and southwest regions of China are predominantly categorized within the Laggards cluster, signifying a comparatively lower level of EV sector development. Additionally, the significance of two major cities, Beijing and Shanghai (classified as provinces), underscores the urban-rural divide. These spatial trends highlight the diverse attributes of EV sectors among provinces and emphasize the necessity of comprehending the underlying factors contributing to this diversity. Such insights can provide valuable guidance to policymakers when designing more effective policies and strategies.

In the second step, I conducted a comparative case study, selecting one representative province from each cluster to explore the factors contributing to variations in provincial EV development. The results highlight that provincial economic and socio-demographic factors, in conjunction with policy combinations, significantly influence this variation. More specifically, wealthier provinces in the coastal regions of Eastern China, characterized by higher GDP per capita, displayed elevated rates of EV production and adoption, as well as more advanced EV infrastructure. The findings also reveal an urban-rural divide, with urbanized provinces generally surpassing rural areas in various aspects of EV development.

The results underline the significance of the local industry and how a strong automotive sector can boost the development of EVs. Conversely, an excessive protectionist stance by provincial governments can impede the integration of new technologies and the acceptance of novel business models. These findings open avenues for future research regarding the impact of protectionism on energy transitions and the intricate role of well-established traditional automotive industries in the shift toward new mobility solutions.

The significance of policy mixes is also a notable finding. While the Chinese central government establishes goals, formulates strategies, and provides guidelines, a considerable portion of policymaking, especially implementation, is delegated to subnational levels. Consequently, provincial EV policies closely align with the central government regarding core content but exhibit variations in policy specifics and execution across provinces. Local policies play a pivotal role in addressing unique challenges and steering local EV sector development. Therefore, measures tailored to address specific local needs appear to be particularly crucial. The study's findings highlight the continued strong government intervention and support in driving the EV sector in China. This raises a significant question for future research: How can the future development of EVs transition away from reliance on government policies? This concern is not exclusive to China but extends to other nations, as long-standing financial incentives have been the primary global drivers of EV adoption.

1.4.4 How does local context matter? Assessing the heterogeneous impact of electric vehicle incentive policies in China

The fourth paper endeavors to reassess the efficacy of EV policies while shedding light on potential disparities in the influence of these policies across distinct jurisdictional landscapes. To achieve this goal, in the first step, this study employs a panel data analysis approach to examine the EV incentive policies enacted in 80 pilot cities across China, covering the period from 2010 to 2022. The results indicate that purchase subsidies, parking benefits, driving privileges, and charging infrastructure positively impact the market share of EVs. These policies can be categorized into two types: financial instruments, which encompass total purchase subsidies and parking benefits, and non-financial instruments, including driving privileges and charging infrastructure. Nevertheless, there is no significant evidence to determine which type or stage of policy is more effective.

In the second step, I categorize these cities based on levels of income, traffic pressure, population density, and political hierarchy to assess the varying impacts of EV policies in different local contexts. The results indicate that total purchase subsidies, parking benefits, and charging infrastructure have significant positive effects in cities with lower income levels and cities experiencing lower traffic pressure. In contrast, driving privileges prove effective in cities with higher income levels, more traffic pressure, and higher population density. This pattern is logical because financial subsidies can effectively offset the price disadvantage of EVs, making them more appealing to price-sensitive individuals with lower incomes. On the other hand, in densely populated and congested areas, EVs can benefit from their usage advantages, such as exemptions from driving restrictions, which increase their appeal and efficiency for consumers, consequently boosting their market share.

However, these results highlight a significant policy mismatch within China's EV landscape. Notably, the data in this study reveal that cities in the high-income category tend to provide more generous purchase subsidies for EVs, averaging 1038 RMB more per EV. However, total purchase subsidies are more effective in stimulating EV adoption in low-income cities. Such policy mismatches can undermine the effectiveness of fiscal policies and result in fiscal losses. Additionally, the findings indicate that the number of newly constructed charging stations has a more significant impact on EV adoption in areas with low population density. Nevertheless, the data show that most public charging stations are concentrated in economically developed coastal cities, resulting in significant urban-rural disparities. Suburban areas with low population density typically have fewer charging stations. Policy mismatch issues also arise among cities with differing levels of traffic congestion and political hierarchy.

For instance, EV policies tend to perform better in cities with lower political hierarchy, especially in the case of parking benefits, charging infrastructure, and driving privileges. However, in China, provincial capital cities hold higher administrative status compared to other cities and play a leading role in local industrial planning. They enjoy priority access to central and provincial funding and receive preferential policy support from the provincial government. The findings in this study suggest that the existing policy focus on provincial capitals may not be the most effective approach to drive sustainable EV adoption. Instead, policies may need to be more inclusive and target a wider range of cities to achieve more equitable and efficient outcomes of EV promotion.

In the third step, this study applies the DID estimation method to investigate the changing effects of these policies over time, providing additional evidence in line with the results obtained from the panel model. The findings indicate that the effects of these three policies are increasing over time, suggesting that usage-based policies can continue to drive effective EV adoption. This indicates a shift in consumer preferences as the EV market matures. Consumers are no longer solely focused on incentives related to the initial purchase but are increasingly considering the convenience and benefits they can derive during the usage phase. This finding holds significant implications for policymakers, underscoring the importance of adapting policies to reflect the evolving nature of the market.

This study reveals the importance of acknowledging that uniform, one-size-fits-all policy approaches are insufficient for addressing the diverse contexts within a country. It highlights that neglecting local characteristics can undermine policy effectiveness. When viewed from the perspective of a just transition, existing policies in China have exacerbated disparities in EV distribution, further marginalizing low-income groups and rural residents during the transition process. Over the 13 years of purchase subsidy implementation, these subsidies have primarily benefited high-income cities and affluent individuals (Guo & Kontou, 2021). To achieve a more equitable and effective transition, it is essential to implement tailored policies. These may involve redirecting subsidies toward lower-income individuals and shifting policy focus toward the usage phase in densely populated and congested urban areas. Such targeted policies can help to strike a balance between policy effectiveness and equity, promoting a more just transition to EVs.

1.5 Conclusion

Global imperatives underline the need for sustainable development. With the world facing critical environmental issues and striving to curb carbon emissions, the significance of sustainable transformations across various sectors cannot be overstated. China, being the largest emitter of CO2 and the biggest energy consumer, has the potential to make substantial contributions to global climate and energy challenges through its sustainability transition.

In this context, the importance of policies supporting sustainability transition is evident. These policies have the potential to provide incentives for the research, development, and adoption of environmentally friendly technologies and to guide businesses and individuals toward more sustainable practices. Furthermore, well-designed policies are important for ensuring that sustainability transitions are inclusive and that they benefit marginalized communities and promote social justice. Thus, effective policy support is not only desirable but essential for achieving sustainability transitions, making studies in this field crucial. This cumulative dissertation comprises four interlinked papers, presenting a comprehensive exploration of the crucial role that policies play in propelling sustainability transitions. Its objective is to shed light on the complex interplay between governance structures, policies, and sustainability outcomes, recognizing the multifaceted nature of sustainability transitions, which span various governance levels, geographies, and dimensions. Within this intricate landscape, the significance of adopting a multilevel and geographical perspective becomes apparent. This dissertation contributes to a deeper comprehension of how policies can guide societies toward a more sustainable and resilient future.

The first paper of this dissertation centers on the critical domain of green finance policy mix, a pivotal component of sustainability transitions. It undertakes a comprehensive examination of the evolution of China's green finance policy mix, highlighting the importance of considering temporal and scaling aspects in policy formulation. Furthermore, it delves into the transition toward a more market-oriented financial sector and the dynamic vertical interactions between various levels of government. This paper significantly contributes to bridging the research gap in the realm of China's green finance studies. Secondly, it advances our comprehension of transition policy design by incorporating both temporal and multilevel perspectives. It shows that policy changes adhere to specific paradigms, with past policy goals and instruments continuing to influence current policies and overall policy outcomes. Simultaneously, policy evolution is shaped by a variety of vertical interactions. Lastly, this paper enhances the international community's understanding of the Chinese government's policy design and evolution in the realm of sustainability financing, elucidating its contributions to global sustainability efforts.

The second paper concentrates on the process of policy implementation, a pivotal aspect of the analysis of sustainability transition policies. It delves into the phenomenon of over-implementation in the context of an energy transition program for heating systems, considering the changes in China's environmental governance landscape and the evolving interactions across various levels of government. By dissecting the factors contributing to the shift from policy under-implementation to over-implementation, this paper presents a novel perspective on the prevailing environmental authoritarianism in China and its far-reaching consequences. Notably, it addresses a significant research gap concerning policy over-implementation, expanding our comprehension of implementation gaps within environmental policies. It also enriches the existing body of literature concerning the influence of contextual changes on policy regimes and their implementation, thereby advancing theories related to implementation gaps. Lastly, it offers valuable insights into the discourse surrounding recentralization in China's environmental governance and its effects on policy outcomes. Not only do the findings of this paper expose issues of injustice and energy poverty stemming from authoritarian environmentalism, they also hold substantial implications for the study of implementation gaps, authoritarian environmentalism in China, and the successful execution of environmental policies.

The third paper focuses on the dynamic realm of EV sector development, a domain of importance for clean and sustainable transportation. It examines the spatial distribution of the EV sector across China's provinces, uncovering regional disparities and classifying these provinces into distinct clusters. This paper delves into these disparities, shedding light on the multifaceted factors that shape the diverse contexts in which the EV sector evolves. In doing so, it makes a valuable contribution by addressing a notable research gap pertaining to the spatial dimension of energy transition and the subnational distribution of EVs. Furthermore, it provides a pioneering framework for measuring and assessing the overall development of EVs, an area where existing literature has fallen short. Lastly, this study aligns with the broader discourse on energy transition as a geographical process, contributing to the understanding of the unequal distribution of costs and benefits that accompany sustainability transitions.

The fourth paper narrows its focus to undertake a comprehensive evaluation of the effectiveness of EV incentive policies. Building upon the foundational insights garnered from the third paper, which unveiled the substantial influence of policies on the heterogeneous development of the EV sector, this paper employs a rigorous empirical approach to assess the impacts of these policies across a broad spectrum encompassing 80 pilot cities in China. Significantly, it illuminates the marked variability in the influence of these policies within cities characterized by distinct local contexts, thereby shedding light on the inherent policy mismatch challenges that can hinder progress toward sustainable mobility. This study aspires to provide a nuanced and in-depth understanding of the interplay between local contextual factors and the outcomes of EV policies, ultimately offering valuable input for more informed and effective policymaking in the realm of EV promotion. In essence, this research significantly enhances our comprehension of the multifaceted process of decarbonizing transportation in various contextual settings and advances the discourse on fostering a just energy transition. The findings serve as a vital source of insights to guide the development of effective and equitable policies aimed at promoting EV adoption.

This cumulative dissertation underscores the complexities and nuances involved in achieving sustainability transitions within a large, diverse, and rapidly developing nation like China. It reveals the pivotal role of policies, institutions, and their geographical contexts in steering the trajectory of sustainability transition. The employment of a multilevel governance framework elucidates how institutional structures shape transition governance by examining the dynamic relationships among actors and the distribution of power across multiple governance levels. The geographical perspective illuminates how transitions and policies are distributed and function across different regions and local contexts, fostering a more holistic approach to addressing multifaceted sustainability challenges.

Crucially, this dissertation highlights the importance of a just sustainability transition (Carley & Konisky, 2020). It argues that significant regional differences exist in sustainability transitions. Many transition processes exclude disadvantaged groups or regions, which can have various negative impacts, including the exacerbation of existing social inequalities. Policies aimed at promoting sustainability transitions often fail to address these inequities and, in some cases, may worsen them. The design and evaluation of transition policies should be more comprehensive and scientifically informed. This dissertation not only enhances our understanding of sustainability transitions within China but also contributes to the broader global discourse on sustainability, offering valuable insights into policy formulation, implementation, and evaluation. By bridging multilevel governance and geographical perspectives in policy analysis, it provides a comprehensive framework for understanding sustainability transitions.

1.6 References

Alkemade, F., Hekkert, M. P., & Negro, S. O. (2011). Transition policy and innovation policy: friends or foes?. *Environmental innovation and societal transitions*, *1*(1), 125-129.

Bachtrögler, J., Fratesi, U., & Perucca, G. (2020). The influence of the local context on the implementation and impact of EU Cohesion Policy. *Regional Studies*, *54*(1), 21-34.

Balta-Ozkan, N., Watson, T., & Mocca, E. (2015). Spatially uneven development and low carbon transitions: Insights from urban and regional planning. *Energy Policy*, *85*, 500-510.

Bennett, N. J., Blythe, J., Cisneros-Montemayor, A. M., Singh, G. G., & Sumaila, U. R. (2019). Just transformations to sustainability. *Sustainability*, *11*(14), 3881.

Bhamidipati, P. L., Haselip, J., & Hansen, U. E. (2019). How do energy policies accelerate sustainable transitions? Unpacking the policy transfer process in the case of GETFiT Uganda. *Energy Policy*, *132*, 1320-1332.

Binz, C., Coenen, L., Murphy, J. T., & Truffer, B. (2020). Geographies of transition—From topical concerns to theoretical engagement: A comment on the transitions research agenda. *Environmental Innovation and Societal Transitions*, *34*, 1-3.

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. *Energy policy*, *53*, 331-340.

Cai, C., Jiang, W., & Tang, N. (2022). Campaign-style crisis regime: how China responded to the shock of COVID-19. *Policy Studies*, 43(3), 599-619. https://doi.org/10.1080/01442872.2021.1883576.

Capano, G., & Howlett, M. (2020). The knowns and unknowns of policy instrument analysis: Policy tools and the current research agenda on policy mixes. *SAGE Open*, *10*(1), 2158244019900568. https://doi.org/10.1177/2158244019900568

Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, *5*(8), 569-577.

Coenen, L., & Truffer, B. (2012). Places and spaces of sustainability transitions: geographical contributions to an emerging research and policy field. *European Planning Studies*, *20*(3), 367-374.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research policy*, *41*(6), 968-979.

Daniell, K. A., & Kay, A. (2017). Multi-level governance: An introduction. *Multi-level Governance: Conceptual challenges and case studies from Australia*, 3-32.

Di Gregorio, M., Fatorelli, L., Paavola, J., Locatelli, B., Pramova, E., Nurrochmat, D. R., ... & Kusumadewi, S. D. (2019). Multi-level governance and power in climate change policy networks. *Global environmental change*, *54*, 64-77.

Eaton, S.,& Kostka, G. (2014). Authoritarian Environmentalism Undermined? Local Leaders’ Time Horizons and Environmental Policy Implementation in China. *The China Quarterly*, 218, 359–380. https://doi.org/10.1017/s0305741014000356.

Ehnert, F., Kern, F., Borgström, S., Gorissen, L., Maschmeyer, S., & Egermann, M. (2018). Urban sustainability transitions in a context of multi-level governance: A comparison of four European states. *Environmental innovation and societal transitions*, *26*, 101-116.

European Environment Agency. (2018). Perspectives on transitions to sustainability.

Faller, F. (2014). Regional strategies for renewable energies: Development processes in Greater Manchester. *European Planning Studies*, *22*(5), 889-908.

Fan, H., Zhao, C., & Yang, Y. (2020). A comprehensive analysis of the spatio-temporal variation of urban air pollution in China during 2014–2018. *Atmospheric Environment*, *220*, 117066.

Flanagan, K., Uyarra, E., & Laranja, M. (2011). Reconceptualising the ‘policy mix’for innovation. *Research policy*, *40*(5), 702-713. https://doi.org/10.1016/j.respol.2011.02.005

Gagliardi, L., & Percoco, M. (2017). The impact of the European Cohesion Policy in urban and rural regions. Regional Studies, 51(6), 857–868. doi:10.1080/00343404.2016.1179384

Geels, F. (2005). Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective. *Technology in society*, *27*(3), 363-397.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, *31*(8-9), 1257-1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research policy*, *33*(6-7), 897-920.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*, *1*(1), 24-40.

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of transport geography*, *24*, 471-482.

Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current opinion in environmental sustainability*, *39*, 187-201.

Geels, F. W., & Schot, J. (2010). The dynamics of transitions: a socio-technical perspective. *Transitions to sustainable development: New directions in the study of long term transformative change*, *1*, 11-104.

Genus, A., & Coles, A. M. (2008). Rethinking the multi-level perspective of technological transitions. *Research policy*, *37*(9), 1436-1445.

Gibson, R. (2019). Searching for multi-level collaborative governance. *The theory, practice, and potential of regional development: The case of Canada*, 79-101.

Girod, B. (2016). Product-oriented climate policy: learning from the past to shape the future. *Journal of Cleaner Production*, *128*, 209-220.

Grin, J., Rotmans, J., & Schot, J. (2011). *Transitions to sustainable development: new directions in the study of long term transformative change*. Routledge.

Guo, S., & Kontou, E. (2021). Disparities and equity issues in electric vehicles rebate allocation. *Energy Policy*, *154*, 112291.

Hafner, S., Jones, A., Anger-Kraavi, A., & Pohl, J. (2020). Closing the green finance gap–A systems perspective. *Environmental Innovation and Societal Transitions*, *34*, 26-60.

Haley, B. (2017). Designing the public sector to promote sustainability transitions: Institutional principles and a case study of ARPA-E. *Environmental Innovation and Societal Transitions*, *25*, 107-121.

Hansen, T., & Coenen, L. (2015). The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. *Environmental innovation and societal transitions*, *17*, 92-109.

Hepburn, C., Qi, Y., Stern, N., Ward, B., Xie, C., & Zenghelis, D. (2021). Towards carbon neutrality and China's 14th Five-Year Plan: Clean energy transition, sustainable urban development, and investment priorities. *Environmental Science and Ecotechnology*, *8*, 100130.

Hess, D. J. (2014). Sustainability transitions: A political coalition perspective. *Research Policy*, *43*(2), 278-283.

Howlett, M., & Rayner, J. (2007). Design principles for policy mixes: Cohesion and coherence in 'new governance arrangements'. *Policy and Society, 26*(4), 1-18. https://doi.org/10.1016/S1449-4035(07)70118-2

Huang, P. (2019). The verticality of policy mixes for sustainability transitions: A case study of solar water heating in China. *Research Policy*, *48*(10), 103758. https://doi.org/10.1016/j.respol.2019.02.009

IEA (2022). Global Energy Review: CO2 Emissions in 2021. Avaliable at: https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2

Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and corporate change*, *13*(5), 815-849.

Jia, K.,& Chen, S. (2019). Could Campaign-Style Enforcement Improve Environmental Performance? Evidence from China's Central Environmental Protection Inspection. *Journal of Environmental Management*, 245, 282–290. https://doi.org/10.1016/j.jenvman.2019.05.114.

Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *The International Journal of Sustainable Development & World Ecology*, *14*(1), 78-91.

Kern, F., & Rogge, K. S. (2018). Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey. *Environmental innovation and societal transitions*, *27*, 102-117.

Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, *48*(10), 103832.

Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research policy*, *45*(1), 205-217.

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., ... & Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental innovation and societal transitions*, *31*, 1-32.

Kostka, G.,& Nahm, J. (2017). Central–Local Relations: Recentralization and Environmental Governance in China. *The China Quarterly*, 231, 567–582.

Kuerban, M., Waili, Y., Fan, F., Liu, Y., Qin, W., Dore, A. J., ... & Zhang, F. (2020). Spatio-temporal patterns of air pollution in China from 2015 to 2018 and implications for health risks. *Environmental Pollution*, *258*, 113659.

Lawhon, M., & Murphy, J. T. (2012). Socio-technical regimes and sustainability transitions: Insights from political ecology. *Progress in human geography*, *36*(3), 354-378.

Li, L., & Taeihagh, A. (2020). An in-depth analysis of the evolution of the policy mix for the sustainable energy transition in China from 1981 to 2020. *Applied Energy*, *263*, 114611.

Liesbet, H., & Gary, M. (2003). Unraveling the central state, but how? Types of multi-level governance. *American political science review*, *97*(2), 233-243.

Lindberg, M. B., Markard, J., & Andersen, A. D. (2019). Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. *Research policy*, *48*(10), 103668.

Lo, K. (2021). Authoritarian environmentalism, just transition, and the tension between environmental protection and social justice in China's forestry reform. *Forest Policy and Economics*, 131, 102574. https://doi.org/10.1016/j.forpol.2021.102574.

Markard, J., Geels, F. W., & Raven, R. (2020). Challenges in the acceleration of sustainability transitions. *Environmental Research Letters*, *15*(8), 081001.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research policy*, *41*(6), 955-967.

Markard, J., Wirth, S., & Truffer, B. (2016). Institutional dynamics and technology legitimacy–A framework and a case study on biogas technology. *Research Policy*, *45*(1), 330-344.

Meadowcroft, J. (2011). Engaging with the politics of sustainability transitions. *Environmental innovation and societal transitions*, *1*(1), 70-75.

Milhorance, C., Sabourin, E., Le Coq, J. F., & Mendes, P. (2020). Unpacking the policy mix of adaptation to climate change in Brazil's semiarid region: Enabling instruments and coordination mechanisms. *Climate Policy*, 20(5), 593-608.

Naqvi, S. A. A., Shah, S. A. R., Anwar, S., & Raza, H. (2021). Renewable energy, economic development, and ecological footprint nexus: fresh evidence of renewable energy environment Kuznets curve (RKC) from income groups. *Environmental science and pollution research*, *28*, 2031-2051.

Parris, T. M., & Kates, R. W. (2003). Characterizing a sustainability transition: Goals, targets, trends, and driving forces. *Proceedings of the National Academy of Sciences*, *100*(14), 8068-8073.

Patterson, J., Schulz, K., Vervoort, J., Van Der Hel, S., Widerberg, O., Adler, C., ... & Barau, A. (2017). Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions*, *24*, 1-16.

Qiu, Y. Q., Zhou, P., & Sun, H. C. (2019). Assessing the effectiveness of city-level electric vehicle policies in China. *Energy Policy*, *130*, 22-31.

Raven, R., Schot, J., & Berkhout, F. (2012). Space and scale in socio-technical transitions. *Environmental innovation and societal transitions*, *4*, 63-78.

Rayner, J., Howlett, M., & Wellstead, A. (2017). Policy Mixes and their Alignment over Time: Patching and stretching in the oil sands reclamation regime in Alberta, Canada. *Environmental Policy and Governance*, *27*(5), 472-483. https://doi.org/10.1002/eet.1773

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620-1635.

Rogge, K. S., Kern, F., & Howlett, M. (2017). Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research & Social Science*, *33*, 1-10.

Rosenbloom, D., Markard, J., Geels, F. W., & Fuenfschilling, L. (2020). Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help. *Proceedings of the National Academy of Sciences*, *117*(16), 8664-8668.

Salvador, M., & Sancho, D. (2021). The role of local government in the drive for sustainable development public policies. An analytical framework based on institutional capacities. *Sustainability*, *13*(11), 5978.

Schreifels, J.J., Fu, Y., & Wilson, E.J. (2012). Sulfur dioxide control in China: policy evolution during the 10th and 11th Five-year Plans and lessons for the future. *Energy Policy*, 48, 779–789.

Schreurs, M. (2017). Multi-level climate governance in China. *Environmental Policy and Governance*, *27*(2), 163-174.

Shove, E., & Walker, G. (2007). CAUTION! Transitions ahead: politics, practice, and sustainable transition management. *Environment and planning A*, *39*(4), 763-770.

Signé. (2017). Policy Implementation–A Synthesis of the Study of Policy Implementation and the Causes of Policy Failure. *Policy paper, OCP Policy Center, Rabat, Morocco*.

Smith, A., Voß, J. P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research policy*, *39*(4), 435-448.

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, *47*(7), 1267-1282.

Sovacool, B. K., Martiskainen, M., Hook, A., & Baker, L. (2019). Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions. *Climatic Change*, *155*, 581-619.

Strambach, S., & Pflitsch, G. (2020). Transition topology: Capturing institutional dynamics in regional development paths to sustainability. *Research Policy*, *49*(7), 104006.

Su, X., & Tan, J. (2023). Regional energy transition path and the role of government support and resource endowment in China. *Renewable and Sustainable Energy Reviews*, *174*, 113150.

Truffer, B., & Coenen, L. (2012). Environmental innovation and sustainability transitions in regional studies. Regional studies, 46(1), 1-21.

Truffer, B., Murphy, J. T., & Raven, R. (2015). The geography of sustainability transitions: Contours of an emerging theme. *Environmental Innovation and Societal Transitions*, *17*, 63-72.

van Rooij, B. (2006). Implementation of Chinese Environmental Law: Regular Enforcement and Political Campaigns. *Development and Change*, 37(1), 57–74. https://doi.org/10.1111/j.0012-155X.2006.00469.x.

Verbong, G., & Geels, F. (2007). The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy policy*, *35*(2), 1025-1037.

Wang, X., & Lo, K. (2021). Just transition: A conceptual review. *Energy Research & Social Science*, *82*, 102291.

Welling, A. (2017). Green Finance: Recent developments, characteristics and important actors. *FEMM Working Papers 170002*, Otto-von-Guericke University Magdeburg, Faculty of Economics and Management.

Williams, S., & Doyon, A. (2019). Justice in energy transitions. *Environmental Innovation and Societal Transitions*, *31*, 144-153.

Yao, X., Ma, S., Bai, Y., & Jia, N. (2022). When are new energy vehicle incentives effective? Empirical evidence from 88 pilot cities in China. *Transportation Research Part A: Policy and Practice*, *165*, 207-224.

Zhang, S., & Chen, W. (2022). Assessing the energy transition in China towards carbon neutrality with a probabilistic framework. *Nature communications*, *13*(1), 87.

2 The policy mix of green finance in China: An evolutionary and multilevel perspective[*]

Written together with Dr. Ping Huang

Abstract. Against the background of climate change, green finance has received worldwide attention in recent years, as policymakers bring the 'green' idea into financial sectors and encourage investments in green projects. From an evolutionary and multilevel perspective, this study conducts a comprehensive review of the policy mix of green finance in China. Our analysis emphasises the dimensions of time and scale of a policy mix that are important elements to understanding the evolution process. We identify a transition process in green finance policies in China with changes in both policy objectives and policy instruments. China has gradually shifted its policy focus from direct public intervention and investment to the construction of a green finance market. From the multilevel perspective, the dynamic vertical interactions between different levels of government have played an important role in this transition.

2.1 Introduction

In the face of climate change and ecological degradation, low-carbon transition offers a promising pathway towards a sustainable and low-carbon future. Many countries have embarked on changing demand and supply patterns into an environmentally friendly system (Capellán-Pérez et al., 2018; Le Billon et al., 2021). Though green finance (or sustainable finance), and investing guided by environmental, social and governance (ESG) principles, are receiving more attention today, the question of how to finance green projects remains largely unanswered (OECD, 2021). According to innovation theory, financial institutions and private investors often lack interest in green investment in the early stages of technological innovation, deterred by low return rates and by the perception of associated risks (Noh, 2019). The COVID-19 pandemic and the energy crisis sparked by the war in Ukraine have presented both challenges and opportunities to the low-carbon transition in many countries, including China. While there has been a shift in priority from energy transition to energy security and economic rebound, leading to increased investment in fossil fuels (Gosens & Jotzo, 2020; Li et al., 2021; Taghizadeh-Hesary et al., 2021), the energy crisis has also provided an opportunity to accelerate the green transition.[2] In fact, data indicates that transition investment has matched fossil fuel investment for the first time in 2022.[3] Green finance is a practical option to attract private capital; it does so by creating vehicles through the development of good policies, appropriate regulation, and financial frameworks (Wüstenhagen & Menichetti, 2012; Azhgaliyeva et al., 2018).

Public policies play an essential role in financing green projects because of the public characteristics and externalities of green investments (David, 2017; Gramkow & Anger-Kraavi, 2017; Bhandary et al.,

---

[*] Published in *Climate Policy*, 2023, Taylor & Francis

[2] "Energy crisis sparked by Ukraine war to speed up green transition – IEA" (Reuters, October 2022).

[3] "Global Low-Carbon Energy Technology Investment Surges Past $1 Trillion for the First Time" (Bloomberg BNF, January 2023)

2021). Green finance policy encompasses a variety of policy goals and instruments that change over time. Likewise, these policies are designed and implemented at different scales. The complexity highlights the necessity of a strong policy mix, one that combines several policy instruments and focuses more on systemic arrangements, as a comprehensive approach in this field (Reichardt & Rogge, 2016).

In this study, we adopt an evolutionary (time) and multilevel (scale) perspective to analyse the evolution of China's green finance policy mix. China's ambitious low-carbon transitions are taking place at various scales, and its green finance market is rapidly developing and maturing. As reported by the Climate Bonds Initiative (CBI), China has become the world's second-largest green bond market since 2020,[1] attracting growing attention as a significant contributor to global green investment and the clean energy transition. This is highlighted in various studies, including Climate Policy’s special issue on Green Finance in Asia.[2] Nevertheless, low-carbon transition entails a high rate of investment in infrastructure (Hall et al., 2017). In China, the significant funding gap between available fiscal resources and expanding green investment demand is a major challenge, with public funds covering only about 15% of estimated demand (Peng et al., 2018). For China to achieve its commitments of carbon peak by 2030 and carbon neutrality by 2060, it is necessary to explore new financial instruments and policies that can attract private financing for low-carbon and environment protection sectors (Hall et al., 2017). Green finance policy has great potential to elevate the private sector’s share of investment to fill the green financing gap by increasing the rate of return (Sachs et al., 2019). Thus, it has received increasing attention in both academic and policy circles (Zhang et al., 2019).

In recent years, China has been advancing steadily towards developing a green financial system that functions across the country and at different levels of government. All levels of the Chinese government have introduced a package of policies to “green” the financial system. Despite progress, the absence of market-based green finance mechanisms hinders the acquisition of private capital in China. Unlike western countries with relatively mature market mechanisms for incentivizing green financing, China relies more on governmental administration and financial regulation to guide financial institutions. Reform focusing on establishing market mechanisms has become the latest trend in green finance in China, bringing new goals and challenges to green finance policy design. Thus, investigating how green finance policies evolve in China’s multilevel governance system can bring important insights into the dynamic interactions between the components of the green finance policy mix (Matti et al., 2017).

This analysis focuses on the dimensions of *time* and *scale* (Scordato et al., 2018) of China’s green finance policy mix. We identify a transition process of the policy mix with changes in both policy objectives and policy instruments. Looking across time, China has gradually shifted its policy focus from direct intervention and investment to the development of a green finance market. Looking at the dimension of scale, China has transitioned its green finance policy mix from a top-down driven process

[1] China is the world’s second largest source of labelled green bond issuance with USD44bn issued in 2020
[2] Green Finance in Asia: Challenges, Policies and Avenues for Research

to a one with interactions across multiple levels of governance (referred to here as multi-level interactions).

The remainder of this paper is structured as follows. Section 2 provides background on the development of green finance in China and reviews the literature on policy mix, with a particular focus on the dimensions of time and scale. Section 3 introduces the method and data of the research. Section 4 traces the evolution of China's green finance policy mix in five-year increments and presents the policy change process from the dimension of time and scale. Section 5 explains the identified temporal and vertical patterns of China's green finance policy mix and Section 6 concludes.

2.2 Green finance development and policy mixes in China

As the world's largest energy consumer and CO_2 emitter, China is radically decarbonising its coal-based energy system (Li & Taeihagh, 2020; Jiang & Green, 2018; Guo et al., 2019). During its 11th Five-Year-Plan (FYP) period (2006-2010), the Chinese government started to attach greater importance to a low-carbon transition (Tosun & Rinscheid, 2020; Dikau & Volz, 2021).

Broadly speaking, "green finance" refers to channelling public and private green investment through a green financial system supported by green finance policies (Eyraud et al., 2011; Zadek & Flynn, 2013; Welling, 2017). The People's Bank of China (PBOC) (2016) defines green finance as "financial services provided for economic activities that are supportive of environment improvement, climate change mitigation, and more efficient resource utilization." Due to different political systems and financial markets, the policy design and taxonomies of green finance may vary from country to country. For instance, nuclear energy is included in green finance in China and in the European Union but excluded in Korea and Bangladesh. The term "green finance" is closely associated with related concepts, such as sustainable finance. Though it is difficult to draw a line between them in practice, as institutional investors usually take ESG impacts into account simultaneously when identifying appropriate investments (European Commission, 2017), strictly, we understand green finance as a subset of sustainable finance. Green finance places more emphasis on the environmental pillar of ESG criteria, as a response to increasing concerns about climate change, pollution, and energy issues.

Green finance in China emerged in 2006 and is primarily policy-driven due to the heavy government involvement in the financial system, which is dominated by state-owned banks under the control of the Chinese government (Ren et al., 2020; Xu & Gui, 2019). Currently, the Chinese banking system is composed of China's central bank (PBOC), three policy banks, six state-owned banks, 12 joint-stock commercial banks, and many city commercial banks, rural commercial banks, and rural credit unions. The Chinese government and state-owned shareholders own policy banks and the majority interest in all the other banks. Therefore, Chinese banks operate under the control of the Chinese government and undertake a variety of policy functions. In the case of green finance policy, the PBOC and the China Banking Regulatory Commission (CBRC) are the main supervisory entities of financial institutions. Their policies regulate all aspects of financial activities and allocate financial resources (Lu & Yao, 2009). Despite a shift in the financial structure towards a more market-based structure (Ji et al., 2019), state-owned banks still dominate the Chinese financial system and play the main role in the practice of green finance (Wang & Wang, 2021).

China has made noticeable achievements in green financial policymaking, practices, and products. The *Guidance on the Construction of a Green Financial System*, for instance, outlines the basic framework for China's green financial system and represents a top-level policy design for green finance (Gilbert & Zhao, 2017). In 2017, the designation of eight green finance pilot zones marked a more radical implementation of green finance at the local level. Despite noteworthy progress, considerable challenges remain that hinder the expansion of green finance in China. For example, as the main actor in the Chinese financial system, banks are not motivated to invest in green projects because of their reluctance to take risks; moreover, underdeveloped financial markets and the lack of venture capital limit the funding sources for green projects (Sachs et al., 2019). For instance, the investment in renewable energy from financial institutions highly relies on the fiscal and pricing policies from the government and is vulnerable to changes in national policies on clean energy subsidies, meanwhile governmental funds to support green transition are limited. The design and development of the green finance policy mix are expected to confront these challenges.

This article aims to investigate the evolution of the green finance policy mix in China. The investigation of the policy mix with respect to multiple policy goals and instruments, processes of policy formulation, and the evolution of instrument selection is gaining ground in policy science research over time (Howlett & Rayner, 2013; Kern et al., 2017). *Time* and *scale* are two important dimensions of a policy mix, as policy strategies and instruments change over time, and policies are designed and implemented at different scales (Flanagan et al., 2011; Scordato et al., 2018; Milhorance et al., 2020).

The temporal changes of policy mixes follow different paradigms (Capano & Howlett, 2020) and are often unravelled through the analysis of the shift in policy focus and instrument (Knill et al., 2012). Scholars have identified several common mechanisms of policy mix development (Wellstead et al., 2016). "*Policy patching*" occurs when new policy goals or instruments are added to the existing regime. The layering of elements may lead to incoherence amongst the goals, and inconsistency of instruments (Rayner et al., 2017). "*Policy stretching*" occurs when policy elements are extended to cover areas they were not intended to. Policy stretching may cause inconsistency between the old and the new policy instruments or pose risks of incongruence between the old instruments and new goals (Howlett & Rayner, 2007). 'Patching' or 'stretching' a policy are common measures in China and many other countries. These mechanisms also can be identified in the evolution of green finance policy. Though some scholars argue that policy patching and stretching may bring sub-optimal outcomes (Howlett & Rayner 2007), they are also possible to create effective policy mixes by cautious design.

The vertical interactions between instruments and actions at different levels of governance are also important in policy mix analysis (Flanagan et al., 2011; Colenbrander et al., 2018). Policy instruments enacted at one governance level would exert influences on policymaking of other governance levels

(Bressers & O'toole, 2005). The outcomes of policy implementation at the local level would also trigger policy responses from higher-level governments. Particularly relevant to this vertical dimension of the policy mix is the multilevel political structure of China (Huang, 2019). In China, policy goals are generally set by the central government, but implementation experiments are introduced at the regional or local level (Schreurs, 2017). Rather than passively receiving policies, in many cases, subnational governments would reshape and tailor policies according to specific local contexts. To implement the green finance policy, China has launched eight green finance pilots. Pilot areas serve as an ideal arena for analysing the verticality of the policy mix for green finance, particularly how overarching policy objectives are aligned with local contexts.

Investigating how policy mixes evolve over time and across different levels of government is a promising research direction for policy studies, particularly for understanding green finance policymaking in China (Ongaro et al., 2019). Nevertheless, while existing literature has analysed individual instruments within a single governance level, little attention has been paid to the interactions between components of a policy mix over time and across different governance levels. In the following section, we analyse the evolution of the green finance policy mix, and how different instruments interact, in China, from the two dimensions of time and scale.

2.3 Research methodology and data

In this study, we use document analysis to trace the development of China's green finance policy mix. We first conduct a systematic review of the national and provincial policy documents to uncover the evolution and characteristics of the green finance policy mix in China. Data were extracted from the "PKULAW" (www.pkulaw.cn) and "BAILUZHIKU" (www.bailuzhiku.com) databases, both of which incorporate China's national and local policy documents. In the end, we downloaded 418 relevant policy documents (127 national documents and 291 provincial documents), including notices, guides, announcements, plans, and government work reports, all published between 2006 and 2020. Appendix A.1 elaborates on the coding framework, and Appendix A.2 lists the most relevant policy documents. We cite the related policies in this study using the corresponding coding numbers. Both Appendices can be found in the Supplementary Materials (SM): Appendix A.

In the literature, policy instruments are generally categorised as either technology-push versus demand-pull, or regulatory versus economic instruments (Bernstein, 1993; Di Stefano et al., 2012; Xu & Su, 2016). In the analysis, we follow Vedung (1998) and Park (2015) and categorise policy instruments using a tri-fold or three-part classificatory scheme that includes command and control, market-based, and information instruments. Command and control policy instruments are regulatory instruments implemented by governments to influence targets through authoritative means (Park, 2015). Market-based instruments are also referred to as economic instruments; they are designed based on the market failure theory, using prices, market-based rights, and economic incentives to influence actors' strategic choices (Filoche, 2017). Information instruments target people and influence behaviour through knowledge transfer, communication, and persuasion (Park, 2015). Appendix A.3 presents a detailed classification of the typology of policy instruments (see SM: Appendix A).

While our threefold typology for coding policy instruments is based on conventional typologies in the literature, the approach is not without limitations. The primary limitation is that the typology we use is uniquely focused on our subject of green finance, which means it might neglect some other significant distinctions of the policy instruments. Therefore, alternative typologies may reveal different patterns of policy instruments and lead to additional insights and results. However, these limitations also provide opportunities for more nuanced exploration in further research.

2.4 Evolution and periodic policy characteristics

Figure 2.1 shows the temporal distribution of green finance policies at the national and provincial levels. As can be seen, green finance policymaking at the provincial level significantly lags behind the central level, as central-level policy documents began to emerge in 2006 and provincial documents not until 2011. The number of issued policies changes in provincial policies showed a similar trend to those at the central level in the early stages but later started to exhibit different patterns.

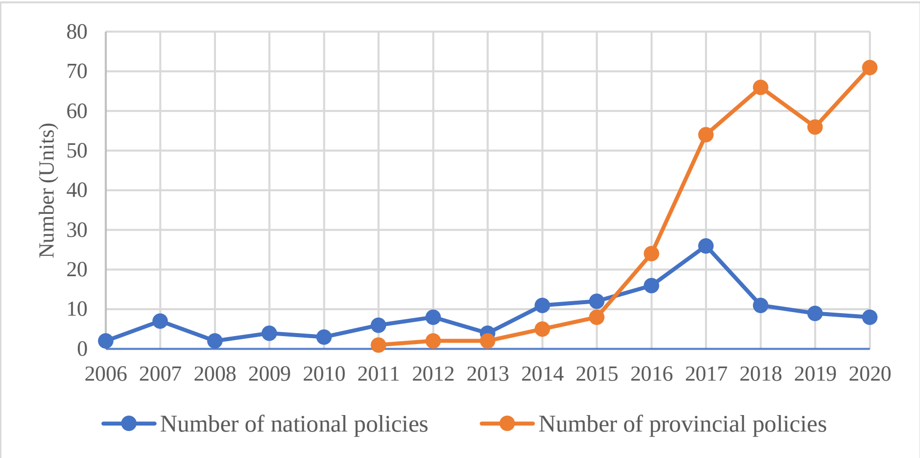


Figure 2.1. The temporal distribution of China's green finance policies.

Data source: The 418 policy documents collected in the database (The Appendices, which contain some of the main policy documents, can be found in the Supplementary Material for this article.).

Since 2016, the number of green finance policies at the provincial level has surged. This development is likely to be driven by the *Guidance on the Construction of a Green Financial System* (policy document *N38*[1]), which was released by the central government in August 2016. Because in the early stages, subnational governments lacked the experience and capacity to explore green finance, they relied mainly on policy guidance from the central government (see, e.g. provincial document *P10, P19,*

[1] In this article, policy documents are coded as two categories. We use "Nx" to code national policies, where listed policy documents can be found in SM Appendix A.2, Table A.2.1; we use "Px" to code provincial policies, where listed documents can be found in Appendix A.2, Table A.2.2.

P31-33). However, as policies, instruments, and technologies matured, subnational governments gained more experience, so they no longer simply followed the guidance of central policies but instead developed more detailed or diverse policies adapted to local contexts.

Table 2.1. The evolution of green finance policy objectives and instruments in China during 2006-2020 (national level).

		Policy objectives and policy instruments		
		11th FYP (2006-2010)	12th FYP (2011-2015)	13th FYP (2016-2020)
Instrument type	objective	(1) Environmental protection and energy conservation by financial measures. (N7) (2) Develop green credit. (N5)	(1) Environmental protection, reduce carbon and energy intensity. (N14, N15, N26) (2) Green financial products innovation. (N17, N15, N32)	(1) Support green development by green finance. (N33, N49) (2) Build a market-orientated green finance framework (N38)
Command and control		Credit access or restraint (N1) Information-sharing for corporate environmental protection (N2) Environmental audit (N5) Administrative penalty (N10)	Credit access or restraint (N20) Information-sharing for corporate environmental protection (N20) Simplified procedure (N27) Entry barrier removal (N28) Environmental audit (N16) Approval process (N30) Administrative penalty (N14)	Credit access or restraint (N33) Information-sharing for corporate environmental protection (N55) Approval process (N65) Green banking evaluation (N68) Green index and standard (N39) Administrative penalty (N36) Market monitoring and evaluation (N38)
Market-based		Loan (N5) Grants for R&D (N12) Government direct investment (N4) Subsidised interest rates (N12) Environmental pollution liability insurance (N8) Clean Development Mechanism Fund (CDM Fund) (N13)	Loan (N17) Subsidised interest rates (N21) Grant and award (N13) PPP (N21) Green bond (N29, N31) Environmental pollution liability insurance (N18, N23) Tax incentives (N16, N21) Special Fund (N16, N32) CO_2 ETS (N25)	Long-term loan (N54) Government guarantee fund (N44) Grant and award (N59) Subsidised interest rates (N59) PPP (N43) Green bond (N34, N65) Certificate and license (N36) Pricing (N40, N41) Environmental pollution liability insurance (N58) Tax incentives (N59, N67) Green development fund (N64) CO_2 ETS (N36)
Information		Mandatory disclosure (N9) Moral persuasion (N2)	Voluntary disclosure (N29) Moral persuasion (N16)	Risk exposures (N37) Mandatory/Voluntary disclosure (N44) Moral persuasion (N64)

Source: Authors (based on collected policy documents. The Appendices, which contain some of the main policy documents, can be found in the Supplementary Material for this article.).

Periodically, the evolution of the green finance policy mix parallels China's FYPs, which guide the country's economic and social development. By setting environmental and energy goals, FYPs help to accelerate the demand for green investment. Studies have shown that a transparent and stable governmental strategy may positively influence investors' risk-return perceptions (Falcone & Sica, 2019; Guild, 2020). In this regard, FYPs that endorse emission reduction and low-carbon transition can act as a political stimulus for private investments (Zhou et al., 2020). In light of this, we divide the development of green finance policy between 2006 and 2020 into three phases following the periods covered in successive FYPs: 11th FYP (2006-2010); 12th FYP (2011-2015); and 13th FYP (2016-2020). Table 2.1 presents the policy mix evolution and reviews policy objectives and instruments for green finance in China according to these three phases.

Vertically, as the central government plays the main role in designing top-level policies to guide subnational policy design and implementation, green finance policies at the provincial level highly align with those at the central level. On the other hand, local experimentation of green finance explores different development models against different circumstances, hence offering diverse practical samples for promoting green finance across the country and in turn, influencing policy design at the central level.

2.4.1 Phase 1: 11th FYP (2006-2010)

Since the 11th FYP, China started to place greater emphasis on environmental protection, with a shift in policy direction that sought to integrate financial sectors into environmental protection and use financial instruments to restructure the economy. In 2006, the issuance of the first green credit product for energy conservation and emission reduction indicated the emergence of green finance in China (Papapano, 2020). Policy objectives in this period were quite focused and targeted, as the main aim of the green finance policy mix was to reduce pollution and energy intensity by financial means (see, e.g. *N7*). Policy mixes for green finance during this period lacked a comprehensive framework, and the primary policy objective revolved around the promotion of the green credit system (see, e.g. *N3, N5*).

During this period, China implemented policies supporting the green credit system (see, e.g. *N10; P1*), which became the primary financial channel for green investment in the country (Zhang et al., 2021). These policies call on banks to approve loans by considering compliance with environmental regulations and by introducing Equator Principles[1] into green credit. The focus was on clean technologies in highly polluting and energy-consuming industries, with support for (cleaner) coal power. Information sharing between the former State Environmental Protection Administration (SEPA) and financial sectors was another key measure, with corporate environmental violations incorporated into the corporate credit system and shared with financial institutions to evaluate investment risks. This measure significantly reduced the likelihood of loans for polluting enterprises (see, e.g. *N2*). The policy mixes during this period also mentioned green insurance and green security but did not offer specific guidance for policy implementation (see e.g. *N8*).

The government also favoured command and control instruments in this period; specifically, it used supervision and regulation to guide bank credit and to give loan support to green projects. We identify

[1] The Equator Principles were formulated in 2003 based on sustainability standards from the International Finance Corporation (IFC). It serves as voluntary guidelines for financial institutions to identify, assess and manage environmental and social risks when financing projects.

supervision in environmental pollution liability insurance and mandatory environmental audits. In addition to command and control instruments, the government introduces a few economic incentives, such as loan pricing and government funds, mainly to support research and development of green technology. During this time, economic instruments relied heavily on direct governmental investment instead of private capital. Information instruments were supplementary to command and control approaches.

Looking vertically at lower levels of governance, at this stage we do not find any policy that refers to green finance at the provincial level. The 11th FYP was a period of exploration and introduction of green finance policy at the central or national level of governance. The concept of green finance is not introduced at sub-national levels of government until later.

2.4.2 Phase 2: 12th FYP (2011-2015)

During the 12th FYP, the political priority of energy conservation and emission reduction significantly increased the demand for green investment. In 2012, building an ‘ecological civilisation’ is considered one of China’s national priorities, necessitating robust financial infrastructure. Consequently, renewable energy development became an important arena in green finance (see, e.g. *N16*; *N31*). In this period, green finance policy aims to introduce more innovative financial instruments based on a market mechanism and to build a more pluralistic green finance system; it is based on green credits, green bonds, and green insurance.

We observe a few significant developments in policy instruments in this period. First, China initially builds a practical green credit system, the focus of which transitioned from (cleaner) coal power to renewable energy (see, e.g. *N17*). Since 2013, the loan balance of green credit for renewable energy projects continued to increase, especially for solar and wind capacity investments (Li et al., 2021). Second, green bonds are introduced as a new financing channel (Kidney & Oliver, 2014). The Chinese government supported green bond issuance by lowering restrictions on issuers and by raising incentives, such as investment subsidies for purchasers, government guarantee schemes, and bond interest discounts (see, e.g. *N32*). Third, China’s carbon trading market developed rapidly from 2013; as commercial banks moved into the fledgling carbon markets, helping clients hedge carbon-trading risks and financing new investments using carbon certificates as collateral (Munnings et al., 2016).

During the 12th FYP, the green finance policy mix in China also became more pluralistic. As for policy instruments, economic incentives played an important role in supporting green investment. A set of financial incentives, including investment subsidies, green credit guarantee schemes, and fiscally subsidised interest rates, were used to attract green investment through multiple channels. Further, the establishment of special funds became common practice to increase profitability and decrease the risk of green investments, specifically private sector investment (see, e.g. *N13*).

Vertically, following policy guidance from the central government (e.g. *N4*, *N7*), some subnational governments began to engage with green finance policy practices. In 2011, to achieve targets for energy-saving and carbon reduction assigned by the State Council, Beijing Municipal Government proposed green finance approaches, encouraging financial institutions to establish green credit mechanisms and to set up funds to support emerging green industries (e.g. *P3*). In following years, other regions replicated this practice to extend green credit and to develop environmental pollution liability insurance, including in Hebei and Gansu (e.g. *P4, P6*). Moreover, the Chinese central government designed a pilot CO_2 Emissions Trading System (ETS) in 2011 and launched seven pilots at sub-national level in 2013 (Li & Taeihagh, 2020). The emergence and development of green finance at the subnational level occurs during the 12th FYP period, where we notice that subnational governments largely follow suit of the central government, not only in policy design but also in the implementation of green finance policy.

2.4.3 Phase 3: 13th FYP (2016-2020)

Promoting green finance to facilitate the development of a low-carbon and green economy is one of the major foci of the 13th FYP. In 2016, the Chinese government promulgates the *Guidance on the Construction of a Green Financial System* (*N38*). Green finance thus enters a new stage of systematic development, with a policy mix that focuses on framework establishment, financial products innovation, and market construction. In this period, progress is made in the development and implementation of green finance standards in constructing a framework to expand green credit; to evaluate green banking; to securitise green loans; to expand and improve performance of the pilot CO_2 ETS; and to implement the Green Development Fund (GD Fund).

Building on existing green credit policy, governments at the provincial level encouraged financial institutions to issue more green loans through mechanisms such as interest subsidies, on-lending, and loan guarantees, while preventing the extension of loans to highly polluting industries through regulatory and information means (see, e.g. *N54*). To balance the development of diverse financial channels, the central government established a more comprehensive policy mix for green bonds and the market-based GD Fund for leveraging private capital. To motivate banks in green finance, the CBRC developed a green banking evaluation system (see, e.g. *N68*). Moreover, the development of new financial technologies ("fintech"), such as blockchain and big data, made green investment more efficient in this period.

During 2016-2020, the policy mixes for green finance in China were significantly influenced by market factors. A primary focus was on developing innovative green financial products and establishing a financial market mechanism (see, e.g. *N32*; *N60*), which was supported by various economic incentives like discount interest, re-loans, macro-prudential assessments, and government guarantee schemes (see, e.g. *N38*). The GD Fund became an important instrument, with both central and provincial governments adopting a Public-Private Partnership (PPP) to leverage private capital with limited use of government funding. Though less dominant, command and control instruments, such as stricter credit constraints on polluters, continued to play an important role in addition to market-based instruments.

Additionally, we observe vertical development of the green finance policy mixes ranging from the carbon trading market to the local demonstration and uptake of green finance mechanisms. The carbon trading market in China was expanded nationwide, building on the experience gained from sub-national carbon trading pilots. This process demonstrated the interaction between central policies and local experimentation. Furthermore, in June 2017, the State Council approved the establishment of eight "National Pilot Zones for Green Finance Reform and Innovation" to explore innovative development pathways in unique local contexts and to offer practical means of diffusing, locally-tailored green finance policy across the country. So far, these pilot zones have made considerable progress in the design and implementation of green products and services, in the specification of supporting policies, and in market construction for green finance. Some innovations have diffused to other provinces and, in turn, informed the policy design at the central level. For example, environmental equity like carbon emission allowance as an innovative financing tool, which was first initiated in Guangdong, has now diffused nationwide.[1]

2.5 Discussion

2.5.1 Analysis of the policy change from the temporal dimension

We identified a temporal transition process of China's green finance policy mix. Over the years, green finance policy objectives have been quite coherent, from broader environmental protection and energy conservation (see, e.g. *N5, N7*) to more specific carbon emission reduction, energy efficiency (see, e.g. *N14-15*) and green development (see, e.g. *N33, N49*). The instruments in place have evolved from command and control tools to a more complex instrument mix, to include market-based and information instruments (see Table 1). Specifically, China has gradually shifted its policy approach from direct government intervention and investment to the construction of a green finance market that builds upon a market-oriented mechanism and market-based financial products.

China's initial approach to green finance policy relied mainly on government intervention, supervision and administrative measures. But in later stages, through the use of various financial products, such as green credit and green bonds, economic incentives became more important instruments for supporting green finance. Those economic incentives include subsidies, tax incentives, grants, long-term loans, green development funds, etc. Lately, green finance policy has developed into a comprehensive policy mix stressing both command and control and market-based policy instruments in the context of market reform, where a key objective is to establish a systematic and practical green financial system framework; this framework consists of a combination of policies, incentives, and disincentives, and a regulatory structure, aiming to mobilise private capital markets to support green projects. Increasingly, market mechanisms are being used in combination with regulatory measures to promote green investment and green growth.

[1] *Environmental Equity Financing Instrument (financial industry standard)* officially launched (cfstc.org).

The establishment of the GD Fund shows a significant process of "policy patching" used to address gaps in the existing green finance policy framework. "Policy patching" is the addition of new policy goals or instruments to an existing regime (Rayner et al., 2017). The Chinese government officially established a National GD Fund in 2020 (Qu & Tian, July 2020). It originated from the Clean Development Mechanism Fund (CDM Fund) and the Renewable Energy Development Fund (RED Fund). The CDM Fund was established in 2007 to support the development of low-carbon industries, while the RED Fund, established in 2011, provided electricity tariff subsidies for renewable energy (Lewis, 2010; Mo, 2018). Unlike its predecessors, the GD Fund serves the new objective of building a market-oriented green finance system. It aims to diversify investment channels for environmental protection and use market mechanisms to support green development. The GD Fund adopts leverage-based mechanisms, and through professional management, it shifts the government's focus toward a public finance system that generates a leverage effect to attract private investment. Additionally, the GD Fund helps multiple stakeholders share the risk of investing in green projects and provides stakeholders with diversified asset distribution channels. The establishment of the GD Fund indicates that the government prefers to add new instruments to the old ones to serve new objectives, based on an assessment of what is missing; this is what we refer to as policy patching.

The introduction of CO_2 ETS onto administrative penalty presents a "policy stretching" process. "Policy stretching" occurs when policy elements are extended to cover areas they were not intended to (Howlett & Rayner, 2007). The environmental administrative penalty is a long-standing administrative tool in China, originating from the "*Measures on Administrative Penalties for Environmental Protection*" promulgated in 1999. Currently, the most common penalty is administrative fines on companies that exceed their emissions quota. China began piloting CO_2 ETS in seven cities in 2013 (see, e.g. *N15*) and launched the national carbon emissions trading market in 2021. Although the environmental administrative penalties and ETS both follow the principle of quantifying environmental costs and "the polluters pay," they differ in specific policy targets. The purpose of administrative environmental penalties is to control the total amount of pollutant emissions. China's ETS is essentially a tradable performance standard (TPS): it targets reductions in the CO_2 intensity of economic activity rather than total CO_2 emissions (Karplus, 2021). In other words, the ETS extended the instrument functions of administrative penalties, thus our reference to policy stretching.

2.5.2 Analysis of the policy change from the vertical dimension

We also identified a vertical pattern in China's green finance policy mix evolution from a largely top-down, national process to multi-level interactions. In the early stages of green finance policy development, China's policymaking was "top-down" in nature. The practice of green finance at the subnational level significantly lagged behind the central level policy design and implementation. The central government played the main role in policy design and guided local governments on how to develop and implement relevant policies (e.g. *N7, N17, N38*). Subnational governments mainly followed central-level guidelines, and no distinctive local instruments emerged in the earliest period of green finance in China (e.g. *P31, P33, P36*). With time, local experimentation occurred, and subnational governments no longer passively implemented central policies but took more proactive actions to stimulate local innovation (see, e.g. *P52*). These innovations, in return, influenced green finance policy design of the central government and other jurisdictions.

The success of CO_2 ETS is a good example of vertical or bottom up innovation influencing central policy. In 2013 and 2014, China established seven pilots for CO_2 ETS (Li & Taeihagh, 2020). These pilots have effectively reduced carbon emissions in the pilot regions and have provided rich experience on which to base the construction of a national carbon market. As of the end of May 2019, a total of 310 million tons of CO_2 had been traded in the pilot carbon markets (Hong, 2020). In 2017, the National Development and Reform Commission (NDRC) issued the *National Carbon Emission Trading Market Construction Plan (Power Industry)*, and in July 2021, following the same trading mechanism as those used in the pilot areas, the national carbon emissions trading market was officially launched. This approach "from point to surface" shows the interactions between central and local governments: the central government designs the policy goal, but rather than releasing a policy package directly, it allows and encourages local policy innovations that absorb and adapt the ideas into local contexts for implementation.

Table 2.2. An overview of the "National Pilot Zone for Green Finance Reform and Innovation"

Pilot zone	Province	Key task
Huzhou Quzhou	Zhejiang	○ Explore effective ways for green finance to support the transformation and upgrading of the industrial structure ○ Explore effective ways for green finance to promote the optimization of regional economic structure
Ganjiang New District	Jiangxi	○ Explore effective ways for financial support to promote the development of an ecological economy ○ Build a green financial organization system ○ Explore innovative credit products and financing modes in the fields of energy conservation and emission reduction, and clean energy ○ Explore the policy effects of financial support for the development of green finance
Guangzhou	Guangdong	○ Explore a new development model compatible with green financial reform and economic growth ○ Encourage the establishment of new energy automobile finance companies and actively carry out the innovation of financial products for new energy automobiles
Guian New District	Guizhou	○ Explore effective ways for green finance to guide the economic transformation and development of underdeveloped areas in Western China ○ Explore innovative green agricultural credit products, focusing on supporting agricultural industry projects such as modern urban agriculture, organic ecological agriculture, rural water conservancy project construction, and agricultural sewage treatment
Hami Changji Prefecture Karamay	Xinjiang	○ Combine the development of green finance with local endowments such as agriculture, clean energy resources, and energy-related, high-end manufacturing industries ○ Explore innovative green agricultural credit products such as innovative wind power, (photovoltaic) power generation index insurance, the first set of insurance packages for major technical equipment, etc.

Source: Authors (based on program data, policy documents, and government websites).

The design of green finance pilots follows a similar approach. China has currently launched eight pilot zones for green finance reform. Each pilot zone was assigned specific tasks that were rooted in local contexts to address place-specific challenges (Table 2.2). For instance, for more developed areas, such as the provinces of Zhejiang and Guangdong, a key focus was the structural transformation of the local economy, while for more underdeveloped regions, such as Guizhou and Xinjiang, special attention was paid to greener and more efficient utilisation of local resources. As an example, Xinjiang is emphasising the development of innovative green agricultural credit products as well as index insurance for wind power and photovoltaic power generation due to its abundant renewable energy resources and strong agricultural sector.

Given the different tasks, the policy design varied among regions. For example, two regions prioritised the energy sector in green finance development. Guangzhou had a more comprehensive and pluralistic approach to green finance development, with policies covering different dimensions such as institutional infrastructure, green finance products, and services. In comparison, Changji focused on targeted sectors such as agriculture and renewable energy, seeking innovative measures to efficiently boost production factors. The policy tools selected by local governments were also closely related to local governance capacities. In Guangzhou, economic instruments such as subsidies and awards were frequently used by the municipal government to incentivise the engagement of enterprises in green finance development. By comparison, economic incentives were rare in Changji, and the local government played a more enabling and mediating role between enterprises and financial institutions.

As can be seen, the central government authorises and guides local experimentation, but local governments differentiate policy innovations to adapt to unique local and regional contexts. These dynamic vertical interactions are rooted in complex central-local relations in China. China has a multilevel political structure under a decentralised authoritarian regime (Landry, 2008). As environmental rights often conflict with short-term economic growth in China, the central government typically plays the primary role in the policy design for sustainability. This is evident in the early policy design of green finance at the national level (e.g. *N7, N17, N38*) and the similar policy contents at the provincial level (e.g. *P3, P11, P12, P13*).

However, local governments in China are not only responsible for implementing central policies, but also have the authority to create local policies. With the decentralisation reform in China, which shifted central-local relations to federalist principles, local governments have some discretion in policy implementation and innovation (Zheng, 2006). Some of these local innovations can be recognised and adopted by the central government to further refine policy design. One such example is the adoption of green bonds and carbon emission rights as collateral for bank loans in Guangdong Province. In 2014, the first successful carbon allowance collateralised finance was implemented in Guangzhou, with Huadian New Energy Company obtaining a mortgage of RMB 5 million using carbon emission allowances allocated by Guangdong Province.[1] This policy innovation has now been adopted by the PBOC and is being implemented in many other provinces across China. In 2021, the PBOC released the *Environmental Equity Financing Instrument*, which clarifies the implementation process of environmental equity financing instruments and provides guidance for its nationwide implementation.[2]

2.5.3 Green finance policy in the new stage

Despite changes in policy over time and across different levels of government, China's green finance policy is characterised by notable government intervention in financial activities, and public actors are the main driving force behind green finance development. This approach contrasts with that of developed countries, where green finance is typically spearheaded by financial institutions and operated under a market-based mechanism. For example, in 1992, a group of commercial banks, including Deutsche Bank, HSBC Holdings, Royal Bank of Canada brought attention to the environment and sustainable development in the banking sector (Jeucken, 2010). Similarly, the now widely used Equator Principles were initially proposed by a number of private banks (Xu & Li, 2020). In developed countries, investor communities, non-profit associations, and a wide array of civil society actors are drivers of green finance development. Nevertheless, in many developing countries (e.g. Brazil and India), the development of green finance is highly policy-driven and features a top-down design. This is particularly true in China, where banks, particularly state-owned banks, serve as an agent of central policy, and the influence of the private sector and civil society is thus less significant (Huang, 2022).

China's green finance policy has recently endeavoured to foster the engagement of non-state actors in green finance activities (e.g. *N55-56*, *N64*). More non-state stakeholders, such as listed companies, institutional investors, and insurance companies, alongside traditional financial institutions, seize the opportunity to actively participate in green finance services and green financial products innovation (Green Finance Committee, 2021). The impetus for this expansion of participation is the escalating demand for green investments, brought about by China's commitment to reach carbon peak by 2030 and carbon neutrality by 2060. Following the commitment, we can observe augmented support for green finance policies, with the introduction of targeted policies by the central government and the People's Bank of China, such as the national emissions trading system, fiscal incentives, tax breaks for low-carbon activities, and disclosure of carbon reduction for loans (State Council, 2021; PBOC, 2021). Thus, the changes in green finance policies can be seen as a response to the nation's development strategies in the new stage.

As the pace of development of green finance continues to accelerate in China, the country's efforts to seek international collaboration are also evident in its green finance policies. In 2022, the NDRC issued the "*Opinions on Promoting Green Development of 'One Belt, One Road*'," which proposed to

[1] The first carbon allowance collateralised finance succeeded in Guangzhou successfully completed (https://www.cnemission.com/article/cgal/201505/20150500000892.shtml).

[2] Environmental Equity Financing Instrument (financial industry standard) officially launched (https://www.cfstc.org/jinbiaowei/2929436/2980681/index.html).

align domestic and international green financial standards through international cooperation and to promote the orderly two-way opening of the green financial market. The latest edition of the *Catalogue of Green Bond Support Projects* in 2021 incorporates the widely accepted "Do No Significant Harm" principle to improve the alignment of China's domestic green bond standards with international standards. The aforementioned policies aim to not only enable Chinese capital to enter foreign countries but also to entice international green investment into China. Consequently, the push for international green financial cooperation has necessitated further development of green financial policies in China beyond green standards. Further investigation is necessary to determine how the incorporation of these new factors may impact future changes in China's green finance policy.

2.6 Conclusion

'Green finance' represents a 'green' shift in the financial system to promote low-carbon transitions. The development of green finance needs to be guided by public policies through a combination of regulations, economic incentives, and market-based mechanisms. This study provides a detailed interpretation of the development of China's green finance policy mix from both temporal and multilevel governance perspectives. It speaks to the literature on green finance policy by emphasising time and scale (or level of governance) as important elements in policy evolution.

The comprehensive document analysis conducted here reveals that the central government's FYPs have a dominant role in guiding policymaking in China. The development of green finance policies is closely aligned with the objectives of the FYPs, as they are designed to complement and fulfil them. We identify a temporal transitional process in China's green finance policy mix, characterised by a shift from direct public intervention and investment towards the construction of a green finance market. This involves placing greater emphasis on attracting private investment and financing and moving away from top-down intervention towards a market-based, polycentric approach with greater engagement and interaction with the private sector, including developing more market-based financial products (e.g. ETS, green bond) and motivating the participation of varied actors (e.g. insurance companies, angel investors, and venture capital). Moreover, the dynamic vertical interactions between different levels of government have also played an important role in this transition. For instance, local experimentation of green finance policies explores different development models for the local financial system against diverse local contexts, and these have, in turn, both influenced policy design of the central government and in some instances diffused to other jurisdictions.

In the past years, in response to rising demand for green finance stemming from strengthened climate and environmental governance, the Chinese government carried out significant efforts to develop green finance, including at a system level. The COVID-19 pandemic highlighted the importance of using green finance to enhance green investments to achieve climate-related goals, in parallel to responding to the global economic crisis, calling for more attention to new policy approaches. Despite noticeable progress made in green finance development in China, substantial challenges lie ahead, which include, but are not limited to, the integration of green standards, the re-translation of local experiences into central policy design and implementation, the need for active participation of non-state stakeholders, and the overall fostering of a market-based financial system.

2.7 References

Azhgaliyeva, D., Kapsaplyamova, Z., & Low, L. (2018). *Implications of fiscal and financial policies for unlocking green finance and green investment* (No. 861). ADBI Working Paper. Available at: https://www.adb.org/publications/implications-fiscal-financial-policies-unlocking-green-finance-and-green-investment.

Bernstein, J. D. (1993). *Alternative approaches to pollution control and waste management: regulatory and economic instruments*. Washington, DC: The World Bank.

Bhandary, R. R., Gallagher, K. S., & Zhang, F. (2021). Climate finance policy in practice: A review of the evidence. Climate Policy, 21(4), 529-545. https://doi.org/10.1080/14693062.2020.1871313

Bressers, J. T. A., & O'Toole, L. J. (2005). Instrument selection and implementation in a networked context. In P. Eliades, M. M. Hill, & M. Howlett (Eds.), *Designing government: from instruments to governance (pp. 132-153).* McGill-Quenn's University Press.

Capano, G., & Howlett, M. (2020). The knowns and unknowns of policy instrument analysis: Policy tools and the current research agenda on policy mixes. *SAGE Open*, *10*(1), 2158244019900568. https://doi.org/10.1177/2158244019900568

Capellán-Pérez, I., Campos-Celador, Á., & Terés-Zubiaga, J. (2018). Renewable Energy Cooperatives as an instrument towards the energy transition in Spain. *Energy Policy*, *123*, 215-229. https://doi.org/10.1016/j.enpol.2018.08.064

Colenbrander, S., Dodman, D., & Mitlin, D. (2018). Using climate finance to advance climate justice: the politics and practice of channelling resources to the local level. *Climate policy*, 18(7), 902-915. https://doi.org/10.1080/14693062.2017.1388212

David, M. (2017). Moving beyond the heuristic of creative destruction: Targeting exnovation with policy mixes for energy transitions. *Energy Research & Social Science*, *33*, 138-146. https://doi.org/10.1016/j.erss.2017.09.023

Di Stefano, G., Gambardella, A., & Verona, G. (2012). Technology push and demand pull perspectives in innovation studies: Current findings and future research directions. *Research policy*, *41*(8), 1283-1295. https://doi.org/10.1016/j.respol.2012.03.021

Dikau, S., & Volz, U. (2021). Out of the window? Green monetary policy in China: window guidance and the promotion of sustainable lending and investment. *Climate Policy*, 1-16. https://doi.org/10.1080/14693062.2021.2012122

European Commission (2017). Defining "green" in the context of green finance – final report. Brussels. https://ec.europa.eu/environment/enveco/sustainable_finance/pdf/studies/Defining%20Green%20in%20green%20finance%20-%20final%20report%20published%20on%20eu%20website.pdf

Eyraud, L., Wane, A. A., Zhang, C., & Clements, B. (2011). Who's going green and why? Trends and determinants of green investment. *IMF Working Papers*, 1-38.

Falcone, P. M., & Sica, E. (2019). Assessing the opportunities and challenges of green finance in Italy: An analysis of the biomass production sector. *Sustainability*, *11*(2), 517. https://doi.org/10.3390/su11020517

Filoche, G. (2017). Playing musical chairs with land use obligations: Market-based instruments and environmental public policies in Brazil. *Land Use Policy*, *63*, 20-29. https://doi.org/10.1016/j.landusepol.2017.01.012

Flanagan, K., Uyarra, E., & Laranja, M. (2011). Reconceptualising the 'policy mix'for innovation. *Research policy*, *40*(5), 702-713. https://doi.org/10.1016/j.respol.2011.02.005

Gilbert, S. and Zhao, L. (2017). The Knowns and Unknowns of China's Green Finance, Contributing paper for The Sustainable Infrastructure Imperative: Financing for Better Growth and Development. New Climate Economy, London and Washington, DC. Available at: http://newclimateeconomy.report/misc/working-papers.

Gosens, J., & Jotzo, F. (2020). China's post-COVID-19 stimulus: no green new deal in sight. *Environmental innovation and societal transitions*, 36, 250-254. https://doi.org/10.1016/j.eist.2020.07.004

Gramkow, C., & Anger-Kraavi, A. (2017). Could fiscal policies induce green innovation in developing countries? The case of Brazilian manufacturing sectors. Climate Policy, 18(2), 246-257. https://doi.org/10.1080/14693062.2016.1277683

Green Finance Committee (2021). A green finance roadmap study under a carbon neutral vision. http://www.greenfinance.org.cn/upfile/file/20210925213448_991183_73419.pdf.

Guild, J. (2020). The political and institutional constraints on green finance in Indonesia. *Journal of Sustainable Finance & Investment*, *10*(2), 157-170. https://doi.org/10.1080/20430795.2019.1706312

Guo, H., Davidson, M. R., Chen, Q., Zhang, D., Jiang, N., Xia, Q., & Zhang, X. (2020). Power market reform in China: Motivations, progress, and recommendations. *Energy Policy*, *145*, 111717. https://doi.org/10.1016/j.enpol.2020.111717

Hall, S., Foxon, T. J., & Bolton, R. (2017). Investing in low-carbon transitions: energy finance as an adaptive market. *Climate policy*, 17(3), 280-298. https://doi.org/10.1080/14693062.2015.1094731

Hong, R. (2020). Annual summary of China's carbon market 2019. Available at: http://www.tanjiaoyi.com/article-30146-1.html.

Howlett, M., & Rayner, J. (2007). Design principles for policy mixes: Cohesion and coherence in 'new governance arrangements'. *Policy and Society*, *26*(4), 1-18. https://doi.org/10.1016/S1449-4035(07)70118-2

Howlett, M., & Rayner, J. (2013). Patching vs packaging in policy formulation: Assessing policy portfolio design. *Politics and Governance*, *1*(2), 170-182. DOI: 10.12924/pag2013.01020170

Huang, P. (2019). The verticality of policy mixes for sustainability transitions: A case study of solar water heating in China. *Research Policy*, *48*(10), 103758. https://doi.org/10.1016/j.respol.2019.02.009

Huang, Y. P. (2022). *The value of finance: reform, innovation, regulation and our future.* Beijing, CITIC Press Group.

Jeucken, M. (2010). *Sustainable finance and banking: The financial sector and the future of the planet.* Routledge.

Ji, G., Kim, D. S., & Ahn, K. (2019). Financial structure and systemic risk of banks: Evidence from Chinese reform. *Sustainability*, *11(13)*, *3721*. https://doi.org/10.3390/su11133721

Jiang, X., & Green, C. (2018). China's future emission reduction challenge and implications for global climate policy. *Climate Policy*, 18(7), 889-901. https://doi.org/10.1080/14693062.2017.1388211

Karplus (2021). China's CO2 Emissions Trading System: History, Status, and Outlook. https://www.belfercenter.org/sites/default/files/files/publication/karplus-china-national-ets-june-2021-english.pdf

Kern, F., Kivimaa, P., & Martiskainen, M. (2017). Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Research & Social Science*, *23*, 11-25. https://doi.org/10.1016/j.erss.2016.11.002

Kidney, S., & Oliver, P. (2014). Developing China's green bond market. *IISD Report*. Available at: https://www.climatebonds.net/files/files/growing-green-bonds-ch.pdf.

Knill, C., Schulze, K., & Tosun, J. (2012). Regulatory policy outputs and impacts: Exploring a complex relationship. *Regulation & Governance*, *6*(4), 427-444. https://doi.org/10.1111/j.1748-5991.2012.01150.x

Kuhn, B. M. (2022). Sustainable finance in Germany: mapping discourses, stakeholders, and policy initiatives. *Journal of Sustainable Finance & Investment, 12(2),* 497-524. https://doi.org/10.1080/20430795.2020.1783151

Landry, P. F. 2008. *Decentralized Authoritarianism in China: The Communist Party's Control of Local Elites in the Post-Mao Era*. New York: Cambridge University Press.

Le Billon, P., Lujala, P., Singh, D., Culbert, V., & Kristoffersen, B. (2021). Fossil fuels, climate change, and the COVID-19 crisis: pathways for a just and green post-pandemic recovery. *Climate Policy*, 21(10), 1347-1356. https://doi.org/10.1080/14693062.2021.1965524

Lewis, J. I. (2010). The evolving role of carbon finance in promoting renewable energy development in China. *Energy Policy*, *38*(6), 2875-2886. https://doi.org/10.1016/j.enpol.2010.01.020

Li, L., & Taeihagh, A. (2020). An in-depth analysis of the evolution of the policy mix for the sustainable energy transition in China from 1981 to 2020. *Applied Energy*, *263,* 114611. https://doi.org/10.1016/j.apenergy.2020.114611

Li, M., Hamawandy, N. M., Wahid, F., Rjoub, H., & Bao, Z. (2021). Renewable energy resources investment and green finance: Evidence from China. *Resources Policy*, 74, 102402. https://doi.org/10.1016/j.resourpol.2021.102402

Li, T. T., Wang, K., Sueyoshi, T., & Wang, D. D. (2021). ESG: Research progress and future prospects. *Sustainability*, 13(21), 11663. https://doi.org/10.3390/su132111663

Lu, S. F., & Yao, Y. (2009). The effectiveness of law, financial development, and economic growth in an economy of financial repression: evidence from China. *World Development, 37(4), 763-777*. https://doi.org/10.1016/j.worlddev.2008.07.018

Matti, C., Consoli, D., & Uyarra, E. (2017). Multi level policy mixes and industry emergence: The case of wind energy in Spain. *Environment and Planning C: Politics and Space*, 35(4), 661-683. https://doi.org/10.1177/0263774X16663933

Milhorance, C., Sabourin, E., Le Coq, J. F., & Mendes, P. (2020). Unpacking the policy mix of adaptation to climate change in Brazil's semiarid region: Enabling instruments and coordination mechanisms. *Climate Policy*, 20(5), 593-608. https://doi.org/10.1080/14693062.2020.1753640

Mo, X. (2018). Promote green financial innovation and promote the development of clean energy industry. *14th China Energy Strategic Investment Forum*. Available at: https://www.china5e.com/news/news-1027896-1.html.

Munnings, C., Morgenstern, R. D., Wang, Z., & Liu, X. (2016). Assessing the design of three carbon trading pilot programs in China. *Energy Policy, 96, 688-699.* https://doi.org/10.1016/j.enpol.2016.06.015

Noh, H.J. (2019). *Financial Strategies to Accelerate Green Growth. Handbook of Green Finance. Sustainable Development*. Springer, Singapore, pp. 37–62.

OECD (2021), ESG Investing and Climate Transition: Market Practices, Issues and Policy Considerations, OECD Paris, https://www.oecd.org/finance/ESG-investing-and-climatetransition-Market-practices-issues-and-policy-considerations.pdf.

Ongaro, E., Gong, T., & Jing, Y. (2019). Toward multi-level governance in China? Coping with complex public affairs across jurisdictions and organizations. *Public Policy and Administration*, *34*(2), 105-120. https://doi.org/10.1177/0952076718799397

Papapanou, E. E. (2020). China as a Leader in Green Finance. In *Modern China* (pp. 107-120). Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-39204-8_9

Park, S. (2015). State renewable energy governance: Policy instruments, markets, or citizens. *Review of Policy Research*, 32(3), 273–296. https://doi.org/10.1111/ropr.12126

PBOC (2021). People's bank launches carbon emission reduction support tool. http://www.gov.cn/xinwen/2021-11/08/content_5649848.htm.

Peng, H., Luo, X., & Zhou, C. (2018). Introduction to China's Green Finance System. *Journal of Service Science and Management*, *11*(1), 94-100. doi: 10.4236/jssm.2018.111009

Qu, Z., & Tian, H. (July 2020). National Green Development Fund Co., Ltd. Established. *People's Daily*. Available at: http://paper.people.com.cn/rmrb/html/2020-07/16/nw.D110000renmrb_20200716_4-02.htm.

Rayner, J., Howlett, M., & Wellstead, A. (2017). Policy Mixes and their Alignment over Time: Patching and stretching in the oil sands reclamation regime in Alberta, Canada. *Environmental Policy and Governance*, *27*(5), 472-483. https://doi.org/10.1002/eet.1773

Reichardt, K., & Rogge, K. (2016). How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany. *Environmental Innovation and Societal Transitions*, *18*, 62-81. https://doi.org/10.1016/j.eist.2015.08.001

Ren, D., Li, Y., Shao, J., Feng, M., Jiang, X., Shi S., & Yin, J. (2020). Policy-driven or Market-driven? Calvulation of green finance development index and analysis of influencing factors based on text mining technology. *Southwest Finance 4, 78-89.*

Sachs, J.D., Woo, W.T., Yoshino, N., Taghizadeh-Hesary, F. (2019). Importance of Green Finance for Achieving Sustainable Development Goals and Energy Security. In: Sachs, J., Woo, W., Yoshino, N., Taghizadeh-Hesary, F. (eds) *Handbook of Green Finance. Sustainable Development.* Springer, Singapore. https://doi.org/10.1007/978-981-13-0227-5_13

Schreurs, M. (2017). Multi-level climate governance in China. *Environmental Policy and Governance*, *27*(2), 163-174. https://doi.org/10.1002/eet.1751

Scordato, L., Klitkou, A., Tartiu, V. E., & Coenen, L. (2018). Policy mixes for the sustainability transition of the pulp and paper industry in Sweden. *Journal of Cleaner Production*, 183, 1216-1227. https://doi.org/10.1016/j.jclepro.2018.02.212

State Council of the People's Republic of China (2021). Opinions on the accurate implementation of the new development concept to achieve carbon peaking and carbon neutrality. http://www.gov.cn/zhengce/2021-10/24/content_5644613.htm.

Taghizadeh-Hesary, F., Yoshino, N., & Phoumin, H. (2021). Analyzing the characteristics of green bond markets to facilitate green finance in the post-COVID-19 world. *Sustainability*, 13(10), 5719. https://doi.org/10.3390/su13105719

The People's Bank of China (2016). Guidelines for Establishing the Green Financial System. http://www.pbc.gov.cn/english/130721/3133045/index.html.

Tosun, J., & Rinscheid, A. (2020). The Clean Energy Ministerial: Motivation for and policy consequences of membership. *International Political Science Review*, 0192512120942303. https://doi.org/10.1177/0192512120942303

Vedung, E., Bemelmans-Videc, M., & Rist, R. (1998). Policy instruments: typologies and theories. *Carrots, sticks, and sermons: Policy instruments and their evaluation*, *5*, 21-58.

Wang, X., & Wang, Y. (2021). Research on the Green Innovation Promoted by Green Credit Policies. *Management World, 6, 173-188.*

Welling, A. (2017). Green Finance: Recent developments, characteristics and important actors. *FEMM Working Papers 170002*, Otto-von-Guericke University Magdeburg, Faculty of Economics and Management.

Wellstead, A., Rayner, J., & Howlett, M. (2016). Alberta's oil sands reclamation policy trajectory: the role of tense layering, policy stretching, and policy patching in long-term policy dynamics. *Journal of environmental planning and management, 59(10),* 1873-1890. https://doi.org/10.1080/09640568.2015.1098594

Wüstenhagen, R., & Menichetti, E. (2012). Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. *Energy Policy*, *40*, 1-10. https://doi.org/10.1016/j.enpol.2011.06.050

Xu, G., & Gui, B. (2019). From financial repression to financial crisis? The case of China. *Asian-Pacific Economic Literature*, *33(1), 48-63*. https://doi.org/10.1111/apel.12249

Xu, L., & Su, J. (2016). From government to market and from producer to consumer: Transition of policy mix towards clean mobility in China. *Energy Policy*, *96*, 328-340. https://doi.org/10.1016/j.enpol.2016.05.038

Xu, X., & Li, J. (2020). Asymmetric impacts of the policy and development of green credit on the debt financing cost and maturity of different types of enterprises in China. *Journal of Cleaner Production, 264*, 121574. https://doi.org/10.1016/j.jclepro.2020.121574

Zadek, S., & Flynn, C. (2013). South-originating green finance. Available from: https://doc.rero.ch/record/208970/files/06-south-originating.pdf.

Zhang, D., Zhang, Z., & Managi, S. (2019). A bibliometric analysis on green finance: Current status, development, and future directions. *Finance Research Letters*, *29*, 425-430. https://doi.org/10.1016/j.frl.2019.02.003

Zhang, S., Wu, Z., Wang, Y., & Hao, Y. (2021). Fostering green development with green finance: An empirical study on the environmental effect of green credit policy in China. *Journal of Environmental Management*, 296, 113159. https://doi.org/10.1016/j.jenvman.2021.113159

Zheng, Y. 2006. “Explaining the sources of de facto federalism in reform China: intergovernmental decentralization, globalization, and central-local relations.” *Japanese Journal of Political Science* 7 (2): 101. doi:10.1017/S1468109906002222.

Zhou, Y., Evans, M., Yu, S., Sun, X., & Wang, J. (2020). Linkages between policy and business innovation in the development of China's energy performance contracting market. *Energy Policy*, 111208. https://doi.org/10.1016/j.enpol.2019.111208

3 Implementation gap of China’s environmental policies: Logic behind the over-implementation of the Coal to Gas transition*

Abstract. China has implemented numerous energy-related policies to tackle environmental and energy challenges, but not all policies have yielded desired outcomes. While policy failure due to insufficient implementation is often highlighted, less attention has been given to the issue of over-implementation. In the last decade, China has experienced a process of power recentralization, which has brought about systemic changes in environmental policy implementation. Over-implementation has emerged as a prevalent phenomenon in environmental governance. The questions thus arise are: why does over-implementation happen? What are the consequences? This study examines the phenomenon of policy over-implementation within China's environmental governance system, using the coal-to-gas clean heating project as a case study. The findings reveal that China's recentralization efforts have addressed long-existing root problems in the environmental governance system. The strong environmental commitment from the central government, coupled with authoritarian pressure and positive incentives, has resulted in local implementers self-reinforcing for better career prospects, leading to over-implementation of policies. However, such authoritarian enforcement may overlook conflicts at the street bureaucratic level and opposition from those affected by the policies, potentially causing social injustice.

3.1 Introduction

China’s economic growth has been accompanied by high energy and environment costs. As the world's largest energy consumer and carbon dioxide (CO2) emitter, China is facing severe energy and environmental challenges (Heggelund, 2021). The burning of coal, which accounted for approximately 58% of China's total energy consumption in 2019 (Wang, 2019) is a major contributor to CO2 emissions and a leading cause of severe air pollution in the country. As such, transitioning to renewable energy sources and implementing energy-efficient practices not only allows China to tackle its energy and environmental issues, but also plays a crucial role in global climate change mitigation and the improvement of public health. As concerns over pollution and climate change has escalated alongside the substantial energy demand of economic growth, the Chinese central government has sought measures to overcome the country's energy-environmental dilemma (Lo, 2015). Numerous energy-related policies have been enacted to reduce the country’s dependency on coal, prioritise investment in renewable energy, and enhance energy efficiency.

However, despite the best intentions behind policy formulation, not all policies yield the desired outcomes. Policy implementation is one of the general factors that cause policy failure, as it largely determines the effectiveness of a policy system (Tosun, 2012). In fact, implementation gap poses a

*Published in *Journal of Environmental Policy & Planning*, 2023, Taylor & Francis.

significant challenge to environmental governance (Schreifels et al., 2012). Studies on implementation gap attempt to explore why and how policies deviate from their intended outcomes (Signé, 2017). Existing literature primarily focuses on explaining the weak and inefficient enforcement of policies, commonly known as under-implementation (van Rooij, 2006). Scholars have argued that factors such as the distribution of authority (O'Brien & Li, 1999), conflicts of interest across different levels of government (Van Rooij, 2006), China's fragmented vertical and horizontal governance structure (Kostka, 2014) and local incentive structure (Ran, 2013) may impede the implementation of environmental policies, resulting in under-implementation.

Under China's authoritarian regime, policy over-implementation is a well-known phenomenon in certain areas such as anti-corruption and the response to COVID-19 crisis (Cai et al., 2021). However, in the field of environmental governance, this phenomenon is relatively new and has emerged over the last decade. Despite extensive literature on policy under-implementation, there is a limited amount of research focusing on over-implementation, which forms the opposing pole of implementation deficit to under-implementation. This study aims to fill this research gap by examining the reasons behind the occurrence of over-implementation. Additionally, this study explores whether there have been systemic changes in the implementation of local environmental policies in China, leading to a shift from under-implementation to over-implementation.

Policy over-implementation in China is often associated with an authoritarian approach. Scholars have classified China's environmental governance as authoritarian environmentalism (Eaton & Kostka, 2014), highlighting the role of a strong central power in ensuring rapid and effective implementation of environmental policies. In recent years, the centralized reform of China's environmental governance system has been driven by the power recentralization of the central government and its strong environmental commitment since 2012 (Kostka & Nahm, 2017). These changes have resulted in significant improvements in the local implementation of central environmental policies and occasional instances of over-implementation of environmental policy. However, the question remains whether China has overcome the fundamental challenges of inefficient environmental governance through environmental recentralization.

The issue of social justice stemming from environmental authoritarianism has garnered scholarly attention, as it is widely acknowledged that the top-down and non-participatory decision-making processes in environmental authoritarianism can result in a trade-off between rapid environmental response and the protection of individual freedoms and rights (Jia & Chen, 2019; Hu, 2020; Lo, 2021). This trade-off creates a heightened tension between environmental governance and social justice, as local governments are incentivized to prioritize efficiency over the interests of residents (O'Brien & Li, 1999). For instance, during the 13th FYP period (2015-2020), some provinces resorted to counterproductive and short-term strategies, such as electricity supply cuts, to achieve the "double control" targets, which aimed to control energy intensity and total energy consumption. [1]Environmental authoritarianism may aggravate existing inequalities and further marginalizes disadvantaged social groups (Lo, 2021).

This study aims to investigate the reasons behind the over-implementation of China's environmental policies and the resulting consequences. Focusing on the coal-to-gas clean heating program (CTG), it explores how China's environmental policy implementation has addressed longstanding challenges in the environmental governance system, leading to over-implementation. The study also examines the consequences of authoritarian enforcement and policy over-implementation. The findings underscore the contextual change, higher political pressure, administrative benefit and economic incentives in reshaping the interactions between multilevel governments and the behaviour of local implementers. However, an authoritarian approach may disregard the conflicts that arise at the street bureaucratic level and the opposition from policy receivers, leading to potential social injustice.

The contribution of this paper is threefold. Firstly, it addresses the research gap on policy over-implementation, expanding the understanding of implementation gaps in environmental policies. Secondly, it enriches the literature on the influence of contextual changes on policy regime and implementation, advancing implementation gap theories. Thirdly, it provides insights into the debate on recentralization in China's environmental governance and its impact on policy outcomes, while also shedding light on issues of injustice and energy poverty caused by authoritarian environmentalism (Jia & Chen, 2019; Hu, 2020; Fan et al., 2022). The findings of this study have significant implications for the study of implementation gaps, authoritarian environmentalism in China, and the successful implementation of environmental policies.

The rest of the paper is structured as follows. Section 2 provides theoretical rationales and analytical framework. Section 3 describes the methods and data used. Section 4 conducts an analysis of the case study on CTG. Finally, Section 5 discusses and concludes the main findings.

3.2 Theoretical rationales and framework

3.2.1 Implementation gaps in environmental governance

The success or failure of a policy is heavily influenced by its implementation strategy (Durlak and DuPre, 2008; Knill & Tosun, 2020). Scholars have extensively studied policy implementation outcomes and have developed theories of implementation failures through case studies (Hogwood & Gunn, 1984). Numerous analytical frameworks have emerged in "implementation gap" research, including top-down, bottom-up, and comprehensive approaches (Sabatier, 1986; Lipsky, 1980; Goggin, 1990). The implementation gap refers to the difference between a policy's intended objectives and its actual results, as policies may suffer from delayed implementation or unintended consequences (Palfrey, 1999). The literature has identified several factors that contribute to unsuccessful implementation, including overly

[1] Three reasons behind the impact of China's power cuts and restrictions on residents' lives (BBC News).

optimistic expectations and ambiguous policy design (Hudson, 2019), diverse perceptions of policy goals and the preferences of implementers in dispersed governance (May & Winter, 2007), policy resources and agency capacity (Van Meter & Van Horn, 1975), incentive structures (Ran, 2013), and intergovernmental relations (van Rooij, 2006).

The issue of policy implementation gaps in environmental governance is a significant challenge in China (Zhang & Cao, 2015). While the central government in China recognizes the importance of addressing environmental issues and has implemented a range of policies to tackle them, many of these policies have faced difficulties in achieving their intended outcomes, resulting in an implementation deficit (Zhan et al., 2014). Several scholars ascribe this to institutional constraints, particularly the distribution of authority and the incentive structure (van Rooij, 2006; Ran, 2013).

China's approach to environmental governance is dominated by a powerful party-state and a reliance on command and control instruments (Liu et al., 2012). However, scholars argue that the effectiveness of environmental policies and authoritarian central power is usually offset by the dispersion of implementation, as local bureaucracies often prioritize their own interests and lack the motivation to implement environmental policies (Ahlers & Shen, 2018). The decentralization reform initiated in the 1980s led to a “decentralised authoritarian regime” (Zheng, 2006; Landry, 2008), which has posed challenges for policy implementation at the subnational level. Fiscal decentralisation in 1994 has created financial competition among local governments, leading them to prioritize economic development over environmental concerns (van Rooij, 2006). Despite the issuance of environmental standards by the central government, these standards have had limited impact on local environmental conditions, as subnational governments often lower them to attract capital (Luo & Ling, 2020). Therefore, the decentralised authoritarian regime has created disincentives for environmental policy implementation, resulting in policy conflicts and under-implementation due to conflicting interests between different levels of governments often (Wang & Lin, 2010).

3.2.2 Recentralisation and over-implementation

Policy regime theory emphasizes the significance of incorporating politics into the understanding policy implementation, as political context influences policy legitimacy, coherence, and durability (May & Jochim, 2013; Liu et al., 2015). Over the past decade, China has experienced both political recentralization and changes in environmental governance. Under the leadership of Xi Jinping, measures have been implemented to increase the central government's control over local actors by reducing the powers and discretion of local governments, recentralising administrative control, and introducing new monitoring and sanctioning practices (Kostka & Nahm, 2017). Concurrently, the central government has shifted its focus from pursuing economic growth to prioritising sustainable development (Hansen et al., 2018). Consequently, the central government has demonstrated a stronger commitment to environmental protection and employed more authoritarian and top-down approaches to policy enforcement (Lo, 2021).

The contextual changes have led to positive shifts in the implementation of environmental policies, addressing some fundamental issues associated with China's decentralized authoritarian regime, including conflicts between different levels of government. Figure 3.1 presents the conceptual framework illustrating the transformed dynamics of environmental policy implementation resulting from the recentralization of power and increased environmental commitment in China. The opposition from local stakeholders to environmental policies, arising from conflicting interests and institutional fragmentation, may diminish as higher-level governments demonstrate a stronger commitment to environmental protection (Liu et al., 2018). Three mechanisms contribute to explaining the reshaping of these interactions.

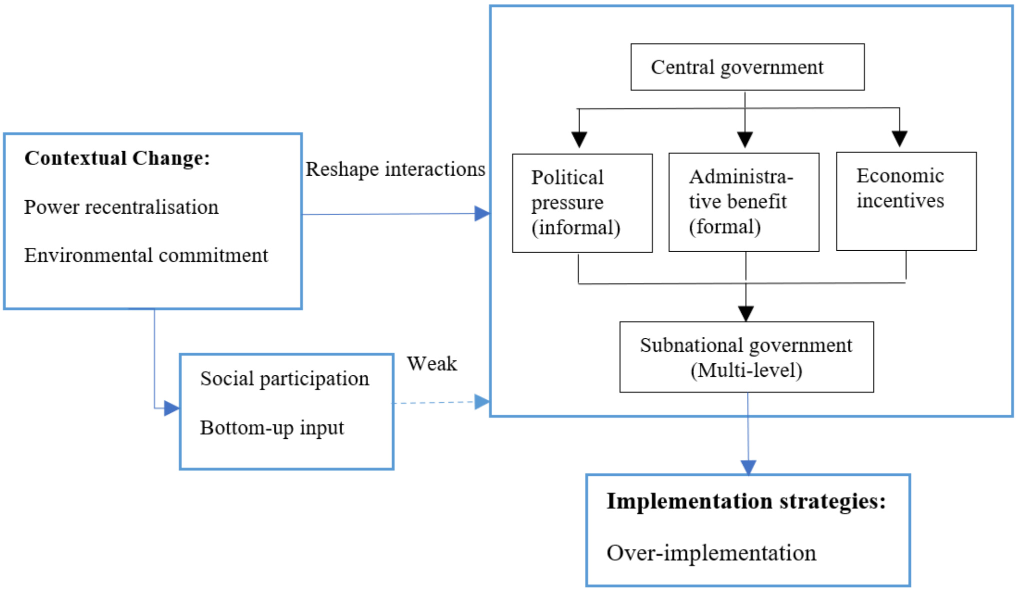


Figure 3.1. Conceptual framework.

Political pressure

Existing literature highlights the significant influence of political factors on China's environmental performance. As a unitary system led by the Communist Party of China (CPC), the central government and CPC utilize “political philosophy” (*zheng zhi li nian*) to regulate and mobilize subnational governments. This guiding ideology serves as the fundamental framework for implementing policies (Zhu & Moser, 2014). Consequently, effective policy programs are often driven and supported by explicit political efforts rather than relying solely on legal mechanisms (Eaton & Kostka, 2014). However, this influence operates informally. Environmental protection in China has been positioned as a political imperative by the government. The recentralization reforms have signalled the central government's strong commitment to environmental protection, thereby motivating them to faithfully implement environmental policies. Subnational government officials, driven by their career aspirations, often engage in self-reinforcement strategies, demonstrating a behaviour of “political awareness” or “high political sensitivity” (Zhu, 2012).

However, subnational governments are also facing an "over-mobilization problem" as they seek to elevate their governance goals and establish more stringent assessment mechanisms during policy implementation process. The increasing political pressure, which cascades down the hierarchy, often undermines the hierarchical incentive logic based on "order-obey" and "assessment-incentive," reflecting the internal dynamics of self-reinforcement among local officials. Furthermore, the authoritarian approach and limited participation or bottom-up input in the policymaking process often overlook the conflict of interest among policy makers, implementers, and policy recipients. The pursuit of policy efficiency often comes at the cost of curtailing individual freedoms and rights (Hu, 2020). In the process of recentralisation, the resurgence of central government power may also have a "crowding-out effect" on citizen participation and market mechanisms (Beeson, 2010).

Administrative benefit

The central government mobilizes subnational government formally through its administrative system. The career advancement for Chinese government officials relies heavily on the approval and recommendations from higher-level leadership (Li et al., 2019). In the recentralization process, the central government has strengthened the evaluation of local officials, thereby reinforcing its power. This has intensified the "yardstick competition" where lower-level officials compete for promotion based on their performance evaluations (Caldeira, 2012). Consequently, local officials are incentivized to not only perform well but also outperform their competitors by setting higher targets than those set by higher-level governments. In recent years, the central government has increased the importance of the ecological environment in the assessment of officials by raising the proportion of ecological indicators in overall performance evaluations, implementing the environmental protection target responsibility system, and implementing the "one vote veto" in ecological environment assessments (Kostka & Nahm, 2017). The introduction of penalty mechanisms and promotion pressure has compelled local governments to prioritize environmental protection and achieve the targets set by higher-level governments.

Furthermore, the recentralization of environmental governance in China has not only consolidated power in the environmental sector, but has also facilitated intersectoral collaboration, addressing the issue of administrative fragmentation. This is evident in the increased power of environmental bureaucratic agencies, which have become more centralized at the provincial level, and the adoption of campaign-style enforcement in environmental governance over the past decade. By mobilizing administrative resources and all actors, campaign-style enforcement can overcome the fragmentation typically associated with hierarchical governance and help establish sustainable cooperation mechanisms (Jia & Chen, 2019).

Economic incentives

Local governments heavily depend on central fiscal incentives and their own financial resources to carry out environmental policies. In order to promote and support local governments in enhancing environmental protection, the central government employs a range of strategies. Transfer payments are utilised as a mechanism to offset the opportunity costs associated with environmental protection, effectively aligning the interests of both central and local authorities in environmental preservation.

Additionally, the central government provides economic support in the form of subsidies and rewards for the implementation of environmental policies. The level of budgetary support and the size of the subsidy or reward received by local governments are contingent upon their spending and performance. Consequently, local governments engage in competition to complete more projects and secure larger subsidies, which are then incorporated into their local fiscal systems. With the recentralization of power and a stronger commitment to environmental protection, the central government has consistently increased transfer payments, incentives, and subsidies, including the establishment of special funds dedicated to local environmental protection (Zhou, 2018). These measures serve as effective motivators for local governments to actively implement environmental protection policies.

3.3 Methodology

3.3.1 Case selection

This study focuses on the implementation of the CTG policies in China. Energy-related pollution has been a persistent environmental issue in the country, and the reduction of coal usage has been considered as an option to address air pollution (Heggelund, 2021). In response to the worsening smog problem, China launched the Air Pollution Action Plan (2013-2017) during the 12th Five-Year Plan period, with the aim of improving air quality within five years. As part of this plan, the CTG clean heating program was implemented to phase out the use of bulk coal for heating in rural areas of Northern China (Zhang et al., 2021). The central government initiated a campaign-style enforcement of CTG in 2017 to achieve the environmental goals set by the 2013 Action Plan (Hu, 2020). However, the implementation of CTG has also resulted in issues such as over-implementation, gas shortages, and inequity (Xie et al., 2022).

3.3.2 Data collection

This study employed a combination of secondary and primary data. The analysis primarily relied on publicly available secondary data, which were sourced from governmental websites, social media, local newspapers, academic literature, and other public texts. In addition to secondary data, primary data was collected through 13 semi-structured interviews. The interviews were conducted in two cities from, Yantai in Shandong province and Duandian Township in Linfen, Shanxi province. The interview participants included three villagers from Lvjiagou Village, one government official from the Housing and Urban-Rural Development Administration of Fushan District, two village heads from the government office of Gaotong town. In the jurisdiction of Duandian Township, participants included one city-level official from Linfen Environmental Protection Bureau (EPB), three township-level officials from Duandian Township, one village head, and two villagers from Xideng village.

The data collection for this study has certain limitations. While primary data from semi-structured interviews were collected, they alone were not sufficient to form the main data of this study. Moreover, the sample did not include some important actors such as national and provincial level officials, natural gas companies and installation enterprises. As a result, secondary data were used as the main data, and primary data were used to supplement it. To ensure accuracy, sufficient secondary data were collected to cross-check all the important information presented in this study.

3.4 Analysis and results

CTG is a state-led initiative to reduce bulk coal consumption in the heating sector by replacing it with natural gas, thereby improving air quality and reducing emissions. The project was initiated in 2013, implemented in early 2017, suspended shortly later that same year due to problems related to over-implementation, and is currently operational in certain provinces. Although the project was designed with good intentions and fully implemented by local governments, the over-implementation caused by the authoritarian enforcement style led to gas shortages and social injustice (Hu, 2020).

3.4.1 The policy implementation process

In 2013, the Chinese State Council issued an *"Action Plan for the Prevention and Control of Air Pollution"* to combat smog. This plan set out clear targets for air quality improvements in specific areas over a five-years period. Addressing coal consumption was a key focus of the plan. However, despite the plan's objectives, air pollution remained a serious problem by 2017, the year set for assessment (Wang & Ren, 2021). In light of this, the Chinese government regarded the CTG project as a necessary policy to be implemented if the country was going to achieve clean heating.

In 2017, a series of policy documents was issued to facilitate the successful implementation of the CTG project. The guiding documents included the *"2017 Work Plan for Air Pollution Prevention and Control in Jing-Jin-Ji and Surrounding Areas" and a "Notice on the Central Financial Support of Clean Winter Heating Pilot in Northern Areas"*. These policies chose "2+26" cities (presented in Appendix B.1) as pilots for implementing the CTG project. According to the project goal, six provinces and cities were required to complete a target of 300,000 (Beijing), 290,000 (Tianjin), 1.8 million (Hebei), 390,000 (Shanxi), 350,000 (Shandong), and 420,000 (Henan) households' worth of coal-to-gas-conversion respectively (Ministry of Environment Protection (MEP), 2017).

All these provinces created detailed plans to restructure clean heating (coal-to-gas) and allocated targets to local municipalities, enabling them to develop action plans accordingly. Under the pressure of achieving project goals, all levels of local governments set higher targets than their allocated targets, which resulted in the conversion rates far exceeding the central government's plans (Wang, 2018). For example, in Hebei province, the total CTG conversion rate, which is a sum of the targets set by the local governments, reached 2.56 million households' worth (Wang & Ren, 2021), which accounted for 142% of the target set by the central government. By the end of October 2017, Hebei had completed the conversion of 2.3 million households, exceeding the central target by nearly 30% (Yu, 2017). Similarly, other provinces achieved about 162% of the target set by the central government for 2017 (Ma & Wei, 2018). This over-implementation reflects the pressure faced by local governments to demonstrate progress and meet ambitious goals.

However, many problems arose during the CTG project, of which the most severe was a gas shortage. In 2017, the gas demand from industries, civilian usage, and power generation increased while the gas supply decreased. The CTG project further exacerbated the imbalance between supply and demand. Data revealed that daily gas consumption in December 2017 increased by 20% on the previous year over the same period, with the CTG project contributing approximately 30% of the new demand (Gao, 2017). This led to a severe "gas shortage" in northern China during the winter of 2017, which spread to the middle region of the country and a few provinces in the south (Huang & Liu, 2021). In November 2017, Hebei issued an orange warning (level 2 warning) for gas supply, which entails reducing or stopping gas supply by order of the provincial government (Dong, 2017). Southern regions such as Hunan, Hubei, and Jiangxi were also affected by the gas shortage. In December 2017, the MEP issued an urgent document to suspend the CTG project in winter, allowing coal burning again to alleviate the "gas shortage" (MEP, 2017).

In 2018, the CTG program experienced a slowdown, but it continued in 2019 with the release of a new three-year plan (Hu, 2020). However, challenges such as gas shortage and high heating costs also continued (Clean Heating Industry Committee, 2021). In July 2019, the National Energy Administration issued the "*Notice on Addressing Issues Related to the Promotion of Coal-to-Gas, Coal-to-Electricity and Other Clean Heating*". It proposed a shift away from the campaign-style enforcement of the CTG program and advocated for a more flexible approach that takes into account local conditions. This change marked a departure from the previous "one-size-fits-all" approach to clean heating implementation.

3.4.2 The logic of over-implementation

CTG is a campaign that took place during a significant shift in China's environmental governance. The central government has demonstrated a strong commitment to ecological civilization and environmental protection since 2012. As a result, the incentive system for local governments has undergone restructuring, placing greater emphasis on meeting environmental targets (Kostka & Nahm, 2017). In 2014, China implemented the strictest responsibility and assessment system for air quality management, which made the achievement of air quality improvement a mandatory assessment indicator and introduced a "one-vote veto" mechanism. In 2016, a central environmental protection inspection system was launched to monitor local implementation of environmental policies and regulations (Jia & Chen

2019). The *"Action Plan for the Prevention and Control of Air Pollution"* was launched in response to the mounting pressure placed on local governments.

The “Action Plan” set a target of controlling the annual average PM2.5 concentration in Beijing at 60 micrograms per cubic meter by 2017. However, according to the 2016 interim assessment conducted by the MEP, the existing approach was insufficient to achieve this target (MEP, 2016). Bulk coal burning was identified as one of the primary sources of pollution (Liu et al., 2016). Government officials who failed to meet the emissions targets faced rectification and suspension from office. Thus, to meet the emissions targets, the CTG project was employed as a strategy to mitigate pollutants produced by coal burning, as gas conversion proved to be effective in this regard (Hu, 2020). The implementation of target responsibility and accountability has had a significant impact on local governments who previously prioritized economic growth over environmental protection. This approach sends a clear message that environmental policies must be implemented without selective enforcement. The Linfen EPB official mentioned that: “*the mayor just had an admonishing talk (yuetan)*[*] *with the MEP due to the deteriorating air quality before the coal-to-gas conversion was implemented, so we definitely had to act aggressively*.”

The CTG project's low level of conflict between the policy designer (central government) and policy re-designers (provincial and municipal governments) has facilitated its extensive roll-out. The author's survey revealed that the over-achievement of CTG conversion was largely due to the provincial and municipal governments' autonomy to increase the task targets during the policy interpretation and redesign process. Unlike many other environmental policies that directly impact local enterprises and economies, the CTG programme targeted the clean heating for households, thereby avoiding any harm to local development and generating positive policy benefits, considering that environmental governance is a local government responsibility. Additionally, as the procurement of gas equipment is often contracted by local companies, the CTG project was perceived as an opportunity for related local industries to benefit and contribute to local economic growth. As an official from Fushan District explained, *"We have to procure our gas fireplaces through a tender process, but the bidders are mainly local companies. We require bidders to have after-sales maintenance sites within the local area; although it's more difficult for foreign companies, this requirement is necessary for the convenience."*

To further reduce the conflict, the central government provided financial incentives. Substantial financial subsidies and awards were allocated to local CTG projects, creating an additional motivation for local governments. Beijing and Tianjin were eligible to receive an annual subsidy of one billion RMB, while provincial capitals could receive 0.7 billion RMB annually, and other cities could receive 0.5 billion RMB annually (Ministry of Finance, 2017). These incentives, combined with the low conflict level, led to local governments setting more ambitious targets than those set by the central government

[*] To enhance the environmental governance of local governments and promote greater accountability, the MEE initiated a system of administrative admonishing talks starting in 2014. These talks were conducted with local government leaders who were identified as having insufficient implementation of environmental policies.

(Wang, 2018). As pointed out by an official from Duandian Township, *"Any locality will want to take advantage of subsidies to step up their efforts, because the subsequent subsidy support policy is not yet clear."* However, this proactivity ultimately led to over-implementation.

The CTG project benefitted from an empowered and centralized governmental bureaucracy, which effectively addressed institutional fragmentation and fostered intersectoral collaborations during implementation. This was achieved through a redistribution of power that increased the authority of higher-level environmental agencies in appointing personnel and overseeing lower-level environmental agencies. Simultaneously, it reduced the influence of local governments over environmental agencies of similar status (Jia & Chen, 2019). Local environmental protection departments were granted more authority to coordinate with other government departments in implementing environmental policies. Interviews revealed that the local environmental protection department, acting as the coordinating department through the "inter-ministerial joint meeting" mechanism, played an active role in promoting the CTG project.

The excessive roll-out of the CTG project can also be attributed to the mobilization capacity of an authoritarian regime. The central government's clear support and the top-down pressure from environmental authoritarianism create a strong political incentive for lower levels of government. Multiple policy documents have been issued by the central government to assign task goals and establish strict assessment systems for ministries, provinces, and municipalities. These policy objectives are considered political tasks, aiming to enhance local motivation for policy implementation. The pressure to achieve environmental targets can be intense, as exemplified by an EPB official: "*we had one leader preferred to fabricate data rather than admit that the target was not met*." Lower-level local governments tend to engage in self-reinforcement for career advancement, demonstrating a behaviour of “political awareness” or “high political sensitivity” (Zhu, 2012).

Furthermore, the result-oriented control in China's current administrative performance appraisal mechanism grant local governments autonomy in implementing policies (Wu et al., 2017), which activates their proactivity and prioritization of short-term interests. The CTG project serves as an example of this trend, as it was planned and executed within a span of 10 months using top-down approaches such as cascading, tasking, and fast-tracking of policy implementation. Moreover, political mobilization was utilized to concentrate resources and efforts towards achieving specific objectives. An official from Duandian Township confirmed that many cadres feel that *“achieving more work brings political achievements (Zhengji), while less work may lead to criticism from superiors. As a result, the cadres responsible for this project are very active.”* The over-implementation of the CTG project is a result of multiple factors, including strong environmental commitment from the central government, intense top-down political pressure, favourable financial incentives, administrative performance appraisal mechanism, self-reinforcing pursuits of local implementers, and a high level of state control over society in the context of recentralization of environmental authoritarianism.

3.4.3. Varieties of conflicts and injustices

While recentralisation can help resolve conflicts between environmental policy designers and re-designers, it may introduce new conflicts among local implementers at different levels. As part of its enforcement of CTG, The Chinese central government allocated targets to provincial governments, who then distribute detailed tasks to municipal, county and township governments and local cadres (Zhang, 2020). The increased targeting by provincial and municipal governments in translating higher-level policies and setting policy targets for lower levels of government is the main cause of the over-implementation of CTG. Local cadres, responsible for ground-level implementation, have the least discretionary power but face the highest pressure, as stated by a local cadre in Gaotong town: *"The decision on which village to implement coal-to-gas conversion is made by the province, and all villagers have to participate. We (local cadres) are only responsible for implementation. But the villagers do not cooperate, and our work is very difficult."*

The CTG project is a highly centralized decision-making process that excluded the participation of ground-level implementers. The upper levels of government imposed significant pressure on lower levels due to the tight schedule and heavy workload. In the case of Duandian Township, since October 2020, the responsibility for coal-to-gas conversion was entrusted to the township government, which then assigned tasks to regional heads and administrative village cadres through target responsibility letters. To ensure progress, the township government formed an inspection team to provide daily feedback on CTG conversion, and the work was integrated into the assessment system for township and village cadres. "Zeroing in on bulk coal burning" became a “hard” target. Failure to achieve the target within the stipulated timeframe would face rectification for local cadres, while villages that completed the requirements on time would receive financial incentives. Driven by this top-down pressure, Duandian Township completed the clean heating renovation for all 34 administrative villages, totaling 11,482 households, in a remarkably short period of six months.

Conflicts not only arise between policy designers and implementers but also between implementers and recipients, resulting in various challenges during the implementation of the CTG project. One notable issue is the gas shortage, which led to the suspension of industrial and commercial gas use in certain cities, and a rapid increase in gas prices. Additionally, some local governments failed to fulfil their subsidy commitments due to over-implementation of the policy (Qi & Xiao, 2019). In more extreme cases, individuals like a construction worker in Xinzhou, Shanxi, faced administrative detention for burning coal outdoors for heating (Liu, 2017). Villagers express concerns about the rising cost of heating, as gas subsidies are insufficient to cover the additional cost. The high price of natural gas makes heating more expensive than coal. As one villager mentioned, *"We usually use it for cooking, but we can't really afford to use it for heating. In rural areas with large rooms, it costs at least 50 yuan a day to heat rooms with gas, and even more if you want to get warmer."* Another villager mentioned that *“some households in their village still do not have gas connections even after two years. People purchase additional stoves to burn coal, which is not as strictly enforced as before.”*

The conflicts that emerged during the implementation of CTG project failed to impede its excessive expansion. Scholars often analyze China's environmental policies through the lens of authoritarian environmentalism, which differs from the democratic approach that prioritizes public participation, decentralization, and civil society's role in environmental governance (Beeson, 2010). Authoritarian environmentalism involves the central government's authoritative control over local governments and the state's domination over society, restricting individual liberties and public participation (Gilley, 2012). The priorities of the authorities may not necessarily align with those of other stakeholders, even if the latter are the ones directly affected by the policies. Unlike in an electoral system, the Chinese authoritarian system holds local governments accountable to their superiors rather than their constituents. Consequently, local governments prioritize conflicts with their superiors over those with policy beneficiaries. Other stakeholders who are affected by the policies are often compelled to accept them passively. This practice is deeply ingrained in China's longstanding authoritarian regime which inevitably leads to injustice for these stakeholders.

3.5 Discussion and conclusion

In China, resource limitations often lead local governments to prioritize certain policies over others (O'Brien & Li, 1999). The interest conflicts between government levels, power discretion, poorly designed incentive mechanism and institutional fragmentation often result in under-implementation of environmental policies (Schreifels et al., 2012; van Rooij, 2006; Wang & Lin, 2010; Ran, 2013). However, recent centralization reforms have brought about some changes in this context. When the central government shows strong commitment to environmental protection, sets hard targets, and offers significant incentives, the interest conflicts between government levels may shift. Under high top-down pressure, local governments will be forced to prioritize certain policies according to the central preference and mobilize all available resources to meet the assigned targets. Furthermore, when a higher level of government initiates a governance campaign, local governments may tend to over-implement certain policies to enhance their political achievements and compete with other governments.

This study sought to pinpoint the logic behind the over-implementation of energy-related environmental policies in China, focusing on the case of the CTG project. It investigates how policy implementation overcomes long-standing problems in the environmental governance system, leading to over-implementation. It argues that the context of environmental governance recentralisation and stronger environmental commitment have reshaped the interactions between multilevel governments. Policy over-implementation can be attributed to several factors, including political pressure, administrative benefit, positive economic incentives, combined with a high degree of state control over society in the context of environmental authoritarianism.

It is important to recognize that recentralization can increase the likelihood of over-implementation, although it is not always the outcome. Over-implementation tends to occur in areas that are explicitly prioritized by the central government and face significant pressure from higher levels of government, particularly in environmental issues, also can be seen at the COVID-19 response. The occurrence of over-implementation is influenced by a combination of power pressure and operational discretion, reflecting the awareness and self-reinforcement of lower levels of government towards the concerns of the central government or higher levels of government. Subnational officials continuously adapt their strategies to align with the policy priorities of the central government and allocate limited resources accordingly.

However, the centralized policy-making process that excludes the participation of local implementers fails to address conflicts at the street bureaucratic level. The authoritarian enforcement of policies also disregards opposition from policy receivers, potentially causing harm to certain social groups and communities and perpetuating social injustice and inequality. When the interests of non-participants are affected, they may seek to draw the attention of the central government through petitions and social media, exerting pressure for a change in the implementation approach of a particular policy, as observed in the CTG project. While the Chinese government often responds to public opinion with responsive and remedial measures to maintain social stability (Qiaoan & Teets, 2020), scholars argue that procedural or participatory justice is essential for promoting justice. Meaningful participation of all stakeholders, especially those affected by the policy, in the policy-making process is crucial (Walker & Day, 2012).

The implementation of environmental policies is a crucial issue in environmental and energy studies as even well-designed policies can fail if not implemented properly at the local level. This study offers a unique contribution to the literature on policy implementation gap by analyzing the political and policy regime factors (Kostka & Nahm, 2017; Li, 2010; Liu et al., 2018) underlying the over-implementation of environmental policies, a relatively new phenomenon. It also sheds light on China's authoritarian environmentalism and the root problems in its environmental governance system. Implementation gaps are common across various political regimes, and the factors that cause these gaps are particularly noteworthy when comparing different systems. While discretion among implementers may result in implementation gaps in a democratic regime (Edwards, 1980), an authoritarian system may enable more faithful policy implementation due to the concentration of authority.

China has undergone a recentralisation process over the past decade (Chen & Lees, 2019), which has aimed to achieve policy targets through coercive measures. However, this study highlights that authoritarian environmentalism is more effective in producing policy outputs than outcomes, particularly when local governments prioritize environmental targets under high political pressure by sacrificing other local needs. This perspective challenges the assumption that increasing the power of the central government through recentralization will lead to better outcomes. By offering a diversified perspective, this study contributes to the ongoing debate on the advantages and disadvantages of authoritarian environmentalism (Kostka & Nahm, 2017; Li et al., 2019).

Some limitations of this study should be acknowledged. Firstly, the methodology section outlines the data limitations. Secondly, the focus on China restricts the generalizability of the findings. Thirdly, the study only examines the gap between central policy design and local policy implementation, without delving into the nuances between different local governments. As some scholars have pointed out, a uniform policy implemented by the central government may have different outcomes in different political jurisdictions due to their varying situations, such as uneven levels of development and unequal distribution of resources (Ahlers & Shen, 2018). Hence, the implementation gap in local governance could be an important area for further research.

3.6 References

Ahlers, A. L., & Shen, Y. (2018). Breathe easy? Local nuances of authoritarian environmentalism in China's battle against air pollution. *The China Quarterly*, *234*, 299-319. https://doi.org/10.1017/S0305741017001370.

Beeson, M. (2010). The Coming of Environmental Authoritarianism. *Environmental Politics*, 19(2), 276–294. https://doi.org/10.1080/09644010903576918.

Cai, C., Jiang, W., & Tang, N. (2022). Campaign-style crisis regime: how China responded to the shock of COVID-19. *Policy Studies*, 43(3), 599-619. https://doi.org/10.1080/01442872.2021.1883576.

Caldeira, E. (2012). Yardstick competition in a federation: Theory and evidence from China. *China Economic Review*, *23*(4), 878-897. https://doi.org/10.1016/j.chieco.2012.04.011.

Chen, G. C.,& Lees, C. (2019). Political Recentralisation and the Diffusion of Solar Energy in China. *Europe-Asia Studies*, 71(7), 1162–1182. https://doi.org/10.1080/09668136.2019.1619669.

Clean Heating Industry Committee (2021). Clean Heating Industry Report 2020, http://www.chic.org.cn/Home/Index/detail1?id=1141, 2021.

Dong, R. (2017). Hebei Province's Gas Supply Has Been Put on 'Orange Alert'. *Economic Observer Network*. http://www.eeo.com.cn/2017/1201/317996.shtml, 2017.

Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American journal of community psychology*, 41 (3), 327-350. https://doi.org/10.1007/s10464-008-9165-0.

Eaton, S.,& Kostka, G. (2014). Authoritarian Environmentalism Undermined? Local Leaders' Time Horizons and Environmental Policy Implementation in China. *The China Quarterly*, 218, 359–380. https://doi.org/10.1017/s0305741014000356.

Edwards, G. C. (1980). *Implementing Public Policy.* Washington: Congressional Quarterly Press.

Fan, S.,Zha, S.,Zhao, C.,Caoji, Y., & Chen, X. (2022). The Policy Instruments and the Risk of Conflict in Rural Village Energy Transition: The Case of the Coal-to-Gas Policy in Hebei Province, China.

Gao, J. (2017). Energy Experts Explain the Recent 'Gas Shortage' Phenomenon. *Xinhua News Agency*. https://weibo.com/ttarticle/p/show?id=2309404185909934340024, 2017.

Gilley, B. (2012). Authoritarian Environmentalism and China's Response to Climate Change. *Environmental Politics*, 21(2), 287–307. https://doi.org/10.1080/09644016.2012.651904.

Goggin, M. L., Bowman, A. O'M., Lester, J. P., & O'Toole, L. J. (1990). Implementation theory and practice. *Scott, Foresman and Company, Glenview, IL.*

Hansen, M. H., Li, H., & Svarverud, R. (2018). Ecological civilization: Interpreting the Chinese past, projecting the global future. *Global Environmental Change*, 53, 195-203. https://doi.org/10.1016/j.gloenvcha.2018.09.014.

Heggelund, G. M. (2021). China's Climate and Energy Policy: At a Turning Point? *International Environmental Agreements: Politics, Law and Economics*, 21(1), 9–23. https://doi.org/10.1007/s10784-021-09528-5.

Hogwood, B. and Gunn, L. (1984). Policy Analysis for the Real World. *Oxford: Oxford University Press.*

Hu, Z. (2020). When Energy Justice Encounters Authoritarian Environmentalism: The Case of Clean Heating Energy Transitions in Rural China. *Energy Research & Social Science*, 70, 101771. https://doi.org/10.1016/j.erss.2020.101771.

Huang, P.,& Liu, Y. (2021). Toward Just Energy Transitions in Authoritarian Regimes: Indirect Participation and Adaptive Governance. *Journal of Environmental Planning and Management*, 64(1), 1–21. https://doi.org/10.1080/09640568.2020.1743245.

Hudson, B., Hunter, D., & Peckham, S. (2019). Policy failure and the policy-implementation gap: can policy support programs help? *Policy Design and Practice*, 2 (1), 1-14. https://doi.org/10.1080/25741292.2018.1540378.

Jia, K.,& Chen, S. (2019). Could Campaign-Style Enforcement Improve Environmental Performance? Evidence from China's Central Environmental Protection Inspection. *Journal of Environmental Management*, 245, 282–290. https://doi.org/10.1016/j.jenvman.2019.05.114.

Knill, C., and Tosun, J. (2020). Public policy: A new introduction. *Bloomsbury: Red Globe Press.*

Kostka, G. (2014). Barriers to the implementation of environmental policies at the local level in China. *World Bank Policy Research Working Paper*, (7016).

Kostka, G.,& Nahm, J. (2017). Central–Local Relations: Recentralization and Environmental Governance in China. *The China Quarterly*, 231, 567–582. https://doi.org/10.1017/s0305741017001011.

Landry, P. F. (2008). Decentralized Authoritarianism in China: The Communist Party's Control of Local Elites in the Post-Mao Era. *New York: Cambridge University Press*.

Li, L. (2010). Central-Local Relations in the People's Republic of China: Trends, Processes and Impacts for Policy Implementation. *Public Administration and Development*, 30(3), 177–190. https://doi.org/10.1002/pad.573.

Li, X.,Yang, X.,Wei, Q.,& Zhang, B.(2019). Authoritarian Environmentalism and Environmental Policy Implementation in China. *Resources, Conservation and Recycling*, 145, 86–93. https://doi.org/10.1016/j.resconrec.2019.02.011.

Lipsky, M. (1980). Street-level bureaucracy: Dilemmas of the individual in public service. *New York: Russell Sage Foundation.*

Liu, J., Mauzerall, D. L., Chen, Q., Zhang, Q., Song, Y., Peng, W., ... & Zhu, T. (2016). Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source. *Proceedings of the National Academy of Sciences*, 113(28), 7756-7761. https://doi.org/10.1073/pnas.1604537113

Liu, L.,Zhang, B.,& Bi, J. (2012). Reforming China's Multi-Level Environmental Governance: Lessons from the 11th Five-Year Plan. *Environmental Science & Policy*, 21, 106–111. https://doi.org/10.1016/j.envsci.2012.05.001.

Liu, N., Tang, S. Y., Zhan, X., & Lo, C. W. H. (2018). Political commitment, policy ambiguity, and corporate environmental practices. *Policy Studies Journal*, 46(1), 190-214. https://doi.org/10.1111/psj.12130.

Liu, X. (2017). Construction worker in Shanxi Xinzhou detained for outdoor coal burning, deemed atmospheric pollution by police. *China News*. https://www.thepaper.cn/newsDetail_forward_1885302.

Lo, K. (2015). How Authoritarian Is the Environmental Governance of China? *Environmental Science & Policy*, 54, 152–159. https://doi.org/10.1016/j.envsci.2015.06.001.

Lo, K. (2021). Authoritarian environmentalism, just transition, and the tension between environmental protection and social justice in China's forestry reform. *Forest Policy and Economics*, 131, 102574. https://doi.org/10.1016/j.forpol.2021.102574.

Luo, B., and H. Ling. (2020). The Internal Mechanism of Environmental Decentralization and Regional Economic Growth: Based on the Adjustment of Central- Local Relationship. *Journal of Yunnan University of Finance and Economics*, 2, 32–48.

Ma, S. and Z. Wei. (2018). Analysis of the Current Situation and Problems in the Implementation of Coal-to-Gas Conversion. *Journal of Technology and Economic Guide*, 26(22), 32–33.

May, P. J., & Jochim, A. E. (2013). Policy regime perspectives: Policies, politics, and governing. *Policy Studies Journal*, 41(3), 426-452. https://doi.org/10.1111/psj.12024.

May, P. J., & Winter, S. C. (2007). Collaborative service arrangements: Patterns, bases, and perceived consequences. *Public Management Review*, 9(4), 479-502. https://doi.org/10.1080/14719030701726473.

MEP (2016). Interim Assessment Report on the Implementation of the Air Pollution Control Action Plan. http://www.gov.cn/xinwen/2016-07/06/content_5088795.htm.

MEP (2017). 2017 Work Plan for Air Pollution Prevention and Control in Jing-Jin-Ji and Surrounding Areas, Policy document, https://www.sohu.com/a/130963994_470091.

MEP (2017). Letter on Comprehensive Management of Bulk Coal and Work to Ensure Warmth for the Winter, https://www.waizi.org.cn/doc/27962.html

Ministry of Finance (2017). Notice on the launch of the pilot project of central financial support for clean winter heating in northern areas, http://www.gov.cn/xinwen/2017-05/20/content_5195490.htm.

O'Brien, Kevin J., & Lianjiang Li. (1999). "Selective Policy Implementation in Rural China." *Comparative*

Oliver, H., & Ortolano, L. (2006). Implementing cleaner production programmes in Changzhou and Nantong, Jiangsu province. *Development and Change*, 37(1), 99-120. https://doi.org/10.1111/j.0012-155X.2006.00471.x.

Palfrey, C. (1999). Key Concepts in Healthcare Policy and Planning: An Introductory Text. *Basingstoke: Macmillan*.

Politics, 31 (2): 167–86. https://doi.org/10.2307/422143.

Qi, J., and J. Xiao. (2019). The Interpretation of Administrative Law of the Calling Off of the "Coal to Gas" Project. *Journal of Huazhong University of Science and Technology (Social Science Edition)*, 33(4), 82–92.

Qiaoan, R., & Teets, J. C. (2020). Responsive Authoritarianism in China -- a Review of Responsiveness in Xi and Hu Administrations. *Journal of Chinese Political Science*, 25(1), 139–153. https://doi.org/10.1007/s11366-019-09640-z.

Ran, R. (2013). Perverse Incentive Structure and Policy Implementation Gap in China's Local Environmental Politics. *Journal of Environmental Policy & Planning*, 15(1), 17–39. https://doi.org/10.1080/1523908X.2012.752186.

Sabatier, P. A. (1986). Top-down and bottom-up approaches to implementation research: a critical analysis and suggested synthesis. *Journal of public policy*, 6 (1), 21-48. https://doi.org/10.1017/S0143814X00003846.

Schreifels, J.J., Fu, Y., & Wilson, E.J. (2012). Sulfur dioxide control in China: policy evolution during the 10th and 11th Five-year Plans and lessons for the future. *Energy Policy*, 48, 779–789. https://doi.org/10.1016/j.enpol.2012.06.015.

Signé. (2017). Policy Implementation–A Synthesis of the Study of Policy Implementation and the Causes of Policy Failure. *Policy paper, OCP Policy Center, Rabat, Morocco*.

Tosun, J. (2012). Environmental Monitoring and Enforcement in Europe: A Review of Empirical Research. *Environmental Policy and Governance*, 22(6), 437–448. https://doi.org/10.1002/eet.1582.

Van Meter, D. S., & Van Horn, C. E. (1975). The policy implementation process: A conceptual framework. *Administration & society*, 6(4), 445-488. https://doi.org/10.1177/009539977500600404.

van Rooij, B. (2006). Implementation of Chinese Environmental Law: Regular Enforcement and Political Campaigns. *Development and Change*, 37(1), 57–74. https://doi.org/10.1111/j.0012-155X.2006.00469.x.

Walker, G.,& Day, R. (2012). Fuel Poverty as Injustice: Integrating Distribution, Recognition and Procedure in the Struggle for Affordable Warmth. *Energy Policy*, 49, 69–75. https://doi.org/10.1016/j.enpol.2012.01.044.

Wang, Q. (2019). 2019 Energy Data. *Energy Foundation China*. https://www.efchina.org/Reports-zh/report-lceg-20200413-zh. 2019.

Wang, C., & Lin, Z. (2010). Environmental policies in China over the past 10 years: progress, problems and prospects. *Procedia Environmental Sciences*, 2, 1701-1712. https://doi.org/10.1016/j.proenv.2010.10.181

Wang, R.& Ren. L. (2021). Logic and Its Unexpected Consequences of Local Environmental Policy Excessive Implementation. *Journal of Public Management*, 18(1), 33–44.

Wang, S. (2018). The Rights and Wrongs of 'Coal to Gas Conversion'. *Ecological Economy*, 3(2), 10–13.

Wu, J.,Zuidema, C.,Gugerell, K.,& Roo, G. de. (2017). Mind the Gap! Barriers and Implementation Deficiencies of Energy Policies at the Local Scale in Urban China. *Energy Policy*, 106, 201–211. https://doi.org/10.1016/j.enpol.2017.03.057.

Xiao, Z., & Moser, A. (2014). The laws, policies, and politics of regulating lead pollution in China. *Frontiers of Law in China*, *9(2)*, 186-207. https://doi.org/10.3868/s050-003-014-0012-4.

Xie, L.,Hu, X.,Zhang, X.,& Zhang, X.-B. (2022). Who Suffers from Energy Poverty in Household Energy Transition? Evidence from Clean Heating Program in Rural China. *Energy Economics*, 106, 105795. https://doi.org/10.1016/j.eneco.2021.105795.

Yu, W. (2017). Press Conference on Air Pollution Control and Energy Conservation and Emission Reduction. http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/hebei/Document/1605470/1605470.htm, 2017.

Zhan, X., Lo, C. W. H., & Tang, S. Y. (2014). Contextual changes and environmental policy implementation: a longitudinal study of street-level bureaucrats in Guangzhou, China. *Journal of Public Administration Research and Theory*, 24(4), 1005-1035. https://doi.org/10.1093/jopart/mut004.

Zhang, B.,& Cao, C.(2015). Policy: Four Gaps in China's New Environmental Law. *Nature*, 517(7535), 433–434. https://doi.org/10.1038/517433a.

Zhang, F.(2020). The Implementation Gap in Responding to Beijing’s Air Pollution: Explanation and Policy Recommendations. *Doctoral dissertation, Arizona State University*.

Zhang, S.,Wang, Y.,Liu, Z.,& Hao, Y.(2021). The Spatial Dynamic Relationship Between Haze Pollution and Economic Growth: New Evidence from 285 Prefecture-Level Cities in China. *Journal of Environmental Planning and Management*, 64, 1985–2020. https://doi.org/10.1080/09640568.2020.1854694.

Zheng, Y. (2006). Explaining the sources of de facto federalism in reform China: Intergovernmental decentralization, globalization, and central–local relations. *Japanese Journal of Political Science*, *7*(2), 101-126. https://doi.org/10.1017/S1468109906002222.

Zhou, L. (2018). A Study of the Impact of Transfer Payment Methods on Local Government Environmental Protection Spending. *Public Economics and Policy Studies*, 2, 92-105.

Zhu, Q. (2012). An Analysis on the Policy Implementation Behaviour of Local Governments. *Journal of Xi’an Jiaotong University (Social Sciences)*, 32, 40–46.

4 Why does electric vehicle deployment vary so much within a nation? Comparing Chinese provinces by policy, economics, and socio-demographics*

Written together with Mile Mišić

Abstract. Despite the global growth of the electric vehicle (EV) market, disparities in EV distribution within countries remain apparent. To shed light on the issue, this study investigates the spatial dimension of China's EV sector. Using five EV-related indicators and the c-means clustering method (FCM), this study conducts a cluster analysis to examine the spatial distribution of the EV sector across 25 provinces in Mainland China. By selecting one representative province from each cluster, a comparative case study was subsequently performed to uncover the factors contributing to variations in EV development among provinces. Our findings reveal the presence of regional imbalances and identify four distinct clusters: producers (five provinces), retailers (two provinces), green transport (seven provinces), and laggards (eleven provinces). The study reveals that provincial economic and socio-demographic factors, along with policy mixes, play significant roles in shaping this heterogeneity. A robust economy drives EV demand and support the establishment of charging infrastructure and new technologies. Additionally, a thriving automotive sector can facilitate the EV development. However, protective tendencies exhibited by provincial governments towards existing production hinder the adoption of new technologies and impede EV sector growth. The proactive approach of governments and the integration of policies into the local context are vital for fostering the growth of the EV sector.

4.1 Introduction

Global sales of electric vehicles (EVs)[2] peaked in 2019, with 2.3 million units sold and the United States, Europe, and China sharing around 90% of the market (Gersdorf, 2020). Compared to two years earlier, the sales volume doubled, continuing a perennial trend since 2012 (Hertzke, 2018). This remarkable growth mirrors the efforts and funds that governments, through subsidies and other policies, have invested in EVs, seeing them as a cornerstone of their strategies for energy transition in the transport sector (Zhang & Bai, 2017; Li et al., 2019; Zheng et al., 2022).

Energy transition, among others, represents a governance challenge that demands action from multilevel actors, including nation-states and subnational actors (Köhler et al., 2019; Hsu et al., 2020; Bjerkan et al., 2021). While governments set the tone and steer the transitions, there are many other factors that can influence it (Sovacool, 2017; Sovacool et al., 2019; Trencher et al., 2021). From the literature, we know that energy transitions take place in socio-economic contexts with specific institutions, histories, infrastructures, and energy mixes and that the results are usually not equally distributed spatially (Balta-Ozkan et al., 2015). This can occur in microregions, countries, or even different jurisdictions within a country. Uneven energy transition results in problems when concomitant

---

* Published in *Energy Research & Social Science*, 2023, Elsevier.

[2] In China, EVs are called new energy vehicles (NEVs), a term which encompasses BEVs (battery electric vehicles), PHEVs (plug-in hybrid electric vehicles), and fuel cell electric vehicles (FCEVs).

new technologies, investments, and jobs cluster in more affluent areas, further aggravating the economic stagnation of the laggards (Naqvi et al. 2021; Laurentis & Pearson 2018; O'Sullivan et al. 2020; Bouzarovski & Tirado Herrero, 2017; Eicke & Goldthau, 2021; Sovacool et al., 2020). Considering the increased concerns about regional inequality, this problem might be even more serious within a country (Lipps & Schraff, 2021; Riva et al., 2021). However, although some recent studies have examined the development of EVs on the national and international levels (Yan, 2018; Rietmann & Lieven, 2019; Bellocchi et al., 2019), only a few have analysed the distribution of the EV sector at the subnational level.

In light of this, we pose two questions: How does the EV sector develop within countries? How can we explain the variation? To answer these questions, we focus on the case of China and propose two explanations. First, China accounted for more than 50% of all EV sales in 2019, being both the largest producer and the largest market (Balta-Ozkan et al., 2015; Li et al., 2021). Secondly, there seem to be striking differences between Chinese provinces in terms of performance and the overall development of the EV sector. For instance, between 2011 and 2017, more than 50% of all battery electric vehicle (BEV) sales in China were made in only five provinces (Zheng et al., 2020). As expected, the charging infrastructure follows a similar pattern, with more than 93% of the new charging and battery swapping stations planned for the more developed coastal provinces (Ji & Huang, 2018). Additionally, the production of EVs appears to be rather concentrated, with six provinces producing almost 60% of all the EVs manufactured in China in 2018 (China Automotive Technology Research Center, 2019).

Methodologically, we first conducted a cluster analysis based on five variables to assess and classify the development of the EV sector among Chinese provinces. Secondly, we selected one province from each cluster and conducted a comparative case study. By comparing the EV sector and local contexts in selected provinces, we shed light on factors that may explain the observed differences. Our results indicate that the local economic context plays an important role. A strong economy can drive local EV demand, enhance EV infrastructure, and support the technological development of EVs. Moreover, a well-established vehicle industry often facilitates the development of the EV sector. However, an entrenched industry focused on internal combustion engines can also impede the progress of EVs due to protectionism. Furthermore, our results highlight the significant role of provincial government policies and actions in shaping the development of the EV sector in China. Also, our study confirms previous findings that more affluent provinces tend to outperform others in all aspects of the EV sector.

This study makes a significant contribution to filling the research gap regarding the spatial dimension of energy transition and the distribution of EVs at the subnational level. Our study speaks to the literature on energy transition as a geographical process (Bridge et al., 2013) and the notion of the unequal distribution of costs and benefits that arise from these transitions (Eicke & Goldthau, 2021; Sovacool et al., 2020). Furthermore, this paper is relevant to researchers studying inequalities in China and to policymakers focusing on EVs.

The rest of this paper unfolds as follows. Section 2 provides the theoretical background and a brief history of EVs in China. Section 3 explains the methods and data used in the study, followed by the presentation of the cluster analysis results in Section 4. In Section 5, we analyse and discuss selected case studies, and this is followed by a comprehensive discussion in Section 6. Finally, Section 7 concludes the study.

4.2 Regional inequalities and EVs in China

Mobility transition is an important, highly complex, and very expensive undertaking, costing up to 0.1% of China's total GDP per year (Markard, 2018; Riesz et al., 2016). It is also a strategic priority of the Chinese government, which aims to establish China as the global leader in automotive transformation, ensuring early market dominance. The government has made substantial investments in national EV programs, significantly expanding both the supply and demand of the domestic EV sector. Moreover, China plays a leading role in international bodies, such as the Clean Energy Ministerium, advocating for EVs (Tosun & Shyrokykh, 2021). Consequently, both the central government and researchers perceive the EV sector in China as a critical emerging industry. From the perspective of provincial governments, those at the forefront of the mobility transformation will receive greater political and economic benefits from the central government (Cao et al., 2021). As a result, competition among provinces in the EV sector is intense.

For a country as large and complex as China, it is reasonable to expect that the transition will probably not be homogenous on the provincial level. However, it might pose a problem for planners and politicians, as there are conspicuous economic differences between the coastal and inland regions. Following the economic reforms of the 1980s, the regions were encouraged to achieve as much economic growth as possible, leading to a restructuring of the whole industry and practically dividing the country into Western, Central, and Eastern clusters of provinces (Fan, 2006; Fan & Sun, 2008). In addition, previous studies suggest that there is a clear division in China in other aspects of energy transition, such as renewable energy development (Wang et al., 2020), green buildings (Zou et al., 2017), and energy efficiency (Li & Hu, 2012).

The Chinese model of experimentation may partially account for the emergence of frontrunners and laggards during the early stages of a transition. The history of EVs in China dates back to 2009 when a pilot program called "Ten Cities, Thousand Vehicles Demonstration and Deployment Program" was initiated. This program initially targeted 10 cities with the aim of deploying at least 1000 vehicles in the same year (Dong & Liu, 2020; Muniz et al., 2019). The program initially focused on public transport, but gradually expanded to include the private sector in 2011 (Zhang & Qin, 2018). From 2013 to 2015, the promotion of EVs extended to 88 pilot cities, representing the evolution of the EV scheme, until achieving national coverage in 2015. Figure 4.1 illustrates the distribution of pilot cities and clusters in the EV deployment programs between 2010 and 2015.

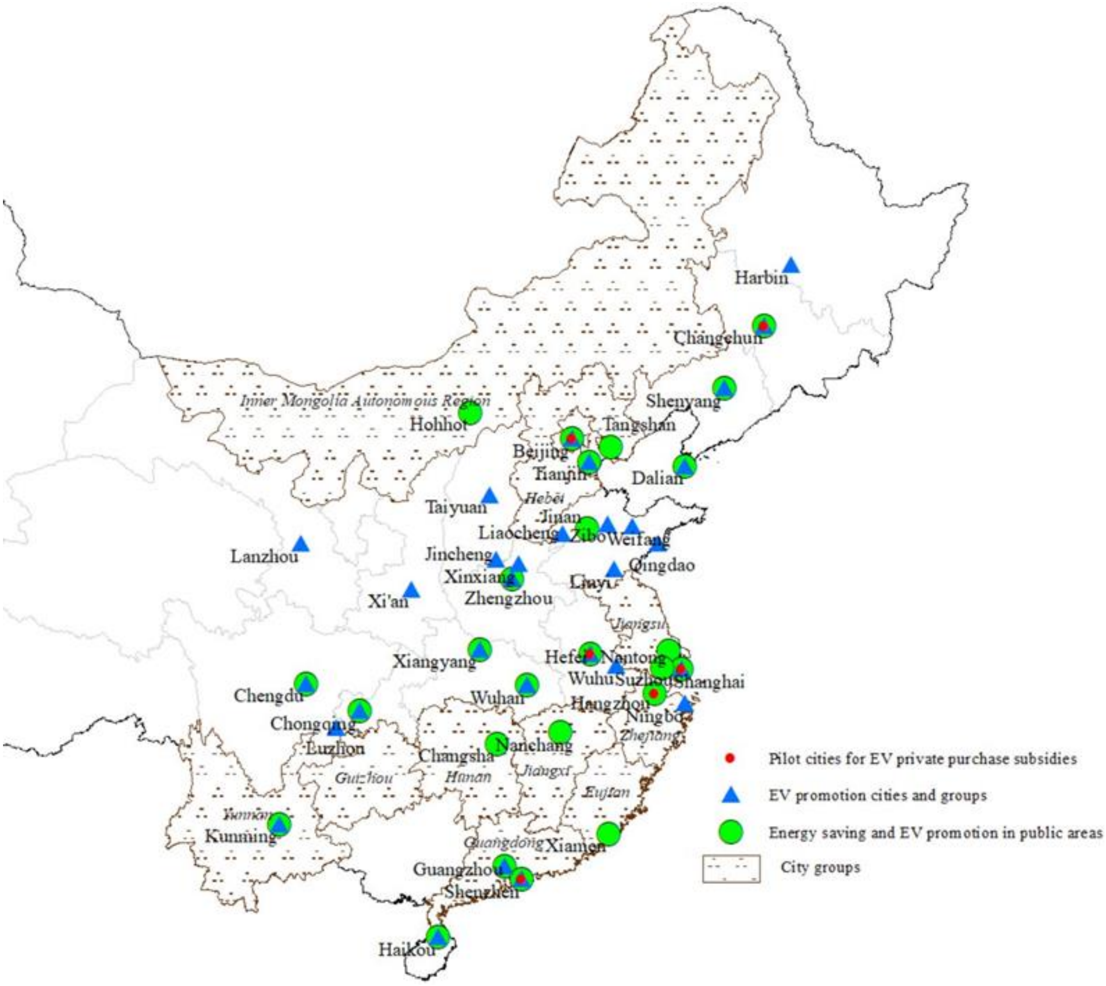


Figure 4.1. Distribution of pilot cities, promotion cities, and city groups.

The program demonstrated remarkable efficiency, as evidenced by the cumulative production of Chinese EVs surpassing 1% of the entire vehicle market by November 2015 (Wang & Yu, 2016). Figure 4.2 depicts the substantial increase in EV sales and production volume between 2011 and 2018. According to data released by the China Association of Automobile Manufacturers, national EV sales reached 74,800 units in 2014 and surged to 1.256 million units in 2018. Internationally, China accounted for approximately one-fifth of global sales in 2014 and 62.23% in 2018 (Meng & Jin, 2019). Nevertheless, the market development exhibited an imbalance, with EV sales primarily concentrated in a limited number of provinces and cities (Wan et al., 2015).

The rapid growth of China’s EV sector has given rise to new domestic brands and companies focusing on EVs, alongside the introduction of electric models by established car manufacturers. With the surge in EV sales in China, the market landscape has changed significantly, with urban micro-EVs emerging as the dominant product since 2017 and maintaining that position to this day (Wang, 2020).

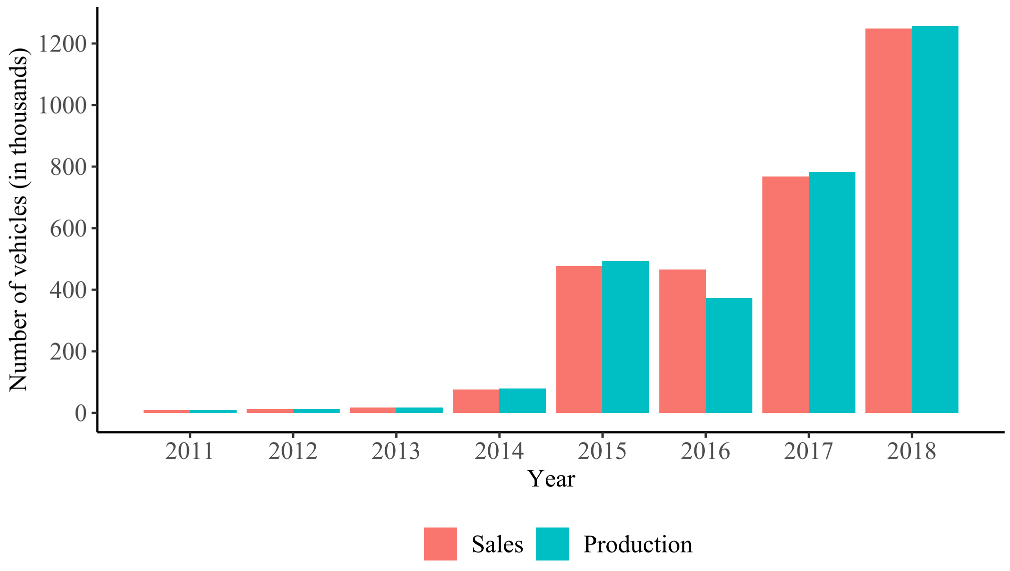


Figure 4.2. EV sales and production volume in China between 2011 and 2018.

The development of EVs has also spurred the rapid expansion of the charging infrastructure industry. Starting from 2014, China has opened market access for EV-related infrastructure construction and actively encouraged equity capital investment in charging pile construction. Currently, China boasts the largest number of charging piles globally, with over 730,000 by the end of 2018 (Tang et al., 2019). The provinces with the highest number of charging piles include Beijing, Shanghai, Guangdong, Jiangsu, Shandong, and Zhejiang. However, overall, the construction of charging infrastructure in China still lags behind the growth rate of EVs, with a charging port to EV ratio of 1:3.19, which falls significantly short of the required 1:1 ratio (Ma et al., 2018).

4.3 Methods and data

To investigate the spatial distribution of EVs at the subnational level in China and identify the factors influencing it, we employ a two-step analysis approach. In the first step, we utilise five indicators related to EVs as variables and conduct a cluster analysis. This analysis allows us to identify four distinct clusters characterised by different developmental patterns in the EV sector, as defined in our study. Subsequently, in the second step, we select one province from each cluster and examine it as a case study. Our analysis in the first step encompasses 25 provinces in Mainland China [1]: Anhui, Beijing, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Shandong, Shanghai, Shaanxi, Shanxi, Sichuan, Tianjin, Yunnan, and Zhejiang. We exclude six provinces due to unavailable data.

[1] Mainland China has 31 provinces.

4.3.1 Cluster analysis

The five variables used in the clustering analysis are presented in Table 4.1, together with relevant descriptive statistics.

Table 4.1. Description of variables, data sources, and descriptive statistics.

Variable	*Description*	*Data source*	*Obs*	*Mean*	*Std. dev.*	*Min*	*Max*
EV production	Share of the total national EV production, per province	Energy saving and new energy vehicle yearbook	25	4.16	3.60	0.01	10.70
EV purchase	Share of the EV sales in total vehicle sales, per province	State and provincial bureaus of statistics	25	1.50	1.55	0.16	6.69
EV patents	Share of the total national EV-related patents, per province	State intellectual property office	25	4.00	4.46	0.05	17.20
Charging infrastructure	Ratio between the total number of chargers and EV ownership, per province	Energy saving and new energy vehicle yearbook; China EV charging Infrastructure promotion alliance	25	34.37	21.90	8.11	87.83
Electric buses	Share of electric buses in total bus fleet, per province	National report on urban transport development 2018	25	5.20	1.39	2.50	7.90

We have selected these five variables for two specific reasons. Firstly, they align with the strategic direction of the EV sector's development in China, as emphasised in various government five-year plan for EV development since 2010, such in as the *"Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020)"* (State Council, 2012), and *"The 12th Five-Year Plan for Energy Development"* (State Council, 2013). Also, these five variables have been consistently highlighted in these plans, indicating their importance in assessing the development of the EV sector at the provincial level.

Secondly, these five variables have been extensively studied in the scientific literature either as indicators of progress towards policy goals or as influencing factors (Tang et al, 2019; Biresselioglu et al., 2018; Golembiewski et al., 2015; Qiu et al., 2019; Aschhoff & Sofka, 2009). Therefore, we believe that by considering these variables, we can provide a comprehensive and systematic overview of the EV sector's development, encompassing both the demand side (EV purchase) and the supply side (the other four variables). Now, let's delve into each variable in more detail.

The variable *"Production"* reflects the level of development and capacity of the local EV industry to supply the market. In the context of China, it holds strategic significance as it supports the country's ambition to transform the automotive industry, achieve sustainability goals, and establish itself as a major EV exporting country (Tang et al, 2019). Given the mainstreaming of automotive transformation in China, the EV industry presents a high-potential opportunity for provinces to boost their local economies, leading to intense competition between them (Cao et al., 2021). Some provincial governments even employ measures to protect and promote their own EV brands by imposing restrictions on the entry of other brands (Zhang & Bai, 2017).

The variable *"Purchase"* or EV adoption is an indicator to assess the development of the local EV market and the acceptance of EVs by the local population. EV adoption plays a crucial role in evaluating the effectiveness of EV policies, and numerous studies have explored this topic from both policy and consumer perspectives (See e.g. Kumar & Alok, 2020; Tomasi et al., 2021; Hardman et al., 2018).

The variable *"Patents"* reflects the level of local technological progress and innovation in the field of EVs. This is significant because the development and innovation of core EV technologies contribute to maintaining a competitive advantage for local companies (Sun et al., 2018), aligning with the perception of provincial governments that the EV sector is a strategic asset.

The variable *"Charging infrastructure"* captures the extent of local support for EV use and the capacity to accommodate an increasing number of EVs. The adequacy of charging infrastructure significantly influences the consumer experience with EVs and the rate of EV adoption in a particular area. Numerous studies have examined charging infrastructure (Qiu et al., 2019; Hardman et al., 2018; Mersky et al., 2016) and highlight its crucial role in the transition towards a low-carbon transportation sector (Chen et al., 2020).

The variable *"Electric buses"* reflect the proactivity of local authorities in promoting EVs. Since private EV consumption is influenced by various factors, the share of electric buses in the public transport sector primarily depends on the commitment of the local authorities, illustrating the ambition of the respective government (Bakker & Trip, 2013). Moreover, public procurement can stimulate market demand, generate demonstration effects, and mitigate the impact of limited information about new technologies, in this case, EVs (Egnér & Trosvik, 2018).

We employ the fuzzy c-means clustering method (FCM) to conduct our analysis. This approach allows for a more comprehensive assessment of the development level of EV sectors by integrating multiple indicators and generating spatial patterns in the distribution of the EV sectors and identifies their characteristics in different regions. Unlike hard-clustering techniques such as k-means clustering, FCM does not assign observations to a single cluster alone. Instead, it provides degrees of membership as an output, expressed in percentages, indicating the extent to which each observation belongs to each cluster (for details, see Caloffi & Mariani, 2018; D'Urso et al., 2019). This feature is particularly valuable for our case selection, as we believe that the most representative province of a cluster is the one with the highest degree of membership to that specific cluster.

One of the crucial steps when conducting FCM is the choice of the number of clusters. In our study, we utilised the Xie-Beni Cluster Validity Index, which is a commonly used approach among several approaches (such as Partition Coefficient, Fukuyama-Sugeno Index, Partition Entropy) (Xie & Beni, 1991; Zhang et al., 2008). To set the upper bound of the optimal number of clusters for testing, we calculated the square root of the theoretically maximal number of clusters (Yu & Cheng, 2001). Since we are analysing 25 provinces (meaning that 25 is the maximal number of clusters), the square root and the upper bound is five. Consequently, we tested models with two, three, four, and five clusters, and the results indicate (see Appendix C.1) that four clusters represent the best fit for our dataset.

For the analysis, we employed the R software along with the 'e1071' package (R Core Team, 2020). Prior to conducting the analysis, we scaled the data using min-max normalisation, in order to decrease the influence of different ranges in the variables. The results of the clustering, as well as all other maps presented in this study, were geographically visualised using ESRI’s ArcGIS 10.6.1 software (ESRI, 2018).

4.3.2 Comparative case study

We start the comparative case study by choosing one representative province from each cluster for comparison. To accomplish this, we employed the degree of membership from the clustering results, as described in detail in Appendix C.2, for case selection. By utilising the degree of membership, where a higher value signifies a greater affiliation with a particular cluster, we identified one province with the highest degree of membership from each cluster. Therefore, our analysis focuses on four provinces, with each province serving as a representative of one cluster.

Our goal is to understand the reasons behind the differences observed among clusters of provinces, and to achieve this, we turn to the existing literature. Previous studies have identified various factors that influence the EV sector. Economic and socio-demographic factors, such as GDP per capita, income per capita, degree of urbanisation, population density (Mersky et al., 2016; Egnér & Trosvik, 2018; Guo et al., 2020), vehicle ownership (Westin et al., 2018), and other demographic factors (Simsekoglu, 2018; Sovacool et al., 2018; Liu et al., 2020) have been frequently cited. Additionally, considering the disruptive nature of EVs in the automotive industry (Wilson, 2018), they might have negative effect on entrenched business models for conventional fossil fuel vehicles (Hardman et al., 2013). We therefore also investigate the role of existing automotive industries in the development of EVs. However, we acknowledge that this list of influencing factors is not exhaustive. Due to the methodology and data employed in this study, certain demographic factors like age, social norms, or family size, which are particularly important for the EV adoption rate from the consumers’ perspective (Simsekoglu, 2018; Tomasi et al., 2021).

Furthermore, within the realm of policy studies, a significant body of literature underscores the critical importance of policy mixes for the EV sector, not only in terms of EV adoption (Griffiths et al., 2021; Lam & Mercure, 2021; Melton et al., 2020; Li et al., 2019; Jenn et al., 2018; Zhang et al., 2017), but also in relation to the EV industry (Sun et al., 2019; Liu & Kokko, 2013; Yang et al., 2019), EV patents (Naqvi et al., 2021; O'Sullivanet al., 2020; Shao et al., 2021), and charging infrastructure construction (Baumgarte et al., 2021; Yang et al., 2018). We examine the details of policy instruments in these cases separately, as we perceive them as external interference.

4.4 The spatial patterns of the EV development in China

We start this section with a visual presentation of the spatial patterns of EV development in China, based on the analysis of the five variables used in the clustering analysis. As we can see in Figure 4.3, manufacturers in several adjacent coastal provinces in Eastern China, together with Beijing, Guangdong, and Shaanxi, have made significant progress in restructuring their production around EVs. Moreover, these provinces exhibit a greater share of patents related to EVs, indicating substantial investments in research and development. In terms of EV sales, EVs are particularly popular in the major cities of such as Beijing, Tianjin, and Shanghai, as well as Guangdong and Hainan Island. The maps also highlight the distribution of charging infrastructure. Shanghai, Beijing and Hebei province are notable for their well-established charging networks. Finally, regarding electric buses, there is some variation among provinces. While the overall percentage of electric buses is rather small, certain provinces show a higher deployment of electric buses. Interestingly, Beijing scores rather low on this variable, likely due to its large existing bus fleet that requires gradual electrification.

We now turn to the results of the clustering analysis. Figure 4.4 shows four distinctive clusters of provinces, which we have labelled as Retailers, Producers, Green transport, and Laggards. The Retailers cluster consists of two major cities, Beijing and Shanghai, which are classified as provinces. This cluster is characterised by above-average values for EV sales, charging infrastructure coverage, and EV patents (see Table 4.2). The Producers cluster includes the coastal provinces of Guangdong, Fujian, and Jiangsu, along with Anhui and Shaanxi. Provinces in this cluster have a high share of EVs in their overall vehicle production and a significant share of electric buses in their total bus fleet. The cluster Green transport is marked by its high proportion of electric buses in the total bus fleet but lower scores for other indicators. This cluster encompasses the provinces such as Shanxi, Henan, Shandong, Jiangxi, Hunan, and Hainan, along with the major city of Tianjin. Lastly, the cluster Laggards includes all the remaining provinces and exhibits low values across all the variables, indicating an underdeveloped EV sector, as can be seen in Table 4.2.

The clustering analysis reveals several geographical patterns of EV development in China. First, coastal regions tend to outperform other areas in terms of production and sales, aligning with the overall economic development at the provincial level. On the other hand, the northeast and southwest regions of China predominantly consist of provinces classified under the Laggards cluster, indicating a relatively low level of EV sector development in these regions. Moreover, the prominence of two major cities, Beijing and Shanghai, which are also classified as provinces, suggests a divide between rural and urban areas. This finding aligns with previous research on patterns of energy usage (See e.g. Balta-Ozkan et al., 2015) and correlates with studies examining other aspects of energy transition in China (Wang et al., 2020; Zou et al., 2017; Liu et al., 2020). The spatial patterns highlight the distinct characteristics of EV sectors across provinces, underscoring the importance of understanding the underlying factors contributing to this heterogeneity. Such insights can aid policymakers in designing more effective policies and strategies.

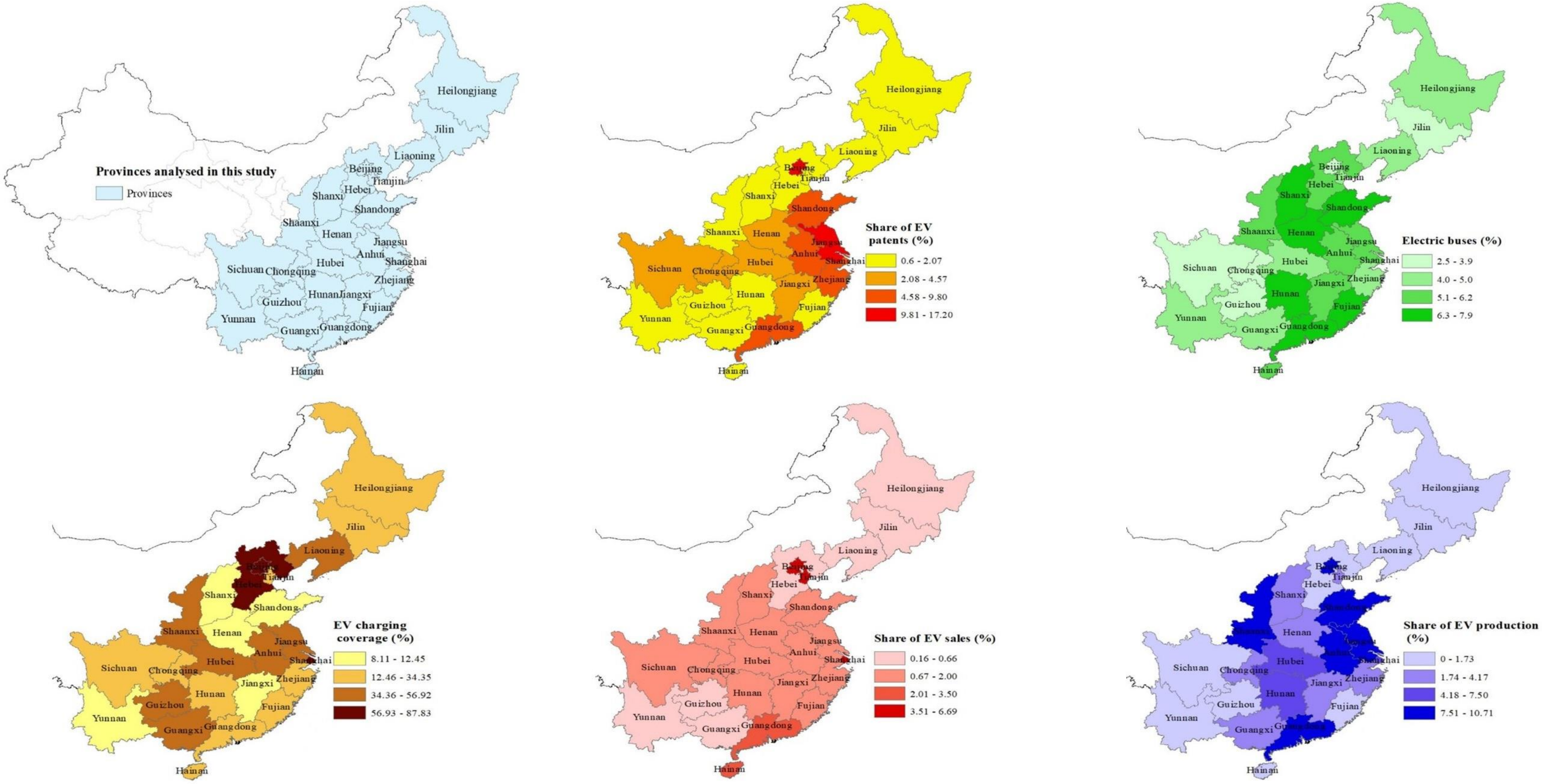


Figure 4.3. Geographical visualisation of the five variables.

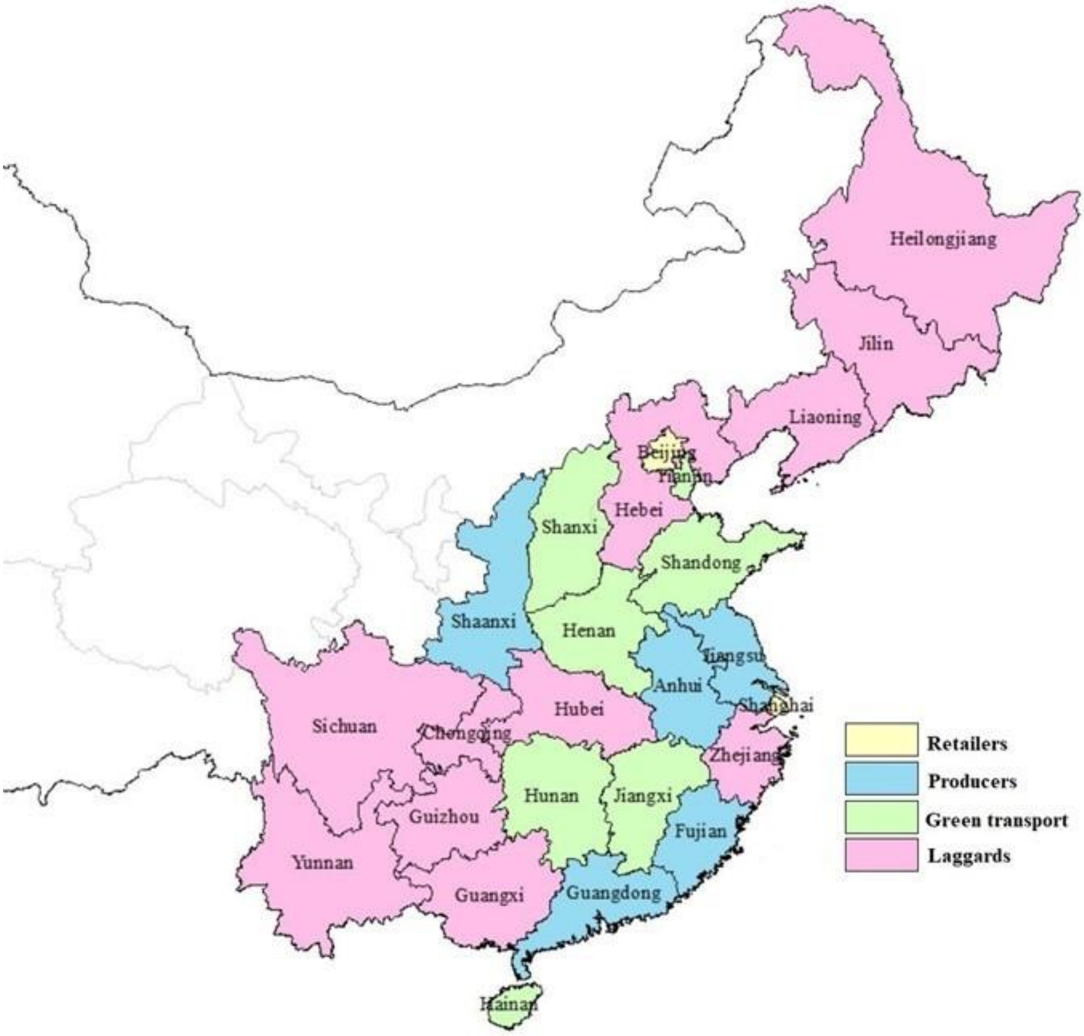


Figure 4.4. Geographical representation of the clusters.

Table 4.2. Summary of centroids.

	EV sales	EV production	Charging infrastructure	Electric buses	EV patents
Producers	0.19	0.83	0.40	0.62	0.41
Retailers	0.80	0.37	0.86	0.37	0.49
Green transport	0.19	0.25	0.12	0.72	0.13
Laggards	0.07	0.13	0.29	0.30	0.11

4.5 Analysis of the influencing factors

In this section, we undertake two tasks. Firstly, following the methodology outlined in sub-section 3.2, we select one province from each cluster to conduct a case study. Secondly, we analyse the underlying factors that may explain the observed differences between provinces and clusters.

Based on our analysis, Anhui Province is chosen as the representative of the *Producers* cluster. Anhui has established itself as one of the major EV production bases in China, accounting for 12% of the country's total EV production (Economic and Information Department of Anhui, 2019). Shanghai is selected to represent the *Retailers* cluster. Being one of the first batch of EV pilots, Shanghai has consistently been at the forefront of EV industrial development and application. With approximately one-tenth of the country’s EV ownership, Shanghai boasts the highest EV density in China (Liu & Rui, 2021). Jiangxi province is chosen as the representative of the *Green transport* cluster. It exhibits the highest level of electric public transport and the average daily operating mileage of electric buses in the capital city surpasses the national average (China Academy of Transportation Sciences, 2020). Lastly, Jilin Province represents the cluster of *Laggards*, displaying low performance values across all variables. Table 4.3 presents the indicators of development within in the EV sector for these four provinces.

Table 4.3. An overview of five EV-related indicators across selected provinces.

	EV sales (%)	**EV production** (%)	**Charging infrastructure** (%)	**Electric buses** (%)	**EV patents** (%)
Anhui	1.15	9.95	49.38	49.28	5.83
Shanghai	6.69	5.16	88.49	37.84	5.92
Jiangxi	1.15	3.4	18.07	60.43	3.05
Jilin	0.16	0.72	18.00	40.31	1.15

Data source: authors collected data from the Energy saving and new energy vehicle yearbooks, the websites of traffic management bureaus, and provinces’ Yearbooks. Note: For descriptions of the variables please see Table 1.

The presence of distinct cases suggests that the development of the EV sector exhibits spatial variation across different jurisdictions. Our analysis indicates that local factors heavily influence the (uneven) development of the EV sector, with economic/socio-demographic factors and policy mixes both playing significant roles. Drawing on the literature and considering the Chinese context, we present a summary of the economic/socio-demographic factors in Table 4.4.

Table 4.4. Economic and socio-demographic factors related to the EV sector in the four provinces.

	Anhui	**Shanghai**	**Jiangxi**	**Jilin**
GDP per capita (RMB*)	60762	159384	55060	45755
Income per capita (RMB)	23984	64183	29205	22798
The number of vehicles per capita	0.17	0.16	0.12	0.16
Vehicle production in 2018	911600	2453500	422800	2270200
Population density in urban areas (/km²)	2599	3823	4818	1831
Percentage of urbanisation	54.7%	88.1%	56.0%	57.5%
Percentage of secondary education	13.3%	33.9%	11.9%	16.7%
Gender ratio (male/100 female)	103.9	107.3	106.6	99.7

Data source: authors data collected from the provinces' Yearbooks as well as the Energy saving and new energy vehicle yearbooks, 2019.

We conducted a detailed analysis of the EV policy documents issued by the four selected provinces between 2009 and 2018. The Shanghai government stands out with the highest number of policies, with 33 in total, while the Jilin government has issued the fewest policies, with only eight policy documents. Jiangxi and Anhui have issued 11 policies each during the same period. Table 4.5 lists the main policy instruments employed by the respective governments.

In the following subsections, we will delve into the four selected provinces and explain how economic, socio-demographic factors, as well as policy mixes, contribute to explaining the variation observed in their respective EV sectors.

* The Renminbi (RMB) is the official name of China's currency.

Table 4.5. EV policy instruments used by the four provinces.

Province	Purchase	Usage	Production	Infrastructure
Shanghai	Purchase subsidy. Tax waiver. Timeshare lease subsidy. Group purchase discount. Exemption from purchase restriction. Government procurement target.	Parking fee discount. Vehicle and vessel tax waiver. Exemption from traffic restriction. EV bus operation subsidy. Dedicated parking space. Dedicated licence plate.	R&D tax reduction. R&D subsidy. Investment subsidy. Entry regulation. Product standard. Dual credit. Openness to foreign capital.	Construction subsidy. Operation subsidy. Charging subsidy. Infrastructure reward. Information service platform. Infrastructure regulation. Building infrastructure targets. Infrastructure land use priority. Price regulation for charging electricity.
Jilin	Purchase subsidy. Tax waiver. Government procurement target.	Vehicle and vessel tax waiver. EV bus operation subsidy. Dedicated parking space. Dedicated licence plate.	R&D tax reduction. R&D subsidy. Entry regulation. Product standard. Dual credit.	Construction subsidy. Infrastructure regulation. Infrastructure land use priority.
Anhui	Purchase subsidy. Tax waiver. Vehicle replacement subsidy. Group purchase discount. Government procurement target.	Parking fee discount. Vehicle and vessel tax waiver. Insurance cost subsidy. EV bus operation subsidy. Dedicated lane. Dedicated parking space. Dedicated licence plate.	R&D tax reduction. R&D subsidy. Investment subsidy. Subsidised interest. New product reward. Entry regulation. Product standard. Dual credit. Open to foreign capital. Battery recycling subsidy.	Operation subsidy. Private charging subsidy. Information service platform. Subsidised credit interest. Infrastructure regulation. Building infrastructure targets.
Jiangxi	Purchase subsidy. Tax waiver. Government procurement target.	Vehicle and vessel tax waiver. EV bus operation subsidy. Dedicated lane. Dedicated parking space. Dedicated licence plate.	R&D tax reduction. R&D subsidy. New product reward. Entry regulation. Product standard. Dual credit. Battery recycling subsidy.	Construction subsidy. Operation subsidy. Infrastructure regulation. Building infrastructure targets. Price regulation for charging electricity. Infrastructure land use priority.

Data source: Policy content analysis results, based on policy documents issued by the four provinces between 2009 and 2018.

4.5.1 Shanghai (Retailers)

Previous studies have shown that EV ownership is influenced by income levels, with wealthier individuals being more likely to choose EVs (Hidrue et al., 2011) and own more EVs (Sovacool et al., 2018). Thus, it is not a surprise that in China, where income disparities exist across regions, EV ownership is concentrated in the more developed regions, with Shanghai being the focal point of EV sales.

Additionally, the high degree of urbanisation in Shanghai coincides with a higher rate of EV adoption, as urban areas typically have a more concentrated market for vehicles (Sun & Yang, 2015). Similarly, the high level of education in Shanghai may also contribute to its higher EV adoption rate (Egnér & Trosvik, 2018; Westin et al., 2018). Well-educated individuals not only have higher earning potential, enabling them to afford EVs, but they also tend to prioritise social responsibility and show greater interest in purchasing environmentally friendly vehicles (Singh et al., 2020).

Interestingly, the case of Shanghai challenges the assumption that the number of vehicles per capita is positively correlated with the EV adoption rate. This can be attributed to vehicle regulation implemented by the Shanghai government. To control excessive vehicle growth, the government restricts the total number of vehicles allowed in the city. Consequently, the number of vehicles per capita in Shanghai does not accurately reflect the actual demand for vehicles.

The extensive coverage of charging infrastructure is a notable feature of Shanghai. We argue that the strong local economy plays an important role in this aspect, as an active economy means larger public budgets for the investments in public facilities (Peng, 2018). Since 2016, the Shanghai government has provided a 30% construction subsidy, along with an operating subsidy, to incentivise the construction of charging facilities, (Shanghai Municipal People's Government, 2016). Additionally, each district in Shanghai offers supplementary subsidies for charging infrastructure construction. For instance, in 2016, Minhang District increased the subsidy to 50% of the construction costs for enterprises that build operational EV charging piles and are registered within the district (Minhang District People's Government, 2016). As a result, Shanghai leads the country in the construction of charging facilities. By the end of 2018, the city had achieved an EV vehicle-to-pile ratio of 1.13:1 (Municipal Commission of Economy and Information Technology, 2018), reflecting its effective capacity to cope with and meet the rapidly growing demand for EV charging services.

Shanghai also leads in the number of EV-related patents. The strong local economy and higher education levels greatly support the research and development (R&D) of EV technology. Not only do local governments in these areas allocate more funding for technological development, but EV technology alliances often involve universities, research institutes, and EV companies, working together over a long period to invent patents and advance technology (Shi et al., 2019). As China's educational resources are concentrated in developed regions, it is within these areas that technological alliances are more mature, and where EV patents and technological breakthroughs usually originate (Sun et al., 2018). Moreover, a robust local economy and reputable engineering universities and research institutes attract professional talents and start-ups, making Shanghai the largest R&D hub in the Yangtze River Delta (Wei et al., 2012).

Regarding policy mixes, Shanghai has the largest and most comprehensive set of policies to support EVs. While most policy measures are similar across regions, as they are designed by the central government, Shanghai has implemented unique initiatives to address local needs, such as the provision of free licence plates and market-opening policies. To control the total number of vehicles, Shanghai strictly limits the issuance of vehicle license plates each year, typically through auction. The conflict between high demand and the low issuance of licence plates makes EVs an attractive alternative for consumers, as they are exempt from city license plate restrictions (Ma et al., 2017). Additionally, licences for traditional fuel vehicles are costly, making the policy of free license plates for EVs even more appealing to potential consumers. This has created a strong market pull for EVs in Shanghai.

Unlike many other provinces that implement protectionist policies favouring their own brands by restricting competition, Shanghai has adopted an open market approach and became the first city to allow the entry of solely foreign-owned companies. Moreover, Shanghai not only encourage the entry of local EV brands in the market but also supports the entry of all other brands by offering them the same purchase subsidies as local brands. This market opening strategy has had a significant impact on the EV market in Shanghai, leading to an increased number of EV brands establishing factories in the city to be closer to the consumer market, and further boosting EV production.

4.5.2 Anhui (Producers)

Thanks to its already thriving automotive industry, Anhui province has emerged as one of the largest EV production hubs in China (Zhao et al., 2011). This does not come as a surprise, and it confirms that the EV industry can leverage the strength of an established traditional automotive sector (Borgstedt et al., 2017; Proof & Kilian, 2012). EVs are often seen as an upgrade and breakthrough in the automotive industry, providing established companies with a competitive advantage in new and emerging markets. In terms of organizational structure, EV production sites tend to follow the spatial layout of the existing automotive industry. For instance, Chery Automobile, one of the largest automotive companies in China, has established its EV production base at its headquarters in Anhui Province.

Policy mixes focused on supporting the EV production can further enhance our understanding of why Anhui province represents the cluster of Producers. According to the provincial government's industrial plans, the development of the EV sector has been identified as a crucial driver of economic growth in Anhui Province (Zhao, 2017). The production activities are primarily concentrated in Hefei, the capital of Anhui province, and Wuhu, to leverage the benefits of spatial agglomeration (Wang, 2022). The primary goals of government policies include nurturing influential vehicle enterprises, fostering competitive component manufacturers, establishing strong brands, and building a world-class EV industry cluster. To achieve these goals, the Anhui government provides substantial governmental investment to attract new EV manufacturers – a strategy commonly known as "investment attraction". For example, in 2019, the government invested 7 billion RMB (0.8 billion GBP) of state-owned capital in NIO (an EV manufacturer), which resulted in NIO settling in Hefei (Li, 2020).

In addition to production policies, Anhui Province has also provided strong policy support and allocated dedicated funds for technological development (General Office of Anhui Provincial People's Government, 2021). As a result, the province has become a hub for EV research centres and national key laboratories (e.g., the research centre for energy-saving and environment-friendly vehicles), positioning it at the forefront of EV technology (Zhao, 2017). The significant number of EV patents in Anhui can be partially attributed to its thriving EV production sector. In the process of searching for EV patents data, we observed that EV patents in Anhui are concentrated in a few key EV enterprises, such as Chery Automobile and Ankai Bus. EV patents have a strong connection to EV enterprises, because technology improvement can improve the enterprises' competitiveness in the EV market (Li et al., 2019).

4.5.3 Jiangxi (Green transport)

The EV sector in Jiangxi Province is demonstrates mediocre performance in many aspects, except for its notable achievement in the electrification of public transport. Despite the significant growth of China's automotive industry since 2002, Jiangxi province has experienced limited development, which could be attributed to its weak automotive industry (Zhang & Wen, 2017). Furthermore, the EV market in Jiangxi has been relatively slow to expand. One contributing factor is the presence of a subsidy policy that exhibits strong local protectionism. Prior to 2017, the government only offered subsidies for EVs produced by the local Jiangling Group, hindering the entry of other brands into the Jiangxi EV market. For instance, EVs produced in other provinces often exceeds 200,000 RMB in price. With a central government subsidy of 40,000 RMB, the cost to consumers would be 160,000 RMB. In contrast, vehicles manufactured in Jiangxi receive not only the central government subsidy but also a provincial subsidy, resulting in a significantly lower final price for consumers (under 100,000 RMB). This limited market choice has posed challenges to the promotion of EVs in Jiangxi and has consequently hindered market development.

However, in response to the central government's mandate to promote EVs, the Jiangxi provincial government has placed significant emphasis on electrifying the public transport sector and has set an ambitious target of having electric buses account for over 75% of its bus fleet by 2020 (Jiangxi Provincial Government, 2022). To achieve this goal, the government has implemented strict regulations regarding the percentage of new bus purchases that must be electric, in addition to providing subsidies for the purchase and operation of electric buses. Notably, Jiangxi province stands out as the only province in the country to have established a comprehensive policy specifically promoting electric buses. In fact, it has set even higher targets, aiming to reach 88% electric buses by 2020 and 92% by 2022 (Jiangxi Provincial Government, 2020). These ambitious targets explain the significant presence of EV bus in Jiangxi province. Furthermore, Jiangxi Province boasts the highest population density in urban areas among the provinces, coupled with the lowest number of vehicles per capita. This unique combination provides greater opportunity for the development of electric public transport.

4.5.4 Jilin (Laggards)

Automotive industry plays a significant role in the provincial economies of north-eastern China, particularly in Jilin, Heilongjiang, and Liaoning (He et al., 2018). Jilin Province places great strategic importance on its automotive industry, which contributes to over half of the province's industrial profits (Xu, 2021). However, it is surprising to observe that EV production in Jilin remains negligible, in contrast to the situation in Anhui. This raises the question of how the established automotive industry in Jilin impedes the local development of EVs.

One possible explanation lies in the unique industrial structure of Jilin Province, dominated by the FAW Group and its subsidiaries, which form the main automotive industry system (Sheng & Mou, 2016). FAW primarily focuses on the production of conventional fossil fuel vehicles, as the EV market, especially in the northeast, is still relatively small. Furthermore, there is no other automotive company in Jilin that can rival FAW or possesses the resources to develop and produce EVs. This aligns with the findings from Juan (Juan, 2011), who argues that certain companies exhibit low proactivity in embracing new technology. With mature technology in traditional fuel vehicles and satisfactory profitability, they are reluctant to allocate additional funds for the development of alternative products. Consequently, despite the strong presence of Jilin's automotive industry, the persistence of traditional fuel vehicles continues to hinder the growth of the EV sector.

The underperformance of Jilin Province in terms of EV adoption and charging infrastructure can be partially attributed to its weak economy, as indicated by its lowest GDP per capita and income among the four case-study provinces. The high cost of EVs and the construction of charging facilities require economic support, which Jilin lacks. However, we argue that the province's low performance can also be attributed to its policy mixes. The Jilin provincial government has displayed a lack of proactivity in promoting EVs, as evident from Table 5, which shows the province having the lowest number of policy instruments. Unlike other provinces, Jilin lacks unique local policy tools and primarily aligns its EV policy with content of the central government policies, merely meeting the minimum standards. For instance, while Shanghai provides a higher EV purchase subsidy than the central government, Jilin has maintained a low subsidy level, representing only 25% of the central subsidy in 2018.

We contend that excessive local economic protectionism contributes to this situation. Jilin Province's industrial layout revolves around FAW Group, and its economic development highly relies on the output of the automotive industry. To safeguard the local economy, the government has long pursued a policy of protecting and supporting the FAW Group. Being one of the country's largest manufacturers of traditional fuel vehicle, FAW's product offerings are influenced by various factors, such as the leaders' attitude and changes in corporate earnings. Furthermore, the cold temperatures in the northeast regions pose challenges for EV battery performance, resulting in a limited EV market in these areas. Consequently, FAW has maintained its focus on the conventional car sector and made slow progress in researching and developing EV products. The R&D and production policies for EVs have had minimal impact on FAW's industrial layout. Due to the small scale of both EV purchase and production, the Jilin government also appears to lack enthusiasm for promoting EV usage and infrastructure policies.

4.6 Discussion

Our findings align with previous studies highlighting the significance of overall economic development in facilitating successful energy transitions (Yu et al., 2019; Laurentis & Pearson, 2018). Specifically, we observed that wealthier provinces in the coastal regions of Eastern China, with higher GDP per capita, exhibited higher EV production and adoption rates, along with more developed EV infrastructure. These provinces also demonstrated the presence of strong supportive policies for EV development. Additionally, our results indicate a disparity between rural and urban areas, with urbanised provinces generally outperforming rural regions across various aspects of EV development.

The role of local industry emerged as a crucial factor that warrants further attention from researchers. Our findings suggest that a robust automotive sector, as seen in Anhui and Shanghai, can facilitate the development of EVs. Conversely, the case of Jilin highlights how excessive protectionism by provincial government, driven by a desire to preserve existing production, can hinder the uptake of new technologies and the adoption of new business models. These insights provide opportunities for future research on the effects of protectionism in energy transitions and the complex role of entrenched traditional automotive industries in mobility transitions. Moreover, exploring the Chinese governance system and investigating the strategies employed by provinces to safeguard their economic interests would contribute valuable insights to the field. Understanding the dynamics of these strategies can shed light on the interplay between regional economic considerations and the transition to sustainable energy systems.

While our cases show that economic and socio-demographics factors affect the variation of EV development across provinces, there are certain aspects where the influence mechanisms are not clearly delineated. For example, although previous studies have shown the effect of population density on EV market share (Li et al., 2020), our cases do not provide sufficient evidence to support this. We assume that the population density act as a mediating factor, influencing EV market share through its interaction with other factors, but this hypothesis requires further examination. Similarly, the expectation that higher vehicle ownership per capita would correlate with higher rates of EV adoption is contradicted by the case of Shanghai. Here, local regulations that control the total number of vehicles to curb its excessive growth might explain the discrepancy between vehicle ownership per capita and actual demand for vehicles.

Regarding the gender ratio, our findings corroborate earlier studies (Sovacool et al., 2018; Plötz et al., 2014; He et al., 2018) indicating that a higher male-to-female ratio could coincide with a higher adoption rate of EVs. Shanghai, with both the highest gender ratio and highest EV ownership, exemplifies this trend, while Jilin Province exhibits the lowest figures for both indicators. We speculate that this correlation could be attributed to cultural norms in China, where men are more likely to drive and invest in vehicles. However, the limitations of our case studies warrant caution, and further empirical evidence is needed to establish a robust relationship between gender and EV adoption. In fact, exploring potential differences in social norms among Chinese provinces could be a fruitful avenue for future research to understand their influence on the EV sector.

Moreover, the importance of policy mixes emerges as a significant finding, which aligns with previous studies (Langbroek et al., 2016; Xu & Su, 2016; Jiang et al., 2018). While the Chinese central government sets the goals, formulates strategies, and issues guidelines, a substantial part of the policymaking, especially implementation, is left to the sub-national levels (Zhang & Bai, 2017; Zhu & Zhao, 2021). This has resulted in provincial EV policies aligning closely with the central government in terms of their main content but showing variations in policy details and their implementation across different provinces. Local policies play a key role in in addressing specific challenges and directing the development of the local EV sector. Therefore, measures that are locally crafted to address unique needs, such as exemptions from traffic restrictions in overpopulated Shanghai, seem to be particularly important.

Lastly, our analysis highlights that the EV sector in China still seems to be highly policy-driven, with strong governmental intervention and support. This raises an important question for future research: how can the future development of EVs move beyond reliance on government policies? It is a common concern not only for China, but also for other countries, as these long-standing financial incentives to stimulate adoption have been the main drivers globally.

4.7 Conclusion

This paper sought to investigate how the energy transition in the mobility sector is being carried out on the ground and explore the reasons behind the variations observed within a single country. To address our research questions, we conducted a two-step analysis. Firstly, we conducted a cluster analysis using five variables that we argue measure the overall development of the EV sector. To the best of our knowledge, the existing literature lacks a comprehensive framework for measuring and assessing the overall development of EVs, and our approach, specifically tailored for the Chinese context, can serve as a valuable starting point for future studies focusing on different geographical areas. Secondly, we analysed one representative province from each cluster, drawing on the literature. This approach highlights the importance of contextualising energy transitions and the significance of pre-existing socio-economic inequalities, which have the potential to support, hamper, or alter transition efforts. Conversely, energy transitions can deepen and reinforce these inequalities, or induce new ones.

The results reveal an uneven development of the EV sector in China, creating transition frontrunners and laggards. An important distinction runs along the old cleavages where more affluent coastal provinces outperform the others. A more nuanced analysis of the case studies also identifies the influence of economic and socio-demographic factors such as GDP, income, and education. In addition, provincial governments in China also appear to be an important factor. Their impact is evident in the formulation of EV promotion policies, particularly when tailored to address specific local needs rather than simply replicating generic measures from the central government. Furthermore, when there is a traditional automotive industry under a provincial governments' jurisdiction, the provincial government can play an ambivalent role. While some provinces may promote EVs to leverage technological advancements and gain recognition from the central government, others may impede mobility transitions through excessive protectionism if they perceive EVs as a threat to local industries.

It is important to acknowledge the limitations of this study. First and foremost, the study is focused on China, which means that the generalisability of our findings is limited. Secondly, clustering analysis provides a snapshot in time and may overlook temporal trends and dynamics, which are crucial for understanding emerging technologies. Similarly, due to methodological constraints and data availability, we were not able to examine all the factors that could potentially explain the differences between provinces. Nevertheless, we strongly argue that the spatial perspective and research on unevenness in energy transitions on the subnational level should find better traction in energy studies. We hope that our paper, among others, has taken a step in this direction.

4.8 References

Anhui Provincial Economic and Information Department (2019). Anhui produced 158,000 new energy vehicles last year, up 1.3 times year-on-year. http://jx.ah.gov.cn/zzqs/czcy/142170361.html

Aschhoff, B., & Sofka, W. (2009). Innovation on demand—Can public procurement drive market success of innovations?. *Research policy*, *38*(8), 1235-1247. https://doi.org/10.1016/j.respol.2009.06.011.

Bakker, S., & Trip, J. J. (2013). Policy options to support the adoption of electric vehicles in the urban environment. *Transportation Research Part D: Transport and Environment*, *25*, 18-23. https://doi.org/10.1016/j.trd.2013.07.005.

Balta-Ozkan, N., Watson, T., & Mocca, E. (2015). Spatially uneven development and low carbon transitions: Insights from urban and regional planning. Energy Policy, 85, 500–510. https://doi.org/10.1016/j.enpol.2015.05.013

Baumgarte, F., Kaiser, M., & Keller, R. (2021). Policy support measures for widespread expansion of fast charging infrastructure for electric vehicles. *Energy Policy*, *156*, 112372. https://doi.org/10.1016/j.enpol.2021.112372.

Bellocchi, S., Klöckner, K., Manno, M., Noussan, M., & Vellini, M. (2019). On the role of electric vehicles towards low-carbon energy systems: Italy and Germany in comparison. Applied energy, 255, 113848. https://doi.org/10.1016/j.apenergy.2019.113848

Biresselioglu, M. E., Kaplan, M. D., & Yilmaz, B. K. (2018). Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes. *Transportation Research Part A: Policy and Practice*, *109*, 1-13. https://doi.org/10.1016/j.tra.2018.01.017.

Bjerkan, K. Y., Bjørge, N. M., & Babri, S. (2021). Transforming socio-technical configurations through creative destruction: Local policy, electric vehicle diffusion, and city governance in Norway. *Energy Research & Social Science*, *82*, 102294. https://doi.org/10.1016/j.erss.2021.102294.

Borgstedt, P., Neyer, B., & Schewe, G. (2017). Paving the road to electric vehicles – A patent analysis of the automotive supply industry. Journal of Cleaner Production, 167, 75–87. https://doi.org/10.1016/j.jclepro.2017.08.161

Bouzarovski, S., & Tirado Herrero, S. (2017). The energy divide: Integrating energy transitions, regional inequalities, and poverty trends in the European Union. European Urban and Regional Studies, 24(1), 69–86. https://doi.org/10.1177/0969776415596449

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy, 53, 331–340. https://doi.org/10.1016/j.enpol.2012.10.066

Caloffi, A., & Mariani, M. (2018). Regional policy mixes for enterprise and innovation: A fuzzy-set clustering approach. Environment and Planning C: Politics and Space, 36(1), 28-46. https://doi.org/10.1177/2399654417691515.

Cao, J., Chen, X., Qiu, R., & Hou, S. (2021). Electric vehicle industry sustainable development with a stakeholder engagement system. *Technology in Society*, *67*, 101771. https://doi.org/10.1016/j.techsoc.2021.101771.

Chen, T., Zhang, X. P., Wang, J., Li, J., Wu, C., Hu, M., & Bian, H. (2020). A review on electric vehicle charging infrastructure development in the UK. *Journal of Modern Power Systems and Clean Energy*, *8*(2), 193-205. https://doi.org/10.35833/MPCE.2018.000374.

China Academy of Transportation Sciences (2020). China's Experience in Promoting and Applying New Energy Urban Buses. https://www.efchina.org/Attachments/Report/report-ctp-20210325

China Automotive Technology Research Center, Beijing Guoneng energy information technology Co., Ltd., & "Energy Saving and New Energy Vehicle Yearbook" compilation office (2019). Energy Saving and New Energy Vehicle Yearbook 2019. China Railway Publishing House.

D'Urso, P., Manca, G., Water, N. and Girone, S. (2019). Visualizing regional clusters of Sardinia's EU supported agriculture: A spatial fuzzy partitioning around medoids. Land Use Policy, 83, 571-580. https://doi.org/10.1016/j.landusepol.2019.01.030.

Dong, F., & Liu, Y. (2020). Policy evolution and effect evaluation of new-energy vehicle industry in China. Resources Policy, 67, 101655. https://doi.org/10.1016/j.resourpol.2020.101655

Egnér, F., & Trosvik, L. (2018). Electric vehicle adoption in Sweden and the impact of local policy instruments. Energy Policy, 121, 584–596. https://doi.org/10.1016/j.enpol.2018.06.040

Eicke, L., & Goldthau, A. (2021). Are we at risk of an uneven low-carbon transition? Assessing evidence from a mixed-method elite study. Environmental Science & Policy, 124, 370–379. https://doi.org/10.1016/j.envsci.2021.07.009

Fan, C. C. (2006). China's Eleventh Five-Year Plan (2006-2010): From "Getting Rich First" to "Common Prosperity". Eurasian Geography and Economics, 47(6), 708–723. https://doi.org/10.2747/1538-7216.47.6.708

Fan, C. C., & Sun, M. (2008). Regional Inequality in China, 1978-2006. Eurasian Geography and Economics, 49(1), 1–18. https://doi.org/10.2747/1539-7216.49.1.1

General Office of Anhui Provincial People's Government (2021). Notice on the Issuance of the Action Plan for the Development of New Energy Vehicle Industry in Anhui Province (2021-2023), https://www.ah.gov.cn/public/1681/554020761.html.

Gersdorf, T. e. a. (2020). McKinsey Electric Vehicle Index: Europe cushions a global plunge in EV sales. http://www.libralato.co.uk/docs/mckinsey%20ev%20index%202020.pdf

Golembiewski, B., Vom Stein, N., Sick, N., & Wiemhöfer, H. D. (2015). Identifying trends in battery technologies with regard to electric mobility: evidence from patenting activities along and across the battery value chain. *Journal of Cleaner Production*, *87*, 800-810. https://doi.org/10.1016/j.jclepro.2014.10.034.

Griffiths, S., Del Rio, D. F., & Sovacool, B. (2021). Policy mixes to achieve sustainable mobility after the COVID-19 crisis. *Renewable and Sustainable Energy Reviews*, *143*, 110919. https://doi.org/10.1016/j.rser.2021.110919.

Guo, J., Zhang, X., Gu, F., Zhang, H., & Fan, Y. (2020). Does air pollution stimulate electric vehicle sales? Empirical evidence from twenty major cities in China. Journal of Cleaner Production, 249, 119372. https://doi.org/10.1016/j.jclepro.2019.119372

Hardman, S., Jenn, A., Tal, G., Axsen, J., Beard, G., Daina, N., ... & Witkamp, B. (2018). A review of consumer preferences of and interactions with electric vehicle charging infrastructure. *Transportation Research Part D: Transport and Environment*, *62*, 508-523. https://doi.org/10.1016/j.trd.2018.04.002.

Hardman, S., Steinberger-Wilckens, R., & Van Der Horst, D. (2013). Disruptive innovations: the case for hydrogen fuel cells and battery electric vehicles. *International Journal of Hydrogen Energy*, *38*(35), 15438-15451. https://doi.org/10.1016/j.ijhydene.2013.09.088.

He, X., Zhan, W., & Hu, Y. (2018). Consumer purchase intention of electric vehicles in China: The roles of perception and personality. *Journal of Cleaner Production*, *204*, 1060-1069. https://doi.org/10.1016/j.jclepro.2018.08.260.

He, Z., Wang, J., Wu, J., Liu D. (2018). Industrial map and industrial layout of China's automobile manufacturing industry, Economic Geography 38, 118–126.

Hertzke, P., Müller, N., Schenk, S., Wu T. The global electric-vehicle market is amped up and on the rise. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise, 2018, (accessed 10 August 2021).

Hidrue, M. K., Parsons, G. R., Kempton, W., & Gardner, M. P. (2011). Willingness to pay for electric vehicles and their attributes. *Resource and energy economics*, *33*(3), 686-705. https://doi.org/10.1016/j.reseneeco.2011.02.002.

Hsu, A., Höhne, N., Kuramochi, T., Vilariño, V., & Sovacool, B. K. (2020). Beyond states: Harnessing sub-national actors for the deep decarbonisation of cities, regions, and businesses. *Energy Research & Social Science*, *70*, 101738. https://doi.org/10.1016/j.erss.2020.101738.

Jenn, A., Springel, K., & Gopal, A. R. (2018). Effectiveness of electric vehicle incentives in the United States. Energy Policy, 119, 349–356. https://doi.org/10.1016/j.enpol.2018.04.065

Ji, Z., & Huang, X. (2018). Plug-in electric vehicle charging infrastructure deployment of China towards 2020: Policies, methodologies, and challenges. Renewable and Sustainable Energy Reviews, 90, 710–727. https://doi.org/10.1016/j.rser.2018.04.011

Jiang, C., Zhang, Y., Bu, M., & Liu, W. (2018). The Effectiveness of Government Subsidies on Manufacturing Innovation: Evidence from the New Energy Vehicle Industry in China. Sustainability, 10(6), 1692. https://doi.org/10.3390/su10061692

Jiang, C., Zhang, Y., Bu, M., & Liu, W. (2018). The effectiveness of government subsidies on manufacturing innovation: Evidence from the new energy vehicle industry in China. *Sustainability*, *10*(6), 1692. https://doi.org/10.3390/su10061692.

Jiangxi Provincial Bureau of Statistics. (2020). Jiangxi Provincial Statistical Yearbook 2018. http://tjj.jiangxi.gov.cn/col/col38595/index.html

Jiangxi Provincial Government, Opinions on accelerating the development of new energy vehicle industry http://www.jiangxi.gov.cn/art/2018/5/25/art_4975_212307.html, 2018 (accessed 25 July 2022).

Juan, Z. (2011). R&D for environmental innovation and supportive policy: the implications for new energy automobile industry in China. Energy Procedia, 5, 1003-1007. https://doi.org/10.1016/j.egypro.2011.03.177

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., ... & Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental innovation and societal transitions*, *31*, 1-32. https://doi.org/10.1016/j.eist.2019.01.004.

Kumar, R. R., & Alok, K. (2020). Adoption of electric vehicle: A literature review and prospects for sustainability. *Journal of Cleaner Production*, *253*, 119911. https://doi.org/10.1016/j.jclepro.2019.119911.

Lam, A., & Mercure, J. F. (2021). Which policy mixes are best for decarbonising passenger cars? Simulating interactions among taxes, subsidies and regulations for the United Kingdom, the United States, Japan, China, and India. *Energy Research & Social Science*, *75*, 101951. https://doi.org/10.1016/j.erss.2021.101951.

Langbroek, J. H., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. Energy Policy, 94, 94–103. https://doi.org/10.1016/j.enpol.2016.03.050

Laurentis, C. de, & Pearson, P. J. (2018). Understanding the material dimensions of the uneven deployment of renewable energy in two Italian regions. Energy Research & Social Science, 36, 106–119. https://doi.org/10.1016/j.erss.2017.11.009

Li, G., Wang, X., Su, S., & Su, Y. (2019). How green technological innovation ability influences enterprise competitiveness. *Technology in Society*, *59*, 101136. https://doi.org/10.1016/j.techsoc.2019.04.012.

Li, L., & Hu, J. (2012). Ecological total-factor energy efficiency of regions in China. Energy Policy, 46, 216–224. https://doi.org/10.1016/j.enpol.2012.03.053

Li, W. (2020). NIO China officially settles in Hefei, injects $7 billion for 24.1% stake, Jiemian News, https://www.jiemian.com/article/4318507.html, 29 April.

Li, W., Long, R., Chen, H., Chen, F., Zheng, X., & Yang, M. (2019). Effect of policy incentives on the uptake of electric vehicles in China. Sustainability, 11(12), 3323. https://doi.org/10.3390/su11123323

Li, W., Long, R., Zhang, L., Cheng, X., He, Z., & Chen, F. (2021). How the uptake of electric vehicles in China leads to emissions transfer: An Analysis from the perspective of inter-provincial electricity trading. *Sustainable Production and Consumption*, *28*, 1006-1017. https://doi.org/10.1016/j.spc.2021.07.026.

Li, X., Liu, W., Zhang, B., & Meng, D. (2019). New entrants versus establishers in China and US electric vehicle marketplace: a comparative analysis. Asia Pacific Business Review, 25(1), 19–39. https://doi.org/10.1080/13602381.2018.1512258

Li., X., Liu, Y., & Yang, J. (2020). On the regional differences of new energy vehicle promotion policy in China. China Population. Resources and Environment, 30, 51–61.

Lipps, J., & Schraff, D. (2021). Regional inequality and institutional trust in Europe. European Journal of Political Research, 60(4), 892-913. https://doi.org/10.1111/1475-6765.12430

Liu, L., Zhang, T., Avrin, A. P., & Wang, X. (2020). Is China's industrial policy effective? An empirical study of the new energy vehicles industry. *Technology in Society*, *63*, 101356. https://doi.org/10.1016/j.techsoc.2020.101356.

Liu, M., & Rui, M. (2021). Leading development with innovation to build Shanghai’s world-class auto industry cluster. Journal of Science Development, 150, 15–23.

Liu, Y., & Kokko, A. (2013). Who does what in China’s new energy vehicle industry?. *Energy policy*, *57*, 21-29. https://doi.org/10.1016/j.enpol.2012.05.046.

Liu, Y., Wang, M., & Feng, C. (2020). Inequalities of China's regional low-carbon development. Journal of Environmental Management, 274, 111042. https://doi.org/10.1016/j.jenvman.2020.111042

Ma, J., Liu, X., Chen, Y., Wang, P., et al. (2018). Current status and countermeasures for China’s new energy automobile industry and technology development. China Journal of Highway Transport, 31, 1–19.

Ma, S. C., Fan, Y., & Feng, L. (2017). An evaluation of government incentives for new energy vehicles in China focusing on vehicle purchasing restrictions. *Energy Policy*, *110*, 609-618. https://doi.org/10.1016/j.enpol.2017.07.057.

Markard, J. (2018). The next phase of the energy transition and its implications for research and policy. Nature Energy, 3(8), 628–633. https://doi.org/10.1038/s41560-018-0171-7

Melton, N., Axsen, J., & Moawad, B. (2020). Which plug-in electric vehicle policies are best? A multi-criteria evaluation framework applied to Canada. *Energy Research & Social Science*, *64*, 101411. https://doi.org/10.1016/j.erss.2019.101411.

Meng, F., & Jin, X. (2019). Evaluation of the development capability of the new energy vehicle industry: An empirical study from China. Sustainability, 11, 2635. https://doi.org/10.3390/su11092635

Mersky, A. C., Sprei, F., Samaras, C., & Qian, Z. (2016). Effectiveness of incentives on electric vehicle adoption in Norway. Transportation Research Part D: Transport and Environment, 46, 56–68. https://doi.org/10.1016/j.trd.2016.03.011

Minhang District People's Government (2016). Minhang district promotion and application of new energy vehicle funds subsidy management measures. http://xxgk.shmh.gov.cn/

Municipal Commission of Economy and Information Technology (2019). Shanghai's new energy vehicle registrations surpass 70,000 units in 2018, with cumulative ownership reaching 240,000. https://www.shevdc.org

Muniz, S. T. G., Belzowski, B. M., & Zhu, J. (2019). The trajectory of China's new energy vehicles policy. International Journal of Automotive Technology and Management, 19(3/4), 257–280. https://www.inderscienceonline.com/doi/abs/10.1504/IJATM.2019.100913.

Naqvi, S. A. A., Shah, S. A. R., Anwar, S., & Raza, H. (2021). Renewable energy, economic development, and ecological footprint nexus: fresh evidence of renewable energy environment Kuznets curve (RKC) from income groups. Environmental Science and Pollution Research, 28(2), 2031-2051. https://doi.org/10.1007/s11356-020-10485-w

O'Sullivan, K., Golubchikov, O., & Mehmood, A. (2020). Uneven energy transitions: Understanding continued energy peripheralization in rural communities. Energy Policy, 138, 111288. https://doi.org/10.1016/j.enpol.2020.111288

Peng, H. (2018). Influencing factors on spatial distribution of China's new energy automobile industry. Northeast Asia Economic Research, 8, 78–93.

Plötz, P., Schneider, U., Globisch, J., & Dütschke, E. (2014). Who will buy electric vehicles? Identifying early adopters in Germany. *Transportation Research Part A: Policy and Practice*, *67*, 96-109. https://doi.org/10.1016/j.tra.2014.06.006.

Proff, H., & Kilian, D. (Eds.). (2012). Competitiveness of the EU automotive industry in electric vehicles. University of Duisburg-Essen.

Qiu, Y. Q., Zhou, P., & Sun, H. C. (2019). Assessing the effectiveness of city-level electric vehicle policies in China. *Energy Policy*, *130*, 22-31. https://doi.org/10.1016/j.enpol.2019.03.052.

R Core Team (2022). R: A language and environment for statistical computing (Version 4.1.3). URL https://www.R-project.org.

Redlands, C.E.S.R.I., ArcGIS Desktop: Release 10.5, 2018.

Riesz, J., Sotiriadis, C., Ambach, D., & Donovan, S. (2016). Quantifying the costs of a rapid transition to electric vehicles. Applied Energy, 180, 287–300. https://doi.org/10.1016/j.apenergy.2016.07.131

Rietmann, N., & Lieven, T. (2019). A comparison of policy measures promoting electric vehicles in 20 countries. In The Governance of Smart Transportation Systems (pp. 125-145). Springer, Cham.

Riva, M., Makasi, S. K., Dufresne, P., O'Sullivan, K., & Toth, M. (2021). Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy. *Energy Research & Social Science*, *81*, 102237. https://doi.org/10.1016/j.erss.2021.102237.

Shanghai Municipal People's Government. (2016). Shanghai support measures to encourage the development of electric vehicle charging and switching facilities. https://www.shanghai.gov.cn/

Shao, W., Yang, K., & Bai, X. (2021). Impact of financial subsidies on the R&D intensity of new energy vehicles: A case study of 88 listed enterprises in China. *Energy Strategy Reviews*, *33*, 100580. https://doi.org/10.1016/j.esr.2020.100580.

Sheng, Z., Mou, X. (2016). Study on the upgrading problems and countermeasures of automobile industry clusters in Jilin Province, Economic Vision 1, 23–28.

Shi, X., Jing, R., Hou, G. M., & Wang, J. P. (2019). Network position advantage and technological innovation of China's new energy vehicle based on the perspective of network theory. *Sustainability*, *11*(7), 2098. https://doi.org/10.3390/su11072098.

Simsekoglu, Ö. (2018). Socio-demographic characteristics, psychological factors and knowledge related to electric car use: A comparison between electric and conventional car drivers. *Transport Policy*, *72*, 180-186. https://doi.org/10.1016/j.tranpol.2018.03.009.

Singh, V., Singh, V., & Vaibhav, S. (2020). A review and simple meta-analysis of factors influencing adoption of electric vehicles. *Transportation Research Part D: Transport and Environment*, *86*, 102436. https://doi.org/10.1016/j.trd.2020.102436.

Sovacool, B. K. (2017). Experts, theories, and electric mobility transitions: Toward an integrated conceptual framework for the adoption of electric vehicles. *Energy Research & Social Science*, *27*, 78-95. https://doi.org/10.1016/j.erss.2017.02.014.

Sovacool, B. K., Hook, A., Martiskainen, M., Brock, A., & Turnheim, B. (2020). The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa. Global Environmental Change, 60, 102028. https://doi.org/10.1016/j.gloenvcha.2019.102028

Sovacool, B. K., Kester, J., Noel, L., & de Rubens, G. Z. (2018). The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. *Global Environmental Change*, *52*, 86-100. https://doi.org/10.1016/j.gloenvcha.2018.06.008.

Sovacool, B. K., Kester, J., Noel, L., & de Rubens, G. Z. (2019). Income, political affiliation, urbanism and geography in stated preferences for electric vehicles (EVs) and vehicle-to-grid (V2G) technologies in Northern Europe. *Journal of Transport Geography*, *78*, 214-229.

State Council (2012). Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020). http://www.gov.cn/zwgk/2012-07/09/content_2179032.htm

State Council (2013). The 12th Five-Year Plan for Energy Development. http://www.gov.cn/zwgk/2013-01/23/content_2318554.htm

Sun, H., Geng, Y., Hu, L., Shi, L., & Xu, T. (2018). Measuring China's new energy vehicle patents: A social network analysis approach. Energy, 153, 685–693. https://doi.org/10.1016/j.energy.2018.04.077

Sun, W., & Yang, C. (2015). A study on the difference between urban and rural consumer markets with changing income distribution: Empirical evidence on car consumption based on CHFS data. Social Science Front, 3, 51–60.

Sun, X., Liu, X., Wang, Y., & Yuan, F. (2019). The effects of public subsidies on emerging industry: An agent-based model of the electric vehicle industry. *Technological Forecasting and Social Change*, *140*, 281-295. https://doi.org/10.1016/j.techfore.2018.12.013.

Tang, B., Wang, X., Wang, B., Wu, X., et al. (2019). Analysis and prospect of China's new energy vehicle industry development level. Journal of Beijing Institute of Technology (Social Sciences Edition), 21 (2), 6–11.

Tomasi, S., Zubaryeva, A., Pizzirani, C., Dal Col, M., & Balest, J. (2021). Propensity to Choose Electric Vehicles in Cross-Border Alpine Regions. *Sustainability*, *13*(8), 4583. https://doi.org/10.3390/su13084583.

Tosun, J., & Shyrokykh, K. (2021). Leadership in high-level forums on energy governance: China and Russia compared. Post-Communist Economies, 1–24. https://doi.org/10.1080/14631377.2021.1964742

Trencher, G., Truong, N., Temocin, P., & Duygan, M. (2021). Top-down sustainability transitions in action: How do incumbent actors drive electric mobility diffusion in China, Japan, and California?. *Energy Research & Social Science*, *79*, 102184. https://doi.org/10.1016/j.erss.2021.102184.

Wan, Z., Sperling, D., & Wang, Y. (2015). China's electric car frustrations. *Transportation Research Part D: Transport and Environment*, *34*, 116-121. https://doi.org/10.1016/j.trd.2014.10.014.

Wang, Q. (2022). Anhui Finance Empowers High Quality Development of New Energy Vehicle Industry, Anhui News, http://ah.anhuinews.com/szxw/202207/t20220718_6177386.html, 19 July.

Wang, X., Yu, Z. (2016). Current situation and future trend of new energy vehicles in China. Science and Technology Review, 34, 13–18.

Wang, Y., Zhang, D., Ji, Q., & Shi, X. (2020). Regional renewable energy development in China: A multidimensional assessment. Renewable and Sustainable Energy Reviews, 124, 109797. https://doi.org/10.1016/j.rser.2020.109797

Wang, Z. (2020). China Small Pure Electric Passenger Vehicle Travel Data Report. White Paper.

Wei, Y. D., Zhou, Y., Sun, Y., & Lin, G. C. (2012). Production and R&D networks of foreign ventures in China: Implications for technological dynamism and regional development. *Applied geography*, *32*(1), 106-118. https://doi.org/10.1016/j.apgeog.2010.06.008.

Westin, K., Jansson, J., & Nordlund, A. (2018). The importance of socio-demographic characteristics, geographic setting, and attitudes for adoption of electric vehicles in Sweden. *Travel Behaviour and Society*, *13*, 118-127. https://doi.org/10.1016/j.tbs.2018.07.004.

Wilson, C. (2018). Disruptive low-carbon innovations. *Energy Research & Social Science*, *37*, 216-223. https://doi.org/10.1016/j.erss.2017.10.053.

Xie, X. L., & Beni, G. (1991). A validity measure for fuzzy clustering. IEEE Transactions on pattern analysis and machine intelligence, 13(8), 841-847. https://doi.org/10.1109/34.85677.

Xu, L., & Su, J. (2016). From government to market and from producer to consumer: Transition of policy mix towards clean mobility in China. Energy Policy, 96, 328–340. https://doi.org/10.1016/j.enpol.2016.05.038

Xu, W. (2021). Jilin Province is the cradle of the new Chinese automobile industry. Jilin Daily News. http://jl.news.cn/2021-10/16/c_1127964047.htm

Yan, S. (2018). The economic and environmental impacts of tax incentives for battery electric vehicles in Europe. Energy Policy, 123, 53-63. https://doi.org/10.1016/j.enpol.2018.08.032

Yang, D. X., Qiu, L. S., Yan, J. J., Chen, Z. Y., & Jiang, M. (2019). The government regulation and market behavior of the new energy automotive industry. *Journal of cleaner production*, *210*, 1281-1288. https://doi.org/10.1016/j.jclepro.2018.11.124.

Yang, T., Long, R., & Li, W. (2018). Suggestion on tax policy for promoting the PPP projects of charging infrastructure in China. *Journal of cleaner production*, *174*, 133-138. https://doi.org/10.1016/j.jclepro.2017.10.197.

Yu, J., & Cheng, Q. (2001). The upper bound of the optimal number of clusters in fuzzy clustering. *Science in China Series: Information Sciences*, *44*, 119-125. https://doi.org/10.1007/BF02713970.

Yu, S., Zheng, Y., & Li, L. (2019). A comprehensive evaluation of the development and utilization of China's regional renewable energy. Energy Policy, 127, 73–86. https://doi.org/10.1016/j.enpol.2018.11.056

Zhang, L., & Qin, Q. (2018). China's new energy vehicle policies: Evolution, comparison and recommendation. Transportation Research Part a: Policy and Practice, 110, 57–72. https://doi.org/10.1016/j.tra.2018.02.012

Zhang, X., & Bai, X. (2017). Incentive policies from 2006 to 2016 and new energy vehicle adoption in 2010–2020 in China. Renewable and Sustainable Energy Reviews, 70, 24–43. https://doi.org/10.1016/j.rser.2016.11.211

Zhang, X., Liang, Y., Yu, E., Rao, R., & Xie, J. (2017). Review of electric vehicle policies in China: Content summary and effect analysis. Renewable and Sustainable Energy Reviews, 70, 698–714. https://doi.org/10.1016/j.rser.2016.11.250

Zhang, X., Wen, S. (2017). Path choice of auto industry upgrading under the background of industrial transfer: taking JMC as an example, Journal of Nanchang Hangkong University (Social Science) 19, 35-42.

Zhang, Y., Wang, W., Zhang, X., & Li, Y. (2008). A cluster validity index for fuzzy clustering. *Information Sciences*, *178*(4), 1205-1218. https://doi.org/10.1016/j.ins.2007.10.004.

Zhao, H., Xu, G., Zhang, B., Dou, C. (2011). SWOT analysis of the development of new energy vehicle in Anhui province, Journal of Hefei University of Technology (Social Science) 25, 1–5.

Zhao, X. (2017). Research on the transformation of the automobile manufacturing industry in Anhui Province: Taking new energy vehicles as an example, Modern Business Trade Industry 28, 47–49.

Zheng, J., Sun, X., Jia, L., & Zhou, Y. (2020). Electric passenger vehicles sales and carbon dioxide emission reduction potential in China’s leading markets. Journal of Cleaner Production, 243, 118607. https://doi.org/10.1016/j.jclepro.2019.118607

Zheng, X., Menezes, F., Zheng, X., & Wu, C. (2022). An empirical assessment of the impact of subsidies on EV adoption in China: A difference-in-differences approach. Transportation Research Part A: Policy and Practice, 162, 121-136. https://doi.org/10.1016/j.tra.2022.05.020.

Zhu, X., & Zhao, H. (2021). Experimentalist Governance with Interactive Central–Local Relations: Making New Pension Policies in China. Policy Studies Journal, 49(1), 13–36. https://doi.org/10.1111/psj.12254

Zou, Y., Zhao, W., & Zhong, R. (2017). The spatial distribution of green buildings in China: Regional imbalance, economic fundamentals, and policy incentives. Applied Geography, 88, 38–47. https://doi.org/10.1016/j.apgeog.2017.08.022

5 How does local context matter? Assessing the heterogeneous impact of electric vehicle incentive policies in China*

Abstract. This study comprehensively evaluates electric vehicle (EV) incentive policies in 80 Chinese pilot cities from 2010 to 2022 using panel data analysis. Cities are stratified based on varying income levels, traffic congestion, population density, and administrative hierarchy, enabling an in-depth examination of the heterogeneous impacts of EV policies across diverse local contexts. Additionally, the study employs the Difference-in-Differences (DID) estimation method to scrutinize the dynamic effects of these policies over time, bolstering the credibility of the panel model results. Findings reveal significant positive impacts of EV policies, including purchase subsidies, parking benefits, driving privileges, and charging infrastructure, on EV market share. Regional heterogeneity is evident across divergent local contexts. Financial incentives are more effective in low-income, low-traffic, low-density, and capital cities, while driving privileges are significant in high-income, high-traffic, high-density areas, reflecting local convenience considerations. Usage-phase policies increasingly drive EV adoption over time, offering promise despite subsidy reductions. This study highlights the mismatch between EV policies and local contexts in China. It further provides insights into using policy measures to promote a just transition in the transportation sector.

5.1 Introduction

The adoption of electric vehicles (EVs) is pivotal for advancing the energy transition in the transportation sector and reducing greenhouse gas emissions (Hu et al., 2013; Hao et al., 2017; Requia et al., 2018). It also contributes to mitigating hazardous road traffic pollutants (Tessum et al., 2014; Ferrero et al., 2016), thereby improving public health (Ji et al., 2015). As the world's largest emitter of carbon emissions and plagued by persistent air pollution, China has set ambitious goals, including achieving carbon neutrality by 2060, and has taken significant steps to combat pollution. The electrification of the transportation sector an important breakthrough for Chinese government to achieve those objectives (Du et al., 2019).

Driven by various policies since 2009, EVs (including battery electric vehicles and plug-in hybrid vehicles) have witnessed substantial growth in China. According to official data released by the Chinese government, EV sales surged from a modest 5,000 units in 2010 to a staggering 6.887 million units by the year 2022.[2] In 2022, China assumed a commanding position, accounting for more than 60% of the global electric vehicle sales (IEA, 2023). However, it is crucial to recognize that EV adoption is far from uniform across China's diverse regions (Yao et al., 2022). Remarkably, the concentration of EV

* Under review at *Journal of Cleaner Production*.

[2] The production and sales of new energy vehicles in China have ranked first globally for eight consecutive years (People's Daily).

sales was notably pronounced in eight cities that had implemented automobile purchase restrictions, comprising 45% of the total in 2017, which later reduced to 38% by 2020 (Li et al., 2022). In stark contrast, the fifth-tier cities, totaling 128 in number, witnessed a mere 2% share of the overall EV sales (Yao et al., 2022). Figure 5.1 portrays the landscape of EV ownership across 80 pilot cities involved in EV promotion initiatives in China. The shading of the map corresponds to the level of EV ownership, with darker hues indicating higher ownership rates. This visual representation underscores the glaring disparities in EV distribution among these pilot cities.

Figure 5.1. EV ownership across cities in China in 2022.
Source: collecting from the local traffic management bureau in China.

This phenomenon can be attributed to a myriad of factors, encompassing economic development levels, historical and cultural backgrounds, and demographic characteristics, all of which exert a profound influence on the patterns of EV adoption (Westin et al., 2018; Simsekoglu, 2018; Guo et al., 2020; Dall-Orsoletta et al., 2022). The role of policy support is equally significant (Egnér & Trosvik, 2018). Policies originating from the central government are customized by local governments, and the degree of policy implementation can markedly differ among regions owing to their unique sets of interest preferences (May & Winter, 2007). Furthermore, geographical factors have the propensity to amplify the impact of EV policies in specific areas (Hardman, 2019; Qiu et al., 2019). For instance, prior research has identified disparities in the effectiveness of EV policies across cities with differing air quality, sizes or how densely populated (Yao et al., 2022; Egnér & Trosvik, 2018). These collective findings underscore the strong likelihood of the uneven distribution of EVs being intrinsically tied to the misalignment between EV policies and diverse local contexts.

Nevertheless, in contrast to the extensive body of literature assessing the effectiveness of electric vehicle policies, existing studies have not delved comprehensively into the subtleties of the local level and the pivotal role of local context in shaping policy outcomes. The tendency to overlook regional heterogeneity and its potential ramifications on policy results has contributed to the empirical findings of previous studies often yielding inconsistent and contradictory results (Beresteanu & Li, 2011; Zhang et al., 2013; Ma et al., 2017; Qiu et al., 2019; Yao et al., 2022). Given the conspicuous regional disparities evident in EV adoption, there is a compelling rationale for probing into the heterogeneous impact of policies on EV adoption within diverse regions of the same country. This avenue of research holds significant promise in shedding light on the nuanced interplay between policy measures and local dynamics.

Comprehending the diverse landscape of EV adoption across regions and reassessing the existing policy frameworks are pivotal steps towards achieving a just energy transition. The stark imbalances in EV adoption within China run contrary to the principles of a just transition, which aims to ensure that safe, affordable, and sustainable energy is accessible to all individuals, regardless of their income, wealth, gender, or ethnicity (Wang & Lo, 2021; Dall-Orsoletta et al., 2022). Ideally, well-designed policies should be instrumental in rectifying these disparities; however, current local-level EV policies often fall short of this objective. In certain instances, they may even exacerbate pre-existing societal inequalities (Sovacool et al., 2019). For instance, studies have revealed that tax expenditures and other financial incentives for EVs predominantly benefit higher-income groups (Guo & Kontou, 2021; Borenstein, 2016). Paradoxically, while these policies contribute to greater inequalities, they do not necessarily facilitate the continued growth of the EV market (Lee et al., 2019).

Against this backdrop, this study endeavors to reassess the efficacy of EV policies while shedding light on potential disparities in the influence of those policies across distinct jurisdictional landscapes. To achieve this goal, this study employs a panel data analysis approach to examine the EV incentive policies enacted in 80 pilot cities across China, covering the period from 2010 to 2022. These cities are stratified based on levels of income, traffic pressure, population density, and political hierarchy to evaluate the varying impacts of EV policies within different local contexts. Furthermore, this study harnesses the Difference-in-Differences (DID) estimation method to explore the evolving effects of these policies over time, thus corroborating the findings derived from the panel model. Through this multifaceted research approach, this study aims to provide a nuanced understanding of the intricate interplay between local context and EV policy outcomes, ultimately contributing to more informed and effective policymaking in the realm of EV promotion.

This study brings substantial contributions to two crucial domains. Firstly, it considers the diverse impact of policies across regions characterized by varying attributes. This perspective is paramount as overlooking regional policy disparities can result in pronounced inefficiencies. Secondly, it enriches our comprehension of the process of decarbonizing transportation across diverse contextual settings while concurrently advancing the discourse on facilitating a just energy transition. In practical terms, the findings of this study provide valuable insights for the development of effective and equitable policies aimed at promoting EV adoption.

The subsequent sections of this paper are structured as follows: Section 2 furnishes the research background and leads to the research questions under investigation. Section 3 delineates the dataset and outlines the empirical strategy applied. Section 4 presents the results and analysis, supplemented by robustness tests. Section 5 engages in an insightful discussion, and Section 6 offers the concluding remarks.

5.2 Heterogeneous impact of EV policies on EV adoption

5.2.1 EV policies in supporting EV adoption and their impact

Scholars have shown considerable interest in assessing the effectiveness of EV policies across various countries (Langbroek et al., 2016; Jenn et al., 2018; Münzel et al., 2019; Wu et al., 2021). In China, policies are widely recognized as a pivotal factor influencing EV adoption. Given that EVs represent a technology niche, their innovation and market expansion rely heavily on a combination of diverse policy instruments (Yin & Huang, 2023). When examining the demand side, previous research has sought to evaluate the efficacy of various policy instruments, encompassing financial and regulatory measures, as well as purchase and usage incentives (Zhang et al., 2017; Li et al., 2019; Liu et al., 2021).

However, it is worth noting that different studies have sometimes yielded conflicting findings regarding the effectiveness of EV policies (Ma et al., 2017; Qian et al., 2019), particularly in relation to non-financial incentives (Hardman & Tal, 2016; Sheldon & DeShazo, 2017; Mersky et al., 2016). One plausible explanation for these disparities is that many existing studies have tended to overlook the heterogeneity of policy impacts, especially in a vast and diverse country like China, characterized by substantial regional disparities in development. Failing to account for these regional nuances may result in less robust and inconclusive outcomes.

From an evolutionary perspective, policy support has been a consistent thread throughout the entire development of EVs in China. A pivotal moment for EVs in China occurred in 2009 with the launch of the *Ten Cities, Thousand Vehicles Demonstration and Deployment Program* (Muniz et al., 2019). Initially focusing on public transportation, the program gradually expanded to encompass the private sector in 2011. Between 2013 and 2015, the EV promotion program extended to 88 pilot cities and clusters, leading to the diffusion of EV policies across the entire nation and establishing them as a nationwide initiative (Zhang & Qin, 2018).

The purchase subsidy has been recognized as the primary policy tool to incentivize electric vehicle (EV) adoption, with numerous studies showcasing its positive impact in mitigating the price disadvantages associated with EVs (Hao et al., 2014; Zhang et al., 2017; Sheldon & Dua, 2020). China introduced a subsidy reduction policy to assist the emerging EV industry. The purchase subsidy decreased by 20% in 2016 and 50% in 2019 compared to the subsidies from the previous year and finally terminated by the end of 2022. As the abolishment of purchase subsidy could lead to a decline in EV sales, it is important to examine if other policies, especially the usage-based policies can make up for the negative impact of purchase subsidy abolishment (Kong et al., 2020). Free parking is another monetary policy at the use stage to raise the sales of EVs. It reduces the total cost of ownership therefore enhances the utility of EVs, because parking fees in many urban areas can be a significant expense for vehicle owners (Langbroek et al., 2016).

Regarding non-financial policies, two key usage-based policies influence EV adoption in China: driving privileges (Liu et al., 2023) and charging infrastructure (Qiu et al., 2019). Driving privileges, such as exemption from driving restrictions or access to bus lanes to avoid congestion, can enhance the utility of EVs, thereby stimulating the demand from the consumer side. The implementation of driving privilege policies in cities like Beijing and Shanghai significantly boosts the market share of EVs (Xiong & Liu, 2022). Charging stations are essential components of the consumer environment for EVs that can significantly enhance EV adoption intent by lowering range anxiety, lowering perceived mobility restriction, and more positive pro-BEV subjective norms (Sierzchula et al., 2014; White et al., 2022).

RQ1: To what extent do EV policies influence the adoption of EVs?

RQ2: What is the impact of different types of policies on the adoption of EVs?

5.2.2. The heterogeneity of impact in different local contexts

There are two dimensions of heterogeneity in policy implementation: heterogeneity in the policies themselves, including divergent instruments and the degree of implementation (Tosun & Leininger, 2017), and second, heterogeneity in policy effectiveness affected by other elements, especially local characteristics (Bachtrögler et al., 2020). Previous studies have investigated how some local characteristics can explain the differential impact of a policy (Cappelen et al., 2003; Gagliardi & Percoco, 2017). Indeed, there have been studies focusing on the field of EV policies, examining how factors such as population density (Egnér & Trosvik, 2018), travel patterns, and consumer preferences (Hardman, 2019), as well as city size and local air quality (Yao et al., 2022), can influence the effectiveness of policies. While some local features may reinforce the effect of EV policies in favour of adoption, others may constrain such relationships. Given regional disparities in China and variations in local conditions, how can policies be tailored to suit the characteristics of each region? This necessitates an exploration of the regional heterogeneity in policy effectiveness.

Income levels. In China, there is noticeable regional disparity in EV distribution based on the income levels of residents in different regions. Studies have revealed that lower-income groups often lag behind their wealthier counterparts in technology adoption due to cost barriers (Hsu & Fingerman, 2021), and financial support for technology adoption tends to primarily benefit high-income groups, exacerbating social inequality (Guo & Kontou, 2021). Moreover, the reliance solely on financial policies is unsustainable, as research has shown that the affordability of EVs is not limited to higher income levels anymore (Christidis & Focas, 2019), and high-income groups may not represent the largest group of PEV adopters in the future (Lee et al., 2019). While individuals with higher consumption capacity may exhibit greater affordability and a willingness to adopt environmentally friendly products (Hidrue et al., 2011, Sovacool et al., 2019), they also have a lower marginal consumption tendency, making it challenging to stimulate domestic demand by increasing their consumption levels. On the other hand, affordable and innovative products are more likely to motivate low-income groups (Xiong et al., 2019).

Traffic pressure. Due to the significant number of vehicles on the road, several cities experience exceptionally high traffic congestion. In response, certain local governments have implemented vehicle license plate restrictions, wherein a limited number of license plates are issued annually through methods such as lotteries and auctions (Li et al., 2019). This scarcity of license plates, coupled with high demand, has driven consumers to consider electric vehicles (EVs) as a viable alternative, since EVs are exempt from these city license plate restrictions. Currently, there are three provincial-level municipalities, four cities, and one province in China that enforce such license plate restrictions (Zhang et al., 2017). Research indicates that the substantial pent-up demand resulting from these restrictions is a significant factor contributing to the high market share of EVs (Li et al., 2019; Zhuge & Shao, 2019). Vehicle purchase restrictions suppress the demand for conventional fuel cars, consequently mitigating the price disadvantage of EVs in the market and moderating other factors that influence EV sales (Ma et al., 2017).

Population density. Population density is another factor that can significantly influence the effectiveness of EV policies (Egnér & Trosvik, 2018). For instance, individuals residing in regions with lower population density may need to commute longer distances, leading to concerns about range anxiety and an increased demand for accessible charging infrastructure (Li et al., 2020). However, the presence of range anxiety may diminish the effectiveness of purchase subsidy policies as incentives. Areas with lower population density might not face the same parking and traffic control challenges, potentially reducing the appeal of these policy measures for EV adoption. In contrast, regions with high population density tend to exhibit the opposite trend, where residents may be more responsive to policies that enhance convenience for EV usage.

Political hierarchy. The political hierarchy is a significant factor that has received limited attention in terms of its impact on policy effectiveness. In China, resources such as funds, land, and policies are allocated in a hierarchical manner, starting from the central government down to local governments and from higher-level cities (including provincial capitals or municipalities directly under the central government) to lower-level cities. This hierarchical allocation implies that higher-level cities enjoy greater convenience in resource allocation (Jia et al., 2021). For instance, provincial capital cities typically assume a leading role in local industrial planning and often serve as demonstration models. Consequently, they are more likely to receive priority funding support, enabling them to advance ahead of other cities (Gao et al., 2022). However, it's important to note that administrative allocation operates differently than market allocation and is less responsive to price signals and profit motives (Jiang et al., 2018).

RQ3: Does the impact of EV policies differ across different local contexts, particularly concerning income levels, traffic conditions, population density, and political hierarchy?

5.3 Data and Methodology

5.3.1 Variables

The dependent variable in this study is the EV market share of each city, considered a more reliable indicator of EV preference than EV sales volume. The independent variables encompass various EV policies, comprising two financial policies: total purchase subsidy and parking benefits (free parking), along with two non-financial policies: driving privilege and charging infrastructure. Purchase subsidy is treated as a numeric variable, calculated as the sum of national, provincial, and city-level subsidies. Charging infrastructure is represented by the annual number of new charging stations constructed, also measured as a numeric variable. The remaining policies are treated as binary variables, with a value of "1" indicating implementation in a city and "0" signifying their absence.

Table 5.1. Description of variables and sources.

Type	Variables	Abbrev-iation	Definition	Sources
Dependent variable	EV market share	EVMS	EV market share of new registered vehicles per year.	Using compulsory insurance coverage data from CBIC
Explanatory variables	Total purchase subsidy	TPS	The Sumption of central and local purchase subsidies.	Policy documents from the central, provincial and city governments
	Parking benefits	PB	Binary variable. If a city is implementing parking benefits for EVs, such as free parking or discount.	
	Driving privilege	DP	Binary variable. Exemption of EVs from traffic management measures such as license plate-based and time-based restrictions on mobility.	
	Charging Infrastructure	CI	The annual number of new charging stations constructed.	The Yearbook of Energy Conservation and New Energy Vehicles (2011-2022); reports from local transportation departments.
Control variables	Per capita disposable income	PCDI	The per capita disposable income of urban residents.[1]	Statistical Bulletin of National Economic and Social Development (2011-2023) of each city; the Statistical Yearbooks (2011–2023) of each city.
	Average years of education	AYE	Average years of education per resident	
	Vehicle ownership	VO	Private vehicle ownership	
	Urbanization rate	UR	Permanent resident urbanization rate	

[1] Due to variations in statistical methods in the statistical yearbooks of different cities, many cities do not compute the per capita disposable income for all residents collectively; instead, they often report separate figures for urban and rural residents for statistical purposes. Consequently, I have employed the per capita disposable income of urban residents as a proxy variable in this analysis.

Regarding the control variables, this study has included various socio-economic factors such as per capita disposable income, average years of education[1], civil vehicle ownership, and urbanization rate. Detailed information about these variables and their respective sources can be found in Table 5.1.

To examine the impact of EV policies across different income levels, the 80 cities were categorized into two groups (high/low) based on the 2022 national average per capita disposable income. Concerning the traffic pressure levels within cities, they were divided into two groups (high/low) depending on whether the city had implemented purchase restrictions on conventional fuel vehicles. To explore the impact of EV policies in different political hierarchy groups, the cities were split into two groups: cities serving as provincial capitals or municipalities directly under the central government were classified as having a high political hierarchy, while all other cities were considered to have a low political hierarchy. Regarding population density, following the approach of He et al. (2022), the city of Yangzhou in 2022 was used as the dividing point. Consequently, the 80 cities were divided into two groups (high/low) based on population density.

5.3.2 Data source and description

The data on EV market share was collected based on the annual amount of compulsory insurance coverage for vehicles reported by the China Banking and Insurance Regulatory Commission (CBIRC). Information regarding purchase subsidies was compiled by aggregating national, provincial, and city-level subsidies, sourced from government documents such as the "Notice on Improving the Financial Subsidy Policy for Promoting the Application of New Energy Vehicles." Similarly, details on other incentive policies were verified by reviewing relevant documents available on the government portal websites of each city. Examples of these policies include the "Various Measures for Promoting Electric Vehicles," "Policies on Motor Vehicle Parking Service Charges," and "Notices Regarding Exemption of New Energy Vehicles from Traffic Restrictions on Mobility." Data concerning charging stations in each city were extracted from the "Yearbook of Energy Conservation and New Energy Vehicles" (2011-2022) and reports from local transportation departments. Per capita disposable income, civil vehicle ownership, average years of education, and urbanization rate data were sourced from the "Statistical Bulletin of National Economic and Social Development" (2011-2023) and the "Statistical Yearbook" of each city (2011–2023).Due to significant data gaps in several cities that were excluded from the sample, this dataset included data from 80 EV demonstration pilot cities, encompassing a wide geographic range across 29 provinces (out of 31) in mainland China (elaborated in Appendix D.1). Data collection spanned from the year 2010, marking the initiation of EV promotion policies in China, to 2022, which was the most recent year for which data had been published and also the final year of purchase subsidies.

[1] The average years of education per capita, as calculated by the author using data from official statistical yearbooks, is derived using the following formula: Average Years of Education = (Number of Primary School Graduates × 6 + Number of Junior High School Graduates × 9 + Number of High School Graduates × 12 + Number of College Graduates and above × 16) / Total Population aged 6 and above.

Table 5.2 offers the descriptive statistics of the variables, while Appendix D.2 provides comprehensive details of the dependent and independent variables across the pilot cities.

Table 5.2. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
EVMS	1040	0.055	0.091	0	0.505
TPB	1040	44847.902	25893.157	5432	120000
PB	1040	0.354	0.478	0	1
DP	1040	0.15	0.357	0	1
CI	1040	2352.437	8558.67	0	144000
PCDI	1040	36970.079	13920.376	13740	84034
AYE	1040	5.823	2.19	0.927	13.341
VO	1040	1195456.3	1020853.3	38124	8202100
UR	1040	66.206	14.831	26.18	100

5.3.3 Empirical strategy

The panel data model has gained widespread acceptance for analyzing policy effects due to its ability to provide more accurate predictions of individual effects by utilizing a larger number of degrees of freedom and sample variability (Qiu et al., 2019). Equation (1) below presents the static panel data model used for assessing the impact of EV policies on EV market share.

$$EVMS_{it} = \alpha+\beta X_{it} +\rho C_{it} +\mu_i +\gamma_t +\varepsilon_{it} \qquad \text{Eq. (1)}$$

i and t represent the i-th city and the t-th year, respectively. Therefore, $EVMS_{it}$ represents the EV market share in the t-th year in the i-th city. α is the intercept; X and C represent the independent variables and control variables, respectively; β denotes the regression coefficient of independent variables; ρ is the regression coefficient of control variables; μ_i and γ_t represent the individual effect and time effect, respectively; and ε denotes a random disturbance error.

Incorporate the variables from this study into the model and take the logarithm of variables with high standard deviation. The specific panel data model is given in this paper as follows:

$$EVMS_{it} = \alpha + \beta_1 lnTPS_{it} + \beta_2 PB_{it} + \beta_3 DP_{it} + \beta_4 lnCI_{it} + \rho_1 lnPCDI_{it} + \rho_2 AYE_{it} + \rho_3 lnVO_{it} + \rho_4 UR_{it} + \mu_i + \gamma_t + \varepsilon_{it} \qquad \text{Eq. (2)}$$

5.4 Results

The estimation process was conducted in two steps. Initially, I estimated the effects across all regions to address RQ1 and RQ2. Subsequently, to address RQ3, I conducted estimations for different regions based on the scenarios outlined in section 2.2.

5.4.1 The impact of EV policies on EV adoption

The results of the Hausman test suggest that applying a fixed effects model is appropriate for this study. Table 5.3 presents the outcomes of the static panel data model. Models (1) and (2) are employed to investigate RQ1. Model (1) includes only the main explanatory variables, while Model (2), based on Eq. (2), incorporates the control variables.

When focusing on the impact of the independent variables, the results reveal that all of them have positive and statistically significant effects on EV market share. The statistical significance is particularly high for total purchase subsidy, parking benefits, and driving privilege. It is lower for charging infrastructure but still a one percent level. Importantly, the magnitudes of the coefficients remain consistent across the different models. These findings align with prior research that underscores the pivotal role of EV policies in promoting EV adoption (Xiong et al., 2019; Li et al., 2019; Ma et al., 2017).

Models (3) and (4) are employed to assess the impact of different types of policies. Total purchase subsidy and parking benefits represent financial instruments, while driving privilege and charging infrastructure are non-financial instruments. Additionally, purchase subsidy primarily targets the purchase stage of EVs, whereas the other three instruments benefit the usage stage. In comparing the coefficients, it can be observed that the coefficient value of total purchase subsidy is larger than that of charging infrastructure, indicating that the effect of total purchase subsidy is relatively stronger. On the other hand, driving privilege outperforms parking benefits. Consequently, there is no significant evidence to determine which type or stage of policy is more effective.

Regarding the control variables, per capita disposable income does not have a significant impact on EV market share, while an increase in the average years of education has a significantly positive effect. However, mixed results of these two variables also exist in previous studies (Egnéra & Trosvikb, 2018; Li et al., 2019), which further indicates the necessity of heterogeneity analysis. Both vehicle ownership and urbanization rate exhibit significant negative impacts on EV market share. One possible explanation is that these two variables lead to a greater number of conventional fuel vehicles, which can negatively influence EV adoption. In regions with a high prevalence of traditional vehicles, individuals may be more inclined to follow the trend.

Table 5.3. Empirical results with full sample: the impact of EV policies.

Variable	Model (1)	Model (2)	Model (3)	Model (4)
lnTPB	0.049***	0.054***	0.056***	
	(0.014)	(0.012)	(0.012)	
PB	0.013***	0.013***	0.015***	
	(0.004)	(0.003)	(0.003)	
DP	0.028***	0.019***		0.019***
	(0.006)	(0.005)		(0.005)
lnCI	0.008***	0.005**		0.007***
	(0.002)	(0.002)		(0.002)
lnPCDI		0.018	-0.003	0.032
		(0.047)	(0.048)	(0.048)
AYE		0.007**	0.008***	0.007**
		(0.002)	(0.002)	(0.002)
lnVO		-0.074***	-0.078***	-0.073***
		(0.013)	(0.013)	(0.014)
UR		-0.004***	-0.004***	-0.004***
		(0.000)	(0.000)	(0.000)
_cons	-0.189**	0.393*	0.524**	0.569**
	(0.061)	(0.228)	(0.229)	(0.222)
Time effect	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes
Individuals	80	80	80	80
Observations	1039	1039	1039	1039
Adj R-squared	0.8730	0.8939	0.8916	0.8899

Note: Standard errors appear in parentheses. *** p < 0.001, ** p < 0.01, * p < 0.05.

EVMS: EV market share; TPS: Total purchase subsidy; PB: Parking benefits; DP: Driving privilege; CI: Charging Infrastructure; PCDI: Per capita disposable income; AYE: Average years of education; VO: Vehicle ownership; UR: Urbanization rate.

5.4.2 Heterogeneity of policy impact

I categorized the 80 cities into different groups based on regional characteristics including income levels, traffic pressure, population density, and political hierarchy, as explained in detail in section 3.1. The empirical findings are displayed in Table 5.4.

Table 5.4. Empirical results of EV policy impact in different groups.

Variable	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)	Model (11)	Model (12)
Scenario	High income	Low income	High traffic pressure	Low traffic pressure	High population density	Low population density	Capital city	Non-capital city
lnTPB	0.026	0.090***	0.014	0.059***	0.023	0.08***	0.076***	0.057***
	(0.015)	(0.018)	(0.033)	(0.012)	(0.015)	(0.017)	(0.023)	(0.014)
PB	0.002	0.021***	0.012	0.016***	0.012**	0.017***	0.005	0.018***
	(0.004)	(0.005)	(0.011)	(0.003)	(0.004)	(0.004)	(0.006)	(0.004)
DP	0.038***	-0.008	0.048***	-0.008	0.028***	-0.032*	0.018**	0.092***
	(0.006)	(0.008)	(0.01)	(0.007)	(0.005)	(0.013)	(0.007)	(0.018)
lnCI	0.002	0.010***	-0.005	0.011***	0.0003	0.013***	-0.000	0.011***
	(0.002)	(0.003)	(0.005)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
lnPCDI	0.287***	-0.222***	-0.042	-0.054	0.219***	-0.155**	0.238**	-0.087
	(0.066)	(0.062)	(0.176)	(0.044)	(0.64)	(0.059)	(0.079)	(0.060)
AYE	0.002	0.005	-0.003	0.004*	0.002	0.006*	0.008*	0.006*
	(0.003)	(0.003)	(0.006)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
lnVO	-0.113***	0.009	-0.079	-0.011	-0.134***	0.002	-0.093***	-0.039*
	(0.018)	(0.018)	(0.049)	(0.013)	(0.021)	(0.016)	(0.026)	(0.015)
UR	-0.006	-0.002***	-0.009***	-0.002***	-0.005***	-0.002**	-0.006***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.0004)	(0.0006)	(0.001)	(0.001)	(0.001)
_cons	-0.290	0.639*	-0.149	0.169	0.150	0.397	-0.447	0.523
	(0.323)	(0.290)	(0.879)	(0.208)	(0.322)	(0.279)	(0.408)	(0.280)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individuals	38	42	9	71	36	44	28	52
Observations	494	545	117	922	470	569	364	675
Adj R-squared	0.9364	0.8676	0.9501	0.9025	0.9412	0.8738	0.8979	0.9029

Note: Standard errors appear in parentheses. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Looking at income levels, I observe that total purchase subsidy, parking benefits, and charging infrastructure have a significant positive impact on cities with lower income levels, whereas driving privileges show effectiveness in cities with higher income levels. This pattern is logical when considering that EVs typically have a pricing disadvantage compared to traditional gasoline-powered vehicles. Financial subsidies can effectively mitigate this disadvantage. Individuals with lower incomes are typically more responsive to financial policies and are likely to be incentivized by price reductions. Conversely, for high-income groups, the convenience of using EVs can boost their willingness to make a purchase.

When looking at traffic pressure, the driving privilege policy has a significantly positive effect in cities with high traffic pressure, while the other policies show effectiveness in cities with lower traffic pressure. This pattern makes sense because in cities with high traffic congestion, EVs can benefit more from their usage advantage. For instance, EVs may enjoy exemptions from driving restrictions, making them more efficient and appealing to consumers, ultimately increasing their market share. Conversely, in cities with lower traffic congestion, the driving privilege policy may not be as attractive, but other policies such as purchase subsidies and charging infrastructure can still play a significant role in promoting EV adoption.

When considering population density, policy impacts also vary. In densely populated areas, driving privileges significantly boost EV market share due to common road congestion issues. For example, the ability to use bus lanes to avoid traffic, enhance the efficiency of EV use, leading to greater EV adoption. Conversely, in sparsely populated areas, which are typically rural regions, financial policies have a more pronounced positive impact on EV adoption. Additionally, in low-density population areas, people often need to travel longer distances. Therefore, the accessibility and availability of charging facilities play a significant role in influencing the attractiveness and utility of EVs, which affects EV adoption rates.

From the political hierarchy perspective, both total purchase subsidy and driving privilege have a significant impact in both capital and non-capital cities. However, when tested with Fisher's Permutation test, the p-value for total purchase subsidy is 0.04, indicating a significant difference between the impact of total purchase subsidy in capital and non-capital cities, with a larger impact in capital cities. On the other hand, parking benefits and charging infrastructure only show a significant impact in non-capital cities. Interestingly, EV policies tend to perform better in cities with lower political hierarchy.

5.4.3 *Robustness checks*

I employed a DID regression analysis following the structure outlined in Eq. (3) to assess the robustness of the results presented in Section 4.1. Additionally, while panel data models provide insights into the effects of policies over a substantial period, the DID method allows for an investigation of dynamic changes in policy effects over time.

$$EVMS_{it} = \alpha + \beta * Treated_{it} + \rho \sum Controls_{it} + \mu_i + \gamma_t + \varepsilon_{it} \qquad \text{Eq. (3)}$$

This study employed a time-varying DID model to account for the varying implementation times of policies in different cities. the dependent variable is the EV market share, while the independent variables include purchase subsidy, parking benefits, driving privileges, and charging infrastructure. These policy variables are represented as binary variables, with a value of "0" before policy implementation and "1" after implementation. The definitions of driving privilege (DP) and parking benefit (PB) can be found in Table 5.1. As for total purchase subsidy and charging infrastructure, which are numeric variables, proxy variables were created for the DID method. Local purchase subsidy (LPS) was introduced as a proxy variable for the purchase subsidy. It takes a value of "1" if a city offers a municipal subsidy in addition to the central purchase subsidy, and "0" otherwise. Following the approach outlined in the study by Xiong and Liu (2022), the per capita charging infrastructure (PPCI) from 2016 (with a baseline value of f=0.009533) was used. Cities with a per capita charging station value below this baseline were assigned "0". while those above it were assigned "1". Additionally, control variables such as per capita disposable income, average years of education, civil vehicle ownership, and urbanization rate were included in the analysis to account for potential confounding factors.

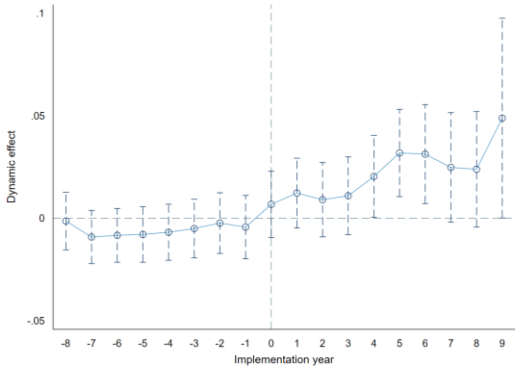
Table 5.5 presents the empirical results of the analysis. To assess the validity of the DID approach, common trends tests were conducted and the results are displayed in Figure 5.2. It's worth noting that the local purchase subsidy (LPS) did not pass the common trends test and is therefore not included in the results.

The analysis revealed that parking benefits, driving privileges, and charging infrastructure all have a significant positive impact on EV market share. This outcome aligns with the findings presented in Section 4.1, which were derived from panel models. Furthermore, the results suggest that the effects of these three policies are on an upward trend, indicating that their influence on the EV market share is increasing over time. This suggests that consumers are placing a growing value on the convenience offered by EVs.

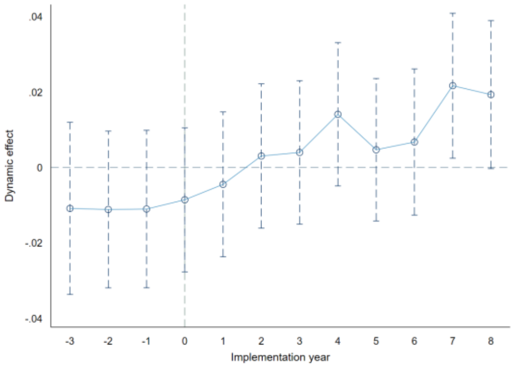
Table 5.5. Results of DID estimation.

Variable	Model (13)	Model (14)	Model (15)
PB	0.016*** (0.003)		
DP		0.02*** (0.006)	
PPCI			0.03*** (0.004)
lnPCDI	-0.015 (0.048)	0.015 (0.048)	0.008 (0.047)
AYE	0.008** (0.002)	0.007** (0.002)	0.008*** (0.002)
lnVO	-0.076*** (0.014)	-0.073*** (0.014)	-0.071*** (0.013)
UR	-0.004*** (0.000)	-0.004*** (0.000)	-0.003*** (0.000)
_cons	0.818*** (0.222)	0.665** (0.222)	0.611** (0.216)
Time effect	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes
Individuals	80	80	80
Observations	1039	1039	1039
Adj R-squared	0.8894	0.8883	0.8944

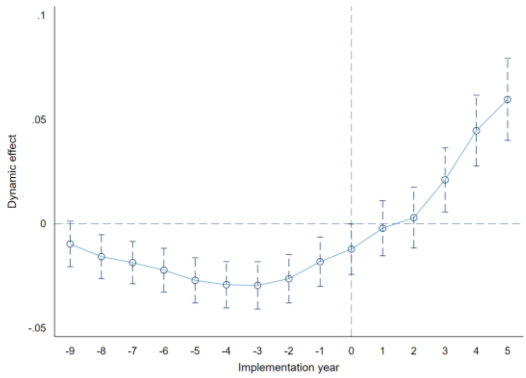
Note: Standard errors appear in parentheses. *** p < 0.001, ** p < 0.01, * p < 0.05.



(a) Parking benefit (PB)



(b) Driving privilege (DP)



(c) Per capita charging infrastructure (PPCI)

Figure 5.2. The results of the common trends test.

Because the result of local purchase subsidy did not pass the common trends test, to further validate the results and ensure their robustness, several additional robustness checks were conducted. These checks included: The method includes (1) Changing the estimation method to assess the impact of local purchase subsidy (model 16); (2) Changing the research period to 2015-2022 (model 17); (3) Using a one-period lag of EV market share as an independent variable (model 18); (4) Using "EV ownership per hundred people" as the dependent variable (model 19). The results of these additional analyses are presented in Table 5.6. These regressions consistently align with the findings in Section 4.1, reinforcing the robustness of the results and providing further confidence in the validity of the conclusions drawn in the main analysis.

Table 5.6. Robustness check.

Variable	Model (16) EVMS	Model (17) EVMS	Model (18) EVMS	Model (19) Ownership
L.EVMS			0.896*** (0.026)	
LPS	0.012*** (0.003)			
lnTPB		0.087*** (0.016)	0.027*** (0.008)	0.606*** (0.135)
PB	0.014*** (0.003)	0.013** (0.005)	0.006** (0.002)	0.096** (0.036)
DP	0.019*** (0.005)	0.030** (0.014)	0.009** (0.004)	0.197*** (0.059)
lnCI	0.006** (0.002)	0.010*** (0.003)	0.003** (0.001)	0.020 (0.020)
lnPCDI	0.012 (0.048)	0.102 (0.137)	0.008 (0.034)	0.939* (0.519)
AYE	0.007*** (0.002)	0.008** (0.003)	0.000 (0.002)	0.091*** (0.024)
lnVO	-0.073*** (0.013)	-0.142*** (0.035)	-0.024** (0.010)	-0.743*** (0.145)
UR	-0.004*** (0.000)	-0.407*** (0.075)	-0.001*** (0.000)	-0.056*** (0.004)
_cons	0.663** (0.220)	0.290 (0.662)	0.081 (0.166)	0.884 (2.493)
Time effect	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes
Individuals	80	80	80	80
Observations	1039	639	959	1039
Adj R-squared	0.8933	0.9014	0.9559	0.7388

Note: Standard errors appear in parentheses. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

5.5 Discussion

The results of this study underscore a significant policy mismatch within China's EV landscape. Notably, data in this study shows that cities in the high-income category tend to offer more generous purchase subsidies for EVs, averaging 1038 RMB more per electric vehicle. This aligns with previous research, which found that high-income cities like Shanghai, Beijing, Shenzhen, and Hangzhou provide greater financial incentives compared to others (Zhang et al., 2017). However, the Fisher's Permutation test results indicate a substantial difference in the impact of total purchase subsidies between high-income and low-income cities, with a 1% significance level. Surprisingly, total purchase subsidies are more effective in stimulating EV adoption in low-income cities. Such policy mismatches can undermine the efficacy of fiscal policies and lead to fiscal losses. Additionally, the nationwide withdrawal of purchase subsidy policies in 2022 is likely to have a more pronounced impact on the EV market share in low-income cities. Policy mismatch issues also manifest among cities with varying levels of traffic pressure.

Another notable observation pertains to the impact of policy implementation during the usage phase, specifically regarding the construction of new charging stations. This study finds that the number of newly constructed charging stations has a more significant influence on EV adoption in areas with low population density, while its impact lacks statistical significance in high-density population areas. Data indicates that the majority of public charging stations are concentrated in economically developed coastal cities (71.4%), and there are substantial urban-rural disparities (China EV Charging Infrastructure Promotion Alliance, 2023). Suburban areas with low population density typically have fewer charging stations. Consequently, the addition of charging stations can significantly improve the convenience of EV use in suburban regions, thereby boosting the EV market share in those areas. This situation highlights a policy challenge: existing policies have not effectively addressed the urban-rural gap in charging station distribution and may inadvertently exacerbate this disparity by subsidizing the construction and operation of charging stations primarily in economically developed urban centers.

It is worth noting that, intriguingly, all policies except for purchase subsidies demonstrate a more significant impact in non-provincial capital cities. In China, provincial capital cities hold higher administrative status compared to other cities and often serve as gateways to their respective provinces. They typically play a demonstrative and leading role in local industrial planning, enjoying priority access to central and provincial funding and receiving preferential policy support from provincial government (Jiang et al., 2018). This special status has historically led to differential development compared to other cities. However, the results in this study challenge this conventional wisdom by suggesting that policies have greater potential in non-provincial capital cities. This finding implies that the existing policy focus on provincial capitals may not be the most effective approach to sustainably drive EV adoption. Instead, policies may need to be more inclusive and targeted towards a wider range of cities to achieve more equitable and efficient outcomes in promoting EVs.

This study underscores the importance of recognizing that one-size-fits-all policy approaches are inadequate for addressing the diverse contexts within a country, emphasizing that overlooking local characteristics can undermine the effectiveness of policies. This finding aligns with prior research (Yao et al., 2022). When viewed through the lens of a just transition, existing policies have exacerbated the disparity in EV distribution, further marginalizing low-income groups and rural residents during the transition process. Over the 13 years of purchase subsidy implementation, these subsidies have predominantly benefited high-income cities and affluent individuals (e.g., Guo & Kontou, 2021; Borenstein, 2016). To achieve a more equitable and effective transition, it is crucial to implement differentiated policies. These might include redirecting subsidies towards lower-income individuals, and shifting policy emphasis towards the usage phase in densely populated and congested urban areas.

Such targeted policies can help strike a balance between policy effectiveness and equity, fostering a more just transition to EVs.

The results of the DID estimation reveal a notable upward trend in the effectiveness of usage-phase policies, which is a positive development, particularly in light of the discontinuation of purchase subsidies. This trend suggests that usage-based policies can continue to drive EV adoption effectively, offering a viable alternative to traditional purchase subsidies. Purchase subsidy policies have historically been the primary drivers of EV adoption in many countries, including China, as evidenced by numerous prior studies (Diamond, 2009; Aasness & Odeck, 2015; Zhang & Qin, 2018; Zhang & Bai, 2017). However, as the EV market matures, consumer preferences are evolving. Consumers are no longer solely focused on incentives related to the initial purchase but are increasingly considering the convenience and benefits they can derive during the usage phase. This finding holds significant implications for policymakers, highlighting the importance of adapting policies to reflect the dynamic nature of the market. Policymakers should invest in the development and enhancement of policies targeting the usage phase to facilitate the continued growth of the EV market. Customizing policies to specific regions entails not only recognizing regional disparities but also aligning with the changing demands and preferences of consumers in the market.

5.6 Conclusion

This paper employs a panel data analysis method to comprehensively examine the EV incentive policies implemented in 80 pilot cities in China spanning from 2010 to 2022. These cities are categorized based on income levels, traffic pressure, population density, and political hierarchy. Subsequently, an analysis is conducted to assess the diverse impacts of EV policies in varying local contexts. Furthermore, this study utilizes the DID estimation method to investigate the dynamic effects of policies over time and to validate the results obtained from the panel model.

The findings of this study indicate that EV policies in China, encompassing purchase subsidies, parking benefits, driving privileges, and charging infrastructure, generally have a significant positive impact on EV market share. However, this impact varies across different local contexts, reflecting regional heterogeneity. Financial policies are more effective in cities with lower income levels, lower traffic congestion, lower population density, and in provincial capital cities. This aligns with prior research (Xiong et al., 2019). Conversely, driving privileges are more effective in cities with higher income levels, higher traffic congestion, and higher population density. The study also reveals that the effectiveness of usage-phase policies is steadily increasing, suggesting their potential to drive EV adoption even in the absence of purchase subsidies.

The observed regional heterogeneity in the impacts of EV policies suggests that the one-size-fits-all approach commonly employed in China may result in reduced policy effectiveness. Moreover, this uniform policy approach could exacerbate the existing disparities in EV distribution and disadvantage certain groups, such as low-income individuals and rural residents. Such policies may run counter to the principles of a "just transition" in the context of energy transformation. Consequently, this study not only addresses the gaps in existing research related to regional variations in policy effects but also offers insights into how customized policies can optimize their effectiveness and promote just transition in the automotive sector.

Nonetheless, it's important to acknowledge the limitations of this study. Firstly, it focused exclusively on Chinese EV promotion demonstration cities as its sample, which, while representing a significant portion of China's EV market, might not fully capture the diversity in policy effectiveness across the entire country. Future research could explore the heterogeneity in policies and their impacts in other cities beyond the demonstration ones, which would provide a more comprehensive understanding of the EV policy landscape in China. Furthermore, the generalizability of the study's results beyond the Chinese context may be limited. Comparative analyses of EV policies and their regional heterogeneity in different countries with distinct environmental conditions, political systems, policy backgrounds, and cultural characteristics could yield valuable insights for a broader understanding of policy effectiveness in the EV sector.

5.7 References

Aasness, M. A., & Odeck, J. (2015). The increase of electric vehicle usage in Norway—incentives and adverse effects. *European Transport Research Review*, *7*, 1-8.

Bachtrögler, J., Fratesi, U., & Perucca, G. (2020). The influence of the local context on the implementation and impact of EU Cohesion Policy. *Regional Studies*, *54*(1), 21-34.

Borenstein, S., & Davis, L. W. (2016). The distributional effects of US clean energy tax credits. *Tax Policy and the Economy*, *30*(1), 191-234.

Cappelen, A., Castellacci, F., Fagerberg, J., & Verspagen, B. (2003). The impact of EU regional support on growth and convergence in the European Union. JCMS: Journal of Common Market Studies, 41(4), 621–644. doi:10.1111/1468-5965.00438

Christidis, P., & Focas, C. (2019). Factors affecting the uptake of hybrid and electric vehicles in the European Union. *Energies*, *12*(18), 3414.

Dall-Orsoletta, A., Ferreira, P., & Dranka, G. G. (2022). Low-carbon technologies and just energy transition: prospects for electric vehicles. *Energy Conversion and Management: X*, *16*, 100271.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy policy*, *37*(3), 972-983.

Egnér, F., & Trosvik, L. (2018). Electric vehicle adoption in Sweden and the impact of local policy instruments. *Energy policy*, *121*, 584-596.

Ferrero, E., Alessandrini, S., Balanzino, A., 2016. Impact of the electric vehicles on the air pollution from a highway. Appl. Energy 169 (x), 450–459.

Gagliardi, L., & Percoco, M. (2017). The impact of the European Cohesion Policy in urban and rural regions. Regional Studies, 51(6), 857–868. doi:10.1080/00343404.2016.1179384

Gao, M., Gu, Q., & He, S. (2022). Place-based policies, administrative hierarchy, and city growth: evidence from China. *Economic Modelling*, *115*, 105952.

Guo, J., Zhang, X., Gu, F., Zhang, H., & Fan, Y. (2020). Does air pollution stimulate electric vehicle sales? Empirical evidence from twenty major cities in China. *Journal of Cleaner Production*, *249*, 119372. https://doi.org/10.1016/j.jclepro.2019.119372.

Guo, S., & Kontou, E. (2021). Disparities and equity issues in electric vehicles rebate allocation. *Energy Policy*, *154*, 112291.

Hao, H., Cheng, X., Liu, Z., & Zhao, F. (2017). Electric vehicles for greenhouse gas reduction in China: A cost-effectiveness analysis. *Transportation Research Part D: Transport and Environment*, *56*, 68-84.

Hao, H., Ou, X., Du, J., Wang, H., & Ouyang, M. (2014). China's electric vehicle subsidy scheme: Rationale and impacts. *Energy Policy*, *73*, 722-732.

Hardman, S. (2019). Understanding the impact of reoccurring and non-financial incentives on plug-in electric vehicle adoption–a review. *Transportation Research Part A: Policy and Practice*, *119*, 1-14.

Hardman, S., & Tal, G. (2016). Exploring the decision to adopt a high-end battery electric vehicle: role of financial and nonfinancial motivations. *Transportation Research Record*, *2572*(1), 20-27.

He, Z., Cao, C., Kuai, L., Zhou, Y., & Wang, J. (2022). Impact of policies on wind power innovation at different income levels: Regional differences in China based on dynamic panel estimation. *Technology in Society*, *71*, 102125.

Hidrue, M. K., Parsons, G. R., Kempton, W., & Gardner, M. P. (2011). Willingness to pay for electric vehicles and their attributes. *Resource and energy economics*, *33*(3), 686-705.

Hsu, C. W., & Fingerman, K. (2021). Public electric vehicle charger access disparities across race and income in California. *Transport Policy*, *100*, 59-67.

Huo, H., Zhang, Q., Wang, M.Q., Streets, D.G., He, K., 2010. Environmental implication of electric vehicles in China. Environ. Sci. Technol. 44, 4856–4861. https://doi.org/10. 1021/es100520c.

International Energy Agency (2023). 2023 Global Electric Vehicle Outlook. Report. Available at: https://www.iea.org/reports/global-ev-outlook-2023.

Jenn, A., Springel, K., & Gopal, A. R. (2018). Effectiveness of electric vehicle incentives in the United States. *Energy policy*, *119*, 349-356.

Ji, S., Cherry, C.R., Zhou, W., Sawhney, R., Wu, Y., Cai, S., Wang, S., Marshall, J.D., 2015. Environmental justice aspects of exposure to PM2.5 emissions from electric vehicle use in China. Environ. Sci. Technol. 49, 13912–13920. https://doi.org/10.1021/acs. est.5b04927.

Jia, J., Liang, X., & Ma, G. (2021). Political hierarchy and regional economic development: Evidence from a spatial discontinuity in China. *Journal of public economics*, *194*, 104352.

Jiang, T., Sun, K., Nie, H. (2018)., City level, total factor productivity and resource mismatch. Management World,34(3):38-50,77.

Kong, D., Xia, Q., Xue, Y., & Zhao, X. (2020). Effects of multi policies on electric vehicle diffusion under subsidy policy abolishment in China: A multi-actor perspective. *Applied energy*, *266*, 114887.

Langbroek, J. H., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. *Energy Policy*, *94*, 94-103.

Lee, J. H., Hardman, S. J., & Tal, G. (2019). Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion. *Energy Research & Social Science*, *55*, 218-226.

Li, D., lv, W., Ding, K., Yi, L., & Guan, Y. (2022). Comparison and Analysis of New Energy Vehicle Policies in Cities with Vehicle Purchase Restrictions. Automobile Applied Technology, 18, 22-27.

Li, G., Luo, R., Gu, Y. (2019). Government’s Promotion Policies and the Demand of New-Energy Vehicles: Evidence from Shanghai. China Industrial Economics, 4(3), 42-61.

Li, W., Long, R., Chen, H., Chen, F., Zheng, X., & Yang, M. (2019). Effect of policy incentives on the uptake of electric vehicles in China. *Sustainability*, *11*(12), 3323.

Li, W., Long, R., Chen, H., Chen, F., Zheng, X., & Yang, M. (2019). Effect of policy incentives on the uptake of electric vehicles in China. *Sustainability*, *11*(12), 3323.

LI., X, Liu, Y., & Yang, J. (2020). On the regional differences of new energy vehicle promotion policy in China. China population, resources and environment, 30(8): 51-61.

Liu, X., Sun, X., Zheng, H., & Huang, D. (2021). Do policy incentives drive electric vehicle adoption? Evidence from China. *Transportation Research Part A: Policy and Practice*, *150*, 49-62.

Liu, Y., Zhao, X., Lu, D., & Li, X. (2023). Impact of policy incentives on the adoption of electric vehicle in China. *Transportation Research Part A: Policy and Practice*, *176*, 103801.

Ma, S. C., Fan, Y., & Feng, L. (2017). An evaluation of government incentives for new energy vehicles in China focusing on vehicle purchasing restrictions. *Energy Policy*, *110*, 609-618.

May, P. J., & Winter, S. C. (2007). Collaborative service arrangements: Patterns, bases, and perceived consequences. *Public Management Review*, 9(4), 479-502.

Mersky, A. C., Sprei, F., Samaras, C., & Qian, Z. S. (2016). Effectiveness of incentives on electric vehicle adoption in Norway. *Transportation Research Part D: Transport and Environment*, *46*, 56-68.

Muniz, S. T. G., Belzowski, B. M., & Zhu, J. (2019). The trajectory of China's new energy vehicles policy. *International Journal of Automotive Technology and Management*, *19*(3-4), 257-280.

Münzel, C., Plötz, P., Sprei, F., & Gnann, T. (2019). How large is the effect of financial incentives on electric vehicle sales?–A global review and European analysis. *Energy Economics*, *84*, 104493.

Qiu, Y. Q., Zhou, P., & Sun, H. C. (2019). Assessing the effectiveness of city-level electric vehicle policies in China. *Energy Policy*, *130*, 22-31.

Requia, W. J., Mohamed, M., Higgins, C. D., Arain, A., & Ferguson, M. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. *Atmospheric Environment*, *185*, 64-77.

Sheldon, T. L., & DeShazo, J. R. (2017). How does the presence of HOV lanes affect plug-in electric vehicle adoption in California? A generalized propensity score approach. *Journal of Environmental Economics and Management*, *85*, 146-170.

Sheldon, T. L., & Dua, R. (2020). Effectiveness of China's plug-in electric vehicle subsidy. *Energy Economics*, *88*, 104773.

Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy policy*, *68*, 183-194.

Simsekoglu, Ö. (2018). Socio-demographic characteristics, psychological factors and knowledge related to electric car use: A comparison between electric and conventional car drivers. *Transport Policy*, *72*, 180-186. https://doi.org/10.1016/j.tranpol.2018.03.009.

Simsekoglu, Ö. (2018). Socio-demographic characteristics, psychological factors and knowledge related to electric car use: A comparison between electric and conventional car drivers. *Transport Policy*, *72*, 180-186. https://doi.org/10.1016/j.rser.2016.11.250.

Sovacool, B. K., Kester, J., Noel, L., & de Rubens, G. Z. (2019). Income, political affiliation, urbanism and geography in stated preferences for electric vehicles (EVs) and vehicle-to-grid (V2G) technologies in Northern Europe. *Journal of Transport Geography*, *78*, 214-229.

Sovacool, B. K., Martiskainen, M., Hook, A., & Baker, L. (2019). Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions. *Climatic Change*, *155*, 581-619.

Tessum, C.W., Hill, J.D., Marshall, J.D., 2014. Life cycle air quality impacts of conven- tional and alternative light-duty transportation in the United States. Proc. Natl. Acad. Sci. U. S. A 111, 18490–18495. https://doi.org/10.1073/pnas.1406853111.

Tosun, J., & Leininger, J. (2017). Governing the interlinkages between the sustainable development goals: Approaches to attain policy integration. *Global challenges*, 1(9), 1700036.

Wang, X., & Lo, K. (2021). Just transition: A conceptual review. *Energy Research & Social Science*, *82*, 102291.

Westin, K., Jansson, J., & Nordlund, A. (2018). The importance of socio-demographic characteristics, geographic setting, and attitudes for adoption of electric vehicles in Sweden. *Travel Behaviour and Society*, *13*, 118-127. https://doi.org/10.1016/j.tbs.2018.07.004.

White, L. V., Carrel, A. L., Shi, W., & Sintov, N. D. (2022). Why are charging stations associated with electric vehicle adoption? Untangling effects in three United States metropolitan areas. *Energy Research & Social Science*, *89*, 102663.

Wu, Y. A., Ng, A. W., Yu, Z., Huang, J., Meng, K., & Dong, Z. Y. (2021). A review of evolutionary policy incentives for sustainable development of electric vehicles in China: Strategic implications. *Energy Policy*, *148*, 111983.

Xiong, Y., Huang, T., & Li, X. (2019). Regional differences in the implementation effect of New Energy Vehicle consumption promotion policy. China population, resources and environment, 29(5), 71-78.

Xiong, Y., Liu, H. (2022). The influence and difference of " non-subsidized" policy in new energy vehicles promotion and application. Science Research Management, 9, 83-90.

Yao, X., Ma, S., Bai, Y., & Jia, N. (2022). When are new energy vehicle incentives effective? Empirical evidence from 88 pilot cities in China. *Transportation Research Part A: Policy and Practice*, *165*, 207-224.

Yin, C., & Huang, Z. (2023). The evolving policy network in sustainable transitions: The case of new energy vehicle niche in China. *Journal of Cleaner Production*, *411*, 137299.

Zhang, L., & Qin, Q. (2018). China's new energy vehicle policies: Evolution, comparison and recommendation. *Transportation Research Part A: Policy and Practice*, *110*, 57-72.

Zhang, L., & Qin, Q. (2018). China's new energy vehicle policies: Evolution, comparison and recommendation. *Transportation Research Part A: Policy and Practice*, *110*, 57-72.

Zhang, X., & Bai, X. (2017). Incentive policies from 2006 to 2016 and new energy vehicle adoption in 2010–2020 in China. *Renewable and Sustainable Energy Reviews*, *70*, 24-43.

Zhang, X., Liang, Y., Yu, E., Rao, R., & Xie, J. (2017). Review of electric vehicle policies in China: Content summary and effect analysis. *Renewable and Sustainable Energy Reviews*, *70*, 698-714.

Zhuge, C., & Shao, C. (2019). Investigating the factors influencing the uptake of electric vehicles in Beijing, China: Statistical and spatial perspectives. *Journal of cleaner production*, *213*, 199-216.

Supplementary materials

Appendix A to The policy mix of green finance in China: An evolutionary and multilevel perspective

Table A.1 Coding framework

<table>
<tr><th>Primary code</th><th>Secondary code</th></tr>
<tr><td>Basics</td><td>Policy document title: ____
Scale: National level – N; Provincial level - P
Policy document No.: ____</td></tr>
<tr><td>Temporal aspects</td><td>1) The policy document was effective from dd/mm/yyyy
2) The policy document was terminated/amended on dd/mm/yyyy</td></tr>
<tr><td>Actors involved</td><td>The government authority (or authorities) issuing the policy document is ____
<table>
<tr><th>Authority</th><th>Label</th><th>Chinese name</th></tr>
<tr><td>State Council</td><td>SC</td><td>国务院</td></tr>
<tr><td>Former China Banking Regulatory Commission</td><td>CBRC</td><td>中国银监会(已撤销)</td></tr>
<tr><td>China Banking and Insurance Regulatory Commission</td><td>CBIRC</td><td>中国银保监会</td></tr>
<tr><td>China Insurance Regulatory Commission</td><td>CIRC</td><td>中国保监会(已撤销)</td></tr>
<tr><td>China Securities Regulatory Commission</td><td>CSRC</td><td>中国证监会</td></tr>
<tr><td>Former State Environmental Protection Administration</td><td>SEPA</td><td>国家环境保护总局(已撤销)</td></tr>
<tr><td>Former Ministry of Environmental Protection</td><td>MOEP</td><td>环境保护部(已撤销)</td></tr>
<tr><td>Ministry of Ecology and Environment</td><td>MOEE</td><td>生态环境部</td></tr>
<tr><td>China Banking Association</td><td>CBA</td><td>中国银行业协会</td></tr>
<tr><td>Standardization Administration of China</td><td>SAOC</td><td>国家标准委</td></tr>
<tr><td>National Development and Reform Commission</td><td>NDRC</td><td>国家发展和改革委员会</td></tr>
<tr><td>General Office of the Chinese Communist Party</td><td>GOCCP</td><td>中共中央办公厅</td></tr>
</table></td></tr>
</table>

		State Council	SC	国务院
		People's Bank of China	PBOC	中国人民银行
		Agricultural Bank of China	ABC	中国农业银行
		Ministry of Finance	MOF	中国财政部
		National Energy Administration	NEA	国家能源局
		Ministry of Commerce	MOC	商务部
		Shenzhen Stock Exchange	SZSE	深交所
		Shanghai Stock Exchange	SHSE	上交所
		State Taxation Administration	STA	国家税务总局
		Ministry of Industry and Information	MOII	中国工业和信息化部
		Ministry of Science and Technology	MOST	科学技术部
		Former Ministry of Agriculture	MOA	农业部(已撤销)
		Ministry of Natural Resources	MONR	自然资源部
		Ministry of Foreign Affairs	MOFA	外交部
		State Administration of Foreign Exchange	SAOFE	国家外汇管理局
		Asset Management Association of China	CAMA	中国证券投资基金业协会
		China Green Finance Committee	CGFC	中国绿色金融专业委员会
		All-China Federation of Industry and Commerce	CFIC	全国工商业联合会
		(Provincial) People’s Government	PG	（省）人民政府
		(Provincial) Committees of the Chinese Communist Party	COCCP	中共省委
		Former (Provincial) Bureau of Financial Work	BOFW	（省）金融工作局
		(Provincial) Administration of Financial Regulatory	AOFR	（省）金融监督管理局
		Former (Provincial) office of China Banking Regulatory Commission	(P)CBRC	（省）银监局 （已撤销）
		Former (Provincial) Bureau of Environmental Protection	(P) BOEP	（省）环保厅（已撤销）

		(Provincial) Bureau of Finance	BOF	（省）财政局
		(Provincial) Development and Reform Commission	PDRC	（省）发展和改革委员会
		Former (Provincial) Taxation Administration	TA	地方税务局(已撤销)
Policy objective	A) Environmental protection and energy conservation B) Reducing CO2 emission (or GHG) C) Reduce energy intensity D) Green financial products E) Planning F) Others			
Policy instrument	1) Does the policy document mention a specific policy instrument or a set of policy instruments? 2) If yes, what is the policy instrument (or, what are the policy instruments)? ____ 3) Types of the policy instrument (or, what are the policy instruments)? ____ A) Command and control B) Market-based C) Information 4) The geographic scope where the policy instrument is implemented: ___			

Table A.2 Policy documents and instruments

Table A.2.1 National Policy documents and instruments

No.	Policy documents	Issued by	Effective time	Related policy instrument	Description
N1	Notice on Continuing to Deeply Implement National Macroeconomic Control Measures to Effectively Strengthen Credit Management	CBRC	2006.6.6	Credit access or restraint; Approval process	Strict loan approval system to control loans to high energy-consuming industries
N2	Notice on Issues Related to Sharing of Corporate Environmental Information	PBOC, SEPA	2006.12.31	Information-sharing system for corporate environmental protection; Moral persuasion	Incorporate environmental information of enterprises into the enterprise credit system as an important basis for processing credit
N3	Notice on Implementing the National Macroeconomic Control Policy to Prevent Loan Risks in Highly Energy-Consuming and High Pollution Industries	CBRC	2006.6.4	Credit access or restraint	Strengthen continuous monitoring of loans to key high energy-consuming and high-polluting enterprises
N4	Guidance on improving and strengthening financial services in the field of energy conservation and environmental protection	PBOC	2007.6.29	Credit access or restraint; Simplified procedure; Entry barrier removal; Government direct investment	Restrict credit investment in high-energy-consuming and high-polluting industries; Loans to support technological innovation in energy conservation and emission reduction
N5	Opinions on the implementation of environmental protection policies and regulations to prevent credit risks	PBOC, SEPA, CBRC	2007.7.12	Credit access or restraint; Environmental audit; Grants for RD&D	Controlling the flow of loans to polluting projects and enterprises.
N6	Notice on Further Regulation of Environmental Protection Verification for Production and Operation Companies in Key Pollution Industries Applying for Listing or Refinancing	SEPA	2007.8.13	Environmental audit	Environmental audit of manufacturing and operating companies in heavily polluting industries
N7	Guidance on Crediting for Energy Conservation and Emission Reduction	CBRC	2007.11.23	Credit access or restraint Information-sharing system for corporate environmental protection	Adjust and optimize the credit structure to support energy conservation and emission reduction; incorporate environmental protection into the corporate credit system
N8	Guidance on the work of environmental pollution liability insurance	SEPA, CIRC	2007.12.4	Green insurance	Establishing and improving the environmental pollution liability insurance system
N9	Guidance on strengthening supervision and management of environmental protection in listed companies	SEPA	2008.2.22	Environmental audit; Mandatory disclosure;	Environmental audit and environmental information disclosure mechanism for listed companies
N10	Notice on Further Improving Green Credit Information Sharing	PBOC, MOEP	2009.6.6	Green credit; Information-sharing system; Administrative penalty;	Green Credit Information Sharing Mechanism; Collect information on environmental violations by enterprises
N11	Opinion on strengthening environmental emergency management	MOEP	2009.11.9	Green insurance	Environmental risk assessment; Green insurance

N12	Opinions on Accelerating the Implementation of Contract Energy Management to Promote the Development of Energy Saving Service Industry	NDRC, STA, MOF, PBOC	2010.4.2	Green credit; Simplified procedure; Tax incentives; Subsidised interest rates; Grants for R&D	Innovate credit products, simplify application and approval procedures, and provide financing and other financial services to energy-saving companies
N13	China Clean Development Mechanism Fund Management Measures	MOF; NDRC; MOST; MOEP; MOA; MOFA	2010.9.14	Special funds	Clean Development Mechanism Fund
N14	Opinions on Strengthening the Key Work of Environmental Protection	SC	2011.10.17	Environmental audit; Green credit; Green bond; Green insurance; Administrative penalty	Support enterprises to issue bonds for environmental protection projects. Establish a credit evaluation system for environmental behavior. Compulsory liability insurance for environmental pollution
N15	Notice on the Pilot Project on Carbon Emission Trading	NDRC	2011.10.29	Emissions Trading System (ETS)	Emissions Trading System
N16	12th Five-Year Plan for Environmental Protection	SC	2011.12.15	Environmental audit; Certificate and license; Special funds; Electricity pricing; Special funds; Tax incentives; Moral persuasion	Promote emissions trading market, environmental tax reform, establish a credit evaluation system for corporate environmental behavior, and special funds for ecological compensation
N17	Green Credit Guidelines	CBRC	2012.1.29	Green Credit; Green banking evaluation (MPA)	Banking financial institutions should strengthen their green credit capacity building, and regulators should strengthen the assessment of green credit
N18	Guidance on the Pilot Project of Compulsory Liability Insurance for Environmental Pollution	MOEP	2013.1.21	Green insurance	Clarifying the scope and procedure of pilot compulsory environmental pollution liability insurance
N19	Notice on the Submission of Green Credit Statistics Form	CBRC	2013.7.21	Green credit; Green banking evaluation	Banking financial institutions should report on green loans every six months
N20	Enterprise Environmental Credit Assessment Scheme	MOEP	2013.12.18	Credit access or restraint; Information-sharing system for corporate environmental protection	Banking and financial institutions conduct corporate environmental credit assessment
N21	Several Opinions on the Development of Financial Services for the Issues of Agriculture, Farmer and Rural Area	SC	2014.4.20	Green credit; PPP; Special funds; Tax incentives; Subsidised interest rates	Improve green credit. Innovative rural financial products; Simplify financial services procedures; Policy guidance
N22	Opinions on the Financial Support Services for Agricultural Development of the Agriculture, Farmer and Rural Area	SC	2014.4.22	-	Vigorously develop green finance to promote water-saving, recycling and eco-friendly agriculture
N23	Several Opinions on Accelerating the Development of Modern Insurance Services	SC	2014.8.13	Green insurance	Leverage the role of insurance companies as institutional investors
N24	Guidance on the development of government and social capital cooperation	NDRC	2014.12.2	PPP	Establishing mechanisms for cooperation between government and private capital

N25	Interim Measures for the Management of Carbon Emissions Trading	NDRC	2014.12.10	Pricing	Certificate and license; Emissions Trading System (ETS)
N26	Energy Efficiency Credit Guidelines	CBRC, NDRC	2015.1.13	Credit access or restraint; Green credit; Government guarantee fund; Tax incentives	Banking and financial institutions provide credit to support enterprises in improving energy efficiency and reducing energy consumption
N27	Opinions on the Introduction of Third-Party Treatment of Environmental Pollution	SC	2015.1.14	Green credit; Green bond; Green insurance; PPP; Simplified procedure; Tax incentives; Subsidised interest rates; Certificate and license	Promote energy efficiency loans, green finance leasing, carbon finance products, energy saving and emission reduction revenue rights and emission rights pledge financing
N28	Guidance on the Banking Sector's Support for Major Construction Projects in Key Areas	CBRC, NDRC	2015.8.10	Green credit; Approval process; Entry barrier removal	Simplify credit approval, actively innovate green financial products and services, and implement green finance
N29	Green Financial Bond Announcement	PBOC	2015.12.15	Green bond; Voluntary disclosure	Green Finance Bonds support the development of green industry projects
N30	Opinions on several policy measures to support the development and opening up of key areas along the border	SC	2015.12.24	Financial product innovation; Approval process	Encourage financial innovation, broaden financing methods and channels, and adjust credit approval authority
N31	Green Bond Supported Projects Catalogue	CGFC	2015.12.22-2021.4.2	Green bond	-
N32	Green Bond Issuance Guidelines	NDRC	2015.12.31	Green bond; Government guarantee fund; Subsidised interest rates	Governments support the issuance of green bonds and the implementation of green projects through various means, such as investment subsidies, guarantee subsidies, bond interest subsidies and fund injections
N33	Several Opinions on Financial Support for Industry to Stabilize Growth, Adjust Structure and Increase Efficiency	PBOC, NDRC; MOII; MOF; MOC; CSRC; CBRC; CIRC	2016.2.16	Credit access or restraint; Green credit; PPP; Emissions Trading System (ETS); Environmental resource pricing	Promote innovation in financing mechanisms for industrial enterprises; develop green credit and actively support energy-saving and environmental protection projects and services
N34	Notice on the launch of the Green Corporate Bond Pilot	SHSE	2016.3.16	Green bond	-
N35	Notice on the launch of the Green Corporate Bond Pilot	SZSE	2016.4.22	Green bond	-
N36	Industrial Energy Efficiency Management Approach	MOII	2016.4.27	Certificate and license; Emissions Trading System (ETS); Administrative penalty	Establish initial allocation of energy use rights and carbon emission rights and carry out trading of energy use rights and carbon emission rights

N37	Industrial Green Development Plan (2016-2020)	MOII	2016.6.30	Green credit; Green bond; PPP; Tax incentives; Environment standard; Risk exposures	Expand the scale of industrial green credit and green bonds, and innovate financial products and services; Set up an industrial green development fund
N38	Guidance on the Construction of a Green Financial System	PBOC, NDRC; MOEP; MOF; CSRC; CBRC; CIRC	2016.8.31	Regulation; Financial product innovation; Financial expenditure; Pricing; Disclosure; Market monitoring and evaluation	Green credit; Green bond; PPP; Green insurance; Tax incentives; Environment standard; Risk exposures; Green banking evaluation (MPA); Certificate and license; Environmental resource pricing; Emissions Trading System (ETS);
N39	Opinions on the Establishment of a Unified System of Green Product Standards, Certification, and Labelling	SC	2016.11.22	Environment standard; Green index and standard; Voluntary disclosure	-
N40	Comprehensive work program on energy saving and emission reduction	SC	2016.12.20	Green credit; Green bond; Special funds; Environmental resource pricing; Electricity pricing; Emissions Trading System (ETS)	Develop green finance, resource and environmental price reform, emissions trading price system, fiscal and tax incentive policies
N41	Notice on the Implementation of Renewable Energy Green Power Certificate Issuance and Voluntary Subscription and Trading System	NDRC; NEA; MOF;	2017.2.3	Certificate and license; Electricity pricing; Emissions Trading System (ETS)	-
N42	Guidance on Supporting the Development of Green Bonds	CBRC	2017.3.2	Green bond	-
N43	Guidance on Promoting Green Belt and Road Construction	MOEP; MOC; NDRC	2017.4.26	PPP; Special funds; Government guarantee fund; Voluntary disclosure	Promote the development of a green financial system, the sharing and disclosure of environmental information, the National Green Development Fund, and PPP
N44	"Belt and Road Initiative" Ecological and Environmental Protection Cooperation Plan	MOEP	2017.5.12	Green bond; Special funds; Green insurance; Disclosure	Promote the development of green financial policies and formulate standards for green investment; establish the "Belt and Road" Green Development Fund; improve the level of environmental information disclosure
N45	Action Plan for Industrial Energy Efficiency and Green Standardisation (2017-2019)	MOII	2017.5.19	Environment standard; Green index and standard	Strengthening industrial energy efficiency and green standards development and revision
N46	Development Plan for the Construction of a Standardised System for the Financial Sector	PBOC; CSRC; CBRC; CIRC; SAOC	2017.6.9	Environment standard; Financial product innovation	Strengthen the implementation of standards in the financial sector and establish a system for monitoring and evaluating standards in the financial sector
N47	Jiangxi Ganjiang New Area: A Master Plan for Building a Green Financial Reform and Innovation Pilot Zone	PBOC, NDRC; MOEP; MOF; CSRC; CBRC; CIRC	2017.6.26	Financial product innovation	-

N48	Opinions on the Implementation of Promoting Third Party Governance of Environmental Pollution	MOEP	2017.8.9	Special funds; PPP; Tax incentives; Subsidised interest rates; Certificate and license	Establish a Green Development Fund; Promote emission rights pledge financing
N49	Opinions on Innovative Institutional Mechanisms to Promote Green Development in Agriculture	GOCCP	2017.9.30	Green credit; PPP; Green insurance; Environment standard	Increase green credit support and innovate green and ecological agricultural insurance products. Increase the promotion and application of PPP in the field of green agricultural development
N50	Notice on Promoting Financial Support for Green Development in Agriculture	MOA; ABC	2017.11.21	Financial product innovation; Green credit; Green insurance	Improve credit support policies, expand the scale of green credit, and explore a multi-party cooperation model for financial services
N51	National Carbon Emissions Trading Market Construction Programme (Power Generation Sector)	NDRC	2017.12.18	Pricing	Electricity pricing; Emissions Trading System (ETS)
N52	Notice on Issuing the Implementation Plan for Green Bank Evaluation in the Banking Sector of China	CBA	2017.12.26	Green banking evaluation (MPA)	-
N53	Green Bond Assessment and Certification Practice Guidelines	PBOC, CBRC	2017.12.26-2021.12.23	Green Bond	Appraisal and certification agencies launch green bond appraisal and certification business
N54	Notice on the Establishment of A Special Statistical System for Green Loans	PBOC	2018.1.05	Green credit	-
N55	Notice on Matters Relating to the Strengthening of Supervision and Management of Green Financial Bonds	PBOC	2018.2.5	Green Financial Bonds, Mandatory disclosure	Strengthen supervision, management, and information disclosure of green financial bonds
N56	Vision and Action Plan for Advancing Green Finance in the Service of Green Development (2018-2020)	SHSE	2018.4.25	Green bond; Voluntary disclosure; Green stock index	Guide listed companies to disclose environmental information; Develop green equity indices and fund products
N57	Notice on Matters Relating to Reducing the Burden on Enterprises in the Renewable Energy Sector	NEA	2018.4.26	Green credit; Green bond;	Reduce corporate finance costs through green finance; Increase credit allocation to companies investing in renewable energy projects
N58	Measures for the Administration of Compulsory Liability Insurance for Environmental Pollution	MOEE	2018.5.8	Green insurance	-
N59	Implementation Opinions on Strengthening Ecological Protection and Resolutely Fighting the Battle of Pollution Prevention and Control	GOCCP, SC	2018.6.24	Green credit; Green bond; Environmental resource pricing; Electricity pricing; Grant and award Tax incentives	Develop green credit, green bonds and other financial products. Establish a national green development fund. Implement price policies and tax incentives conducive to ecological and environmental protection.
N60	Opinions on Innovation and Improvement of Price Mechanism for Green Development	NDRC	2018.7.2	Pricing	Certificate and license; Environmental resource pricing; Electricity pricing; Emissions Trading System (ETS)

N61	Green Investment Guidelines	CAMA	2018.11.10	Financial product innovation	Defining the meaning of green investment and clarifying the scope of application of the Guidelines
N62	Notice on Promoting Financial Support for Green Development of County Industries	MOII; ABC	2018.11.20	Green credit; Green insurance	Innovative Green Financial Products; Increase the scale of green credit business and reduce lending risks
N63	Notice on Conducting Green Credit Performance Evaluation of Banking Depository Financial Institutions	PBOC	2018.12.31	Green banking evaluation (MPA); Green credit	-
N64	Opinions on supporting and serving the green development of private enterprises	MOEE; CFIC	2019.1.17	Green credit; Green bond; Green insurance	Establish a national green development fund, improve the compulsory insurance system for environmental pollution liability, innovate green financial products
N65	Notice on Supporting the Issuance of Green Debt in the Pilot Green Finance Reform and Innovation Zone	PBOC	2019.4.26	Green bond	Supporting enterprises in the pilot zone to register and issue green debt financing instruments
N66	Views on Financial Support for the Construction of Guangdong, Hong Kong and Macao Greater Bay Area	PBOC; CBIRC; CSRC; SAOFE	2020.5.14	Financial product innovation; Emissions Trading System (ETS)	Promoting Green Financial Cooperation in the Greater Bay Area of Guangdong, Hong Kong, and Macau
N67	Implementation Opinions on Creating a Better Development Environment to Support the Development of Private Energy Conservation and Environmental Protection Enterprises	NDRC; MOEE; MOII; CBIRC; CFIC; MOST	2020.5.21	Green credit; Green bond; Environmental resource pricing; Tax incentives	Actively develop green credit, unify the criteria for defining green bonds and broaden the ways of credit enhancement for environmental industries
N68	Notice on the Issuance of the Green Financial Performance Evaluation Program for Depository Financial Institutions in the Banking Sector	PBOC	2020.7.21	Green banking evaluation (MPA)	-

Table A.2.2 Provincial policy documents and instruments

No.	Policy documents	Issued by	Effective time	Related policy instrument	Description
P1	Opinions on the implementation of the promotion of green credit	Zhejiang CBRC, BOEP	2011.4.11	Green credit; Information-sharing system for green credit	Building a green credit information-sharing mechanism between environmental protection departments and the CBRC
P2	Opinions on financial support for the development of the green economic circle around the capital	Heibei PG	2011.7.13	Credit access or restraint	No financial support for highly polluting and energy-consuming industries
P3	Opinions on strengthening green credit construction to support energy conservation and emission reduction in the capital	Beijing CBRC, BOEP	2011.8.22	Green credit; Credit access or restraint	Financial institutions optimize credit structure and innovate energy-saving and emission-reduction credit products
P4	Opinions on Strengthening the Reduction of Total Emissions of Major Pollutants during the 12th Five-Year Plan Period	Guizhou PG	2011.12.30	Green credit; Green insurance; Pricing; Tax incentives; ETS	Support green credit and environmental pollution liability insurance through prices and taxes. Explore paid use and trading of emission rights
P5	Decision on Further Strengthening Environmental Protection and Promoting Ecological Civilisation	Guangdong COCCP, PG	2011.12.31	Green credit; Credit access or restraint	Implement green economy policies, strengthen green credit and promote pollution control
P6	Evaluation of the effectiveness of Hebei's green credit policy	Hebei PBOC, CBRC, BOEP	2012.2.24	Green banking evaluation	-
P7	Green Hunan Construction Outline	Hunan PG	2012.4.20	Green credit; Green bond; Tax incentives; Subsidised interest rates; Green insurance	Actively develop green financial products, strengthen investment and financing services and international cooperation in energy conservation, environmental protection, and new energy development
P8	Guidance for Banking and Financial Institutions on Enhancing Green Credit Efforts	Zhejiang CBRC	2012.11.17	Green credit; Simplified procedure	Establishing a classification mechanism for credit investment to support pollution reduction; Simplify loan approval procedures and give priority to credit support
P9	Notice on the Guidance on the Pilot Project of Compulsory Liability Insurance for Environmental Pollution	Beijing CIRC, BOEP	2013.2.21	Green insurance	Pilot Compulsory Liability Insurance for Environmental Pollution; Conduct environmental risk assessments and enhance information disclosure
P10	Notice on the Guidance on the Pilot Project of Compulsory Liability Insurance for Environmental Pollution	Gansu BOEP	2013.3.21	Green insurance	Pilot Compulsory Liability Insurance for Environmental Pollution; Conduct environmental risk assessments and enhance information disclosure
P11	Opinions on strengthening environmental protection and promoting green credit	Liaoning CBRC, BOEP	2013.8.3	Green credit; Information-sharing system for green credit	-

P12	Beijing Clean Air Action Plan 2013-2017	Beijing PG	2013.9.12	Green credit; Green bond; Environmental resource pricing; Tax incentives	Promote emissions trading and develop green credit and green bond.
P13	Tianjin Green Supply Chain Management Pilot Implementation Plan	Tianjin BOEP, DRC, BOF	2013.12.10	Financial product innovation; Tax incentives	Scale up green finance through tax incentives
P14	Notice on the joint establishment of a credit information sharing mechanism for environmental protection	Jiangsu CBRC, BOEP	2013.12.31	Information-sharing system for corporate environmental protection; Green credit	Establishing an environmental protection credit information sharing platform and practicing green credit standards
P15	Hainan Province Air Pollution Prevention and Control Action Plan Implementation Rules	Hainan PG	2014.2.17	Credit access or restraint; Green credit; Administrative penalty	Improve green credit and green securities, and restrict loans and public financing for companies that violate environmental laws
P16	Financial Support for Economic Restructuring and Transformation and Upgrading Work Implementation Plan	Jilin PG	2014.3.2	Green credit; Information-sharing system for corporate environmental protection	Increase credit investment in energy-saving and emission-reduction technologies and environmental protection enterprises
P17	Guidance on the Banking Sector's Support for Economic Restructuring and Transformation and Upgrading	Anhui CBRC	2014.5.9	Credit access or restraint; Green credit;	Develop green credit and increase credit investment in green industries. Support key enterprises to carry out mergers and acquisitions and restructuring
P18	Guidance on the Support of Banking Institutions in the Jurisdiction to Promote Green Credit in the Construction of the Early Demonstration Zone of Ecological Civilization	Fujian CBRC	2014.7.17	Credit access or restraint; Green credit;	Banking institutions should improve their green credit management mechanisms, innovate green financial products and increase their support for the green economy
P19	Opinions on the Implementation of Financial Services for The Development of the Agriculture, Farmer and Rural Area	Chongqing PG	2014.9.11	-	Green finance supports the transformation of the agricultural development approach
P20	Opinions on Accelerating the Establishment of an Investment and Financing Mechanism Conducive to the Construction of Ecological Civilisation	Jilin PG	2015.2.25	Green credit; Green bond; Special fund; Environmental resource pricing	Increase credit support for ecological construction projects; set up an investment fund for ecological civilization construction; encourage green bonds; strengthen international cooperation in green finance
P21	Implementation Opinions on Promoting the Transformation, Upgrading and Innovative Development of State-level Economic and Technological Development Zones	Ningxia PG	2015.7.23	Green credit; Credit access or restraint; Tax incentives; Grant and award	Encourage banks, insurance and other financial institutions to give financial support to industrial transformation and upgrading. Increase credit support for green and environmental projects
P22	Opinions on the Implementation of Third-Party Treatment of Environmental Pollution	Heilongjiang PG	2015.9.17	PPP; Entry barrier removal; Administrative penalty; Tax incentives; Environmental resource pricing	Encourage localities to adopt PPP and attract private capital by removing entry barrier; trading of emission rights; implementation of tax, price, subsidy, financing and other supporting policies

P23	Opinions on Accelerating the Development of Energy Conservation and Environmental Protection Industry	Yunnan PG	2015.10.20	Green credit; Credit access or restraint	Develop green credit, innovate green financial products and services, broaden the scope of collateral for loans, and guide credit funds to energy conservation and environmental protection industry
P24	Measures for the Administration of Emission Rights Mortgage Loans for Major Pollutants in Hunan Province (for Trial Implementation)	Hunan PBOC, BOEP, BOF	2015.12.08	Green credit	Promote the construction of green credit and broaden the financing channels for enterprises to reduce emissions.
P25	Guidance on Further Improving the Quality and Effectiveness of Banking Services to the Real Economy	Shanxi CBRC	2016.4.5	Green credit; Credit access or restraint	Innovate green financial products and develop energy efficiency credit to support the development of the energy conservation and environmental protection industry
P26	Guidance on Strengthening Green Financial Services	Shandong CBRC	2016.4.15	Green index and standard; PPP; Pricing	Establish a green list, identify areas of green financial support, and support green financial innovations such as carbon emission rights and PPP projects
P27	Implementation Plan for the Introduction of Third-Party Environmental Governance and Services (Trial)	Inner Mongolia PG	2016.6.23	Environmental audit; Entry barrier removal; Green banking evaluation; Green credit; Green bond	Giving priority to companies that actively combat pollution for approval in listing and issuing bonds. Carry out green credit, green leasing, carbon finance and green banking evaluation systems
P28	Opinions on the Implementation of the Transformation and Development of Commercial Banks in the Jurisdiction	Guangdong CBRC	2016.6.27	Green credit; Green index and standard; Credit access or restraint	Develop green credit, implement stricter environmental standards and control loans to high energy-consuming and high-polluting enterprises
P29	Notice of the Thirteenth Five-Year Plan for the Development of Tianjin's Financial Sector	Tianjin DRC	2016.9.14	Financial product innovation; Green bond	Increase green financial support for environmental protection, guide financial institutions to innovate green products and issue green bonds
P30	Notice on the Issuance of A Work Programme to Foster the Development of the Green Fund	Inner Mongolia PG	2016.9.30	Special fund	-
P31	Opinions on the Implementation of Accelerating the Development of Green Finance	Guizhou PG	2016.11.22	Regulation; Financial product innovation; Pricing; Disclosure	Green credit; Green bond; PPP; Green insurance; Green development fund; Tax incentives; Environment standard; Risk exposures; Emissions Trading System (ETS);
P32	Anhui Province Green Financial System Implementation Plan	Hefei PBOC, Anhui CBRC, BOEP, BOF	2017.1.17	Financial product innovation; Green banking evaluation; Administrative penalty; Grant and award	Establish a green finance incentive and penalty mechanism; incorporate green finance development into the assessment of financial institutions
P33	Opinions on the Implementation of Building a Green Financial System	Inner Mongolia PG	2017.2.16	Regulation; Financial product innovation	Green credit; Green bond; Green insurance; Green insurance; Environmental resource pricing; Green development fund

P34	Notice of the 12th Five-Year Plan for the Development of Jilin's Financial Sector	Jilin PG	2017.3.2	Green credit; Green index and standard; Credit access or restraint; Green bond; Special fund	Innovate green financial products and support banking financial institutions to set up special green financial sub-branches. Promote the inclusion of green enterprises in green indices and priority financing
P35	Implementation Opinions on the Construction of Green Finance in Fujian Province	Fujian PG	2017.5.19	Green credit; Green insurance; Green development fund	Develop green credit, promote capital market support for green investment, develop green insurance and build a pilot ecological civilization zone
P36	Implementation Measures for Building a Green Financial System in the Capital	Beijing BOFW, DRC, CBRC	2017.9.17	Regulation; Financial product innovation; Financial expenditure; Pricing; Disclosure; Market monitoring and evaluation	Green credit; Green bond; PPP; Green insurance; Environmental resource pricing; Emissions Trading System (ETS)
P37	Jiangxi 13th Five-Year Plan for Building a Green Financial System	Jiangxi PG	2017.9.22	Green banking evaluation; Special funds; Certificate and license; Emissions Trading System (ETS)	Promote the adoption of the Equator Principles by Jiangxi Bank to become a green bank. Increase green credit. Set up a carbon emissions trading market. Promote green fund.
P38	Green Finance Development Plan (2017-2020)	Chongqing PBOC, DRC, CBRC, BOEP, BOEP	2017.10.26	Financial product innovation; Tax incentives; Subsidised interest rates	Establishing a multi-level green financial market system, a diversified green financial product system and a green financial policy support system
P39	Opinions on the implementation of accelerating the development of green finance	Jiangxi PG	2017.12.6	Financial product innovation; Simplified procedure; Pricing; Disclosure	Green credit; Green bond; PPP; Green insurance; Environmental resource pricing; Emissions Trading System (ETS)
P40	Opinions on Building a Green Financial System	Gansu PG	2018.1.3	Information-sharing system; Green banking evaluation; Environment standard; Green index and standard; Green credit; Green bond; Emissions Trading System (ETS)	Establish a mechanism for sharing information on green projects; Encourage financial institutions to set up green finance divisions; Develop classification criteria for green projects; Participate in the construction of a national carbon emissions trading market
P41	Implementation Plan for the Reform and Development of Green Finance in Hainan Province	Hainan PG	2018.3.29	Green credit; Green banking evaluation; Green bond; Subsidised interest rates	Develop green credit. Use financial subsidies to support financial institutions to provide more green financial products and services. Establish a green financial assessment mechanism and develop green bonds.
P42	Notice on the Issuance of the Implementation Rules for the Construction of a Pilot Green Financial Reform and Innovation Zone in Guangzhou, Guangdong Province	Guangdong PG	2018.5.5	Green banking evaluation; Financial product innovation	Develop green credit, green bond, green insurance. Build environmental interests trading market. Establish a green financial evaluation system for financial institutions.
P43	Monetary Policy Tools to Support the Development of A Green Economy in the Pilot Green Finance Reform and Innovation Zone	Xinjiang PBOC	2018.5.9	Green credit; Government guarantee fund; Tax incentives; Subsidised interest rates	Give priority to financial institutions that grant green loans in the pilot zone in terms of financial support, incentives and facilitation

P44	Notice on the Implementation Opinions on Accelerating the Development of Green Finance in the Banking Sector in Guangdong	Guangdong CBRC	2018.10.12	Financial product innovation; Green credit; Green banking evaluation	Increase financial support for key green support areas; Set social responsibility indicators in the performance appraisal of banking financial institutions and increase the weighting of green financial development indicators
P45	Guizhou Environmental Pollution Liability Insurance Risk Assessment Guide (Trial)	Guizhou BOEP	2019.1.10	Green insurance	-
P46	Notice on the Issuance of Several Policies on Financial Support for Ecological Environmental Protection in Henan Province	Henan PG	2019.2.2	Tax incentives; Subsidised interest rates; Green credit; Green bond; Environmental resource pricing	Support green bonds and guide enterprises to issue green asset securitization products by subsidies; explore the credit and pledge financing system for resource and environmental rights and interests.
P47	Notice on Several Measures to Establish Positive Incentive Mechanism to Promote Quality Economic and Social Development	Fujian PG	2019.4,29	Tax incentives; Subsidised interest rates; Green credit; Green insurance; Green bond	Declare a pilot green finance zone, increase support for refinancing and rediscounting, and support innovative green finance products
P48	Notice on Organizing the Declaration of Green Finance Award and Subsidy Funds in Jiangsu Province	Jiangsu BOEP, BOF	2019.9.5	Grant and award; Tax incentives	-
P49	Several Opinions on Promoting the Development of Green Finance	Jilin PG	2019.11.8	Green credit; Government guarantee fund; Green banking evaluation; Subsidised interest rates; Green insurance; PPP	Provide incentives or subsidies for green credit; promote the establishment of a green bank evaluation mechanism; establish a mechanism for sharing information on green projects; Develop green insurance
P50	Implementation Plan for the Establishment of a Market-based and Diversified Ecological Protection Compensation Mechanism	Henan DRC	2019.12.6	Environment standard; Green index and standard; Certificate and license; Environmental resource pricing	Establish and improve green labeling, green procurement, green finance, and green benefit-sharing mechanisms to guide social investors to compensate ecological protectors
P51	Opinions on Promoting Green Industry Development	Jiangsu PG	2020.3.27	Green credit; Green bond; Green Guarantee; Green insurance	Encourage innovation in financial services and support the creation of a national pilot zone for green financial reform and innovation
P52	Initiatives on Deepening the Implementation of Financial Support Policies to Promote Early and Pilot Implementation in the Yangtze River Delta Eco-Green Integrated Development Demonstration Zone	Shanghai DRC, PBOC, BOFW, CSRC; Jiangsu CBIRC, BOFW, CSRC	2020.4.2	Tax incentives; Green credit; Government guarantee fund; Environmental resource pricing; Green insurance	Green finance recognition criteria, financial subsidies and interest subsidies. Support financial institutions to set up green finance divisions or green sub-branches, encourage the development of green credit, and accelerate the development of green insurance
P53	Opinions on the Implementation of Building a Green Financial System	Hebei BOFW	2020.9.9	Green credit; Green bond; Green insurance; Environmental resource pricing; Emissions Trading System (ETS); Tax incentives	Innovative Green Financial Products; Use fiscal, financial, industrial, taxation and environmental protection policies to stimulate the development of green finance

Table A.3 Classification and practical application of policy instruments for green finance

Type	Policy instrument	Practical application
Command and control	Supervision	Credit access or restraint
		Information-sharing system for corporate environmental protection
		Environmental audit
		Green banking evaluation (MPA)
	Regulation	Approval process
		Entry barrier removal
		Administrative penalty
		Environment standard
		Green index and standard
		Green stock index
		Simplified procedure
		Market monitoring and evaluation
Market-based	Financial product innovation	Green credit
		Green bond
		Green insurance
		PPP
		Grants for RD&D
		Special funds
		Government direct investment
		Government guarantee fund
		Tax incentives
		Subsidized interest rates
		Grant and award
	Pricing	Certificate and license
		Environmental resource pricing
		Electricity pricing
		Emissions Trading System (ETS)
Information	Disclosure	Mandatory disclosure
		Voluntary disclosure
		Risk exposures
	Moral persuasion	

Appendix B to Implementation gap of China's environmental policies: logic behind the over-implementation of the Coal to Gas transition

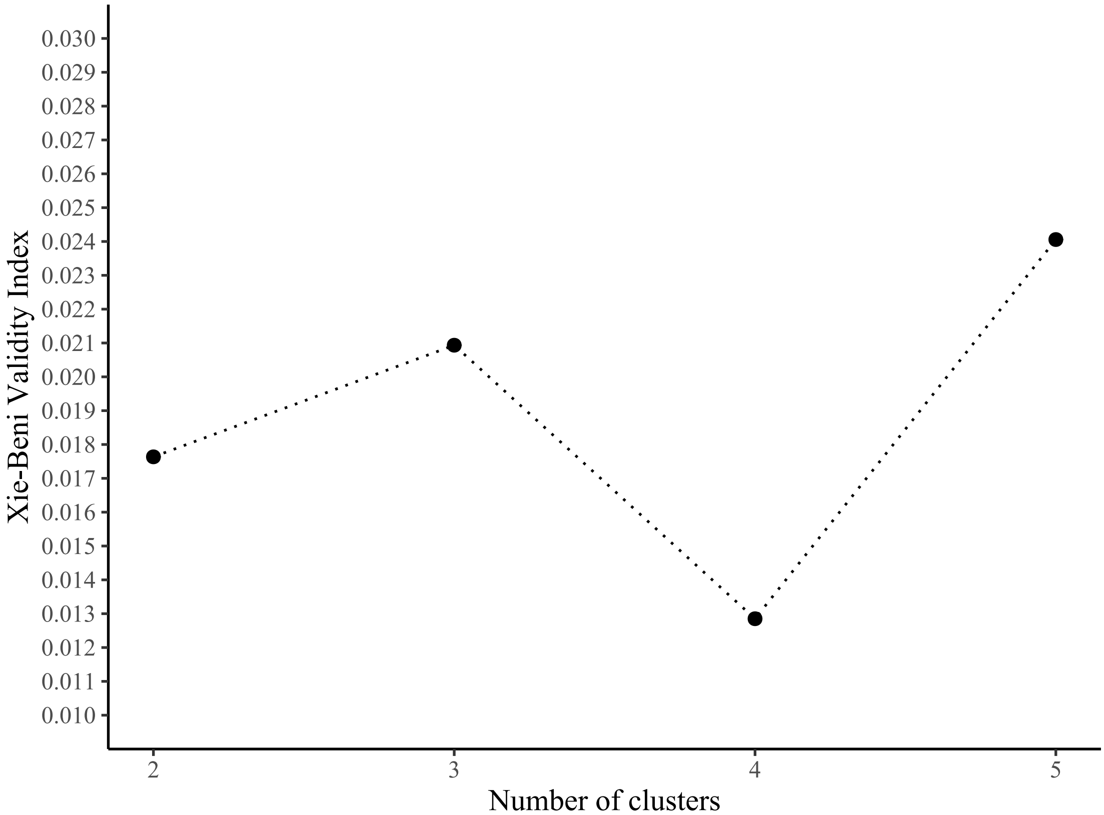
Table B.1 "2+26" pilots of CTG project, 2017

Centrally administered municipality	Beijing, Tianjin	
Province	Hebei	Shijiazhuang, Tangshan, Langfang, Baoding, Cangzhou, Hengshui, Handan, Xingtai
	Henan	Zhengzhou, Xinxiang, Hebi, Anyang, Jiaozuo, Puyang, Kaifeng
	Shanxi	Taiyuan, Jincheng, Changzhi, Yangquan
	Shandong	Jinan, Zibo, Liaocheng, Dezhou, Jining, Bingzhou, Heze

Source: "2017 Work Plan for Air Pollution Prevention and Control in Jing-Jin-Ji and Surrounding Areas", issued by MEP.

Appendix C to Why does electric vehicle deployment vary so much within a nation? Comparing Chinese provinces by policy, economics, and socio-demographics

Figure C.1 Comparison between models with different number of clusters



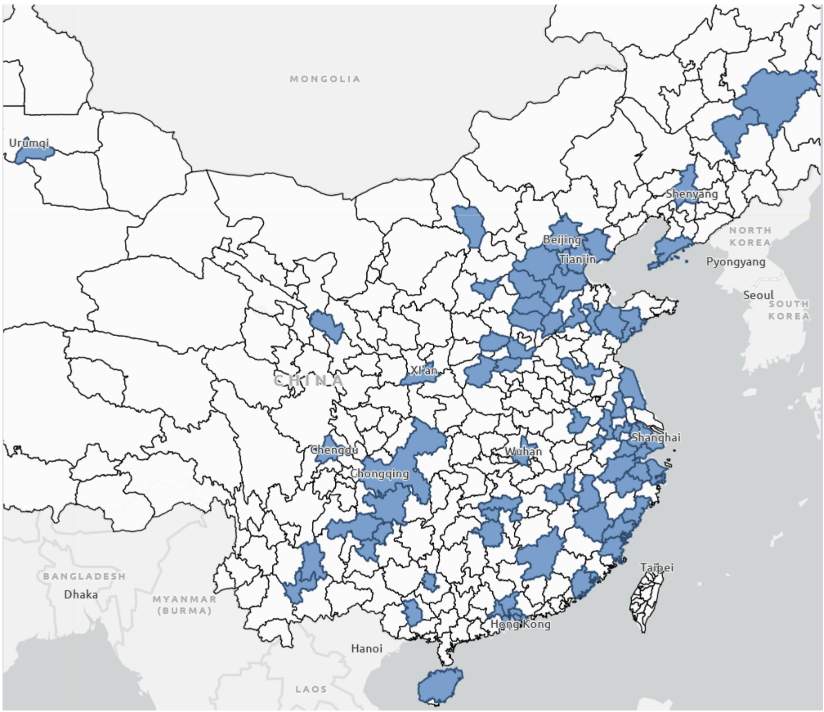
Note: Lower value indicates better fit.

Table C.1 Degrees of membership

	Producers	Retailers	Green transport	Laggards
Hebei	0.182	0.189	0.237	0.392
Shanxi	0.030	0.014	0.892	0.064
Liaoning	0.018	0.012	0.052	0.918
Jilin	0.045	0.031	0.121	0.803
Heilongjiang	0.041	0.028	0.207	0.724
Jiangsu	0.626	0.137	0.127	0.111
Zhejiang	0.243	0.112	0.287	0.358
Anhui	0.869	0.038	0.049	0.044
Fujian	0.619	0.072	0.200	0.109
Jiangxi	0.109	0.014	0.890	0.067
Shandong	0.064	0.023	0.781	0.132
Henan	0.115	0.037	0.738	0.111
Hubei	0.326	0.138	0.197	0.340
Hunan	0.238	0.061	0.565	0.136
Guangdong	0.692	0.083	0.147	0.079
Hainan	0.064	0.048	0.640	0.247
Sichuan	0.044	0.032	0.096	0.829
Yunnan	0.051	0.035	0.212	0.701
Shaanxi	0.598	0.094	0.162	0.146
Guangxi	0.049	0.027	0.144	0.780
Beijing	0.159	0.528	0.134	0.180
Tianjin	0.129	0.183	0.368	0.320
Shanghai	0.080	0.803	0.059	0.059
Chongqing	0.064	0.042	0.115	0.779
Guizhou	0.072	0.072	0.141	0.716

Appendix D to How local context matter? Assessing the heterogeneous impact of electric vehicle incentive policies in China

Figure D.1 The selected 80 cities in this study as sample

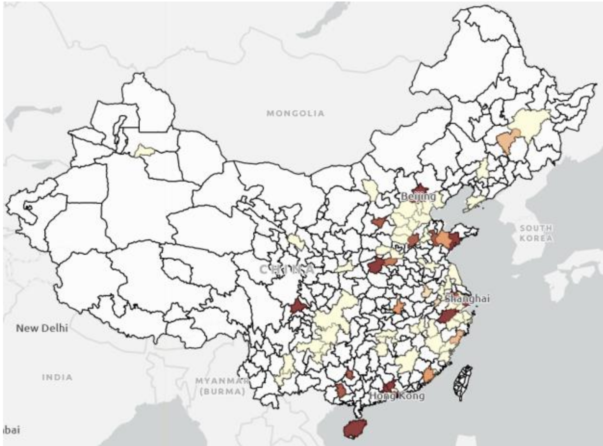


These cities include Beijing, Tianjin, Taiyuan, Tangshan, Baoding, Langfang, Hohhot, Shenyang, Dalian, Changchun, Shanghai, Nanjing, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Hangzhou, Ningbo, Jinhua, Hefei, Wuhu, Fuzhou, Xiamen, Nanchang, Qingdao, Zibo, Weifang, Liaocheng, Zhengzhou, Xinxiang, Wuhan, Changsha, Guangzhou, Shenzhen, Foshan, Dongguan, Zhongshan, Nanning, Liuzhou, Chongqing, Chengdu, Guiyang, Xi'an, Lanzhou, Haikou, Kunming, Jinan, Shijiazhuang, Harbin, Shaoxing, Huzhou, Xiangyang, Wuxi, Wenzhou, Xuzhou, Luoyang, Jincheng, Zhuzhou, Xiangtan, Zhuhai, Ningde, Ganzhou, Pingxiang, Jiaxing, Hengyang, Cangzhou, Handan, Nanping, Xingtai, Hengshui, Zhangzhou, Lijiang, Yuxi, Zunyi, Urumqi, Bijie, Shangrao, Fuzhou, Anshun.

Figure D.2 EV market share and policies across cities in 2022

Market share of new registered EVs

(Darker colour means higher value)



Purchase subsidy

(Darker colour means higher value)

Charging stations

(Darker colour means higher value)

Parking benefits

- Implemented parking benefits
- No parking benefit

Driving privileges

- Implemented driving privileges
- No driving privilege