The Party leads: Chinese air pollution as complex system

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Abstract

This research offers a complex systems framework for understanding the local-national dynamics of Chinese governance, with reference to rapid improvements in Chinese air quality over the period 2008-2018. There are a number of competing explanations for the historically poor implementation of air quality laws and policies: a mismatch between local economic incentives and air quality laws; low ranking environmental bureaucracies are overpowered by other interests; environmental projects are unlikely to lead to cadre promotions; polluting SOEs are able to avoid or easily pay off environmental fines. Empirical data was collected from satellite and official pollution data, government documents and a case study of a winter heating SOE. Analysis showed that pollution abatement was caused by local government's significant capital investment in upgrading winter heating technologies. Funding in turn was caused by greater political emphasis on air quality by central government. It is hypothesised that the core governance mechanism explaining differences in environmental implementation consists of the simple parameter financial resources and a complex parameter, policy emphasis. Computational models of winter heating governance support this hypothesis, producing an approximate measure of changing environmental emphasis over time. Overall, the proposed governance framework remains hierarchical, but local governments exercise varying degrees of policy-specific independence. This study thus highlights the dynamic roles of both decentralisation and authoritarian environmentalism in shaping Chinese environmental governance outcomes.

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Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Abbreviations

Abbreviation	English name	Chinese name
Party	Chinese Communist Party	中国共产党
NPC	National People's Congress	全国人民代表大会
NDRC	National Development and Reform Commission	国家发展和改革委员会
MCA	Ministry of Civil Affairs	民政部
MEE	Ministry of Ecology and Environment	生态环境部
MEP	Ministry of Environmental Protection	环境保护部
SEPA	State Environmental Protection Administration	国家环境保护总局
5YP	Five-Year Plan	五年规划
MOHURD	Ministry of Housing and Urban-Rural Development	住房和城乡建设部

Table 0.1: Chinese state bureaucracy

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1 North South East West Centre, the Party leads everything

东西南北中，党是领导一切的

— (Mao 1962)

This thesis has two main objectives. Firstly, to explain the abrupt reduction in Chinese air pollution after decades of weak environmental policy implementation. The second is methodological: to achieve this explanation from first principles, by iteratively developing and testing theory against empirical data, and by creating testable computational models to validate the theoretical framework developed here–the *core governance mechanism.* I proceed by elimination of hypotheses through three empirical chapters, before generating a theoretical framework, the *core governance mechanism* and testing derived concrete computational models. Much recent environmental governance scholarship has tackled this problem, and created explanations of historical causes for an implementation gap, and detailed reasons for recent successes. This thesis' major contribution is not a *new* explanation of that phenomenon. Indeed, the major empirical finding is well attested: **policy implementation exists with *various degrees of political sponsorship,* from the very weak to the very strong. Policy implementation cannot necessarily be predicted by analysing the laws and policies themselves, but by the political strength that is massed in its support.** The reason for historically weak environmental implementation, and recent stronger implementation, therefore, is variation in *policy emphasis.* However, I contend that the substantive explanation is less important than the methodological framework that produces it. This research advances methods in Chinese politics by constructing a general theoretical framework designed to reach robust conclusions where there is a scarcity of good data, and many competing explanations for the same phenomena. The central finding—a *renewed centralisation in Chinese environmental governance*—is well supported in the wider literature on Chinese politics and environmental governance, as well as in empirical pollution mitigation data, particularly in the winter heating sector. Crucially, this finding emerged from the iterative methodology itself and was only later confirmed against existing scholarship. This research design allowed for freedom in evaluating historical explanations while avoiding *over-fitting*, *hypothesis dredging*, *multiple realisability* and *ad hoc* explanations tailored to the literature.

In the winter of 2012, the newly appointed General Secretary of the Communist Party took office amidst great changes: economic growth was slowing, the urban population overtook the rural, and China's middle class was in the ascendent (Sicular, Yang, and Gustafsson 2022). The preamble to the 11th Five Year Plan noted that China was undergoing new structural conditions, leading to a new historical epoch[1]. The urban middle class was growing increasingly knowledgeable, and critical, of poor governance. Above all, urban Chinese were increasingly critical of the widespread corruption that was the implied cause of serious scandals in food safety (Lu and Wu 2014) medicine safety (Du et al. 2008); housing (Ting 2010) and poor air and water quality (Deng and Yang 2013). While air quality is the focus of this thesis, poor implementation of already existing laws is far from unique to environmental policy. It is unclear if these are indeed independently occurring problems with unique sources, or whether they are symptoms of deep-rooted structural problems in Chinese governance. Environmental policy implementation inescapably takes place within a broader governance structure, albeit one in which poor quality and incomplete data are commonplace. Despite decades of empirical research, with scholars analysing perhaps tens of thousands of government documents, and carrying out many thousands of case studies, each giving strong empirical evidence for particular governance dynamics in specific bounded conditions, there is little academic consensus on a fundamental model of Chinese state politics. How does Party politics at the top effect civil servants or directors of minor state-owned enterprises at the bottom, or vice versa? When faced with a large and persistent decrease in air pollution between 2008-2018, contrary to a history of poor environmental implementation, decades of research presents two broad possibilities: air pollution improved due to hierarchical, top-down policy decisions, or due to anti-hierarchical, bottom-up decisions by local officials. Naturally, Chinese political research has a number of particular challenges related to data collection, but this fact alone could not reasonably explain the lack of a generally accepted governance model. I believe that complexity theory presents a reasonable explanation for this

[1] "我国经济社会发展呈现新的阶段性特征." (National People's Congress of the People's Republic of China 2006, ch. 1)

phenomenon; in a complex system, there is no single mechanism that may be applied to the whole system to predict outcomes. Instead, there may be a number of different mechanisms, each interacting with each other in non-determinitive ways; minor changes to a single variable may generate cascading changes to the whole system. This thesis uses a variety of research methods to overcome the serious epistemological problems inherent in researching complex systems, ultimately aiming to distill a number of possible governance mechanisms to a single, foundational governance structure. Due to the epistemological challenges inherent in complex systems, and further challenges in data collection, the aim of this thesis is not to generate a finished model that may be applied to all of Chinese environmental governance, or even to all of winter heating governance, but rather to eliminate governance mechanisms and explanations which *could not* be part of such a general model. The possible mechanisms of air pollution reduction are enumerated in the literature review, and thereafter three empirical chapters work to gradually eliminate possible explanations until just one is left. A case study focusing on a small/medium sized winter heating SOE provides essential micro-level empirical data. Although the winter heating sector is small by volume of coal consumption, due to inefficient technology, it contributes an outsized proportion of winter air pollution. Whether winter heating SOEs are largely independent and able to make decisions on pollution mitigation themselves, or whether they are ultimately dependent upon the local district or city governments to decide and fund policy for them is ultimately an issue of governance structure. Lack of academic consensus on this core aspect of Chinese governance contributes to a wide variety of explanations, each based on reasonable empirical evidence, but ultimately unable to produce a general governance model. The classic structural view of Lieberthal and Oksenberg (Lieberthal and Oksenberg 1988) presents Chinese governance as consisting of a loosely independent collection of local and central government bodies together with State Council bodies, each competing for power and funding. On the other hand it may resemble a strict socialist authoritarian state (Fu 1993), whereby the fundamental structure is that of “leadership by Party committees, mobilisation of the entire Party membership, mobilisation of the masses” (Mao 1951): central government passes instructions down through government and party, with local governments implementing. There is a large range of different interpretations of Chinese governance with conflicting evidence gathered over several decades of field work in local governments and SOEs. Academic discourse on governance contains fundamental disagreements regarding its structure and dynamics. Given the lack of a reliable general theory on Chinese governance, researchers must content themselves with surveys of particular areas and sectors. But even here the lack of a theory on governance structure can greatly affect research outcomes; since field research is always incomplete and open to interpretation, researchers must use their knowledge of the larger context to make necessary assumptions. These challenges have no simple solution, and a general theory of Chinese state dynamics is well beyond the scope of this research. Nonetheless, I take the view that downplaying these methodological problems merely hides the assumptions made. I have taken a number of decisions on research techniques throughout which are driven by a core methodological commitment to complex systems theories. I believe the evidence points to Chinese environmental governance being best characterised ontologically as a complex system. There are a number of theories and methods associated with complex systems research, which I describe in detail in chapter three. However, the most appropriate description for this research is a system in which global variables are unable to explain or predict the phenomena described; rather, local dynamics play the characteristic role. However, it would be wrong to conclude that complex systems are entirely non-linear, and the dynamics entirely caused by forces at the micro rather than macro level. Instead, complex system dynamics are a mix of linear and non-linear dynamics, global and local forces intertwined. However, it is the non-linear processes that make complex systems less predictable, and therefore characterise the system as a whole. It is this understanding of complex systems that informs much of the research methodology taken in this thesis. Environmental governance can be characterised as a complex system because it contains micro-level dynamics which play a large part in the system, but it takes place within a larger Chinese state structure which may be largely hierarchical and linear. It is the interaction between the linear and non-linear which makes complex systems particularly unpredictable and resistant to simple explanations. Historically, Chinese environmental governance was widely supposed to be weak. Although environmental laws existed, they were poorly implemented (Chan et al. 1995; Lo et al. 2012; Kostka and Hobbs 2012; Lo 2014; Zhan, Lo, and Tang 2013; Kostka 2014; Eaton and Kostka 2014). In northern China especially, winter became synonymous with thick smog; clouds of yellow, brown or grey smoke hung above cities, sometimes not moving for weeks. These pollution 'episodes' rely on a mixture of air pollution, atmospheric inversions, low wind and little precipitation in which pollutants could rise as high as 10 times safe levels, as happened during Beijing's 'airpocalypse' pollution event in winter 2012 (Ferreri et al. 2017). It was not just the capital city that was affected by particularly extreme pollution. The whole north China plain region with Beijing-Tianjin-Hebei at its core, together with major cities in the

Northeast and Northwest have persistent and extremely high levels of pollution. Extreme pollution episodes could lead to thousands of residents developing localised asthma-like conditions, especially dangerous for the elderly, the infirm, and young children. Outside of these obvious and extreme events, everyday levels of pollution throughout northern China often had Air Quality Index levels above one hundred and fifty, three times higher than healthy levels[2]. While at-risk groups should avoid going outside in extreme smog, it is high everyday levels of pollution that have the highest impact on residents' health. Years of exposure to air pollution can have large effects on levels of cancer, heart disease, lung disease, strokes and other cardiopulmonary diseases (Liu, Xu, and Yang 2018). Epidemiological research estimates that well over a million deaths every year are caused by air pollution (Yin et al. 2020).

1.1 Research focus

Having reviewed some of the major issues surrounding research in Chinese environmental governance, I will introduce the research questions in depth. Further, I review the major scholarly explanations for historically poor implementation of environment policy, and its apparent improvement.

1.1.1 Question one: What caused the reduction in air pollution 2008-2018?

This research question focuses on the 'what' of air pollution reduction. It aims to discover the physical and governance causes of the observed approximate 30% reduction in air pollutants in northern China over the period. The research focuses especially on the winter heating sector due to its importance for winter air pollution in northern China, and the relative lack of scholarly research in this area. This research question aims to address both the physical technology and infrastructure that directly caused pollution reduction, as well as the political, bureaucratic, and financial factors driving these infrastructural changes. The physical changes

[2] AQI is a composite index, calculated from the relative concentration of a number of pollutants (see chapter four)

are critical, as they provide a solid epistemological foundation for the much more complex and uncertain political and bureaucratic research to build upon. The period 2008-2018 aligns with that of the Ministry of Environmental Protection (MEP, 环境保护部) as the key environmental agency. This period was selected both because it corresponds with the largest recorded decrease in Chinese air pollution, but also to reduce research complexity. Focusing on the MEP era minimises the number of variables affecting pollution mitigation, thereby reducing the complexity of the study.

1.1.2 Question two: How does the structure of Chinese governance affect implementation of environmental policy?

The research then focuses on the 'how' of pollution reduction, by focusing on the structure of governance networks as a methodological framework through which to explain governance dynamics. This hypothesises that the topology of Chinese governance, hierarchical, complex or random, provides the core mechanism generating policy implementation dynamics on the ground. This follows well established literature in Chinese politics, including concepts such as decentralised authoritarianism, authoritarian environmentalism, and the growing application of complex systems theory to the dynamics of social systems. Through computational modelling of the structure of environmental governance, it can bring validation to more general hypotheses about how environmental decision-making happens in practice. It is important to note that the model presented in this thesis is not intended to be a classical complex systems one, but a necessary preliminary step towards building such a model. Its purpose is to identify, explain (and thereby eliminate) non-complex phenomena, thereby isolating the parts of the governance network where complex dynamics occur and clarifying the key variables involved.

1.2 Literature

There is a popular view in both western and Chinese media that the cause of air pollution is effectively a form of corruption (The Economist 2012; Financial Times 2015; CPC News 2015; Communist Party Member Net 2013). This explanation has the advantage of clarity: it was intransigent local governments that for years had failed to carry out the policy of central government. As environmental policy became more politically important, career advancement for local officials may rely upon improving air quality almost as much as economic growth (Gao et al. 2022). This explanation relies upon a Chinese state structure that is largely decentralised; local governments have the freedom to disregard environmental laws if they interfere with other goals, most notably economic growth. This is far from the only explanation offered for the sudden increase in environmental policy implementation. While some research problems are motivated by a lack of research, this is not the case here; instead, there are many explanations for the same phenomena, each offering a different interpretation. Thus, the first motivation for this research is to decide between the multiple explanations available, specifically focused on the case of the winter heating sector, which has an outsized effect on winter air pollution in Chinese cities. Secondly, as illustrated above, each possible explanation cannot be independent from the larger Chinese governance structure with which it is associated. Below I will lay out several other explanations, each of which is supported by empirical evidence and scholarly literature.

1.2.1 War on Pollution

Quite apart from the public health effects, which put a strain on health services, cause long term disabilities, and dependence on family and public welfare, public perceptions of air pollution became increasingly negative and vocal throughout the 2000s. Government officials were also concerned that it showed Chinese cities in a bad light, and this feeling was amplified by the need to 'show off' China to the world during the 2008 Beijing Olympic games. Officials promised that it would be a 'green games', and publicised winning the fight to increase 'blue sky' days (Andrews 2008). As a result cars, factories, and commercial buildings were highly regulated by the Beijing government during the Olympic games; this successful project was coordinated by then vice President Xi Jinping as director of the Olympic small leading group. Indeed, Xi Jinping is very closely associated with the public image of a renewed importance given to environmentalism and air pollution mitigation. There is a public perception that

General Secretary Xi Jinping and Premier Li Keqiang are the direct cause of an unprecedented 1/3 reduction in pollution between 2008-2018. After increasing media attention paid to air pollution in the winter of 2012, the issue became so important that Li Keqiang elevated air pollution to the same political importance as fighting corruption. He announced a 'war on pollution' in 2013, and the 1.3 trillion RMB Clean Air Action Plan shortly thereafter ("国务院关于印发大气污染防治行动计划的通知" 2013; Li 2014). It was the political importance given to environmental policy by Xi Jinping's administration that finally caused local government officials in the provinces to take the issue seriously. This is a timeline commonly seen in media reports, and in some prominent statistical studies (Xue et al. 2020; Feng et al. 2019) to explain the subsequent drop in pollution. This also assumes that local SOEs will avoid following environmental laws if these reduce their capacity to pursue their goals, which may include producing products at a price point that is able to compete with other state-owned and private companies. Since investment in pollution mitigation technologies is expensive, this was avoided. SOEs even try to avoid censure by the local environmental protection authorities who should inspect and fine them if their practices do not conform to pollution laws (Eaton and Kostka 2017; Li and Chan 2015). Meanwhile, local environmental protection bureaux are institutionally weak, and dependent upon the local government for the majority of their budget. In effect, they cease to be independent bodies who carry out the instructions of their superiors, but instead serve the local government (X. Qiu and Li 2009). Where SOEs are fined, the penalties are so low that they can be paid as part of routine operating costs (Maung, Wilson, and Tang 2015). Although national air pollution laws existed since 1987[3], and policies to enforce these laws were implemented by a specialist environment protection body, polluting entities often flouted these regulations (Florackis, Fu, and Wang 2023; Pommeret, Yu, and Zhang 2022). Investigations by the environmental protection body were often limited; where air quality laws were found to have been broken, fines were often not levied. Some companies, perhaps especially large SOEs, simply refused to pay any fines (Eaton and Kostka 2017). The bureaucratic position of local environmental protection bodies was such that they had no power to force such entities to pay fines; large SOEs outranked them, and therefore could do as they pleased. This situation was exacerbated by other factors: a huge population in Chinese cities ensured that when industrialisation increased markedly from the 1990s onwards, many more coal-burning boilers were concentrated in urban areas than

[3] Air Pollution Prevention and Control Law, 1987 (大气污染防治法). Revised 2000, 2015 ("中华人民共和国大气污染防治法" 2015)

industrialising cities in other parts of the world. This problem of scale ensured that as China's economy improved, and urbanisation increased rapidly, Chinese cities were increasingly covered in a blanket of pollution. This situation was especially extreme in northern Chinese winters, as coal was used to heat homes, encouraged by Chinese policy which regarded winter heating as a basic right to be afforded to all Chinese citizens.

1.2.2 Cadre evaluation

These huge environmental challenges were increasingly a focus of scholarly and governmental concern from the late 1990's. However, this shift was not enough to keep up with China's huge economic growth during this period. Massive economic growth in the 2000's, and a concurrent increase in polluting industries was measured and discussed by Chinese and international scholars. It is from this period that western scholarly consensus of Chinese environmental pollution chiefly derives. It notes an 'implementation gap' between laws and local government actions on pollution. Scholarship from this period is often concerned with the mismatch between central government and local government; the implementation gap is often hypothesised to derive from a concern for local government to improve GDP growth, which during this period is highly correlated with an increase in the polluting manufacturing sector. The implementation gap is therefore theorised as a principal-agent problem, whereby the interests of the local government diverge from the central government. Accordingly, policy suggestions were made to improve this problem by attempting to ensure that local government preferences aligned more closely with that of the central government. This could be achieved by including environmental protection as an important goal in cadre evaluation, the primary means whereby government officials from the township to city levels are evaluated by their superiors. Furthermore, it was suggested that the environmental protection bureau was still too bureaucratically weak; by elevating it to full Department level, it would have the power and resources to properly implement environmental policies. These two major changes occurred in 2006 (Cadre evaluation law) and 2008 (creation of the Ministry of Environmental Protection). This would finally allow the newly formed MEP to properly implement the existing environmental laws, and finally reduce the 'implementation gap'.

1.2.3 Campaign style enforcement

There are a number of different government departments, ministries and bodies involved in winter heating regulation, including the State Council, National Development and Reform Commission, Ministry of Finance, Ministry of Housing and Urban-Rural Development, Ministry of Environmental Protection, Ministry of Land and Resources, and National Energy Administration. In order to produce well-evidenced and funded planning proposals, these bodies must have a degree of cooperation which may be difficult to achieve in practice. Further convincing local government at the provincial or city level to fund these projects may be even more difficult. These hard to solve problems give rise to a practical work-around: so-called *campaign-style enforcement,* whereby government intervenes in extra-legal enforcement, outside of the bounds of environmental laws and policies, in order to enforce those very same laws and policies (Liu et al. 2015; Rooij 2016; Wang, He, and Liu 2024). This is often seen as a failure of the Chinese governance system, since campaign style enforcement is by its nature a short-term reflexive action, which due to its strong target-oriented methods, may cause unintended harm to the sector they are enforcing (D. van der Kamp 2023). Further, it has been argued that campaign-style enforcement undermines the rule of law in China, creating local incentives for short-termist thinking and even corruption (Kostka and Zhang 2018).

1.2.4 Institutional power

The *bureaucratic weakness* of environmental bodies is another widely cited explanation; local environmental protection bodies are overpowered by other local interests (Lo et al. 2012; 2016; Yee, Tang, and Lo 2014). The environmental body was the State Environmental Protection Authority from 1998, and was then upgraded to the Ministry of Environmental Protection in 2008, and finally from 2018- present upgraded again to the Ministry of Ecology and Environment. Each change resulted in a higher bureaucratic rank, increased funding as well as powers to investigate and fine polluters. This increase in bureaucratic power therefore presents a powerful explanation for a decrease in air pollution.

1.3 Approach to research

The research design overall has been highly motivated by the need to avoid the serious epistemological challenge of *multiple realisability*, whereby entirely different model mechanisms may arrive at the same output, however this may be measured: statistically; in raw absolute values; or else in qualitative terms. This epistemological challenge is described in detail in chapter 3, and is related to the Duhem-Quine thesis (Quine 1951). In brief, while this problem theoretically relates equally to all possible models of a given data set, in practice simple and random data may be modelled with much less difficulty than complex data. This effect is further compounded since this research aims to decide between extant explanations, all of which have reasonable theoretical and empirical underpinnings. The research design is therefore generated in order to meet these foundational challenges, while avoiding *hypothesis dredging*, and *over-fitting* of explanation to consensus literature. This research picture is further complicated by scarce and unreliable empirical data, resulting from limited access to government decision-making processes, together with possible deliberate data falsification in government pollution statistics. It is therefore not trivial to decide which candidate mechanisms should be modelled and tested. These challenges required taking a conservative approach to eliminating candidate explanations: analogous to Constraint Satisfaction Problems (CSP) in computational algorithms like the Arc Consistency 3 (AC-3): instead of using logic or statistical constraints to *select the likeliest candidate*, the algorithm instead "prunes" possible candidates by *applying logical constraints to reject unlikely candidates* ; this is especially helpful in situations where the state-space of possible explanations is large, but the constraints (in this case, empirical evidence) is too scarce to identify a single solution. Analogously, **this research was designed to iteratively eliminate unlikely candidates, rather than positively identify the likeliest**. The *core governance mechanism* presented in chapter seven, is the result of a prolonged iterative series of deductive and inductive logic throughout this thesis,with each chapter aiming to reduce the number of possible causal mechanisms. Through this iterative process, the four possible causal mechanisms outlined in Section 1.2 were reduced to two candidate models. These were clarified and formalised as hypotheses H1 and H2. Of these, H2–the ‘ hierarchical governance hypothesis’, in which central government strengthens environmental policy emphasis that then diffuses through the governance network, generating increased environmental funding at each level—was selected as the foundation for the *core governance mechanism.*

The scholarly explanations in Section 1.2 are all evidenced with a variety of empirical data over decades of research, and no doubt each play some part in the overall pollution reduction. However, in the case of winter heating this thesis rejects these explanations in favour of a change in top-down political ideology. Below, I summarise the approach taken to research design, summarising the main hypothesis of *policy emphasis*, the methodological challenges encountered, and how complex systems theory is applied to produce a testable computational model.

1.3.1 Policy emphasis

After analysing empirical evidence of various types, this research rejects the previous explanations offered: '*war on pollution*', *cadre evaluation*, *institutional power*, and *campaign-style enforcement.* These explanations may account for some aspects of rapid decrease in air pollution, and may be more important for other polluting sectors, however within the winter heating sector it is not the driving factor. This thesis therefore offers a new explanation: pollution mitigation was ultimately driven by a change in *policy emphasis. Policy emphasis* can be understood as a broader interpretation of the "war on pollution" explanation. While the "war on pollution" is tied to a specific time period and is undermined by the fact that its effects preceded the stated cause[4], the underlying logic fits within a framework whereby political priority and political support determines the outcome of policy. **Law and policy are not implemented as is, but interpreted through *policy emphasis,* which is derived from the political context of the policy**. In the case of the *war on pollution*, the emphasis on environmental, particularly air pollution policy, was reinforced by political speeches from key Party leaders, state media coverage, and subsequent changes in laws, policies, and state and Party ideology. *Policy emphasis* hypothesises that policy implementation depends largely upon how government officials perceive the political importance of the policies they enforce. This emphasis is independent of the actual content of the policies or laws. Instead, officials gauge the importance of a policy through informal signals from their superiors, interpreting its priority relative to other directives. I hypothesise that *policy emphasis* is not a single

[4]The majority of pollution mitigation change occurred *prior* to 2013

mechanism, hence why *cadre evaluation* and *institutional power* were rejected as reasonable explanations for the observed phenomena. Instead, *policy emphasis* is hypothesised as a complex system, whereby central government creates the political conditions for greater policy emphasis, but cannot control it directly. Policy emphasis is therefore assumed to be the outcome of complex dynamics between different government and Party departments. The rapid decrease in air pollution concentrations in urban Chinese areas was overwhelmingly caused by central government directives, planned and promoted by powerful central government organs. Provincial-level government and Party members followed these directives in order to ensure their political survival, while attempting to ameliorate the negative effects of pollution reduction on local GDP and employment. This narrative of centralised control emphasises the utility of technology-based changes to the most important sectors causing air pollution: power plants, industry, transport, and winter heating. It also de-emphasises the utility of the Ministry of Environmental Protection (MEP) as a major agent of change. The MEP did improve its governance capacity during this period, and contributed to the regulatory environment in which polluting companies found themselves. However, its contribution was minor compared to the political mandate given by more important central government bodies. Crucially, important central government bodies had the political power to *change the political importance* of environmental protection, and also to *finance the technological and structural changes* needed to make those changes happen.

1.3.2 Methodological challenges

In attempting to understand air pollution governance in the Chinese winter heating sector, it is necessary to acknowledge that research requires a wider context. Firstly, a winter heating SOE in an urban location is nested within a larger city governance structure, which is again nested within a larger provincial, and then national governance network. The decisions taken at the lowest level cannot be understood without the wider context of the governance network as a whole. Secondly, analysis of the winter heating sector is limited by sparse data; compared to other air pollution sources, academic research on this area has been very limited, and Chinese government statistics relating to this sector is likewise inconsistent. Some cities have chosen to publish data on the built heating network, and the technology used in generating heat, while others have not. As well as sparse and missing data across cities and provinces, depth of knowledge on winter heating is also lacking. There is extremely limited data on how exactly winter heating state-owned enterprises function: how are they organised and governed? Who set them up? What is their business model? How are ordinary and extraordinary expenditures funded? How closely are they connected to government? Which level of government are they connected to? How is pollution abatement governed? Are polluting companies fined, and are fines a serious threat to ongoing operations? A case study of a winter heating state-owned enterprise (SOE) in Hebei province, addresses most of the specific knowledge gaps on operational questions. While this case study is invaluable in detailing specific mechanisms for heating governance at the lowest level, the practices of a single entity may not accurately reflect the entire winter heating sector. To put these methodological challenges into perspective, the winter heating sector is conceptualised as a complex system embedded within overlapping layers, influenced both by formal government bodies and by longstanding path dependencies. The number of different variables influencing the winter heating sector is very large, and at least includes: executive governance, legislation, energy sector, housing sector, urban development, migration, and economic development. These interconnected, nested layers operate at multiple scales, from the district level to the national level, and create dynamic conditions that are difficult to measure, much less predict. Compounding the challenges of complex, interconnected governance structures and limited data availability in the winter heating sector, Chinese government structures and decision-making processes are often inherently opaque. While the 'open governance' policy (Environmental Protection Administration] 2007) has encouraged more frequent publishing of policy documents and government statistics, decision-making procedures, policy motivations, and implementation details are severely lacking. Chinese governance has even been described as a 'black box' (Lu 2013; Chen, Lu, and Wu 2023), and often publishes details of governance structure that downplay the role of the Party, emphasising the role of apparently democratic structures such as the People's Congress, and the presence of multiparty decision-making ("中国的政治制度" 2024). This characterisation is widely acknowledged to be misleading (Shambaugh 2000; Economy 2021; Lam 2016; Bo 2019). These methodological challenges create a research environment whereby foundational facts, upon which all scholars agree, are very few. Instead, scholars may analyse Chinese governance using a range of analytical lenses, derived from diverse empirical sources. Given such theoretical heterogeneity, and the lack of broad and deep data, it is possible that any given data may be supported by apparently mutually exclusive theoretical stances. Improvements in air pollution may support both a centralised state governance (Rooij et al. 2017; Kostka and Nahm 2017; Jia and Chen 2019), and a weak central government (Chan et al. 1995; Ran 2017; Guo 2023; Kostka 2014), and many pointing to a mixed picture (Lo 2015; Eaton and Kostka 2014; Li et al. 2019; Bo 2021). Such a lack of agreement on foundationally important questions of Chinese governance creates difficulties in research. More starkly, the methodological complexity may lead us to be caught on either horn of a dilemma. Either we accept some insufficiently supported assumption, which allows the research to come to a positive conclusion; or else we accept that the situation is extremely complex, and instead produce an open-ended list of variables, with little conclusion as to mechanism. This thesis has attempted to avoid both horns through use of complex systems theory, with some success, albeit while limiting research scope.

1.3.3 Complex systems

I utilise the new science of complex systems in order to analyse, conceptualise, and model this change. Although complexity has been theorised in a number of different ways by mathematicians, and by natural and computer scientists, I use a common definition of complexity that was born in mathematical network theory, and later used by scientists from a number of different fields: complexity as a distinct class of phenomena, related but different to both simple and random systems. At the structural level it is identifiable by the interconnectedness of the elements in the system, being in a middle state between less connected simple networks, and more connected random networks. At the level of phenomena, it is identified as being ‘on the edge of chaos’, i.e. having characteristics such as self-organisation, non-linear dynamics, adaptation, and feedback loops (Packard 1988). Complex systems theory is now widely recognised as a mature scientific theory in the natural sciences, being used to model dynamical processes at the atomic scale all the way up to planetary weather systems; complex systems based models have exceeded previous best models in predictive power in many domains. In the social sciences, complex systems theories have made great advances, and are being used to model economic systems, urban transport dynamics, trade flows, crowd control, and most recently was widely used in virus transmission models of Covid19, relied upon by governments and international organisations (Kerr et al. 2021; Hinch et al. 2021). Although their use in the human sciences has been much less successful in both explanation and prediction than in the natural sciences, this is in line with previous experience of formal mathematical and statistical models in the social sciences.

1.3.4 Methodology of complex systems

The theory of complex systems as I have described it appears to lend itself more readily to the analysis of natural science: variables may be more easily measured, separated and sterile laboratory conditions applied to the system under study. In contrast, political science operates under far more complex conditions: events unfold in real-time and cannot be replicated; the number of variables is often unknown and cannot be isolated; and models can only be rigorously tested against past events, as variables continue to evolve in the future. In the philosophy of science, interpretivist critiques of applying natural science theories to the social sciences are well established. However, subjectivist explanations of social phenomena have arguably been no more successful, especially in terms of predictive accuracy. Moreover, many interpretivist models rely on folk psychological explanations, which implicitly depend on a theory of mind that is, at its core, also causative. All social science approaches encounter similar methodological challenges, which I would characterise as inherent to complex systems. I would further argue that methodological choices that acknowledge the fundamentally complex nature of social science are better suited to describe and explain such systems effectively. However, this does not mean abandoning interpretivist research. Interpretivist explanations are successful in terms of depth and specificity compared to simple and statistical models in political science, which can often preference objectively measurable effects over subjective reports of experts. Instead, complex systems theory offers compelling reasons to incorporate data from the widest possible range of sources, whether objective and measurable or based on documentary and interview evidence. The theory highlights that apparently small, local variables can trigger systemic changes; it is therefore crucial to analyse and incorporate data from as many sources as practically possible. Ignoring such information runs counter to the core principles of complex systems theory. Complex systems theory reflects the need for historically derived, time-specific, and dynamic causal explanations. In its rejection of traditional reductionist scientific methodology, it can be seen as accepting important critiques of interpretivism within an objectivist epistemology. Complexity science offers distinct methodological advantages for understanding the structure of the Chinese governance system, both as a static framework through network analysis and as a dynamic computational model. Computer models provide significant flexibility in incorporating both qualitative and quantitative data into model inputs and analysing the resulting outputs. These models enable the generation of outputs that reveal large-scale, statistically important changes in governance networks over time, while allowing for the coding of model parameters in a way that allows the testing of imprecise concepts. This thesis collects case study data in the form of thousands of internal winter heating SOE documents, extensive interviews with a company insider, dozens of national laws, 5YP, policies and projects were analysed, as well as winter heating statistical data from dozens of sources which the author collected into a single document, as well as measures of pollution collected from many different sources, from government statistics on coal consumption and local air quality index to China-wide satellite measurements of key pollutants. The mixed-methods approach is crucial for enhancing the reliability of research outcomes, allowing for triangulation between qualitative and quantitative data, and reducing biases inherent in any single method. Furthermore, triangulation between a variety of empirical sources is the only reliable method to analyse and eliminate a number of extant explanations for historically poor environmental implementation. The figure below shows an overview of the modelling process, with various theoretical constructs and sources of empirical data finally culminating in acceptance of hypothesis 2.

Below, I summarise the key challenges and findings of each chapter, with a particular focus on the methodological obstacles encountered and the strategies employed to address them.

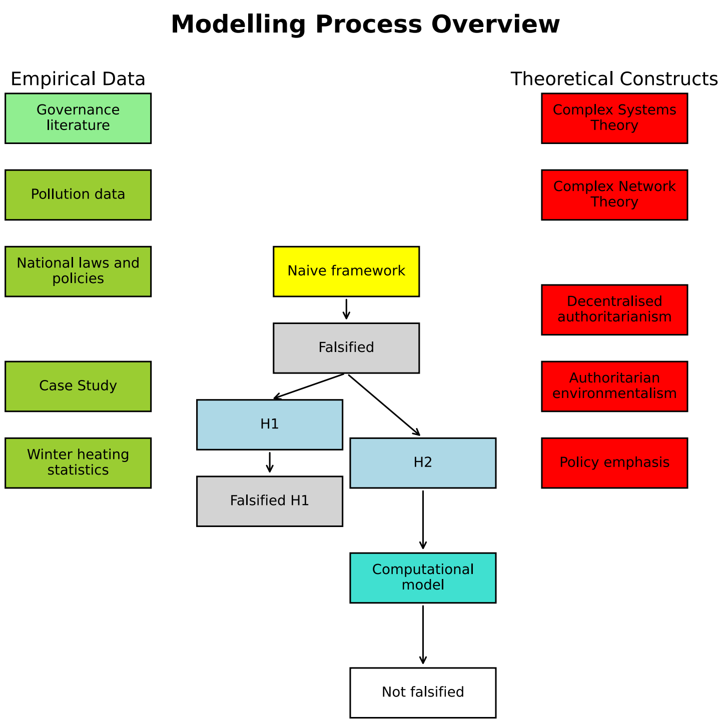

Figure 1.1: Overview of the research and modelling process, source: author

1.4 Findings

The thesis concludes that the reduction in air pollution overwhelmingly resulted from an increase in capital investment directed by central and provincial governments, rather than independent action by winter heating SOEs or greater regulatory pressure from inspections and fines by the Ministry of Environmental Protection (MEP). This outcome reflects the close dependence of heating SOEs on local government for resources and oversight, as shown in the case study and in the computational models of chapter eight. Most institutional reforms of the 2000s and 2010s–such as the creation of the MEP in 2008 and its upgrade to the Ministry of Ecology and Environment (MEE) in 2018, incremental funding increases, the shift toward vertical environmental management, and cadre evaluation reforms– had only a negligible effect on winter heating pollution outcomes. These measures improved bureaucratic capacity and signalled environmental concerns, but did not independently drive large-scale reductions in emissions. In fact, central government policy shifts embedded in successive Five-Year Plans —particularly the introduction of energy efficiency targets after 2006 and the launch of large-scale, funded Winter Heating projects–were the decisive drivers of change. When central government prioritised air quality, provincial and local governments responded quickly, allocating funding to environmental projects and steering SOEs toward compliance. This process was hierarchical and centralised rather than bottom-up: local autonomy persisted, but its exercise is bounded by political expedience. The political will of the central government to prioritise one policy or law over another I term *policy emphasis*. This factor is crucial for understanding both the persistence of the environmental *implementation gap* and its opposite, cases of *over-zealous implementation*. Local governments must balance their own needs and capacities, but as this thesis argues, they must also pay close attention to the *political will of the centre*. Scholars have described this dynamic as "selective implementation" (O'brien and Li 2017; Li et al. 2019), "policy winds" (Zweig 1985), or "rule by mandate" (Birney 2014). In practice, priorities are often set less by formal directives than by informal conversations with superiors and by close political reading of central government documents and leadership speeches. The emperor may be far away, but local leaders know it is unwise to act against clear priorities set by the centre. This finding challenges the notion that improvements in air quality were primarily the result of strengthening the overall governance network or tightening cadre evaluation metrics. Instead, the evidence suggests that the real turning point was the alignment of central government priorities with funded policy instruments. Winter heating SOEs in northern China, as shown in the case study, operate as public service providers tied closely to local governments and subject to strict political oversight. Their leaders hold relatively low bureaucratic rank and have limited opportunities for career advancement, except when they can align with state priorities. Most SOEs lack independent access to capital or political leverage and remain dependent on local government decisions. As such, they were not the primary agents of pollution mitigation but rather the instruments through which centrally prioritised projects were implemented. Furthermore, this finding implies that the environmental *implementation gap* has not in fact been resolved (Zhou and Schubert 2025); ordinary governance capacity has improved only incrementally. If central government were once again to de-emphasise environmental issues, many of the advances achieved could quickly be reversed.

Factor	Incentive	Policy / Law created	Effect on winter heating pollution
Weak institutional power of environmental body[5]	Negative	Creation of MEP (2008), upgrade to MEE (2018)	Negligible
Limited financial/staff resources of environmental body	Negative	MEP funding increases roughly in line with inflation	Negligible
Local environmental bureau financially dependent on local government	Negative	Vertical environmental management system reforms, Tax reforms	Negligible
Environmental issues are not sufficiently incentivised by local government	Negative	Cadre evaluation reform	Negligible
Local government cadre evaluation incentivises GDP and employment	Negative	Cadre evaluation reforms; environmental indicators alongside GDP targets	Negligible
Central government disincentivises environmental policies	Negative	Five-Year Plan energy effeiciency targets (post-2006), funded Winter Heating projects	Major driver of change

Table 1.1: Key factors shaping environmental policy implementation, source: author

1.5 Contributions

This research makes several contributions to the study of Chinese governance. Its central contribution is the formulation of the *core governance mechanism*: a theoretical framework that explains variation in policy implementation not by the laws and policies themselves, but

[5]State council environmental body 1998–2008: SEPA; 2008–2018: MEP; 2018–present: MEE

by the degree of *policy emphasis* that central government attaches to them. This framework demonstrates that policy implementation exists across a spectrum of political sponsorship, from very weak to very strong. Historically weak environmental governance, and its more recent strengthening, can both be explained as outcomes of variation in central *policy emphasis*. The *implementation gap* and cases of *over-zealous implementation* are not fundamentally different phenomena, but arise from the same structural dynamics of the Chinese governance system. What differs between them is simply the degree of *policy emphasis*–political will–applied in each case.

Methodologically, this thesis shows how such a *core governance mechanism* can be derived from first principles, tested against empirical data, and validated through computational modelling against out-of-sample data and scholarly literature. Rather than proposing a *new* substantive explanation of the implementation gap, the contribution lies in the iterative elimination of weaker hypotheses, the construction of a generalisable framework, and its confirmation against existing scholarship and data. This approach provides a robust method for reaching conclusions where data is scarce and competing explanations abound, while avoiding *over-fitting*, *hypothesis dredging*, *multiple realisability* and *ad hoc* reasoning. This same method can be substantially re-used with minimal changes to methodology to further research Chinese environmental governance in other sectors, and Chinese governance in general.

In empirical terms, this research makes a further contribution by documenting the winter heating sector-an underexplored but important driver of pollution in northern China. The Hebei case study provides a granular account of the institutional rank, duties, and funding mechanisms of winter heating SOEs, and a timeline of pollution abatement projects. These findings support the broader conclusion that SOEs are not independent actors but extensions of local government decision making, and that funding priorities shift rapidly when central government places strong emphasis on environmental policy.

Finally, this research contributes to wider debates on Chinese governance by offering a parsimonious but well-evidenced framework of decision making. The *core governance mechanism* clarifies the real topology of the governance network as a hierarchical tree where local autonomy persists but is constrained by political priorities. This framework helps explain both the persistence of the *implementation gap* and the conditions under which rapid environmental improvements are possible.

1.6 Thesis structure

Literature Review

Sets out some major issues in Chinese governance structure, especially centralisation and decentralisation. The chapter focuses on the implementation gap in Chinese environmental governance, which refers to the discrepancy between strong environmental laws and their weak enforcement.

Research Design

Summarises the methodological problems associated with modelling complex systems, and lays out the benefits of computational models. Data is derived from a variety of sources: measures of pollution; analysis of national laws and policies; case study data from a winter heating SOE, and two hypotheses presented.

Air Pollution: Sources and Statistics

Presents the characteristics and metrics of common air pollutants, utilising data from national statistics and satellite observations. The non-linear relationship between emissions and air pollution is examined, highlighting that air pollution levels cannot serve as a direct indicator of environmental policy implementation.

Ideology Law and Policy

Laws, policies, air pollution standards, 5YP and funded projects at the central and provincial level are examined, noting the major laws and national policies in the academic pollution governance literature which were claimed to have the most impact on pollution levels. The timeline of these documents are cross-indexed with the physical air pollution data in chapter four.

Case Study: Hebei District Heating SOE

The study examines a Hebei province winter heating SOE in detail, presenting the three major funded projects that reduced pollution emissions. Five hundred and nineteen files of internal company documents were examined, consisting of thousands of pages of company reports, technical specifications and applications for funding. This written data was supplemented by an in-depth interview with a company insider.

Winter Heating I: Core Governance Mechanism

This chapter takes empirical data from preceding empirical chapters, categorises the complex dynamics of the case study into a simplified structure, and generalises these dynamics to create a general model of governance. The *core governance mechanism* created hypothesises that funding decisions on environmental policy are decided by *financial resources* and *policy emphasis.*

Winter Heating II: Models and Analysis

The modelling logic developed in chapter seven is tested using networks in three phases: Hebei province only; north China plain model; fifteen province model. This chapter serves as a verification of the core governance mechanism, using out of sample data of winter heating pollution and policies.

Conclusion

The thesis concludes by setting out answers to the two research questions. It further summarises methodological and data collection issues with the research, and suggests avenues for future research.

2 Literature review

> "*Once a political line has been set, it has to be concretely implemented by people, and the results will vary depending on who does the implementing*"
>
> — (Deng 1984, p. 197)

Alongside rapid economic growth, China's reform and opening up led to a massive increase in environmental pollution, adding to the already heavily degraded natural environment resulting from Mao Zedong's leadership. The effects of pollution are said to not only harm Chinese people's health (Zhou et al. 2014), hold back economic growth (Wu 2006; Li and Shapiro 2020, p. 9), but also tarnish China's image as an up and coming superpower (Zhang and Barr 2013, p. 5). It has even been suggested as an existential threat to the leadership of the Party (Breslin 1997). How China governs environmental problems while encouraging economic growth is one of the great challenges China currently faces. Far from being a natural consequence of economic development, "environmental degradation is more likely a consequence of governance failure (or institutional failure) than an outcome of market failure" (Xu, Xu, and Xu 2018a). While China's central leadership has increasingly emphasised the importance of the environment, local governments have not; environmental legislation is not executed to the full extent of the law, leading to an 'implementation gap' in environmental governance. Local government have great autonomy, and are able to avoid or reduce environmental obligations in favour of increasing local GDP. Despite these serious governance contradictions, air pollution improved markedly between 2008 and 2018, the period when the Ministry of Environmental Protection (MEP) was the main government pollution regulator. There are a number of research literatures that are pertinent to this area. Work on Chinese environmental governance provides the core to this research, especially work on the *implementation gap*. Naturally, the implementation gap problem takes place within a larger context: that of state governance in general, where discussion on *decentralisation* is particularly important. I will consider 'structural' explanations of Chinese governance in particular, such as (Lieberthal and Oksenberg 1988; Landry 2008a; Birney 2017). These support the view that governance outcomes, positive and negative, are highly influenced by the *structure of the state*: the intra-governmental relations between different departments, levels of local government and the Party itself. I then relate this structural theme with research on complex systems and its intellectual ancestors, cybernetics and general systems theory. I note that structural theories of the Chinese state and complex systems form a coherent, and as yet under-explored research project within Chinese politics: Chinese governance can be analysed as a complex system. The *structure* of China's governance system consists of various government and Party organs, and it is the *relations* between these organs which best explains the 'messy reality' of China's environmental governance.

2.1 Structure of Chinese governance

Chinese governance structure is often summed up as the 'Party-State' (Guo 2012, ch. 9), the same word used to describe governance in the Soviet Union. However, Post-Mao Chinese governance is unique, even amongst communist single-party states (Perry 2007; 许耀桐 2012). The Chinese state, through changes in the 'reform and opening up' era, has stepped back from 'total control' (Economy 2004, p. 132), where state and party are integrated fully at all levels of state power[6]. Chinese governance also differs from the Western democratic model whereby ruling parties are separated from the bureaucratic organs involved in day to day governance. China's governance structure is therefore a 'hybrid' type. The Party (Executive) and State structures (bureaucracy) are in a state between fully separated and fully integrated. However, this rough classification tells us very little about how governance decisions are actually made: do Party committees regularly overrule government bodies?; are there power struggles between Party committees and Government bodies?; how do government bodies cooperate or compete with each other to solve problems? This Party-governance ambiguity makes the workings of the Chinese state particularly opaque, especially when combined with a historical (Lieberthal and Lampton 1992, p. 4) and ongoing (Tsai 2010; Ruth and Yu 2019) high levels of secrecy and censorship towards foreign and Chinese researchers. State secrecy can make direct study of Chinese governance practices extremely difficult (Carlson 2010, p. 3), but this

[6]Recent reforms to the Party-government structure which reject 'separation of powers' after the 19th Party congress are outside the scope of this study (see (Snape and Wang 2020))

secrecy is not only an issue for those outside of the bureaucracy; secrecy produces silos of information which can generate rivalry between state organs, or reduce cooperation between organs (Jahiel 1998).

2.1.1 Overview of governance structure

2.1.1.1 Systems, kuai and tiao

At the coarsest level of analysis, dispensing with distinctions between Party and Government, (Lieberthal and Lampton 1992) suggests systems (系统) as a reasonable classification; separate organisational units bunched together by their overall aims. (Lieberthal and Lampton 1992, p. 2-3) gives six overall core systems (or *clusters*) of nationwide hierarchies with strong powers, although other formulations (Barnett 1986, p. 456) have been suggested. These consist of: economic bureaucracies (planning organisations, banking); propaganda and education bureaucracies (mass media, schooling, research units); organisation and personnel bureaucracies (Party, government and military personnel departments); civilian coercive bureaucracies (police, judiciary, prison camps, intelligence units); military system (people's liberation army (PLA) including land army, navy and air force); communist party territorial committees (local committees of the Party at provincial, municipal, township and village levels). These systems can be further analysed by the relations between different units (again, ignoring Party/Government distinctions for the moment). These have been called *tiao* (条) and *kuai* (块). *Tiao* are basically the vertical lines of hierarchy from the very top of a given *system* (say the Party military affairs committee in the 'military system') all the way down to a particular unit of the PLA (People's Liberation Army).*Tiao* are defined by hierarchy, with directions given at the top and carried out at the bottom. Conversely, information moves up the chain of command from the bottom, all the way up to the Generals and thence to the Party military affairs committee who then make strategic decisions based on that information. In contrast, *Kuai* refers to the formally non-hierarchical relations between government organs of the same bureaucratic rank; the relations between the local office of a state council ministry such as education, and the provincial government can be described as a *kuai*. Formally, the provincial government has control over the education system within its territory, however the provincial government must follow national education policy, and thus are 'advised' on education matters by the provincial branch of the education ministry. This relationship is not a straightforward one whereby one commands the other; rather, they must cooperate in order to produce concrete education policy that both follows national policy standards and is appropriate to provincial conditions. This contrast of *tiao* and *kuai* is fundamentally a structural relation; on the one hand *tiao* is hierarchical, a simple 'command and control' relationship between two organs. On the other hand, *kuai* is non-hierarchical, the relationship between two organs is not straightforward; competition and cooperation between two government organs of the same rank is not predictable, but highly complex.

2.1.1.2 State governance

Under the Chinese constitution, the governance structure consists of separate legislative, executive, judiciary and military branches, however in reality some constitutionally important organs, notably the main legislative body the National People's Congress, is extremely weak, and has been called a 'rubber-stamp legislature'[7] (Heilmann 2016, p. 127-129). Formally, the National People's Congress (NPC) is the highest body in China, responsible for far-reaching powers in the Chinese state, including making changes to the Chinese Constitution and other national laws; electing members to the Standing Committee of the NPC, and the most important positions such as President, Vice President, members of the Central Military Commission; and examining and approving national economic and development plans ("Constitution of the People's Republic of China" 2019, article. 57). In reality, the NPC has little independent power; it never fails to ratify proposals by the central leadership, and there is no forum for dissent or debate within the NPC (Heilmann 2016, p. 29). Until the 2017 change to the Chinese Constitution, the Communist Party of China had no special role under the law, despite being the pre-eminent power in all levels of government, judiciary and military. Until 2017, the constitution of China did not even mention the Communist Party, and in fact states categorically ("Constitution of the People's Republic of China" 2019, article. 5) that the constitution is the supreme authority above all organs of government, and that no government can break constitutional laws: "All state organs, the armed forces, all political parties and public organizations, and all enterprises and undertakings must abide by the

[7]The NPC has certainly increased in power since the 'reform and opening' period, and there are some scholars who think the 'rubber stamp' view is largely out of date (Chen 2016). However, despite this movement towards independent power, the NPC is at best an alternative centre *of* power (sometimes being in competition with the State Council) (Chen and Stepan 2017), rather than a democratic alternative *to* Party power

Constitution and the law". For most of its existence then, the Party was the preeminent power of the state, but its power was always outside, or above, the law. The Communist Party of China (CPC) has its own constitutional text, which describes the CPC as the 'vanguard' of the people, and notes that Chinese state success is due to the Party; it states that "The Party exercises *overall leadership* over all areas of endeavour in every part of the country" (emphasis added, ("Constitution of the Chinese Communist Party (中国共产党章程)" 2022)). In reality, the role of the Party is like that of a 'hidden government' operating within, and alongside the official government; it acts to guide executive decisions so that they align with those of the central leadership. Deng Xiaoping noted that the party's role should be to shape larger questions of policy direction, whereas government's role was to execute those policies (Deng, 1994[8]. The Party is present as the ruling political party in the legislative organ, but also exists within and alongside executive governance, judicial governance and military governance at all levels, from the highest central bodies to the township and village level. For every government organ at every level of hierarchy there is an attendant Party committee at that same level, which is itself part of the whole Party hierarchy. While the Party exists at every level of governance (including State-owned enterprises) as an independent body at that level (the Party branch), many government officials (in the State Council, or Military commission, or provincial government for example) are also members of the Party, and sit on the Party Committee at that level (Guo 2012, p. 135-138). As government officials they are therefore beholden to the hierarchy of the State, but as Party members, they are accountable to the Party hierarchy; any conflicts that arise are dealt with by the ultimate authority of the Party over government organs (see below). When one takes the Party into account, it is clear that it possesses a parallel hierarchy to the official government organs – a 'state within a state' (Guo 2012, p. 135), and that Party decisions take precedence over those of the government. In actuality, the highest decision-making organ of governance is the highest level of Party authority, nominally the National Party Congress[9] this body meets only once every five years. When the Congress is not in session, power is held by the Central Committee of the Communist Party (中央委员会) which meets once every year. However, day to day authority is held by the Political Bureau of the Central Committee (Politbureau: 中央政治局), which is supposed to be nominated by members of the Central Committee but appears in fact to be a

[8]"Strictly speaking, party organisations at all levels should delegate as much of the daily administrative work and affairs as possible to the government and business departments. The party's leading organs, apart from mastering the guidelines and policies and deciding the use of important departments, free up the time and energy to do ideological and political work, work for people. Work for the masses." (Deng 1984, Vol. 2,p. 365)

[9]Consisting of 2280 Party members as of 2019-09-01

self-perpetuating body, with already existing members of the Politbureau suggesting new members (Li 2013). It is clear that Chinese governance structure on paper, and in reality are two different things. While official governance structure has clear lines of control, in reality communication between government and Party organs is unclear, and lines of control are blurred. The simple, unitary edifice of the Party-state is in fact a hugely complex series of interlocking institutions. The 13th Party Congress in 1987 emphasised separation of Party and State (党政分开), but this has been undermined by Xi Jinping (Lam 2016, p. xiii), along with rule by 'collective leadership' advocated by Deng Xiaoping. (许耀桐 2012) characterises the new Chinese model as party and state being both 'separate and unitary' (党政分合); it contains elements of separation of powers, and elements of the unitary Soviet party-state system. (Wu 2013) notes the importance of 'democratic centralism' (民主集中制) and 'dual leadership' (双重领导) as organising principles of party-state structure and control. Democratic centralism combines both centralised control with leadership by committee, so that although the structure remains hierarchical between levels, within the same level, decisions are taken in committee form. This theoretically means that any problems with policy is thrashed out in the committee, and then handed down to lower levels of governance, who cannot question that policy. Dual leadership further strengthens the hand of the Party over various government organs by instituting hierarchical relations between a government organ, the Party committee at the same level of governance, and the local structure and Party committee one level higher up. However, in practice government organs and Party committees are more intertwined than this picture would lead us to believe. This is because the Party committee contains many important members who are also leaders in the local government organs; the order of their seniority is given by the 'nomenklatura' system (Heilmann 2016, p. 115-118). It is helpful to clarify this elaborate theoretical structure with an illustrative case: the prefecture-level government of Xi'an city in Shaanxi province. The Municipal Party committee of Xi'an has three top leaders, and eight ordinary members. In strict order of seniority, they are (correct November 2019): Secretary Wang Jie, and two deputies, City mayor and leader of Xi'an city government Li Mingyuan, followed in seniority by Secretary of the Party 'political and legal affairs committee' and Secretary of Xi'an party school Han Song. The remaining members of the Party committee include the heads of the 'united front department'; 'organisation department'; 'discipline and inspection committee'; secretary of the Party committee on Xi'an's 'special economic area'; deputy Mayor of Xi'an city; secretary of Party 'work committee'; and lastly a professor of medicine (Xi'an City

Government 2019). From the above example, one can see that the top position in government (city Mayor) is secondary to that of the Party secretary, while the second top position in government (Deputy Mayor) is the eighth most important position in the Party committee. Since the Xi'an Party committee sits above Xi'an City government in the hierarchy of authority, any disagreements that arise between government and Party should be resolved in the Party committee's favour, although obviously the Committee will be influenced by the City Mayor, the second most senior member of the committee. Further to this muddying of roles between Party and Government, many government officials are Party members, and due to the personnel system in place, may well have served official roles within the Party in the past before being placed within the government. Conversely, government officials may well be moved from their current roles into Party roles in the future. One should not therefore think of the Party and Government as completely independent bodies, but rather as an interlocking system, where high levels of interdependence are encouraged, while the two organs have a different overall focus: the Party upon maintaining the 'direction' stipulated by the central leadership, and the Government upon translating the often vague or even contradictory central policy statements into efficient mechanisms that suit particular local conditions. Formally, though, Chinese governance structure is clearly hierarchical. Not only do government officials exist within a ranked hierarchy, but the government bodies where they work are also ranked by importance (Lieberthal 1997; Lieberthal and Oksenberg 1988, p. 142-145; Jahiel 1998). Thus, central ministries are ranked above provincial ministries, but are of the same rank as the provincial government. Thus bodies of the same rank may give advice, but cannot give orders (Lieberthal 1997). For matters of mutual interest then, they must cooperate. Such cooperation does not appear to be an easy matter: "Government agencies that lack high administrative ranking and reliable sources of funding are often forced to develop on an individual basis their own ways to attain the nominal levels of ascribed authority necessary to conduct their jobs" (Jahiel 1998). This has led Lieberthal to claim that negotiation among government bodies is a significant part of Chinese governance, perhaps just as importance as hierarchy itself:

> Officials at all levels of the political system have become increasingly adept at negotiating for additional flexibility from those at the next higher level — or of concealing activities that violate restrictions imposed from above.
>
> — (Lieberthal 1997)

2.1.2 Decentralisation

An important strand of 'reform and opening up' consisted of decentralising power. Deng Xiaoping noted that ""Bureaucracy, overconcentration of power, patriarchal methods, life tenure for leading positions and privileges of various kinds" were all barriers to China improving governance in the Party and civil service." Research at the local level (Saich and Yang 2003; Wang and Yao 2007; Teets and Hurst 2014), and at the level of the state (Yang 2004; Tsang and Kolk 2010; Saich 2013) makes clear the importance of decentralisation to governing the Chinese state. Although there have been some periods of centralisation (such as the 1994 tax reforms, and recent centralisation of power under Xi Jinping) (Chen and Schubert 2024), China has become one of the most decentralised states in the world (Landry 2008b). I will first examine some aspects of decentralisation, and how these affect governance. When comparing central government organs, for example those of the State Council, with Provincial government organs, there is evidence that local government bodies tend to be relatively more powerful. This can be measured in several ways, with spending power (Landry 2008b), and representation at the Central Committee (Bo 2007) being represented in the literature. I then explore some key literature seeking to understand Chinese governance in light of this post-Mao, decentralised model.

2.1.2.1 Fiscal decentralisation

As a broad characterisation, Chinese government statistics show that the vast majority of government expenditure is spent at the Provincial level and below (Landry 2008b). From 2012-2017 (Xi Jinping's first term as Party Secretary and President) local expenditure was consistently 85% of total government expenditure, while local tax revenue was on average 13% higher than central tax revenue over the same period ((National Bureau of Statistics of China 1999, years 2013-2018). (Wu 2013; Landry 2008a, p. 3) note that China's governance model is one of the most decentralised in the world. This in itself is curious since decentralisation is generally the mark of democratic governance (Landry 2008b); authoritarian leaders may rightly fear decentralising power to the provinces, since alternate sources of power could ultimately destabilise the regime (Treisman 1999; Landry 2008a, p. 10). Not only is China unusual in being authoritarian and decentralised, many scholars are convinced that it was decentralised governance that led to the remarkable improvement in Chinese living standards over the past 40 years since Deng Xiaoping's 'reform and opening up' (Montinola, Qian, and Weingast 1995; Blanchard and Shleifer 2001). There are a number of scholars (Lin and Liu 2000; Shirk 1993; Ding, McQuoid, and Karayalcin 2019) who point to the Jiang Zemin and Hu Jintao era (1992–2012) as accelerating fiscal decentralisation, despite the 1994 tax reforms. On this view, one of the major reasons for China's economic success was the freedom of local government officials to pursue different strategies that encourage growth (Jin, Qian, and Weingast 2005). In general, the effects of government decentralisation are not entirely predictable: it is theorised to lead to increased democratisation and therefore, according to some, increased accountability and efficiency (Hayek 2021). Others, however, point to decentralisation leading to increased inequality, conflicts of interest, and corruption (Ivanyna and Shah 2010). Fiscal decentralisation can have positive effects when the ability of local governments to more accurately map the needs of the population leads to greater efficiency (Hayek 2021; Oates 1972; Wu 2013), or when local governments compete with one another for government resources, thus increasing efficiency of local government spending (Tiebout 1956). The complex and unpredictable nature of government re-structuring (whether increasing centralisation, or reducing it) can be seen in (Wu 2013) study of personnel spending by local governments. Far from leading to simple outcomes, like increased efficiency, or increased corruption as outlined above, it may lead to a complex picture of positive and negative outcomes. Wu notes a sharp increase in spending on salaries as pay rises were put under the centralised control of the Ministry of Finance and the Ministry of Personnel. Salaries as a proportion of overall spending for Fujian provincial government rose from 52% in 2002 to 74% in 2008. Despite this, Wu claims that decentralisation contributes to 'local capture': "Occupying power and money (both public and private), local leaders are able to capture any resources flowing from both top and bottom despite constant resistance and constraints from various sources" (ibid.). However, increasing centralised control of personnel budgets did not improve the matter, rather, local governments took advantage of the higher personnel budgets to increase their number of employees, and in the process probably increased nepotistic hiring practices to capture this money.

2.1.2.2 Political decentralisation

It has been noted that fiscal decentralisation is allied with political centralisation in the Chinese state (Landry 2008a; Montinola, Qian, and Weingast 1995). Cadre personnel management has been seen as a powerful tool for Central Party to control appointments in the provinces. Central structures like the Party Central Committee (CC) are widely recognised as the heart of state power (Guo 2012, p. 140-144). Political decentralisation is therefore a more complicated picture than that found in western federal systems. While political power is highly concentrated at the upper echelons of the state, as one moves down the state hierarchy, power is not apportioned equally but instead is concentrated in the hands of provincial leaders instead of central government leaders (Bo 2007). Bo Zhiyue argues that by examining the membership of the CC, one can see the real power concentration in the state, and it is heavily biased towards the provinces, especially richer provinces. The highest positions in the State bureaucracy are those of the Party Central Committee, of which there are 204 full members, and 172 alternate members (December, 2019). Those few officials that make it as full serving members of the Committee are at the apex of Chinese politics and are extremely powerful and influential. The State personnel system is centrally administered at above Municipal level (Landry 2008a, p. 81) via the Organisation Department of the Party. However, it is not clear how Central Committee members are chosen. Formally, they are voted into position by the members of the National Party Congress every five years (Shih, Adolph, and Liu 2012a), using a list of names given by the Organisation Department of the Party. However, this vote appears to be heavily influenced by senior members of the Party, including General Secretary of the Party and members of the Politburo through augmenting the list of names, but also through hints as to who should be promoted to the Central Committee (Shih, Adolph, and Liu 2012a). Although factional politics is shown to be an important factor in gaining seats to the CC (Meyer, Shih, and Lee 2016), they cannot be promoted from junior ranks. Favoured officials must first be highly-ranked, often 'Ministerial level' officials such as provincial Party Secretary or Minister of a State Council Central department. Through examining the position held by CC members, (Bo 2007) theorises that this serves as a proxy indicator of the importance of the various arms of the state. He examines members elevated to the sixteenth Party Congress and notes the large advantage that provincial leaders have over both leaders of Central government departments and also high ranking leaders of the PLA. This evidence is used to conclude that provincial government and Party leaders hold more power within the Chinese state than do equally-ranked members of the central government. This evidence points towards a state that has ultimate central control, but is politically decentralised to a significant extent.

2.1.2.3 Theorising decentralisation

The extent, and consequences of decentralisation have been explored in a number of key works, including (Lieberthal and Oksenberg 1988) 'fragmented authoritarian' model; (Montinola, Qian, and Weingast 1995) 'federalism, Chinese style' and Landry's (Landry 2008b) 'decentralized authoritarianism'. Although less well known, (Birney 2014) 'rule by mandate' model of Chinese governance has important consequences, and I will examine it in turn. All of these scholars theorise decentralisation using concepts that rely heavily on the *structure of Chinese governance* as the main contributing factor. The relative autonomy of local governments and the struggle for power of different government organs amongst themselves is thus a problem of the structural arrangements of government. I will later (section 3) relate these 'structural theories' of Chinese governance with theories of complex, interconnected systems known as complex systems theory. Complex systems theory is able to subsume structural theories of Chinese governance within a larger framework, and thus to bring in new tools and theories of complex systems that can be applied to understand Chinese governance more fully.

Fragmented Authoritarianism: The 'fragmented authoritarianism' model (Lieberthal and Oksenberg 1988) sees authority below the top echelon of the Chinese political system as "fragmented and disjointed" (Lieberthal and Lampton 1992, p. 8). Since the system is not strictly hierarchical, bureaucratic bodies often have to reach consensus together with other bodies before policy implementation can commence. This model tends to emphasise 'structure' and 'policy process' over the study of 'values', partly for reasons of research difficulty (Lieberthal and Lampton 1992, p. 8). However, it seems to me that the fundamental core of this model assumes that decentralisation will have certain effects; namely, that it leads to conflict or cooperation between government organs, since *not all policies can be implemented at once, and with equal emphasis*. I would argue that this is correct, but that a focus on structure is not just incidental, it is baked into the core assumptions of the model. As (Lieberthal and Lampton 1992, p. 23-24) explains, a large part of 'reform and opening' was a *shift from vertical relations to rule-guided or market relationships* again, this is a structural argument. Reform and opening is described in terms of the structure of government operations. Compare this with work on 'cybernetics' or 'complex systems', where it is the *structure or relations between units* which, to a great extent, create the properties of the system as a whole. Cyberneticists like (Deutsch 1952) viewed governance as a problem of information, where structural differences in governance institutions had huge effects on how the system was governed. Modern research in complex systems is interested in how the structure of systems (the relations between elements) produces divergent outcomes; hierarchical and non-hierarchical relations have different dynamics, and can produce remarkably different outcomes. I will explore these literatures in more detail in section 3, but it is useful to keep these parallels in mind when thinking about how Chinese decentralised governance has been explained.

Federalism, Chinese style: (Montinola, Qian, and Weingast 1995) followed by (Cao, Qian, and Weingast 1999; Jin, Qian, and Weingast 2005) have claimed that fiscal decentralisation has led to 'federalism, Chinese style'; not only has decentralisation created economic freedoms for the provinces, it has created a situation where there are 'credible limits' on central government power. (Montinola, Qian, and Weingast 1995) argue that from the perspective of Western-style federalism, local government independence is based upon a great degree of democratisation. However, in the Chinese model, 'democracy' takes place within the Party-state system, not among the populace at large. Instead, by giving greater political power to the provinces over central government, the Chinese have produced a 'market-preserving' federalism. This style of federalism promotes competition among subnational political units by: instituting a hierarchy of government units whereby each unit is autonomous within its own sphere of authority; subnational governments have authority over their regional economy; national government has the power to promote fair competition across subnational governments; governments face hard budget constraints through limited borrowing; this political structure is relatively durable and free from interference (Ibid., 1995). This results in local experimentation, where successful systems are copied by others, and unsuccessful ones are abandoned; such processes can quickly lead to a positive feedback loop where successful local governments can quickly overtake their neighbours in economic, and even (in the case of Guangdong for example) political power. Such effects make initially economic processes quickly turn into political ones; this results in much higher levels of political autonomy: "In the past, central authorities retained a variety of incentives to control the behavior of lower officials: fiscal control of local government operations allowed them to manipulate local decision making, and individuals were promoted for appropriate behavior and punished for behavior deemed inappropriate. Each of these incentives has been weakened under the current arrangement" (Ibid., 1995).

Decentralised Authoritarianism: Landry (Landry 2008b) claims that China is one of the most decentralised states in the world, and yet, contrary to other examples of highly decentralised states, also one of the most authoritarian. This problem led him to emphasise a highly centralised core, together with a decentralised periphery. The centralised core manages to keep control of the periphery largely through cadre appointments. Landry's research indicates, contrary to some scholars (Edin 2003; Whiting, Naughton, and Yang 2004) very limited performance-related promotions. It seems that in fact central Party guidance on age limits for officials were more correlated with promotions. (Landry 2003; Bo 2019; Byrne 2002; Shih, Adolph, and Liu 2012b) emphasise the extent to which the Party has kept control of local leadership. For example, (Landry 2003; 2008a) argued that Central Party control is based to a large extent on the effectiveness of the nomenklatura system; by controlling the posting of important cadres, the Central Party is able to effect control of the whole Party-state. (Tsang and Kolk 2010) noted that governance reform, together with an insistence on Party control, were defining characteristics of Chinese governance. However, scholars have noted that it is not only decentralisation that has been important in China's economic growth, but a special combination of decentralised governance with strong central control (Wu 2013; Landry 2008a). Landry posits the Party organisation, especially the cadre appointment mechanism as being extremely important in the centre's control of the periphery. In short, the central leadership is effective in controlling the periphery where it deems close control important (Lieberthal 1997). When the central government has a policy that is of great importance, they can quickly mobilise the Party and government at all levels to ensure it becomes a priority. However, these priority or crisis governance tactics cannot work long-term, since they bypass the normal running of government. One may think of it like a spotlight; wherever the central government shines the light, it has complete control, but it cannot direct it everywhere at once. The country is too large and too heterogenous to be controlled easily from the centre. So instead, they must pick and choose where to wield control, and only do so where it is necessary and effective: "When top leaders turn their attention to the issue and publicize their concern about it, local officials tread more carefully. When the attention of those at the top shifts elsewhere, compliance levels may quickly fall off" (Lieberthal 1997).

Rule of Mandates: (Edin 2003) notes the limited governance capacity of the Chinese state. Although the state is able to fulfil some key objectives, it cannot complete all of its targets. It must therefore choose what to implement, and what not to implement. (Birney 2014) takes this idea a little further. She defines the Chinese political system as neither 'rule of law', or ‘rule of man’ but ‘rule of mandates’. In other words, local officials must follow the ‘mandate’ of the Party, rather than implementing all legislation, or following the whims of leaders. Thus the role of the Party committee vis a vis governance is to translate the vast number of laws, demands, competing interests and points of cooperation into a much more practical to-do list; it is an acknowledgement that the government simply does not have the capacity to enact all the legislation that exists. It therefore must pick and choose what to do, and the Party committee tries to make clear what central Party priorities actually are.

> “Instead of directing officials to implement the regime’s laws and policies unconditionally, the party directs them to implement a subset of “mandates” according to their relative prioritization. As I invoke the term here, mandates do not simply represent an alternate set of laws parallel to the public body of laws. In contrast to a body of laws, mandates are directives that are hierarchically ranked against each other. Lower officials are expected to give more weight to the higher priority mandates, and they are authorized to adjust the implementation of laws and lower priority mandates to aim at the desired ends. In this system, the implementation of laws is thus conditional on their compatibility with higher priority mandates.”
>
> — (Birney 2014, p. 55)

Birney classifies *targets* and *incentives* as ‘mandates’, which are designed to modify Party and government officials’ responses to legislation and policy. It is therefore in opposition to the rule of law, whereby government officials are expected to follow all laws exactly as they have been formulated. Under this model, the Party committee acts as a heuristic device: it takes the vast amount of laws and directives, and pares those down to a small number which the government has the ability to actually enact. The mandate system is therefore a highly effective system that maximises both Party power, and rule of law. “Not only do bureaucrats implement policies and laws; they also formulate them by tailoring central mandates for local implementation and by experimenting with local initiatives” (Ang 2018, p. 41). This policy freedom can, and does, create large divides in how central policy is implemented in each region. As an example, the 3rd plenum of the 18th Central Committee set out a new policy for conversion of State Owned Enterprises to being ‘mixed’ ownership (consisting of State, public and non-public ownership stakes). Although the direction of this policy is set by the centre, it is the provincial-level actors who have to decide how to implement the policy. There can be huge variation in how this is done; in effect the different specific policies in each region can be treated as experiments. Those that produce results can then be copies by other regions. In the early years of Reform and Opening up, Fujian province came up with the idea of collectively owned enterprises, which were highly successful and copied throughout China. “In the 1980s and 1990s, officials were evaluated like CEOs, on their economic performance alone. But today, in addition to economic growth, leaders must also maintain social harmony, protect the environment, supply public services, enforce party discipline, and even promote happiness. These changes have paralyzed local leaders. Whereas officials used to be empowered to do whatever it took to achieve rapid growth, they are now constrained by multiple constituents and competing demands, not unlike democratically elected politicians” (Ang 2018, p. 44). Deng Xiaoping was well aware of the difficulties in governing a vast country like China from the centre, and “Once a political line has been set, it has to be concretely implemented by people, and the results will vary depending on who does the implementing” (Deng 1984, p. 197).

2.2 China’s environment: structural problems in governance

Having reviewed the wider literature on Chinese state governance, this section will focus upon environmental governance, and especially how decentralised governance may negatively affect the execution of environmental laws. Environmental concerns were peripheral, at best, to Mao’s industrialising project (Wong 2005). The Mao years in China were largely focussed on increasing production, both in agriculture and industry: the principal attitude was one of ‘man’s dominance over nature’ (Wong 2005; Shapiro 2001, p. 3). While 1972 saw the establishment of a ‘Small leading group on the Environment’, it was not until 1984 that China established an environmental protection bureau (Wong 2005). Since that time, the political importance of the environment has hugely increased, and been given ever greater policy prominence. Despite increasing institutional power, environmental governance in practice remains relatively weakly implemented. This section will review the environmental laws which the various state organs attempt to uphold (2.1), the institutional structure of China’s environmental governance (2.2), and the apparent problems local Chinese officials have in implementing these laws (2.3). Internal and external factors may influence the execution of those laws: government ‘mandate’ (Birney 2014) as influenced by cadre evaluation measures (2.3.1), and the external influence of public opinion as embodied by environmental non-governmental organisations (2.3.2).

2.2.1 Environmental Law and Environmental Policy

In common with other policy areas, Chinese environmental policy as created by the top leaders in Beijing does not for the most part concern itself with particular targets that must be adhered to throughout the country. Rather, central policy creates a ‘direction’ which consists of general guidelines about how policy should be implemented. In this sense, Chinese governance is extremely decentralised, as each province should interpret the overall policy in a way that both stays true to the spirit of the policy, but also takes into account the particular conditions of that area. The environmental law of China is based upon the State Constitution:

> “The state shall protect and improve living environments and the ecological environment, and prevent and control pollution and other public hazards.”
>
> — (“Constitution of the People's Republic of China” 2019, article 26)

This general principle is further strengthened by the Environmental Law:

> “The state protects the environment and natural resources, and prevents pollution and other public hazards. In regards to pollution levels, clause 6 of the Environmental Law states that: ‘When carrying out new construction, reconstruction and expansion projects, it is necessary to submit a report on the environmental impact, which can only be designed after review and approval by the environmental protection department and other relevant departments’, and that ‘any harmful polluting agent must adhere to national targets’.”
>
> — (Ministry of Ecology and Environment, People's Republic of China 2012, 2019)

Given this framework of national environmental laws, backed up by a clear environmental clause in the State constitution, it seems clear that environmental problems are taken seriously. However, as with other areas of governance, execution of environmental laws becomes complicated by the decentralised and fragmented power structures of the Chinese state.

2.2.2 Environmental Governance

As with other policy areas, decentralisation is a major focus of environmental governance scholarship. Considering the environmental policy area as a system, there are various bodies that are important in deciding policy direction at the top of hierarchies, and thereafter refining and instituting specific policy mechanisms lower down, and lastly implementing those policies at the lowest level. Chinese governance displays characteristics of both "top-down, centralized, authoritarian" (Shapiro 2012, p. 57) policies (Zhou and Tsai 2024; Zhu, Qiu, and Liu 2025; Zhang and Zhao 2025), as well as decentralised, market-led forms such as environmental NGO's and relative freedom for media to report environmental problems (Economy 2004, ch. 5). These two forces of centralised control and grass-roots activism can be in conflict, but ultimately it is the lack of state capacity (Economy 2004, p. 132) in the post-Mao era, together with the need for environmental reform which has forced the leadership to accept outside help to fill this gap. (Beach 2001) notes that "Provincial and local-level political institutions have been given greater authority but often are weak, financially strapped, or inadequately equipped to carry out their new policy responsibilities", although provincial governments have 'considerable power' to set local policies and implementation strategies. (Jahiel 1998) differentiates between 'formal authority', i.e. the administrative rank of an organisation, and 'financial authority', which can include financial independence from other bodies, but also the ability to recruit staff, build infrastructure and purchase equipment to better fulfil their policy brief. As in most bureaucratic systems, highly valued departments are powerful, and command huge resources, whereas less important policy areas command little resources or respect. (Jahiel 1998) notes that the story of environmental protection in China is one of ever increasing importance and institutional power being given to environmental bodies.

Timeline of 'Formal authority' in environmental governance

As can be seen from this administrative picture, the Environment policy area has increased its bureaucratic independence, and is now (as of 2018) classed as a full Ministry under the State Council, on a par with the Finance Ministry, or Ministry of Education, for example. Xi Jinping leading the small working group on the environment, as well as his recent speeches emphasising the role and importance of the environment[10] are all indicators that the environment is taken much more seriously now than has been the case at any time in the People's Republic of China's history.

'Financial authority' of the environmental bureaucracy

In 2011, 2.4% of National expenditure was spent on Environment, whereas in 2017 it was 2.7% of the total budget expenditure. It appears as though the Environment as a department of bureaucracy is not significantly more important than it was at the start of Xi's term in office. According to China's official 2017 budget, of the twelve expenditure areas listed, the Environmental Protection Agency was listed as the 9th largest expenditure (561,700,000,000 Yuan, including both central and local government spending), with only Culture, Sport and Media, and Foreign Affairs having less government expenditure. This appears to indicate that although the formal authority of the environmental organs have been greatly increased during the last decade, its financial resources remain relatively weak compared to other organs. It therefore may attempt to use its increased political clout to convince provincial and lower level government to enforce environmental laws, but it hardly has the independent financial capacity to ensure that the staff and equipment it needs to carry out proper monitoring of factory pollution, for example.

2.2.2.1 The Ministry of Environmental Protection (MEP)

As noted above, central government departments such as the MEP (2008-2018) do not control the mechanisms by which individual local governments execute policy. Their responsibility is to provide a policy framework within which local government must create tailored mechanisms which suit the local conditions. Jordan (Jordan 2010) notes that "The task of local governments is to adhere dutifully to the directions of the state-level agencies and to ensure that coordination of state-directed programs runs smoothly and efficiently". As such, execution of environmental policy is largely in the hands of local government, not the central government Ministry. From 2008 to 2018, the Ministry for Environmental Protection was the main government organ responsible for ensuring that organisations, from private shops and

[10] Xi Jinping's 'environmental thought', 'environmental civilisation' and the National congress on the environment show the high-profile nature of the environment for Xi Jinping's government; 'Xi Jinping thought on Ecological Civilization and the Spirit of the National Conference on Ecological Environmental Protection', (2018 中国生态环境状况公报, 1); '提升生态文明，建设美丽中国')

factories to state-owned enterprises and government-run departments do not pollute the environment during the course of their activities, and that when new facilities are built, these must adhere to environmental policies. I will concentrate upon this organisation, and the period of time (2008-2018) when the MEP was active for a number of reasons which will be explored further in chapter 3[11]. While the MEP sits atop the environmental system, and is a full member of the State Council, with the ability to vote at meetings (Xu, Xu, and Xu 2018a) in order to influence local government it must coordinate with provincial, municipal and other local governments; governments which largely fund the local MEP bureaus (Xu, Xu, and Xu 2018a). (Jordan 2010) notes that "while the MEP is a strong coordinating body with top-down policy-making and managerial power, it is but the apex of an entire governmental ecosystem of bodies interacting to make biodiversity management effective. In other words, the MEP is a network node not constitutive of the full network itself". She introduces the term 'network public management' to describe the network effect of many government and non-governmental bodies working together. She is essentially describing environmental governance in the Chinese context as that of a complex network, although she appears unaware of the extensive literature on complex networks. I will describe complex systems and complex network theories briefly in section 3 of this chapter, and in more detail in chapter three. Developing this theme of a network of actors with different and overlapping competencies, Jordan (Jordan 2010) claims that "The MEP coordinates the relationship between the multiple committees under its jurisdiction through the delegation of policy-making and policy coordination power from the SPC (State Planning Council). Though the exact relationship between the SPC and the MEP is unknown, the importance of their role for the coordination of the remainder of the organizations subordinate to the MEP is clear". In other words, MEP power is not that of vertical control over government organs, but 'bargaining' (Lieberthal and Lampton 1992, p. 9) amongst organs of varying powers in a complex network of relations. Environmental officials often perceive themselves as having little real authority, even as their workloads continue to grow, leading to widespread dissatisfaction (Wen, Tang, and Lo 2020). Failure of the state to implement environmental laws properly can therefore be seen as a consequence of the complex network of interactions among government organs, rather than upon one simple cause.

[11]Briefly, covering the period of a single environmental organ reduces structural differences between e.g. SEPA, MEP and MEE; the newly instituted MEE is too young to have produced much data or scholarship, and the older SEPA likewise provides less data; also officials from the now-defunct MEP may be more willing to discuss poor governance issues without official censure

2.3 Implementation gap

(Chan et al. 1995) noted an 'implementation gap' between policies and practice in environmental protection and pollution control. (Economy 2018, p. 162) claims that "while Beijing can pass laws, the ability to enforce them remains an ongoing challenge". (Lieberthal 1997) says that "much of the environmental energy generated at the national level dissipates as it diffuses through the multilayered state structure, producing outcomes that have little concrete effect". While (Qi and Zhang 2014) claim that "Weak local environmental enforcement has been (sic) become a large obstacle to environmental protection in China". (Jahiel 1998) notes the negative effect of weak bureaucratic structures which badly affect implementation of existing laws. This 'weakness' could be of two types: *individually weak* environmental protection organs are unable to assert themselves over stronger, more prestigious, and better funded rivals. Individual weakness has improved greatly over the last decades, as shown by the increasing bureaucratic importance of SEPA, EPA and MEE (Xu, Xu, and Xu 2018b). Alternatively, cooperation between government bodies is extremely difficult because of *structural weaknesses in cooperation* between bodies, perhaps due to information silos or a desire to 'win' resources and prestige over rival bodies. Due to these factors, "the central government's ability to co-ordinate policy across regions may be seriously limited" (Jahiel 1998). The overlapping nature of environmental protection (involving issue-areas like economic planning, development goals, local government funding, etc) means that environmental protection work is unavoidably complex, and both these weaknesses may well be present. Frequent turnover of local officials may also play a role (Yang, Zhang, and Li 2025), since long-term projects are unlikely to be pursued if the benefits will accrue only to one's successors. For (Lieberthal 1997) structural weaknesses are of two types: distribution of authority (similar to Jahiel's individually weak bodies), and the structure of incentives, (similar to Birney's 'rule of mandates'):

> "Variation in the local implementation of laws is thus an inherent outcome of the rule of mandates, even in the absence of corruption. To meet the mandates, cadres are supposed to adjust the implementation of lower priority laws and policies to better meet higher priority targets."
>
> — (Birney 2014)

(Stern 2010) analysis of judges' decisions in environmental cases may be a microcosm of the larger issue. Although the courts' decision can in theory be made politically, by the court adjudication committee or by the political-legal committee of the local CCP committee. However, it is acknowledged that these bodies only adjudicate in the most important cases. Even if they wanted to exert control over judges' decisions, it would be a practical impossibility; only a tiny percentage of the most politically sensitive cases are thus worthy of political supervision (Stern 2010). However, just because judges' decisions are rarely over-ruled by political bodies, it does not mean that their judgements are non-political. Stern notes that "When law is officially subordinated to the state, party values permeate courts and judges naturally think like apparatchiks. Directions are usually unnecessary when the vast majority of judges are CCP members and all judges are well-steeped in party priorities" (Stern 2010). One can relate this principle to local government environmental controls; it is not necessary that, for example, inspection of factories produce environmental reports that are then overruled by local governments keen to see more economic development in the area. It is sufficient that the needs of the local government are widely known to environmental officers in order to influence the reports they produce.

> "Despite the new vigor demonstrated by the leadership (since 2013) to address the country's air pollution, however, the approach is overwhelmingly government centered and top-down in orientation. Input from the Chinese people and businesses remains highly constrained, depriving the government of important feedback and contributing to significant failures in policy implementation."
>
> — (Economy 2018, p. 163)

It is not clear that top-down governance is necessarily a problem in itself, though. Rather, I think what is meant is that implementation of China's environmental laws would improve given some higher level of incentive-based policy, rather than relying on fines and forced closures.

2.3.0.1 Internal factors: Cadre Evaluation

Following (Landry 2008b; Birney 2014), an important factor in implementing MEP policy might be the emphasis that central leaders put upon these policies. Where policies are not explicitly encouraged through promotion of cadres, they are much more likely to be de-emphasised by local governments in favour of those policies (such as economic growth) which are rewarded. The target responsibility system (目标责任制) is in essence an extra-legal governance structure directly under the control of the Party, not the government bureaucracy. Individual officials are evaluated with the Departmental leaders evaluation (领导干部考评), which is implemented by the Party's Organisation Department at each level of administration, not by the local government, and certainly not by the EPA. The cadre environmental evaluation system is a policy procedure that relies upon the power of incentive, rather than top-down bureaucratic control. Like economic incentives in a market-place, it aims to achieve greater environmental care by cadres through indirect means. Individuals and group leadership is evaluated according to anonymously submitted evaluation cards from the entire staff of government and Party, and this meeting is also attended by Party members from higher echelon levels. The veto system (一票否决) in place means that missing one hard target is sufficient (in theory) to disbar an official from possible promotion (Zhang 2017a). (Wang 2012) notes the importance of the 11th five-year plan (2006-2011) under Hu Jintao as marking a change in the importance of environmental policy in China. Specifically, he notes the key policy of linking environmental targets with Cadre evaluation, although the effect of this policy is contended (Liu, Li, and Chu 2021). These 'hard target' environmental standards are linked explicitly to promotion within China's vast bureaucracy, and therefore act as a 'mandate' to protect the environment alongside other state priorities. The environmental cadre evaluation system is overseen not by the MEP, but rather feeds into the much larger and centrally administered cadre evaluation system. The apparent success of this innovation (Xu, Xu, and Xu 2018b) obscures a larger problem though. As Wang notes, Chinese environmental laws and the EPA itself were widely seen as powerless and ineffectual. Environmental evaluation of cadres' records by-passes the EPA rather than increasing its power. This policy decision highlights the impotence of the environmental governance framework. If the EPA were effective, new environmental laws and standards would be implemented through the only specialised government organ that is competent to deal with the environment. That this policy chooses to bypass the EPA entirely is telling; the Chinese environmental governance structure is so unreliable that in order to achieve results, Hu Jintao must bypass it. (Heberer and Trappel 2013, I) that the cadre evaluation system is an "expression of institutional distrust of the political centre in the lower echelons". They note that one reason for use of the cadre evaluation system is that central leaders recognise the difficulties of local leaders to perform well in a landscape of shifting targets, many perhaps beyond their practical ability to reach:

2.3.0.2 External factors: Non-governmental actors

Outside of the governance structure of the MEP, and of local government and Party, the larger society as a whole is of course greatly affected by environmental problems. Although governance issues in the bureaucratic structure are often cited as reasons for the 'implementation gap', the role of the public, in the form of citizen networks and the media in reporting pollution, as well as environmental non-governmental organisations (NGO's) have become an increasing factor in improving environmental governance in recent years (Economy 2018). Starting from the 1990's, the Chinese government has allowed, and tacitly encouraged environmental NGO's. (Wong 2005) notes that these organisations are NGO's 'with Chinese characteristics': they require government approval to form, some have close ties to the government itself, and they do not protest against government activities or policies, rather they function to raise awareness of environmental issues. In fact, their presence may be welcomed by central government, since they are able to monitor local pollution and other environmental concerns out-with the structure of the bureaucracy, while still staying within the bounds of the 'safe' topics that are open to them (Wong 2005). Given the implementation gap mentioned above, and with a similar logic to environmental targets for cadre evaluation, it is possible that central government are using these NGO's in order to put independent pressure on local government and EPA bureaus to improve environmental governance practices. This, again, is an indication that central government has some difficulty controlling the behaviour of organs within the state bureaucracy.

2.4 Politics as a complex system

Considering that many scholars have cited structural difficulties of Chinese governance as one of the main contributing factors to the implementation gap, it makes sense to try to look at this problem structurally, using topographical tools which allow one to see relationships between bodies, and to model how they interact. The Chinese historian (Bai 2001, vol. 2p. 2) claims that problems of governance are actually problems of the 'form' or 'structure' of the state. If this is so, then a realistic appraisal of the structure and form of those bodies will answer a great part of the problems and contradictions that actual governance throws up. This view emphasises the 'structure' of large systems over the decisions of individuals within the system, or the culture of those that live within and create those systems. Below I review some general concepts in cybernetics, systems theory and complex systems; these take the 'structure' of a system to be vitally important to understanding the system as a whole. To trace the intellectual predecessors of complex systems in a thorough way would be outside the scope of this literature review. I will briefly review cybernetics and complex systems here, while explaining technical concepts in complex systems in chapter three. Norbert Wiener's classic work 'Cybernetics, or Control and Communication in the Animal and the Machine' (Wiener 1961), drawing heavily from Shannon's 'information theory' (Shannon 1948), outlined a theory of communication and feedback that gave birth to cybernetics, systems theory and complex systems (Heylighen and Joslyn 2003; Seising 2010). The core of this work explored the mathematical basis for communication: sending and receiving messages. Machines and computational devices operate on the basis of communication; from simple electronic circuits to large computer programs, 'messages' in the form of electrical impulses or computer code is basic to how these systems create 'difference', and therefore instructions of some kind. So, too, in animals; the biologist von Bertalanffy thought of the nervous system as a communication device (Seising 2010); all systems, whether alive or not, receive 'information' and produce certain outputs, whether or not they are conscious of doing so. Large-scale social systems, such as modern states, can therefore be seen in cybernetics terms as a communication system. This thought led to major social science theories including Talcott Parsons' 'social action theory' (Parsons and Shils 2017), the 'Systems theory' of Niklas Luhmann (Luhmann 1982) and Karl Deutsch's 'political cybernetics' (1986). Steinbruner's *Cybernetic theory of decision* (Byrne 2002) attempts to use concepts of governance from cybernetics to overturn rational decision theory. The political scientist Karl Deutsch's 'Nerves of government' (Lang, n.d.) sees human groups as forming a single system, in which communication is the basic unit of measurement; his formulation of the nation as a "large, general-purpose communication net" (Deutsch 1979) typifies the cybernetics approach to modelling large-scale human groups. The state's "systemic survival is based on communication and learning—meaning that the system has to adapt to changes in its environment and to respond (either directly or indirectly) to articulated demands and expectations" (Noesselt 2017). Outside of politics, businesses have had a longstanding interest in increasing organisational efficiency. 'Planning theory' posits the size of organisations as crucial in understanding why decentralisation occurs: it more efficiently deals with complexity (Cremer 1980) compared with strict hierarchical structures. (Chandler 1992; Williamson 2001) studied the changing structure of large US companies, from centrally organised- 'functional', to more decentralised, 'multidivisional' structures. They claim that larger organisations, with greater planning complexities are more efficient when they utilise a decentralised structure, albeit one with a highly centralised core. 'Contingency theory' posits that organisational efficiency is not a function of closeness to some fixed, ideal state, but rather that the most efficient organisational structure is a function of the environment it finds itself within, its size, and its organisational aims (Donaldson 2001). As these elements change, the organisation must change also, in an attempt to find the most efficient form. These ideas have been developed further into management cybernetics (Beer 2002; Malik 2016). While critics see cybernetics as mechanistic and reductionist (Geyer and Zouwen 1994), Niklas Luhmann attempted to go beyond normal sociological concepts that separate the individual and the society, or structure and process. (Nassehi 2005) paraphrased this "A system is not a mechanical device that controls everything which happens inside of it. In short: it *is* what happens inside of it". Society is not then something which can be controlled from outside, but rather the huge complexities of individual and group dynamics reacting against each other creates the whole system. Luhman's thesis is therefore somewhat closer to *complex systems*, where "the operation of no one part can be fully understood without reference to the way in which the whole itself operates" (Easton 1957). To take a complex systems view of political questions is quite simply to view politics as an indivisible whole. To be sure, one can demarcate this or that area according to specific criteria, and these can be called 'parts', but it is a mistake to think that the parts are anything but arbitrarily defined, or that a simple combination of such parts will result in an accurate picture of the whole (Esfeld 1998; Esfeld 2001; 2010). It is therefore the view that *relations between parts* are as vital as the properties of the parts themselves in establishing an ontological whole (Esfeld 1998). The 'structure' of a system is simply a schematic of the relations between its parts. Complex systems has become increasingly popular in social science with the advent of cheap processing power in the 1990′s (Squazzoni 2010). It is therefore a relatively new method, and although growing fast, has not entered widespread use in political science. Having said that, there are a number of introductory works that have served to popularise complex systems in social science, such as (Sawyer 2005; Urry 2005; Byrne 2002; Cilliers 2002). Now one can begin to model complex processes using computer simulation; to grow a complex system from the ground up (Epstein

2012, p. 7). Agent Based Modelling (ABM) and other computational methods have become increasingly popular. If the micro-level interactions of a system are well understood (like the interaction between air molecules, for example), one simply needs to populate a system with the numbers and types of molecules of interest, and 'program' their rules of interaction according to the physical laws. Computational models are explored in more detail in chapter three.

2.5 Summary

In line with existing scholarship (Ross 1988, ch. 1; Economy 2004, ch. 4), I divide environmental governance into two distinct phases: first, environmental legislation and policy, and secondly the execution of those laws/policies. This research will focus on the execution of existing policies and laws in order to analyse the possible reasons for apparently weak implementation. Chinese environmental scholars have long noted an 'implementation gap' (Chan et al. 1995; Kostka and Hobbs 2012; Kostka and Mol 2013; Lo 2014; Ran 2013) although environmental laws are relatively strong, their implementation is severely lacking. This results in a large gap between the apparent intentions of the central leadership and what actually happens in the provinces.

3 Research design

> "it is rather common for rules that have extremely simple descriptions to give rise to data that is highly complex, and that has no regularities that can be recognized by any of our standard methods"
>
> — (Wolfram 2002, p. 632)

3.1 Methodological Approach

In the previous chapter, I offered an overview of Chinese governance, discussing significant structural theories and highlighting academic gaps in understanding. In this chapter, I further analyse the methodological challenges in research, noting that environmental governance exhibits key characteristics which resemble a complex system. As such, I argue that complex systems theories are best placed to effectively and reliably analyse such a system. The claim that Chinese environmental governance is a complex system is not simply a figure of speech, but rather a specific claim about the dynamics of the system. If this system is indeed complex, this ontological fact has epistemological and methodological consequences which must be taken into account. This is because complex systems are characterised by dynamics which are not well captured by standard research techniques, both quantitative and qualitative; thus complex phenomena may be forced into existing categories of simple or random. When faced with complex systems phenomena, standard social science research techniques are unable to provide a systematic framework, and researchers must explain phenomena in an ad hoc fashion. Thus the use of complex systems theories provides both an existing theoretical framework and accompanying research techniques which help to improve explanatory power. In this thesis, complex systems are primarily understood as complex adaptive systems and complex networks. These are phenomena where small, local-level dynamics can lead to unpredictable, large-scale effects. Local interactions can be effectively modelled using graph theory, where a network of nodes and links represents objects and their dynamic relationships. Specifically within a social network context, small world properties are particularly relevant for deciding whether a system is likely to lead to unpredictable outcomes. Complex networks are theorised to give rise to emergent phenomena; characteristic properties of the system are not readily predictable from a reductionist analysis of the individual elements which make up the system. In the context of this research, if the Chinese environmental governance network is complex, environmental governance outcomes such as policy implementation cannot be predicted by a reductionist analysis of government bodies or their laws and policies alone. Only through analysis of the structure and dynamics of Chinese governance can implementation outcomes be explained and minimally predicted. This chapter proceeds by first examining some technical details of complex systems and complex networks. I will point out where these characteristics bear prima facie resemblance to Chinese environmental governance, and address the challenges to this view. I then compare the use of various analytical frameworks with complex systems, and defend the use of computational modelling as an important technique. Lastly, I present several competing hypotheses designed to be reasonable and representative of the academic literature and in theory falsifiable with the collected data.

3.1.1 Defining the complexity framework

The concept of complexity does not have a single agreed definition; research takes place across multiple fields, and has produced multiple novel definitions appearing in mathematics, computer science, and natural science. In ordinary language, complexity is often taken to be related to difficulty; very roughly it is this sense which informs many technical definitions and measures of complexity. The complexity researcher Seth Lloyd compiled a list of some 46 definitions, which he classified into three basic categories: difficulty of description; difficulty of creation; and degree of organisation (Lloyd 2001). Complex adaptive systems, the focus of much of social science interest in complexity, is taken by Lloyd to be a 'related concept' (Lloyd 2001). Ideally, a rigorous definition of complexity should be able to measure the complexity of some object or system, so that any two systems can be compared by their degree of complexity. However, a cross-disciplinary definition of complexity has yet to emerge . In the interests of space, I will not review all the major definitions in each class here, but rather pick out two definitions relevant to this research: complex adaptive systems, and complex networks.

3.1.1.1 Complex adaptive systems

Rather than adopting a strict definition of complexity, complex adaptive systems seeks to define complexity by its observed characteristics. That is, we cannot define it exactly, but we know complexity when we see it. The concept of emergence is of central importance here; complex systems produce emergent phenomena; phenomena which are entirely determined by micro-processes within the system, yet are not reducible to the properties of those micro-processes. There has been considerable debate surrounding the existence of emergence as a genuine ontological phenomenon, due to some versions of emergence apparently contradicting the principle of causal closure in physics, which holds that all physical events are caused solely by other physical events within the system (Mclaughlin 1997; Chalmers 2008). Philosophically, emergence has been generally described in strong and weak forms, corresponding to ontological and epistemological emergence. While strong emergence is often criticised for being overly physically determined (Smart 1981), weak emergence is generally assumed to be consistent with physical theories of reality (Bedau 1997). Hereafter, references to emergence and complexity will refer to weak or epistemological emergence; reference to complexity as an ontological phenomena similarly refers to a weak version of emergence, described in ontological terms. The branch of complexity research called complex adaptive systems, associated with the Santa Fe Institute, and with one of its founders the Nobel Laureate Murray Gell-Mann, is concerned with the observed qualities of real phenomena that have been identified as being complex, and this complexity definition is of course much more of an ongoing project. Just as the concept of 'gravity' is not a definition, but is theorised through observing empirical phenomena, and building models that attempt to recreate these data, so too complex adaptive systems is an empirical project, not purely definitional. There are a number of physical, biological and social phenomena which have been suggested as exhibiting complexity, from weather systems to the dynamical communications between neurons in the human brain (Mitchell 2006). The group behaviour of social organisms as in flocks of birds, schools of fish, and swarming insects have long been noted for their peculiar dynamic qualities: while they are made of hundreds or thousands of individual organisms, when moving as a large group they appear to behave as if they were one creature (Reynolds

1987). The group dynamics of the swarm are distinct from the dynamics of each individual creature within the group. Complex adaptive systems theorists call these phenomena emergent because the macro-level behaviour appears to emerge unpredictably from micro-level behaviour. Within human social systems, group behaviour also leads to emergent phenomena; from unpredictable and dangerous group dynamics in crowds (Moussaïd, Helbing, and Theraulaz 2011), to unpredictable collapses in stock market prices (Sornette and Sornette 2017) and 'social contagion' of political views on social media (González-Bailón et al. 2011). Group dynamics can be seen throughout human social systems, and it is this claim which leads complexity theorists to hypothesise that political systems can also display complex characteristics such as emergence. Emergence can be seen where "the rules specifying interactions among the system's components are executed using only local information, without reference to the whole pattern" (Camazine et al. 2020, ch. 7-8). This makes clear that emergent behaviour, as seen in crowd dynamics, results from many local interactions between single crowd members and their two or three neighbours, instead of a large-scale variable which affects the whole crowd at once. Here, complexity can be defined as a third ontological category; related to both simple and random phenomenon, but distinct from both (Bar-Yam 2010; Watts and Strogatz 1998). While random phenomena like the movement of gases contain perhaps trillions of individual atoms, each moves independently from every other; there appears to be no pattern to their movement, and no way to predict the future position of any one atom, or the shape and position of the gas as a whole. On the other extreme, in simple phenomena like the rolling of a billiard ball, at the micro-level individual atoms which make up the object still move randomly, but at the macro-level everything appears to move at the same time, in the same direction, and the movement of the ball can be reliably predicted. A complex phenomenon is one that contains elements both of simple and random systems: it contains both simple patterns, and apparently random ones mixed together. A classical example of complexity is in fluid dynamics. The movement of water in laminar flow states is simple; water molecules move in linear movements, with no mixing between layers of molecules. However when water velocities reach a certain limit, the simple laminar flow becomes a turbulent flow, where a multitude of eddies and swirls form, apparently random movements that go against the unidirectional main pattern. The prediction of flow in the laminar state is relatively simple, while predicting individual flows in a turbulent state is extremely difficult. While the above definition is useful as a starting point, due to the highly variable dynamics involved, more precise models of complexity as an emergent phenomena are often made in reference to individual examples of complex adaptive systems. While the dynamics of organic cells, political movements and weather systems are all described as complex adaptive systems, the particulars of each system may vary widely. However, an essential characteristic is that of the importance of micro-level variables over those of macro-level variables.

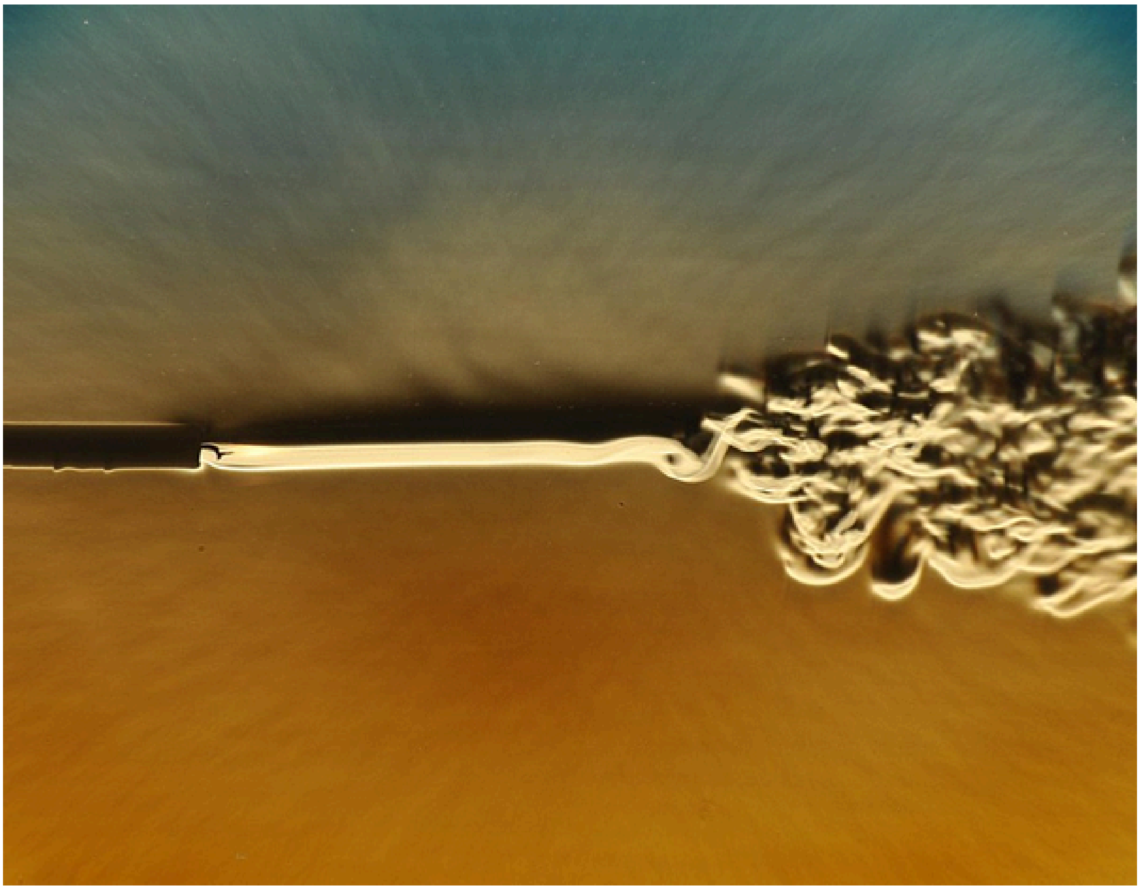

Figure 3.1: Thermal convection plume in laminar and turbulent states (Hargather and Settles 2010)

3.1.1.2 Complexity in politics

There has been an increasing interest in complexity theories as an ontological framework to analyse the social and political sciences. Although complexity science originated in physics and chemistry, the number and variety of complex systems in biology seems to explode. Even more so in social science, where the majority of human systems appear to display complex systems characteristics . The concept of turbulent movement as complex system can be seen here too; James Rosenau (Rosenau 1990; 1997) thought that international politics of the late

1980′s showed signs of a distinct break from the past; a "historical discontinuity" (Rosenau 1990, p. 4) that was caused by 'turbulence'. International relations was not only changing because of the breakdown of the Soviet Union, but was becoming increasingly turbulent; complex and unpredictable. Some of the rise in complexity may be attributed to a reduction in the importance of international borders (Rosenau 1997). As borders become more porous, it became more difficult to control migration; hierarchy decreases and complexity in international politics increases. Much scholarship around complexity in politics has followed his lead, focusing upon international relations (Kavalski 2007). Many naturally occurring complex systems appear to include a degree of randomness ; this concept found a ready audience in international relations scholars. It appears to coincide with the Realist position that international relations is inherently one of formal equality between states, and therefore that lack of central authority leads to unpredictable outcomes (Morgenthau 1970, p. 253; Gaddis 1992; Rathbun 2007). Within many natural examples of complex systems, from swarming insects to the dynamic movements of the stock markets, to interactions of neurons in the brain there is also an assumed equality between elements in the system. There is no central authority directing insects in the swarm, or single stock trader that directs the market, or single brain cell that directs events from the top down. Although international relations is filled with examples of unpredictability, it is the absence of a central authority that makes complex systems an especially appealing framework for its analysis. So too in informal, 'leaderless' political movements, such as the 2011 'Arab Spring', or 2010 'Occupy Wall street', where complex adaptive systems has been used as a framework to analyse the apparently unpredictable dynamics involved (Downey 2014; Davenport 2011; Dornschneider and Edmonds 2021). However, decentralised movements are arguably rare in politics; the vast majority of political systems take place within a formal organisational structure. Democratic, monarchical, authoritarian and theocratic governments all have the organisational structure of a nested hierarchy. Indeed, so strongly is a hierarchical structure associated with governance that degree of hierarchy was used as part of formal typologies of society in 20th century anthropology (Lévi-Strauss 2017; Fried 1967). Similarly, the absence of a formal hierarchical governance structure is strongly associated with a 'failed state' (Zartman 1995). It is therefore less obvious that large, hierarchically structured state governments can also display characteristics of complex adaptive systems. After all, they do not display the same flat network structure as canonically complex systems like swarms. And indeed, complex systems within governance structures and bureaucracies have been relatively under-researched; see

(Robert and Rihani 2010; Geyer and Rihani 2012; Lecy, Mergel, and Schmitz 2013; Cairney 2015) for some notable exceptions. Complex adaptive systems in the natural sciences do not only take place within non-hierarchical structures. Indeed, research indicates that perhaps the majority of naturally occurring complexity takes place within biological systems, where hierarchy occurs not as formal roles of leadership, but as linear dynamics which are central to the workings of cells, protein regulatory networks (Yu and Gerstein 2006; Kauffman 1990), or in ecosystems (Anand et al. 2010; Rai, Anand, and Upadhyay 2007). Without these central 'nodes' of linear, simple dynamics, the larger system of cells, neurons, or ecosystems which possess characteristic complexity of non-linearity, unpredictable dynamics, and emergence could not exist. For many naturally occurring complex systems, linear and non-linear dynamics do not exist in pure form. Indeed, it is the hierarchy in biological systems which themselves give rise to complexity (Corominas-Murtra et al. 2013; Ravasz and Barabási 2003). It is a blend of simple, complex and random dynamics that is characteristic of many naturally occurring complex systems. I argue that similar dynamics exist within formally hierarchical state governance networks. In a formally hierarchical system, non-linear dynamics may exist within a single hierarchical level, while hierarchical and linear dynamics may exist between levels of the network. In Chinese state governance, bureaucratic bodies within a state's governance network are held within a hierarchical structure, but they also have connections with other bodies at the same bureaucratic level. Bureaucratic bodies of equal rank therefore interact essentially outside of any formal hierarchy. (Lieberthal and Oksenberg 1988) claim this is a major driver of unpredictable shifts in Chinese policy-making and implementation at the elite level of decision-making. In environmental governance, the provincial government and Central Ministry of Environmental Protection have the same formal bureaucratic rank. The MEP therefore has no formal authority over the provincial government, even in environmental policymaking. Such conditions of formal equality mean that the MEP must persuade provincial governments to pursue some action, they cannot order them to do so. Even though they are both held within a hierarchical, centrally controlled government network, their relationship has the same essential properties as two states in the international system. Taken together with empirical evidence of unpredictability in implementation, Chinese environmental governance exhibits characteristics of a complex adaptive system. In order to theorise complexity as arising between governance structures that contain elements of both hierarchical and non-hierarchical structure, another concept of complexity is needed; that of complex networks. Below I survey some common types of networks, and analyse their ability to model Chinese governance networks that display the required complex characteristics.

3.1.1.3 Complex networks

Complex network research provides a clear theoretical groundwork to pursue a governance network as being complex, in the sense of leading to complex dynamics such as non-linear dynamics, unpredictable outcomes that 'emerge' from the interactions of the various elements of the system. Stemming ultimately from a branch of mathematics known as graph theory, it uses just a few simple elements to describe a 'graph'; henceforth a 'network'. The network consists of just two basic elements: 'nodes' and 'links'. The nodes are individual elements in a system, with the links being connections between those elements . A social network of four friends for example, may be described as the connections between four nodes in a network. Where each friend has an independent connection to each other friend, in total there are six links; a special type of network known as a complete graph . Most real world networks are not complete graphs, and they do not tend to display complex properties. Another type of network is both naturally occurring and can display complex characteristics: scale-free networks. These networks have the special property that their degree distribution follows a power law . This type of network has central hubs that are hyper connected, whereas most nodes are peripheral to the network. (Albert and Barabási 2002) mapped a large number of connections between web pages on the world wide web; the connections between web pages was shown to follow a power law degree distribution. Similar topographic features are found in airline connections between airports (Amaral et al. 2000), and the collaboration of authors on scientific papers (Barabási et al. 2002). However, examples of scale-free networks seem do not seem to coincide with social networks (Amaral et al. 2000). This may be attributed to aspects of human social psychology. True social networks rely on repeated and ongoing interactions to sustain relationships, and because of our limited capacity to remember and stay in touch, social networks inherently have a restricted size (Dunbar 1992). Where social connections are not adequately maintained, individuals may choose to disengage from former social groups and form new ones. This can be modelled as a high social 'cost' associated with maintaining connections (Arenas, Díaz-Guilera, and Guimerà 2001; Guimerà et al. 2003), which explains why social networks do not exhibit scale-free properties. In contrast to scale-free networks, empirical examples of social networks of all types are relatively sparse; while some nodes are much more connected than others, there are no hyper-connected nodes. A social network may consist of discrete groups, 'clusters' of individuals that are connected only indirectly; a person may have social connections to school friends, work colleagues, family members, sports club members etc. While they are all connected indirectly by a single individual, each individual is not directly connected to every other. Even in a hierarchical organisation, one may be closely connected to other individuals within a work department, but only connected indirectly to colleagues in other departments. Many networks as found naturally are networks of this type: small-world networks. There are several models used to explain the growth of complex networks: the Watts-Strogatz model (Watts and Strogatz 1998) defines a complex network as the middle state of a process whereby lattice networks are transformed into random networks. In this model, while simple, complex and random are qualitatively different in the sense of exhibiting entirely different network characteristics, they are theorised to be related. Quantitatively, the difference between simple, complex and random networks is the degree of randomness with which any two nodes are connected in a network. Simple networks have a very low probability of two non-neighbouring nodes being connected, whereas in random networks this probability is much higher. On this conception, complexity remains in a middle state between simple and random networks.

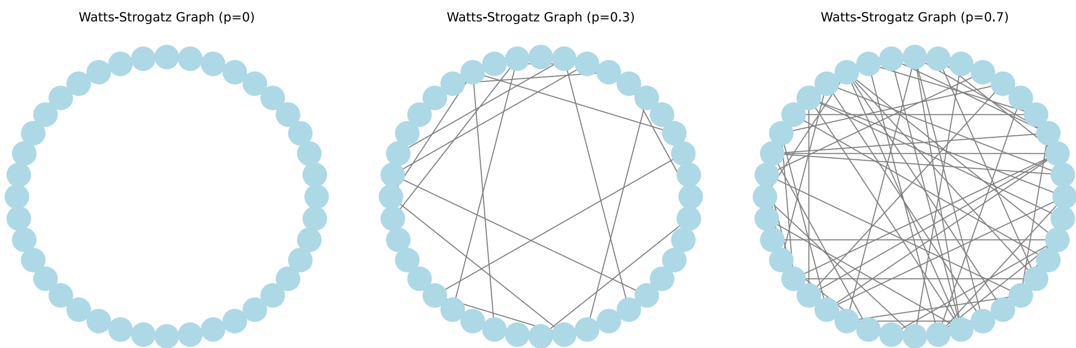

Figure 3.2: Watts–Strogatz graphs with probability (p) of random links increasing from left to right, source: author

In contrast, the Barabasi-Albert model (Albert and Barabási 2002) grows a complex network through a process of preferential attachment to existing nodes with high degree (many connections to other nodes). Thus a new node will have a higher probability of being attached to a 'hub'- a node with many existing connections. This research project has expanded from early attempts to identify complex networks based on network characteristics, to a more theoretical focus on exploring different typologies of complex networks, and ways of representing complex networks mathematically. If one were to randomly select a link between nodes, and re-connect that node with another random node, the regular pattern of the lattice would be broken. However, the 'connectivity' of that network would be increased. If we were to imagine that each node in the network were a city, and the links between them were roads, then the average connectivity of all the cities could be measured by the average number of different roads (links) one must traverse in order to reach any city from any other city. Where every city is directly connected to every other city by a dedicated link, it is maximally connected, and the average length needed to travel the network would be 1. Thus the three classes of phenomenon described by Bar-Yam (Bar-Yam 2010); simple, complex and random, have approximate models in simple, complex and random networks. Just as the connections between nodes in a network produce qualitatively different network features, so the interactions of physical bodies such as water molecules in the example in figure 3.1 produce complex dynamics. Large networks such as email communications in an organisation (Guimerà et al. 2003; 2006) show a similar network topography where each member of the network has much less than one independent link to all other networks. Real world human social networks often display the properties of 'small world networks' (Watts and Strogatz 1998); they display high degrees of 'clustering', and short average paths between nodes in the network. This network type is typical of real-world social networks as described above; discrete clusters of individuals with a high number of links between them are connected to other clusters by just a few individuals. These networks reproduce several properties of complex systems as described above. These networks can be contrasted with 'random networks,' such as the Erdős-Rényi graph (Erdős and Rényi 2022), where the network is created by assigning a fixed probability that any given node will be connected to another. On the other extreme is a 'lattice network'; here nodes are connected according to rules whereby only the immediate neighbours of a node are connected together. They do not contain direct connections to distant nodes, and produce features such as very low or zero 'clustering coefficient' and average high 'path lengths', the average distance between any two nodes, compared to scale-free, random and small-world networks. Like scale-free and random networks, pure lattice networks are not found in social systems. However, hierarchical tree structures reproduce some of the key features present in lattice networks. In a hierarchical organisation, even the 'root' node in the tree which acts as the hub for the whole network has a relatively low average degree, and the average path length is long. The director of a large company is not directly connected to either shop-floor workers or middle managers, but only to the senior management level. Thus communication between the shop-floor and the director is indirect, making the network slow to diffuse information compared to scale free and random networks. The tree topology is closest to the organisational structure described in chapter two: central government can be modelled as the root node, connected to provincial nodes, which in turn are connected to county level nodes, and finally to township government nodes. This highly simplified structure does not take into account the Party structure, or that of the State Council, Ministries and other bodies such as NDRC or People's Congress. Nonetheless, it represents the basic bureaucratic levels of state governance. This network topology resembles that of a 'command and control' structure common in military organisations (Song et al. 2015). The topology of such networks indicate that the number of connections is relatively few, clustering coefficient is very low, and path length is high. Topological analysis of hierarchical structures compared with small world and random networks indicate that theoretically, communication in such a network should be relatively difficult (Guimerà, Arenas, and Díaz-Guilera 2001).

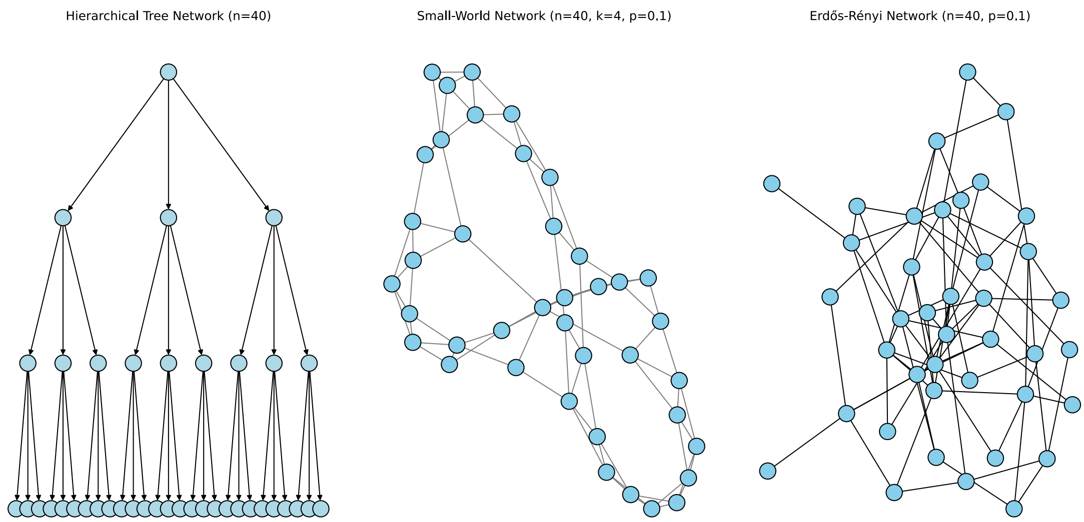

Figure 3.3: Probability of any single node being connected to another increases (from left to right), source: author

In Figure 3.3 above, each network contains the same number of nodes but distinct patterns of connection. Viewed statically these patterns may seem insignificant; however, introducing dynamic movement in networks reveals striking differences in system behaviour. Networks with shorter average paths between nodes have higher communication throughput, and lower latency (Guimerà, Arenas, and Díaz-Guilera 2001). As noted by (Rosenau 1997), this may be likely to create ‘turbulent’ conditions. Small-world network structures are more likely to give rise to unpredictable dynamics, and organisations with this kind of flat structure are highly innovative, but also highly unstable. In contrast, hierarchical structures are more likely to be highly stable and persistent, although less innovative (Staggenborg 1989), and less likely to give rise to unpredictable behaviour. Complex networks allow a mathematical definition of complexity that is hypothesised to produce the varied complex behaviour seen in social systems. Thus complex systems and complex network theory provide a theoretical basis for research of governance networks as complex networks. Complex network research theorises that it is the connections between elements in a system that give rise to complex behaviour, rather than the number and makeup of elements per se (Ravasz and Barabási 2003). However, the Chinese governance network as described in official organisational literature (“中国的政治制度” 2024) seems to more closely resemble a tree network than the small-world network we might expect of complex behaviour arising from social interactions. In Section 3.2.2, I discuss this challenge further, and propose two hypotheses.

3.1.2 Social science methods and complexity

It is important to recognise that complex systems dynamics create limits in what can be known and predicted compared to simple and random systems. It is not possible for researchers to iterate over every possible technique in order to find a suitable research tool; the research problem must be approximated and methodology reduced to a small subset before work can begin. Given the prima facie evidence of unpredictable behaviour in environmental governance, complex systems theory is used as the foundational epistemological framework. This framework allows a more nuanced approach to analysing unpredictable behaviour than simple or random systems. Above I sketched the basic properties of a complex system, and how these relate to complex networks. I noted that complex systems are often characterised by their ability to produce ‘emergent’ phenomena, and that how local governments follow environmental policy is one example. How local governments enforce policy is not a simple system, with linear dynamics, but a complex one. I argue that while no technique has the ability to describe complex phenomena in its entirety, some techniques have natural advantages compared to others. I will briefly note the advantages and disadvantages of two major research methods in social science, statistical and interpretive research, and their applicability to complex systems. I then introduce a third method, Agent Based Models, as the single best tool social scientists currently have, although it should be bolstered by other tools wherever possible.

3.1.2.1 Statistical methods

Statistical techniques are extremely important to most quantitative research in social science. I will argue they are not suitable in complex systems research when used in isolation, however alongside interpretive and computational models, they are a key method used in this research. Statistical techniques may refer to a number of more fundamental mathematical methods in measure theory, however it is in reference to probability theory that statistical models are built (Shao 2003, ch. 1). All modern statistical tests rely upon foundational probability theory as an essential measure for the likelihood that a set of data is random. Given the discussion of complex systems above, there is a fundamental difficulty in distinguishing complexity from random processes (Crutchfield 1994, p. 13). Complex systems (like other non-linear dynamical systems such as chaotic systems) produce patterns of interaction which can be highly variable; at one moment they can seem highly predictable, and the next moment appear random. Since statistical tests are designed to measure the extent to which some data differs from a completely random process, this is a huge problem. Statistical tests of a complex system may easily be indistinguishable from randomness; indeed, randomness appears to be an essentially subjective concept (ibid.). Further, complex systems contain many different variables that interact with each other in ways that are not obvious (Auchincloss and Diez Roux 2008). Statistical tests demand independent variables, often with identical probability distributions. Many complex systems do not meet these criteria. Despite these challenges in analysing complex systems, probabilistic measures are extremely valuable in distinguishing simple systems. The process of searching for an adequate statistical model is useful in postulating variables and mechanisms that are supported by the statistical evidence. For example, analysis of Chinese city governments that implement the environmental law (2008) mandating the publishing of all environmental data in the public sphere notes that city GDP explains around half of the variance (公众环境研究中心 2018); while this single-variable model may not provide a satisfactory explanation for the differing behaviour of city governments, it does provide a starting point for attempts to build a complex systems analysis of that variance. Further, simple descriptive statistics are used throughout this research for basic analysis of quantitative measures of pollution; use of coal, natural gas and renewable energy; measures of winter heating network size; socio-economic measures.

3.1.2.2 Interpretive methods

Interpretive or qualitative methods are those where, minimally, empirical data cannot be counted but must be interpreted in light of culturally specific knowledge or folk psychological concepts. As such, the analysis of such data as government and Party documents and interviews with a winter heating SOE insider must be interpreted. Although criteria for interpretation should be discussed and analysed, it remains subjective. The researcher is therefore given a prominent role in interpreting the meaning of phenomena. I adhere to a weak form of interpretivism, following Dilthey and Weber (Martin 2018), rather than the strong interpretivism found in (Geertz 1973), or in the related perspectives of phenomenology (Schutz 1962), and hermeneutics (Heller, 1989). Qualitative methods may range across a number of different techniques, such as interview, ethnography, document analysis; they assume that meaning or intentionality of human subjects are at the core of social scientific explanations. Although interpretive methods are not specifically designed to deal with complex systems dynamics, they hold some advantages over statistical methods. The complexity of human beings themselves may be a distinct advantage in examining the complexity of the world (Wolfram 2002, ch. 12). Indeed, it is the human ability to keep track of several different elements at the same time, to differentiate between them, and to create a narrative around their relative importance that creates explanations that are psychologically satisfying. While statistical techniques rely upon foundational theories of probability to differentiate patterns from randomness, humans have developed keen pattern-seeking cognition over millions of years of evolution (Geary 2012). Interpretation of planning documents, leaders speeches, laws, Party and State constitutional changes and media coverage with numerical analysis alone will miss much. Any analysis of Chinese governance must therefore include interpretive analysis to some degree, even if only implicit acceptance of other scholars' interpretive work. However, interpretive pattern-seeking may often lead to perceiving patterns where none exist, or to misperceiving those that do exist (Tversky and Kahneman 1974); this may be a particular difficulty in recognising and interpreting complex phenomena (Simon 2012, ch. 3). Humans have a limited cognitive capacity to hold in mind large numbers of distinct objects with different characteristics; where the complexity of the phenomenon exceeds the capacity of the human mind, it leads to massive inaccuracies. For example, although predicting the weather has interested people for millennia, whatever heuristics were developed, have been vastly surpassed by computational models. There is at least reason to doubt the claim that interpretive explanations of human behaviour are more reliable than heuristics (Jones 1998). It is not that interpretive explanations for human behaviour are good, simply that for many real-world problems, computational models of psychology are even worse. Human cognition displays a great many biases; these have been explored in psychology and neuroscience from the latter half of the 20th century, and include biases of confirmation (Nickerson 1998), anchoring (Tversky and Kahneman 1974), availability heuristics (Tversky and Kahneman 1973) and dozens more. The qualitative answer to these problems of reliability include concepts such as reflexivity (Salzman 2002), where researchers deliberately and systematically question their assumptions and biases in order to reduce this problem. However, as Salzman argues (Salzman 2002), reflexivity fails to solve some of the problems outlined above. While reflexive practices may be helpful in curbing some of the more obvious cultural and personal biases, there are limits to its effectiveness.

3.1.3 Computational modelling

I outlined the methodological challenges in analysing and modelling complex systems using common statistical and qualitative techniques above. The most common methods for analysing and predicting complex systems in the natural and social sciences rely on computational models: where accurate equations exist, they often cannot be solved analytically; in cases where no such precise dynamics exist, the models must be constructed from scratch to approximate system behaviour. I summarise two common computational models, partial differential equations and agent based models, and decide on a third approach which aims to utilise the low quality data in as conservative a way as possible. Computer programs are made of data structures and algorithms (Shaffer 1997): the rules-based application of mathematical operators on data, and therefore can in principle be translated into mathematical statements. Physics models used in climate modelling are most often created using partial non-linear differential equations (PDE) which often cannot be solved using analytical methods. Instead, numerical methods divide the problem into discrete blocks, and PDEs for each point on a grid may then be solved iteratively using computers. A computer simulation works by calculating step by step, in a discrete manner. The ‘state’ of the model is changed by each calculation, and the next step of the model is calculated from the conditions of the previous step. In this way there is no need to final an analytic solution to a PDE, and computational difficulty is kept to a minimum. Updating the state of the model after each time step needs to be done carefully, because each updated state changes the computation for neighbouring cells, so the order which updating happens is highly important. This method is not generally suitable for social science research because it relies upon very well evidenced physical laws and models which do not exist in social and political science. There are no known laws of human dynamical behaviour which can be used as the foundational building blocks of such models. Whereas PDE models start with a well evidenced algorithm to update the model state, social science models must try to narrow down this mechanism from an often very large number of theoretical possibilities. Agent Based Models (ABM) are an alternative computational technique designed to use independent ‘agents’ which interact with the environment and each other according to the set of rules developed by the researcher. Depending on the rule-set, ABM can lead to complex dynamics that are similar to those of real-world complex systems. Agent-based simulation has been described as a “third way” of conducting social science, distinct from both verbal argumentation and mathematical modelling (Gilbert and Terna 2000). When attempting to model non-linear phenomena, the logic of reductionistic analysis is reversed; instead of breaking down a phenomenon into its constituent parts, a simulation attempts to ‘grow’ the phenomena (Epstein and Axtell 1996) from the ground up. The aim of each ABM falls along a continuum from highly abstract to realistic models with highly testable outcomes. Abstract models are designed to reproduce the major qualitative or coarse statistical features of a complex system and can be used as an aid to thinking about possible mechanisms (Di Paolo, Noble, and Bullock 2000); these models can be useful in demonstrating that a phenomenon might possibly be complex, instead of simple or random. On the other end of the scale are highly realistic models, whose aim is to act as a simulation of reality, and therefore to make accurate predictions about the outcome of the system under various conditions. Semi-realistic models, such as models of human settlement patterns (Axtell et al. 2002) or simulations of viral infections spreading in urban centres (Barrett, Eubank, and Smith 2005) have been produced which attempt to produce testable predictions. Such simulations were heavily researched and used during the covid19 pandemic (Kerr et al. 2021; Gostoli and Silverman 2022). Although ABM provides the advantages of relative clarity in the model, computable results, and in principle reproducible results, it still cannot adequately deal with the Duhem-Quine thesis of multiple realisability in models. Indeed, while ABM has no greater problems in this regard than any other method, the ease that models can be changed throws this disadvantage into sharp relief (Conte and Paolucci 2014). It is important therefore that models should not only be accurate, in the sense that they faithfully reproduce the phenomena in reasonable detail given the inputs, but that the behaviour of agents in the model be reasonable, given everything currently known about the phenomenon. (Levins 1966) notes that models must balance precision, generality, and realism, and that a model design aiming to maximise one dimension must sacrifice another. To this, (Silverman and Bullock 2004) add the dimension of tractability. Unfortunately, ABM can produce testable outcomes from understandable core mechanisms, but due to the complex nature of the model dynamics, this can come at the expense of being able to analyse the process that led from core algorithm to final output.

The strong claim of some researchers in agent based modelling is that the rule-set (called 'microspecification' below) when used to generate a model outcome with good fit to empirical data, may be sufficient to be considered as the correct mechanism.

> "if the microspecification m does not generate the macrostructure x, then m is not a candidate explanation. If m does generate x, it is a candidate. If there is more than one candidate, further work is required at the micro-level to determine which m is the most tenable explanation empirically."
>
> — (Epstein 1999, p. 43)

Epstein notes that there *may* be more than one candidate explanation. However, this seems overly optimistic. The scenario in which a candidate explanation may be uniquely able to generate the empirically observed data seems extremely rare. It is more likely that any non-trivial complex system may be generated by a large number of different mechanisms. This epistemological issue was strongly stated in the Quine-Duhem thesis (Quine 1976), where a number of problems with empiricism were addressed, including underdetermination. While Epstein's optimism may at least be doubted in general terms, in the case of Chinese environmental governance it is not contentious at all. Knowledge of Chinese governance practices in general, and environmental governance in particular is so imprecise that there may be a very large number of candidate explanations (see chapter two), all of which may suggest possible micro-level mechanisms that could generate the empirically observed data. This is not simply a trivial matter of epistemology, which may be solved by "further work" at the micro-level (Fagiolo, Moneta, and Windrum 2007). In contrast, a great deal of work has concentrated on post-modelling validation via some form of parameter calibration (Xiang et al. 2005; Collins, Koehler, and Lynch 2024), even via live role-playing (Bousquet et al. 1999; Barreteau et al. 2003). 'Evolutionary model discovery' is a notable exception (Gunaratne and Garibay 2020; Gunaratne et al. 2023) that attempts to make the model mechanisms themselves the focus of research, rather than the model output. While rule-discovery is a useful and interesting technique, I believe the number and variety of different mechanisms, together with the scarcity of empirical data in this case warrant a more conservative approach. Abstracting from a complex case study, in which the act of generalising itself may eliminate stochastic and complex elements from the system, together with the problem of multiple realisability, mean that eliminating unsuitable mechanisms is a more reasonable aim than discovering correct ones. This method does not aim to generate outcomes that are precisely correct, but to eliminate incorrect ones, while iterating towards ever more accurate outcomes. The table below summarises the main computational techniques, and adds to this the method pursued in this research: conservatively modelling the complex phenomena as if it was simple, and thereby extracting an approximate *locus of complexity* (where in the network complexity is likely to exist), and *degree of complexity* (how likely it is that a simple model may reasonably predict outcomes). This method I refer to as *Computational Method of Residues*, named after Mill's *Method of Residues*:

> "Subduct from any phenomenon such part as is known by previous inductions to be the effect of certain antecedents, and the residue of the phenomenon is the effect of the remaining antecedents."
>
> — (Mill 2008, 406)

Method	Summary
Need for computational models	Complex systems cannot usually be solved analytically. Computational simulations approximate behaviour where equations are unsolvable or non-existent.
PDE models	Widely used in physical sciences. Rely on established laws and numerical methods. Unsuitable for social science because no equivalent behavioural laws exist.
Agent-Based Models (ABM)	Build macro-dynamics from rules for individual agents. Range from abstract to highly realistic. Useful for exploring possible mechanisms and producing testable outputs. Unsuitable for present research due to challenges with scarce data and *multiple realisability*; could be used in future research
Computational Method of Residues	Inspired by ABM, but applies the principle of exclusion: by modelling only the simple, well-specified elements of the system, the unexplained 'residue' is taken to indicate the locus and degree of complexity. This allows indirect measurement of complex behaviour without presuming the full underlying mechanism.

Table 3.1: Summary of computational modelling approaches and challenges, source: author

3.2 Epistemological framework

This thesis aims to test competing explanations through the use of empirical data from a variety of sources. It is central to the research design throughout this thesis that there is a lack of high quality data available to researchers in Chinese governance. Further, that given this deficiency, any single source of data should not be used as the sole consideration for explaining, constructing or validating models. Since this is central to the research design it is important to briefly explain the theoretical basis for this, and how it affects the epistemological framework for data collection and model validation. While collecting data on governance practices for any state tends to present difficulties, Chinese governance is particularly challenging. The central question of this thesis may be re-stated as "how do government officials make environmental policy decisions?" A theoretically ideal but unrealistic data collection might involve access to internal government and Party documents relating to spending decisions; further, recording the discussions of local Municipal government committee members as they discuss environmental issues and spending allocations. While such a scenario is unrealistic, it is helpful to acknowledge the epistemological distance between the data that actually exists and the data that can be gathered by academics. This helps to allocate a degree of objective analysis to the empirical data. The reliability problem of Chinese governmental data in general has been noted by researchers (Koch-Weser 2013; Eaton and Kostka 2017). When serving as Party secretary of Liaoning, former Premier Li Keqiang is reported to have said that China's economics statistics were "man-made" and "for reference only" (Wikileaks 2007). In many cases there is no way to know the true reliability of documents and statistics unless it is corroborated by independent sources. For many of the sources of data, independent sources of corroboration do not exist. Significant uncertainty in data quality, combined with unsystematic data publication across central, provincial and city governments requires a research design that prioritises data collection and analysis as the central methodological challenge.

3.2.1 Data collection and analysis

To meet this challenge, data collection takes place across every level of government, but prioritises the highest quality data, which comes from two sources: satellite timeseries of pollution data; and case study data consisting of internal SOE company documents and interview with company insider. In many instances, high quality data such as satellite pollution timeseries is able to largely corroborate official Chinese air quality measurements at the national and regional level (see chapter four). Pollution is a local phenomenon however, and satellite data cannot give accurate results for city or district pollution levels. At the most local level, case study data consists of hundreds of internal company records and local government documents relating to the SOE itself and its environmental projects. In some cases these documents have official government stamps and signatures of local government officials, or consist of internal documents relating to project spending or expansion of winter heating services with raw excel spreadsheets. An interview with a company insider was able to corroborate much of this data. Other, lower quality and quantity empirical data gathered consist of dozens of central, provincial and city government documents that are openly available to the public, consisting of laws, policies, plans and other official documents; statistics of various types, consisting of local air quality measurements, winter heating network statistics. Although this data is relatively simple to collect, analysis is particularly difficult. This class of empirical data consists of official documents and statistics that may not be completely reliable, or where missing data seriously affects analysis. Statistics may be available for several years, but not available otherwise; such cases are particularly numerous in city level government. The most first class of official documents are central government, Party and State documents that are clearly written but somewhat ambiguous in intent. They may be described as proclamations: laws, standards relating to laws, and ideology as published in the State and Party constitutions. These documents may not be directly practical. Central Party, State Council or People's Congress officials do not usually face cadre evaluations based on their upholding of a law or ideological goal . Laws and ideology may not always be scrupulously upheld, and therefore their purpose may be partly practical and partly symbolic. An important source of government data on practical policies and projects are 5YP documents. While these are numerous and easily available, planning documents are not a reliable record of work completed, but rather of policies and projects planned. Since a central thesis of the environmental implementation gap is that centrally planned policies are not carried out in reality, planning documents cannot be used as an uncritical source of evidence. Conversely, they represent evidence of government policy, and therefore cannot be dismissed. Navigating these grey areas of document evidence is particularly challenging. Open access to Chinese government documents has improved greatly since the passing of the 'open government' law in 2007 (revised 2019). The open government law requires central and local government bodies to publish many government documents with a public interest, such as: "Administrative regulations, rules and normative documents; National economic and social development plans, special plans, regional plans and related policies; Statistical information on national economic and social development" (State Council of the People's Republic of China 2019, article 9,section 4). A great deal of the official documents analysed originate from publicly available documents of this class; including central, provincial and city government 5YP (National People's Congress of the People's Republic of China 2001; 2006; 2011; 2016a) and other environmental planning documents produced by the NDRC. However, another class of documents included in the open government law is not always published: "Financial budget and final accounts reports". While central and provincial government is more likely to publish spending, these reports often aggregate spending into such wide-ranging groups that environmental and winter heating spending cannot be ascertained. City governments often publish little spending accounts, or block city government websites from being accessed from abroad. Blocking access to some government pages available within China is typical of many government bodies; some pages may be accessed while others cannot. At times these restrictions can be circumnavigated with use of a Virtual Private Network (VPN). At the start of the period of record publishing (2008), the best-performing local governments published only 20% of all supervision records produced in that year, while the worst-performing published hardly any at all. The situation has steadily improved over years (2008-2018), and now the best performing cities publish 75% of all documents, with the worst performing publishing around 40% of all documents (公众环境研究中心 2020).

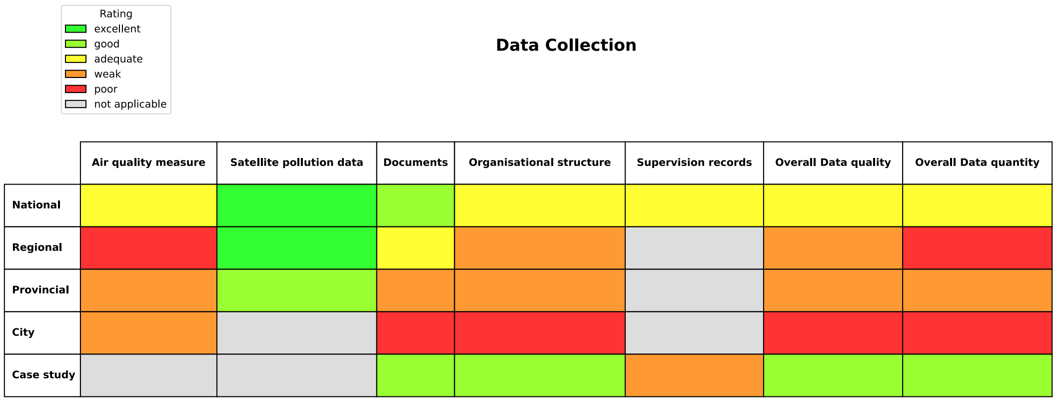

Table 3.2: Major items of empirical data, with data quality rating, source: author

The table above shows the major categories of data collected, each with a quality rating. This shows at a glance that the best data quality and quantity is at the lowest level- the case study, and at the level of regional pollution. National-level documents are not as reliable, and other documents less than that.

3.2.1.1 Hypothesis construction

Given the broad scope of data collection and the varying quality of data, the research is structured around a central practical consideration: explanations must be tested and modelled in such a way that utilises the data available. This requires a relative focus on the good quality data while de-emphasising the ambiguous data. In practice this means that case study data and large-scale pollution data are the foundation of research and model building. Due to limited data collection at the city and provincial government levels, explanations that rely solely or predominantly on this evidence cannot be reliably modelled and tested. Further, data from central government documents, supplemented by evidence from academic literature, is primarily used to provide broader context for modelling. Explanations must be able to account for two distinct phenomena:

'Strong' structural framework In order to explain the design decisions made around hypotheses 1 and 2, I first lay out a naïve framework, which satisfies the major requirements above, and is in line with a 'strong' version of the structural explanation. I define the strong structural explanation as the claim that it is the organisational structure of the governance network alone that gives rise to simple or complex behaviour in environmental implementation. I then summarise the empirical evidence that challenge this view and propose two hypotheses that are able to meet all requirements while going beyond this naive interpretation. The strong framework is a historically complex governance network, satisfying requirement 1. This network undergoes structural changes due to the increased bureaucratic authority granted to the MEP in 2008, thereby fulfilling requirement 2. Following from the Watts-Strogatz graphs, whereby simple networks are adjusted by creating random links between existing nodes, complex networks can be created by adding random links, or simplified back into a tree network by taking away random links. The figure below shows this process in the case of a tree network (a), which transforms through an intermediate stage (B) to a complex network (c).

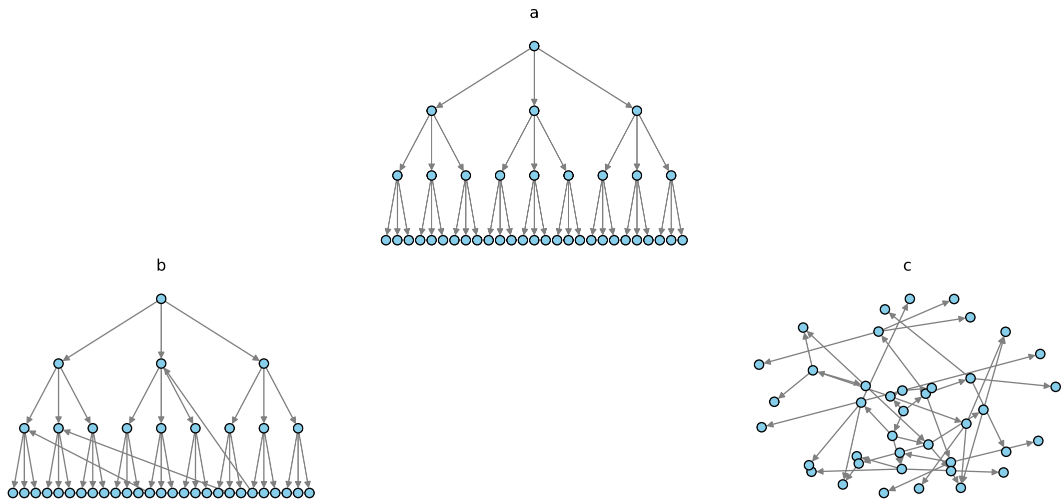

Figure 3.4: 'Strong framework': transformation of tree network to complex network through random linking, source: author

In the figure above, the naive framework represents historically poor environmental implementation as network c). Through a process of increasing hierarchical governance structure, as a consequence of the creation of the Ministry of Environmental Protection and new cadre evaluation laws (2006), this network becomes simplified into network b). Although prima facie the model has reasonable theoretical and empirical evidence supporting it, it relies upon a governance network in which communication links are physically changed. Not only does the MEP and cadre evaluation rules have to change the working practices of officials, the framework assumes that lines of communication actually differ markedly because of these interventions. Given the large changes in structure described by the framework, the change should be quite obvious. There simply is no evidence that this is the case; as far as research described in chapters four, five, and six there is no evidence for such a shift in the communication hierarchy of government.

3.2.2 Hypotheses

In rejecting the naïve framework, two further hypotheses are created. While both use the governance network as a foundational framework, they reject a change in the network structure itself as giving rise to increased environmental implementation. Both hypotheses are created from the same basic topology, a tree network. However the properties of each network differ along one dimension: the independence of each local government from their parent. This is illustrated in the figures below by the angle of the child nodes relative to their parent nodes. In H1, the nodes are spread out, indicating relative independence, while in H2, the nodes are positioned directly beneath their parent nodes, indicating dependence. H1 network topology theorises a tree network with relatively independent peripheral nodes; a city government has a large degree of independence from their provincial government. Meanwhile H2 network is highly hierarchical, the city government is more dependent on their provincial government. While H1 relies upon a bottom-up change in local incentives to increase implementation, H2 relies upon a top-down change in political emphasis.

H1 The first hypothesis, taking into account a large body of scholarly literature, was that local incentives played the major role in increasing environmental governance implementation. Prior to changes in the Cadre evaluation checklist (2006), local government officials were incentivised through cadre evaluation to favour policies and projects that increased GDP, employment and 'social harmony'. After changes to formal cadre evaluation procedures, local officials became more incentivised to strongly pursue environmental targets, and fine polluters. This explanation assumed that although environmental laws and policies may be made at the centre, they were ignored at the periphery. In other words, the implementation gap was a version of the principal-agent problem. While the centre may set laws and national-level policy; within its territory, local government is effectively sovereign. This is captured by the famous Ming dynasty saying: "Heaven is high, and the emperor is far away", indicating the difficulty of the emperor in Beijing from influencing local-level officials in far-away provinces.

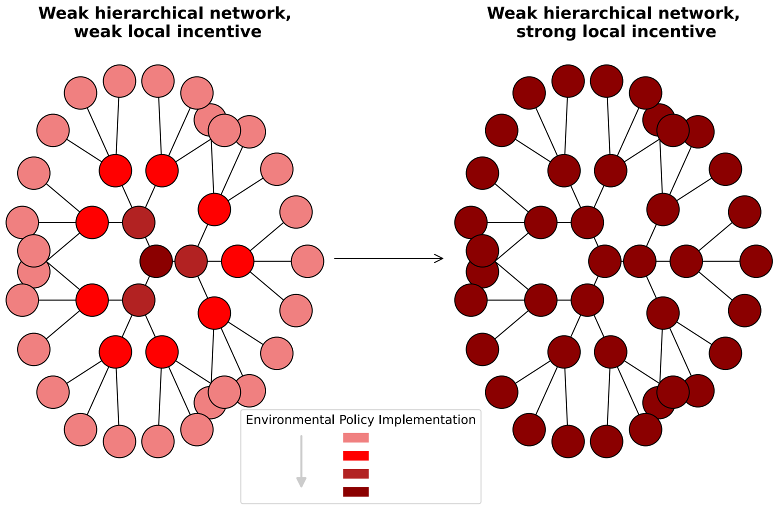

Figure 3.5: H1 showing largely independent local government, with increasing local incentives, source: author

H2 This hypothesis proposes a network topology that is strictly hierarchical. Unlike in H1, where peripheral nodes have more freedom than central nodes, here peripheral nodes are more tightly controlled, resulting in a classic hierarchical structure. To modify this rigidly hierarchical system and allow for variations in environmental implementation, I introduce the parameter 'policy emphasis.' This parameter represents the political support given to a particular policy area. It is assumed to be a complex parameter influenced by decisions at the central government level, but it cannot be directly set. Instead, it emerges from the interactions of laws, policies, five-year plans, party and state ideology, leaders' speeches, and media content. While the central government can influence policy emphasis, it cannot control it with precise accuracy.

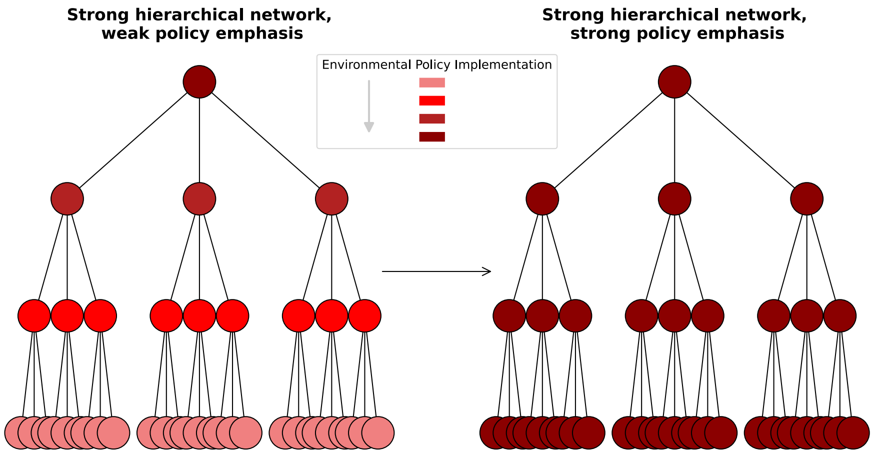

Figure 3.6: H2 showing strongly hierarchical local government, with increasing policy emphasis, source: author

Although the governance mechanism in each model is clearly distinct, major qualitative and quantitative outcomes are similar. This aligns with the 'implementation gap' thesis, where central government appears motivated to drive environmental policy, while each successive level of peripheral government shows decreasing enthusiasm for implementing these policies, illustrated by node colour in the figures. Secondly, the rapid decrease in pollution occurs in both cases because government at all levels aligns with central government law and policy, illustrated with the alignment of node colours.

3.2.2.1 Testing hypotheses, validating models

Given the quality and quantity of data, it is important to produce hypotheses and models that are simple enough to test, and for which test outcomes are relatively unambiguous. Given these challenges, and the focus on complex systems as a major explanatory framework, the data collection phase focused most upon local level data, while provincial and national level data was predominantly used to give wider context. This decision means that hypotheses that rely more heavily on local-level data can be tested more thoroughly, whereas hypotheses relying on national-level data will have some further challenges. H1 hypothesises that local incentives increase pressure on local government and polluting winter heating SOEs to implement pollution abatement, which can be adequately proven by local-level data showing an increase in taxes and fines levied at SOEs. Winter heating companies themselves would improve their practices and invest in efficient, less polluting equipment in order to ensure they remain financially viable. Conversely, H2 hypothesises that winter heating SOEs decrease pollution through top-down policies and projects, funded by local, provincial and central government, not the SOE itself. This scenario would see a lack of taxes and fines, and the local MEP bureau would remain relatively weak. Instead, centrally planned projects would invest capital funds into increasing energy efficiency and pollution mitigation. The hypothesis is structured to use the best quality empirical evidence, local-level data, particularly from the case study, to make a binary, mutually exclusive test. Theoretically, the hypotheses are designed in such a way that empirical data could not show equal evidence for both. In reality, testing social science hypotheses typically relies upon more ambiguous evidence than is ideal. Empirical evidence may support one hypothesis more than the other, but is unable to dismiss the alternative mechanism entirely. Alternatively, the case study may unambiguously support one hypothesis, but cannot be taken as representative of the whole winter heating sector. This ambiguity therefore requires a second phase of testing, where computational models are created based on the surviving hypothesis. These models aim to validate the remaining hypothesis by testing the robustness of the mechanism through building generative computational models. The assumptions of the hypothesis are used to create a core governance mechanism, which is then populated throughout the network, and the results validated against empirical pollution data. One of the chief complaints with ABM, like that of other mathematical models, is that the models produced are not realistic (An, Grimm, and Turner II 2020). They are either overly simplistic because they make assumptions that help in the modelling but do not reflect reality, or they produce models with mechanisms which are 'ad hoc', with little to no empirical basis, other than their ability to produce the results modellers want to see (Conte and Paolucci 2014). These two criticisms are related to a well-known problem in the philosophy of science; the Duhem-Quine thesis. It states that for any model which is found to fit the empirical data available, and therefore to provide a mechanism that explains that data, there are an indefinite number of other models which fit the same data equally well. Although Quine's argument (Quine 1951) is equally applicable to any explanations whatsoever, whether mathematical or qualitative, it is thought to be particularly relevant for computer simulations (Conte and Paolucci 2014). Agent based modellers can change the 'rules' which govern the behaviour of agents extremely easily, perhaps much more so than any other modelling tool. It is therefore important that modellers have strong reasons to choose one set of rules over another, reasons that must be based on the empirical evidence rather than expediency of ‘growing’ the results alone. In this thesis, I employ computational modelling techniques inspired by ABM , while adopting a conservative approach that addresses concerns of ad hoc modelling. Given the emphasis on local-level data collection and the priority of testing and choosing between two hypotheses, the models are intentionally kept simple, focusing on linear dynamics within the system. This approach allows for the isolation of any remaining complex elements. By modelling linear dynamics, the conservative approach effectively isolates and eliminates linear effects, highlighting the complex parts of the system while maintaining robust, reliable models. One advantage of computational models built from a bottom-up mechanism is that the output is not entirely designed into the model; instead, the model output grows from the core governance mechanism. While the computational modelling I use here is not as unpredictable as ABM output, the simplicity of the modelling process is a huge advantage in analysing the model data. The model output is more likely to be smooth and robust compared to a more complex model. This approach provides an environment whereby the model may provide genuinely novel data which can then be compared with validation data; this is data that has been held back from all previous iterations of hypothesis and modelling process. The out of sample data used in this thesis consists of winter heating network data, used to calculate approximate pollution levels for each location in the model.

4 Air pollution: sources and statistics

"向污染宣战[12]"

— (Li 2014)

The governance of urban air quality shows some characteristics of non-linear dynamics; the changes in law and policy do not necessarily lead to changes in pollution governance. In addition to the complexity of *governing* air pollution in China, air pollution itself has an independent physical and chemical existence, quite apart from how people or governments choose to act. This chapter aims to clarify the sources and effects of air pollution in order to address the underlying complexity of air pollution dynamics itself. This underlying complexity has two important consequences for how air pollution data is collected and analysed, and also in how government policy affects air quality:

- Local air pollution measures cannot accurately determine pollution source or volume
- Good air quality is not causally dependent upon strong policy implementation

This complex physical reality lies at the foundation of further research into policy implementation. The practical consequence of this is that cities like Beijing and Tianjin with the most highly developed air pollution regulations may nonetheless have high air pollution with sources elsewhere such as in nearby cities like Tangshan and Shijiazhuang. Conversely, cities that are high sources of pollution may never suffer with poor air quality due to local weather conditions, due to high wind or high precipitation. Although urban air pollution is largely man-made, undoing these effects must take into account the science of how pollutants are emitted and how they interact with atmospheric processes, as well as political questions of economic development, technological change, government incentives, cadre assessment and promotion. Government bodies like the Ministry of Environmental Protection have to deal with an incredibly varied set of circumstances, in which simple, monolithic policy

[12] "Declare War on Pollution"

pronouncements may produce a varied set of local responses. Part of the reason for these complex responses lies in the varied geography of China: policies to cut emissions affect ambient pollution in cities differently. For cities that exist in an unlucky confluence of geographic factors, reducing emissions may have little effect on pollution levels, and may therefore affect how local governments choose to pursue these policies. Further, although fossil fuel combustion is the main source of air pollutants, burning of coal, oil and natural gas produce different compositions of chemicals, so that policies that cut coal use may have great effects in one city, and little in another. This chapter is arranged in two parts: first, I examine the main air pollutants and sources of urban pollution: power plants, industry, winter heating, and road transport. I briefly outline the main issues in each sector, and the changes that have taken place to reduce pollution over 2008-2018. Secondly, I look at pollution data in the north China plain. Pollution data comes from both Chinese ground sensors (MEP data), and NASA satellite sensors. These data are then compared, and the reliability of MEP pollution data analysed. I find that there is an unmistakeable trend of reduction in pollution over this decade, with broad agreement between Chinese and NASA satellite data, although there are significant fluctuations in satellite data that are not seen in the official statistics. While MEP data shows a gradual and continual decline in pollution, satellite data shows air pollution fluctuating, with some increases in pollution detectable. These differences may be explained by a number of different factors, from problems with reliability of MEP data, including deliberate data falsification, to inaccuracies of satellite data. While MEP data shows an almost universal and gradual year on year decrease in pollution, satellite data shows some counter-trends, where pollution has increased before finally falling. Within the satellite data, although different pollution types show different peaks in pollution, both $PM_{2.5}$, NO_2, and SO_2 had peaked by 2013. I will explore the timeline and importance of Chinese policy in the next chapter, but note that the data show the major events leading to pollution reduction as taking place sometimes several years before 2013.

4.1 Defining air quality pollution

This research focuses upon pollution as it pertains to *outdoor air quality*, also known as *ambient air pollution,* not air pollution as a contributor to global warming, which consists of a number of greenhouse gases. There is often an overlap between ambient air pollution and greenhouse gases: sources of both types of pollution are often, although not always, the result of fossil fuel combustion. Although gases and other airborne substances may have complex interactions in the atmosphere, ambient air pollution and greenhouse gas scientific research and public policy have traditionally been researched as distinct areas (Department for Environment, Food and Rural Affairs (DEFRA) 2007). Ambient air pollutants can be loosely defined as substances which cause harm to human, animal, or plant health; they are known as air quality pollutants. In contrast, greenhouse gases may not cause direct harm to any living organisms, but rather cause indirect harm through a gradual warming of the Earth's atmosphere. In general, ambient air pollution is regarded as having effects fairly localised around the site of emission, whereas greenhouse gas pollution has intercontinental or global effects. Indeed, ambient air pollutants such as sulphur dioxide, ammonium, PM_{10}, $PM_{2.5}$[13], and nitrogen oxide may in fact contribute to atmospheric cooling (Department for Environment, Food and Rural Affairs (DEFRA) 2007, p. 15). Conversely, greenhouse gases like carbon dioxide, nitrous oxide, water vapour, and methane may have no effect on human health, with CFC's having deleterious effects on some lifeforms only (Department for Environment, Food and Rural Affairs (DEFRA) 2007, p. 15). However, a reduction in the burning of fossil fuels results both in a lowering of greenhouse gases and of ambient air pollutants; I will discuss the main sources of ambient air pollutants below. Hereafter, unless explicitly stated air pollution refers to ambient air pollutants only. In light of this distinction between air quality and greenhouse gas pollution, there are a number of substances commonly defined as air pollutants. The World Health Organisation (WHO) has produced a number of influential reports on air pollution leading to international guidelines on air pollution. Their 1987 report contained health assessment on the 28 most common pollutants (World Health Organization. Regional Office for Europe 1987) in Europe, while the updated report in 2000 contained health analysis of 37 pollutants (Air Quality and (aqe) 2000), again in Europe. The (Air Quality and (aqe) 2006a) update noted the importance of air pollution worldwide, especially to a number of low and middle-income countries in Asia. Due to funding constraints, the (Air Quality and (aqe) 2006a) guidelines concentrated on the most important air pollutants worldwide:

[13]Airborne particles are commonly identified by their diameter: PM_{10} and $PM_{2.5}$ being particles of less than 10 micrometres (10μm) and 2.5 micrometres (2.5μm) diameter respectively

particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) (Joint WHO/Convention Task Force on the Health Aspects of Air Pollution 2006). The Chinese MEP has largely followed this classification, concentrating its efforts upon these pollutants. This list should not be seen as exhaustive; there is a huge number of more uncommon and localised chemicals which have damaging effects on human health. Chemicals causing air pollution may come from a single specialised industrial process localised within a small area, such as happened in the 1984 Bhopal disaster in India. This event caused 3,800 deaths through a methyl isocyanate leak (Broughton 2005), with thousands more seriously injured. Apart from highly localised industries, the burning of fossil fuels may release trace amounts of elements such as arsenic, cadmium, and selenium (Vouk and Piver 1983, p. 202) which are naturally present within coal, and which can be dangerous to human health. Other trace amounts of chemicals such as benzene are released in internal combustion of petroleum, and relatively high levels of this carcinogen may contribute to cancers in China (Zhang et al. 2015). Ammonia released in rural areas from chemical fertiliser, and from industrial processes and transport is an important component of photochemical haze and $PM_{2.5}$ pollution (Liu et al. 2019), and may be seriously under-estimated in China (X. Zhang et al. 2017). However, ammonia is not commonly measured by ground sensors in China, and so will not be treated in this research. The table below summarises the main health effects and some physical characteristics related to the most common pollutants as identified by the WHO, as well as some other common pollutants as defined by DEFRA (Department for Environment, Food and Rural Affairs (DEFRA) 2020), the UK's main government body dealing with environmental concerns.

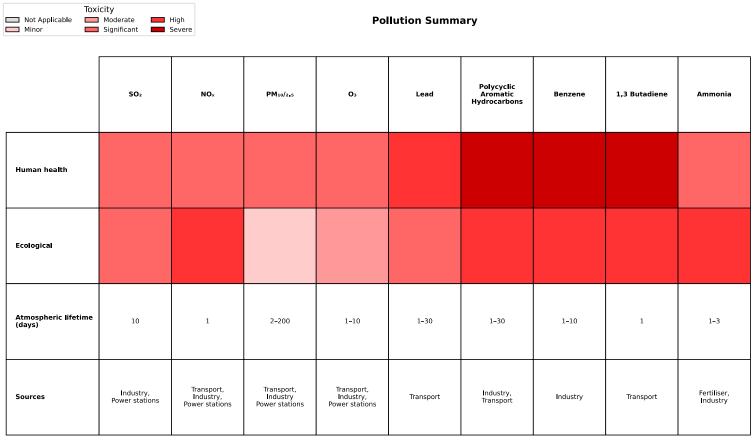

Table 4.1: Properties and sources of various pollutants, source: (Department for Environment, Food and Rural Affairs (DEFRA) 2007; Air Quality and (aqe) 2006a; 2006b; Flagan and Seinfeld 1997; 2012)

4.1.1 Defining the research scope

This research will focus upon only a few of these air quality pollutants: SO_2, NO_x[14]$PM_{2.5}$, PM_{10}, CO, and O_3. The reason for this is purely practical; the MEP has routinely measured these pollutants, and thus claims of reducing air pollution, and how these reductions were achieved, is best measured through these pollutants. Secondly, this research will focus upon urban air pollution only. The vast majority of air pollution monitors in China are within urban areas, and satellite data showing various measures of air pollution indicate that air pollution is overwhelmingly centred around large urban areas[15]. Media reports of air pollution have been focused on cities too, and major environmental policies have focused upon reducing air pollution in major urban centres (see chapter 5). Thirdly, while urban air pollution affects a large number of Chinese cities, geographical differences introduce factors which cause air pollution to concentrate in some cities, and quickly disperse in others. In order to reduce such effects to a minimum, I will concentrate upon one large geographical area with similar conditions and high levels of pollution: the north China plain. A fuller analysis of air quality

[14]NOx refers to two distinct chemicals, NO and NO_2; although they have different effects on health, since NO readily converts to NO_2 in the presence of sunlight, these two closely related chemicals are often co-present in the atmosphere in differing concentrations depending upon local weather conditions. NO_x is thus used as shorthand for NO and NO_2

[15](Zheng et al. 2025) reports the newly instituted China Air Pollution Data Center (CAPDC) as a possible source of high quality air pollution in the future, funding more data collection, and bringing together data under a single research body.

conditions in China and the north China plain are given in the appendix, however it may be summarised thus: i) the north China plain is a contiguous, geographically bounded area, with relatively similar weather conditions, ii) air pollution in various cities of the north China plain is amongst the worst in China, iii) the north China plain contains cities like Beijing and Tianjin, and 400 million inhabitants, making it politically and economically important. Pollution in the north China plain is thus an important test area for Chinese air pollution as a whole.

4.1.2 Varied sources of air pollution

The majority of anthropogenic air pollutants are the products of fossil fuel combustion. These products produce a cocktail of many different gases and particulates in different proportions depending upon the form of fossil fuel being burned, and the circumstances of its combustion. Sources of air pollutants can be categorised into primary and secondary sources (Joint WHO/Convention Task Force on the Health Aspects of Air Pollution 2006). Primary sources refer to pollutants that retain the same form in the atmosphere as when emitted: sulphur dioxide and particulate matter are primary sources. The chemicals involved in this kind of pollution can form 'London smog' type pollution (Gaffney, Marley, and Frederick 2009, p. 26) where large volumes of sulphur dioxide and particulate matter are the principal substances. This type of smog is often associated with widespread combustion of high sulphur coal. Secondary sources of pollution occur when primary pollutants undergo chemical changes in the atmosphere: nitrogen dioxide (NO_2) readily converts to ozone (O_3) in the presence of sunlight, forming 'Los Angeles type smog', also known as photochemical smog (Tiao, Box, and Hamming 1975, p. 261). Ozone is a pollutant that is almost entirely formed through post-emission reactions, and therefore is hardly present in 'emission inventories', documenting chemicals and their volumes emitted from a pollution source (Joint WHO/Convention Task Force on the Health Aspects of Air Pollution 2006, p. 10). Photochemical smog contains a high proportion of ozone, as well as small particles ($PM_{2.5}$) and is often associated with car exhaust pollution. As detailed in the table above, some pollutants quickly react to form secondary pollutants, while others may persist as primary pollutants for perhaps several weeks. 'London smog' and 'Los Angeles smog' can be thought of as typologies of smog that rarely exist in a pure form; instead, as well as Chinese urban smog differing by urban location, smog also differs according to the season and weather conditions, with chemical and particle composition changing over several years (Fan, Zhao, and Yang 2020). Thus, policy responses to smog are best when they take account of the pollution source; policies to reduce use of coal have little effect on areas with high levels of transport pollution. For example, as the use of coal-fired boilers in Beijing has diminished over the period of this study (Tan-Soo, Qin, and Zhang 2018), automobile use has increased, gradually changing the composition of air pollution, and therefore the importance of photochemical smog (Shi et al. 2019). Guangzhou, a major city in Guangdong province, southern China, was found in one study (Wang et al. 2006) to have aerosol pollution mainly from vehicle exhaust sources (38%), followed by coal burning (26%). Since Guangzhou is not provided with public heating in winter, the majority of the coal burning can be attributed to industrial and power-generating sources. In contrast, Beijing in northern China does have winter heating provided by 'district heating' systems, run predominantly by coal-fired boilers. Winter air pollution was found (Sun et al. 2004, p. 4) to be considerably greater than summer pollution: both PM_{10} and $PM_{2.5}$ increased hugely, by up to 50% compared to summer levels. An analysis of chemical composition found that coal burning (which includes industrial and domestic sources) and vehicle exhausts account for the majority of air pollution over summer and winter (Sun et al. 2004, p. 5). While both Guangzhou and Beijing have pollution from coal and oil burning, effective policy must take account of the different importance of district heating and transportation in each city. The precise source of air pollutants as measured by ground-based pollution sensors and satellite sensors is usually difficult to ascertain with any great certainty. This is due to three main variables: i) fossil fuel combustion in factories, transport, power stations all produce a similar combination of pollutants, although in differing concentrations, and ii) the dynamic nature of atmospheric mixing transports pollutants away from the pollution source, and iii) some pollutants undergo chemical reactions while in the atmosphere further obscuring their source. This chapter will focus upon three main anthropogenic sources of aerosol pollution: industrial, domestic, and transportation[16] , with winter heating pollution being a statistically minor component of air pollution by volume. Due to the highly dynamic nature of air currents, aerosol pollution rarely stays where it is produced, it is therefore difficult to ascertain the exact source of air pollution with great certainty. However, chemical

[16]Apart from anthropogenic sources, dust storms affect the north China plain in spring particularly, although this natural phenomenon is heavily affected by desertification through anthropogenic factors (Chen et al. 2021). These dust storms combine with aerosol pollution from other sources to produce dust storms containing high amounts of pollutants (Huang et al. 2010)

composition of air pollution is a good indicator of the kinds of processes that produce certain chemicals, and therefore a good overall indicator of the sectors that are responsible for various pollutants.

4.1.2.1 Air pollution concentrations

I laid out the main sources of pollutants above, and note that statistically, larger volumes of pollutants emitted result in greater concentrations of pollutants. This is correct on average; where cities emit large volumes of pollution, they are more likely to have higher concentrations of pollutants. However, this is far from the whole story. The concentration of air pollutants is also hugely affected by the geography and local atmospheric conditions. These physical factors may act to disperse pollutants away from an urban area, or to concentrate pollutants within a city, even taking air pollutants from outside the city and trapping them in a particular location, greatly increasing air pollutant concentrations. There is a body of research suggesting that Beijing has been particularly affected by air quality pollutants whose source is outside Beijing itself (Zhang et al. 2016).

4.2 Pollution measurement

This complex picture is further muddied by how pollution is measured, especially placement of pollution measurement equipment. The immediate location of measurement equipment can have a large effect on the types and concentrations of pollutants that are measured in a given area. Equipment placed close to major roads can be expected to give a different picture of pollution when compared to measurement equipment placed in an industrial area, or a park. Generally speaking, industrial and power station pollutants in China predominantly produce SO_2, and PM_{10}, followed by $PM_{2.5}$ and lower concentrations of CO, NO2. Conversely, vehicle emissions produce higher volumes of $PM_{2.5}$, NO_2, CO and O_3. Given the variety of air pollutants, their diverse sources, and their behaviour once released into the environment, it is useful to classify this “pollution soup” into categories based on the specific air quality challenges faced by Chinese cities. The focus of MEP air quality is entirely based on the products of burning fossil fuels, and the source of these pollutants are often categorised into polluting sectors. Given this common categorisation, Chinese urban air quality pollution overwhelmingly has four sources: power stations, industry, district heating, and road transport. For policy reasons, this can be further re-categorised into three sources: high flues (industry, power stations), mid-level flues (district heating), and low-level flues (road transport). The physical environment into which pollution is emitted has a huge impact upon the health of people in that environment. While high-level flues overwhelmingly emit the largest volume of pollutants, it is low level (vehicle tailpipes) and mid-level (district heating boilers) sources of pollution that are much more potent forms of air pollution for people living in an urban environment. This is because high-level flues increase gas and substance dispersal over a much larger area, and therefore concentrations of pollutants in the air decreases as flue height increase. The effects of air pollution are overwhelmingly breathed in by people at ground level, and sources of pollution that lie closest to ground-level have an outsized effect on human health. Since heavy particles of pollution falls to the ground, high flues in power stations and heavy industry also affect people's health. However, depending on the height of flues, the distance from population centres, and the prevailing winds, power stations and heavy industry can indeed be the major cause of air pollution that afflicts people in urban centres; the height of the flue itself is generally designed so that pollutants are dispersed quickly, reducing pollutant concentrations in any one area (Scungio et al. 2015). The temperature which flue gases and substances are emitted from the flue are also important factors causing dispersal. High temperatures compared to ambient air temperature cause the emissions to be transported high up into the atmosphere, where they are much more likely to be dispersed over a larger area. Conversely, relatively low temperatures at point of emission, combined with low flue height, as in domestic fireplaces, are much more likely to cause low levels of dispersal, causing the effluents to fall to ground level over a much shorter distance, and to be more concentrated when they do so. For these reasons, although power stations and heavy industry factories are the greatest polluters by volume, these sectors are not necessarily the major cause of local poor air quality (Shuangchen et al. 2017). Road vehicles (Yang and He 2016) and district heating (Xi et al. 2019) may have an outsized effect on poor air quality.

4.2.1 Sources of urban air pollution

Due to the number of pollutant types involved in air quality pollution, the different sources of pollution, and the extent to which they travel from their pollution source, improving air quality in a location is very rarely achieved through reducing one particular pollutant, or one source of pollution. The different pollutants tend to co-mingle in the atmosphere, so that pollution type and concentrations vary throughout the day and season, as well as over years (Shi et al. 2019). (Qi et al. 2017), using data from individual factories and power plants, including data from restricted databases, finds that industry overwhelmingly provides the highest emissions as compared with other sectors, on average 70% of all emissions in cities surveyed. The next highest polluting sector by volume is residential, followed by transportation and power. As I discuss in the next section, pollution emissions by volume do not necessarily equate to concentration of pollutants at ground level. Below I outline the main sectors in which air pollution is emitted. Small-scale technological efficiencies as well as larger policy changes are briefly noted, and these will be taken up in more detail in chapter five.

4.2.1.1 Power plant emissions

Electricity-producing power plants are a major source of air pollutants, due to the huge volume of fossil fuels, often coal, that are combusted to produce electricity for large Chinese cities (Qi et al. 2017). In 2011, at the peak of air pollutant emissions from power plants, around 1.75 billion tonnes of coal were used to power China's coal-fired power stations. This represents the greatest single source of coal combustion in China. Despite being the largest user of coal, power plants emitted around 30% of pollutants by volume (Li et al. 2017, sec. 3.1), far behind industrial sources of pollution. This disparity may be largely caused by the efficiency of coal-burning plants compared with smaller industrial boilers. The peak in power plant emissions of SO_2 occurred in 2006 (J. Zhang et al. 2017, fig. 1), which was due to the widescale introduction of flue gas desulphurisation (FGD) technology to power plants during the 11th five year plan (2006-2010) (National People's Congress of the People's Republic of China 2006), with installed FGS technology rising from 12% in 2005 to 82% in 2010 (Wang and Hao 2012). (Tong et al. 2018) produced power plant emissions inventory from 2010-2015, and noted a precipitous decrease in all air quality emissions after an emissions peak in 2011. Compared with 2010 figures, SO2 decreased by 50%, NO_x decreased 46%, $PM_{2.5}$ decreased 25%, PM_{10} decreased 23% (Tong et al. 2018, table 1). In the same period, CO_2 emissions (a greenhouse gas, and not an air quality indicator), rose 14%, indicating that air quality emissions reductions in this period were due to technical factors such as newer technology, not due to a rapid decrease in the use of coal as power plant fuel. From 2010-2015, the reduction in air quality pollutants was largely down to two factors: increasing efficiency, and increasing use of post-combustion controls. Increasing power plant combustion efficiency is generally achieved through replacing combustion systems with newer technology, which could include retrofitting existing combustion systems, replacing with new, or decommissioning older power stations with purpose-built new plants. While newer combustion technologies increase efficiency greatly, this is generally expensive. Average efficiency, measured by electricity produced per gram of coal, increased by 6% from 2010-2015 (Tong et al. 2018). While combustion efficiency improved then, it cannot account for the majority of pollution reduction achieved. Fitting of desulphurisation and nitrogen oxide control technologies also increased greatly. From 2010 to 2015, average removal efficiency of SO_2 reducing equipment increased from 78% to 88.6%. In the same time period, NO_x removal devices were introduced for the first time to Chinese plants, increasing removal efficiency from 0-62%, a significant factor in reducing nitrogen oxide pollution from power plant sources (Tong et al. 2018). A further factor is scale: large-capacity power plants are much more efficient than lower-capacity plants. Measured in megawatts (MW), a 600 MW plant is on average 17% more efficient than a 100MW plant (Aden, Zheng, and Fridley 2009, p. 22). Replacing a large number of small-capacity plants with fewer large-capacity plants therefore greatly increases efficiency, and reduces use of the coal and the associated air pollutants. Another efficiency gain is in the use of more modern, higher pressure and temperature combustion systems. A 17% efficiency gain comes from moving from sub-critical technologies to the latest IGCC technology, which converts pulverised coal dust to a gas before burning (Aden, Zheng, and Fridley 2009, p. 22). Reducing or eliminating coal as a fuel for power stations is therefore a major component to improving urban air quality, however this requires a comprehensive national energy plan to replace coal with a mixture of natural gas, oil, nuclear, and renewable power (see chapter 5). (Guan et al. 2018) study of China's carbon dioxide (CO_2) emissions noted a peak in 2013, coinciding with a peak of coal use. While as noted in the introduction to this chapter, carbon dioxide is considered a greenhouse gas, not an air quality pollutant, fossil fuels produce CO_2 as the major by-product of combustion; further post-combustion carbon dioxide controls are much more expensive and inefficient than desulphurisation and nitrate controls. A reduction in carbon dioxide is therefore a much stronger indicator of reducing coal use in both power plant and industrial settings.

Furthermore, (Guan et al. 2018) analysis of factors leading to changes in CO_2 emissions makes clear the importance of economic growth for increasing carbon dioxide emissions, and three main factors reducing emissions: changing industrial structure, reducing energy intensity, and reducing the proportion of coal as a total of China's energy production. The larger factors contributing to carbon dioxide emissions are equally important in air quality pollutant emissions: economic growth, industrial structure, energy intensity, and coal's share of energy. These factors of course also vary between localities in China, and these local differences are a possible reason for local differences in pollution concentration. It is important to note that post-combustion controls are not sufficient to reduce air pollution to zero, or even to a very low level. Largescale change in air pollution requires a largescale structural change in how energy is produced, energy efficiency, and even the economic structure; moving away from a manufacturing economy and towards a service-oriented economy is a major part of this change.

4.2.1.2 Industrial emissions

Industrial air pollution is a large factor in urban air pollution, perhaps the largest single sector contributing to air pollution, contributing as much as 70% by volume of China's air pollutant emissions (Qi et al. 2017). In particular, the steel industry is the largest single polluting sector (Yang et al. 2019a; Qi et al. 2017, p. 161), followed by cement making (Qi et al. 2017, p. 161). The cement and steel industries are extremely important in China, not only as major sectors in China's economy and as raw materials for other important industries such as construction, but also politically. China frequently relies upon large-scale, state-sponsored construction to boost its domestic economic output (Shi and Huang 2014; Mele and Magazzino 2020, p. 4). Cement and steel production, and their pollutant emissions, are therefore frequently boosted by government spending on infrastructure. From 1998 to 2009, the cement making industry in China decreased pollution emissions[17] by 65%, despite increasing cement production (Shen et al. 2017), while in the same period steelmakers *increased* pollution emissions by 46% (Fujii, Managi, and Kaneko 2013, table 4). (Cai et al. 2009) note that central government directives encouraging smaller, energy inefficient cement works to shut down, and preferential treatment given to 60 large cement making companies caused a shift towards larger factories with the financial means to invest in newer more efficient technologies. The steel making

[17]During this period only sulphur dioxide, soot and dust were available for analysis

industry in China seemed relatively unaffected by this movement towards larger, more efficient steelworks during the same period, indeed energy use in steelmaking increased (Lin and Wang 2014, p. 88). Energy and emissions intensity were around 20% greater in China in 2006 compared to the USA (Hasanbeigi et al. 2014), i.e. on average producing one ton of steel in China required 20% more energy input, and produced 20% more pollutants compared to the USA. Following the 2008 financial crisis, the steel industry quickly regained volume as public stimulus affected production (Mele and Magazzino 2020). Concentration of production capacity in the steel sector accelerated after 2009, when Minister of Industry and Information Technology announced encouragement and financing for mergers in the steel sector, and upgrading of technology (SMM Metals News 2009). As of 2019, the largest steel producers in China[18] are predominantly State Owned Enterprises (SOE) who have undergone large mergers during the period 2008-2018. This period of mergers has resulted in smaller factories and older technology being sold off and scrapped, just as happened in the cement industry a decade earlier. (Li, Qiao, and Shi 2019) studied the effect of the Air Pollution Prevention and Control Action Plan 2013, and noted that reduction of pollution in the Beijing, Tianjin, Hebei area was associated with a 6.7% reduction in manufacturing output, 2013-2015. Thus, central government plans to reduce industrial emissions are related to manufacturing output, and therefore to employment and the wider economy. Although emissions by volume is dominated by industry, the extent to which residents in urban areas experience such pollutants depends greatly on local conditions. Industrial pollution may be the cause for 20-25% of air pollution (Rohde and Muller 2015, p. 5) as measured by ground-based measuring equipment in cities across China. The reasons for this discrepancy between volume of emissions and pollution as measured on the ground is largely due to the dynamic effects of weather and flue height on particle concentrations at ground level. Air pollution in Beijing is often blamed on factories in surrounding Hebei and Tianjin, with pollutants from outside Beijing contributing approximately 1/3 of total $PM_{2.5}$ during Beijing's 2013 'airpocalypse' (Zhang et al. 2016). In particular, Tangshan's steel industry has been singled out for causing a disproportionate amount of Beijing's air pollution (Yang et al. 2019b). State owned enterprises (SOE) are an important part of heavy industry in China, with many of the largest manufacturers of steel and cement being SOE's. Large-scale heavy manufacturing sites contribute greatly to

[18]Top 5 steel companies: 1. China Baowu, (SOE);
2. Hesteel, (SOE); 3. Shagang, (private); 4. Angang (SOE); 5. Jianlong

(private). Figures (World Steel Association 2019) pollution emissions by volume, however these larger sites are more likely to have larger flue heights, and therefore their effect on pollution concentrations at ground level may not be so clear cut. There is evidence that SOE's may be more liable to commit large-scale illegal pollution (Eaton and Kostka 2017). Of 2,370 violations reported by environmental protection[19] records between 2004 and 2016, six large companies committed 62% of all violations reported. 'Central protectionism' of SOE activities by local government is cited as an important reason for this imbalance: state companies may be protected by local officials from complying with environmental directives, or else are more leniently treated when such infractions are discovered by the MEP or through media reports and public complaints. However, due to the revolving-door of officials between government and SOE, there is also reason to suppose that SOE's are relatively more likely to comply with strong central government directives to reduce pollution emissions. On this interpretation, as central government directives more strongly emphasise pollution control, as they have done from the 11th five year plan onwards, SOEs are more likely to strongly change their polluting behaviours compared to private companies. In addition, private companies within the highest polluting industries (steel and cement) are likely to be disadvantaged in markets dominated by SOEs, they are likely to be much smaller companies, with smaller factories and outputs. This in turn leads private companies to have smaller, less efficient boiler systems, and lower flue heights, resulting in a relatively low emissions volume, but much higher relative impact upon local air quality. Heavy industries require large volumes of coal for industrial processes. As with coal combustion in power plants, heavy industrial use of coal can be greatly reduced with more efficient combustion processes, as well as other efficiency gains throughout the industrial process itself. As well as reducing air pollutants through more efficient use of energy in industrial processes, the use of post-combustion controls such as flue gas desulphurisation markedly reduce the emission of particular gases and particles. These processes have economic costs to factories, however, and in some cases actually reduce the energy efficiency of industrial processes (Poullikkas 2015, sec. 3.11). Another, more drastic policy choice is that of forcing factories to curtail production, or forcing them to relocate to another area entirely. Before the Beijing Olympic games in summer 2008, many factories surrounding Beijing were forcibly closed in order to reduce smog (Central Government Portal of the People's Republic of China 2012). The success of these measures has led to more frequent, and temporary factory

[19]2255 cases in Eaton and Kostka's database were reported by local EPB, with 204 major cases between 2014-2015 reported by MEP

shutdowns, especially coinciding with important international conferences (Fu, Ma, and Peng 2020).

4.2.1.3 Winter heating emissions

In northern China, the majority of domestic heating in urban areas is provided not by individual household heating appliances, but by larger, often coal-fired public heating systems (district heating,中供暖) which by government policy are only available in Northern China (following the line of the Qinling mountains and the Huai river), and run from approximately November 15th to March 15th, depending on local weather conditions. These systems use heated water and steam which is pumped through pipes to homes and offices. The majority of fuel consumed is coal (91% in 2011) which is burned in boilers (51%) or Combined Heat and Power (CHP); electricity-producing power stations divert heat which is used to heat water (Gong and Werner 2014, p. 24). Heating is provided by boiler substations, providing heating for a large group of buildings. This produces heating inefficiencies; as much as 30% of heat energy is lost through long pipe networks before entering residential properties (Gong and Werner 2014, p. 38). By volume air pollution from district heating systems is relatively low, around 4.4% of CO_2 emissions, by one estimate (Wang et al. 2011). However, due to the relatively small size and low efficiency of coal boilers and pipe networks, and the lack of end-user temperature regulation, these systems are extremely inefficient (Chen et al. 2013). Generally speaking, heating technology lags behind power plant and industrial sectors, and the pollution produced escapes from low flue heights (Xu, Fan, and Yu 2014) close to residential housing, ensuring that the impact of pollution emissions is much greater than the volumes of pollution suggests. (Liu et al. 2016, p. 7756) note the large role that winter heating pollution plays in pollution exposure as opposed to pollution emissions by volume. While winter heating emissions during January and February may represent as much as 32% of $PM_{2.5}$, and 71% of carbon monoxide in Beijing Tianjin and Hebei regions, their model calculates an effect on pollution concentration of on average 36% in the Beijing-Tianjin-Hebei area, with up to 52% in pollution hotspots (Liu et al. 2016, p. 7758). This model of the real effects of winter heating are corroborated by other studies noting the importance of the winter heating season as compared with other times (Zhao et al. 2013; Cao et al. 2007); turning on winter heating may increase pollution from 36% (Fan, He, and Zhou 2020) to 50% (Xiao et al. 2015, p. 6). District heating provision itself is associated with a marked improvement in air quality as compared with individual charcoal and coal braziers used in individual homes (Xue et al. 2016). Efficiency of district heating may be rapidly improved with use of Combined Heat and Power technology from power plants, larger and more efficient district heating boilers, and more energy efficient measures in pipe design and end user controls (Xu, Fan, and Yu 2014). Xu surveyed 45 district heating systems in 15 cities, finding that State Owned Enterprises dominated district heating companies, with only 15% being privately owned. Nearly 78% of heating systems were fed by coal, with CHP and gas systems both comprising around 11% of heat. Thermal energy efficiency of coal-fired systems varied widely, from around 30% to over 80% efficiency (Xu, Fan, and Yu 2014, fig. 6). However, this is a great improvement upon past energy use in heating systems, with a 38% decrease in energy use from 2001-2015 (Luo and Xia 2020). A large component of increasing energy efficiency has been the replacement of small-scale coal boilers with larger and more efficient coal boilers, and increasingly after 2016, the replacement of coal systems with CHP and gas-fired heating systems.

4.2.1.4 Vehicle emissions

Internal combustion engines typically run on petroleum and diesel fuels, which emit a different pattern of pollutants compared to coal-burning: pollutants are primarily nitrogen oxides (NO_x), carbon monoxide (CO) and ground-level ozone (O_3) as a secondary pollutant, with a minor but significant element of fine particulate matter ($PM_{2.5}$). Urban air pollution caused from road transportation including buses, lorries, cars and motorcycles contribute a relatively low percentage of pollution by volume, with a large contribution to air quality at street level (Yang and He 2016). It has been estimated that 15-25% of urban air pollution is caused by petrol and diesel combustion engines (Rohde and Muller 2015), while (Hao and Wang 2005) find that 74% of ground-level NO_x is due to road transport sources, with power plants contributing 2% and industry 11%.

4.3 Air pollution over time

Having defined air quality pollutants, together with the major sources of urban air pollution, I examine how this measurement has changed over the period 2008-2018. Where available, data preceding this period is given for context. The official statistical data is then compared with satellite data of air pollution. In general, it appears that official statistics do not vary greatly from satellite data; thus, may provide a good basis for time-series comparison with laws, policies and planning described in chapter five.

4.3.1 Official statistics

There are several data sources to examine air pollution, including the quantitative data sourced from the National Bureau of Statistics. The data below is taken from (National Bureau of Statistics of China 1999); air quality and pollution emissions data is collected by SEPA (1998-2008), and the MEP (2008-2018). National air quality statistics consists of data collected from thirty-one provincial capitals, autonomous regions, and municipalities. Data collection is through purpose-built air quality monitoring stations, located in perhaps a dozen locations throughout each city. Each location's data may differ greatly within a single city, influenced by its proximity to roads, factories, parks and green spaces, residential areas, and other environmental factors. The data published to the statistical yearbook consists of a single value, an average for the collected chemicals in a city for a single year. The data is not always collected in the same way across all years, and this creates difficulties in analysing the timeseries. $PM_{2.5}$ is particularly important; it is a measure of small-diameter particulate matter that is particularly relevant for human health, since the small size of particles when breathed are able to travel deeply into the lungs, and even into the bloodstream. Small sized particulate matter is thus much more dangerous for human health than larger particulate matter PM_{10}, but was not measured at all prior to 2013. Further, as noted in chapter three, there are reasons to doubt the accuracy of measurement data. The data plotted below is converted to a common scale: 'micrograms per cubic metre'.

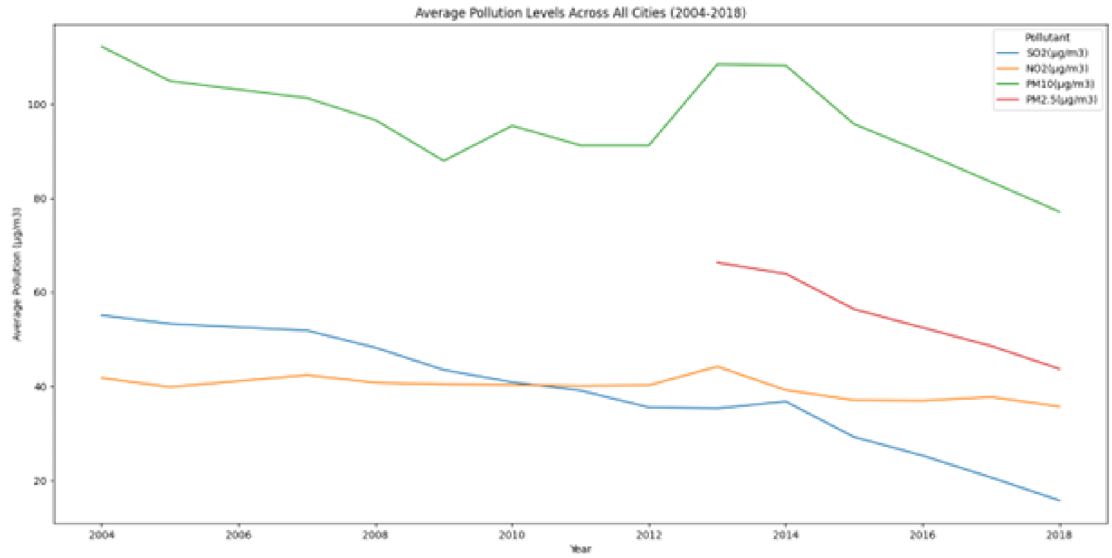

Figure 4.1: Mean air quality of NO_2, SO_2, PM_{10}, $PM_{2.5}$, 2004–2018, source: (National Bureau of Statistics of China 1999)

The air quality plot in figure 4.1 shows a strong downward trend in pollution over time on all measures, except nitrogen dioxide (NO_2) which remains relatively flat. This suggests a gradual change in urban pollution sources, with road transport emissions becoming more significant as pollution from power plants and factories reduces. An overall 33% reduction in pollution of all types from 2008-2018 is observed[20]. The reduction is most pronounced in sulphur dioxide at −67.39%, followed by $PM_{2.5}$ at −34.07% and PM10 at −20.18%, while NO_2 shows a smaller but still significant decrease of −12.47%.

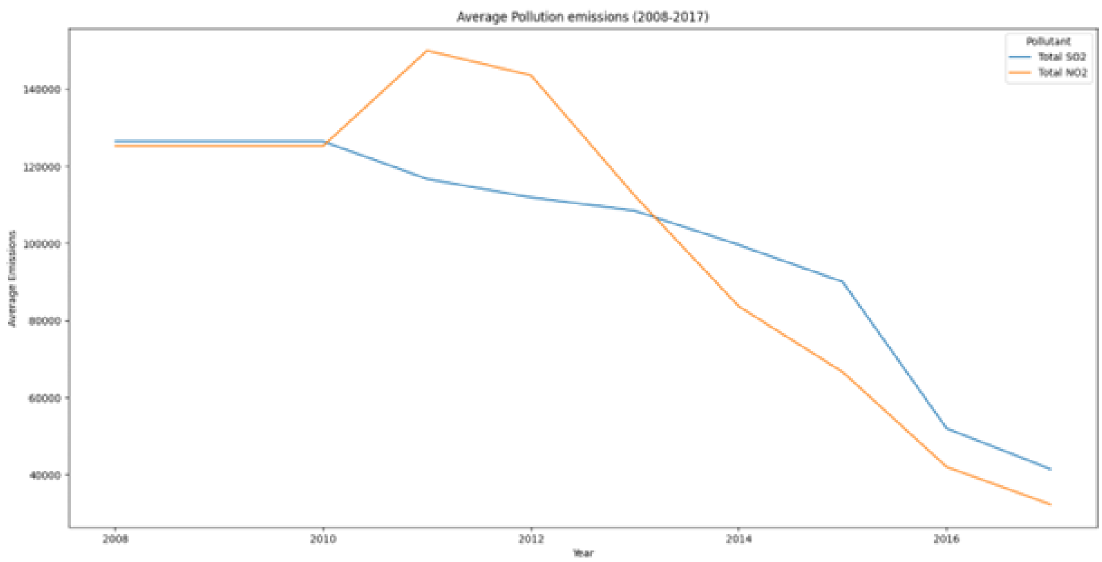

Figure 4.2: Pollution emmissions measured at source (SO_2, NO_2)

[20]The mean reduction in air pollution from 2004-2018 for each pollutant is −38%

The figure above plots pollution emissions at source, as measured by continuous emissions equipment fitted to power stations and factories. Theoretically, sampling pollution emissions at source will give a much more accurate account of changes than pollution data captured by monitoring equipment. However, in practice only larger polluters are fitted with emissions equipment, and there have been instances where this equipment is tampered with in order to meet local pollution targets (Li et al. 2022; China News Network 2018). Nonetheless, data shows a marked decrease in pollution emitted over the period, with sulphur dioxide decreasing by −67.20%, approximately in line with local air quality measurements, while nitrogen dioxide reduced by −74.22%, far in excess of the small decrease measured by air quality monitoring stations. This can be attributed to differences in emission sources: SO_2 is primarily a result of coal combustion in power plants and factories, whereas NO_2 has two major sources—large coal-fired boilers and exhaust emissions from road transport. While reducing emissions from power plants and factories lowers both SO_2 and NO_2, emissions from road transport remain unaffected.

4.3.2 Satellite data

There are a number of studies seeking to use satellite air quality measurements in order to verify air quality measurements made on the ground (Karplus, Zhang, and Almond 2018; Ma et al. 2019). Studies find a large spike in air pollution over the Beijing-Tianjin-Hebei area in the winter of 2012-2013 (Ma et al. 2019), aligning with the ‘airpocalypse’ identified by the media. This is basically replicated in the data presented below. However, it is important to note that the cause of the short term spike in air pollution is highly unlikely to be a sharp rise in pollution emissions. Firstly, the rise in air pollution is limited to the north China plain only, and is not replicated in other areas of China. Secondly, the area is well known to be subject to winter atmospheric boundary inversions (Xu et al. 2019; Zhao et al. 2019) in which colder air and air pollution is trapped close to the ground. While pollution emissions are the ultimate cause of pollution events, the proximate cause is identified with local weather conditions. These events are highly likely to take place during the colder winter months in northern China, and exacerbate any existing pollution already in the air. Short term spikes of high air pollution aside, comparing satellite data with official statistics gathered through ground stations presents evidence of a peak in air pollution around 2010-2013, depending upon the pollutant. The data presented below is taken from NASA satellites (NASA Earth Science Data and Information System (ESDIS) 2025), using three key measurements: NO_2 measurements, Aerosol Optical Depth measurement (used to measure particulates in the air), and SO2 measurement. Each of these measures present different challenges for interpreting the data, and analysing what satellite pollution data means for ground-level pollution. Although measurements show a decrease in pollutant concentrations over time in the north China plain, both NO_2 and AOD show initial increases in pollutant concentrations, before reaching a peak in 2011-2012 (NO2) and 2012-2013 (AOD), and rapidly decreasing thereafter. SO2 in contrast, shows a different spatial concentration of pollutants compared to NO_2 and AOD, and falls slowly and steadily over the whole period 2008-2018.

4.3.2.1 NO2 measurements

The first measure of air quality available from satellite data is NO_2. Uniquely among the satellite data available, NO_2 measures are able to more accurately pin-point the origin of air pollution compared to other measures, since NO_2 has a very short atmospheric lifetime (it quickly undergoes chemical reactions in the atmosphere to form other nitrates and ozone). Given this short atmospheric lifespan, measures of NO_2 by satellite are able to much more precisely give the location of emissions compared to both AOD and SO_2 measures. Data clearly show that north China plain emission hotspots coincide with large industrial cities like Beijing, Tianjin, Tangshan, and the Jinan-Zibo-Weifang area. Located near to the Taihang mountains stretching from the north to the southwest of the north China plain are a string of large industrial cities including (from north to south) Baoding, Shijiazhuang, Xingtai, Handan, Anyang, Hebi, Xinxiang, Jiaozuo, Luoyang and Zhangzhou. The data indicates the importance of these cities, stretching from western Hebei to western Henan, to producing large-scale air pollution. Although since NO_2 is quickly transformed into other chemicals in the air, it will not greatly affect cities downwind, this is not the case for longer-lasting pollutants such as SO_2, and particles such as PM_{10} and $PM_{2.5}$. Data shows that NO_2 started at high levels, and increased, reaching their highest point in 2011-2012, before reducing significantly to below 2008 levels at the end of 2018. Below I show the quantitative changes in the form of a 'difference map', which compares the NO_2 pollution between 2008 and 2018. It shows the lightest areas as a decrease in NO_2, and these are particularly prevalent around northern Hebei and particularly the industrial city of Tangshan near to the Bohai coast. In contrast, there has been an increase in NO_2 pollution levels in the bottom-left hand corner of the map, indicating an area of Henan just west of Zhengzhou city, and including Luoyang city.

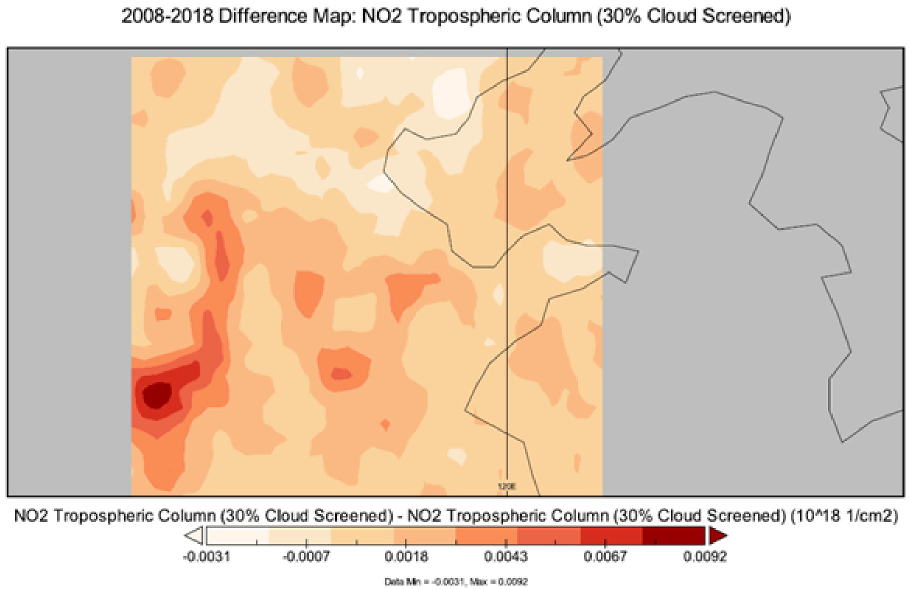

Figure 4.3: Difference map of NO_2 concentration in North China Plain, 2008–2018, source: (NASA Earth Science Data and Information System (ESDIS) 2025)

The below graphs measure the level of NO_2 pollution as captured by the satellite data over the north China plain. It reduces the complexity of the pollution map into a single figure per year of satellite data: the total of all NO_2 pollution captured within the area of interest (north China plain). Of course these figures can only give a very rough impression of NO_2 pollution during this period, but it is nonetheless helpful in confirming the impression given by the pollution maps above: satellite data shows NO_2 pollution as reaching its peak in 2011. This does not necessarily contradict the MEP data, but rather adds to it, since MEP data for NO_2 only starts in 2011 for emission data, and 2013 for air quality measurement. The graph below shows an increase in NO_2 until 2011, with the most dramatic increase between 2009-2011; this broadly aligns with statistical data of pollution emissions (figure 4.1 above), showing a similar increase in nitrogen dioxide from power plant and industrial sources. Satellite data shows a dramatic decrease in NO2 taking place between 2013-2015, while statistical sources note the steepest decline taking place between 2012-2014.

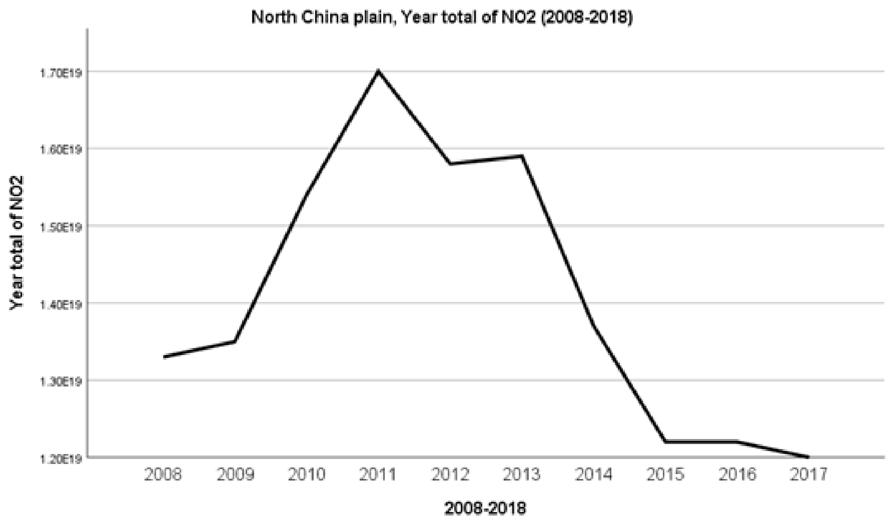

Figure 4.4: Graph of total annual average NO_2 concentration in North China Plain, 2008–2017, Data source: (NASA Earth Science Data and Information System (ESDIS) 2025)

The second satellite measure of NO_2 below is much more accurate, and more ambiguous. It shows a monthly graph of NO2 concentrations over the north China plain, with rising NO_2 up to a visible peak in 2013, a low in 2017, and staying at approximately the same level therafter. NO_2 is emitted by all fossil fuel consumption; while a fall in coal use may reduce NO_2, a rise in tailpipe emissions from cars and lorries counteracts this. Evidence from emissions reductions during covid19, which show an NO_x reduction around 20%, point to the importance of industrial and tailpipe emissions driving nitrogen oxide emissions (Ma et al. 2023).

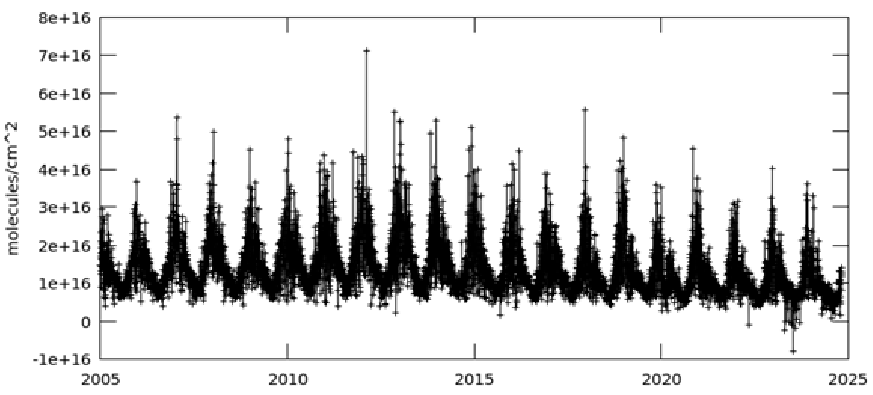

Figure 4.5: Graph of total monthly NO_2 concentration in North China Plain, 2005–2024, source: (NASA Earth Science Data and Information System (ESDIS) 2025)

4.3.2.2 Aerosol Optical Depth

Aerosol optical depth (AOD) is a measurement of the amount of aerosols (or particulate matter) present in the atmosphere. The measurement works by measuring the sunlight reflected back from the Earth to satellites in orbit. The light reaching the satellites must pass through the Earth's atmosphere, and be reflected back into space. Where there are substances suspended in the atmosphere, this causes light to be absorbed, or scattered, causing less light to reach the satellite's sensors. In general, AOD measurements can be used as a proxy for dust and haze in the atmosphere, and thus a general indicator of pollution. Below I have reproduced an AOD-derived map (figure 4.5), using 'Giovanni' NASA's online repository of satellite-derived data.

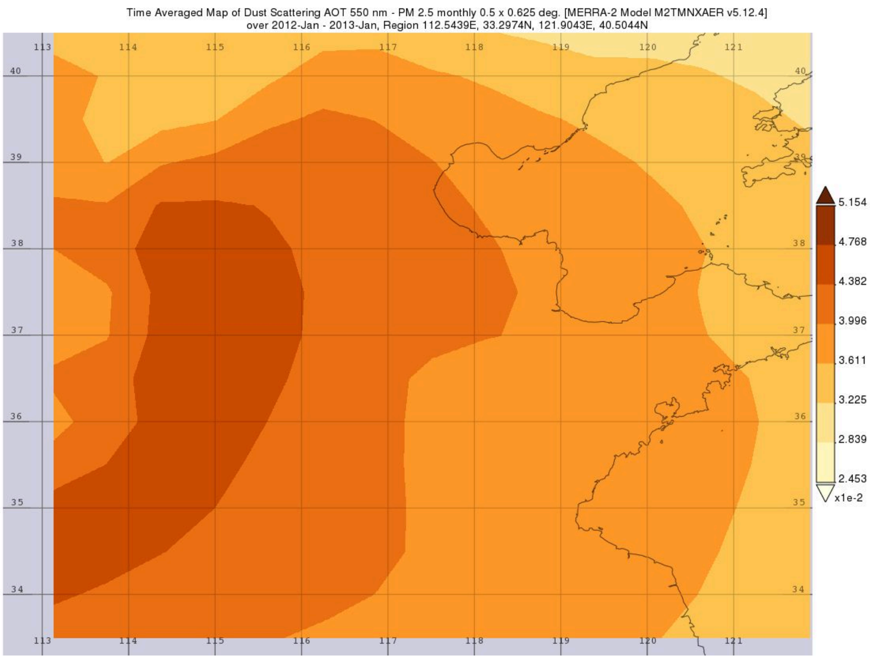

Figure 4.6: Time averaged map of $PM_{2.5}$ concentration over North China Plain, 2012–2013, Data source: (NASA Earth Science Data and Information System (ESDIS) 2025)

The image below (figure 4.6) is calculated from the mean annual average of north China plain satellite data. It is clear that, overall, AOD has significantly decreased during this period, with a local temporary increase in from 2011-2013, and thereafter a sharp decrease. This seems to generally agree with the reduction of pollution in PM_{10} and $PM_{2.5}$ over this period from the MEP's own data (figure 4.0).

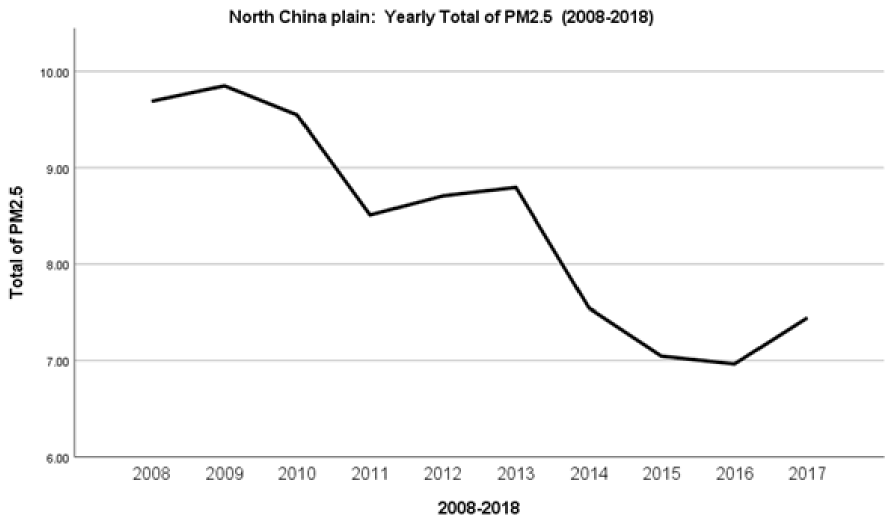

Figure 4.7: Graph showing total $PM_{2.5}$ concentration in North China Plain, 2008–2017, Data source: (NASA Earth Science Data and Information System (ESDIS) 2025)

The image above gives an indication of overall changes in AOD during the period 2008-2017. A closer look at this same AOD data is afforded by a quantitative analysis below. As with the NO_2 measurement above, it shows a 'peak pollution' after 2008; in this case in 2009, although pollution only rises slightly from 2008 to 2009. Again, similar to NO_2 satellite pollution data, this shows a more nuanced picture of pollution over the north China plain than may be seen from MEP data. Although there is a clear downward trend in pollution over this period, it shows three counter-trends: 2008-2009; 2011-2013; and 2016-2017. Below is a 'difference map' which calculates the relative increase or decrease in pollution in the north China plain over the same period, using $PM_{2.5}$ satellite data.

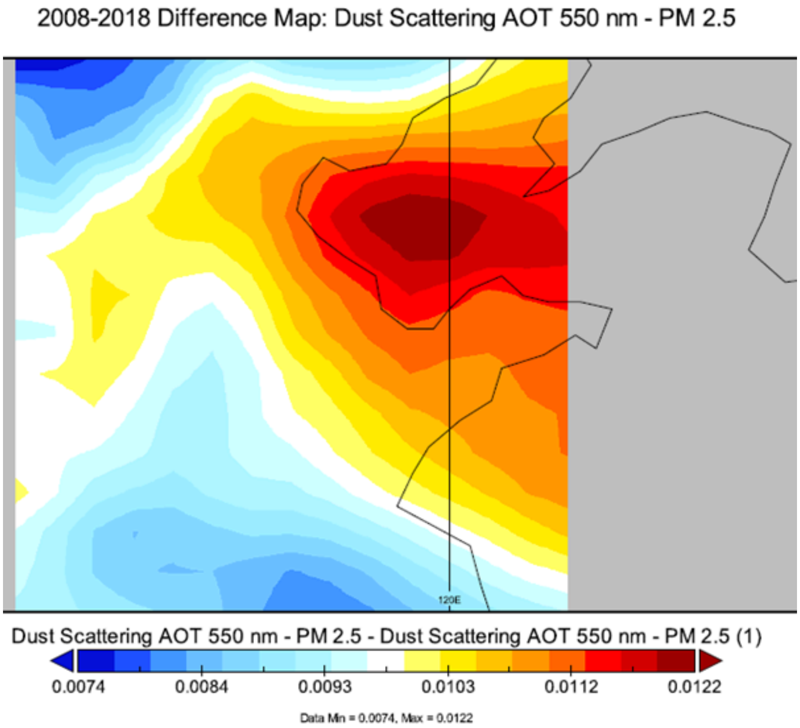

Figure 4.8: Difference map of $PM_{2.5}$ concentration in North China Plain, 2008–2018, source: (NASA Goddard Institute for Space Studies (GISS) 2025)

The difference map above plots the relative change in AOD by local area, using $PM_{2.5}$ satellite data from 2008-2018[21] , with yellow and red indicating a local increase in pollution, and blue indicating a local decrease. Despite the large decreases in pollution overall during the period, the major cities of the North China plain region including Beijing, Tianjin, Tangshan and Shijiazhuang all remain within the yellow-orange area, indicating a slight increase in air pollution over time. Meanwhile, the greatest decrease in air pollution takes place on a band on the border of Hebei and Shandong, from Hengshui and Liaocheng to Puyang. It is clear that air pollution is a local phenomenon, and that a mean decrease in air pollution does not necessarily indicate a decrease throughout all locations.

4.3.2.3 SO2 measurement

The final measurement shown here is that of SO_2. As can be seen from the Giovanni-produced map below, SO_2 concentrations are somewhat different from both NO_2 and AOD. Part of this difference lies in the much more chemically stable nature of SO_2 in the atmosphere, which

[21]Plot generated using data visualiser *Panoply*, version 4.12.0, created by NASA Goddard Institute for Space Studies (GISS)

allows it to stay in the atmosphere much longer, and to be blown by prevailing winds over a wider area, and to be deposited and concentrated in areas with low wind-speed. Secondly, SO_2 emissions are much more common as products of coal combustion, as opposed to gasoline or natural gas combustion. SO_2 emissions are therefore more likely to concentrate in heavy coal-use areas. As can be seen from the maps below, while in general SO_2 concentrations are high over the north China plain, they are greatest in the extreme bottom-left of the map, corresponding to an area to the south west of Henan province, centred around the Luoyang-Zhengzhou-Kaifeng area.

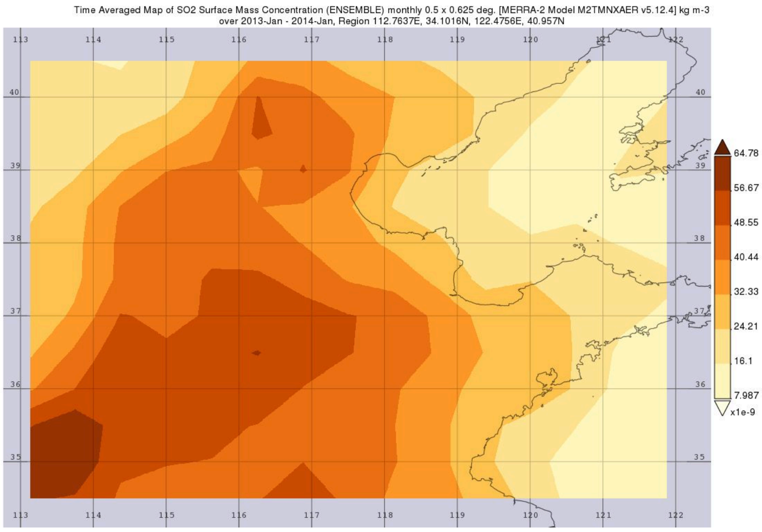

Figure 4.9: Time averaged map of SO_2 concentration over North China Plain, 2013–2014, source: (NASA Goddard Institute for Space Studies (GISS) 2025)

The figure above shows SO_2 concentrations increasing gradually from 2005 until 2013, and then fluctuating until 2020, before falling again. This data does not align well with the available statistical data, either from sulphur dioxide emissions or from locally measured air pollution, both of which indicate a continual and gradual decrease in sulphur dioxide from 2005 until present.

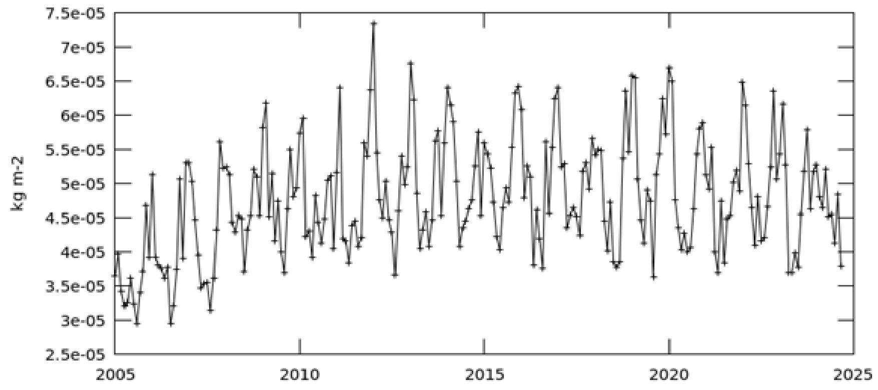

Figure 4.10: Monthly plot of columnar SO_2 concentration over North China Plain, 2005–2024, source: (NASA Earth Science Data and Information System (ESDIS) 2025)

(Wang et al. 2022) also report a mismatch between ground reported SO_2 data and satellite SO_2 monitors, with satellite figures around 150% higher than ground measurements. (Calkins et al. 2016) reports a non-linear correlation between ground measurements and satellite data, but report that these discrepencies are largely a result of atmospheric inversions, low wind speed and low precipitation holding sulphur dioxide in the atmosphere for longer then expected. Meanwhile, (Lin et al. 2019) using measurements from the OMI satellite report a sulphur dioxide peak around 2007, with a gradual and continual decline thereafter. It is clear that satellite data of sulphur dioxide concentrations may be highly affected by both local weather conditions, multi-year patterns in the East Asian winter monsoon, and differences in satellite data collection techniques that are outside the scope of this thesis.

4.4 Data interpretation

Looking at the data above, it shows a complex picture of inexact but general agreement between ground sensors and satellite derived pollution data. Satellite-based measurements are able to provide large-scale snap shots of pollution over time, which show daily, seasonal, and multi-year patterns in pollution concentrations that are not dependent upon the total volume of pollutants emitted, but rather local meteorological conditions. Given that these rather more complex fluctuations should be even more obvious in local ground sensor data than satellite data, nonwithstanding that the figures provided are an average of the whole year, there is some room for doubt that the majority of cities reported a gradual and continual decline in pollution for most years. One indication of falsified data is where the data presented is ‘too perfect’; the data appears to cluster just below a required pollution target, without the fluctuations and randomness observed in genuine data. Nonetheless, while each city’s pollution data may well not be completely trustworthy, in general the trend aligns with the trend of satellite data. Above I outlined the data on Chinese air quality using both data from 1) pollution sensing equipment in China’s major cities, operated by local environmental bureau of the MEP and 2) NASA satellite data. Mindful of doubts about the accuracy of MEP ground sensing data (Global Times 2022), in this section I compare these two data sources for discrepancies, and note that by and large discrepancies between the two data sources remain relatively limited. This points to the general accuracy of MEP data, and effectiveness of the data gathering operation, at least averaged over all of the cities within this dataset. There may well be much larger inaccuracies within the data of individual cities, however limits on the accuracy of satellite data arguably make comparisons between MEP data for individual cities and satellite data subject to such wide variance that direct comparisons at the city level are subject to strong doubts about methodological appropriateness. Satellite data gives a measure of the total pollutants in the atmosphere, whereas ground sensors measure the pollutants making direct physical contact with a sensor located near to the ground. Satellite data is therefore a better measure of the total pollutants in the atmosphere, whereas physical sensors are a much more accurate measure of the pollutants likely to come into contact with the human population. Satellite data may be a more accurate measure where high volumes of pollutants are involved, as in power plant and industry pollution, however these sources are likely to have high flues which carry pollutants over a wide area, and therefore relatively less important for ground-based pollution sensors and human health. Where lower pollutant volumes are emitted from low-level flues, as in winter heating systems and road transportation, they are likely to have a great impact upon local ambient concentrations and human health, but are less visible in satellite data.

4.5 Summary

Comparing MEP and satellite data given in the above section, both NO_2 and $PM_{2.5}$ show an increase in pollution concentrations over the north China plain, leading to a maximum concentration in 2009 for $PM_{2.5}$ and 2011 for NO_2. However, MEP data is unavailable for both NO_2 concentrations and $PM_{2.5}$ concentrations before 2011 for NO_2 and 2013 for $PM_{2.5}$. This means that at no point does the MEP data show an increase in average pollution levels for these two important measures of air pollution. The data consistently shows a decrease in pollution every year, since data was not collected until after 'peak' pollution concentration had been reached in 2009/2011 respectively. In contradiction to some media speculation, increasing Chinese media reporting around air pollution, and the 'airpocalypse' of winter 2013, took place *after* the peak of Chinese pollution, and *after* the central government had had considerable success in reducing pollution during the 11th five year plan (2006-2010). Nevertheless, air pollution as an important political problem and public issue increased greatly after 2013, and air pollution rapidly decreased during the period 2013-2016, before slightly increasing during 2016-2018. However, despite the huge strides made in reducing pollution during the years since 2008, the overall $PM_{2.5}$ levels remain six times above WHO guidelines (Zhao, Wang, and Hao 2024). In the next chapter I discuss the main policy instruments the government used to affect pollution, and how air pollution is affected by a huge number of different policy areas, not restricted to 'environmental policy'.

5 Ideology, law and policy

"*The whole party must adhere to the party's ideological line*[22]"

— Xi Jinping, 2016

This chapter lays out the most consequential government interventions for air pollution in law and policy, and includes important changes made to official Party and state ideology. Analysis of government documents cross referenced with the pollution time series outlined in chapter four indicates there was not a single obvious law or policy responsible for pollution reduction. Furthermore, neither does pollution reduction appear to be an aggregate function of all the policies summed together, since each appears poorly implemented, at least initially. Therefore, it is clear that pollution *did* decrease, but that there is no clear candidate mechanism to explain it. I suggest that the mechanism driving increased implementation of existing policies, together with the addition of new more stringent regulations are outside of the laws and policies themselves; a complex mechanism whereby central government *propaganda* works to indirectly affect implementation. Here, propaganda is defined not just as the work of the Party's Publicity/Propaganda Department (中央委员会宣传部), but more broadly as the conceptual approach of engaging in thought work (思想工作) in order to maintain a clearly defined and communicated Party ideological line (思想路线). This ensures that cadre at all levels of the Party and government have a consistent reference to guide their actions and policies. Aside from the largely slow-changing official ideology as collected in the Party and state constitutions, cadre may refer to leaders' written works on governance and ideology, speeches, official visits, and media coverage. Further, the timing and strength of laws and policies themselves may have an ideological as well as practical component; they function to signal the relative political importance of some policy area, and therefore signal to cadre which policies must be emphasised. I propose that ideology was used to signal the increasing importance of environmental issues to Party and government officials, which then affect local government planning and spending. There are various policy areas that influence air pollution; policies directly targeting environmental issues and others that have a significant

[22]"全党必须把坚持党的思想路线贯穿于执行党的基本路线全过程" (Communist Party of China 2016)

but indirect impact on air quality. While environmental law and policy is naturally important in air pollution mitigation, other laws and policies not directly related to the environment can have an extremely large effect. Due to the central role that fossil fuels play in the modern economy of China, pollution concentrations in Chinese cities are greatly affected by energy policy, industrial policy, transport policy, housing policy and (with the increasing importation of natural gas) foreign policy, as well as demographics and the global and national macro-economic situation. The legal and policy framework related to air pollution is not unified. It cannot be said that one single law, policy, or even policy area is responsible for the rapid improvement in urban air pollution over the period 2008-2018. The 2013 *Air Pollution Prevention and Control Action Plan* is widely regarded as a turning point in China's air quality policy (Q. Zhang et al. 2019; Feng et al. 2019), with nearly 300,000 hospital admissions avoided as a result (Liu et al. 2025). Studies concur on its effectiveness (Peng et al. 2025; Fang et al. 2025), while noting that Henan and Shandong remained outliers in northern China—underscoring the Plan's particular significance for the Jing-Jin-Ji region. By contrast, (Wu 2023) finds that the Plan had less impact in northern China than in the Yangtze and Pearl River Delta regions. The Action Plan itself relied upon a prior wholesale change in government attitudes towards pollution, and was itself only ever viewed as a stepping stone to more rigorous and systematic pollution reduction[23]. The *Action plan* exists within a network of other laws and policies, and could not exist without this prior framework. This chapter presents the Chinese environmental policy sector as itself a network of laws, policies and projects. The various documents that create these laws and policies can be viewed as a framework within which officials work. Party and government officials at the local level must understand and try to implement a huge number of different documents from different levels of the state. Laws and policies may sometimes contradict each other, or most often, there are not enough resources to pursue all policies equally (Ran 2013, p. 23; Birney 2014). Officials must choose between apparently conflicting requirements, the most obvious being that of local GDP growth, and by extension maximising local governments' tax take, as against implementing environmental laws and policies which would in many cases curb such growth: "central government provides political incentives that are often vague and internally compete and conflict with each other" (Ran 2013). In order to create change at the local level, central government must change perceptions of policy emphasis (Birney 2014). In this chapter I argue that substantive changes in environmental policy implementation cannot be explained

[23]The Action Plan may be classified as 项目'project'; it has specific and limited aims and is fully funded

without reference to important changes to Party and State ideology. The extreme smog events of winter 2012/13 in northern China appeared to be important in shifting China's leaders toward greater policy emphasis on air pollution . It led to a declaration of 'war on pollution' by Premier Li Keqiang in 2014′s National People's Congress. These events were preceded by significant amendments to the Party's constitution at the 18th Party Congress in 2012. During this congress, Hu Jintao's "scientific outlook on development" and the concept of "socialist ecological civilisation" (社会主义生态文明) were elevated to prominent positions within official Party ideology. The timing of these changes suggests that it was Hu Jintao's commitment to environmental policy that played a pivotal role in shifting the political focus. Xi Jinping's subsequent ideological commitment to environmental policy carried on the work of the previous Party Congress. The announcement of a "war on pollution" at the 17th People's Congress would likely not have been possible without the groundwork laid during the 11th Five-Year Plan (2006-2010), which ultimately led to the inclusion of environmental issues in the Party constitution. The 2013 *Air pollution prevention and control action plan* represents a sea-change in how local Party and Government leaders viewed air pollution, especially within the three control areas covered by the Plan. It appears that the Plan was the product of discussion by the highest leaders of Party and government, and the Plan's marked similarities with then existing policies (including 11th (National People's Congress of the People's Republic of China 2006) and 12th 5YP (National People's Congress of the People's Republic of China 2011)) indicate that instead of being a radical policy change, the Plan represents a *re-stating*, and *re-emphasis* of earlier policies. The Plan's success highlights the methods employed by Party and government leaders to influence cadre decision-making. By promoting the ideological concept of "socialist ecological civilization", Party leaders establish an overarching narrative that is reinforced through a number of concrete policies, laws, and funded projects, as well as through the assessment and evaluation of cadre performance (Birney 2014). Without concrete policy announcements, Party ideological lines may be ignored by local officials, and conversely without political emphasis of the larger Party ideological direction, particular policies The elevation of environmental thinking to a basic aim of the Party, and the promotion of environmental policies by important leaders through speeches, filters down to ministers and local leaders, indicating that cadres of all levels should place much more emphasis on environmental issues. More concretely, the priority of various policy areas is further strengthened by cadre evaluation measures (Ran 2013); environmental targets were likewise elevated to 'hard' targets after the 12th 5YP (National People's Congress of the

People's Republic of China 2011). Finally in 2018, ecological civilisation assured its place in Chinese politics when it was included as an amendment to the constitution of the P.R.C. As if to underscore the importance of this ideology, the Ministry of Environmental Protection was re-constituted as the Ministry of Ecology and Environment (MEE) in 2018, again signalling the new importance of environmental issues to Party and government officials at all levels. After analysing a range of documents, including laws, policies, Five-Year Plans, and projects, I categorise government interventions during the 2008-2018 period into three distinct phases, which I examine in turn below:

Summary	Term	Planning period
Gradualism and experimentation	Second Hu Jintao term (2008–2012)	11th Five-Year Plan (National People's Congress of the People's Republic of China 2006)
'War on pollution'	First Xi Jinping term (2012–2016)	12th Five-Year Plan (National People's Congress of the People's Republic of China 2011)
Consolidation and wider restructuring of energy infrastructure	Second Xi Jinping term (2016–2018)	13th Five-Year Plan (National People's Congress of the People's Republic of China 2016a)

Table 5.1: Major phases of environmental governance and policy emphasis

5.1 Background

The years immediately preceding this research include the 10th (2001-2005) five year plan, and the first two years of the 11th (2006-2010) five year plan. These were characterised by arguably the first serious attempt to improve air pollution through both post-combustion controls, and market mechanisms. Despite these attempts, large increases in fossil fuel usage and massive GDP growth largely overwhelmed any progress made. There was limited control of sulphur dioxide pollution during the 10th 5YP (National People's Congress of the People's Republic of China 2001), but improvements in coal-boiler efficiency nonetheless led to peak SO_2 emissions in 2006, and thereafter a marked decrease. During this period also, steps were made to add pollution targets to cadre evaluations (2005), including sulphur dioxide emissions and Chemical Oxygen Demand (COD, an indicator of water quality). However, these targets made little practical difference to evaluation since they were not 'strict' targets such as GDP growth rate, tax revenue growth, foreign and domestic investment, and number of protest 'mass incidents' and petitions (Ran 2013). The Energy conservation law (National People's Congress of the People's Republic of China 2018a) was another major milestone that is of particular interest due to its effect on fossil fuel usage: "Saving energy resources is one of China's basic national policies and that the state will give top priority to energy conservation". I will detail in the next chapter how energy conservation policies drove air pollution mitigation efforts in a case study of an urban heating company. As if to signal the increasing importance of environmental issues, in 2007 the *National Leading Small Group for Addressing Climate Change and Energy Conservation and Emission Reduction Work (*国家应对气候变化及节能减排工作领导小组*)* was created under the State Council, and headed by the Premier. The *State Environmental Protection Agency* was elevated to full Ministry status, becoming the *Ministry of Environmental Protection* (环境保护部) in 2008. And finally, in 2008 the *National Energy Administration (*国家能源局*)* was created under the State Council in order to centralise policy-making and governance in the energy sector, long a highly fractured policy space. The major changes affecting environmental policy are contained within the 'Five year plans[24]' (5YP's) produced at three main levels in the state hierarchy: national, provincial and municipal. Five year plans are the most important policy documents that China produces (Kennedy and Johnson 2016, p. 1), containing a broad look at the economic and social issues of importance to Chinese leaders, together with headline 'targets' of economic and social development, as well as environmental targets. Five year plans have diminished in importance as China moved from a centrally planned socialist economy to a 'socialist market economy' (Hu 2013). However, Angang Hu (Hu 2013) claims 5YP's retain considerable importance as a 'public affairs governance plan'. Whereas a centrally planned economy seeks to allocate resources based on a fixed plan, with typically fixed economic targets, China's socialist market economy seeks to utilise market mechanisms to allocate most resources,

[24]Starting from 2006, the 'Five year plan' '五年计划' was re-named as a '五年规划', which softens the word 'plan' closer to that of 'guide'. However, its official English translation remains 'five year plan'

while using planning to supplement and guide the market. Five year plans also serve to highlight the importance of various policy areas for officials at all levels, emphasising some, while de-emphasising others. The national five year plan is produced first, and thereafter provincial leaders study this document in depth, and produce their own five year plan, which has to both follow the main direction and emphasis of the national plan, whilst making sure that the provincial plan meets the unique circumstances and challenges of the province. Similarly, municipal plans are produced by studying closely the national and provincial plans, and producing a policy plan that meets the circumstances of the city. This process of policy planning must follow the overall 'direction' of the higher-level government, whilst being careful to uniquely tailor the policy to local circumstances.

5.1.1 Overview of concrete law and policy actions

The table below provides an overview of key laws, plans, and bureaucratic changes in environmental governance. These represent the central government's concrete actions in the environmental policy arena; those designed to affect physical changes to investment, infrastructure, and assessment of pollution. The next sections will provide detailed explanations for these changes, divided chronologically. Furthermore, changes to the *ideological line* are added to this, reinforcing the increasing political importance of environmental policy, and how these create positive feedback loops further influencing policy implementation.

Date	Law/Regulation	Plan	Bureaucracy
1988 1995 2000	Air Pollution Prevention and Control Law		
1996 2000 2016	Ambient Air Quality Standards		
1998			Creation of SEPA
1998 2007	Energy Conservation Law		
2001		10th Five-Year Plan	
2003 2012	Regulation on Levy and Use of Pollutant Emission Fees		
2003 2012	Cleaner Production Promotion Law		
2003	Environmental Impact Assessment Law		
2004		Medium and Long-term Energy Conservation Plan	
2006		11th Five-Year Plan	
2006			Cadre Responsibility assessment
2007		Medium and Long Term Development Plan for Renewable Energy	
2008			Creation of MEP
2008			Creation of National Energy Administration
2010			Creation of National Energy Commission
2012		12th Five-Year Plan	
2013		Air Pollution Prevention and Control Action Plan	
2014	Environmental Protection Law		
2016		13th Five-Year Plan	
2018		Blue Sky Action Plan	

Table 5.2: Overview of major central government actions on air pollution, 1988–2018, source: author

5.2 2008-2012: Gradualism and experimentation

This period coincides with the leadership of Hu Jintao, and includes several important developments in both the fitting of post combustion controls, and the improvement in coal boiler efficiency which led to a steady improvement in air pollution. The *Regulations on Open Government Information* (2007) came into effect in 2008, and was important in making available many concrete details of government operation that had previously been kept secret; especially relevant in environmental policy is local government statistics on air pollution. The State Environmental Protection Administration (1998-2008) was placed directly under the State Council's control, and was unable to vote in State Council plenary and executive committee meetings (Qiu, 2009, 5; Organic Law of the State Council, 1982). The newly created

Ministry of Environmental Protection[25] (2008-2018) was created in order to increase the bureaucratic power of the environment agency (Tsang and Kolk 2010). This event was hailed as a bureaucratic breakthrough for the environment agency; it would finally have the independent power needed to act strongly against polluters, and would be less likely to be sidelined in local government power struggles. This period also coincided with the Revised Energy Conservation Law (2007) coming into effect. This law emphasised that reducing fossil fuel usage was a key national aim, and thereafter efficiency improvements in coal use were an important feature of provincial and city policymaking (Li et al. 2011). The Energy Conservation Law plays a key role in the case study of a winter heating SOE, discussed in chapter six; government documents cite it as the primary motivation for establishing the SOE. Another important development was that of short-term pollution control. The 2008 Beijing Olympic Games was a major event, highly important for China's international image. An air pollution mitigation strategy was devised consisting of traffic control measures, increased public transport, industry closures in Beijing and surrounding areas, as well as cleaner industry production processes, and new parks and the planting of extensive vegetation (Schleicher et al. 2012), with a total of 85.4 billion RMB allocated to Beijing alone for this purpose. The fourteenth phase intensive control program's '5655 strategy' included: 5 schemes to control coal combustion; 6 vehicle emission control schemes; 5 schemes for retrofitting and upgrading of manufacturing processes; and 5 schemes to reduce dust from bare earth (Fang, Chan, and Yao 2009). This experiment in short-term air quality control was successful in reducing $PM_{2.5}$ by around 50%. Other cities took notice of this success, and similar policies were repeated in other cities. Note that these are short-term actions, and did not increase the overall strength of environmental governance (Gilley, 2012; van der Kamp, 2021). Note that where short-term actions involve investment in physical infrastructure, such as more efficient boilers, they produce long-term effects. The National energy commission (国家能源委员会) was created in 2010, under the State Council, and chaired by the Premier. It is charged with coordinating overall energy policy, and is thought to further centralise energy policy-making, given the lack of institutional power of the *National energy administration* (Tsang and Kolk 2010). Coal production and use is the number one driver of Chinese air pollution, and the creation of the commission serves to create the conditions for top-down control in the production and use of coal, which later culminated in sharp decreases in coal

[25] As discussed in chapter three, elevating the environment agency to a full ministry provides a distinct period for studying changes in pollution levels and policy while maintaining the agency's bureaucratic status as a constant factor

production due to the State Council's 2013 (revised 2016) *Guiding Opinions of the State Council on Resolving Serious Production Overcapacity Conflicts* (Shi, Rioux, Galkin, 2018).

5.2.1 Ecological civilisation

Hu Jintao used the phrase *ecological civilisation* in his work report at the 17th Party Congress in 2007[26] and by 2008 its usage in media and academic papers had increased several-fold.By the 18th Party Congress in 2012 it had become a central concept of Chinese development:

> "The Communist Party of China leads the people in promoting socialist ecological civilisation. It raises its ecological awareness of the need to respect, accommodate to and protect nature; follows the basic state policy of conserving resources and protecting the environment and the principle of giving high priority to conserving resources, protecting the environment and promoting its natural restoration; and pursues sound development that leads to increased production, affluence and a good ecosystem. The Party strives to build a resource-conserving, environmentally friendly society; and preserves China's geographical space and improves its industrial structure and mode of production and the Chinese way of life in the interest of conserving resources and protecting the environment. All this is aimed at creating a good working and living environment for the people and ensuring lasting and sustainable development of the Chinese nation."
>
> — Constitution of the CPC, General Program, Paragraph 17

Hu Jintao's speech to the 18th Party Congress (2012), as outgoing Chairman of the Party, included the promoting of ecological progress as a key section: "Promoting ecological progress is a long-term task of vital importance to the people's wellbeing and China's future" (Hu Jintao report to CPC congress, Section 8, introduction). Note that the important change to the Party's constitution, with the addition of 'ecological civilisation', took place before the air pollution 'airpocalypse' event of winter 2012/13, which is often cited as a turning point in how China's top leaders view environmental concerns. The concept of ecological civilisation helped frame the environment as a 'political narrative' (Geall and Ely 2018). The heavy smog in northern Chinese cities, but especially the capital Beijing, became a talking point on

[26]Prior to the 17th Party Congress, it had only been used by a handful of academics and a forestry report from 2003 (Decision of the CCP Central Committee and the State Council on Accelerating the Development of Forestry-中共中央国务院关于加快林业发展的决定)

Chinese social media and state media over that winter (Ye and Jia 2025). Citizens in Beijing used online tools to receive air pollution indicators almost in real time, and the Chinese media compared the event to London's 'Great Smog' of 1952 (Li, Qiao, and Shi 2019). While air pollution became a serious issue in public consciousness due to the smog, the Party was ready for such a change in public opinion, and did not ignore it. Instead of the smog event causing a change in government policy, it makes sense to think of the later 'war on pollution' as arising from both a naturally occurring public outcry over air pollution, together with the ideological groundwork that had already been laid by Hu Jintao. Without the prior ideological changes to Party constitution, the heavy smog of winter 2012/13 may well have been ignored or downplayed by the state media.

5.3 2013-2016: War on pollution

The 18th Party Congress coincided with the handover of Party leadership to Xi Jinping and the elevation of Li Keqiang to premier of the State Council. It also promoted *ecological civilisation* to the Party constitution, and thereafter environmental concerns were given more weight in Party and Government speeches. Li Keqiang's speech to the 12th National People's Congress (Work report to Congress, March, 2014) contained a section on improving China's natural environment through implementing ecological civilisation, which emphasised several policies made in the 12th 5YP (National People's Congress of the People's Republic of China 2011): eliminate 50,000 small coal-fired boilers, desulphurisation equipment fitted to 15 million kW of electricity capacity, denitrification equipment fitted to 130 million kW capacity, dust removal fitted to 180 million kW capacity, and 6 million 'yellow-label' and older gasoline powered vehicles eliminated (Work report, section 9, 2014). Such high-profile announcements augur an ideological shift towards environmentally sustainable development, and appear to have been further strengthened by public sentiment after the northern China smog of 2012/13. In early 2014, Li Keqiang announced to the State Council his intention to fight a 'war on pollution' (State Council Office, 2014). This rhetoric explicitly elevated the importance of air pollution to the same level as the ongoing 'war on poverty'. More explicit emphasis on pollution by Party and government leaders lead to the production of the 2013 *Action Plan*, a series of hard air pollution targets directed at the leadership of Beijing, Tianjin and Hebei. Meanwhile other factors were important in changing the status of environmental issues in the bureaucracy: increasing the importance of environment in cadre evaluation; the implementation of new air quality standards (2012); and the 'open data' initiative which gave ordinary Chinese citizens access to up-to-date air pollution data in their city.

5.3.1 Cadre evaluation

How Party cadres are evaluated, and thereafter promoted, moved horizontally, or demoted within the Party and government structure, has included an evaluation of 'environmental protection' since 2006 (Central Organisation Department, 2006). The addition of environmental protection to cadre evaluation assessment forms ensured that environmental protection was not only the responsibility of the local environmental protection bureau (EPB), but government cadres and Party cadres also. This includes important members of the city government committee, including Party secretary and city Mayor. The head of the local EPB is not likely to be amongst the most important members of a municipal government, and so will not regularly sit on the committee. Theoretically, changes to cadre evaluation represents a great increase in the bureaucratic importance of environmental protection. However, local cadre are often in position for only 3-4 years (Eaton and Kostka 2014), which may adversely affect the environmental policies they choose to implement. Referring to 'authoritarian environmentalism', some scholars propose (Beeson, 2010; Gilley, 2012; Eaton, 2014) that short-term roles create perverse incentives to produce 'quick, low-quality' environmental actions that are highly visible, and able to be completed within a short timeframe. Short-term actions may be more likely to receive positive evaluations as particular in-post officials may be identified as promoting and signing off on policy decisions. Meanwhile, long-term policies may not yield positive evaluations, as the officials responsible may have already been reassigned, potentially to another province, by the time these policies show results. Further, it has been observed that cadre evaluations may not always be strictly implemented according to the formal guidelines, but instead given importance in line with the policy preferences of their superiors (Eaton and Kostka 2014). This situation seems to have greatly improved after 2013, with the importance of air pollution much more likely to be reflected in cadre evaluations, especially in larger more developed cities. This may be due to leadership rhetoric around pollution serving to signal other Party and government officials of a change in policy emphasis.

5.3.2 Air quality standards

Air quality standards (Standardization Administration of the People's Republic of China 2012) were implemented nationwide after 2013. They included improved air quality standards for a number of pollutants, with the addition of several important pollutants for the first time, including $PM_{2.5}$, O_3, CO, NO_2, as well as SO_2 and PM_{10}, which were included in previous iterations. In 2012, the pilot roll out of the new standards were implemented in 73 ‘key’ cities, all of them prefecture-level cities, thereafter being expanded to 113 key environmental protection cities. By 2015 it was expanded to all prefecture-level cities, and in 2016 it was finally implemented nationwide (Wang, Yin, and Chen 2019). Air quality standards are divided into two classes: class I is stricter, and should be implemented in areas of designated natural parks and other protected areas; class II standards are less strict, and these are applied to all other areas, i.e. urban residential, mixed use and industrial areas and rural areas not otherwise designated as class I (Standardization Administration of the People's Republic of China 2012). Annual average $PM_{2.5}$ standards are 15 μg/m3 for class I areas, and 35 μg/m3 for class II areas. However, the new standards did not have an immediate positive influence on city government air pollution implementation. Since most Chinese cities failed to reach the previous (lower) air quality standard, it seemed unrealistic for many cities to be given a new, higher standard to reach. Analysis of the impact of higher air quality standards reveal an ambiguous link between standards and real-world air pollution concentrations (Wang, Yin, and Chen 2019). The changes to a new, stricter pollution standard were implemented in many prefecture-level cities prior to the large-scale smog event across northern China in winter 2012/13. This was highly visible and publicised in large cities like Beijing and Tianjin, although its effects were often worse in other smaller cities. If such a raising of standards did not coincide with a huge increase in the bureaucratic power of local EPB offices, they could not directly affect how cities governed air pollution. However, new standards may have helped in planning and allocating funds for city projects; new air pollution standards should be applied to existing polluting enterprises as well as new projects. The effects of such standards may be expected to influence government decisions perhaps several years after the nominal start date. Certainly, there was a marked decrease in air pollution over northern China during this time. However, in addition to this, higher air quality standards serve as a further signal of intent: it implicitly raises the importance of air pollution in government and Party officials of all levels, which in turn may have knock-on effects for how cadre evaluation and other environmental policies are implemented.

5.3.3 Open government

One of the challenges of air quality governance was the lack of data available, and the possibility of that data being falsified. The *Regulations on Open Government Information (政府信息公开条例)* (State Council of the People's Republic of China 2007) sought to make government disclosure of information the norm, except where security or other laws prohibit this. This regulation has far-reaching effects for government data of all kinds, including policy documents, financial data, department structures and leadership. Research on the extent to which municipal governments publish pollution measures and environmental inspection reports[27], note a huge increase in air pollution data available since 2008. Environmental supervision records are short documents produced from an in-person supervision visit by the environmental protection bureau; as such they represent raw data as to issues discovered upon inspection. From a low base in 2008, with only a small number of the 120 cities studied publishing most of their environmental inspection records, there were large increases in published data after 2014, and 2016, with further large increases in 2017 and 2018 (公众环境研究中心 2020, p. 13). These increases may be correlated with changes to the Environmental Law (revised, 2014, ch.5), requiring government to release environmental measures and reports, and to make them publicly available (公众环境研究中心 2020, p. 13). Statistical analysis by PITI, and others, suggests that city governments who freely publish most of their environmental reports and other data are very likely to be amongst the least polluted cities, or have great improvements in air quality (公众环境研究中心 2020; Wang, Zhang, and Guo 2025). Of course, such analyses cannot indicate whether there is a causal connection between these outcomes, or whether in fact the least polluted cities are most likely to publish data simply because it makes them look good. However, the publishing of pollution data has

[27]Pollution Information Transparency Index (PITI) is produced by Chinese NGO the Institute of Public and Environmental Affairs (公众环境研究中心), together with the international NGO, Natural Resources Defense Council (NDRC)

increased across all cities over time, and together with an increasing public concern paid to air pollution, indicates at least an increasing acknowledgement amongst the least economically developed cities that GDP growth is not the sole measure of good governance.

5.3.4 The Action Plan

Analysis of policy changes and their effects over the whole period, 2008-2018, indicate that the *Air Pollution Prevention and Control Action Plan (大气污染防治行动计划)* (State Council of the People's Republic of China 2013), and the high intensity smog events of 2012-2013 hold great significance for the overall decrease in pollution. On this view it was the events of the 'airpocalypse' of 2012-2013 that created public pressure for central government officials to take air pollution much more seriously. The Action Plan (2013-2017) was the single most important policy document requiring local governments to take air pollution more seriously, and initially covered three key polluted areas[28]: Beijing-Tianjin-Hebei; Pearl river delta; and Yangtze river delta. In examining the Action Plan itself, it is remarkable in the breadth and depth of targets: it includes a large range of policy issues, from the fitting of post-combustion controls to new environmental regulations and bureaucratic structures. The Action Plan contained both 5 year targets, as well as much longer term ambitions (promote the 'circular economy', promote public participation in fighting pollution). An analysis of changes to $PM_{2.5}$ from 2013-2017, point to six main policy drivers: "Strengthening industrial emission standards, phasing out small and polluting factories, phasing out outdated industrial capacities, upgrades on industrial boilers, promoting clean fuels in the residential sector, and strengthening vehicle emission standards" (Q. Zhang et al. 2019). Zhang analysed these changes as proceeding from the *Air Pollution Prevention and Control Action Plan.* PM2.5 should be reduced by 25% in Beijing-Tianjin-Hebei, 20% in the Yangzi river delta , and 15% in the Pearl river delta. Beijing's $PM_{2.5}$ annual average should not exceed 60μg/m3 (State Council of the People's Republic of China 2013). Remarkably, all of the areas met, and in many cases exceeded the targets set by the Plan. According to analysis (Q. Zhang et al. 2019), of all the measures promoted by the Action Plan, it appears as if the six measures that made the most impact on pollution abatement were mostly of the 'direct intervention' type, with the exception of 'strengthening

[28]The later Action Plan (中华人民共和国国务院 2018) expanded the areas covered to all Chinese cities of prefectural level and above. However, air quality targets were not as ambitious as the 2013 Plan, being in line with air pollution targets in the 13th Five Year Plan (2016-2020)

industrial emission standards'. However, this measure also can be thought of as a direct intervention, since specific technological changes were made to bring factories in line with new emissions standards. It appears therefore that direct interventions were hugely helpful in reducing emissions, much more so than indirect interventions such as strengthening the institutional power of the MEP. However, this may be mistaken. As can be seen by (Q. Zhang et al. 2019) the research methodology, measurement of pollution abatement was achieved by assessing the emission improvements brought by specific technological changes. This method is much easier to measure technological changes than, for example, institutional changes brought on by improvements to the bureaucratic power of the MEP. Although the Action Plan was undoubtedly highly important in reducing air pollution, the Action Plan was not significantly different in content to the policies that had come before it, although the targets themselves were more ambitious. The Action Plan contains policy aims that are very familiar from two previous 5YPs, the 11th 5YP (2006-2010) (National People's Congress of the People's Republic of China 2006), and the 12th 5YP (2011-2015) (National People's Congress of the People's Republic of China 2011). The Plan includes thirty-five separate points divided into ten categories. While the Plan is more detailed on some points, each of the ten categories has been dealt with by previous five year plans, in many cases using the same language that is familiar from many years of Chinese central planning: reducing 'backward production'(落后生产); increasing efficiency; reducing energy use. Evidence from Chinese official data and satellite data (analysed in chapter four), broadly found agreement that peak emissions and peak pollution concentration was reached around 2011 for NO_x and 2009 for $PM_{2.5}$, with evidence for SO_2 being ambiguous. The Action Plan is therefore not the primary cause of a turning point in Chinese air pollution. Given the similarities in content between the Plan and relevant parts of the 11th and 12th 5YP, the importance of the Plan in reducing air pollution is not straightforward. Instead, the Plan might be better understood as a message from the highest levels of Party and State Council to Party and Government officials at all levels of the state, and to the public at large. This message is plainly seen in the provincial-level work reports presented to the provincial People's Congress and People's political consultative conference (CPPCC). Through textual analysis of some 600 documents over the period 1998-2017, (Shi, Shi, and Guo 2019) noticed a clear change in emphasis in the priorities of provincial leaders towards the environment: from 2007 onwards, references to the environment rose more than three times higher than levels before 2004, and stayed at consistently high levels until 2017. Party and government officials were keenly aware of the new ideological line on environment, and were careful to mention this in work reports. It is evident that the political emphasis had shifted towards environmental policy from 2007 onwards, in line with Hu Jintao's new ideological position.

5.4 2016-2018: Restructuring and consolidation

The 13th 5YP (National People's Congress of the People's Republic of China 2016a) was passed by the fourth session of the 12th National People's Congress in March 2016. Although air pollution itself was not quite as prominent as in the 12th 5YP, this is perhaps due to the great improvements in air quality that took place since 2010. Rather, the 13th 5YP greatly emphasised issues in China's energy network, its industrial production, and strictly enforcing 'functional zones' where polluting activities are to be allowed, restricted, or outlawed entirely. This work requires more planning and is much more capital intensive compared to the addition of post-combustion controls, which contributed greatly to the reduction in air pollution from 2013-2017.

5.4.1 Infrastructure

Of the changes to energy policy, the shift from coal to natural gas boilers (gasification) in power plants, industrial processes, and domestic 'district' heating is particularly important, as well as an increase in 'clean' electricity sources from hydropower, wind, solar and nuclear power stations. Added to this, changes to electrical grids were accelerated with Ultra High Voltage (UHV) transmission being given more emphasis (Gohli 2022). This further reduced coal-fired power plants in eastern China, as electricity is transmitted from sites in western China such as Xinjiang. The revised (2015) Law on Prevention and Control of Air Pollution (National People's Congress of the People's Republic of China 2018b), updated the previous air pollution laws, and stipulated several important regulations, including the washing of coal to reduce sulphur and dust (National People's Congress of the People's Republic of China 2018b, ch. 4,sec. 33), reducing the use of coal as primary energy source (National People's Congress of the People's Republic of China 2018b, ch. 4,sec. 32). Building on attempted reforms to the electricity production system in *Power system reform scheme (*发电力体制改革方案*)* (State Council of the People's Republic of China 2002), the State Council published its *Suggestions for deepening reform of the power system* (National Development and Reform Commission of the People's Republic of China and National Energy Administration 2015), also known as *'Document no. 9'*. It aims to implement the marketisation of electricity generation, ensuring that local government and electricity generating SOEs are separate. While these marketisation plans have been difficult to implement in full, they have succeeded in increasing pressure on SOE electricity prices to more accurately reflect production costs. This process has tended to result in more concern in reducing coal usage, increasing production efficiency, and thereby reducing pollution emissions from electricity producing coal plants (Zeng et al. 2016), although (You and Zhang 2023) finds that decentralisation of county power has increased pollution by around 2%. The 13th 5YP's emphasised renewable energy and low-emission electricity production, with a target of 27% of total electricity generation sources to be renewable by 2020. This was exceeded, with nominal 38% of installed capacity being renewable sources by 2018 (Fan, Zhao, and Yang 2020). However, installed capacity only represents the headline figure of maximum possible electricity generation. Actual electricity generation from renewable sources will be much less, and of the electricity generated at source, a smaller proportion of this will be available in domestic and commercial uses at any one time. In 2019, installed capacity reached 39.5% of total capacity, but actual generation was only 27.9% (Yu et al. 2022, p. 2). The Air Pollution Prevention and Control Action Plan for Beijing, Tianjin, Hebei (BTH) and Surrounding Areas in 2017 aimed to reduce coal usage in small boilers in the 2+26 area (Beijing and Tianjin plus 26 surrounding cities in Hebei, Shanxi, Shandong and Henan). This was to be achieved through the retrofitting of natural gas boilers for winter heating and cooking, or through CHP (combined heating and power) systems where possible. Although the campaign led to a reduction in $PM_{2.5}$ of around 17%, with a 34% reduction in SO2 over the whole area (S. Wang et al. 2020, p. 44), it was badly mismanaged. Many residents reported that their schools, businesses and residential coal boilers had been removed, but no gas replacements were fitted, leaving residents without any heat in winter. Where gas boilers were fitted, there were also reported problems of a lack of natural gas supply. The State Council published a new Action Plan to update the 2013 document, which concluded in 2017. The *Three-Year Action Plan for Winning the Blue Sky Defence Battle (*打赢蓝天保卫战三年行动计划*)* (中华人民共和国国务院 2018) set out further goals to improve air quality. The new Action Plan expanded its scope from the three major economic areas of the 2013 Plan, to include all cities in China, which must reduce air pollution to 18% below average pollution in 2015.

Environmental Protection Tax Law (环境保护税法) (National People's Congress of the People's Republic of China 2016b) was not implemented until 2018, but significantly changed how tax is collected, bringing an end to the previous 'pollution discharge penalty fee' for polluting enterprises. This fee was administered by the local environmental protection bureau, and therefore subject to possible local protectionism in the case of larger, more important enterprises, or simply to a lack of administrative power- some companies would simply ignore payment demands from local EPBs. The new law instead replaced this system with a new environmental tax, which is payable by all enterprises that release pollution, and to be administered by the local tax bureau. This change in taxation should make it easier to collect fees from polluting enterprises, and since the tax take is kept by local government, should greatly decrease previous problems of protectionism.

Vertical environmental management system (保机构监测监察执法垂直管理制度) (General Office of the Communist Party of China Central Committee and General Office of the State Council 2016) started to be utilised as a pilot programme in some locations starting from 2016. It represents a systemic change to how environmental issues are managed: leading officials of city environmental protection bureau are appointed and dismissed by their superiors at provincial MEP departments, likewise the provincial MEP office will be responsible for environmental supervision, monitoring, investigation of the cities under its jurisdiction (Zhou 2020, p. 12). City-level offices are therefore relegated to carrying out the orders of their provincial superiors, instead of running the city bureau with the *guidance* of their superiors. Similarly, at the level of county and township MEP offices, these will be under the control of their direct superiors at the city MEP bureau. This arrangement is designed to ensure that local protectionism does not affect the work of the MEP; provincial-level MEP departments are far less likely to be swayed by local concerns of GDP, tax take or employment at the city level than the local government would be (Ma 2017). Improvements in the local power of MEP bureaux may therefore be expected to increase the ability of MEP officials to work according to environmental laws. There is limited evidence that this improvement has actually occurred, however.

Ecological civilisation Finally, in 2018 along with the elevation of "Xi Jinping Thought on Socialism with Chinese Characteristics in the New Era", ecological civilisation was included into the constitution of the People's Republic of China: "Promote the coordinated development of material civilization, political civilization, spiritual civilization, social civilization, and ecological civilization"[29] (Preamble to the Constitution of P.R.C., amended 2018). This further strengthens the impression that environmental issues are an indivisible part of economic development, and therefore that officials in all levels of government must take environmental problems seriously.

5.5 Summary

Scholars have long emphasised the poor implementation of environmental laws. From these questions, a large literature on the 'implementation gap' has developed. This literature explains local government's reluctance to strictly follow environmental laws as being a consequence of several issues: environmental considerations tend to reduce economic growth and cadres are incentivised to increase GDP growth; the environmental agency is bureaucratically weak and unable to overpower local government wishes. According to this interpretation, the challenge is for Chinese bureaucrats to increase the power of the environmental ministry, ensuring that state and private enterprises will take the necessary changes to improve their emissions in line with environmental law. This narrative of bureaucratic weakness is highly supported by decades of empirical evidence. Given the improvements that have been made to air quality over 2008-2018, does the evidence support an improvement in the implementation of environmental law? This chapter supports some improvement in implementation being due to increasing bureaucratic powers. However, these improvements are overshadowed by much greater changes caused by policies with a direct and indirect effect on major polluting sources, which can be categorised into three main policy areas: environmental policy; energy policy; and economic policy. In examining the policies that play a role in air pollution policy, there is a natural inclination to focus upon those policies that are explicitly concerned with pollution and environmental protection.

[29] "推动物质文明、政治文明、精神文明、社会文明、生态文明协调发展"

These are policies that are explicit in reducing pollution by, for example, mandating use of de-sulphurisation, de-nitrification, and soot reduction technologies in boilers. Similarly, policies encourage replacing outdated technology thus increase energy efficiency, and hence the reduction of emissions; these policies are responsible for reducing use of coal in industrial processes by significant volumes (Mao, Zhou, and Corsetti 2014). However, although reducing air pollution is part of the reason to increase energy efficiency, another significant reason lies in China's plan to increase the competitiveness of its' companies, both private and state-owned. Over time, policies evolved from improving the governance structures for air pollution prevention, including elevating the status of the Ministry of Environmental Protection (MEP), enhancing pollution measurement systems, and expanding the authority to impose fines on polluters to more direct interventions. The focus shifted to direct intervention in industrial and energy processes, such as installing post-combustion controls, closing inefficient boilers and factories, upgrading boiler systems and industrial processes, and promoting cleaner fuel use. This included transitioning to natural gas for electricity generation and heating, as well as expanding the use of hydro, wind, and solar power. The importance of greater emphasis on strict targets rather than market-based approaches may support claims of 'authoritarian environmentalism'. Targets for industrial production and economic growth have long been a part of 5YPs: while targets are strictly to be followed, the methods that local government use to produce growth are largely up to local cadres. This allows officials to experiment with policies according to local conditions. The inclusion of 'strict' air quality targets from the 11th 5YP (National People's Congress of the People's Republic of China 2006) onwards is therefore a tried-and-tested governance method, and may be expected to lead to greater emphasis on air quality issues by local cadres. Air quality targets do not only incentivise stricter pollution control; they may incentivise short-term pollution control over longer term, more effective solutions. There has been considerable increase in Party and government activity towards air quality issues over the period of the MEP, although starting from a relatively low base. From changes to Party ideology through *ecological civilisation*, to stricter air quality standards, a renewed legal base through the *Environmental protection law* (2015) and especially through planned policies and projects adopted by the Action Plan and 5YPs, large changes to industrial structure, energy usage, and development of service sector economic growth, have led to a significant overall reductions in coal usage. Therefore, large-scale changes in coal burning boilers are down to several different factors. It is unlikely that policy, or law, or hard targets for pollution abatement alone are responsible for such changes. The 2013 Action Plan essentially reiterates the environmental strategies outlined in the earlier 12th 5YP (National People's Congress of the People's Republic of China 2011), with some additions. Reissuing a plan that had previously been poorly implemented, only for it to later achieve significant success, does not seem logical. This perspective becomes more understandable if the Action Plan is viewed as a document given significant political emphasis, far more so than previous environmental laws, plans, and policies. It is difficult to analyse the political importance of a document viewed in isolation; there is little clue in the document itself whether it will be well or poorly implemented. Analysis of the context surrounding improved implementation of environmental laws, suggest that *policy emphasis* is an important factor. Changes to policy and law after around 2013 were only important because the *perception* of local government officials had been altered by a combination of ideological and policy measures. Without a change in how environmental issues are perceived, new laws and policies could have made very little difference. Conversely, ideological changes as identified in Party *think work* (思想工作), published in leaders' written works, speeches, and finally the Party and state constitutions, may be of little practical importance unless there are laws, plans and policies designed to carry out the concepts of ideological lines in concrete policy terms.

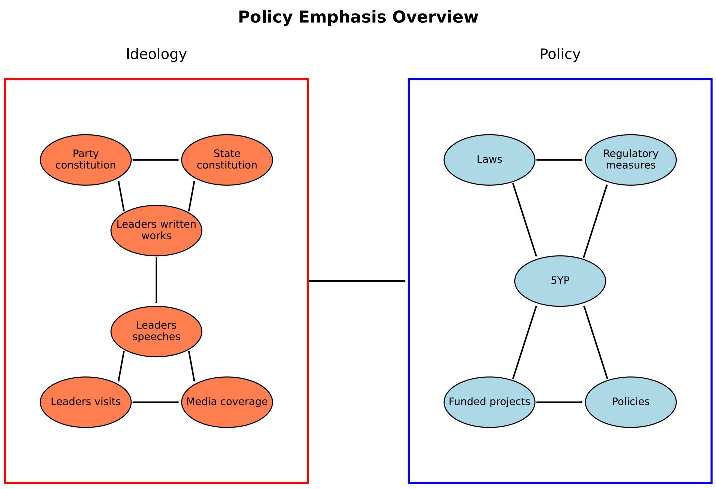

Figure 5.1: Illustrative diagram showing how policy and ideology may reinforce each other, source: author

The figure above highlights key factors that contribute to shifts in policy emphasis within a specific policy area. Policy and ideology are conceptualised as interconnected, with policy documents reinforcing greater ideological focus on environmental issues, and ideology, in turn, increasing policy development. Note that the figure is simply illustrative of potential interactions[30] ideology and policy may be effectively regarded as black boxes. The key argument of this chapter is that the ideology-policy mechanism is not simple, and may be best understood as a complex system. Without direct access to municipal committee meetings and the thoughts of the principal Party and government figures, selective policy implementation can only be analysed from its effects. However, local officials work within a large network, a system of governance in which systemic effects can be analysed. The production and amendment of higher-order ideological positions, and below these the laws and the policies that implement them should therefore be viewed as a whole network. The addition of a single law or policy may have little measurable impact on its own, but acting together with other laws and policies creates a network with systemic effects which are visible and measurable in the system as a whole:

> "Local officials have to devote significant time and other resources to interpreting and understanding central-level policies. They value the cadre performance evaluation system not only because their promotion or demotion is largely determined by it, but also because the evaluation allows them to differentiate the central government's symbolic policies from their real policies, allowing the local officials to implement them selectively."
>
> — (Ran 2013)

[30]The need for further research on national-level ideology and policy-making is outlined in chapter nine

6 Case study: Hebei district heating SOE

> *Efficiently save energy, reduce pollution, reduce heating costs, and reduce resident's heating burden*[31]
>
> — (Hebei Provincial Government 2012)

This chapter presents a detailed account of a winter heating SOE in Hebei province, with particular attention to three pollution mitigation projects, detailing their funding, government bodies involved, and the business model of a winter heating company in China. This is followed by *model 0.1* an abstract computational model of the company, using case study data to output approximate levels of air pollution over time. In the previous chapter I set out the relevant government laws and policies for air pollution as a whole, and concluded that central government and Party incentivised local officials to take pollution seriously by implementing a series of top-down legal, policy and bureaucratic changes that may ultimately derive from a shift in Party ideology. While this provides useful context for understanding environmental governance at the national level, it is too vague to serve as an effective model. The wide range of pollution sources across sectors, each with distinct market and regulatory conditions, requires that air pollution policies be sector-specific; reducing exhaust emissions from internal combustion engines requires a very different governance approach to that of coal-powered electricity plants. Having summarised the general conditions in physical pollution and national-level policy, this thesis will hereafter focus upon the district heating sector in particular. The winter heating sector is both a key polluting sector for northern China, and currently underserved in the political literature, exceptions being (M. Wang et al. 2023; Zhu, Liu, and Wei 2021). However, the winter heating sector has been the subject of a number of studies in atmospheric science journals with statistical studies of the government's 2013 *Air Pollution Action Plan* (Han, Yan, and Sun 2024) who note a 17% reduction in air pollution correlated with the Plan, although the research methods restrict the timeline to 2013–2020,

[31]"有效节约能源、减少污染，降低供热成本，减轻居民采暖负担"

after the Plan had already been put in place, and so any reduction in pollution is assumed to be due to the Plan. The 2017 *Winter Heating Plan for Northern China* has also been correlated with a 20% reduction in winter heating pollution (Xue et al. 2023). The literature also includes studies on the effect of winter heating on air pollution (Xu, Zhou, and Hao 2015; Lin and Ling 2021; Cai et al. 2020), and health effects of winter heating pollution (Fan, He, and Zhou 2020). District heating (集中供热) is the primary method of residential space heating in northern China, supplying an estimated 75% of all urban heating needs, primarily through coal-fired boilers (Ministry of Housing and Urban-Rural Development 2019). This approach to residential heating is also well-established in Russia, where heavily subsidised natural gas is used as the fuel source; the Chinese district heating system was based upon the Soviet model in the 1950s (Zhu, Liu, and Wei 2021). Denmark and Sweden similarly rely on district heating for a significant share of residential heating, employing a mixed private-public model. District heating operates similarly to individual boiler systems but on a much larger scale: water is heated and circulated through radiators within buildings, then returns to the boiler for reheating. In district heating, the boiler is designed to serve multiple buildings. Depending on its capacity, this could range from a few buildings within the same organisation, such as a school or hospital, to numerous buildings in a residential neighbourhood (小区). In the case of large Chinese district heating companies, a group of large boilers, each generating several megawatts (MW) of heat, supplies heated water to hundreds or even thousands of homes. While boilers of larger capacity are much more efficient in converting energy to heat, as the network of buildings served increases in size, much heat is lost in transporting water to homes sometimes several kilometres away from the heat source. Designing an efficient district heating system therefore involves balancing these physical constraints together with the local built infrastructure; high-density urban areas are much more suitable for district heating than low-density suburban or semi-rural areas. Due to Chinese cities being particularly dense, large-scale district heating has been recognised as a very energy-efficient heating method, and has been increasingly employed since the 1980s. (Zhu, Liu, and Wei 2021) analysed 146 central government documents related to winter heating policy, and categorised the development of winter heating governance over time into four periods: 1950s-1985; 1986-2002; 2003-2012; post 2013. Before the early 2000s, residents north of the Qinling-Huaihe line

were expected to receive free provision of winter heating, often together with free housing, provided through their work-unit[32] (*danwei,* 单位). Although the *danwei* system had been dissolved in the 1980s during the *Reform and Opening* period, the built infrastructure remained: many residential neighbourhoods (小区) built by state owned enterprises had coal-burning district heating systems. As new residences were built in the proceeding years, this pattern of providing public heating remained. However, the responsibility for providing this system was shifted to local government instead of workers' *danwei.* In this period during the 1990s to mid 2000s, the heating was sometimes maintained directly by local government agencies, or else by extremely small-scale SOEs whose responsibility did not extend outside the neighbourhood. I refer to this period of small-scale district heating hereafter as the *danwei* heating system. This system was often extremely energy inefficient; physical infrastructure was old, and there was little possibility in investment, as SOEs were unable to raise funds from increasing prices: the "primary goal of the enterprises was not their economic interest but their social responsibility" (Zhu, Liu, and Wei 2021, p. 3). In 2003 a pilot project (*Guiding Opinions on Pilot Work on Urban Heating System Reform*) aiming to reduce inefficient energy use in winter heating through increasing heat metering, reducing 'welfare heating' as described above, and improving housing energy efficiencies through renovation of housing stock was initiated (Ministry of Housing and Urban-Rural Development 2003). This was followed in 2005 by a national policy based on the successful pilot project, *Opinions on further promoting the reform of urban heating system* (State Council of the People's Republic of China 2005)[33]. It is these policies in the 2000s that initiated a large-scale re-organisation of the winter heating system, whereby small scale enterprises were consolidated into large-scale winter heating SOEs with large capacity boilers and the capability to provide heating to thousands of homes. I hereafter refer to these large capacity heating companies as 'winter heating SOEs'. The case study presented below essentially focuses on one particular example of this reorganisation, whereby hundreds of *danwei heating* systems were consolidated into a single *winter heating SOE.* The SOE was later subject to further investment in physical infrastructure through flue gas desulphurisation, and finally to a large-scale reorganisation with a local electric power plant into a Combined Heat and Power (CHP) system. A case study of the forces affecting a winter heating company aims to produce the most accurate micro-level evidence of how air pollution was actually improved over time. This micro-level evidence will

[32]See (Bjorklund 1986; Bray 2005) for an overview of the danwei system

[33]Note that in order to preserve the important central government policies in the winter heating sector as 'out of sample data', the case study, the subsequent core governance mechanism (chapter seven) and computational modelling (chapter eight) was done without knowledge of these important policies. This is important in validating the models produced in chapter eight

be used as the basis for chapter seven's core governance model that incorporates quantitative pollution data (chapter three), as well as law and policy data (chapter four), and case study data (chapter five). The core governance model is then used in chapter eight as the basis for a much larger computational model of winter heating governance. This chapter will present a case study of a state-owned district heating company in a city in Hebei province, with anonymised evidence from company records, and interview with a company insider. I present the company's role in providing winter heating in its context as a state-owned enterprise, with clear conditions and limitations on how company operations are performed, and with particular focus on how this relates to the funding of capital-intensive projects involved in improvements in pollution emissions. The above quotation from a Hebei government document succinctly highlights government goals and their relative priority. The evidence presented in this chapter clearly shows that while government is concerned with air pollution, the efficient use of energy resources (coal, gas, electricity, etc) is the top priority. In fact, it is this focus on reducing energy usage which drives a reduction in pollution, and a reduction in heating costs for the heating companies (and government). Lastly, there is a concern for the final cost of winter heating for consumers: the government regards economical winter heating provision as an important part of Northern resident's quality of life, and has consistently promoted ever greater heating coverage over several decades (Almond et al. 2009). These goals serve to emphasise that heating companies must pursue aims other than profit, and that their scope for increasing profits is greatly limited by laws and policies in particular ways. In effect, although the important 2005 national policy promoted the marketisation of the winter heating sector, and led to the creation of large-scale winter heating SOEs with highly efficient use of energy, SOEs are still largely bound by the same concerns as those in the *danwei* heating era; prices are strictly controlled, and winter heating is viewed as a public good. I provide evidence of three major pollution abatement projects, and show how they were largely funded by government bodies and banks, not through investment of profits from the companies' activities. I conclude that heating company pollution abatement projects are largely a function of government support, not as a result of pressures from regulatory bodies such as the Ministry of Environmental Protection (MEP). The projects undertaken to reduce air pollution are as a result of planned and funded government projects, not as a result of air pollution laws which force companies to improve pollution abatement technologies in order to reduce onerous environmental regulations. This directly contradicts the thesis that reduced air pollution must come as a result of increasing governance capacity, and particularly bureaucratic power of the environmental body (Jahiel 1998; Chan et al. 1995; Xiaoyun Qiu and Li 2009). It supports the thesis that improving air quality was achieved through top-down control, sometimes bypassing local government, or heavily emphasising projects that reduce environmental pollution (Rooij 2006; 2016). Such actions do not improve environmental governance capacity, but rather implicitly acknowledge *state incapacity* by directly taking control of environmental projects (D. S. van der Kamp 2023). I will use the data in this chapter to build the core governance mechanism in chapter seven. To that end, I am particularly focused on the power dynamics among various actors within the governance system, as well as the specific incentives and disincentives that heating companies and government bodies face. This analysis rests on the assumption that national laws and policies are often poorly implemented at the local level due to misaligned incentives for local actors. Heating companies, influenced by a range of local factors, represent the final link in the chain of policy transmission from central government, ultimately implementing air pollution policies based on local incentives.

6.1 Methodological notes

This case study is designed identify factors important at the lowest level of analysis, i.e. the factors affecting heating companies themselves. As with all case studies, it is possible that the particular factors affecting the case study are unique, and that it therefore is not indicative of the wider conditions facing the winter heating sector in general. These challenges to the generalisability of the case study are key to understanding the development of the core governance model in chapter seven, and the validity tests applied to the computational model in chapter eight. I will begin by outlining reasons to believe that the key factors influencing governance in the case study SOE are consistent with those affecting the majority of heating companies in northern China. Case studies are generally used in two ways in political science research. Firstly, as part of a qualitative study which generally aims to focus on detailed, 'thick' research (Geertz 1973), with the understanding that case studies are able to provide a fuller account of human motivations, and the complexity of real world dynamics. Secondly, as part of a mixed methods study (Creswell 1999; Guetterman and Fetters 2018); as a complement to statistical research, and with the understanding that case studies may be used to build a causal model where purely quantitative analysis may not (Ylikoski 2019). Building empirically-derived computational models requires that a number of factors must be taken into account. Researchers must tailor the model's outcomes to a particular level of abstraction; while a single case study may provide good data for a single detailed model, the nature of complex systems means that further abstraction to build a model of 'similar' cases is difficult to justify, since it cannot be assumed that similar dynamics exist across time or space (Janssen et al. 2010). Conversely, models based on statistical data do not provide evidence of causality, which is vital to providing agents' assumptions and priorities at the local level. These challenges must be addressed through the research design. In chapters four and five I have presented quantitative pollution data, as well as national and regional laws and policies. These data respectively target the higher, and middle levels of the entire air pollution network. While these remain important, research at the level of individual companies can provide evidence of polluting entities' needs and priorities at the local level of the network. Only case studies of individual polluting entities can provide evidence of causal interactions at the local level. Verifying the case study as representative of the larger winter heating sector, it is important to note in what ways it is a typical example of environmental governance in the sector. Briefly, the case study follows a linear model of physical infrastructure development observed in the national-level statistics on winter heating: *danwei* heating is replaced by SOE heating, which is then increasingly replaced by 'clean' heating sources, such as natural gas, CHP or renewable energy. Further, the timing of these case study events follow the provincial and national-level statistics. Analysis of empirical data in chapter eight shows that on average, provinces changed from a *danwei* to SOE heating system from 2004-2009, depending upon the province. In the case study, this occurred in 2009, precisely the same year as the Hebei province average. By 2016, the case study SOE had converted to 'clean' energy, while half of all winter heating was converted to clean energy in China by 2018. Statistically, the case study appears unremarkable. This provides some initial confidence that an in-depth examination is warranted. However, it is not the resemblance to statistical averages that enables the case study to support computational modelling. Rather, the essential transformation occurs in chapter seven, where the specific conditions of pollution metrics, project funding, company internal governance, and city and provincial government involvement are analysed against the hypotheses developed in chapter three. Here, the details of the case study are distilled to their most essential elements, disregarding many of the concrete circumstances of the case study to produce a generalisable governance mechanism.

6.1.1 Research ethics and consent

This chapter contains evidence from two principal sources: internal company documents of the heating company, and an interview with a company insider. While neither the company documents, nor the interview reveal personal information of a sensitive nature, the company documents reveal data which is not publicly available, as does the interview with the company insider. As such, I have been careful to anonymise the company itself, and the identity of the interviewee. Although it is unlikely that the company and the interviewee may be identified from those details, I have taken the further step of anonymising the city in which the district heating company is located. It is therefore extremely unlikely that anyone may be able to identify the company or the interviewee from the data presented here. Anonymising the identity of the company, city, or interviewee does not affect the analysis of data in any important respect. Hereafter, I will refer to the district heating company, a State-Owned Enterprise (SOE), located in Hebei province, as ‘the company’; the city in which the company is located I will refer to as ‘the city’, and therefore ‘the city government’ refers to the local government in that city, ‘city government financial bureau’ to the financial bureau of that city, etc. I received ethics approval from my research institution’s ethics board, both for using the obtained internal company documents, and for the interview with the company insider. I provided the interviewee with a description of my research and the purpose of the interview, together with an interview consent form. The interviewee was made aware, both in written and spoken form, that their identity would not be revealed in the research, and that they may withdraw their consent at any time, and that they would not appear in the research. The interview was conducted entirely in Chinese by the researcher.

6.2 Pollution abatement projects

I will examine three major, capital-intensive projects undertaken by the company, with the goal to increase energy efficiency, reduce air pollution, and decrease costs of heating to consumers. In 2009, the company was established to improve energy efficiency by consolidating numerous smaller *danwei* heating into a single, highly efficient entity. In 2012, a project was funded to improve post-combustion soot reduction and de-sulphurisation technology in coal boiler flues. In 2016-2021, the company received funding for a much larger project to eliminate the use of coal boilers entirely, and use Combined Heat and Power (CHP) technology to provide heat sourced from a local thermal electric power station. See Appendix for Project diagrams.

6.2.1 Project 1: SOE incorporation

The company, a State Owned Enterprise (SOE), was granted licence to operate in 2009, with initial capital investment of approximately 500 million RMB. It appears that the company was created due to city government incentives to service the heating needs in one part of the city. A key document detailing the plans for heating company infrastructure and future operations, "Company Central heating project", refers to it as a 'project' that came about as a result of government decisions, in particular reference was made to the "Heating Plan for City Centre and Industrial Agglomeration Areas (City Government 2008)", and "City Development and Reform Commission Investment Decision" (City Development and Reform Commission 2009). (Implementation Opinions on Ten Key Energy-Saving Projects in the "Eleventh Five-Year Plan" (City Government 2006)). Finally, it appears that the (Notice of medium and long-term special plan for energy conservation ("City Government Notice of Medium and Long-Term Special Plan for Energy Conservation" 2004)) and based upon the (Energy Conservation Law of the People's Republic of China (National People's Congress of the People's Republic of China 2018a)[34] was the most important government decision, taken by the National Development and Reform Commission to reduce the overall 'energy intensity', that is the amount of energy used to create a given increase in GDP. The special plan for energy conservation, 2004, planned to reduce the energy consumed to create 10,000 yuan of value, from 2.68 tons of coal in 2002 to 2.25 tons in 2010, and further reduce to 1.54 tons in 2020. The 2007 renewed energy conservation law also contained reference to a changing ideological line,

[34]The energy conservation law was amended in 2007, 2016, and 2018)

further increasing policy emphasis: “Saving energy resources is one of China’s basic national policies and the state will give top priority to energy conservation”. It appears that the creation of a new state-owned heating company, and the subsequent elimination of small boiler capacity was as a result of laws and policies whose aim was firstly to increase energy efficiency, and only secondarily to reduce air pollution. Primarily for reasons of energy efficiency, city governments strongly promoted the expansion of urban district heating: “central finance and provincial finance shall fully implement the transfer payment funds for areas with heating difficulties, and actively raise local finance heating special subsidy funds” (City Policies and Regulations on Investment and Construction of Central Heating Facilities (“City Policies and Regulations on Investment and Construction of Central Heating Facilities” 2009)). On the incorporation of the company, it planned to build a total of 25 km of hot water network and 13 million square metres of heated area, served by eight 68MW coal boilers. However, as of the first winter of operation, 2010, the company had built four 68MW boilers, and burned 148,000 tons of coal, and used 180,000 tons of water to serve 2 million m2 of heated area, both residential and commercial (Internal Company Document 2009a). The company never expanded to eight 68MW boilers, due to a project in 2016 to convert the whole company network to Combined Heat and Power (CHP) heat source. The company planned to keep SO2 emissions to below 793.7 tons per year, and also to “install continuous online monitoring equipment and connect this to the city environmental protection bureau” (“City Environmental Impact Statement” 2009). This appears to refer to CEMS (continuous emission monitoring system), stipulated in (State Environmental Protection Administration of the People's Republic of China (SEPA) 2007), and mandated to be fitted to all key polluters. Being a state owned enterprise, the company leadership had close links to city government, and the company leaders moved between government and company posts (Stanton 2024, 1.5). A major pollution abatement project detailed below gained funding from the world bank, again possibly due to the company having strong links with, and support by, local government. Of the total investment of around 500 million RMB, 300 million was received as bank loan, 5.5 million RMB was received as investment from the city environmental bureau itself (“City Environmental Impact Statement” 2009). The company was given a credit rating of AA (Internal Company Document 2008a), which is the second highest rating according to Bank of China standards, with a claimed return on investment of 9.2% (Internal Company Document 2008b). This very high credit rating for a company that has yet to demonstrate any business history is another reason to believe the company was strongly backed by the City government. The company's large-scale and efficient boilers with the addition of post combustion soot and desulphurisation controls serve to reduce the overall air pollution of households who previously had no access to district heating. Urban buildings without access to district heating may most commonly heat their homes using a small and inefficient open brazier, fuelled with coal briquettes; these produce pollutants at rates 100 times greater than efficient coal boilers (X. Zhang et al. 2019). For residents already with access to an existing *danwei* heating system, greater efficiencies in coal-fed boiler technology greatly reduce the amount of coal burned to produce winter heating. The company's initial investment application claimed that four 68MW boilers would replace the capacity of 181 existing small boilers, and would reduce coal use by 166,000 tons per year, decreasing ash and dust by 76,000 tons and sulphur dioxide emissions by 355 tons per year (Internal Company Document 2009b). The company did not need to build heating hot water pipes into homes and businesses, as they effectively took over the work of some 134 different small heating networks, most being property management companies attached to a residential area (小区物业公司), or heating networks attached to commercial and public buildings such as hospitals, banks, and military facilities. Each of these areas had their own coal fired boiler, which varied in size from 0.2MW to 35MW capacity, and ranged widely in coal resources used, from 20 tons to 4,000 tons per year (Internal Company Document 2009a). In effect the company sought to consolidate heating production into just a few very large boiler units, each with the capacity to burn 360,000 tons coal per year (Internal Company Document 2008b). In 2010 the company's four boiler units should burn 1,440,000 tons coal per year, and in 2015 the company's eight boiler units would burn 2,880,000 tons coal per year.

6.2.2 Project 2: Boiler post-combustion controls

In 2012, the company undertook a project to improve the post-combustion controls on their coal boiler flues. Their existing technology removed soot, through the relatively cheap and simple method of bag filters, which use powerful fans to force flue gas through a series of filters that collect particulates. The filter system needs to be maintained and the resulting deposits cleaned regularly to maintain effectiveness. The second pre-existing post combustion control was a 'wet scrubber' de-sulphurisation technology designed to reduce sulphur dioxide gas through the method of passing the flue gas through a chamber where an absorbing chemical, in this case limestone particles suspended in water, are sprayed. The sulphur dioxide reacts chemically with the limestone (calcium carbonate) to form calcium sulphite. However, these existing controls were deemed inadequate for a number of reasons: they failed to capture soot and sulphur dioxide in the quantities they were designed for because the limestone spray nodules had become clogged, and the flue tower interior had become covered in layers of soot and other particles, greatly reducing the efficacy of existing combustion controls (Company 2012), and resulting in sulphur dioxide levels which exceeded legal limits set by the *Boiler Air Pollutant Emission Standard, 2001*, which was later superseded by stricter standards in 2014 (Ministry of Environmental Protection of the People's Republic of China 2014). Therefore the cause for the company exceeding air pollution standards appeared to be the poor maintenance of the pre-existing post combustion system. In contrast, the company's annual report (Company Name 2012) stated that work to replace post combustion controls were carried out "in order to respond to the national requirements for environmental protection during the "Twelfth Five-Year Plan" period". This explanation seems to imply that refurbishment was part of a planned policy commitment, although it is not stated outright. During an interview with a company insider they stated that they had no direct knowledge of the environmental inspection leading to refurbishment, however unannounced or 'surprise' inspections were often controlled by company management. Inspectors were not allowed entry on-site until they had the permission of the management. They were therefore routinely left to wait at the company gates for perhaps half an hour or more until they were allowed entry. This period allows company engineers time to make sure the boiler and flue are working according to environmental standards (Stanton 2024, 1.3). Post-combustion controls are designed to be switched on and off for routine testing and maintenance procedures. This procedure therefore allows the possibility of switching off post-combustion controls as part of normal running procedure, and only switching these on when inspectors arrive. There is good financial incentive to switch off post-combustion controls due to the cost of replacing the chemical slurry used to react with sulphur dioxide and nitrogen oxides. The poor maintenance of the desulphurisation chamber could therefore be explained by infrequent use of this equipment. It is difficult to obtain accurate figures for the cost of running such post-combustion controls in China, however interview with a company insider suggests that it is considerable (Stanton 2024, 1.2). It is unclear whether the reason for this post-combustion control project was a failure to meet sulphur dioxide emission standards, either in automated emissions measurement (CEMS) attached to each of the four boiler flues, or else due to manual measurement carried out by officials of the local environmental protection bureau. Environmental records for this company are extremely sparse. Although Hebei province should release all environmental records, the city has not done so, and the only extant environmental records relating to the company are records of two fines in 2015, and one in 2022 (Ministry of Environmental Protection 2022a). All fines levied were set at the rate of 50,000 yuan; a relatively low amount, and it is possible that such fines were not a deterrence to the company. Hebei Province's *Twelfth Five-Year Plan for Energy Conservation and Emission Reduction* (Hebei Province National Development and Reform Commission 2012) was published just a month before the application for funds to refurbish post combustion controls was submitted, stipulating that enterprises designated as *Double Thousand (双千)*should "strictly carry out pollution control inspections", and "develop energy conservation and emission reduction implementation plans" (Hebei Province National Development and Reform Commission 2012). This document may be the original source of funding for this project. However, the wording of the available project document, while unclear, states that "after three seasons of winter heating operations, some problems were discovered", making it less likely that the project largely bypassed the local environmental protection bureau, but instead was approved by the city government to improve air pollution. This appears to show, therefore, that not only were the local environmental bureau able to carry out measurement and inspection of FGD equipment, but that the company was unable to refuse to carry out any work. However, even though the local MEP bureau was able to force the company to take action to improve their pollution abatement systems, the company did not pay for such alterations themselves. Application for funds to fit soot removal and desulphurisation equipment, with updated induction fans, was requested from the city government finance bureau (财政局), and from the city government environmental protection bureau (环保局) (Company 2012). The project total cost is 15,013,300 RMB, of which the total requested funds is 4,504,000 RMB, which is 1/3 of total costs; the remainder was requested as bank loans. The loans from the city government finance bureau were approved, with support from the environmental protection bureau. In 2012, the company reported in their application for funds that their 4 boiler units (each 64MW capacity) post-combustion equipment was "coated with soot, seriously reducing capacity to filter soot and sulphur dioxide" (Company Name 2012). The application for funding seeks to replace the current equipment with dry de-sooting technology, and magnesium oxide desulphurisation technology. The application claims that such changes would bring a huge reduction in soot and sulphur dioxide emissions: a claimed

90% reduction in sulphur dioxide (2807.9 tons), and a claimed 99.5% reduction in soot (7995 tons reduced per year). The length of the project is stated as 2 months, and was completed before the start of the 2013 winter heating period. This total project cost of 15 million RMB stands at approximately 41% of the company's total income in 2011 (Company Name 2012). It is therefore an extremely capital-intensive project, and although I could not gain access to company financial records, it is highly unlikely that the company could pay for the project without loans from banks, or funding from government. Evaluating this project from the point of view of the MEP, it appears to be a success: it is highly likely that pressure from the MEP could not be ignored by the company, or by the city government. It therefore seems that by April 2012, air pollution was enough of a priority for the city government, that they were forced to take action. However, the action they took did not in any way punish the company for breaking environmental air quality laws. Instead, they chose to financially support the company by providing funds to purchase new equipment, and the support of banks to provide the remainder. It is therefore a success, but clearly illustrates the challenges of ensuring state owned enterprises take action to mitigate air pollution. Although lack of publicly available records are unable to corroborate this, supervision records by the local MEP bureau in 2015, and 2022 (Ministry of Environmental Protection 2022a; 2022b; 2022c) support a fee of 50,000 RMB being levied against the company; such a fee is unlikely to provide the necessary impetus on its own for the company to change its practices. There remains the possibility that use of post-combustion controls was irregular before 2012, which is consistent with the MEP report that notes poorly maintained equipment. After the installation of improved post-combustion controls in 2012, there is an indication from the interviewee that these controls may not always have been used (Stanton 2024, 1.3), although this could not be confirmed. In 2016, the company reported that soot levels were below 80mg/m3, and that sulphur dioxide levels were below 200mg/m3 (Company Name 2016).

6.2.3 Project 3: Combined heat and power

The third project is much larger, more complicated and expensive, but also much more effective in decreasing air pollution. It involved completely eliminating all of the company's coal fired boilers. Instead, water would be heated by the waste heat from a nearby coal fired thermal electric power station. The heated water would then be pumped to homes as before, and the cooled water pumped back to the thermal power station to be reheated. The project was designed to solve two problems: the first was the many small, inefficient, and polluting small boilers in the project area; secondly, the heating equipment in the project area was insufficient to serve the heating needs of the residents and businesses there (City Government 2015). The total cost of the project was approximately 460 million RMB, of which 210 million RMB was through a loan provided by a well-known international organisation, and the remainder provided by government. The project details were finalised and approved in 2015, work commenced 2016, and was completed in 2021 (Internal Company Document 2021). The thermal power plant is located 15km from the project area, and has 8 x 300MW capacity, of which 2 x 300MW has already been converted to provide Combined Heat and Power (CHP), with further plans to convert the remaining 6 x 300MW units to CHP in the future. The project was authorised by Hebei Provincial Development and Reform Commission in 2015, and planned to provide heat for 8,500,000 m2 of residential and commercial space, serving the needs of 165,000 people (Internal Company Document 2021). The project needed to install 23km of piping to transport hot water from the power plant, and cool water returning to the plant, as well as 44 heat exchange stations. Heat exchangers are a technology designed to transfer heat, in this case reducing the temperature from a source that is too hot for domestic use to a level suitable for household heating appliances. The project eliminated a further 99 small boilers which were still in use in the project area, and installed 1,300 heat metering systems. The original plans required that two coal-fed boilers be retained as peak-load heating sources, to supplement the heating source from the thermal power plant. These were to be converted to natural gas boilers (City Government 2015), however, this work was never completed, due to insufficient supply of natural gas (Stanton 2024, 1.5). The project was highly capital-intensive, and could not have been possible without the financial support of powerful government departments. The project appears to have been planned, and funded, at the level of provincial government, not city government. Hebei provincial government finance department provided 29 million RMB, the company itself provided 5.6 million RMB in funding, (Internal Company Document 2017), while the China development bank provided 40 million RMB. The project itself was already in the late stages of planning by 2014, as shown by applications to the international funding body (Internal Company Document 2015). This document shows that Hebei government requested funding for four separate district heating projects, in different areas of Hebei province. The total cost of the four projects were around 1.2 billion RMB. In northern China as of late 2016, 17% of heating area was provided by CHP systems[35] Hebei provincial government's push for CHP heating systems is part of a larger policy across the heating area in northern China. In fact, plans to convert some, or all, of the city's thermal power plant to a CHP system appears to have arisen as early as 2013, (City Development and Reform Commission 2013), which detailed plans to convert 6 of the power plant's 8 units to CHP (City Government 2015). Following the model of large government projects outlined in the creation of the heating company, this document was most likely the result of a feasibility study conducted some time prior to this decision, with the likelihood that CHP heating policy took place at the level of Hebei government, and possibly above. In 2012, Hebei government passed the (Hebei Province National Development and Reform Commission 2012) in which building heating energy consumption was to be reduced from 2010 levels of 19.2kg coal/m2 to 17kg coal/m2. This plan introduced the 'Double Thousand' (双千) energy reduction plan whereby 1000 Hebei Province companies using over 5000 tons coal/year and 1000 Hebei province SOE key pollutant emission enterprises were selected for strict pollution control measures, with targets to reduce coal usage of 1000 key enterprises by a total of 20 million tons coal/year. CHP project funding report makes clear that the company was included as one of the 'Double Thousand' enterprises mentioned above. Importantly, Hebei government stipulates that 'cogeneration' (CHP) should be implemented across a number of cities in the province: "Accelerate the pace of building cogeneration units with a single unit capacity of 300,000 kilowatts and above in central cities, basically realise central heating in large cities, and develop back-pressure thermoelectricity or central heating transformation in small and medium-sized cities. By 2015, the province will add cogeneration installed capacity of 10.5 million kwh, and standard coal consumption for heating is reduced by 10 kg/gigajoule compared with scattered small boilers" (Hebei Province National Development and Reform Commission 2012).

6.3 Winter heating business model

[35] 'Northern China' is defined as the 14 provincial-level areas in the winter heating area. Heating is provided by: natural gas boilers (11% of total); CHP systems sourced from coal fired thermal plants (17%); renewable energy (4%); electric source heating (2%) (National Development and Reform Commission 2017). The remainder of heating area (66%) is therefore not classed as clean heating, and mostly consists of coal-fired boilers

On examining the company's internal documents, it became clear that heating companies are tightly controlled by government pricing laws, such that company profits cannot be increased by increasing prices. This was verified by the interviewee (Stanton 2024, 1.4). Instead, increasing company income must come from increasing the number of households that the company serves. The company proposes to take over the heating from an existing *danwei* heating company geographically nearby; when agreement is reached, the company must build new underground water pipes connecting the neighbourhood to the nearest branch pipe, building water pumping stations and heat exchange stations as necessary. The old *danwei* heating boilers can then be dismantled. The company uses coal-fed boilers to heat water to a temperature of 130 degrees centigrade (Internal Company Document 2010), and thereafter pumps the water along main pipes, usually situated underground, and finally smaller pipes enter each building in a residential area. After the water has circulated through the pipes, it is then returned along separate pipes back to the boiler house, where it is heated again. The system also requires water pressure to be kept within strict limits, so pressure is increased along the pipe system with water pressure booster pumps. Inefficiencies in the boilers, pipe system, pressure boosters, and final radiators can mean unnecessary heat loss. Excepting staff costs and company overheads, the price of coal is a major expense. The Bohai-rim Steam Coal Price Index gives a price index for coal bought and sold from the port of Qinhuangdao, a major centre for coal distribution in northern China. It can serve to give a general indicator of coal prices throughout China: the price of coal fluctuated quite severely during the company's start of operations in 2010 until 2018. The first period encompasses the 'Golden Decade' of coal production in China (2002-2012), where both supply of coal and price of coal were rising sharply each year; this was due both to rapidly increasing industrial use, and the rapid expansion of the coal industry, supported by local governments (G. Wang et al. 2020). The second period (2013-2015) was characterised by efforts to reduce overcapacity, which resulted in a precipitous drop from around 850 yuan/ton in the winter of 2011 to a low of 390 yuan/ton in the winter of 2015 (G. Wang et al. 2020). Central government introduced policy to reduce coal over-production by shutting down small and inefficient coal mines (中华人民共和国国务院 2013a) and (中华人民共和国国务院 2013b). This was further strengthened with an ever-stricter policy to reduce production in 2016, resulting in the third period (2016-2020) which increased prices to a stable level of around 600 yuan/ton[36]. The central government policy of

[36]After the period under consideration (2008-2018), there was a rapid rise in the price of coal in China. In 2021 there was a massive undersupply of coal, followed by power blackouts across China; prices rose to over 1000 yuan/ton

importance here is the 2010 (中华人民共和国国务院 2016), which sought to reduce coal production capacity by 500 million tons in 3-5 years. Over the next decade, the assets under company control rose from 2010 capacity of 2 million m2 to 8.7 million m2 in 2020, an increase of 335%. This rapid increase in heating provided is a result of two main factors, working together to produce a huge incentive to increase heating area under company control. The first is city government planning: each year, city government gave the company a target to increase heating provided (Company Name 2010; Stanton 2024, 1.5). The second factor is that the price of heating provided by the company is not set by the company itself, but rather set by the government price fixing board. The price is agreed based on research by the price board, and cannot be deviated from. Price increases year on year are small, or else prices remain stable over several years, which can create financial pressures on the heating company to reduce costs, given the inflation of other prices in China. It appears that heating network expansion was entirely funded by company profits; although it is possible this may have been supplemented by bank loans; I found no evidence of this. This company expansion of the heating network therefore represents a significant proportion of total reduction in air pollution over this period. Expansion of the company heating network reduces total pollution by increasing the average efficiency of heating provision, while concurrently reducing resource usage. This latter is a major driver of real pollution mitigation work, as it is supported by major and longstanding central government targets: Energy Conservation Law of the People's Republic of China, (National People's Congress of the People's Republic of China 2018a) (2007); Hebei's Medium and long-term special plan for energy conservation, (Hebei Province National Development and Reform Commission 2004); and the Ten Key Energy-Saving Projects in the "Eleventh Five-Year Plan" (City Government 2006). Energy conservation was therefore a large and important policy decision that pre-empted the adoption of stronger anti-pollution laws and policies. The company was therefore highly encouraged to expand in order to fulfil its founding principles of providing heating services for citizens' use, while reducing the resource usage for heating. Meanwhile, prices for space heating are fixed at the local or provincial level; there is no possibility for winter heating SOEs to increase prices in order to increase profits or to offset investment in new physical infrastructure. It is clear that in terms of the company's income and profits, the city government's directive to increase the coverage of the winter heating network, together with the winter heating price being fixed by the city government's 'Commodity Price bureau' (市政府物价局), creates a massive incentive for winter heating companies to connect more properties to their heating network. Since the company cannot increase profits by increasing prices, it must add new households to its heating network.

6.4 Winter Heating Case Study: *model 0.1*

A simple computational model of the case study winter heating company was written in Python using the *mesa* library (Hoeven et al. 2025). It aims to capture the real-world changes in air pollution caused by administrative and funding decisions at the micro-level, and output an abstract model of heating network growth, and approximate volume of air pollution emitted. The model is entirely deterministic; it aims to recreate the influence of government and other bodies on the company's investment in physical infrastructure over time. The model is later highly simplified in chapter seven where the core governance mechanism is built. The calculations of air pollution and SOE winter heating growth in model 0.1 are then used as the basis for more complex models in chapter eight. In practice the model uses data gathered from the case study on district heating to approximate how buildings are heated and how this relates to local air pollution. The data indicates that for the case study area, there was a massive increase in coal usage efficiency, and an accompanying reduction in coal volume usage. Prior to the creation of the winter heating SOE, 147,000 tons of coal were consumed every year. After the creation of the SOE with large 64MW boilers, in over 2200 hours of annual heating and a total of 55,000 tons of coal consumed (Internal Company Document 2008b); a reduction of approximately 62% in coal volume consumed. Calculating the precise volume of different pollutants is not possible without further data on the coal sulphur content, exact method of firing, etc. Assuming 1-2% sulphur content an approximate figure is from 17.2 kilograms per ton to 34.5 kilograms per ton (United States Environmental Protection Agency 1995) of sulphur dioxide produced. For 147,000 tons of coal per year, that creates 2,533-4,800 tons of sulphur dioxide per year to heat 3.1 million square meters of floor space. Approximately 4.9 to 9.9 kilograms per ton of nitrogen oxides are emitted, depending upon the specifications of the boiler used (United States Environmental Protection Agency 1995). That is a total of approximately 733 to 1,467 tons of nitrogen oxides per year emitted. After 2016, the use of Combined Heat and Power from a local coal-fired power plant reduces the total coal volume burned for the purposes of winter heating to near zero for the case study area. Exact figures are not available, however it is likely that coal usage at the power plant would be increased slightly to accommodate the production of more available heat; the model assumes a total increase of coal consumption of 10% of initial *danwei* heating values, or approximately 14,000 tons total. This represents a decline of 90% from initial *danwei* heating consumption, and a further decrease of 74% from large boiler SOE figures.

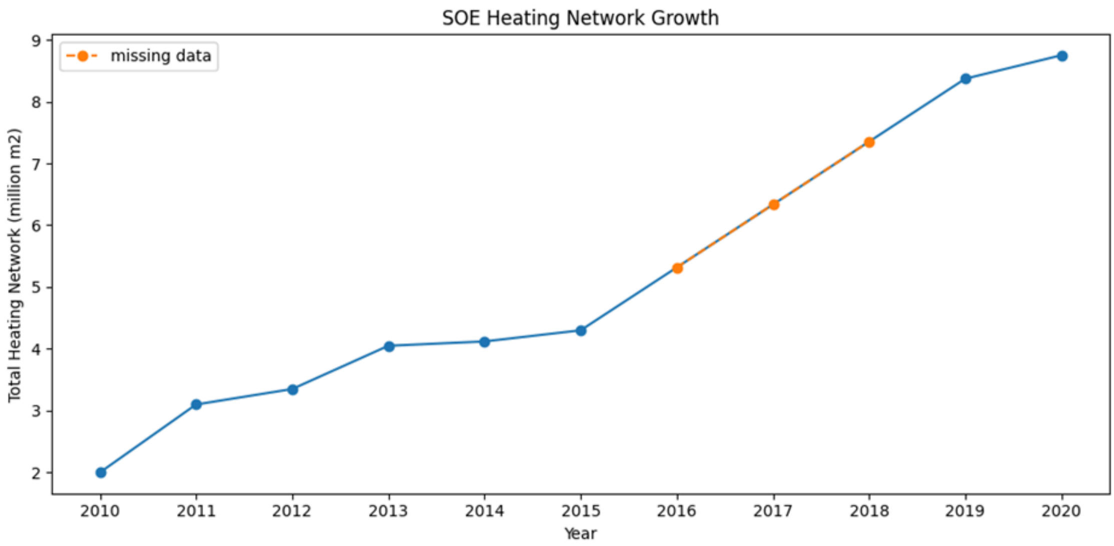

Figure 6.1: Graph showing the heating company network size (million m2), 2010–2020, source: author

6.4.1 Model description

The model aims to faithfully reproduce the elements and dynamics of the case study winter heating SOE, including all of the bodies involved in the three funded pollution abatement 'projects' and ongoing SOE expansion within a single network structure. This model consists of all of the State Council bodies, banking institutions, and local government bodies described in the pollution abatement projects above. Following the empirical data collected in the case study, it is evident that the winter heating SOE does not act in isolation. The actions of the heating SOE are significantly influenced by, and dependent on, the directives and funding established by entities elsewhere in the governance network. The different bodies within the governance network produce a number of documents which are the result of work carried out by their offices, with each document being passed on to other bodies. These bodies may, in turn, be asked to simply implement the procedures outlined, or to approve/reject the document, and pass it onto other relevant bodies for further consideration. For example, the Hebei 'Twelfth Five-Year Plan for Energy Conservation and Emission Reduction' (Hebei Province National Development and Reform Commission 2012) was produced by the Hebei Provincial NDRC, after in turn receiving the National 5YP (National People's Congress of the People's Republic of China 2011) from the National NDRC. This Plan was then passed onto the Hebei Provincial Government committee and the Hebei Provincial People's Congress to be passed or amended, and then passed onto Municipal and County government NDRC for further deliberation and changes according to local needs and finally to be implemented by local government at each level. In the model, the dynamic interaction of different government bodies is instantiated with a simple 'activation' mechanism. When a particular body becomes *activated*, it represents a *positive recommendation to pursue some environmental policy goal.* As described above, each body has a unique position within the governance network, and a unique set of powers, the activation of each body may have a differing ability to influence other bodies within the network. This model is able to incorporate all of the separate projects and expansion dynamics by simply modelling the 'activation' of a node. For example, the 'city NDRC' node is activated, which then activates the 'city government' and 'city MEP' nodes, before activating the 'Heating SOE' node; the activation of the SOE represents the final interaction in the governance chain. The SOE is thereafter allocated funding, and the work is carried out, reducing the pollution emission of the heating SOE.

6.4.1.1 Network structure

The network consists of eleven nodes: consisting of 2 local government nodes, 'Provincial government' and 'City government'; 6 State Council bureau, 'MEP', 'NDRC' and 'Finance' at both Provincial and City government levels; 2 banking institutions: 1 local city bank, 1 international bank; and 1 winter heating SOE node. A total of sixteen connections between nodes: 'edges' exist between the two local governments; between local government and the State Council bodies of the same level; and directly between the same State Council body at different levels; the international bank is connected to Provincial Finance bureau only; the Heating SOE is connected to all other bodies at the City level, including local banks.

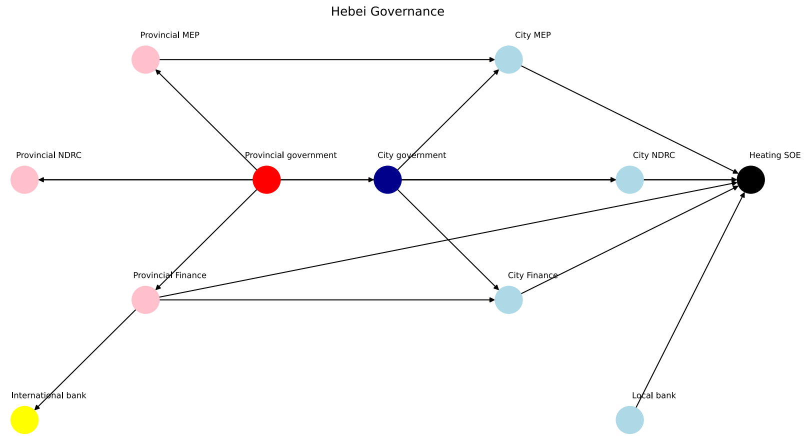

Figure 6.2: *Model 0.1*, network diagram showing nodes and links, source: author

6.5 Model outcome

The images below represent three ‘steps’ in the model, showing its initial condition, where black pixels represent residential buildings connected to a *danwei* heating system; the winter heating SOE starts from the centre of the image and grows in all directions, incorporating buildings into its heating network (green colour). Lastly, the winter heating SOE is shown as it transitions to CHP system (blue colour). The satellite image below depicts a typical residential area in a major Chinese city (Google LLC 2025). In the model, buildings are represented as coloured pixels, while white pixels indicate areas without buildings.

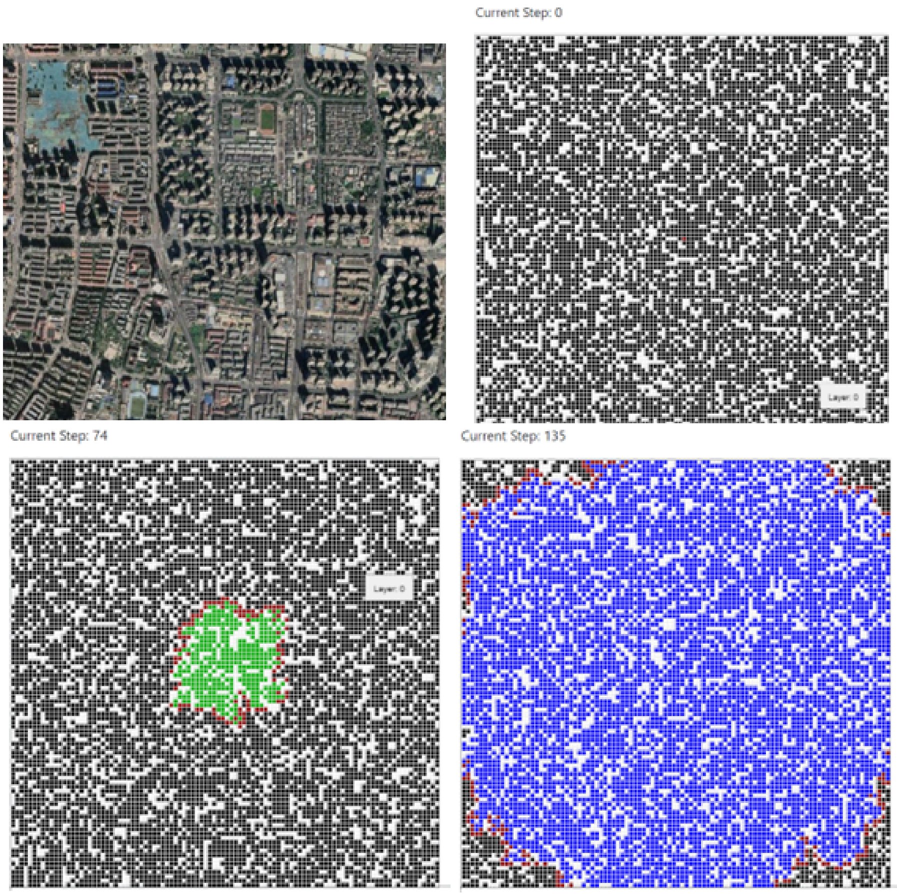

Figure 6.3: *Model 0.1* output, graphic of network growth, Top left: Satellite image of residential area; top right: model at step 0 (2009); bottom left: model at step 74 (2012); bottom right: model at step 135 (2017), source: author

The graph below (figure 6.4) shows the annual air pollution emitted by the urban area modelled above. Since the whole urban area is modelled, not just the heating company, the area initially starts with high pollution emissions from *danwei* heating systems. As the winter heating SOE is first incorporated, expands, and then later changes to a CHP heating system, pollution reduces rapidly.

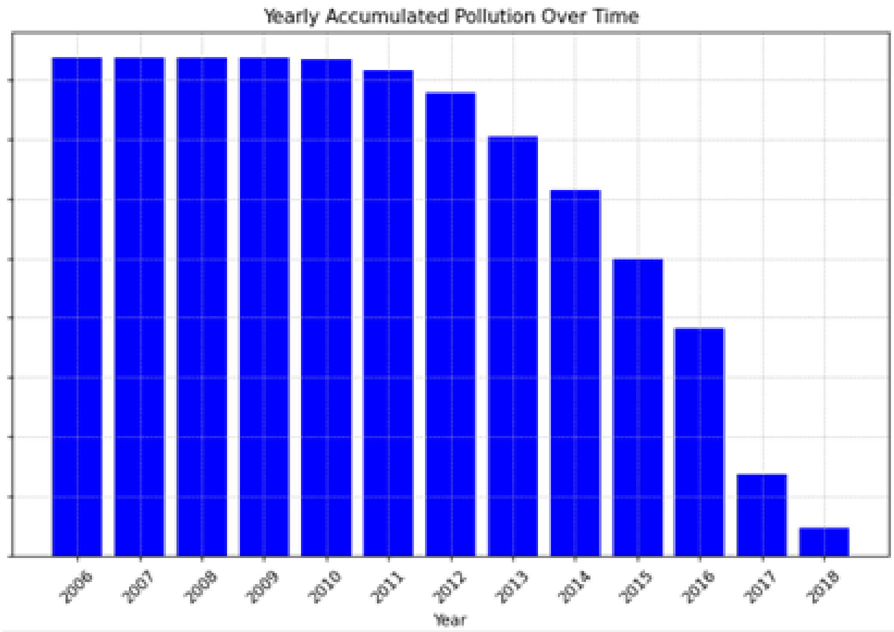

Figure 6.4: *Model 0.1* output, annual pollution bar graph of SOE heating area, source: author

6.6 Summary

This chapter describes a case study of a Hebei winter heating SOE, detailing three important pollution mitigation projects, and the government agencies, laws, policies, and decisions that were involved in physical infrastructure investment that ultimately led to a large reduction in air pollution emissions over the period. Overall, the projects showed that the winter heating SOE itself was not financially responsible for the greatest reductions in air pollution, which were funded by a number of bodies, most importantly the city and provincial governments. It was this allocation of funding which ensured the SOE was formed, and enabled the SOE to change from a coal-fired energy source, to Combined Heat and Power, which drastically reduced air pollution directly caused by the winter heating SOE by 90% or even more. The SOE itself showed no evidence of being pressured or forced into increasing investment in pollution-abatement technologies due to environmental fines or taxes. *Model 0.1* was able to successfully capture the key elements of these events in a simple, abstract form, providing a foundation for the work in chapter seven. There, the model will be further simplified to create a generalised framework for decision-making, a *core governance mechanism*, upon which a larger model on winter heating governance across the fifteen provinces of northern China may be built.

7 Winter Heating I: core governance mechanism

> "*Frequently we are lacking the financial prerequisites to implement the required targets. The diversity of our tasks renders it almost impossible to accomplish all targets at the same time*[37]"
>
> — former Township Party secretary, Qingdao

The *core governance mechanism* presented in this chapter is designed as the foundational and most consequential outcome of this research. The empirically tested models in chapter eight are merely derived *extensions* of the *core governance mechanism.* As such, any inaccuracies in the *mechanism* can have serious consequences downstream in model instantiation. The *mechanism* presented here is the product of dozens of modelling iterations, and aims to be both deeply grounded in empirical environmental data, scholarly theories on environmental governance, and case study evidence. While the core governance mechanism is designed to be derived from empirical data, it must also be generalisable enough that it can be used to create specific models of environmental governance, as in chapter eight. As explained in Section 7.1, there exists an unavoidable tension between complex and *necessarily local empirical data* together with the need for a theory of Chinese governance which must be *logically self-consistent and generalisable* to all specific instances. This tension creates a number of modelling challenges to which there is no perfect solution. I therefore take the view that my task is as much concerned with epistemological and methodological issues as it is with concrete model-making. In line with the epistemological stance I have taken throughout this research, I aim to **reduce the state-space of *possible* general mechanisms by iteratively *eliminating unlikely candidates, rather than positively choosing likely ones*.** The resulting *core governance mechanism* is therefore deliberately designed to be *methodologically conservative.*

[37]Quoted in (Heberer and Trappel 2013, sec. IV)

This thesis distinguishes three hierarchical levels of explanation, each providing the theoretical foundations to the next:-

1. Broad theoretical assumption that *Chinese environmental governance resembles a complex system*[38] a great many epistemological consequences derive from this.
2. The *core governance mechanism* which creates a theoretical framework of Chinese environmental governance, but is itself untestable;
3. Computational models built as concrete instances of the *core governance mechanism.* These instantiate the mechanism in particular contexts, allowing empirical testing.

The aim of this chapter is therefore to set out the theoretical framework through which later modelling is derived. In order to carry out this work it is necessary to first understand the logic by which one or more possible mechanisms have been eliminated. The core challenge of this thesis is to find a method which may be used to evaluate between a number of possible mechanisms to explain an historical *implementation gap* and a recent great reduction in air pollution. The major categories of explanation laid out in chapter one were as follows:

Explanation	Description
"War on Pollution" (2013)	Xi Jinping's administration prioritised environmental protection.
Cadre Evaluation System (2006)	Officials were incentivised to improve air quality.
Campaign-Style Enforcement	*Ad-hoc* interventions enforced environmental policies.
Institutional Power of MEP	Strengthened environmental agencies increased their local bureaucratic power vis-à-vis other agencies.

Table 7.1: Major explanations of pollution reduction in China, source: author

Prima facie, all of the historically popular mechanisms seem apparently reasonable and highly evidenced. In fact, the number of highly evidenced explanations prevents a full and rigorous test of each explanation. Furthermore, I assume that the above explanations together with the empirical evidence provided by each scholar remains a valid explanation for each particular circumstance studied. It is not the purpose of this research to attempt to overturn such studies. Indeed, the opposite is true: the purpose of this research is to generate a theoretical framework that may unite each disparate, apparently mutually exclusive explanation into a single model that may subsume the major prior explanations. A *general* explanation aims to

[38]Explored in chapters one and three

provide an explantion and predictive model that may be applied outside of the empirical data used to create it. Such a model aims to usefully answer such questions as:

> *If the central/provincial/city government were to pass new environmental laws or increase environmental funding; or pursue short-term environmental campaigns; or increase environmental bureaucratic power, how would these affect environmental governance implementation? Which action would likely be most effective?*

The challenges in creating such a general framework are considerable; extant local explanations are certainly on more solid epistemological ground than any possible general model. Given the inherent unpredictability of complex systems, no general model can reliably forecast future events. Researchers must therefore settle for more modest goals: create local models that illuminate specific phenomena but resist generalisation, or broader models that offer only approximate prediction and explanation. Despite these inherent challenges in modelling complex phenomena, as noted in chapter one, it is not possible to answer any research questions of importance without a general theoretical framework. While scholarship describing local conditions (as in the case study of the winter heating SOE in chapter six) remain a core element of Chinese political scholarship, without a theoretical framework these remain simply evidence of isolated, and possibly unique, events, rather than a narrative explanation of environmental governance. Inevitably, scholars must assume some prior theoretical frame in order to create even the slightest narrative around their local data collection. These implicit theoretical assumptions are every bit as important to narrative explanations as the *core governance mechanism* presented here is to the derived computational models. It is important to note that the theoretical framework presented in this chapter, or the concretely derived models in chapter eight are not predictive models, but they may represent the first step towards producing one. The research design overall has been highly motivated by the need to avoid the serious **epistemological challenge of *multiple realisability*** (Quine 1976), whereby entirely different model mechanisms may arrive at the same statistical or qualitative output. Owing to this challenge, together with further problems of *scarce and unreliable empirical data*, it is not trivial to decide which candidate mechanisms should be modelled and tested. Therefore this research was designed to iteratively eliminate unlikely candidates, rather than positively identify the likeliest. The *core governance model* presented in this chapter is a result of a prolonged iterative series of deductive and inductive sieves throughout this thesis, with each empirical chapter aiming to reduce the number of possible causal mechanisms to a testable few. The basic process whereby different possible mechanisms were eliminated are as follows:

Chapter	Explanation eliminated
Air pollution	The chapter confirmed that the 2013 "War on Pollution" does not adequately explain pollution reduction; timing is wrong. Confirmed that reduction in air pollution was real, and not an artefact of data manipulation (contrary to (Ghanem and Zhang 2014; Ghanem, Shen, and Zhang 2020). Furthermore, that air pollution is a complex phenomenon deeply affected by local climate conditions, and therefore the absolute value of air pollutants is not a reliable indicator of environmental governance (contrary to (公众环境研究中心 2020) methodology).
Ideology, law and policy	Confirmed that neither the 2006 Cadre evaluation policy, nor an increase in the institutional power of the MEP, nor local-level campaign enforcement was unambiguously the driving force behind pollution reduction. Indicated that changes in pollution governance tended to reinforce each other, so that no one law, policy, or institutional change was responsible; the whole governance system appeared to exhibit complex behaviour.
Winter heating case study	Confirmed that the MEP was entirely unimportant to pollution reduction of the heating SOE studied. Further, that it was laws and policies specific to the winter heating sector, often unrelated to the aim of pollution reduction, which led to greater investment in high technology heating systems, thereby reducing pollution.

Table 7.2: Elimination of causal mechanisms, source: author

Through this iterative process, the four possible causal mechanisms described in chapter one were reduced to just two candidate models: a top-down change in laws and policies that diffused into local government policy; and a bottom-up increase in local government interest in pollution reduction, driven by local officials according to complex and variable local conditions. These two mechanisms generally conform to the various evidence presented in the empirical chapters, and although they were explicitly designed to be opposite in mechanism, according to the problem of multiple realisability they *may* both display the same empirical outcomes (Quine 1976). These mechanisms were clarified and simplified as hypotheses H1 and H2. This chapter sets out these two hypotheses as clearly and simply as possible as being **identical in network topology, but differing in the point of origin of the governance mechanism: while H1 is designed to reflect a bottom-up dynamic change in local officials' implementation of law and policy, H2 is its logical mirror, a top down change in policy emphasis**. This *point of origin* of the governance mechanism is also identified as the local *nexus of complexity* within an otherwise hierarchical tree network.

Finally, the core modelling methodology is derived from complex systems theory: large-scale phenomena may be generated from modelling micro-scale dynamics with reasonable empirical parameters, but not vice versa. Again, due to the problem of multiple realisability, differing mechanisms may produce outcomes which appear statistically or qualitatively identical (Quine 1976). Complex systems are not reductionistic; system dynamics may be non-linear and non-aggregative, meaning statistical models may capture probabilistic insights but miss essential causal mechanisms. Instead of attempting to produce an accurate complex systems model from the incomplete and unreliable raw data, this thesis is content to interpret, structure and test the data to create the first necessary foundational model which can then be built upon iteratively. This means effectively acknowledging the complex nature of the phenomena, while reducing the computational complexity of modelling by refusing to model it as a whole system, but rather separating the simple, linear mechanisms from the complex, which will be left to later research. This is analogous to heuristic methods used to solve computationally complex problems where exact solutions are not computationally feasible, and therefore heuristics are used to reduce the possible state-space; constraint propagation is an example of this heuristic search algorithm. It attempts to reduce the state-space in combinatorial search problems by "pruning" impossible variations early, thereby vastly reducing the size of later brute-search methods (Rossi, Beek, and Walsh 2006). Similarly, this research faces a potential combinatorial explosion of possible mechanisms; while a classical Agent Based Model approach described in chapter three may serve to create concrete complex models which may be tested for their ability to reproduce the statistical and qualitative outcomes observed in the data, it cannot be relied upon to do the epistemologically prior work of eliminating mechanisms altogether.

This chapter will document the generation of the micro-level mechanism which forms the core logic of later models. This mechanism incorporates the major findings in physical pollution (chapter four), national environmental governance (chapter five) and winter heating case study (chapter six). The preceding empirical chapters provide detailed insights into the key dynamics of Chinese environmental governance, in particular that **improvements in Chinese air pollution during the research period (2008-2018) were principally a result of infrastructure investment**. However, a focus on infrastructure investment itself leaves open how such investment was organised: *how are investment decisions at the local level affected by policy decisions at the national and provincial levels?* This can be related to the initial research question: *How does the structure of the Chinese environmental governance network affect the implementation of environmental policy?* As outlined in chapter three, tackling this question requires explicit focus upon the governance network itself; the computational models developed here make key contributions towards addressing this question. This chapter is designed to not only present the finalised *core governance mechanism*, but to describe clearly how this mechanism was arrived at, both for reasons of explanatory clarity, but more importantly to aid reproducability and scholarly criticism. At any point in the modelling process, a dozen different decisions *could* have been made, and the resulting modelling *path dependancy* would likely create a very different outcome. It is therefore extremely important that this process is well documented[39].

I begin with a brief summary of the *core governance mechanism*; this provides context for the sections that follow and allows readers to compare arguments as they progress. I then explain the epistemological and methodological challenges overcome to generate the mechanism: Section 7.1; especially relevant here are the strategies used to overcome those challenges. Next, in Section 7.2 I explain the concrete modelling choices made, with evidence cited for each decision. Finally, I present the *core governance mechanism* in full detail in Section 7.3, outlining its major elements and noting key differences from the case study model (*model 0.1*) introduced in chapter six.

Section 7.2.2 analyses two hypotheses, H1 derived from the literature review and using the logic of *decentralised authoritarianism* (Landry 2008a), is focused on bureaucratic

[39]The Agent Based Modelling community has lately converged around a modelling documentation schema: (Grimm et al. 2020); this schema was not followed in this instance because its focus on describing “adaptation, emergence, learning”, together with computational verifiability is not suitable here. In contrast, the models presented here are at a rather earlier stage of development; I needed to focus on questions of epistemology and methodology rather than pure technical model description.

strengthening of cadre evaluation and the institutional power of the MEP. H2 is derived from the preceding empirical chapters, and focuses on an increase in 'policy emphasis' (Ran 2013) from the Central government, diffusing down the governance network and increasing funding allocations for environmental projects. Using evidence from the empirical chapters, I reject H1 as unable to account for evidence of top-down planning rather than local-level incentives, and develop the model logic of H2. The *core governance mechanism* is developed from H2, which forms the basis for further expansion into a scalable network model in chapter eight.
Section 7.2 makes it possible to understand and critique each modelling choice in turn. This is absolutely vital for full modelling transparency, and to avoid the charge of *ad hoc* modelling and 'hypothesis dredging' (Dahl et al. 2008).

7.0.1 Overview of *core governance mechanism*

Below is a high-level overview of the *core governance mechanism* to be developed in this chapter.

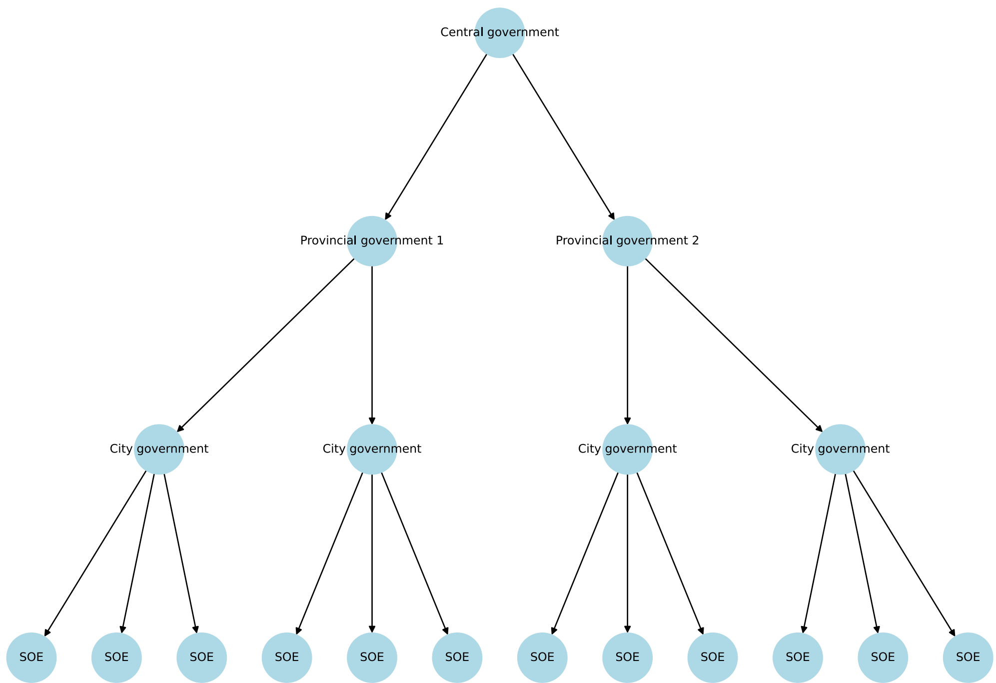

Figure 7.1: Diagram of *core governance mechanism* network, source: author

Mechanism element	Description
Framework type	Abstract and minimal. All concrete models are subsets of the framework; elements can be added but not removed. Designed to allow falsification of the *core governance mechanism* through falsification of its concrete model instances.
Static topology	Tree-structured hierarchy with a single root and multiple nested sub-trees. Parent nodes connect downward to child nodes; leaf nodes mark the periphery.
Node types	Two categories only: government nodes (central, provincial, prefectural, county, township) and SOE nodes (always leaves). All other actors–ministries, banks, NGOs–are excluded.
Direction of links	All links are directed from root to leaves (digraph). Influence flows strictly top-down; no upward feedback is possible within the framework.
Node states	Nodes have distinct states. A node's state determines how it interacts with its children. Timing of changes depends on hierarchy position and link direction.
Probability paths	Each node has a native probability value; the likelihood that the node will change state, and therefore cause funding of pollution mitigation projects to filter down the network; the probability path is the product of all individual node probabilities in a given path from root to leaf node.

Table 7.3: High level overview of *core governance mechanism*, source: author

7.1 Methodological notes

This section focuses on the *epistemological and methodological challenges* that shaped development of the *core governance mechanism*. In particular, this section examines the challenges of modelling complex governance systems under conditions of limited data, and outlines the trade-offs and reasoning that shaped modelling decisions.

The evaluation of complex systems models is complicated by 'epistemic uncertainties', largely caused by incomplete or unreliable data (Beven 2019). This is particularly challenging for complex systems, since interactions between elements are not necessarily analysable from the system's output. There may be an uncountable number of model iterations which can produce the same model outcome (Quine 1976); the problem of *multiple realisability* in modelling is a significant challenge to producing well-fitted models of Chinese governance. *Multiple realisability* acknowledges that two or more models with divergent structures, assumptions, or parameters can nevertheless reproduce the same empirical data. This presents a serious obstacle for validation: if observed outcomes can be matched by many possible models, **model fit alone cannot confirm that the underlying causal mechanism is correctly specified**. For the study of Chinese governance, this means that a model reproducing observed reductions in pollution cannot be assumed to capture the actual dynamics of central–local interactions. Instead, **validation must rest on whether the internal logic of the model is theoretically coherent, empirically plausible, and resistant to *ad hoc* adjustment**, rather than on outcome similarity alone. I address this concern with cross-referencing of empirical data from multiple independent sources, together with analysis of the extensive Chinese governance scholarly literature. Since even these measures are inadequate against the problem of *multiple realisability*, the *core governance mechanism* is expanded in chapter eight, where results of these larger models are validated against out of sample empirical data. As noted in chapter three, many real-world examples of complex systems do not consist entirely of sub-systems which are themselves complex; examples of complexity in biology and ecology describe systems which are basically hierarchical (Corominas-Murtra et al. 2013; Simon 2012; West, Brown, and Enquist 1997; Ma, Buer, and Zeng 2004; Yu and Gerstein 2006); similarly in social and organisational hierarchies (Mihm et al. 2010; Valverde and Solé 2007; Krugman 1996). Simple, linear dynamics combine with complex and unpredictable dynamics within a nested hierarchy to produce whole systems which display both simple and complex behaviour. Such systems may predominantly be driven by either, or both, dynamics at different times. As such, *complex systems may appear as simple, and liable to statistical analysis in one phase, while being complex and unpredictable in another.* Social and biological complex systems have frequently been identified with complex dynamics which take place within hierarchical networks; research on cell metabolic networks address these modelling challenges through "a full description involving the structure, the pattern of organization, and the function" (Aon 2014, sec. 3). In social systems such modelling choices may be achieved by a network of *nodes* and *links*, and the function that their dynamic interactions provide. The computational models presented here, by focusing on the nodes and links in the governance network, aims to hypothesise the *locus of complexity* in the system. That is: in a hierarchical complex network, not every sub-tree or node displays complex behaviour. Thus, to accurately describe the network's topology and dynamics, it is essential to distinguish complex nodes from simple ones. In the context of Chinese governance, it is known that the governance network is highly hierarchical, but that implementation of environmental law and policy appears to display unpredictable dynamics that are potentially complex. **Modelling such a system therefore necessitates an approach that takes into account the *simple, hierarchical dynamics as well as the complex*.** The model design process adopted here emphasises initially simulating simple, predictable dynamics, before integrating more complex elements. This methodologically conservative approach prioritises identifying node locations that display complex dynamics through a process of elimination. As noted in chapter three, *there is no way to positively identify complexity; rather, it is easier to identify the absence of simple mechanisms.* While strict scientific evaluations of model 'fit' are an important component in validity testing, complex systems models are particularly challenging to evaluate, especially in the social sciences. This is because empirical data is frequently inadequate; complex systems are often made of a large number of different elements, interacting in non-obvious ways. While inadequate data in simple systems present important challenges to analysis and modelling, these effects are multiplied in complex systems, due to much starker difficulties in statistical analysis. Since statistical techniques are not very predictive for complex systems, 'filling in' missing data is much more challenging. Statistical correlation in complex systems is less predictive of real-world mechanisms. Where data is available, it may not directly measure the model's outcomes. The use of proxy measures[40] is therefore a necessary but challenging component of any modelling. The models presented here generate two quantifiable outcomes: a *qualitative assessment of heating physical infrastructure type*, i.e. small coal-fired boilers, SOE coal-fired heating networks, and SOE gas/ CHP heating networks; and *the physical scale of SOE renewable energy heating networks.* From this, an approximate measure of air pollution for each location can be calculated. Due to difficulties of model evaluation, and to avoid spurious accuracy, **the fitness of a particular concrete model is not as important as the fitness of the micro-level mechanism that functions as the core assumption of the model**, described in Section 7.3. Further model

[40]The proxy measure of *heating network size* is explored further in chapter eight

iterations may adjust particular parameters, such as the probability of a specific province, municipality, or SOE allocating funds for infrastructure enhancement. However, these adjustments will not change the core mechanism outlined. Further model iterations might be expected to make incremental improvements to the model fit, but will not alter the qualitative shape of *model 0.2* output. If the *core governance mechanism* is incorrect, the model's output will diverge qualitatively from the empirical data, and additional iterations will not improve the fit. Such a result would provide strong evidence that the *core governance mechanism* is fundamentally unsuited to explaining the observed phenomena. In general, methodological problems with modelling complex systems include: naïve comparison of model output with real data; ad hoc decision process for parameter values; and difficulty in understanding the details of model dynamics (Richiardi et al. 2006). To address the challenges of evaluating complex systems models, I adopt four key strategies:

Strategy	Description
Feedback and iteration	Model evaluation should avoid single-event model fitness tests that score the model on its ability to predict high-quality empirical data and thereby falsify an hypothesis. Instead, complex systems models are more likely to be faced with data-poor environments, where the likelihood of highly accurate model prediction is low. Instead of a single event, model evaluation within this environment is a dynamic, exploratory process of feedback, whereby the model is not expected to produce accurate predictions on the first iteration, but instead may be evaluated over several iterations. This evaluation structure more closely resembles the process whereby machine learning algorithms are tested and improved: model fitting is an iterative process, where small adjustments are made repeatedly until the model output is predictive (Braiek and Khomh 2020). Where testing feedback and iteration does not produce marked improvement in output, the algorithm may be abandoned and research begins anew. This process differs from strict hypothesis-testing, which generally requires already detailed knowledge of the system studied; a small number of plausible hypotheses are set out in advance, and these are tested rigorously and abandoned as they are 'falsified' (Banerjee et al. 2009).

Strategy	Description
Strict separation of data	By separating model-building and model-testing data, 'hypothesis dredging' is avoided (Dahl et al. 2008). This principle reduces the likelihood that the model is only able to explain or predict data that it was explicitly designed for. This is related to the creation of 'ad hoc' models that are perfectly able to explain outcomes, but only within a narrow range. A robust model should be able to predict and explain data used in model-building, as well as novel data not used in the creation of the model.
Evaluating model outcomes qualitatively	This involves assessing the general trend or shape of model outcomes over time. If the model is robust, the qualitative distribution of the outcome data should not vary significantly even if the model parameters are adjusted. Where the model's outcome is particularly sensitive to the value of initial parameters, the model will only output correct predictions given a very narrow range of inputs. Unless this sensitivity to a narrow range of parameters is highly evidenced in empirical data, such a model may be regarded as 'ad hoc', and does not robustly capture the underlying dynamic of the system and should be disregarded.
Model evaluation through multiple data sources	This strategy is based on the premise that poor or missing data in one source can be compensated for by utilising different but related data sources. In the context of winter heating data, this means comparing air pollution data (both official and satellite sources) and winter heating infrastructure data (both size of heating network and heating source types). Since no data source can be used to directly measure the fit of models, integrating diverse data sources can help to improve the robustness of model fit.

The empirical foundations for the computational models presented here are based on case study data collected from a winter heating SOE. To avoid over-fitting the model, the data is significantly simplified and abstracted to establish a single core mechanism that can be implemented using simple programming logic; see Section 7.2.1. Additionally, out-of-sample data is reserved to both reduce overfitting and support model validation in chapter eight, Section 8.5.0.1.

7.2 Model design

The purpose of this section is to extract what can be generalised from *model 0.1* while discarding the elements that are too case-specific. *Model 0.1* reproduced the detailed dynamics of one municipal case, but such fidelity cannot serve as the basis for a broader framework. To move from the case study to a usable theoretical model, two alternative mechanisms are considered. The first (H1) assumes a bottom-up dynamic, where stronger bureaucratic incentives drive lower-level governments to act. The second (H2) assumes a top-down dynamic, where central policy emphasis diffuses through the hierarchy. The following analysis evaluates both, before adopting H2 as the more empirically consistent mechanism.

There are a number of ways that models can be created and tested, although a common computational modelling framework mentions two general concepts: 1) the assumptions/parameters of the model; 2) the robustness of model outcomes (Marchi 2005).

Modelling work starts from a reasonably detailed knowledge of micro-level mechanism at the level of heating SOEs; the micro-level mechanism appears largely hierarchical, and results in reasonably simple behaviour (see chapter six, *model 0.1*). Despite the apparently simple, hierarchical, micro-level mechanism, at the macro-level, non-simple behaviour is observed; environmental governance apparently moves from a weak to a strongly implemented regime. H2 posits a framework that bridges the gap between micro and macro level phenomena through varying *policy emphasis.* The source of the policy emphasis mechanism may be a result of either: individual nodes in the network, or multiple nodes in the network; individual links in the network, or multiple links in the network. Therefore, the model-building process aims to address the initial question: *where within the governance network is the source of complexity?* This nexus of complexity can be examined through the development of models that are connected to empirical data. Models that demonstrate a reasonable capacity to predict actual pollution data provide evidence supporting the core mechanisms. However, modelling policy emphasis and its effect on environmental governance could be achieved in a number of ways. The following briefly summarises the possible mechanism and the empirical evidence for each[41]:

Mechanism / Evidence	Description
Mechanism	Varying the properties of edges between nodes, i.e. communication between some nodes is faster, or higher fidelity, than others.
Evidence	There is no evidence that speed or fidelity of communication between nodes is a major issue. Since documents are sent electronically and arrive immediately, communication is nearly costless. Where delays exist, they arise in the *time and resources required to interpret and respond.*
Mechanism	Varying the properties of nodes by governance type, i.e. MEP nodes, NDRC nodes, local government nodes, winter heating SOE nodes, etc. Some nodes may have greater power to make environmental policy decisions than others.
Evidence	SOE appears to have no power to make funding decisions; all projects are funded by local government. MEP has little power to make funding decisions; in the case study it acted to support policies already decided locally. NDRC plans policies and projects but does not fund them. Decision-making power lies with government only, not State Council bodies.
Mechanism	Varying the properties of nodes by governance level, i.e. Central government, Provincial government, Municipal government, Winter heating SOE. Some governance levels have higher policy decision-making than others.
Evidence	Case study data revealed that the SOE lacked authority to make infrastructure decisions; these were made by the Municipal government. High-value projects were decided by the Provincial government. All projects linked back to specific policies and plans established by the Central government.

Table 7.4: Mechanisms and supporting evidence, source: author

[41] A detailed, step by step account can be found in *Appendix*. Variations in nodes and edges in the network, including local government; State Council bodies and winter heating SOEs were analysed for their effect on model dynamics, and in reference to the empirical evidence

7.2.1 Abstracting Case Study: *model 0.1*

Chapter six, Section 6.4 introduced the winter heating case study *model 0.1*, which closely replicated the case study data by producing a deterministic, one-to-one computer simulation of project funding allocations and the resulting reduction in winter heating pollution. As defined in Chapter three, Section 3.1.1.1, a complex system depends on both micro- and macro-level variables. This allows a rich, deterministic mapping of case study data, as in *model 0.1*. The first challenge in building a highly abstract theoretical framework around the case study model lies in the fundamental mismatch between a generalisable abstraction and the specific, complex nature of *model 0.1*. The challenge is more fundamental than a mere practical difficulty: generalising from detailed data always involves a loss of information fidelity. In simple systems this loss is smooth and predictable, and this tends to create highly useful generalised models. For example, GDP per capita can be rounded from $52,463.45 to $52,463.4 to $52,463 with a proportional, predictable loss of information. By contrast, complex systems do not permit such smooth information loss. Generalising relations–such as those between the MEP and a municipal government–does not produce a proportional loss of fidelity, but instead discards essential, non-smooth features of the system. By reducing the fidelity of the model, it may produce a sharp discontinuity; GDP per capita may suddenly drop to $0. In such cases, abstraction risks erasing the very dynamics that need to be explained.

To identify what can be retained from *model 0.1*, it is useful to set out its main limitations. While the model captured the case study in great detail, several of its features cannot be generalised to the broader *core governance mechanism*. The table below summarises these challenges.

Challenge	Description
Case-study determinism	The model reproduces the exact timing and funding path of a single SOE, which is unrealistic when scaled to multiple SOEs.
Limited project data	City-level planning would unrealistically trigger all SOEs at once. In reality, funding is allocated case by case, but data for most SOEs is lacking, forcing ad hoc assumptions.
Excessive detail	Even one SOE requires eleven nodes, sixteen links, and seventy-eight activation events. Scaling to more SOEs and governments would create an overly complex, hard-to-build and hard-to-interpret model. A simpler mechanism is needed.

Table 7.5: Challenges of *model 0.1*, source: author

7.2.2 Hybrid Network

Given the modifications required to derive the *core governance mechanism* from *model 0.1*, there is no evidence to support any network structure other than a simple tree topology. The network must be represented as a hierarchical tree, without the 'random' cross-links between nodes theorised in complex network literature. This raises the key problem: how can a purely hierarchical tree, with no random interconnections, nonetheless give rise to complex outcomes? The most reasonable solution is to preserve the treelike, hierarchical structure while allowing the nodes themselves to be non-simple. Government nodes, in particular, may display complex behaviour because they stand in for the more complex reality in which perhaps a dozen different agencies, departments, or advisory bodies attempt to influence local decision-making. This can be referred to as a 'hybrid' network, since it combines both hierarchy of a tree network, with the complexity of a small-world network. Insights from the theoretical literature on complex networks remain relevant, but for modelling purposes the dense web of advisory interactions can be abstracted into a single government node treated as 'complex' This substitution preserves analytical tractability while still capturing the essential dynamics. Figure 7.2 illustrates the simplification of the governance network: the top diagram represents a classical complex network, where interactions among government and other actors generate complex behaviour; the lower diagram reduces this to a simple tree structure, where complexity is embedded within the behaviour of each government node rather than in the links between them.

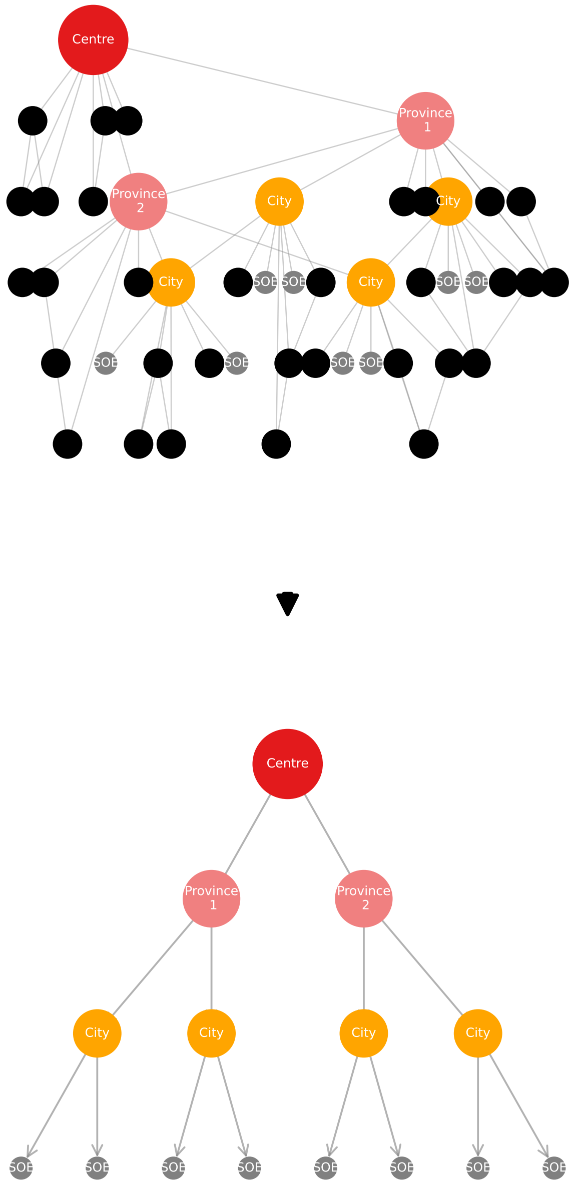

Figure 7.2: Diagram of network simplification; complex network (top) and simple tree network (bottom), source: author

Modification	Description
Removal of State Council nodes	Eliminated MEP and NDRC from the model, as their role in funding decisions was marginal.
Removal of banking nodes	Excluded local, national, and international banks, since funding dynamics can be represented at government level.
Focus on government + SOE nodes	Retained only Provincial and Municipal governments together with SOEs as the core governance actors.
Simplified policy logic	Policies are enacted through the decision to allocate funding; without funding, SOEs cannot change infrastructure or reduce pollution.
Budget constraint mechanism	Assumes more funding requests than available budget, forcing prioritisation by local government.
Decision-making authority	Municipal Party Secretary and Mayor decide which projects receive funding, modelling local political discretion in resource allocation.

Table 7.6: Key modifications from *model 0.1* to the simplified framework, source: author

Table 7.6 summarises the modifications needed to generalise *model 0.1*. The key change is the recognition that State Council bodies—such as the MEP, MOHURD, and even powerful organisations like the NDRC or state-owned banks—operate mainly in an advisory role to local governments. *They can recommend or influence, but they cannot directly compel local authorities to take specific actions*, such as funding a project. The most effective simplification of the model, therefore, is to exclude these higher-level advisory bodies and retain only the local governments and the winter heating SOEs under their control. Building on the simplified tree network in Figure 7.2, the next step is to synthesise historical explanations of the 'implementation gap' into two contrasting hypotheses with an identical network topology: one emphasising bottom-up dynamics and the other top-down control.

7.2.2.1 H1: Bureaucratic hypothesis

Hypothesis: Bureaucratic strengthening of existing institutions and structures create greater incentives for *lower-level government* to decrease air pollution. If hypothesis H1 is correct, then the bottleneck for environmental policy implementation is lower-level government (Rooij 2006; Chan et al. 1995; Lo and Tang 2013, ch. 1, 2, 4, 5). The implementation gap was therefore decreased by increasing environmental policy *incentives* on lower-level government. This hypothesis has the corollary effect that the environmental implementation gap has been effectively 'solved'; the structural governance problems that caused the implementation gap have been counter-acted by structural changes in lower-level governance. It is helpful to tease out a thus far unspoken aspect of the bureaucratic hypothesis: it relies upon the logic of decentralised governance. Local governments are claimed to have a great deal of policy freedom to plan and implement policies that are suitable for their particular local needs. This decentralised logic tacitly assumes that local government is also free to downplay or ignore policy prescriptions that are deemed unsuitable for local conditions. It is unclear if 'decentralised authoritarianism' (Landry 2008b) requires an equal degree of freedom for each level of government, or whether decentralisation is unequally distributed throughout the network. Naturally, each assumption carries a distinct governance dynamic. In order to make the clearest distinction between hypotheses H1 and H2, I will assume that local governments that are bureaucratically furthest from the Centre may have the greatest freedom to act. Local winter heating SOEs, being the most peripheral of state institutions in the governance network may therefore be more likely to ignore or downplay environmental policy from their superiors in the Municipal government. Being closest to the Central government, Provincial government policy is assumed to plan and fund policies that overwhelmingly follow the Central government's policy emphases, with relatively small differences. Municipal governments, while largely following the policy of the Provincial government are given slightly more freedom to interpret these plans. The Central government plan has now gone through two interpretations, and is likely to have quite large differences with the central plan. The freedom to interpret 5YPs and enact local policy I name 'degree of freedom'; this is illustrated below in a toy model of the hypothesis. **The implementation gap is effectively caused by the *degree of freedom* of local governments; *ceteris paribus*, as the *degree of freedom increases, implementation gaps increase*.**

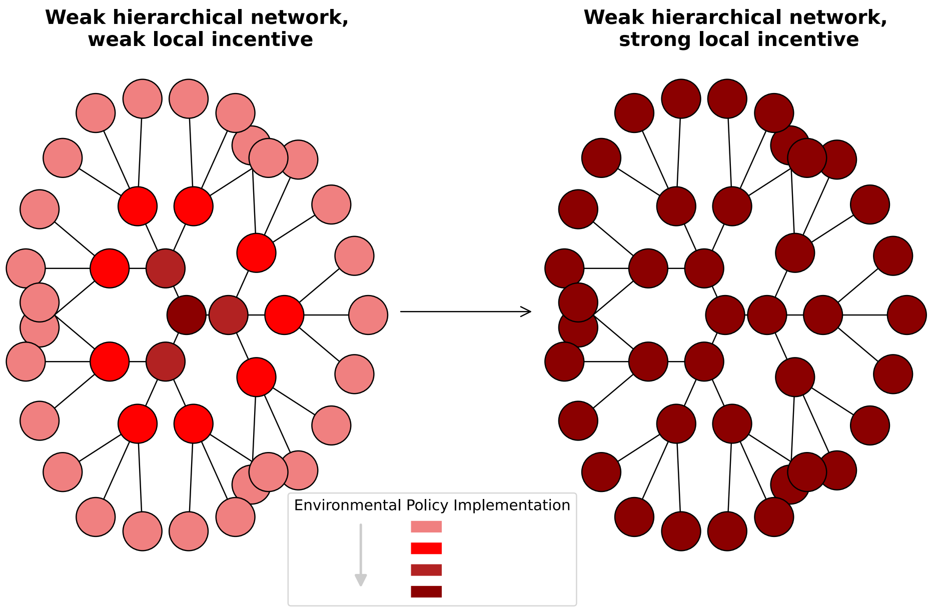

Figure 7.3: H1: network graph of governance levels (top down view), peripheral nodes with greatest 'degree of freedom' at network edge, source: author

Analysis of H1 The internal logic of H1 makes it, prima facie, a reasonable hypothesis to explain the implementation gap: decentralised governance leads to large local differences in implementation. It naturally follows that strengthening bureaucratic powers of environmental bodies and environmental policy area makes reasonable sense to explain the subsequent decrease in air pollution, due to local government incentives. H1 particularly impacts decision-making at the micro-level, and supports a straightforward complex systems explanation, due to bottom-up effects on pollution mitigation. However, this theoretical explanation for the air pollution improvement does not account for the following empirical evidence:

Evidence	Analysis
Pollution data	Large-scale air pollution data (indicating an approximate 2010 date for pollution maximum) suggests that changes to bureaucratic conditions (2006 and 2008) may have only a weak correlation. Pollution from winter heating sources may have peaked around 2016, showing an even weaker temporal correlation. Thus the strongest empirical data in favour of H1 is at best circumstantial.
Top-down funding	the most impactful policy for decreasing air pollution for all sectors was the Action Plan (State Council of the People's Republic of China 2013; Feng and Liao 2016; Xue et al. 2020); for the heating sector specifically this was the Clean Heating Plan (National Development and Reform Commission 2017). These plans were top-down, highly politically impactful policy decisions, with large scale central funding allocations. Planning was not caused by environmental fines or taxes as incentive on local governments.
Infrastructure investment	Detailed case study evidence that top-down infrastructure investment was the cause of pollution mitigation (not bottom-up incentives), and that the particular policies and projects that led to this funding were often not caused by environmental policies at all, but rather by policies focusing on 民生, (social necessity) and 节约, (saving resources).
Independence of SOEs	Detailed case study evidence as to the limited independence in governance and funding of the winter heating SOE: they are bound by the fixed-price of heating set by the government; they must expand the heating network wherever possible, even when the SOE loses money. The major source of funding to mitigate air pollution comes from government sources.

Table 7.7: Summary of evidence for H1, source: author

It is clear from the case study that the winter heating SOE leadership is not entirely free to decide how best to run the business. The winter heating SOE is regarded as a public service and therefore they have to fulfil a number of obligations; the public have access to a ‘hotline’ to complain about service, and dealing with public complaints is extremely important (Stanton 2024, 1.5). If complaints are not correctly dealt with, the local government may take action against the SOE leadership. As an interview subject stated: "we [the company] talk more about social responsibility and government functions, and rarely talk about how much profit we will make. This company is not actually a profit-making company. It is more of a function of taking on social heating responsibilities" (Stanton 2024, 1.5). There is reason to believe that the decentralised governance explanation is not a reasonable hypothesis to explain the majority of pollution mitigation in the winter heating sector, and therefore must be rejected.[42]

7.2.2.2 H2: Hierarchical governance hypothesis

Hypothesis: Central government increases environmental policy emphasis, which diffuses throughout the governance network, causing increased environmental funding at each level. The 'hierarchical hypothesis' is designed as the inverse logic of H1; i.e. instead of decentralised governance, it presumes a strong hierarchical governance logic. On this logic, pollution mitigation was achieved by top-down measures; major national projects such as the 2013 Clean Air Action Plan and the 2017 Clean Winter Heating Plan were specifically aimed at reducing air pollution. However, other national policies such as the 11th 5YP targets for energy-resource reduction of 20% by 2010 (National People's Congress of the People's Republic of China 2006) were hugely important drivers of winter heating infrastructure investment in the case study, and were not primarily focused on air pollution reduction. Furthermore, the expansion of winter heating SOEs within the city are part of the SOEs' founding mission and represents a necessary part of its ongoing function as a subsidiary of the local municipal government.

[42] However, an increase in bureaucratic effectiveness may well represent *a part of the decrease* in pollution in winter heating. Furthermore, throughout other polluting sectors (electricity generation, manufacturing, transport) the decentralised governance hypothesis may well represent a larger proportion of pollution mitigation. This may be an interesting and worthwhile topic for future research (see chapter nine)

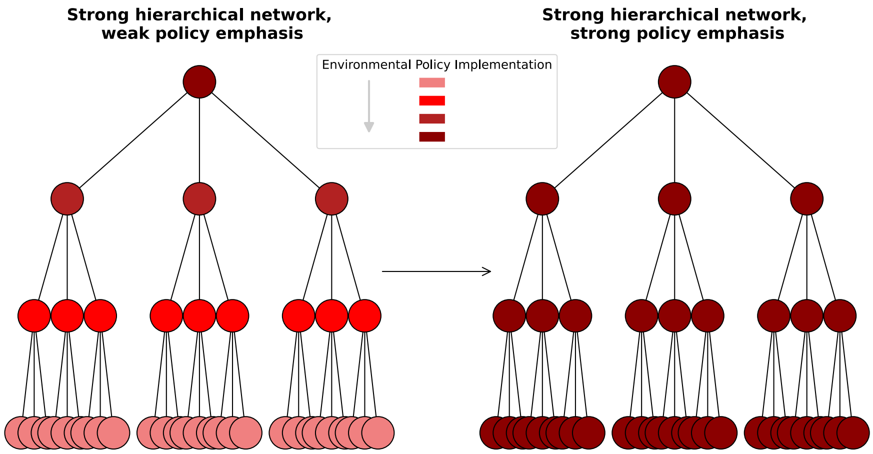

Figure 7.4: H2: network graph of governance levels, peripheral nodes have smallest ‘degrees of freedom’, source: author

The governance network presented in Figure 7.4 is that of a traditional hierarchical structure; similar to a ‘command and control’ governance model, higher-ranking nodes in the network send signals to lower-ranking nodes (‘child nodes’ in the sub-tree) whereupon the child-nodes change their condition to match the parent-node. As an example, the resource saving targets of the 11th 5YP (National People's Congress of the People's Republic of China 2006) were devised by the Central government node, passed to Provincial government nodes, who adjusted the policies to suit local conditions, and then passed the policies onto Municipal governments who have slightly less freedom to adjust the policies, and who then pass these onto winter heating SOEs. Winter heating SOEs are created with the lowest ‘degree of freedom’, i.e. they have the least ability to decide policy. Conversely the Central government node holds a pivotal role in the hierarchical network; policy flows outward from this node, diffusing to its neighbours until eventually the whole governance network holds the same policy goal, although adjusted to various degrees according to their power to do so, and the local conditions.

Analysis of H2 While the governance logic that models top-down policy changes from the central government as a key factor in pollution control offers some benefits in explaining how environmental policy was implemented according to the available empirical evidence, it also presents certain challenges. By adopting a strictly hierarchical, top-down approach to governance, it becomes difficult to account for the existence of an implementation gap in the first place. If a strictly hierarchical governance network alone was an adequate explanation for policy implementation, it should be able to explain environmental implementation in an earlier period. In fact, it cannot; the evidence for an environmental implementation gap is clear in the literature, and highly visible in the air pollution data, but a hierarchical network makes this outcome highly unlikely. It is the apparent mis-match between the implementation conditions of different periods that causes problems for both hypotheses. These characteristics are summarised below:

- H1: a weakly hierarchical network creates conditions whereby implementation problems are expected, but improving implementation by bottom-up incentives are not well-evidenced.
- H2: strongly hierarchical network conditions create a mechanism for strong implementation, but weak implementation becomes much harder to explain.

In order to make H2 a reasonable candidate to explain both weak and strong implementation, there must be a **mechanism that allows the network to change its ability to communicate policy preferences, but yet does not change the network's properties as a whole**. The literature provides a reasonable candidate mechanism: *policy emphasis*, devised to explain why some policies are perceived by local government as more important than others. This proposed mechanism is related to scholarly research on 'selective implementation' (O'brien and Li 2017; Li et al. 2019), 'policy winds' (Zweig 1985); 'rule by mandate' (Birney 2014); and 'campaign-style implementation' (Rooij 2006; Liu et al. 2014; Pan and Hong 2022; Meng, Chen, and Wu 2019; Wang, He, and Liu 2024). These concepts all follow a similar logic: that **policy implementation exists with *various degrees of political sponsorship*, from the very weak to the very strong. Policy implementation cannot necessarily be predicted by looking at the laws and policies themselves, but by the political strength that is massed in its support.** While campaign-style implementation is seen in strongly politicised policy areas, it is usually acknowledged as having a limited effective time-scale, such as Mao's mass mobilisation campaigns (Tsai 1999). In contrast, some very strongly implemented policies such as the one-child policy (Short and Fengying 1998) last for decades, and are consistently strongly enforced throughout. This cannot be reasonably classed as classical 'campaign style' enforcement. Instead, 'policy emphasis' is theorised as a consistent level of political support that can persist over long periods, and lead to either insufficient implementation, or over-zealous implementation[43] depending on the level of

[43]The terminology 'policy emphasis' is used over alternatives due to the slightly differing role of each in the extant scholarly work. It is important that policy emphasis be defined as a mechanism rather than a

policy emphasis. It is important that policy emphasis be understood as a top-down governance mechanism; it does not result from the local needs of government officials or business elites, but rather the needs of central government, communicated by some mechanism throughout the governance hierarchy. This is important because policy emphasis seems to exist outside of the needs of local elites; strongly emphasised policies may result in direct harm to local elites, or to local GDP figures, employment statistics, social stability, etc that are highly important as cadre performance measures for local elites.

I define 'policy emphasis' as: **a common perception among government officials regarding the relative political importance of policies, which has been communicated informally by higher-ranking government bodies**. It must be emphasised that while the extant scholarly work on differing policy emphasis is considerable, its existence as a real ontological entity remains unproven. Empirical evidence of local government officials may implicitly cite the importance of some policy, but rarely *explicitly* explain their governance decisions as resulting from policy emphasis. Policy emphasis must be assumed as an *implicit, informal mechanism*; no such objective criteria for local officials exists in the publicly available records. However, there is ample evidence that some selected policies are quickly and strongly implemented throughout the country, while others may be greatly downplayed. Such strongly emphasised policies often display evidence of *over-zealous implementation*: recent examples include policy measures to combat Covid 19 (Lv, Luo, and Duckett 2022) and policies to increase the area of farmland under cultivation (N. Wang et al. 2023). In chapter five, I summarised the most important national laws and policies relating to pollution mitigation. National laws, policies, and bureaucratic changes increased gradually, but significantly from the 11th 5YP. However, it was clear that increasingly strict laws and pollution targets did not immediately, or directly, lead to reductions in pollution. Instead, the relationship between national policies and their local effects appeared to be non-linear. I hypothesised that implementation of national-level laws and policies may be best understood as a complex phenomenon, and that *perception of political support* attached to a policy is a key consideration in policy implementation. I summarised the perception of political support as arising from the confluence of a number of different factors, including the number and strength of laws and policies relating to a particular policy area, but also the speeches of leaders[44], state media

description; it differs from selective implementation in that it does not describe an outcome, i.e. implementation is not uniform across all policies, but rather a dynamic interaction amongst elements of the governance network leading to such an outcome.

[44]These may be regarded as 'speech acts' or 'performative language'; see (Austin 1975; Searle 1969)

coverage of a policy area, fundamental changes to ideology as illustrated by Party and State constitutions, as well as direct discussions between government officials indicating a change of 'policy wind' (Zweig 1985). The complex phenomenon of political support outlined in chapter five aligns with the previously defined concept of policy emphasis. Consequently, policy emphasis appears to have credible initial empirical support as a significant factor in the implementation of air pollution policy[45], and the modelling of winter heating pollution. We can thus understand H2 as representing a hierarchical network which is modified by policy emphasis. Policy emphasis is itself a complex system, with a number of interacting parts. It seems likely that Central government has no direct control over the policy emphasis given to a particular policy; rather, policy emphasis is effected through indirect means, in the way described above. Under conditions of weak policy emphasis, local governments at each level are much more likely to poorly implement policy, and vice versa under conditions of strong policy emphasis. H2 is thus supported as the most highly evidenced of the possible mechanisms; and this hypothesis will be developed further below into a foundational framework, the *core governance mechanism.*

7.3 Core governance mechanism

The mechanism described below is intended to act as an *abstract, minimal representation* for environmental governance at any particular level. It consists of two parts:

1. The static topology of the governance network
2. The dynamic interactions between nodes on the network

As an *abstract* framework, the *core governance mechanism* does not represent any specific governance network. Instead, it is defined at a level of abstraction such that *every concrete governance model can be understood as a fully specified instance of the abstract framework.* Put differently, the *core governance mechanism* functions as a superset, within which all concrete models sit as subsets. Secondly, as a *minimal* framework, concrete models are created by *adding elements to the framework, never by removing them.* This design is crucial because it

[45] A more precise delineation of the relative importance of each element and their dynamic interaction to the overall policy emphasis requires further research, which due to time constraints cannot be performed here

allows the *core governance mechanism* to be tested indirectly: since validation cannot occur at the level of the abstract framework itself, it must be falsifiable through its concrete instances. Thus, if a concrete model fails empirical testing due to characteristics it inherited from the *core governance mechanism*, this failure serves as a direct falsification of the abstract framework itself. This superset-subset logic has also been extremely important in rejecting candidate abstract frameworks in Section 7.2.

The *core governance mechanism* is designed to support hierarchical nesting to an arbitrary depth; so that one may represent a single township, or the whole country, with nested hierarchiies of: 33 provincial-level entities; 333 prefectural-level; 2,851 county level; and 39,945 township entities[46]

Below I describe the static topology of the governance network, and how those nodes interact dynamically in a purely declarative manner; descriptions of modelling process and decision-making are described in later sections. On initial inspection, the constraints described here may seem too permissive to distinguish between the alternative explanations in Table 7.1, or hypotheses generated from these. However, this is not the case: the explanations outlined in Table 7.1 can be distilled into two contrasting hypotheses. Under the constraints specified here, it is possible to generate *Hypothesis 1*, but not *Hypothesis 2*. To render either of the alternative explanations viable would require substantial modifications to both the static topology and dynamic behaviour of the *core governance mechanism.*

7.3.1 Static structure

7.3.1.1 Topology

The Chinese environmental governance structure is represented as nodes in a tree network. Individual government bodies are represented as single nodes in that network, and each node is connected to at least one other node in the network.

[46] Correct as of 2021 (Huo et al. 2021); the Ministry of Civil Affairs 民政部 are blocking website to foreign IP addresses (2025-09-19).

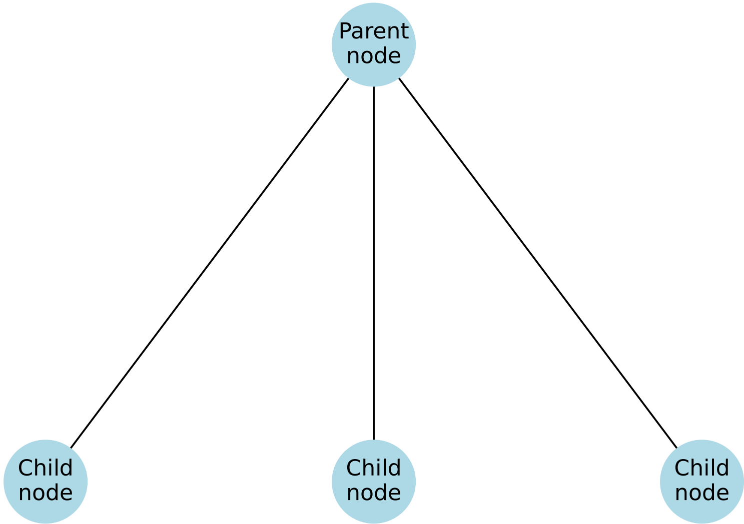

Figure 7.5: Abstract tree network diagram, showing parent and child nodes, source: author

The network topology is structured as a simple tree, in which each parent node has at least as many child nodes, and typically many more. This allows a single 'root' node to represent the centre of the network, while 'leaf' nodes mark the periphery. The structure also permits an arbitrary number of nested sub-trees within the network.

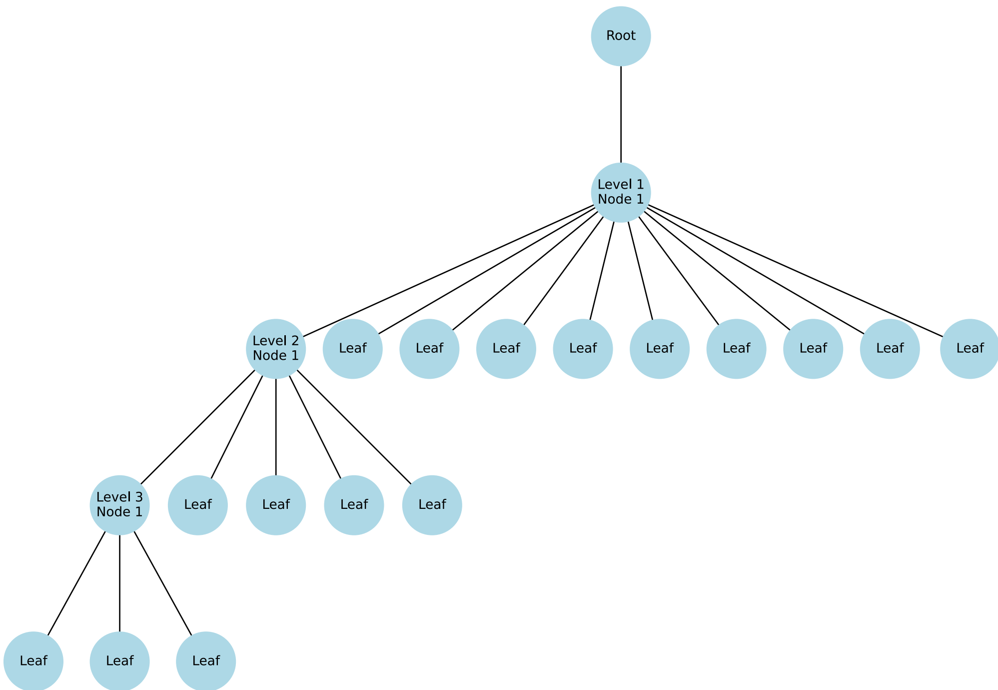

Figure 7.6: Abstract tree network diagram, with nested sub-trees, source: author

7.3.1.2 Nodes

In addition to topology, the static network is also defined by the identities assigned to its nodes; SOEs and government bodies. All leaf nodes in the network are State Owned Enterprise companies; they are the peripheral nodes in the network[47]. No entity is hierarchically subordinate to winter heating SOEs. All leaf nodes are linked to at least one parent node, which represents the immediate supervisory body in the governance hierarchy. Since trees can be arbitrarily nested, government nodes may represent the root node of the network, which may be the 'central government', or one of many local government nodes at different levels in the tree network. Local government nodes may represent Provincial-level government, Prefectural-level government, County-level government, or Township-level government, depending on model design. The specific identities of government nodes within each level themselves differ based on Chinese administrative divisional hierarchy; i.e. the districts of a Provincial-level city like Beijing (市辖区) are hierarchically superior to the district of a prefectural-level city like Xi'an (区), even though they both hold the same relative position within their sub-tree of the network. The network contains only two categories of nodes: government nodes and SOE nodes. Other actors frequently discussed in the literature and in the preceding case study—such as central ministerial-level government bodies (e.g. MEP, NDRC, MOHURD), or state-administered organisations like banks and large media SOEs, or loosely controlled entities like NGOs, and public pressure groups–are not included in the *core governance mechanism.*

7.3.2 Dynamic interactions

7.3.2.1 Direction

Nodes in the network are connected by *links.* A node can influence another only if a link directly connects them; there are no indirect effects without an explicit path of links. The orientation of these links defines the *direction* of the network—that is, the permitted flow of information between nodes. The *core governance mechanism* is therefore modelled as a simple *digraph*, or directed graph, in which every link has an assigned direction of flow. In this

[47] All concrete models in this research represent winter heating SOEs as the only SOE. However, this design leaves open the possibility of modelling SOEs at different levels in the hierarchy; from township-level SOEs to the hundred or so extremely powerful centrally administered SOEs (中央国有企业) such as State Grid and Sinopec. This is shown in Figure 7.6 as leaf nodes in hierarchically superior positions.

configuration, all links point outward from the root node toward the leaves. Information thus travels in a strictly one-way fashion: central government bodies can transmit influence down the hierarchy, but peripheral nodes have no channels by which to send information back upstream. In other words, feedback from the periphery to the centre is structurally impossible within this framework.

7.3.2.2 State

Each node in the network can occupy one of several distinct *states*. A node's state encodes how it will behave toward its neighbouring child nodes: for example, whether it will transmit influence to other nodes, remain inactive, or exhibit some other behaviour. In this way, the state of a node determines the rules governing its local interactions.The *timing* of the network is a derived property that follows from the combination of (a) a node's position in the hierarchy and (b) the directionality of links. Timing expresses the theoretical probability that a given node will experience a state-change as a consequence of state-changes in other nodes to which it is connected. Because this depends on both link direction and the overall topology of the network, timing does not belong to the core structure but emerges from it. The relative hierarchical position is the most important factor in shaping when and how a node is likely to be affected; leaf nodes can only change their state when directly affected by their parent node. Nodes closer to the root are thus more likely to be influenced by some state-change at the root node, whereas nodes closer to the leaves face a higher probability of being less affected by changes cascading down through the network. This distribution of probabilities can be described as the *probability path* of each node.

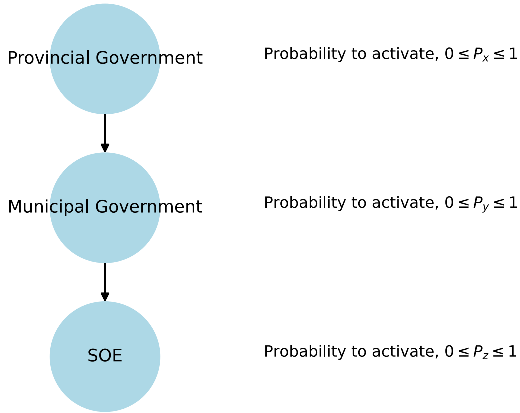

Figure 7.7: Diagram of logical probability path, provincial government to SOE, source: author

Since the probability that any individual node will change its state at a given moment can be determined by its unique *probability path*, the network as a whole can also be assigned a derived probability score. This aggregate measure reflects the combined probabilities of all nodes undergoing state-change across the system. The overall pace of state-change depends heavily on the network's topology. Networks with relatively few nodes, or those that are "broad" but "shallow" (many child nodes branching directly from higher-level parents), tend to propagate state-changes rapidly, as information has fewer hierarchical levels to traverse before reaching the periphery. By contrast, "narrow" and "deep" networks with many nested levels require state-changes to cascade step by step through multiple tiers, slowing the overall diffusion process. In such deep structures, peripheral nodes may take considerably longer to be affected, and the probability of complete network-wide change at any given time is correspondingly lower, as seen in Figure 7.8.

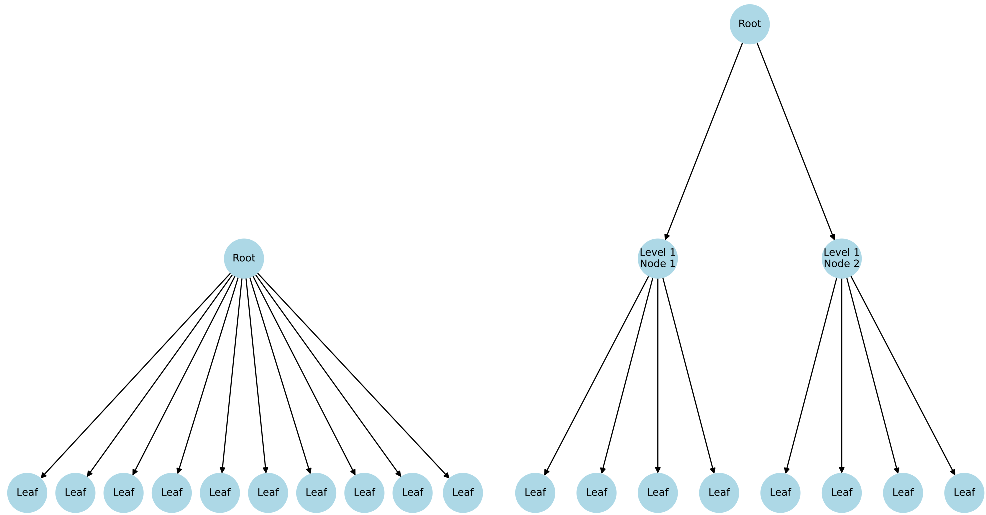

Figure 7.8: (Left) A broad, shallow network with a higher overall probability of rapid state-change; (Right) a narrow, deep network with a lower probability of state-change, source: author

7.4 Model behaviour

Whereas the previous section examined the abstract properties of node states and state-change, I now focus on their practical operationalisation. The following section introduces *model 0.2*, a *toy model* based on the properties of the *core governance mechanism*. Unlike the more detailed models developed in Chapter Eight, *model 0.2* serves as a proof of concept, employing deliberately simplified parameters, but is nonetheless able to validate its simplified output against qualitative data on winter heating pollution mitigation.

7.4.1 Toy model: *0.2*

Each node is assigned an 'agent' governed by simple behavioural rules. Initially in an *inactive state*–"asleep", an agent becomes "activated" when triggered by an active parent node, and then attempts to transmit this condition to its neighbouring child nodes according to a probability value. This probability (ranging from 0–1) specifies the likelihood that activation will pass along a given link. In this way, the abstract probability paths described earlier are translated into explicit agent behaviours that reproduce the hierarchical transmission of policy. For example, in Figure 7.7 the probability of activation for node z (a heating SOE) is conditional on the prior activation of both y (municipal government) and x (provincial government). In this framework, a probability value of 0 means that activation is impossible, while a value of 1 indicates absolute certainty. Intermediate values capture the stochastic character of the process, ensuring that activation at each hierarchical level involves an element of randomness. Building on the probability paths described earlier, the model therefore enforces a tiered activation sequence: subordinate entities (cities and SOEs) can only activate once their superior entities (provinces) have already been activated. This dependency reflects the hierarchical organisation of Chinese governance, where national initiatives cascade downward through provincial, municipal, and eventually project-level planning. In the simulation, provincial nodes become activated only after a predetermined number of steps, establishing a baseline period in which policies are inactive before policy implementation is triggered. This arrangement allows the simulation to begin with a baseline scenario in which environmental policies affecting winter heating and pollution abatement have not yet taken effect. The subsequent activation of the 'Provincial government' node represents the moment when the Central government has already strengthened its policy stance−through revisions to laws, regulations, or ideological priorities. This shift provides the trigger that compels subordinate levels of government to respond. Once activated, the provincial node can influence its connected municipal nodes, but their activation is not guaranteed: each city responds according to its own activation probability function. If a city node activates, it can then affect the SOE nodes within its jurisdiction. Finally, an SOE node must itself activate, according to its probability function, before funding is released for a winter heating project. The program advances in discrete 'steps,' with each step representing one iteration of the model's logic. To translate these abstract steps into a realistic timeframe, each step is assigned to a calendar month. Because winter heating projects can only realistically receive funding on an annual basis, an activation attempt occurs only once per year. Using this step logic, together with the governance network consisting of one provincial government node, one city government node, and ten winter heating SOE nodes (as shown in Figure 7.5), the model can simulate how winter heating infrastructure evolves over time. In the example below, activation probabilities are set to 1 (certainty of activation) for both the city and SOE nodes. This ensures that, once the city node activates, each subsequent yearly step will activate one additional SOE node. Building on the framework of *model 0.1*, each SOE begins in its initial state, representing the heating infrastructure typical of the early 1990s: every residential block (小区) and public building (offices, factories, hospitals, schools, etc.) is heated by a separate small coal-fired boiler. Each activation event then shifts the node's state along a defined trajectory, from high-pollution heating toward progressively cleaner forms:

Number of activations	SOE node state	Pollution
0	‘Danwei’ heating; small inefficient coal boilers	Very high
1	‘Heating SOEs’; Large, centrally administered coal-fired boilers	Intermediate
2	‘Clean fossil’; Large natural gas or CHP heating	Low
3	‘Renewable’; Zero-carbon heating	Near zero

Table 7.8: Sequential progression of SOE heating node states, source: author

This sequence captures the documented process by which urban heating infrastructure in China transitioned from fragmented, coal-intensive systems to progressively cleaner and more centralised technologies.

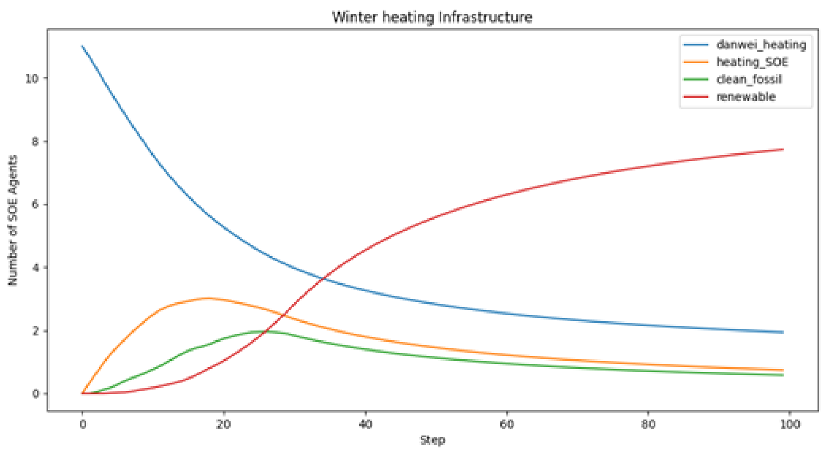

Figure 7.9: *Model 0.2* program run showing the temporal progression of agents' condition, source: author

Figure 7.9 illustrates that, under these idealised parameters, the program requires only about thirty steps for all ten SOE nodes to undergo three activation cycles each. By this point, the simulated city is predominantly supplied by renewable heating. Although these parameter values are intentionally unrealistic, the overall sequence of infrastructure change produced by the model aligns well with the observed trajectory of urban heating development. The simulated transition mirrors the patterns identified in the case study (and in *model 0.1*): heating systems evolve from small, inefficient coal-fired boilers toward progressively larger, cleaner, and more efficient technologies. The shape of the output highlights the most rapid changes in the first thirty steps. During this period, danwei heating declines sharply, while SOE heating expands rapidly until about step 20. This is followed by a more gradual, linear rise in clean fossil fuel heating, which peaks around step 25 before beginning to taper off. This simulated trajectory corresponds closely with national statistics: in 2016, coal-based heating (*danwei* + SOE) accounted for 83% of supply, while clean fossil fuel heating stood at 17%–a distribution that the model reproduces at approximately step 20. Beyond this transitional period, the simulation projects a much slower conversion of all heating systems to renewable energy, taking place between steps 20 and 100. In doing so, the model extends beyond the empirical data captured in the case study, which documents only the 2008–2018 transition from danwei heating to coal-fired SOE systems and then to CHP-based "clean fossil" heating. The model's later trajectory also anticipates the early emergence of zero-carbon heating, reflected in Chinese national data reporting that renewables accounted for 4% of heating infrastructure in 2016 (CHIC (Clean Heating Industry Committee of China Building Energy Conservation Association) 2020), a proportion consistent with the simulation results around step 20.

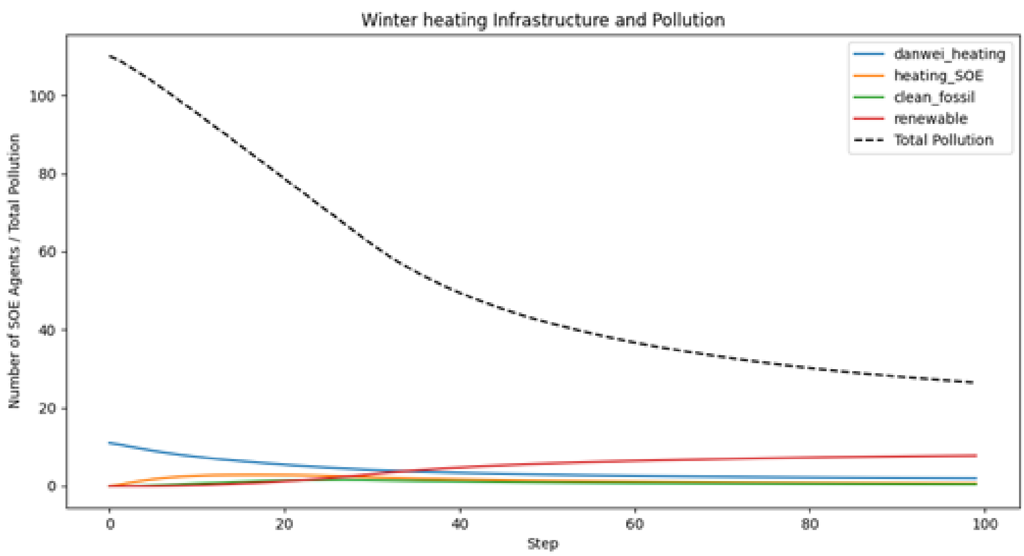

Figure 7.10: *Model 0.2*, showing agents' condition, together with calculated total pollution at each step, source: author

Using the model output above, and by making some simplifying assumptions, we can calculate an approximate level of pollution over time. Here I assume that heating infrastructure produces air pollution at a constant rate, and does not account for either expansion of the SOE heating system, or the use of post-combustion controls such as desulphurisation equipment, both of which were documented in the case study as being important factors in reducing winter heating air pollution. This simplified framework provides a general understanding of how pollution abatement evolves over time within the model. As expected, the most significant improvements in air quality occur within the first 30-40 steps of the simulation, as urban areas quickly shift to efficient coal heating followed by 'clean' fossil fuel heating and finally an increase in zero carbon heating. Following this initial period, the rate of pollution reduction becomes more gradual, showing a slow and consistent decline. This qualitative change is broadly consistent with the breakdown of air pollution over time in the case study.

7.5 Summary

The central contribution of this chapter is the iterative development of the *core governance mechanism* as a simplified yet well-evidenced framework for understanding Chinese environmental governance. By identifying local government funding allocation as the key proximate mechanism, the model reduces the complexity of the case study to its essential elements while remaining consistent with empirical data. There is reasonable empirical evidence to suppose it is the *local government* and their struggle to both please their superiors and balance their fiscal budget that is the immediate source of differences in local implementation. Where provincial government emphasises environmental policy, city government committees are much more likely to allocate funding to those projects. This interpretation of environmental governance entirely disregards the importance of the Ministry of Environmental Protection, and assumes that the National Development and Reform Commission simply acts to advise the local government, not to steer its decisions. Further, it also completely disregards the influence of local business elites, who are assumed to be an important part of environmental governance in other industrial sectors. While local governments are the immediate locus of the implementation gap, the underlying source of policy ambiguity lies at the provincial and central levels. As the most parsimonious and empirically grounded representation of governance in the winter heating sector, the *core governance mechanism* provides the foundation for the expanded modelling undertaken in the following chapters.

8 Winter heating II: models and analysis

"*Taking the promotion of heating system reform as a matter of vital interest to the people*[48]"
— (State Council of the People's Republic of China 2005)

The present chapter aims to parameterise and test the idealised *model 0.2* which was finalised in the previous chapter. I proceed by first reiterating a simplified model of environmental governance, and then presenting and critically analysing the empirical data available. I lay out the data that can act as a reasonable proxy for the models tested, noting challenges. Overall, the models presented here are designed to test the idealised *policy emphasis* + *financial resources* framework; but do so in a highly constrained empirical environment, whereby direct data on *policy emphasis* is not available. Therefore *policy emphasis* is calculated as a latent variable; by varying the parameter *financial resources*, and comparing this with real empirical pollution change. The models presented below are designed to provide a proxy for the *policy emphasis* value, calculated as the residual value after *financial resources* and *pollution change* have been accounted for. This approach is intended as a heuristic only, a first and necessary step; to analyse environemntal governance as a complex system it is necessary to first extract simple, linear relationships in order that I may later continue research while standing on firmer epistemological ground. However, despite these limitations, the models provide good evidence supporting the core governance mechanism as outlined in chapter seven, with both *financial resources* and *policy emphasis* being required to reduce pollution. The complete North China model- *model 1.2* finds good correlation between *pollution change* and *financial resources* over time; this contrasts with smaller models- *1.0 and 1.1*, which focus on Hebei province and the six provinces of the 2013 Air Action Plan respectively. This finding aligns well with the hypothesis that *policy emphasis* is a local, complex phenomenon. As individual cities and regions are aggregated to the whole of China, local-level complexity tends to be attenuated, leaving *financial resources* as the major dominant factor in pollution reduction.

[48] "把推进供热体制改革作为事关人民群众切身利益"

This is good evidence that the core mechanism presented in chapter seven provides a reasonable model of winter heating governance, and is a suitable candidate for further empirical research.

The iterative modelling approach detailed in chapter seven sought to combine evidence from various sources to develop a fundamental governance mechanism that was both simple and empirically derived. By abstracting and generalising from the case study, the core governance mechanism was developed into a two-part decision model for local government: a simple parameter representing available *financial resources* and a complex parameter capturing *policy emphasis*. Given the intrinsic nature of these parameters, along with this thesis' focus on local-level empirical data, financial resources can be adequately parameterised, whereas policy emphasis remains underexplored. This presents practical modelling challenges that cannot be addressed without additional data collection beyond the scope of this research (see chapter nine). I conclude that the model variable *policy emphasis* requires significant further research before it can be incorporated into the model as a fully realised parameter. Premature parameterisation would merely result in an ad hoc model, with unreliable results. To work within these limitations, the computational models below incorporate only *financial resources* as a parameter. This design effectively isolates the financial resources variable, while the model output represents simulated winter heating pollution without distinguishing the impact of policy emphasis. Considering these limitations, the model output is analysed with respect to two categories of out-of-sample data, held back from previous analysis and modelling: winter heating pollution data and winter heating specific laws and policies. The models below simulate pollution emissions, therefore model outputs can be directly compared with winter heating empirical pollution data. Where outputs fit well with empirical data, this indicates the variable *financial resources* alone is a good predictor of local pollution. Where model output does not fit well, this signifies that *policy emphasis* is important in local winter heating pollution, either in producing outcomes that significantly undervalue or overvalue pollution reduction.

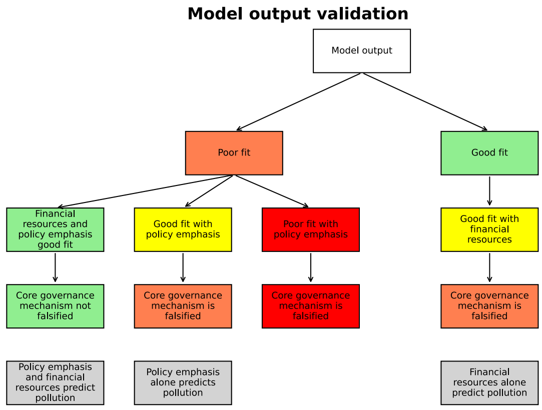

Figure 8.1: Flow chart: model validation overview, source: author

The models presented in this chapter, using financial resources as the sole parameter, consistently predict the baseline level of pollution when compared with out-of-sample pollution data. Specifically, they make reasonably accurate estimates of pollution reduction levels outside periods of exponential decline. In highly developed cities such as Beijing, this exponential reduction eventually stabilizes and returns to the baseline rate of pollution reduction, suggesting it may follow a logistic decay function. The exponential period of pollution reduction is hypothesised to align with a significant phase of *policy emphasis*. The final piece of out-of-sample data involves a major policy event documented in the literature: the large-scale investment in winter heating infrastructure during the 2003 and 2005 reorganisation of the winter heating sector (Zhu, Liu, and Wei 2021). This reorganisation transitioned smaller *danwei*-based heating SOEs into larger, consolidated winter heating SOEs. This period coincides with the exponential reduction phase in pollution levels. Following the validation framework outlined above, the core governance mechanism is not considered falsified if *financial resources* account for part of the predicted pollution output, while the remaining portion is explained by *policy emphasis*. Since the model outputs accurately predict baseline pollution reduction and the exponential reduction phase aligns with a major policy event beginning in 2003, the core governance mechanism is not falsified. It therefore may form the basis for future improvements in modelling suggested in chapter nine. This chapter expands upon, and tests the core environmental governance mechanism by constructing three computational models. *Model 1.0*, covering Hebei province, its eleven main cities, and one hundred and ten winter heating SOEs; *model 1.1*, which includes the six provincial-level regions specified in the 2013 Clean Air Action Plan, including forty-two cities and four hundred and fifty winter heating SOEs; finally, *model 1.2* covers the entire winter heating area of China, with fifteen provinces, one hundred and forty-eight cities, and almost 1,700 winter heating SOEs. Due to lack of high quality data at the level of city government, testing the governance mechanism directly is not possible. These models aim to test the governance mechanism proposed in chapter seven by simulating the governance dynamics involved in winter heating air pollution abatement at varying ranges of empirical granularity. This three-tiered model design is useful in delineating the aggregation effects present in the model, with the larger scale model 1.2 more closely fitting the empirical data compared with the smaller scale model 1.0. This is likely due to aggregation effects: variability at the local level has a larger effect on local-level empirical data, but this effect is 'washed out' as other, opposite local-level effects are added to the data, counter-acting each other. If the core governance mechanism was incorrect, and over-fitted to Hebei province, the fit would decrease as the models increase in scale. Increased model fit would tend to suggest that variability is genuinely local and complex. This is supported by a final aggregate of empirical winter heating data from across China, which shows the closest fit with the model output compared to all previous iterations, with a linear regression of 0.79 Figure 8.17. This chapter proceeds by first summarising the model design in general terms. Secondly, I introduce the models, and evaluate these based on the extant empirical data, varying the nodes' probability function parameter according to GDP per capita. Finally, I discuss the results with reference to H2 and the core governance mechanism.

8.1 Model design

The models below are instantiated on networks representing winter heating governance. The decisions of government committees to emphasise environmental policies takes place through the 'activation' of nodes. Nodes must be activated in sequence, from the highest-ranking government body in the network, to the lowest ranking. The lowest nodes in the network are designated as 'SOE agents', although initially they simply represent an urban area where later a winter heating State Owned Enterprise will operate. As in the core mechanism described in chapter seven, as this SOE agent is activated, its' condition (*agent state*) is adjusted sequentially. The 'activation path' of a particular SOE in the network does not vary; it is dependent upon each higher-level node being activated in turn. This design derives from evidence in chapter six as well as broader literature around Chinese "modernisation" strategies (see chapter four) showing that modernisation efforts are overwhelmingly organised as sequential rounds of funding. However, SOE nodes located in different branches of the network will have different activation paths (patterns of funding), and therefore the total probability value of each activation path varies greatly. Activation path probabilities are given in the activation probability tables provided for each model. All cities and all SOEs are funded in incremental stages, from a starting position whereby each block of residential, commercial or public buildings are heated separately, which I term 'danwei' heating, after the traditional 'work unit' (*danwei* 单位) from which most small heating boilers were organised from the Mao era until the 2000's. Cities that fund the creation of winter heating SOEs produce the first large decrease in pollution, and create the conditions for the second major funding stage to begin. The second stage funds an upgrade in fuelling of the SOE from coal to a 'clean fossil fuel' alternative. Within the Chinese government literature clean fossil fuels include natural gas, Combined Heat and Power (CHP) and other efficient uses of low-pollution fossil fuels. In the final stage of development, funding is made available to convert the SOE to a renewable heating source, which in the Chinese literature includes waste heat from nuclear power, geothermal heating, and electric heating from renewable energy sources. Although it is possible to initially create a heating SOE with renewable energy power, both the statistics and case study support a piece-meal and incremental change to heating sources as being by far the most common dynamic. Under this simple model logic, the instantiation of different model parameters create the conditions for different dynamics.

8.2 Model 1.0: Hebei province

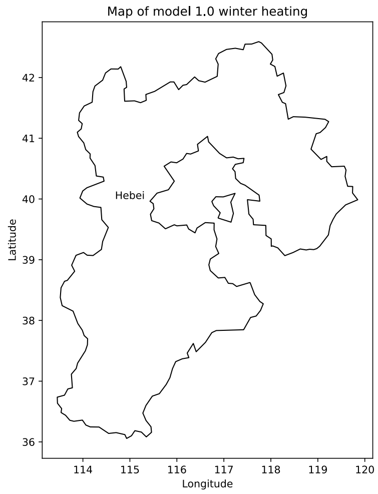

Figure 8.2: Map of Hebei province, a key location for pollution mitigation efforts

This model simulates winter heating governance in Hebei Province, the location of the case study winter heating company. It expands upon *model 0.2* in terms of both scope and realism by including a 'Provincial government' node, and all eleven Hebei 'Prefectural-level city' governments, each with ten heating SOEs, making a total of 110 heating companies for the whole model.

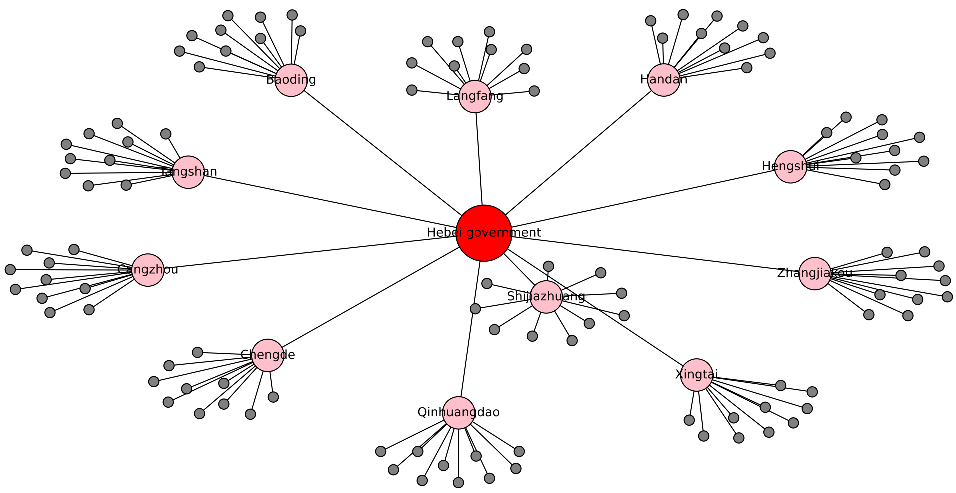

Figure 8.3: Diagram of model 1.0, showing a tree network with 122 nodes and 121 edges. Source: author.

8.2.1 Model description

The financial resources available to local government is composed of two basic sources: local income and financial transfers from provincial or central government. Where government has access to a larger pool of financial resources, it is hypothesised that the allocation of funds for environmental projects will increase. However, access to reliable data is lacking; while central, provincial and city government produce some limited data on expenditure, available data is too limited to be reliable. Environmental protection expenditure (环境保护支出) should ideally be available for each local government. However, city-level environmental spending data is very infrequently available, and where available does not always cover the time period of this research. A further issue relates expenditure records: environmental projects such as investment into efficient winter heating infrastructure may not be counted accurately, or amalgamated into larger funding pools instead of being separated. Local governments tend to count their direct funding of the local MEP bureau under environmental expenditures, with all other environmental projects being categorised as general funding, or infrastructure funding. Where city and provincial environmental projects are categorised in this way, the amount spent on these large-scale environmental infrastructure projects are thus hidden. This explains why China's state-wide funding of 'environmental protection' rose in line with other budgets at the same time as major environmental works throughout the country were underway ("National Data" 2005, 2008-2018). Unfortunately, local government annual expenditure for all expenses are not always available, especially for smaller cities. While an imperfect proxy, city GDP is available for all regions throughout the time period of this study. Since local GDP is the major contributor to government income, as GDP rises government capacity to fund winter heating infrastructure would be expected to rise. Naturally, government expenditures of all types rise with population size, so GDP per capita is best able to capture the approximate amount of funding available for each resident. Rather than using an ordinal ranking of cities, which can overstate differences, GDP per capita is normalised using the min-max method to a decimal scale between 0 and 1, with 2010 values used throughout. Adjustments are made to ensure that no city reaches the maximum value of 1 or the minimum value of 0[49]For example, the funding probability for Tangshan is calculated by normalising the official 2010 figure of 59,000 RMB per capita. This represents the highest GDP/capita within Hebei province, which yields a funding probability value of 0.84 −the highest GDP/capita therefore yields the highest theoretical likelihood that an environmental project would receive funding. In the model, this value represents the probability that the government will allocate

[49]The normalised value is calculated as: $V_{\text{normalised}} = \frac{(V - V_{\min}) + \epsilon}{(V_{\max} - V_{\min}) + 2\epsilon}$ where ϵ is set to 0.1.

resources to environmental projects. Each time the Tangshan government (represented as an 'agent' in the model) considers whether to support a winter heating SOE within its jurisdiction, there is an 84% chance that funding will be approved. In contrast, Hengshui municipality only has a 17% chance of approving winter heating project funding, the lowest in Hebei province. Normalising the city funding probability in this manner recognises that **the model is not designed to generate precise absolute outcome values; instead, it focuses on *relative outcome values***, facilitating easier comparisons across locations. This approach also enables comparison at different geographical scales, i.e. cities, provinces, regions, and the whole country. Following the hierarchical and serial model of Chinese governance summarised in chapter seven, after a given city is 'activated', the winter heating SOE must also be 'activated' in order for final funding to be provided. Finally, SOE activation chance is set at 0.1, representing the reasonable probability that only one of ten winter heating companies will be funded in any given year. This was evidenced by the Hebei case study, whereby funding was allocated on a per-project, per-SOE basis, not as general block funding for the whole sector.

City	City activation chance (GDP)	SOE activation chance	Activation path
Zhangjiakou	0.25	0.1	0.025
Chengde	0.26	0.1	0.026
Qinhuangdao	0.36	0.1	0.036
Langfang	0.40	0.1	0.04
Tangshan	0.84	0.1	0.084
Baoding	0.18	0.1	0.018
Shijiazhuang	0.43	0.1	0.043
Hengshui	0.17	0.1	0.017
Cangzhou	0.38	0.1	0.038
Xingtai	0.16	0.1	0.016
Handan	0.25	0.1	0.025

Table 8.1: Probability table showing Hebei *model 1.0*, and associated city and SOE activation probabilities. Source: author.

8.2.2 Empirical winter heating data

Winter heating data consists of records of the length of physical winter heating networks. Since large winter heating SOEs require significant physical infrastructure in the form of pipes to carry hot water or steam, the length of the pipe network can serve as a simple measure of the extent which large winter heating companies replaced small inefficient boilers. SOE winter heating is overwhelmingly driven by local government capital investment (chapter six); thus it is used as a proxy measure of local government investment in winter heating pollution mitigation. The raw data was collected from publicly available city, provincial and national documents[50][51]. Data was then pre-processed and populated into a single csv document , and was further processed using polynomial interpolation to populate missing data where feasible; Cangzhou city was then rejected due to insufficient data. Data was converted from an absolute measure of heating network length to relative length per population: 'Winter heating network length: 10,000m of network pipes per 10,000 of city population' (Stanton, A. 2024). Finally, the total pollution for each timestep was approximated following the winter heating technology to pollution scheme laid out in chapter six[52]. This calculation was simplified due to lack of accurate data on technology used at each time step; 'clean fossil fuel' technology such as CHP and natural gas, as well as renewable energy were omitted. As such, 'interpolated Hebei winter heating pollution' should only be used as a **relative measure of pollution** within Hebei cities, not an accurate *absolute measure*.

[50]("National Data" 2005, 2000-2023); Various city and province annual work reports, (Various Local Governments, n.d., 1996-2024) (政府工作报告)

[51]For reasons of space, the individual government work reports (6 provincial-level governments and 11 municipal governments) are cited in the *Appendix* under their respective issuing governments. In the text, however, they are referred to collectively as a single series of reports.

[52]Large coal-fuelled winter heating SOE consumes 40% less coal than the equivalent small, inefficient coal-fuelled boilers (Internal Company Document 2009a)

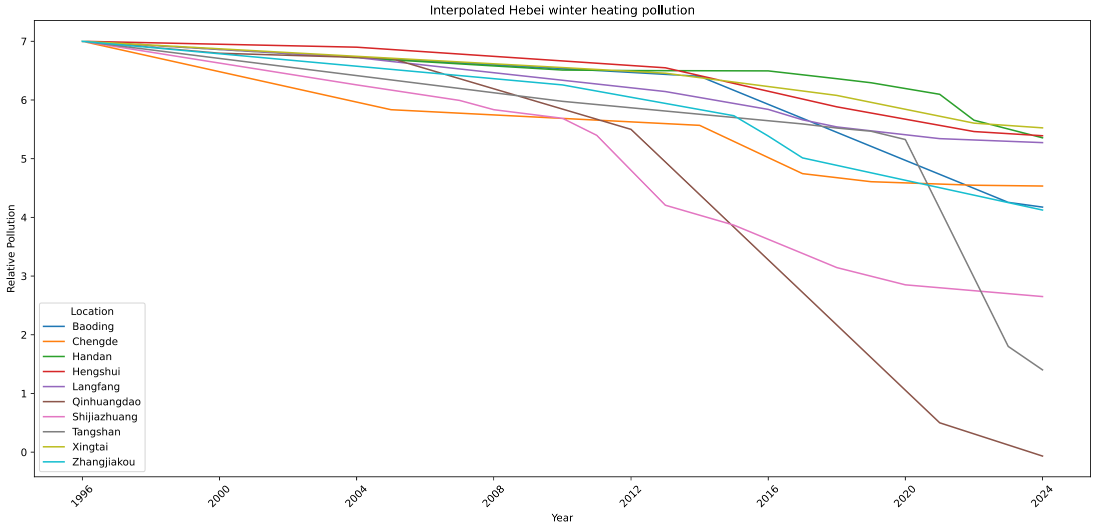

Figure 8.4: Graph of interpolated Hebei winter heating empirical pollution, 1996–2024, source: author

8.2.3 Analysis of *model 1.0* output

The model output was first compared to empirical winter heating data using the simple *linear regression* method, which gives a single measure of correlation, averaged over the whole time period. The regression showed a positive correlation for eight cities, ranging from fairly weak (Hengshui: 0.33) to fairly strong (Chengde: 0.72). However, three cities showed strong negative correlation (Handan: −1.57; Langfang: −0.70; Tangshan: −0.98)[53]. Below I reproduce four representative graphs illustrating the temporal changes in pollution experienced by Hebei cities with both overall positive and negative r^2 values. Both the model output and empirical data measure pollution from winter heating. However, the case study research in chapter six highlights that pollution mitigation is driven by investment in new technologies. As such, both the **model output and empirical data can be interpreted as proxies for capital investment** in environmental technologies. **Where empirical data closely follows model predictions**, as in Shijiazhuang until 2010 and Qinhuangdao until 2012, **this indicates that the city's investment is consistent with its GDP per capita; policy emphasis aligns with GDP**. In cases where the **empirical data falls behind the model**, as in Langfang until 2012 and Tangshan until 2020, this strongly suggests a **reduced policy emphasis on**

[53]All regressions performed by machine learning library scikit-learn (Pedregosa et al. 2011), measured at p-value=0.05

environmental projects. Conversely, if the **empirical data exceeds the model predictions, it implies that the city has increased policy emphasis** on environmental investment. Since modelling closely follows *financial resources*, calculating the difference between simple model output and empirical data gives a reasonable proxy measure of *policy emphasis*.

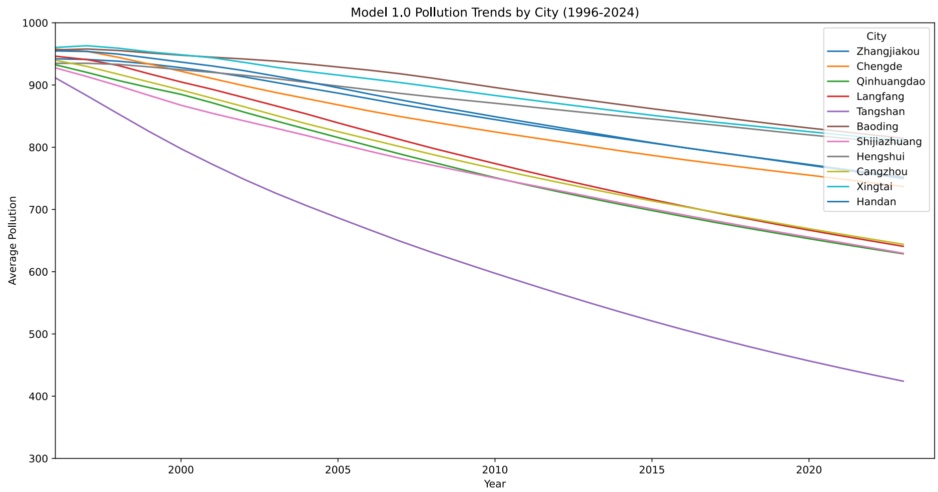

Figure 8.5: *Model 1.0* Hebei winter heating pollution, simulation output, 1996–2024, source: author

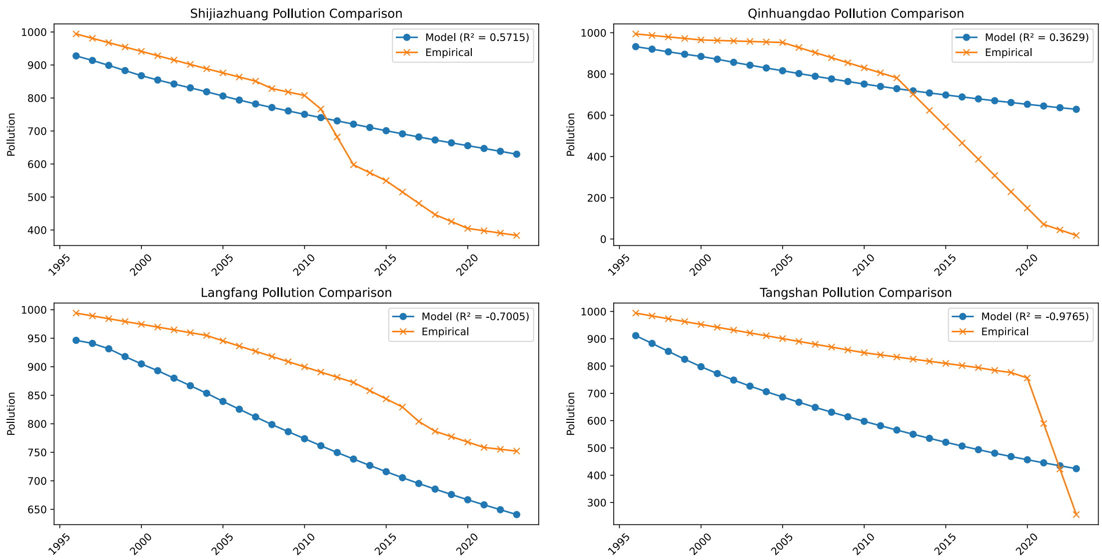

Figure 8.6: Graphs of pollution over time, showing (upper) cities with positive correlation, and (lower) cities with negative correlation, source: author

In examining the data for all cities, the fit between simulation output and empirical data varies significantly over time, showing the strong importance of *policy emphasis* as a temporally bounded phenomenon. Before approximately 2010-2015, the fit is very good, showing that *financial resources* alone are a reasonable mechanism to explain pollution variability across cities in the absence of a special *policy emphasis.* After this date the *financial resources-only* model fit deteriorates, with the predicted pollution level far higher than the empirical pollution level. In this phase of development, cities are spending far more money on air pollution reduction than predicted by *financial resources* alone. It is in this phase that we can pinpoint the possible dates and extent of new **environmental project funding**. The most divergent of all cities are Qinhuangdao and Tangshan. Qinhuangdao diverges from the simulation output around 2012, and dramatically reduces pollution thereafter, creating a marked divergence between predicted and actual pollution by 2024. This was a dramatic increase in *policy emphasis* that was obvious in the data. Tangshan develops rather differently. From 1996-2020 it is consistently more polluting than the model prediction. In other words, Tangshan city government had consistently under-financed environmental projects for 24 out of 28 years recorded. This is a remarkably strong effect that is very noticeable in the data. After 2020 pollution decreases quickly, catching up to model predictions in 2024; there was apparently an extremely strong *policy emphasis* that started in Tangshan around 2020; further research is required to understand why Qinhuangdao and Tangshan differ significantly from predicted values. Qinhuangdao's role as the summer retreat for national Party leaders may have influenced its larger than expected investment in air pollution control. Meanwhile, Tangshan's position as China's largest steel producer may have delayed its investment in green technologies by about a decade compared to other cities in Hebei. As stated above, the r^2 values represent the overall proportional variance of the model against the entire empirical data. As such it does not differentiate between periods where the model fits well versus poorly over time. This means r^2 can mask important temporal patterns in model performance. It also tends to treat simulation output and empirical data as absolute values of pollution, whereas in reality they are *comparative values.* A more appropriate measure would account for both the rate and direction of pollution change, as well as the relative pace of change between cities. First, *Piecewise linear regression* was applied to the empirical pollution data for each city, providing an estimate of the timing of pollution shifts, or 'breakpoints', which ranged from 2010 in Shijiazhuang to 2020 in Tangshan. Second, the slope between two consecutive breakpoints was calculated and normalised to a 0–1 scale, producing a final value that reflects the correspondence between the modelled and empirical slopes. This measure of model fit is better suited to representing temporal change. Unlike a single overall regression score, it captures how the quality of fit evolves over time, offering a clearer view of model performance and allowing the identification of phases when local government prioritises air pollution mitigation or, conversely, neglects it.

Location	Date Range	Model Fit
Baoding	1996–2014	0.94
	2014–2024	0.34
Chengde	1996–2014	0.92
	2014–2017	0.26
	2017–2024	0.96
Handan	1996–2010	0.76
	2010–2016	0.00
	2016–2021	0.72
	2021–2023	0.28
Hengshui	1996–2013	0.91
	2013–2024	0.45
Langfang	1996–2024	0.90
Qinhuangdao	1996–2012	0.95
	2012–2024	0.21
Shijiazhuang	1996–2010	0.84
	2010–2024	0.40
Tangshan	1996–2020	0.68
	2020–2024	0.00
Xingtai	1996–2013	0.82
	2013–2024	0.61
Zhangjiakou	1996–2015	0.87
	2015–2024	0.37

Table 8.2: Showing Hebei cities, pollution breakpoints, and *financial resources* model fit (0–1): green 0.71–1.0; orange 0.4–0.7; red 0.0–0.39, source: author

The table above using the revised model fit measurement shows clear evidence of an increase in winter heating investment by local government, with the majority of investment and therefore *policy emphasis* taking place from 2010-2015, mostly coinciding with the twelfth 5YP

(National People's Congress of the People's Republic of China 2011) (2011-2015), where a considerably increased emphasis on air pollution coincided with the ‘war on pollution’ and the Clean Air Action Plan (Zeng et al. 2019). Before the breakpoint, from 1996 to 2010, the *financial resources* fit alone is generally excellent, ranging from 0.68 (Tangshan) to 0.95 (Qinhuangdao) for all cities, with a mean of 0.86. This coincides with the ninth (1996-2000), tenth (2001-2005), and eleventh (2006-2010) five year plans. The model fit for *financial resources* alone after the breakpoint is significantly weaker, ranging from 0.0 in Tangshan to 0.34 in Baoding. In several locations the alignment with *financial resources* alone, and the input of *policy emphasis* is even more obvious. In Chengde and Handan, there are two breakpoints: the first phase shows a strong model fit, the second phase a very poor fit, and the third phase returns to a strong fit. This pattern suggests that the second phase, characterised by a sharp decrease in pollution, may align with the implementation of a specific policy or project. Once that project had concluded, the cites appear to have reverted to a “baseline level” of gradual pollution reduction in line with *financial resources* alone. This provides reasonable evidence that within Hebei province, the phase of significant reduction coincides with an increase in *policy emphasis*, as proposed by the *core governance mechanism* and H2.

8.3 North China plain

Model 1.0 suggests that for cities in Hebei province, the *financial resources* mechanism alone provides a good fit for most locations until around 2010-2015. Additionally, *policy emphasis* offers a plausible explanation for discrepancies between *financial resource* predictions and observed data after the statistical ‘breakpoint’ occurs. Given that the governance model was developed based on case studies from Hebei province (chapter seven), to further test this mechanism and avoid potential overfitting, it is essential to expand the model’s scope beyond this region. *Model 1.1* extends the simulation to six provinces: Beijing, Tianjin, Hebei, Shandong, Shanxi, and Henan. This model serves two purposes: to test the generalisability of the governance mechanism, and to evaluate the impact of the 2013 *Clean Air Action Plan*, which coincides with the approximate timeframe of the breakpoint for Hebei province, and is highly cited as the greatest policy influence upon pollution mitigation work in China (Feng and Liao 2016).

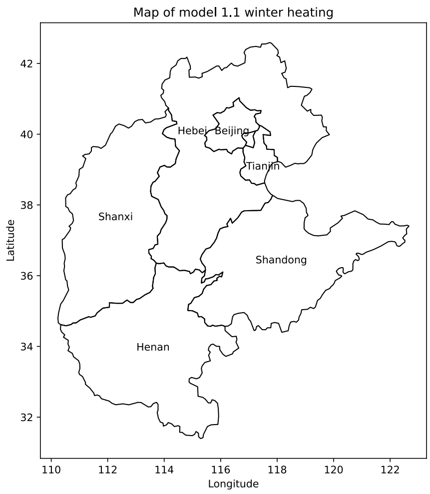

Figure 8.7: Map of north China plain, with six provinces included in the '26 + 2 Plan'

The six provinces simulated in model 1.1 are those named in the 2013-2017 *Clean Air Action Plan (大气污染防治行动计划)*, specifically the '26 + 2' Project, which targets the cities surrounding Beijing on the north China plain, and nearby Shanxi Fen river valley. Atmospheric chemistry research indicates that these locations are majority contributors to Beijing's serious winter air pollution (Panagi et al. 2020). Furthermore, research after the completion of the project found that the Action Plan's effect on air quality was large and statistically significant (Feng and Liao 2016). The reduction in *city air pollution* throughout the north China plain ranges from 17-37% (Feng et al. 2019; Xue et al. 2020; Zeng et al. 2019). Since the *overall reduction in pollution* from 2008-2018 for the north China plain is around 33%, this represents the cause of the vast majority of that reduction. However, the **winter heating sector represents only 10% of the total coal volume of all polluting sectors**. It is not possible to determine the origin of pollutants measured by atmospheric scientists at source. **Therefore general findings of pollution reduction as a whole may not necessarily be from winter heating sources**. The logic behind *model 1.1* is therefore designed to take the *core governance mechanism* described previously and extend it to the cities of the six provinces involved in the '26 + 2' Action Plan, with the assumption that the Plan represents a period of strong *policy emphasis*. **Conversely, where a location's *financial resources* alone is**

sufficient to predict winter heating pollution reduction, this is strong evidence that the winter heating sector was not strongly emphasised within the Plan.

8.3.1 Model description

The basic framework is identical to *model 1.0*, with a hierarchical network of nodes and edges representing various government bodies and their connections. The root node is named as 'central government', representing the national-level Party, State Council, and People's Congress in a single node. The model design acknowledges that the dynamics of national-level government bodies, important planning documents from the National Development and Reform Commission together with important institutions such as the Chinese Academies of Sciences and Social Sciences appear to represent a complex system. The outcome of this system is described in chapter five as: formal changes to Party and State ideology, national-level policy, important speeches by national-level leaders, and coverage by national and local state media. The exact mechanism by which laws, policies, targets and funded projects are decided upon at the central level are extremely complex, and as such highly uncertain. The simulation presented here chooses to disregard this internal complexity[54], instead modelling the verifiable outcome: a relevant national-level policy is decided upon, and documents produced. Lower-level governments then study and implement these documents according to both the larger political landscape, and their local needs. Thus the 'central government' node is not expected to accurately simulate realistic political dynamics; instead, it serves as a simple placeholder for a complex mechanism. Without an 'activation' signal from the central government, no funding would be allocated to improve winter heating technology in the first place. This model further expands the number of provinces, cities and individual heating SOEs, containing all Provincial-level governments included within the North China plain 2013 *Clean Air Action Plan*. The network contains 497 nodes; one 'central government' node connected to six provincial-level nodes. In order to simplify modelling, Hebei, Shandong, Shanxi and Henan are assigned ten city nodes each, although in reality the number of prefecture-level cities (地级市) in each province ranges from eleven to eighteen. Similar to *model 1.1*, each prefecture-level city is assigned ten SOE nodes. As in *model 1.0*, the probability of a government body allocating capital funding to improve winter heating technology is

[54]See *Conclusion* for a detailed description of possible further research

measured by GDP per capita; the probability value is calculated as previously. Not all cities in the six provinces took part in the Action Plan; the proportion included within the plan is taken into account when calculating the location 'activation' probability: Beijing: 100% within *Plan* Tianjin: 100%; Hebei: 82%; Shandong: 50%; Shanxi: 27%; Henan: 17%.

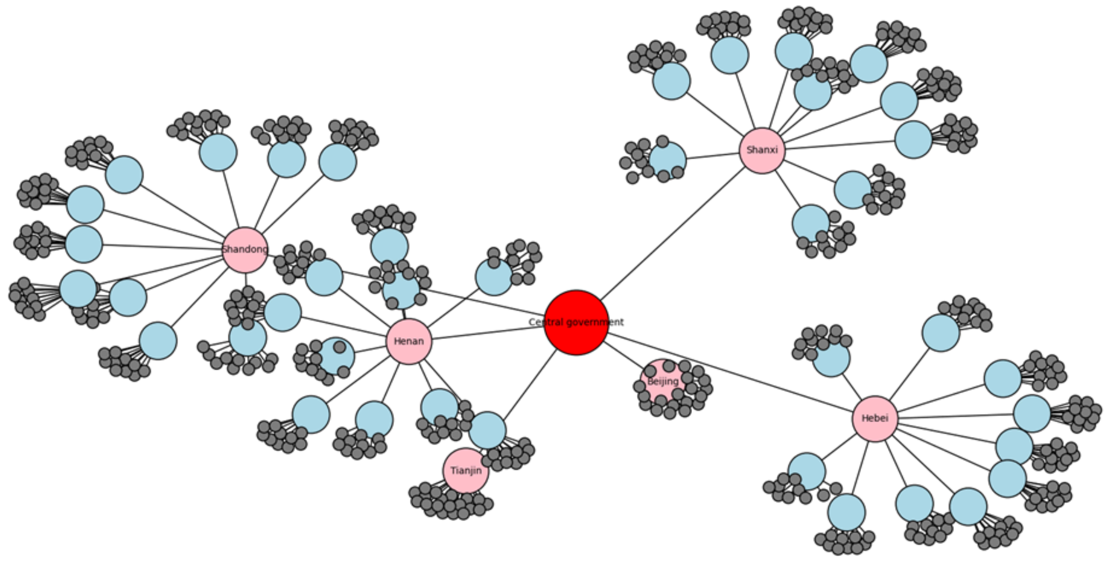

Figure 8.8: *Model 1.1*, showing a tree network with 497 nodes and 496 edges

Chapters five and six document empirical evidence that funds were transferred from both central and provincial finance bureaux in order to fund important environmental projects, such as the '26 + 2' Project. Furthermore, evidence from Hebei *model 1.0* indicates that an increase in the probability of funding winter heating projects broadly coincides with the time of the 2013-2017 *Air Action Plan*. *Model 1.1* thus tests the hypothesis that the *Action Plan* was indeed the major driver of investment in winter heating, just as it was in other sectors such as heavy metals manufacturing. Figure 8.9 illustrates the design logic of *model 1.1*: if an increase in winter heating investment is observed, this indicates that the '26 + 2' Project influenced the sector; if no increase is observed, it suggests that local governments prioritised major polluting industries such as steel over winter heating.

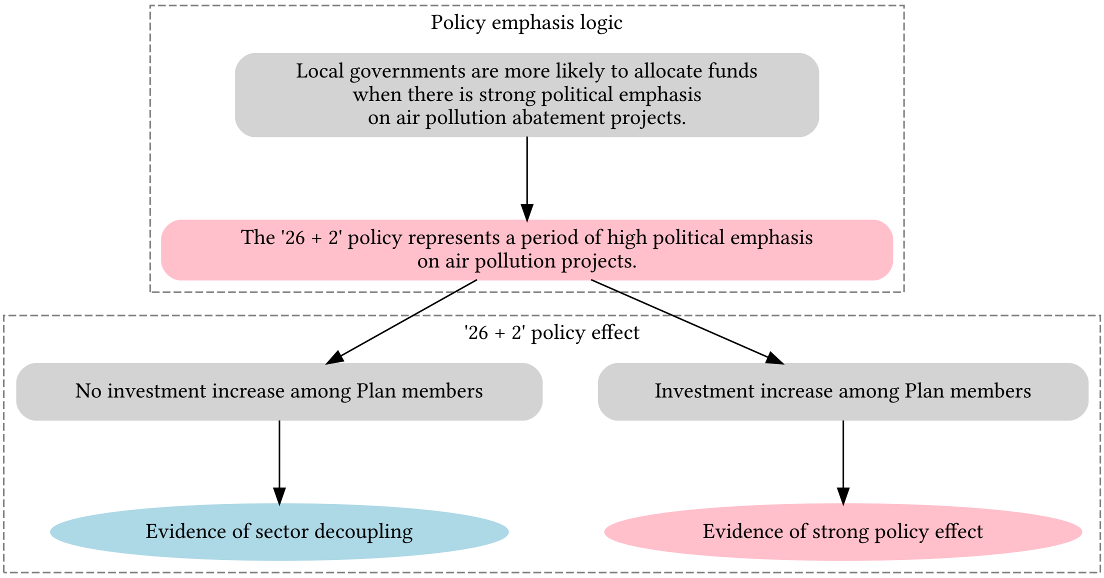

Figure 8.9: *model 1.1* design logic

Model 1.1 is designed to both expand the logic and structure of *model 1.0* to a larger geographic area with different economic, manufacturing, and political conditions, but also to test how membership of the *Action Plan* affects that city's investment in winter heating technology. Where membership of the *Action Plan* area shows a strong correlation with increased winter heating pollution abatement technology, we can be more certain the the *Plan* had a direct effect on funding in the winter heating sector. The model activation mechanism is designed as follows: where a city is named as a member of the 2013 *Clean Air Action Plan*, the **city activation probability will be increased by a fixed margin above that of non-member cities**. The reason a fixed marginal increase was decided upon, as opposed to the other possibility of a variable margin decided by the relative political importance of each location/time to the *Action Plan* is that the political importance is not known *a priori* any attempt to model this more realistic scenario would therefore be entirely *ad hoc*. The marginal value of membership in the *Action Plan* area was set as the *median calculated variance of policy emphasis in model 1.0*[55], i.e. an approximate 138% increase in activation probability when compared with GDP-derived probability alone. The *policy emphasis* accorded by membership in the *Plan* area is therefore calculated as a simple value, which never changes according to location or time. Each sub-provincial government (city and equivalent) is set at a standard probability value of 0.3, the mean for city GDP across the region. Therefore the probability parameter for city activation within the Action Plan will be established at an additional 0.114.

[55]Taking the mean of slope variance is hugely affected by the outlier Tangshan, where the slope is one hundred times the predicted model slope. To prevent this skewing effect, the median value is used instead

For example, since Shijiazhuang is part of the Action Plan, its' activation probability will increase from 0.3 to 0.414. This highly simplified measure of *policy emphasis* was chosen to be the simplest possible model that might measure any effect of the *Plan* on winter heating pollution. In reality, increases in the likelihood of funding winter heating projects are unlikely to be uniform across time and place. Nevertheless, the model design allows this assumption to be tested in a simple and structured way, avoiding *ad-hoc* measures; the design can then serve as a base-line for future modelling. The table below shows the new activation probabilities for all cities. Compared to *Model 1.0*, the activation probabilities for SOE agents remain unchanged. Beijing and Tianjin are classified as provincial-level cities (直辖市)[56].

Province	Province activation chance (GDP)	Base city activation chance (GDP)	SOE activation chance	Activation path
Beijing	0.8667	0.3	0.1	0.026
Tianjin	0.5467	0.3	0.1	0.016
Hebei	0.1600	0.3	0.1	0.005
Shandong	0.2933	0.3	0.1	0.009
Shanxi	0.1600	0.3	0.1	0.005
Henan	0.1333	0.3	0.1	0.004

Table 8.3: North China plain probability activation path, source: author

[56]Two options were considered for organising the special case of Beijing and Tianjin:

1. SOEs placed directly under the provincial-level governments of Beijing and Tianjin (as in *Model 1.0* for prefecture-level cities (地级市).
2. SOEs placed directly under 'district-level' (市区) governments, which are bureaucratically equivalent to city-level governments in provincial-level cities.

Model testing showed that option 2 provided a much closer fit with the empirical data, as well as according with the formal bureaucratic structure of directly-administered municipalities

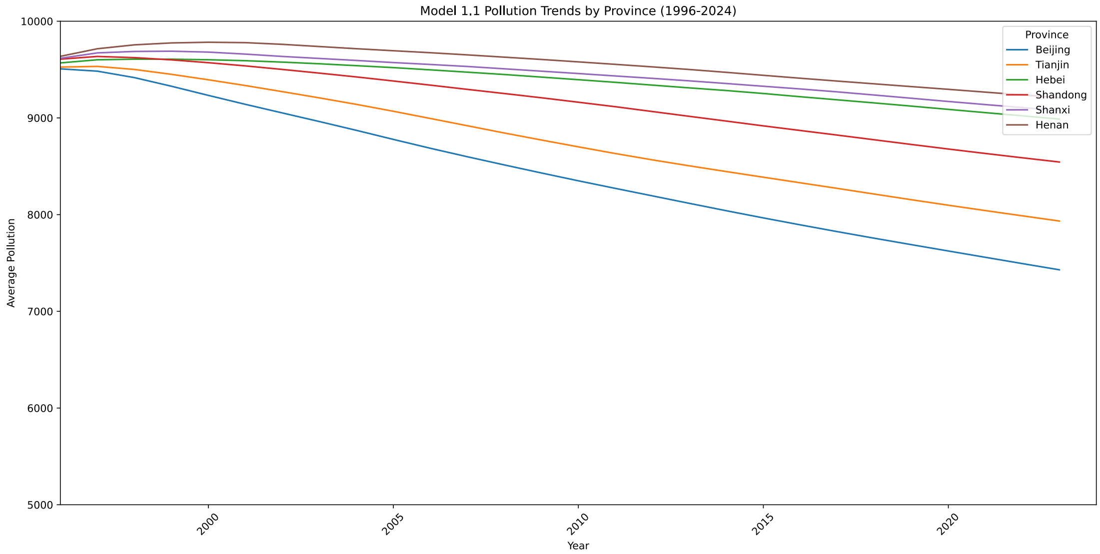

Figure 8.10: *Model 1.1*, winter heating pollution simulation output, 1996–2024, source: author

This model aims to provide a reasonable representation of the so-called '26 + 2′ cities contained within the Clean Air Action Plan, commonly cited as the most important pollution abatement plan in the 2008-2018 period (Feng et al. 2019). The model includes two provincial-level cities (Beijing and Tianjin), and four provinces (Hebei, Shandong, Shanxi, Henan) containing twenty-six cities. Not every city in each province is included within the Action Plan, as the Plan is designed to reduce pollution within the north China plain, and especially those cities along the 'Beijing pollution corridor', i.e. those cities likely to contribute to pollution in Beijing. Therefore, cities geographically distant or separated by geographic barriers such as mountain ranges are not included in the Action Plan, although they are included as part of this model.

8.3.2 Empirical data

Empirical data was collected as previously, derived from raw data of winter heating network length, and processed as before (Stanton, A. 2024). See Appendix for calculation details. Due to the higher quality of data available for provincial-level statistics, with less missing data, the data could be further processed to calculate a more realistic measure of winter heating pollution. This takes into account the large pollution mitigation afforded by investment in 'clean fossil' heating (natural gas and CHP), and renewable energy heating. Although provincial and national statistics of the proportion of coal to clean fossil and renewable heating are limited, they indicate that a change from coal to clean fossil heating is correlated with the proportion of winter heating network length. Length of winter heating network tends to grow *logistically*, with the theoretical 'carrying capacity' reached when all urban citizens are connected to large winter heating networks[57]. Analysis of available statistics covering Beijing and Tianjin cities, as well as an amalgamated statistic covering the whole of China indicate that a shift to clean fossil heating occurs in the exponential growth phase of the function. Approximately 50% clean winter heating is achieved at the midpoint of the function, X_0. A more realistic pollution measure can then be obtained by applying this pattern to all provinces and estimating pollution levels accordingly. Unfortunately since statistics for Henan show it to be still in the exponential growth phase, the midpoint cannot be calculated for Henan, and this province was discarded from the data. As can be seen from the national data below, the midpoint for China as a whole was already reached in 2018, and thus Henan is an outlier. This accords with policy evidence, as Henan was not originally included in subsidised winter heating policy, being located south of the Qinling-Huai river line; only two Henan cities were included in the '26 + 2' Action plan.

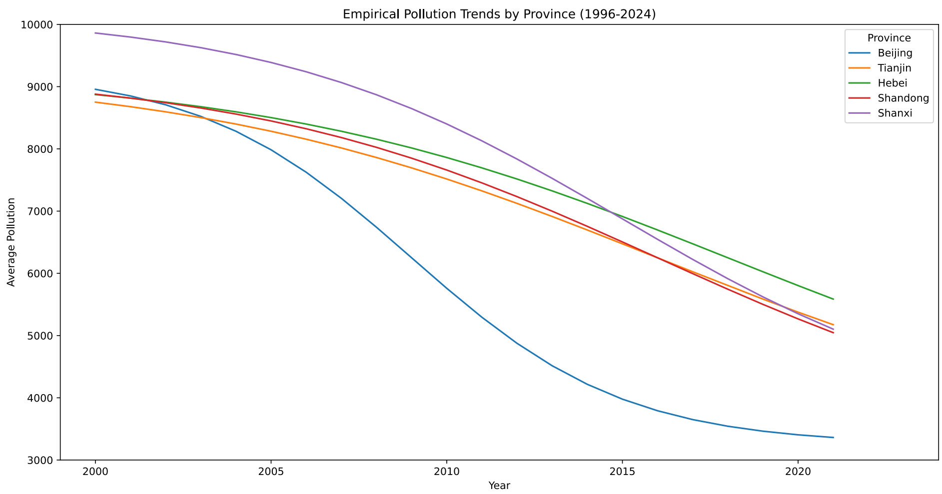

Figure 8.11: Graph of interpolated winter heating pollution decline for North China plain, 2000–2024, source: author

[57]The degree of slope is given by the exponent k, where L is the carrying capacity (the minimum pollution value), x and $x_0$represent the position of the function and midpoint, and e is Euler's constant:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}}$$

8.3.3 Model fit and analysis

Linear regression analysis shows a wide range of r^2 fit, from −0.03 to 0.9, with Shanxi and Hebei provinces displaying the weakest regression fit. Province breakpoints, calculated from piecewise fit in the same manner as previously, show that all provinces departed from the model before the period of the 2013 Action Plan had begun. While the model shows a reasonable fit against empirical data, it is clear that the 2013 Action Plan was not an important source of pollution abatement in winter heating for the provinces surveyed. Even without considering the model predictions, the empirical data shows no significant change in the rate of pollution abatement during the Action Plan period. Contrary to being a strong predictor of winter heating investments in the 26 + 2 Project area, the empirical effect to winter heating pollution abatement investment appears to have been neutral. Beijing had a sharp period of pollution decline between 2005-2013, precisely before the 2013 Air Action Plan had begun. While the model was able to predict the value of the slope before 2005, and after 2013, the intermediate period where pollution declined precipitously departed significantly from the modelled slope. Meanwhile Tianjin initially had a shallower decline in pollution (until 2007) than predicted by the model, which adjusted to approximately the slope of the model after the breakpoint, and continued at the same pace until 2024. This indicates that Tianjin displayed the closest fit to the '26 + 2' Project model; this city was the most affected by financial investment during the period of the Project. Hebei empirical data followed the model slope until pollution started to decline in 2009, and continued until 2024. Hebei displayed the second poorest fit, showing a final empirical pollution level nearly half that of the model prediction[58]. Shandong empirical data followed the model prediction until 2006, then declined sharply. Similarly, Shanxi closely followed the model prediction until 2006, where it declined extremely sharply, causing the poorest final fit, where final pollution was around ¼ of the model prediction; the '26 + 2' Project was unable to predict pollution reduction for these provinces. Figure 8.12 shows a representative sample of model fit for four provinces. Beijing, Tianjin, and Shandong exhibit a reasonable fit with the model, while Hebei and Shanxi show a poor fit.

[58]Taking the mean slope deviation of *model 1.0* as the key contributing parameter to the 26 + 2 Project would overfit the model to Hebei

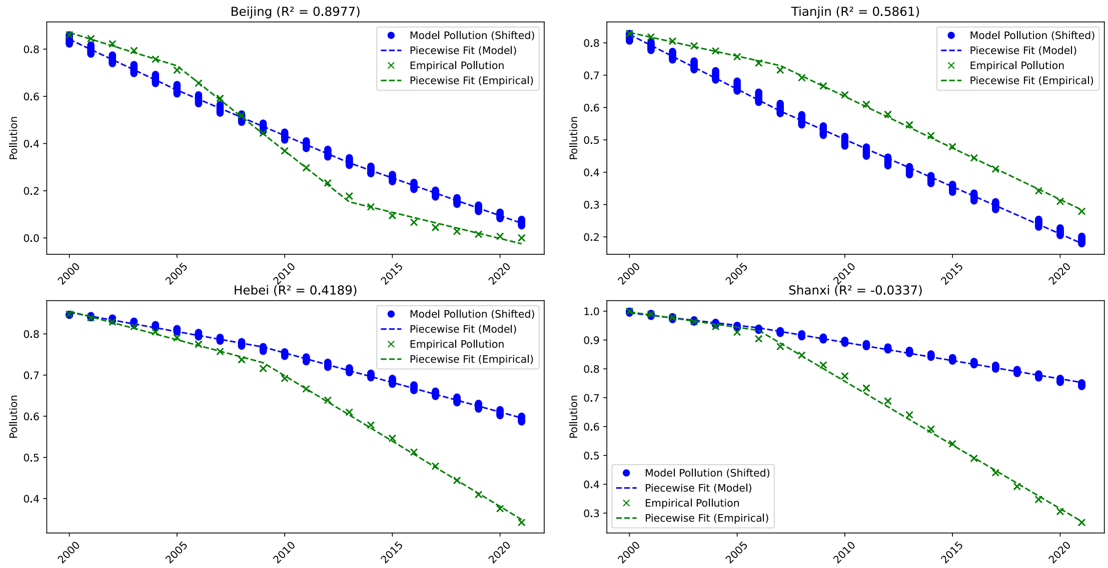

Figure 8.12: Linear regression and piecewise fit, four provinces, 2000–2024, source: author

The adjustments made to cities and districts to reflect increased policy emphasis from the 26 + 2 Project are expected to most significantly impact Beijing, Tianjin, and Hebei, with only half of Shandong's cities affected and a minimal effect on Shanxi and Henan. The largest outlier in the empirical data was Shanxi, which experienced a very large investment in winter heating from 2006 onwards; again, well before the period of the '26 + 2' Project. It is not clear the reason for this discrepancy, however Shanxi is a mountainous, historic coal-mining area, and particularly sensitive to air pollution, with historically the worst pollution of any Chinese province. (Tang et al. 2014) documents a number of projects undertaken by the Shanxi provincial government to mitigate air pollution, particularly during the 11th 5YP and thereafter. Given that Shanxi air pollution was especially serious, these projects may have had particular government emphasis; further research is required.

Location	Dates	% Change
Beijing	2000–2005	34.39
	2005–2013	−86.99
	2013–2024	30.64
Tianjin	2000–2007	56.82
	2007–2024	−9.00
Hebei	2000–2009	−48.83
	2009–2024	−121.20
Shandong	2000–2006	42.71
	2006–2024	−56.06
Shanxi	2000–2006	−23.64
	2006–2024	−249.71

Table 8.4: Model fit: model output vs empirical data as percentage, colour-coded 0–39 (white), 40–100 (grey), 101–180 (orange), 181+ (red), source: author

The statistics above clearly show that the **breakpoints identified in the empirical data do not align with the timeline of the '26 + 2' Project**. This strongly suggests that if the project did influence winter heating investment in these provinces, its impact was not universal or predictable. A strong effect on winter heating should see an appreciable increase in financial investment in physical heating infrastucture, which was not apparent. In order to avoid the possibility that modelling choices may have negatively affected the outcome, I analysed the effect of adjusting the *policy emphasis* parameter; changes to the parameter failed to resolve the weak effect of the '26 + 2' Project's *policy emphasis*. While increasing the *policy emphsis* value improved Hebei's model fit, it caused Tianjin, Shanxi and Beijing to worsen. In order to improve the fit of the model, each province's cities must have a custom probability function, thus emphasising the high local variability in *policy emphasis*. Even a centrally mandated environmental Project, localised in the north China plain is unable to cause each city to act similarly. As such, I must **reject the 2013 Action Plan as a simple cause of winter heating pollution reduction within the north China plain area**. Neither a simple *financial resources* mechanism (*model 1.0*), nor a generalised regional *policy emphasis* mechanism (*model 1.1*) is sufficient to predict winter heating pollution reduction.

8.4 Model 1.2: North China

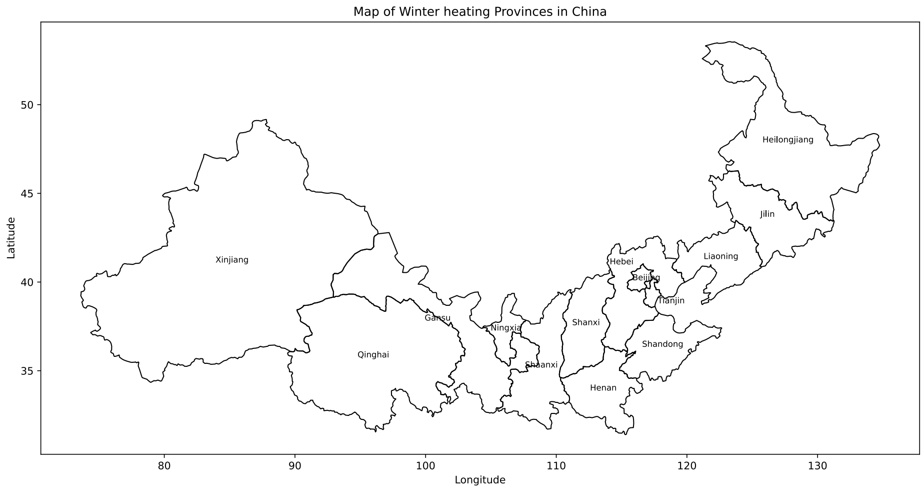

Figure 8.13: Map of northern China, fifteen winter heating provinces

This final model expands the network graph to include the fifteen provinces normally included within China's national winter heating policy. This model includes: Central government node, with Beijing, Tianjin, Hebei, Shandong, Shanxi, Henan, Shaanxi, Gansu, Ningxia, Jilin, Liaoning, Heilongjiang, Inner Mongolia, Qinghai and Xinjiang provincial government nodes. As before, the network graph follows a simplified structure whereby each province has ten cities, with each city having ten winter heating SOEs, resulting in a total of 1666 nodes. As in *model 1.0*, the province activation chance follows each province's GDP per capita, which range from Beijing (0.78) to Gansu (0.15). Province GDP has been normalised (0–1) to better reflect the relative wealth of each province on a single scale. Experience with the environmental policy Action Plan in *model 1.1* indicates that an increase in environmental *policy emphasis* does not necessarily lead to predictable outcomes. The effects of broad policies on specific locations are highly complex: in some areas city governments may invest in clean heating, while in others they may focus on pollution mitigation in other sectors. The current model therefore takes a different approach: instead of predicting local effects directly, it estimates *policy emphasis* indirectly through elimination–any variation not explained by *financial resources* is attributed to *policy emphasis*. This method provides a simple proxy for *policy emphasis* in each location. Tracking these values over time makes it possible to identify when political emphasis increases in response to specific policies.

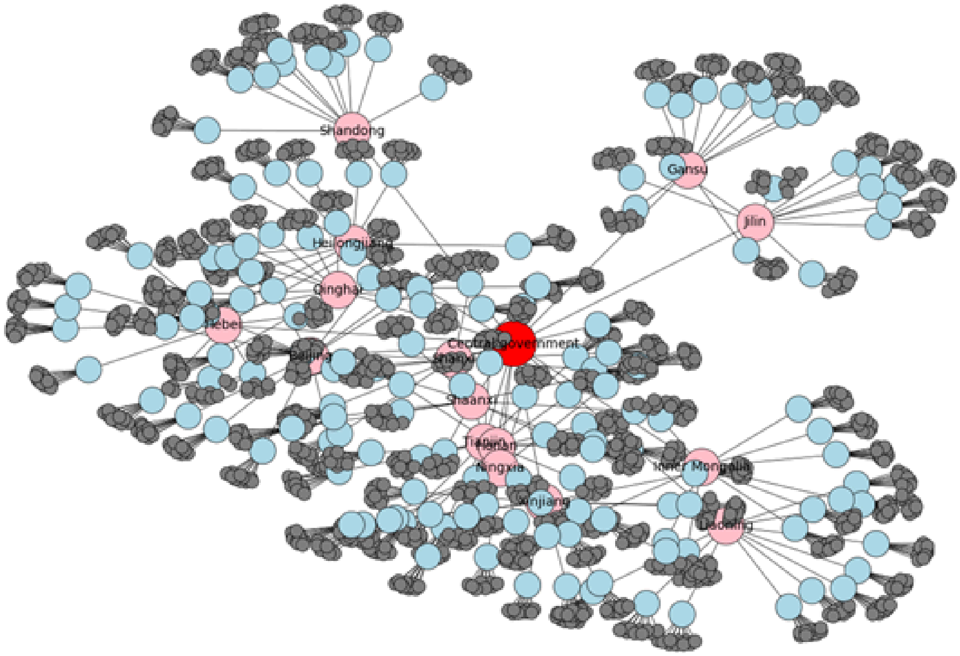

Figure 8.14: *Model 1.2*, graph diagram showing 1666 nodes with 1665 edges, source: author

Table 8.5 shows the relative probability that SOEs in a given province will be activated in any given 'step'. On a *frequentist* view of probability, the activation path probability can therefore be assumed to give the approximate time before a given SOE will be activated, and this is borne out in the model output, where Beijing is simulated as the most advanced location for winter heating investment, followed by Tianjin.

Province	Province activation chance (GDP)	Base city activation chance (GDP)	SOE activation chance	Activation path
Beijing	0.8667	0.3	0.1	0.0260
Tianjin	0.5467	0.3	0.1	0.0164
Hebei	0.1600	0.3	0.1	0.0048
Shandong	0.2933	0.3	0.1	0.0088
Shanxi	0.1600	0.3	0.1	0.0048
Shaanxi	0.2530	0.3	0.1	0.0076
Jilin	0.2169	0.3	0.1	0.0065
Liaoning	0.3253	0.3	0.1	0.0098
Heilongjiang	0.2048	0.3	0.1	0.0061
Inner Mongolia	0.3373	0.3	0.1	0.0101
Xinjiang	0.2409	0.3	0.1	0.0072

Table 8.5: *Model 1.2*, probability activation path, source: author

Again, the relative strength of pollution reduction in each location is borne out by the interpolated pollution data, with some important differences; Beijing has the greatest decrease in pollution, followed by Inner Mongolia and Liaoning, with Tianjin being about average for all locations. It is clear that *financial resources* alone is not sufficient to predict winter heating pollution reduction. The model output was then tested against the interpolated pollution data using regression analysis, as before.

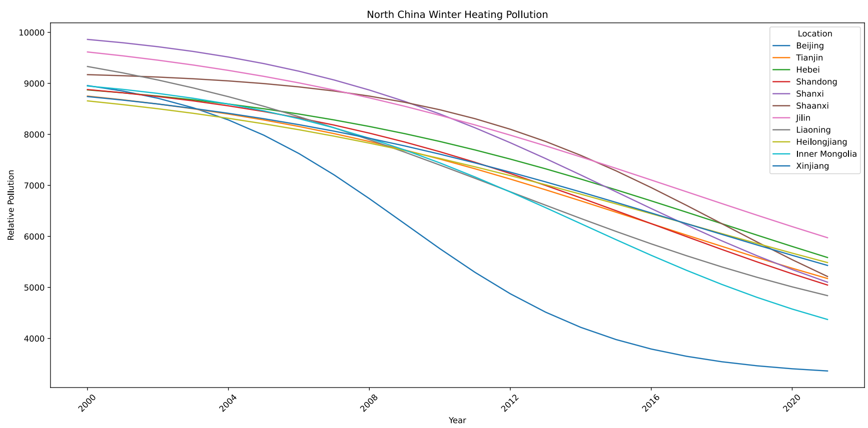

Figure 8.15: Graph of interpolated winter heating pollution for Northern China, 2000–2024, source: author

Figure 8.15 above shows interpolated winter heating pollution for all relevant provinces in northern China. Due to insufficient data for Henan, Gansu, Ningxia, and Qinghai, and to ensure correctness of pollution data these provinces are not included in the above pollution graph or subsequent analyses. Analysis of linear regression and piecewise linear fit indicate that the fit remains fundamentally identical to that seen in *model 1.0*, where *financial resources* were the only parameter tested. During the first period, the model fit is generally strong until around 2005–2009, when winter heating pollution in each location decreases significantly. This indicates that provinces substantially increased their investment in winter heating technologies well before the 2013 Clean Air Action Plan. Figure 8.16 is a representative sample of model fit for four provinces: Xinjiang, Heilongjiang, Shaanxi, and Inner Mongolia. The linear regression fit provides a single value representing the overall distance between the model output and the interpolated empirical data, encompassing all values in the dataset. While linear regression serves as a useful indicator of the overall strength and direction of the fit, incorporating slope calculations with reference to breakpoints, as in previous models, offers a more precise understanding of model accuracy.

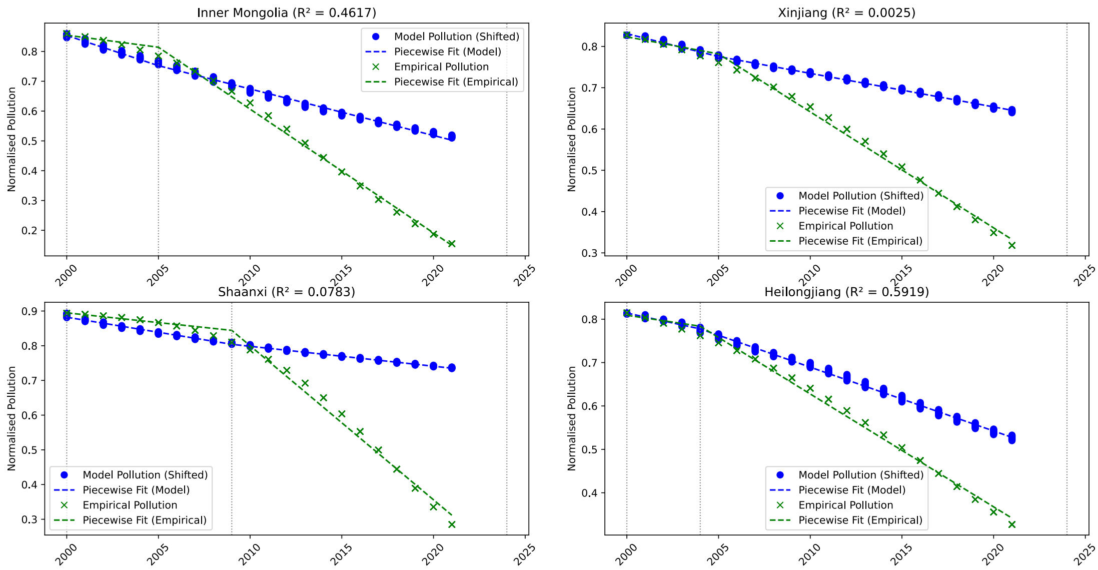

Figure 8.16: Graph of province linear regression and piecewise fit, 2000–2022, source: author

Location	Dates	% Change
Beijing	2000–2005	−4.39
	2005–2013	−462.76
	2013–2024	−316.0
Tianjin	2000–2007	11.71
	2007–2024	−259.05
Hebei	2000–2009	−103.83
	2009–2024	−439.62
Shanxi	2000–2006	−173.54
	2006–2024	−646.67
Shandong	2000–2006	0.63
	2006–2024	−341.86
Shaanxi	2000–2009	35.25
	2009–2024	−672.97
Jilin	2000–2005	−28.02
	2005–2024	−428.81
Liaoning	2000–2005	−136.62
	2005–2024	−335.05
Heilongjiang	2000–2004	30.75
	2004–2024	−77.0
Inner Mongolia	2000–2005	60.02
	2005–2024	−165.89
Xinjiang	2000–2005	25.4
	2005–2024	−245.52

Table 8.6: *Model 1.2* fit as percentage, colour-coded 0–39 (white), 40–100 (grey), 101–180 (orange), 181+ (red), source: author

Table 8.6 shows the variation from the model output over time, with the value given as a percentage. Each location is split by breakpoint, allowing a view of slope fit over time. In cases where the model shows a strong fit before the breakpoint but a very poor fit afterward:

Beijing, Tianjin, Shandong, Shaanxi, Jilin, Xinjiang, this provides strong evidence that **the model design effectively separates financial resources from other exogenous factors.** According to H2 and the core governance mechanism, the major exogenous factor must be attributable to *policy emphasis*. While the model results do not definitively prove this interpretation, the clear fit before the breakpoint and the abrupt divergence afterward do not falsify the hypothesis and lend strong support to it. Locations with less well fitting outputs are of equal interest in describing both weaknesses in the model, and possible local differences in winter heating investment. Hebei, Shanxi, Liaoning and Inner Mongolia are in this second category, whereby a clear break-point can be perceived, but the model output does not predict pre-breakpoint values as well as the first category. For this category of locations, the *empirical pollution data is worse than the model simulations.* Typical examples of this pre-breakpoint under investment can be seen in Inner Mongolia and Shaanxi Figure 8.16. **For their level of GDP, these provinces under-invest in winter heating infrastructure, and therefore produce more pollution than could be expected based on financial resources alone.** Note that **there are no locations in which poor model fit occurs because of a relative *over-investment* in winter heating compared to GDP level.** This finding broadly aligns with the historical scholarship on an *implementation gap* on environmental policy. In order to test variation within the model output, and ensure that the parameter values chosen are not *ad hoc*, and specific to those values, a range of values were tested for each parameter: province parameter, city parameter, SOE parameter. Cities were separated into regions (North China plain, Northwest, Northeast) that coincide with approximate winter temperatures, and city parameters were systematically tested to discover their effects on the model output. As expected, since the model is not designed to interact with complex dynamics, outputs varied smoothly, each location following closely their activation path probability. City activation parameters were varied, and the results measured against empirical data: city parameters of 0.3 for all cities regardless of region was the best result, coinciding with the approximate GDP per capita value for cities in the region, further increasing confidence that these parameters were not *ad hoc*. See Appendix for more details. While a slightly better fit can be achieved in some locations by varying each province city and SOE activation parameters individually, there is no other single universal parameter values that provide a better fit for all locations. The goal of the model is not to over-fit the results with *ad hoc* parameter values, but to test the model with parameter values derived from real-world GDP values. Given this stipulation, and the smooth variance in model output with varied parameters, the model parameter values are both remarkably stable, and the single best fit for all locations. Finally, the mean of all model output locations was compared to the winter heating pollution for the whole of China, including all fifteen winter heating locations: Figure 8.17. The statistics for whole of China data is more reliable than for those of provinces, although since this data is an aggregation of all data at lower levels it smooths out differences between provinces. In general this means that variations in the timing of breakpoints at the provincial level causes the data to flatten out. This causes the curve for whole of China pollution reduction to much more closely follow the model output. The linear regression for the period 2000-2024 stands at 0.79, indicating that financial resources alone are a good fit for pollution reduction for China as a whole.

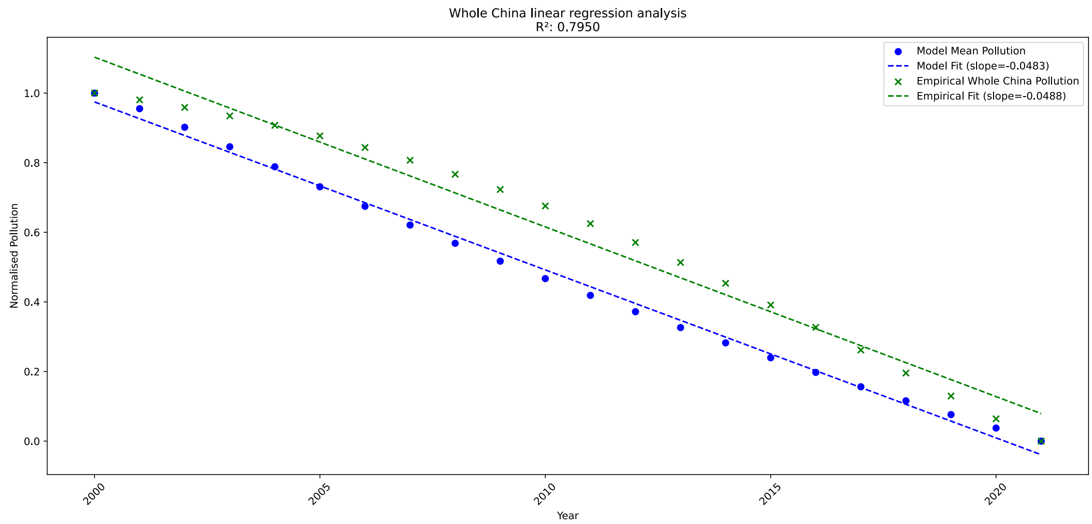

Figure 8.17: Whole China linear regression, mean model vs empirical data, source: author

Complex local variations in the data were aggregated across all of northern China, causing the complex interactions of local *policy emphasis* to be smoothed out. For example, if pollution decreases in Beijing but increases in Hebei, the combined average masks these differences, producing a simpler pattern–a steady linear decline that closely follows *financial resources.* This effect is clearly visible in Figure 8.17.

8.5 Discussion

Models 1.0, 1.1, 1.2 were developed based on the *core governance model*, where governance decisions are guided by two primary criteria: available *financial resources* and *policy emphasis*. While *financial resources* can be parameterised using measures of local GDP, *policy emphasis* presents a greater challenge. *Policy emphasis* is hypothesised to function as a complex system, in which local officials allocate environmental spending based on the political significance of a policy area or the influence of specific laws and regulations. *Policy emphasis* is always administered at the local level, by local officials, whether it originated in national-level laws and policies, or the political choices and whims of local government officials. The complex outcomes of central environmental policies are a case in point; the central government can never have truly direct control over the political choices of local Party and government officials, only influence them indirectly through a variety of means.

8.5.0.1 Out of sample data

The empirical pollution output was calculated based on the size of the heating network in each location, combined with approximate estimates of the proportion of 'clean' energy versus coal-fired energy. These pollution measures represent **novel data that were not included in the modelling phase**. The *core governance mechanism* was primarily derived from case study data, where major investments in winter heating technology occurred in 2010 and 2016. These dates fall outside the average for Hebei and other locations, where similar processes began somewhat earlier: between 2004 and 2009. Consequently, the *core governance mechanism* is not overfitted to the case study data; its predictions do not perfectly align with the 2010–2016 investments but instead reflect approximate averages for the time series. The interpolated pollution data suggests the most significant reduction in pollution occurred between 2005 and 2025, with a predicted plateau around 2040: Figure 10.5. If Hypothesis 2 is correct, the onset of the exponential reduction phase (2004–2009) should align with a significant increase in policy emphasis on winter heating pollution. This appears to be supported by the literature (Zhu, Liu, and Wei 2021, sec. 2.3), which identifies this period as a pivotal for winter heating reforms. Beginning in 2003, a series of large-scale reforms in winter heating provision were initiated, starting with pilot programs in select locations across Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Heilongjiang, Jilin, Liaoning, Shandong, Henan, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang. These programs focused on investing in the transformation of pre-existing *danwei* heating SOEs into larger, consolidated winter heating SOEs. The significant pollution decrease suggested by the interpolated heating data reinforce the validity of these calculations, broadly supporting the hypothesis. (Ministry of Housing and Urban-Rural Development 2003) and (State Council of the People's Republic of China 2005) were pivotal in promoting industrial consolidation. These were followed up by a flurry of other policies during the next decade, the most important of which were: (Ministry of Construction of the People's Republic of China 2006; Ministry of Housing and Urban-Rural Development of the People's Republic of China et al. 2010; State Council of the People's Republic of China 2010; 2012; National Development and Reform Commission of the People's Republic of China 2013; General Office of the Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013; National Development and Reform Commission et al. 2016).

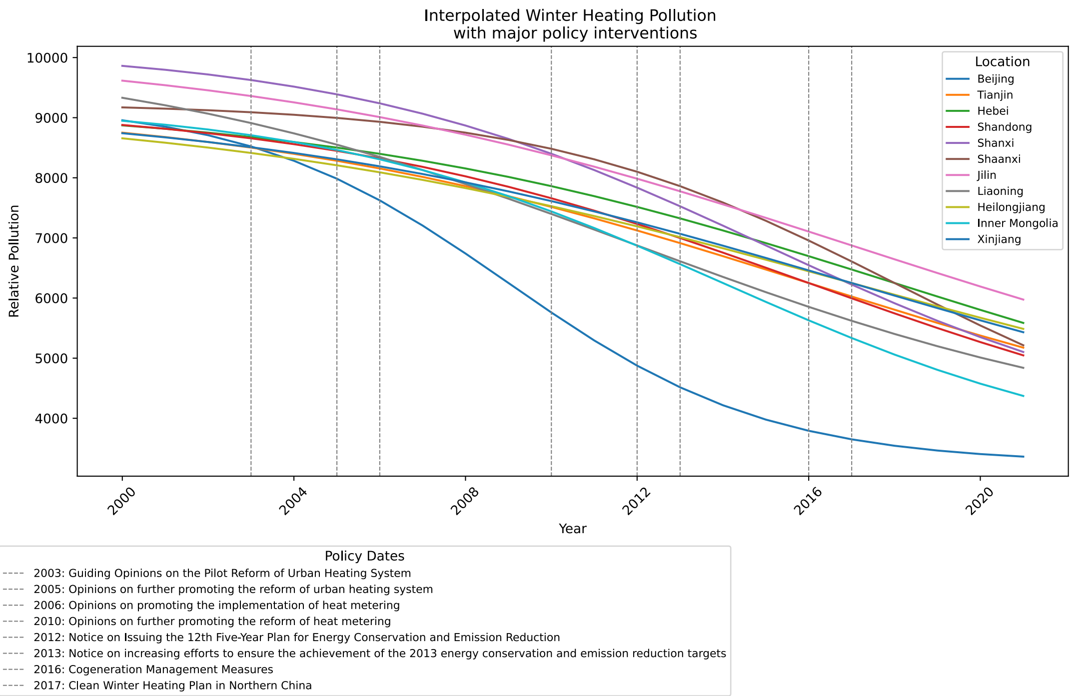

Figure 8.18: Interpolated winter heating pollution, with policy intervention dates (2000–2024)

This period of massive structural reform in winter heating was later followed by increasing policy focus on physical infrastructure investment into ‘clean’ energy in 2013 *Action Plan*, and the 2017 *Clean Winter Heating Plan* in Northern China, which set the target of 70% clean heating in Northern China by 2021. The analysis above suggests that these later interventions were associated with a *continuing decrease* in pollution associated with winter heating, but that interventions in the mid-2000s were overall a much larger driver of change. Further, without the earlier organisational changes which resulted in industrial consolidation, later phases of physical infrastructure investment would not be possible. The key winter heating policy interventions coinciding with significant decreases in winter heating pollution cannot conclusively demonstrate that these interventions caused the reduction. Neither can *policy emphasis* be proven as the most suitable candidate for modelling government actions during this period. However, they do provide strong circumstantial evidence for the importance of *policy emphasis*, and provide reasonable justification for further research with *policy emphasis* as its basis. The *core governance mechanism* underlying the models remains unfalsified.

8.6 Summary

The three-tiered model design presented here allows comparison of fit between each model iteration. There appears to be no major qualitative differences between models. From Hebei province to all of northern China, the model outputs shows a reasonable fit to empirical data until a breakpoint, after which the model fit is extremely poor. After the breakpoint, pollution deteriorates at a rate between 150-650% of the predicted *financial resources* rate. This pattern indicates firstly that the *core governance mechanism* is not over-fitted to the Hebei provincial case, as might be feared given that case study evidence from Hebei province lead to the formation of the mechanism. Secondly, **in general the shape of both the empirical and model data is that of a decaying logistic function**, which aligns with the assumption that **physical winter heating infrastructure is the greatest driver of pollution mitigation** where infrastructure is highly developed and efficient (Beijing), future gains in pollution mitigation will be slight, and highly costly. However, the pollution reduction slope in the empirical data is much steeper than the model predicts, which greatly affects the overall fit—especially during the exponential decay phase of the function. For instance, Henan province adopted an official winter heating policy relatively late, as it lies mostly south of the traditional *Qinling–Huai river line*. As a result, it is currently (2025) carrying out large-scale winter heating infrastructure projects that deliver major annual reductions in pollution—reductions that more established cities like Beijing cannot hope to match. Thirdly, pollution levels in each location do not follow a clear global pattern. The only consistent feature is that all breakpoints occur within a five-year window (2004–2009), spanning the 10th Five-Year

Plan (2001–2005) and the 11th Five-Year Plan (2006–2011). This timing aligns with the (Ministry of Housing and Urban-Rural Development 2003) pilot study and the subsequent (State Council of the People's Republic of China 2005) national policy, which reformed the *danwei* heating system and established the modern winter heating SOE framework. The innovations introduced during this period enabled widespread, though not simultaneous, investment in winter heating infrastructure. These investments are visible in the empirical data as breakpoints. The distinction between random and complex classification is an ongoing area of research in mathematics and complexity science. However, as a first approximation, **complex systems should not be strongly correlated with *global variables***. The models presented here used ‘GDP per capita’ as a parameter, and while this provided a reasonable baseline for investment in winter heating technologies, each province and city showed a distinct surge in investment that the models did not predict. I argue that these surges reflect shifts in *policy emphasis*, which is itself a complex phenomenon. Comparing the fit of different models is crucial for identifying errors within the model: if model fit deteriorates as model size increases, it suggests that fundamental flaws in the design of the governance mechanism might be amplifying errors. Conversely, if the model fit improves with increasing size, it strongly indicates that **variations in local-level government outcomes might be external to the primary governance mechanism, and these variations tend to diminish as the model scales up**. Model fit remained roughly the same across all three iterations, but improved when the models were applied to average winter heating pollution for the whole of northern China. This suggests that the models perform as expected for complex systems: while local-level mechanisms are complex and highly variable, their fluctuations become smoothed out when data are aggregated over a larger region.

9 Conclusion

> "*This company is not actually a profit-making company. It is more taking responsibility for social heating. For an ordinary enterprise, who would care if you complain to the government?*"
>
> — Hebei winter heating company, (Stanton 2024, 1.5)

This chapter will start by summarising a few key elements of the computational models discussed in chapters seven and eight. I will then go on to answer the main research questions laid out in the introduction: the cause of air pollution reduction over the research period; and the effect of Chinese governance structure upon the implementation of environmental policy. I will answer these questions throughout with reference to the winter heating sector, with some limited commentary on air polluting sectors as a whole. I then go on to critically analyse the methodology and scope of the research, and make recommendations on future research. The principal recommendation to the computational models presented here includes a required focus on national level laws, policies and ideology with a view to using a process tracing methodology to model the hypothesised *policy emphasis* effect.

9.1 Pollution abatement in context

Energy is one of the most important factors in producing and maintaining the modern Chinese economy, and Chinese coal has been a driving force in this. China experienced one of the most rapid industrialisations in history, especially among large countries. This transformation from an agricultural to an industrial and more recent drive towards a post-industrial service economy has profound implications for all areas of Chinese life. The economic transformation has been driven primarily by fossil fuels, especially highly polluting coal. Consequently, Chinese economic growth has directly contributed to air pollution throughout the post-Deng era until present. Although low-carbon and zero-carbon energy sources are becoming more available, they have historically been more expensive than conventional fossil fuels, both in initial capital outlay and ongoing costs. This creates a natural competition between two policy aims: reducing pollution and increasing economic growth. Such competing aims are evident in various policy areas: food and medicine standards, building construction standards, and workplace safety and employment standards. However, none are as wide-ranging or fundamental as environmental governance. This is because fossil fuel usage is essential, directly or indirectly, to every industry and is crucial to all economic development in China. Examining environmental governance is therefore not just relevant to the environment but intersects with almost all other policy areas, from industrial and economic development to foreign policy, notably affecting relations with Russia (Kuteleva and Vasiliev 2021). Environmental policy thus involves two highly significant structural factors: it fundamentally opposes one of the most critical policy aims—economic development—and is intertwined with fossil fuel usage, which is essential to nearly all other policy areas in China. This unique position allows for an examination of how competing policy interests are managed within Chinese governance. The process by which air pollution was significantly reduced in a relatively short period offers insights into the workings of the Chinese state bureaucracy. While these insights are valuable, we must be cautious in interpreting and generalising them to all of Chinese governance. However, I believe that with caveats discussed below, this research makes important theoretical and methodological contributions to that literature.

9.2 What caused reduction in air pollution, 2008-2018?

The approximate 30% reduction in air pollution can be largely attributed to changes in physical infrastructure: at first the addition of post-combustion controls; and then increases in the size and efficiency of boilers; culminating in largescale changes to the fuel source itself. These physical infrastructure changes began gradually in the late 1990s, and experienced a substantial acceleration, depending upon the sector, around a decade later. Physical infrastructure changes led to widespread decreases in major pollutant emissions, with measurements focusing on sulphur dioxide, nitrogen oxides and particulate matter (PM10 and PM2.5). The increase in efficiency generally followed a specific pattern: organisational consolidation, installation of large boilers, implementation of post-combustion controls, and transition to low-pollution energy sources. There was considerable variation in the number and length of phases involved, often spanning several decades with multiple rounds of new boilers and different energy sources. However, the underlying governance logic is clear: small companies with inefficient boilers cannot afford expensive post-combustion controls, so they must first undergo organisational consolidation. Once larger companies are established, they can afford to replace several small, inefficient boilers with newer, capital-intensive, larger models. These large boilers can then be equipped with post-combustion controls, which are very costly both in terms of initial capital investment and ongoing maintenance and operational expenses. Large state-owned enterprises (SOEs) are much more likely to have the financial resources to invest in capital-intensive equipment. Politically significant SOEs, such as electricity generation plants and large steel plants, are more likely to receive provincial and central government support and funding for these projects. Conversely, smaller and less politically important sectors and companies have a lower likelihood of attracting government investment for capital-intensive projects. This leads to asymmetric improvements to pollution abatement across sectors. Infrastructure investment followed large-scale national planning, prioritizing the larger coal-consuming sectors first. In general, the largest coal consumption is in thermal power plants, with around 49% of total consumption in 2010, rising to 62% in 2022. Electricity plant sulphur dioxide emissions peaked around 2005. From 2005-2018, SO2 emissions decreased by a factor of twelve at the same time that installed capacity almost doubled (G. Wang et al. 2020, fig. 1), with infrastructure investment passing through four different stages of increasing combustion efficiency, starting from the late 1990s. The second highest consumption sector is industry, with ferrous and other metal manufacturing being an important component, together with the chemicals, with textile, paper and food manufacture being other important sub-sectors. Together, industry represents around half of all coal consumption, although this proportion has been steadily decreasing to less than 40% in 2022 as more industry utilise natural gas and electricity to generate power for manufacturing processes, as well as natural decreases in manufacturing as a share of China's economy. Industrial emissions experienced a later starting point for infrastructure renewal than electric power plants. Taking the steel manufacturing industry as representative, improvements in efficiency started to increase greatly after 2010, with widespread infrastructure changes taking place after 2016. According to (Yu et al. 2023, fig. 23) from 2005 to 2019, China's steelmaking emissions reduced by a factor of 5. Although infrastructure changes accelerated after 2010, the greatest relative gains were made in the years 2005-2010. The winter heating sector is the smallest of the major sources of coal burning pollution, rising from around 5% of total consumption in 2010, to more than 10% in 2020. Being the smallest sector by consumption, large infrastructure changes came latest to this sector, in general accelerating after 2005 to present. The case study of a Hebei winter heating SOE found that similar to other sectors, old infrastructure, particularly small inefficient coal-fired boilers, were replaced by more efficient equipment through several waves of improvements. Changes in coal combustion infrastructure not only impact the companies directly but also have ripple effects throughout the larger marketplace. For instance, when winter heating companies purchase more efficient equipment, it necessitates significant adjustments across many aspects of their operations: hiring highly skilled boiler engineers; managing the purchase of higher-grade coal; organising transport, storage, and transfer of coal; collecting coal ash, and organising its sale for use in industrial chemicals or disposal. The transportation, storage, and preparation of coal require manpower, permanent infrastructure, and specialised transport via trucks and train cars. Numerous industries depend on coal combustion to operate, with coal mining being the largest and most crucial among them. The research period is coincident with a period of reduction in Chinese domestic coal production, and an increase in international coal imports. Following a local peak in 2013, imports dipped slightly and have slowly increased to date. This is due to the generally lower quality of domestic coal deposits; seams in Inner Mongolia, Shaanxi and Shanxi have a generally lower carbon content, and a higher sulphur content than high quality alternatives from Australia, Indonesia and Russia. These higher quality coals are required by Chinese legislation for thermal coals, as well as being required by the coking industry for use in high-heat industrial uses. The place of Australia in coal imports is extremely important, and an informal ban on Australian sourced coal in 2021-2023 following diplomatic tensions created huge difficulties for the Chinese coal market. Mongolian and Russian coal largely replaced Australian coal for this period, however problems with coal quality were not easy to overcome; high efficiency boilers rely on good quality coal to work well. In effect, legislation and investment in high efficiency equipment had locked China in to importing coal from abroad; power plants and industrial production could not be sustained without these high-quality foreign coal imports. Australian coal imports resumed at a high level in 2023-2024. Although air pollution as a whole peaked around 2010-2012 (see chapter three), coal consumption continued to rise to date, 2024. This can be explained both as a result of demand for high-quality coal for industrial uses, and for electricity production. Electricity production more than doubled from 2008-2018, and is expected to rise further, with the majority of electricity production still attributed to coal-fired power stations, although with increasing addition of renewable energy electricity projected. Previous projections by the US *Energy Information Administration* (U.S. Energy Information Administration 2016) assumed that coal consumption for electricity generation would peak around 2018, and remain flat until 2040; so far coal consumption has continued to rise, and new projections (U.S. Energy Information Administration 2023) assume a relatively flat consumption with a peak in 2040. This new outlook follows an increase in coal power generation stations, partly as a result of increasing power demand in general, but especially heightened by electricity for use of electric motors which are expected to replace internal combustion engines in cars, but also in industrial use, space heating, cooking and other domestic uses. The winter heating sector is a relatively small part in the China's coal consumption as a whole, but coal usage here follows the same pattern as in other sectors: an increasing emphasis on elimination of coal where possible, and high-quality consumption where elimination is not possible. Government investment in winter heating infrastructure was the primary driver of pollution mitigation, rather than an increase in environmental pressure on SOE operations. This distinction is crucial for understanding the rapid implementation of equipment changes. Increased powers of local MEP bureaux to aggressively pursue polluting behaviours may be expected to lead to gradual and reluctant changes in SOE operations. Under this logic, a mixture of increasing fines levied to SOEs, together with increasing pressure on local governments from the MEP, led to a change in the political support for environmental policies. As well as the financial pressure of ever greater fines, local government acts to pressure SOEs to change their physical equipment. The dual effects of these changes are that: 1. SOEs increase use of the post-combustion controls they already have in place; 2. SOEs self-fund more efficient boilers and post-combustion controls. This is a local, gradualist approach to environmental governance, exemplified by hypothesis 1 (chapter three). However, there is little evidence to suggest that this actually happened. On the contrary, evidence from the case study suggests that government funding led to the installation of efficient boilers, post-combustion controls and finally, changing of the energy source to Combined Heat and Power from the local electricity power station. Further, the core governance mechanism developed in chapter seven, together with models to test this mechanism in chapter eight, provides good evidence that the case study was not an outlier. Pollution reduction in the winter heating sector as a whole was driven by government investment, not by increases in environmental fines, or the increased bureaucratic power of the MEP. There is little evidence to suggest that the central government's expansion of the environmental agency's bureaucratic powers resulted in a corresponding increase in the authority of local-level environmental bureaux. Investment in winter heating infrastructure is largely explained by two main factors: *financial resources* (local government income), and *policy emphasis* (political support for a policy). Where both policy emphasis and high funding is available, air pollution mitigation work was carried out quickly and thoroughly.

9.3 How does the structure of Chinese governance affect implementation of environmental policy??

I will begin by explaining why this question is crucial for understanding environmental governance. Next, I will outline the fundamental structure of environmental governance. Finally, I will discuss how the governance network dynamically interacts, resulting in complex implementation.

9.3.1 Importance of governance structure

The literature review laid out a number of possible explanations for the historical implementation gap in environmental governance. While a full explanation is out with the scope of this research, an adequate account of the improvement in air pollution must address its historical failure. The logical claim from many scholars is that decreasing air pollution involves solving the specific governance problems identified in the implementation gap literature (Kostka and Mol 2013; Rooij 2006; Lo et al. 2012; Chan et al. 1995). I do not make this claim. Instead, I argue that the successes of the Chinese state in reducing air pollution have largely been orthogonal to the failures identified in the literature. I set up the hypotheses in chapter three to clarify the consequences of two distinct approaches: H1 hypothesises that pollution reduction was as a result of strengthening the bureaucratic powers of the environment agency, while H2 claims that it was a change in policy emphasis that led to direct government investment in physical infrastructure. Explanations of the implementation gap have ranged from weak institutional powers of the environment agency[59] to weak local government incentives; to weak central government incentives. Each explanation for poor implementation may then be paired with an appropriate change in the governance conditions which might ameliorate that problem.

Empirical evidence was able to dismiss the MEP as a major driver of implementation success; the case study found that the MEP were not responsible for implementing the improvements in air pollution, and this hypothesis was modelled in detail producing a reasonable fit with empirical data. The theoretical framework introduced in chapter three assumes that the environmental governance gap can be explained in terms of a complex system. This theoretical framework roughly divides the governance system into three classes: the content of political decisions (laws, policies, five year plans, projects, etc); the governance bodies which take these decisions (each with varying levels of institutional powers); and the larger network topology in which the various bodies exist. There has long been an understanding that structural elements of the Chinese state are an important part of understanding state dynamics. This can be typified by Lieberthal and Oksenberg (Lieberthal and Oksenberg 1988), and more recently developed into *decentralised authoritarianism* by Landry (Landry 2008a). This logic of decentralisation as the major driver of Chinese governance has in recent years been counteracted with another framework, that of *authoritarian environmentalism* (Jahiel 1998; Zhang 2017b; D. S. van der Kamp 2023). On this logic, it is increasing centralisation of government powers, sometimes associated with Xi Jinping's leadership, that counter-acts the historical problem of decentralisation. Both hypotheses of Chinese state dynamics, decentralisation and centralisation, can be modelled and tested by the logic of complex systems. Through network theory and complex systems modelling of environmental governance data, changes in the structure of the network will produce easily visible, and analysable outputs in the model data.

9.3.2 Hierarchical governance, local autonomy

[59] State council environmental body 1998-2008: State Environmental Protection Agency; 2008-2018: Ministry of Environmental Protection; 2018-present: Ministry of Ecology and Environment

The dynamics of the governance system are hugely influenced by the structure of the network in which it operates. This explanation is both concise and powerful; according to complex network theory small changes in network topology are likely to lead to significant changes in network dynamics (Guimerà et al. 2003). The Chinese state structure is fundamentally hierarchical, and this topology shapes how local governments and officials within the network decide work priority. Viewed as a purely hierarchical network, instructions from the central Party leadership should be easily relayed to local government officials. Chinese state governance may be classified as a tree network, with central government at the root, and provincial, county and township governments at the periphery. While the governance network may appear hierarchical overall, a closer analysis reveals that the overarching hierarchy includes sub-branches that are ambiguous, complex, or topologically flat. Local government is not a single, unified entity but rather a composite of Party and government structures, including State Council bodies like the NDRC and other agencies such as the MEP. At the city level, the degree of hierarchy is often ambiguous and may dynamically shift as local Party and government officials manoeuvre in response to local elites or to broader changes within the province or state as a whole. Regardless of individual personalities, officials are tasked with interpreting and prioritising provincial and central policies and targets according to local needs. This produces a dynamic in which local governments retain substantial autonomy in some policy areas, while facing strong constraints in others. Recent reviews of 'top-level design' echo this mixed picture of political autonomy, noting that Xi Jinping's centralisation has not fundamentally overturned the long-standing pattern of decentralisation (Ahlers and Schubert 2021). I hypothesise that the degree of autonomy is signalled by central government in *policy emphasis*; where policy emphasis is weak, local governments have autonomy to decide policy according to local needs; where policy emphasis is strong, local governments clearly increase their capacity to implement central government policy. Where there is strong political support behind a policy, the governance structure is such that top-down policy initiatives can be implemented very quickly, and with great vigour. The governance network appears to move as one single unit, from the Politburo standing committee at the Centre to the smallest, most local units of government and state council at the periphery. In such conditions, there is a high likelihood of over-zealous implementation of environmental policy (Kostka and Zhang 2018; Ahlers and Shen 2017; Li, Qiao, and Shi 2019). This may include ad hoc decisions regarding the closure of factories (Lo 2020) or removing old coal-fired heating boilers without a suitable replacement (Shao 2023; Ran 2024). In contrast, where there is weak political support for a law or policy, the governance structure is similarly able to communicate this level of policy emphasis to all governance bodies (Ran 2013). In such situations, local policy implementation is likely to vary considerably; where local conditions favour such policies, implementation will take place in line with local government funding. These conditions of weak political support at the Centre provide an explanation for cases in which environmental implementation is notably absent in most cases, but strongly implemented in others. These conditions seem to apply to Beijing's implementation of environmental policy. The government appeared to implement air pollution mitigation strategies much more forcefully than other cities throughout the 1980s-2000s. It was not until at least 2010 that other cities in northern China appeared to implement environmental policies to such an extent. This can be seen clearly in Beijing's winter heating data. Other cities only started to implement the creation of large, efficient, winter heating SOEs from around 1996, and at a very low level. However, Beijing had already created heating SOEs from the 1980s, and by 1996 was already well advanced in eliminating small-scale inefficient boilers. By 2008, Beijing was further advanced compared to other cities in winter heating infrastructure, with around half of Beijing's heating provided by clean fuel, including CHP and natural gas. Other important cities in the winter heating area, notably Tianjin, was not nearly as advanced as Beijing. The infrastructure spending in Tianjin was notably higher than other northern cities, but largely in line with local funding income, as measured by GDP per capita. The northeastern cities were the highest ranked of the other cities; this can largely be explained by the importance of winter heating for local quality of life, given the very cold winters. Rather than a question of pollution mitigation, the creation and growth of winter heating SOEs was given policy preference as a quality of life indicator (民生问题). The relative independence of local government is the cause of poor policy implementation. However, the model presented here indicates that local government independence is not absolute, nor equal across all policies. Local government is able to make independent decisions on some policy areas and not on others. Which policy areas are emphasised and which are de-emphasised is not decided by the local government itself; rather policy emphasis is communicated from the centre to the periphery through the hierarchical governance network. Local government receives communication on policy emphasis from their immediate superiors, i.e. provincial government communicates policy emphasis to municipal government. It is not clear how policy emphasis is communicated. The model did not differentiate between Party and Government bodies. The Party may provide a reasonable candidate for communicating policy emphasis from the centre in an organisational hierarchy that is separated from, while being bureaucratically superior to, and in very close communication with, local government. I conjecture that the importance of a law or policy cannot be known by examining the document itself. Instead, laws and policies are given political importance by central Party leaders (Birney 2014). The mechanisms through which Party leaders may campaign for a particular policy area to be given more political significance is outside the scope of this thesis, however writings, speeches, visits and other media appearances may be important. Where top Party leaders at the Politburo are unanimous in giving their approval to a policy, it is vigorously promoted in Party literature such as Qiu shi magazine (求是), or important media such as the People's Daily (人民日报) and official television news (新闻联播). I hope to investigate this possibility in future research. The computational models presented in chapters seven and eight have a reasonable fit with the available empirical data at three different levels of analysis: from a single province, to the north China plain, to the whole of northern China. Local government make funding decisions based upon two basic factors: available funds and the political importance of a given policy. The models are designed to account for half of the hypothesised core governance mechanism, accounting for financial resources, while leaving policy emphasis as exogenous to the model. This was a practical modelling choice which offers some distinct advantages over ad hoc modelling parameters with a currently poorly evidenced policy emphasis. I summarise these modelling choices below.

9.4 Modelling

The models presented in chapters seven and eight emerged from a deliberate series of choices, where each decision represents a hypothesis about the researched phenomenon. These choices, while based upon a wide range of evidence from scholarly literature, empirical data, and theoretical constructs, the available evidence is never strong enough to be unassailable. These assumptions inherently narrow the range of possible models, a necessary aspect of modelling as not all possible models can be investigated equally. Modelling assumptions produce logical path dependencies so that it is impractical to reconsider assumptions already made earlier in the process. As such, this makes early modelling choices extremely consequential. This process carries the risk of discarding models that may more accurately reflect reality, potentially compromising the final outcome. To mitigate against premature modelling decisions, I allowed a plurality of theoretical frameworks to coexist until after finishing the case study. It was only in chapter seven that these diverse pieces of evidence were finally synthesised, leading to the core governance mechanism described. While delaying modelling decisions avoids premature decisions, this approach also has costs. By adopting conservative modelling assumptions and deferring early decisions, the research naturally skews towards breadth at the expense of depth. This strategy itself represents a significant modelling choice, on the premise that given the wide array of explanations of the implementation gap, the major task of this research was in narrowing down the dozens of possibilities. The research design together with computational modelling enabled a systematic, step-by-step approach, providing greater confidence in the results.

9.4.1 Model meta-analysis

The models essentially show a diffusion dynamic, whereby the rapidity with which agents move from their initial to final conditions represents the speed at which environmental policy is implemented in the governance network. Overall, modifying agent parameters based on GDP per capita shows a reasonable fit with empirical data before policy emphasis is increased; membership of the 2013 Action Plan has a poor fit with data. Considering the overall static model fit despite increasing scope, alongside out-of-sample data showing a strong correlation between increased pollution reduction and the winter heating consolidation efforts prompted by (Ministry of Housing and Urban-Rural Development 2003) and (State Council of the People's Republic of China 2005), there is strong evidence to suggest that these policies were predicted by *policy emphasis*. It seems reasonable to conclude that the core governance mechanism is a reasonable predictor of pollution change, and has not been falsified. By combining the simple parameter with a complex parameter *policy emphasis*, the core governance mechanism therefore has the possibility of providing a general framework for Chinese governance beyond the winter heating sector. Viewed abstractly, the models presented here consist of multiple simple mechanisms chained together. The lowest-level mechanism (*model 0.1*) has a simple, linear process at its core: *danwei* heating à SOE coal heating à SOE clean fossil fuel à SOE renewable energy. The 'phase' occupied by a heating system is simply a function of the number of times funding has been allocated, and each phase of heating is directly related to the air pollution produced. This simple, linear process is additive and quite stable; since each phase represents the installation of physical infrastructure, the heating system does not revert to a previous phase. This lower-level mechanism only allows for linear change. The addition of stochastic elements to the model, as in *model 1.0*, attempt to provide mechanisms which may account for complex and unpredictable government funding allocation at the municipal and provincial levels, and ultimately policy and law creation at the central level. The proposed mechanism at each level of government must ultimately account for a degree of unpredictability in policy implementation; both at the level of individual local government, and generally of the whole governance network. The models presented here can be classified as *diffusion* models, which simulate the process observed in natural phenomena whereby objects of high concentration, through a random process, gradually spread out to find equilibrium in a space. Diffusion dynamics have been theorised in a vast diversity of processes, from molecules of gas dispersing in a room to 'innovation diffusion', whereby new technology becomes common in a marketplace (Guidolin and Manfredi 2023), or the diffusion of novel ideas (Staley 2011) and policies (Shipan and Volden 2008) in a government. Policy diffusion may be theorised to take place horizontally, between different governments at a similar level (Shipan and Volden 2008) or vertically as policy diffuses from central and provincial government to local governments (Zhang and Zhu 2018). The models presented here take the form of a vertical diffusion dynamic. The central government adopts an environmental policy which may not be universally and automatically adopted by provincial or city governments. Further, where the environmental policy is adopted, it may be weakly implemented. Conceptually, policy moves through a hierarchical network according to random chance, replicating the random walk of a molecule through space. Where the probability of policy spreading is high (e.g. Beijing), the time taken for those SOE nodes to reach their final state is short; in contrast, where the probability is low (e.g. Henan province) the time taken for those nodes to reach their final state may be very long. The whole model may be viewed as simply a hierarchical structure of IF logic gates, whereby some 'object' (an environmental policy) must fulfil requirements before passing each gate. While the possibility of passing through a particular gate at any one instance may be probabilistic, as the model step count increases, it becomes virtually certain that the policy object will pass through each gate the maximum number of times[60]. While the model parameters adjust the probability of each logic gate, the overall model structure means that so long as the step count of the model is high enough, the differing probabilities will not result in differing agent conditions, but rather differing times at which each agent will reach the final condition. In the end, all SOEs will convert to their final state (renewable energy), and the total pollution emitted will be zero. Viewed in this manner, the probability function associated with each node is indirectly equivalent to the time taken for that node to spread the policy to other parts of the network. Time in the model is measured through a 'step count', where each step produces a change in the model. The number of steps taken to create an output of a given type, is a function of two major properties:

- the time (e.g. step count 12) at which central government node 'activates' an environmental policy;
- the total probability of producing the final agent condition, being the product of the probabilities at each level

The figure below illustrates this principle in a toy model of pollution abatement, whereby pixels start on the left as black (*danwei* heating), proceed to dark grey (coal SOE heating), light grey ('clean' fossil SOE), and white (renewable SOE). The toy model produces outcomes similar to the large models presented in chapter eight; the difference being that this is entirely random, whereas the models in chapter eight produce outcomes that are stochastic but broadly predictable.

[60]The *law of large numbers* states that as iteration approaches infinity, the probability of any non-zero event occurring will approach 1

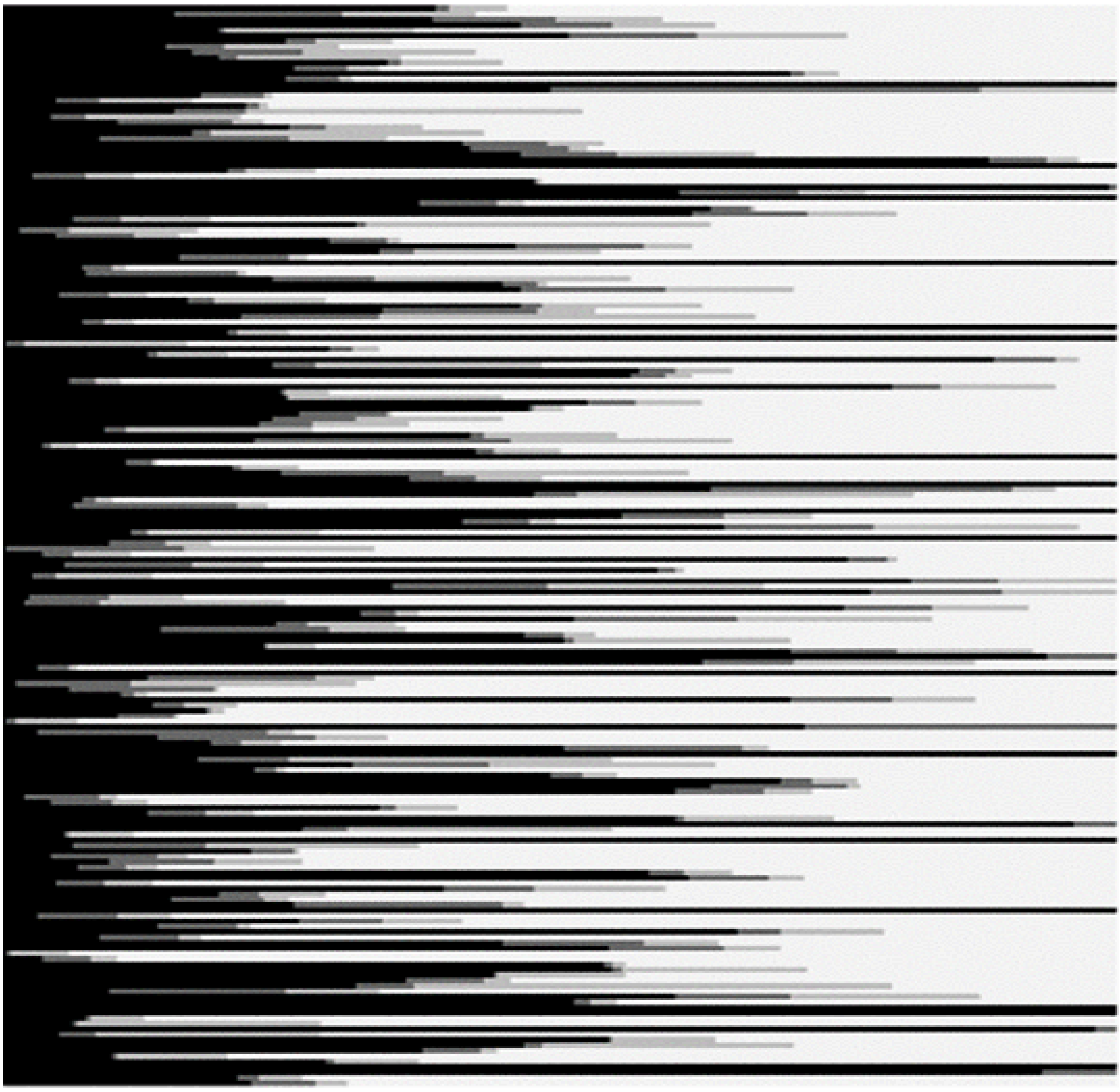

Figure 9.1: Abstract model, showing composition of agents (vertical) and change over time (left to right), source: author

The toy model in figure 9.1 makes it easy to observe the dynamics of the system as a whole; even though the abstract model contains no probability difference between agents, it displays clear path dependence. While some agents quickly progress through to the final condition (white), others remain in the initial condition (black) for the entire length of the model simulation. Similar path dependence outcomes may be observed in each of the empirically-derived models. In the abstract model, as long as activation probability is greater than 0, the model will always complete; time taken to complete is a measure of probability, and vice versa. The model therefore produces a very rough 'time complexity' of the system (He and Yao 2001), whereby the model dynamically calculates the path from a disordered to an ordered system. In the model, the system is disordered when some attribute of the agents, 'activation', is concentrated in a small number of nodes, leaving most nodes un-activated. As the simulation runs, the network as a whole becomes 'activated', all agents have moved to 'renewable energy' phase, and full equilibrium is reached. Where the model total probability is high, the model reaches equilibrium with a small number of steps; conversely where probability is low, it takes a larger number of steps before model equilibrium is reached. In other words, the models presented in chapter eight can be thought of as measuring the time complexity for a location to reach its equilibrium state. This creates interesting questions related to the generality of these models. Beijing implements environmental policies more swiftly and decisively than Henan. Does this dynamic extend to other policy areas? For instance, is Henan likely to lag behind Beijing in implementing measures to improve food and drug safety or in cracking down on corruption? If the time complexity for each location to implement some central policy could be measured, this may provide the foundations for a more rigorous model of Chinese state dynamics. I consider the limitations of this research below, and how it could be further generalised.

9.5 Limitations of the research

While the research presented here can confidently answer the 'what' (the cause of a rapid decrease in air pollution), the 'how' (how network governance affects implementation) is rather more challenging. While I have a high degree of confidence in the first explanation, the second has some important caveats, especially when the question is widened to consider the governance structure and implementation of air pollution policy for other polluting sectors. I consider these challenges and caveats below, and put the research in context. The most important limitation in this research lies in the conditions prevalent in the winter heating sector which are not necessarily present, or present to a different degree, in other major polluting sectors. The first significant factor to consider is that the winter heating sector is predominantly composed of State-Owned Enterprises (SOEs). Even in cases where private companies are involved, they are subject to the same stringent regulations as the public ones. Prices are not determined by the heating companies themselves but are set by the municipal price-setting authorities. As a result, winter heating companies lack the autonomy to adjust prices to generate capital and must instead seek financing through bank loans or municipal government loans. Further, winter heating companies are not considered particularly large or important SOEs; they are bureaucratically ranked at the level of the municipal district (市区) or below. Their low bureaucratic rank makes them formally inferior to municipal government. This is in contrast to large and important polluting SOEs such as coal fired electricity stations, or large steel mills which may be administered by the hundred or so centrally administered SOEs (中央直属企业), which are bureaucratically ranked at 'vice-ministerial level' (副部级). Given that the special characteristics of the winter heating sector above made important contributions to the formation of hypothesis H2, any changes to these characteristics may require an adjustment to the hypothesis, or to the particulars of any models.

Polluting Sector Key Comparison

	Winter Heating	Electrical Generation	Manufacturing	Urban Transport
SOE share of sector %	90%	100%	40%	17%
Autonomous price-setting?	No	No	Yes	Yes
SOE bureaucratic rank	Low	High	Medium	Medium
Natural monopoly?	Yes	Yes	No	No

Table 9.1: Comparison of key sector characteristics, source: (Jia et al. 2020; Song 2018)

The table presented above offers a comparative overview of several crucial factors that influence the formulation of Hypothesis 2. It is evident that the winter heating sector differs significantly from other major polluting sectors. H2 hypothesises that winter heating companies are constrained in their ability to independently raise funds and must rely on local government for decisions on significant capital expenditures. Electrical generation shares some characteristics with winter heating, such as being a natural monopoly with a high proportion of state-owned enterprises (SOEs) and limited pricing autonomy. Historical analysis of the electrical sector reveals that it underwent extensive restructuring and significant investments in pollution control measures approximately a decade earlier than both steel manufacturing—which is the major contributor to air pollution within manufacturing—and the winter heating sector. This aligns well with the H2 framework, which predicts that once policy emphasis is decided at the central level, it will diffuse through the network in a hierarchical manner. Ceteris paribus, higher-ranked SOEs are more likely to initiate pollution abatement projects earlier. The electrical generation sector seems to be a good candidate for further expansion of the current computational models. It is not known how competition may affect pollution abatement investment. The winter heating and electrical generation sectors are natural monopolies, whereby no competition is possible between different SOEs or with privately owned companies. Such is not the case with the manufacturing sector as a whole, and within the car manufacturing sector. These industrial sectors have a much lower share of SOE ownership, and SOEs must compete with other state and privately owned enterprises for market share and profits. Strong competition may create an additional opposing incentive not present in other sectors, forcing manufacturing and transport SOEs to more closely follow trends in the private sector. This may result in later adoption of pollution abatement investment than may be predicted by their size and bureaucratic rank. This conjecture requires further research, and these sectors are not an immediate candidate for expansion of computational models. Further to those industries directly involved in air pollution, there are an even larger number of industries and government bodies that are indirectly involved in both emitting air pollution, and in regulating it. These may be regarded as exogenous factors in air pollution; the share of these exogeneous factors in reducing air pollution should not be discounted. For the winter heating sector, the largest exogenous factors are the fuel source, and the energy efficiency of housing and commercial properties. In China, the fuel source for the majority of winter heating is coal, and the ability of heating companies to switch to lower emissions fuels such as natural gas is quite limited. The availability of natural gas is relatively low, with few gas fields being located in China, and imported natural gas being very expensive compared to coal. Such factors as the availability of natural gas cannot be controlled by winter heating companies, or by local governments or the Ministry of Environmental Protection. In an effort to increase the availability of natural gas for a variety of industrial uses, China has engaged in decades of international negotiation and investment with a number of central Asian states, with the majority of imported pipeline gas coming from Turkmenistan and Russia. The newest pipeline

‘Power of Siberia’ supplies natural gas from Gazprom and was agreed in 2014 (National Energy Administration of China 2014), and came online in 2019. The contract agreed was for $ 400 billion of natural gas to be

supplied over a 30 year period. A further pipeline is currently in the planning stages. Changes in the availability and price of natural gas is a huge factor in the air pollution produced by heating companies in cities, and is exogenous to the governance of pollution. Only decisions made at the highest levels of state governance could account for such changes, and are therefore exogenous to the models presented here. Another major exogenous factor is the energy efficiency of buildings. This is a separate issue to the efficiency of the heating network and final delivery system, which may be improved by the heating company, including the use of user-controlled temperatures. The energy efficiency of buildings includes the thermal properties of building materials, and may include internal partitions but especially is related to the properties of the ‘external envelope’, including walls, windows, and roof. A buildings’ energy efficiency is set by the Ministry of Housing and Urban Rural Development, and refers to standards set in the Energy Conservation Law, 2007 (National People's Congress of the People's Republic of China 2018a). These regulations apply only to new buildings, and therefore even assuming building companies apply these standards, existing buildings are expected to have little or no insulation standards in place. Were existing buildings standards applied across all of the buildings stock, an excess of 50% increase in buildings energy efficiency is expected (World Bank 2001, sec. iv) highlighting this as a huge exogenous factor in heating pollution. Pollution abatement projects are influenced by a number of exogenous factors that are essential for their success. Figure 9.1 below outlines the most immediate exogenous factors beyond environmental policy, which include economic, energy, and foreign policies. Without the prior development of these critical areas, any government pollution abatement project would be unworkable. The development of pollution control technologies is one such area: in the 1990s, high-efficiency coal boilers and post-combustion controls like desulphurisation towers (FGD) were not manufactured domestically in China nor economically feasible due to their high costs, which accounted for about 12% of the total capital cost of thermal power stations (Xu et al. 2000, p. 2). However, by the period from 2003 to 2006, industrial planning reduced these costs by half, resulting in a growing domestic capacity to design and produce FGD systems at scale (Kaneko et al. 2010). The reduction in FGD costs, while immediately due to industrial planning, also depended on second-order causes in education—specifically, the expansion of university-level engineering programs. This example shows that the number of exogeneous factors in a complex system cannot be limited to immediate causes, but may grow as the second and third order causes are included in the analysis. Although not depicted in Figure 9.1, second-order causes are also crucial in creating the conditions under which government may invest in industrial capacity; the number of STEM PhD graduates in China surged sixfold from 2000 to 2015 (Zwetsloot et al. 2021). This increase in specialised knowledge and skills illustrates how interconnected and multiplicative exogenous factors are. Figure 9.1 below illustrates that within winter heating sector alone, there are a number of factors which could not be analysed or accounted for in this research. Naturally, accounting for even the first-order factors that influence the principal polluting sectors is far beyond the scope of this research. The temptation to generalise the findings of this research to Chinese environmental governance as a whole should therefore be rejected.

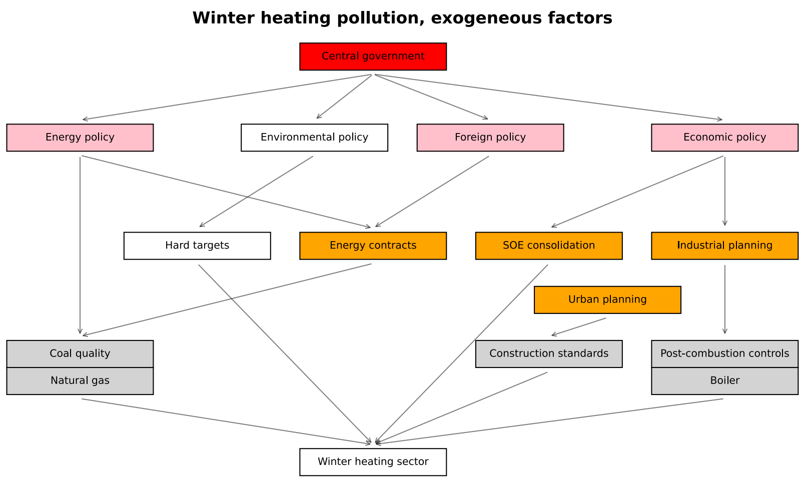

Figure 9.2: Flow diagram, environmental policy within context of first-order exogeneous factors, source: author

9.6 Further research

Given the limitations identified above, I identify the concrete steps that could be taken to enhance governance modelling in future research. I will briefly explore concrete expansions to this thesis, narrowing down to those actions which are likely to have a strong impact on explanatory power while increasing model confidence. I conclude that addressing the gap in evidence of *policy emphasis* requires shifting the focus from micro-level governmental bodies to macro-level governance at the central level.

9.6.1 Ensuring representativeness of case studies

The research design heavily relied upon data from the case study, and this approach was highly effective in addressing specifics of winter heating governance at the micro-level. However, there are natural concerns about the representativeness of any case study, especially if a single case study is used as the basis of a generalised model. I addressed this concern in chapter seven, and noted that the case study appears to be representative of the average winter heating SOE on a number of parameters. However, expanding the number of case studies to include SOEs in different urban municipalities could help to improve confidence in the core model mechanism. The northeast region (东北), is extremely cold, and the site of early winter heating expansion in China, while the northwest region (西北) was developed somewhat later. Incorporating one case study from each region would provide valuable micro-level research into winter heating governance in areas with distinct characteristics, without overwhelming the scope of research.

9.6.2 Expansion of existing diffusion model

Further to correcting issues with model validity, there are a number of areas where the model may be expanded with relative ease. Given the work done in testing the computational models in chapter eight, the core governance mechanism identified in chapter seven can be assumed to be a reasonable core mechanism for further governance modelling. The model as presented in chapter eight, with some necessary adjustments[61], would naturally lend itself to the addition of other SOE dominated polluting sectors: electrical power plants and steel-making SOEs. As summarised in Table 9.1, state-owned power plants and steel mills may be expected to have strong similarities in how they are governed and effected by environmental laws and

[61]Under a basic diffusion model, as in *1.2*, power plant or steel mill SOEs may simply replace winter heating nodes. The bureaucratic rank of the SOE within the governance network may need to be adjusted

policies compared with the winter heating sector. Restricting pollution modelling to SOEs only, 10% of China's coal combustion is caused by winter heating, 40% by power generation, and the remaining 60% to all manufacturing and industrial sectors, of which the single largest source, steel fabrication, is perhaps a 15% share of total coal ("National Data" 2005, 2008). Therefore, modelling just three sectors: winter heating, power, and steel SOE sectors may represent up to 75% of all Chinese coal burning by volume, representing a considerable share of total Chinese pollution. The critical roles of power plants and steel-making industries are vital not only for meeting domestic consumption needs but also for achieving national self-sufficiency in key industrial sectors, and are further considered crucial to China's national defence planning (Cheng, Whitten, and Hua 2019). Power generation is especially important and centralised, with electricity plants comprised of just a few large 'central SOEs' (央企), while steel manufacturing sector consists of a large range of companies, from central SOEs to provincial and municipal SOEs as well as a considerable number of private companies of various sizes. Within the SOE share of these sectors, the average bureaucratic rank may be expected to be higher than winter heating SOEs, and may in many instances out-rank local municipal governments. According to the logic of the diffusion models presented in chapter eight, assuming a strong *policy emphasis*, SOEs with higher bureaucratic rank may be expected to be early adopters of pollution abatement equipment, with this pattern observable in the empirical data. Expanding diffusion computational models is relatively straightforward, enabling research to quickly simulate and assess environmental governance of different sectors. However, to capture the core complex dynamics of *policy emphasis* itself, it is necessary to go beyond the diffusion models presented here.

9.6.2.1 Focus research on central government *policy emphasis*

While the diffusion model is vital in understanding micro-level dynamics in the governance network, this thesis leaves open the question of how macro-level governance networks affect the timing and creation of *policy emphasis*. While chapter five summarised a number of important national-level policies that apparently led to a change in the importance of environmental policy, the precise dynamics involved were left as an open question. To bridge this gap, future research should focus on the central government level to decipher the causal processes that led to a greater willingness to fund environmental projects. Given the groundwork laid in this thesis, initial efforts should target the winter heating sector. This focus on central government should utilise a process tracing methodology, with particular focus on the factors identified in this thesis: laws; 5 year plans; policies; media content; Party and State ideology. Policy emphasis is not theorised as a single decision, either in Party ideology, law, or policy. Instead, a partial and ambiguous sense of policy emphasis is created through the complex interactions of a number of different elements: ideological changes to Party and national constitutions, laws, planning, policy, but also leaders speeches, news and other media coverage, and public opinion. A systematic analysis of government documents in all these areas is extremely challenging; instead, focusing on a few important writings such as 5YPs and Qiu Shi magazine (求是) is a reasonable starting point. Differences in Party and Government have been elided in this thesis. Further research focusing on policy emphasis may require a more granular approach to modelling the state governance network. The Party seems to be a reasonable structure, prima facie, along which policy emphasis may be communicated.

9.7 Summary

The computational models presented in this thesis indicate that although on average the tide of air pollution turned around 2010-2012, for some cities like Beijing and Tianjin this occurred much earlier. Similarly, during the 'war on pollution' period from around 2012-2016, not all cities invested in clean winter heating infrastructure to the same degree. It is likely that those cities closest to Beijing were given much stricter instructions on environmental spending. This indicates the importance of the dynamics of a city within its governance network; dependence on the provincial government in some areas, and independence in others, or changing patterns of dependence across time create a complex governance environment. Although predicting the dynamics of environmental funding during the 'war on pollution' is somewhat challenging, this is relatively straightforward compared to the funding landscape prior to this initiative. This landscape, described by many scholars as a 'gap' between law, policy and implementation was greatly simplified by a shift in emphasis from the central government. The strengthening of environmental policy emphasis re-imposed hierarchical governance effects, effectively reducing the complexity of the implementation landscape as a whole. The central government was unable to effectively use powers of national law, pollution standards, taxation, fines and other legal provisions to change urban air quality. Local governments changed air quality by directly funding projects, not by the indirect threat of a stricter environmental protection standard and a more powerful environmental body. It seems that in this case at least, the central government does not have the power to enforce the laws it passes, or at least it can only do so by the use of a special lever of power: ideology. This is a particularly large and unwieldy power for a number of reasons. Firstly, altering the official ideology of Party and state may require extensive time and negotiation among the country's senior leaders in the Politburo in order to reach consensus. Secondly, achieving a consensus is just the beginning, as it may take several years to influence the actions of Party and government officials across the extensive governance network in provinces, cities, and counties throughout China. Thirdly, ideological change may be a uniquely blunt instrument; it is extremely difficult to control how local officials understand the new ideology, which may lead to costly and dangerous implementation of local policy. This is *zealous over-implementation*, and there is evidence that this took place during the latter phase (2016-2018) of winter heating infrastructure investment. There are reports of villages, towns and small cities where local officials ripped out coal-fired boilers without a credible plan or resources to replace them, causing locals to be left without heat in winter (Shao 2023; Ran 2024). However, notwithstanding these several challenges, huge advances have been made in the winter heating sector. On average, by 2018, Chinese winter heating companies had significantly reduced inefficient use of small, coal-fired boilers, and replaced half of all boilers with either CHP, natural gas, or renewable sources. This change represents a significant improvement in the real, ground-level pollution experience by city-dwellers. Although relatively small, the winter heating sector was particularly liable to emit air pollution, and this pollution was overwhelmingly likely to stay within city environs for longer periods when compared with the electricity generating sector. At least within the winter heating sector, this thesis agrees with scholars that a re-centralisation (Kostka and Zhang 2018; Heffer and Schubert 2023) has occurred, increasing the relative power of the central government and decreasing the relative power of local governments (Luo et al. 2019; Li and Yang 2021; Kostka and Nahm 2017; Tan, Liu, and Xu 2024; Chen et al. 2024; Zhang, Wang, and Wang 2023; Chen and Lees 2018; Schubert and Alpermann 2019; Wu 2025). This research indicates that future expansion of clean energy in the winter heating sector will continue only if central government continues to communicate the importance of environmental issues, and to fund environmental projects where necessary. Where policy emphasis shifts back to improving GDP growth, local governments are bound to again de-emphasise funding for environmental projects.

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10 Appendix

10.1 Case study: Project network diagram

The following diagrams show styalised diagrams for each project, showing connections between the winter heating SOE and other government and non-government bodies.

Project 1: SOE incorporation, 500M RMB investment

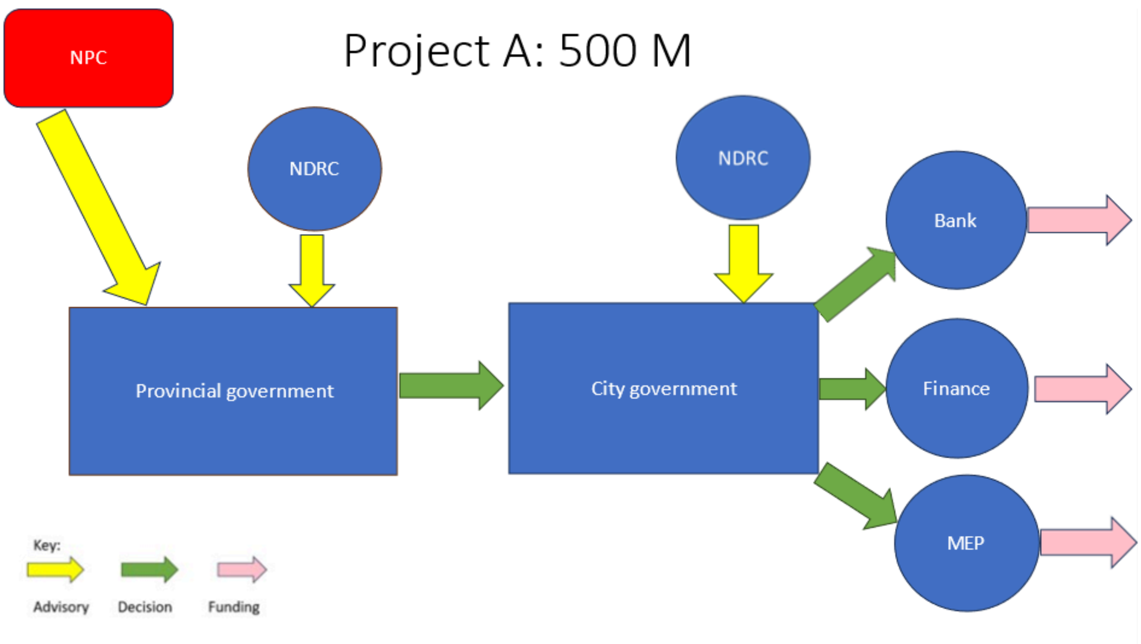

Figure 10.1: Diagram showing advisory, funding and decision-making, source: author

Project 2: Boiler post-combustion cotrols, 15M RMB investment

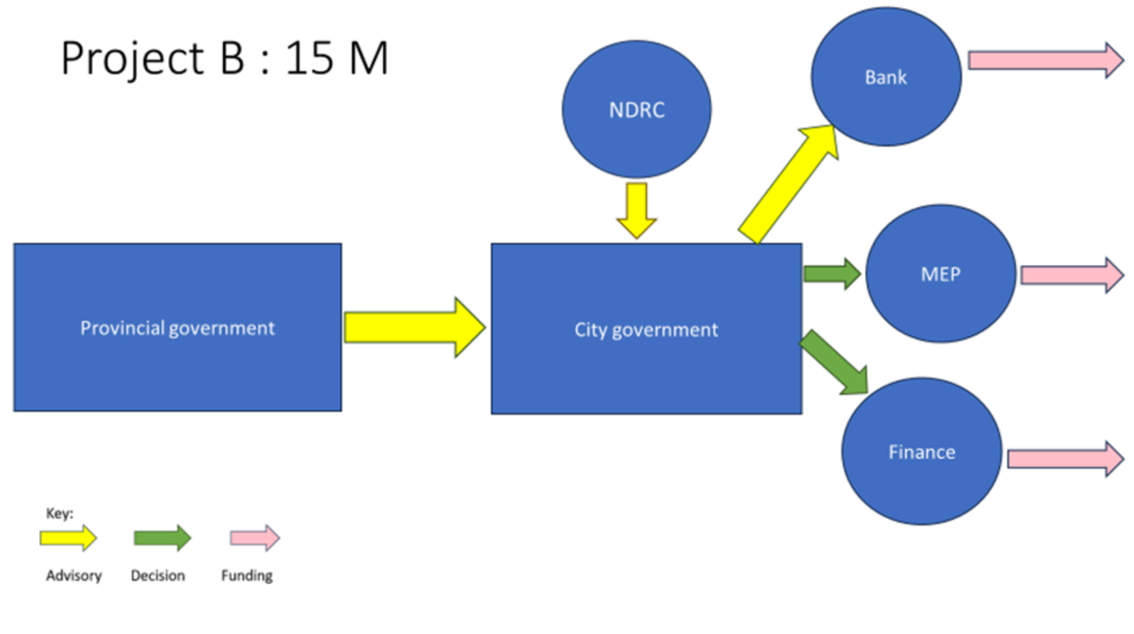

Figure 10.2: Diagram showing advisory, funding and decision-making, source: author

Project 3: Combined Heat and Power project, 460M RMB investment

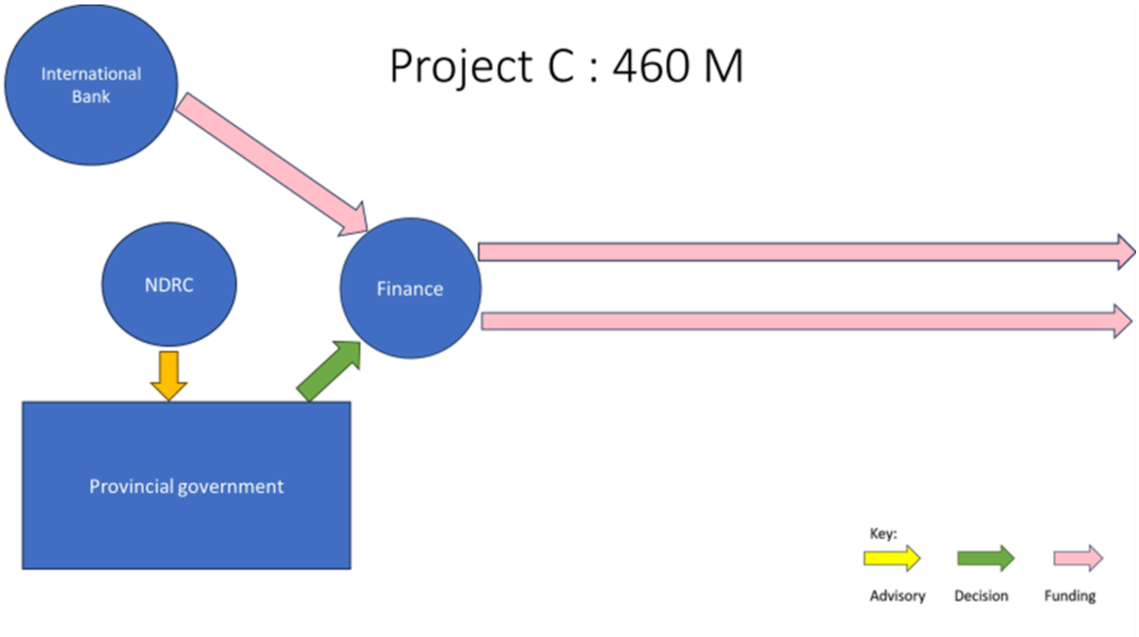

Figure 10.3: Diagram showing advisory, funding and decision-making, source: author

SOE expansion: heating network expansion, unknown investment

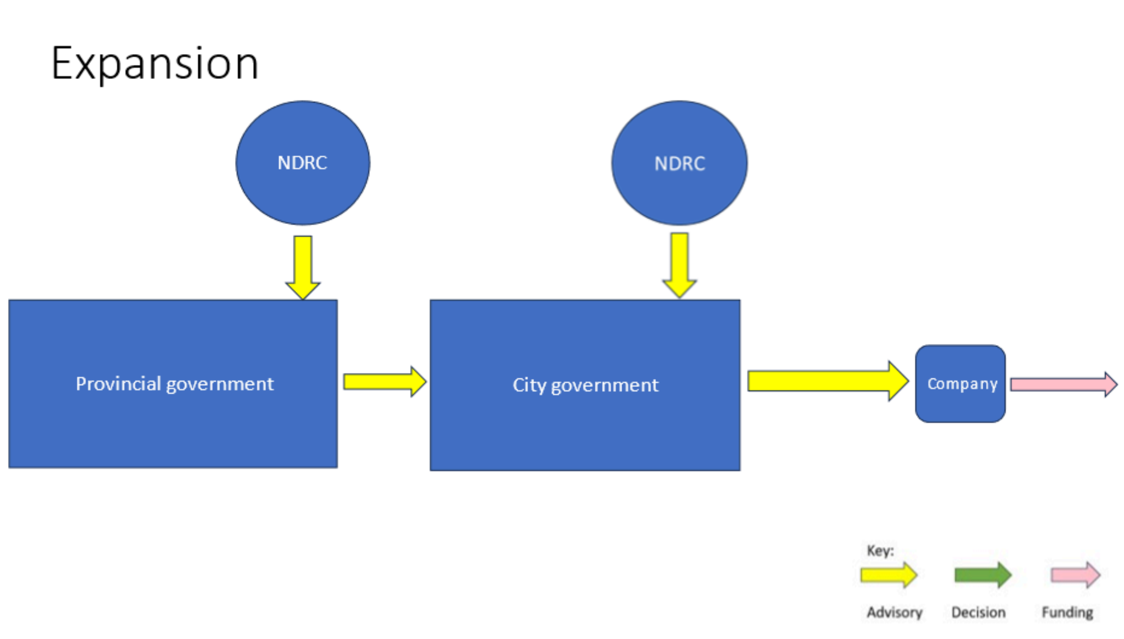

Figure 10.4: Diagram showing advisory, funding and decision-making, source: author

10.2 Calculate winter heating pollution

The following work reports were used to collect winter heating data, especially raw 'heating pipe network' data: (Henan Provincial Government, n.d.; Shandong Provincial Government, n.d.; Shanxi Provincial Government, n.d.; Tianjin Municipal Government, n.d.; Beijing Municipal Government, n.d.; Hebei Provincial Government, n.d.; Hengshui Municipal Government, n.d.; Langfang Municipal Government, n.d.; Cangzhou Municipal Government, n.d.; Chengde Municipal Government, n.d.; Zhangjiakou Municipal Government, n.d.; Baoding Municipal Government, n.d.; Xingtai Municipal Government, n.d.; Handan Municipal Government, n.d.; Qinhuangdao Municipal Government, n.d.; Tangshan Municipal Government, n.d.; Shijiazhuang Municipal Government, n.d.). The raw data was then pre-processed to exclude likely misprints and reporting errors, i.e. unexplained 10x increase and decreases in pipe length in cosecutive years. The intermediate results and calculation method for "interpolated winter heating pollution" is shown below:

1. **Calculate approximate winter heating network for each**

location:

i) The most mature heating networks are in Beijing and Tianjin, whose growth curve clearly shows similarity to a logistic function, which makes sense since each city has a natural maximum limit (L) of floor space. Other cities with more mature heating networks also show a distinct logistic type curve. Less mature cities show heating network with exponential curves.

ii) Assuming all cities will grow logistically, if the steepest point of the exponential curve can be found, it is designated x0. If the location is currently in the exponential phase without slowing, x0 cannot be found, and the location is discarded from the data.

iii) Locations are mapped to their closest logistic function (figure 11.0) below.

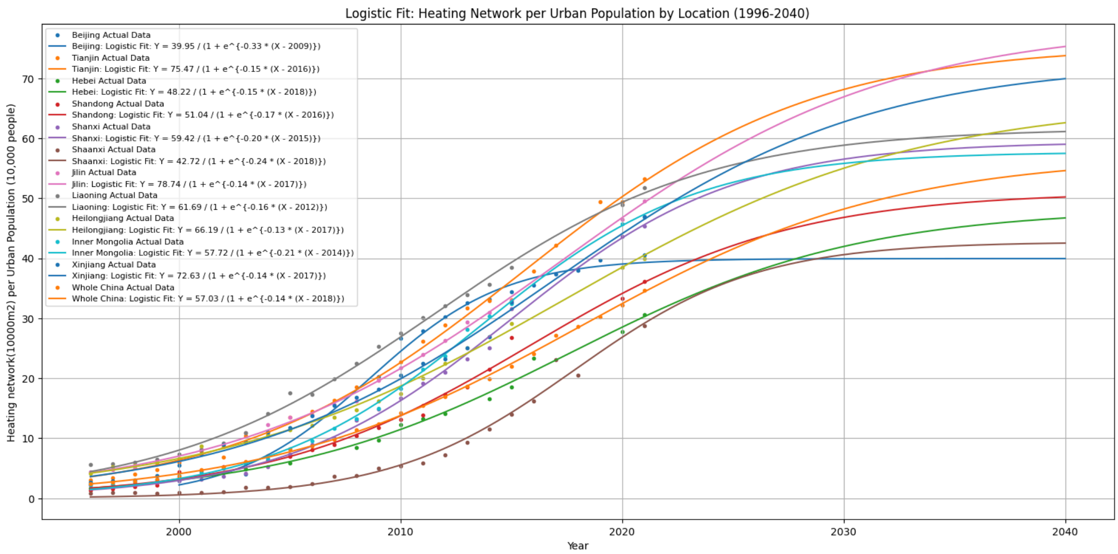

Figure 10.5: Plot of calculated logistic growth functions by location, source: author

2. Calculate approximate point of 50% clean fossil fuel usage

for each location:

i) Winter heating fuel usage is available for the whole of China (figure 11.1, below), Beijing, and Tianjin.

ii) Using data from the whole of China, 50% clean fossil fuel usage was achieved in 2018, the same as x0 for whole of China (see figure 11.2, below). Data was checked with Beijing and Tianjin, and all coicide with x0 for each location, with a small error rate (less than 1.5 years).

iii) Assuming that all locations will switch to 50% clean fossil fuel at the steepest part of their growth curve (x0) makes sense, since this period is the highest phase of investment in winter heating.

iv) Designate the point of 50% clean fossil fuels in each location, using the same method. Using each location"s logistic growth function, calculate the share of clean and coal winter heating on each year.

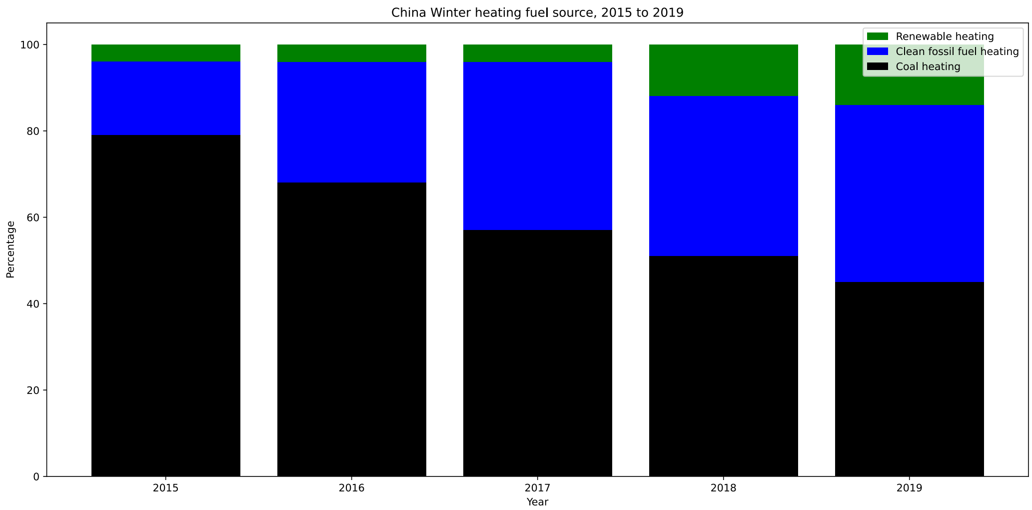

Figure 10.6: China winter heating fuel source, 2015–2019, source: CHIC, 2020

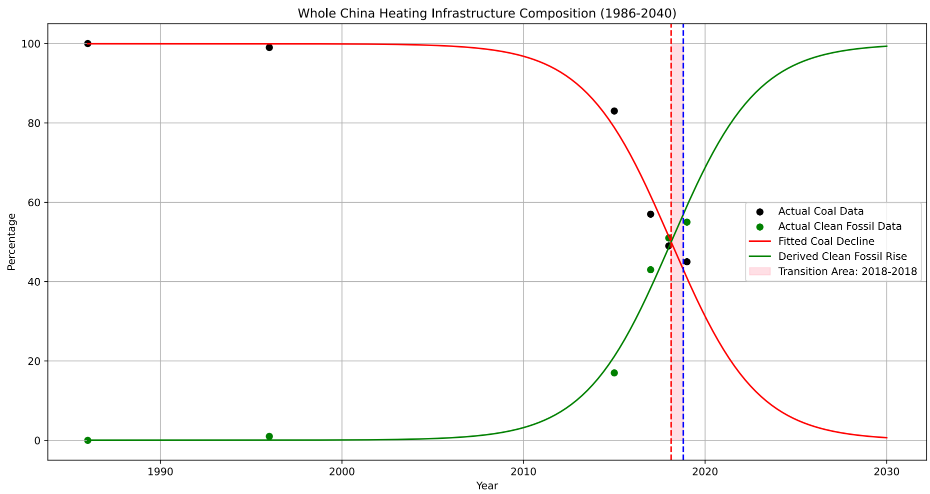

Figure 10.7: Plot showing calculation of "transition area" for whole of China winter heating fuel, source: author

3. Calculate approximate pollution for each year, for each

location: i) Using the approximate share of clean and coal fuel, together with the size of heating network for each location, calculate the size of clean and coal fuel for each location at each year. ii) Using the figures of pollution obtained from Hebei city case study documents, (Boiler room energy consumption index, 2009; Central heating project application report, 2008), the approximate pollution levels were calculated for each location for each year.

10.3 Comparison of model 1.2 fit, differing parameters

The following results compare model 1.2 with differing parameters for city and SOE activation probability:

Results for Model 1:
city: 0.3 SOE: 0.1 (Average R^2 of Slopes: -2.2659)

Location	Segment	Start Year	End Year	Empirical Slope	Model Slope	R2_Slopes
Beijing	1	2000	2005	-0.02823629860653378	-0.027047768319854826	-1.5614685243718291
Beijing	2	2005	2013	-0.07207798683234277	-0.012808082112563388	-1.5614685243718291
Beijing	3	2013	2024	-0.022180738733619726	-0.005331534727623751	-1.5614685243718291
Hebei	1	2000	2009	-0.013907119422234548	-0.006823246506151909	-3.5178905515721945
Hebei	2	2009	2024	-0.0317512232841156	-0.005884369513906917	-3.5178905515721945
Heilongjiang	1	2000	2004	-0.006315597952901764	-0.009119654032123975	0.29950445657483604
Heilongjiang	2	2004	2024	-0.026016541570767365	-0.014699388693716672	0.29950445657483604
Inner Mongolia	1	2000	2005	-0.008098344261782043	-0.02025275824173294	-0.465917222005126
Inner Mongolia	2	2005	2024	-0.04152379187843361	-0.015616727967835989	-0.465917222005126
Jilin	1	2000	2005	-0.009086502933285301	-0.007098229100648723	-1.6561110262314296
Jilin	2	2005	2024	-0.030892794595556692	-0.005841722177441196	-1.6561110262314296
Liaoning	1	2000	2005	-0.023832049292538682	-0.010071678968724008	-10.30373809731097
Liaoning	2	2005	2024	-0.037201483192871254	-0.008550527789783146	-10.30373809731097
Shaanxi	1	2000	2009	-0.0056119481759231305	-0.008666845354720447	-0.9991560240314417
Shaanxi	2	2009	2024	-0.044376156899013745	-0.005740714944075339	-0.9991560240314417
Shandong	1	2000	2006	-0.010030835023311313	-0.010095076681078527	-1.3824649001608909
Shandong	2	2006	2024	-0.03445627730589705	-0.007797548716379869	-1.3824649001608909
Shanxi	1	2000	2006	-0.010679485924314502	-0.0039035331242066595	-1.6918825981615306
Shanxi	2	2006	2024	-0.04415824809091842	-0.005913581706424827	-1.6918825981615306
Tianjin	1	2000	2007	-0.014611593823699285	-0.016550125389453187	-2.57829553433157
Tianjin	2	2007	2024	-0.031855067962354676	-0.008871973276558028	-2.57829553433157
Xinjiang	1	2000	2005	-0.008260457212077332	-0.011072970482218869	-1.0670466380407397
Xinjiang	2	2005	2024	-0.028084358723233397	-0.008128129841366344	-1.0670466380407397

Table 10.1: Showing model output for various parameters, source: author

Results for Model 2:
city: 0.4 SOE: 0.3 (Average R^2 of Slopes: -2.2088)

Location	Segment	Start Year	End Year	Empirical Slope	Model Slope	R2_Slopes
Beijing	1	2000	2005	-0.02823629860653378	-0.02978414289804281	-1.6438145544604352
Beijing	2	2005	2013	-0.07207798683234277	-0.012095958827675668	-1.6438145544604352
Beijing	3	2013	2024	-0.022180738733619726	-0.004289517836139562	-1.6438145544604352
Hebei	1	2000	2009	-0.013907119422234548	-0.003690538033122014	-3.436463917512005
Hebei	2	2009	2024	-0.0317512232841156	-0.007216895623829781	-3.436463917512005
Heilongjiang	1	2000	2004	-0.006315597952901764	-0.020604559112240878	-0.4616783903974202
Heilongjiang	2	2004	2024	-0.026016541570767365	-0.017101153500726808	-0.4616783903974202
Inner Mongolia	1	2000	2005	-0.008098344261782043	-0.028947884436966987	-0.7452320611521535
Inner Mongolia	2	2005	2024	-0.04152379187843361	-0.018280811447251834	-0.7452320611521535
Jilin	1	2000	2005	-0.009086502933285301	-0.007996809431027208	-1.3219847251692625
Jilin	2	2005	2024	-0.030892794595556692	-0.00742193811872143	-1.3219847251692625
Liaoning	1	2000	2005	-0.023832049292538682	-0.013037048262198625	-9.450957259570794
Liaoning	2	2005	2024	-0.037201483192871254	-0.008609889767586254	-9.450957259570794
Shaanxi	1	2000	2009	-0.0056119481759231305	-0.011626803807660803	-0.9963308805493916
Shaanxi	2	2009	2024	-0.044376156899013745	-0.00611744987661722	-0.9963308805493916
Shandong	1	2000	2006	-0.010030835023311313	-0.009351795077869466	-1.4917844873259831
Shandong	2	2006	2024	-0.03445627730589705	-0.0072011677567946596	-1.4917844873259831
Shanxi	1	2000	2006	-0.010679485924314502	-0.003750670780037546	-1.7642436441938951
Shanxi	2	2006	2024	-0.04415824809091842	-0.005414065435269628	-1.7642436441938951
Tianjin	1	2000	2007	-0.014611593823699285	-0.02159474446173924	-2.7479468530333615
Tianjin	2	2007	2024	-0.031855067962354676	-0.009306498292190062	-2.7479468530333615
Xinjiang	1	2000	2005	-0.008260457212077332	-0.01069839031593407	-0.2359493306194036
Xinjiang	2	2005	2024	-0.028084358723233397	-0.012692395367961821	-0.2359493306194036

Table 10.2: Showing model output for various parameters, source: author

Results for Model 3:
city: 0.5 SOE: 0.6 (Average R^2 of Slopes: -2.8459)

Location	Segment	Start Year	End Year	Empirical Slope	Model Slope	R2_Slopes
Beijing	1	2000	2005	-0.02823629860653378	-0.03220819162058604	-2.134270523351599
Beijing	2	2005	2013	-0.07207798683234277	-0.006674065829824605	-2.134270523351599
Beijing	3	2013	2024	-0.022180738733619726	-0.0033618456456077084	-2.134270523351599
Hebei	1	2000	2009	-0.013907119422234548	-0.012845703736281269	-2.544019279475649
Hebei	2	2009	2024	-0.0317512232841156	-0.008021440189932887	-2.544019279475649
Heilongjiang	1	2000	2004	-0.006315597952901764	-0.0465656748969997	-7.40554612462655
Heilongjiang	2	2004	2024	-0.026016541570767365	-0.022678613999296666	-7.40554612462655
Inner Mongolia	1	2000	2005	-0.008098344261782043	-0.029255334849157967	-0.8336668201277542
Inner Mongolia	2	2005	2024	-0.04152379187843361	-0.017508722697171273	-0.8336668201277542
Jilin	1	2000	2005	-0.009086502933285301	-0.01801385629716292	-1.3449314785866386
Jilin	2	2005	2024	-0.030892794595556692	-0.009033548200975922	-1.3449314785866386
Liaoning	1	2000	2005	-0.023832049292538682	-0.015833843493537957	-7.539322186662497
Liaoning	2	2005	2024	-0.037201483192871254	-0.010759178935431365	-7.539322186662497
Shaanxi	1	2000	2009	-0.0056119481759231305	-0.006853068509874031	-0.9651931619959075
Shaanxi	2	2009	2024	-0.044376156899013745	-0.005970792571133991	-0.9651931619959075
Shandong	1	2000	2006	-0.010030835023311313	-0.016600078321569733	-1.5302635053151956
Shandong	2	2006	2024	-0.03445627730589705	-0.007779968186134658	-1.5302635053151956
Shanxi	1	2000	2006	-0.010679485924314502	-0.010322814439452025	-1.4734950335287005
Shanxi	2	2006	2024	-0.04415824809091842	-0.006928509536325783	-1.4734950335287005
Tianjin	1	2000	2007	-0.014611593823699285	-0.025667849102299023	-4.544262477855773
Tianjin	2	2007	2024	-0.031855067962354676	-0.005359454829553924	-4.544262477855773
Xinjiang	1	2000	2005	-0.008260457212077332	-0.017897270543011313	-0.9900233936009273
Xinjiang	2	2005	2024	-0.028084358723233397	-0.01081709022805778	-0.9900233936009273

Table 10.3: Showing model output for various parameters, source: author

Results for Model 4:
city: 0.6 SOE: 0.8 (Average R^2 of Slopes: -2.4328)

Location	Segment	Start Year	End Year	Empirical Slope	Model Slope	R2_Slopes
Beijing	1	2000	2005	-0.02823629860653378	-0.03115826622422817	-2.249700017262562
Beijing	2	2005	2013	-0.07207798683234277	-0.005358421386355602	-2.249700017262562
Beijing	3	2013	2024	-0.022180738733619726	-0.0032407307966168986	-2.249700017262562
Hebei	1	2000	2009	-0.013907119422234548	-0.013496374963832701	-2.736376883926386
Hebei	2	2009	2024	-0.0317512232841156	-0.007365059444350397	-2.736376883926386
Heilongjiang	1	2000	2004	-0.006315597952901764	-0.03243887417766178	-2.5412392577534746
Heilongjiang	2	2004	2024	-0.026016541570767365	-0.023825641825946237	-2.5412392577534746
Inner Mongolia	1	2000	2005	-0.008098344261782043	-0.021363326962535824	-0.35837187741054866
Inner Mongolia	2	2005	2024	-0.04152379187843361	-0.01738113485245281	-0.35837187741054866
Jilin	1	2000	2005	-0.009086502933285301	-0.021469898083017046	-1.5988660515127258
Jilin	2	2005	2024	-0.030892794595556692	-0.009339359067750566	-1.5988660515127258
Liaoning	1	2000	2005	-0.023832049292538682	-0.026415819591833634	-7.610613858997144
Liaoning	2	2005	2024	-0.037201483192871254	-0.009581521551329302	-7.610613858997144
Shaanxi	1	2000	2009	-0.0056119481759231305	-0.006602675606990571	-0.9049247036831927
Shaanxi	2	2009	2024	-0.044376156899013745	-0.006557520879778293	-0.9049247036831927
Shandong	1	2000	2006	-0.010030835023311313	-0.016993203390612777	-1.7647909263785309
Shandong	2	2006	2024	-0.03445627730589705	-0.006594733131781815	-1.7647909263785309
Shanxi	1	2000	2006	-0.010679485924314502	-0.009691919442736544	-1.616245903944022
Shanxi	2	2006	2024	-0.04415824809091842	-0.005880252955358243	-1.616245903944022
Tianjin	1	2000	2007	-0.014611593823699285	-0.024357415790598327	-4.7991015931674905
Tianjin	2	2007	2024	-0.031855067962354676	-0.00415734512657149	-4.7991015931674905
Xinjiang	1	2000	2005	-0.008260457212077332	-0.012044552516684504	-0.580198024711936
Xinjiang	2	2005	2024	-0.028084358723233397	-0.010874497611376646	-0.580198024711936

Table 10.4: Showing model output for various parameters, source: author

Results for Model 5:
city: 0.8 SOE: 0.8 (Average R^2 of Slopes: -3.4767)

Location	Segment	Start Year	End Year	Empirical Slope	Model Slope	R2_Slopes
Beijing	1	2000	2005	-0.02823629860653378	-0.025485143713233495	-2.278024877241061
Beijing	2	2005	2013	-0.07207798683234277	-0.005167136250849885	-2.278024877241061
Beijing	3	2013	2024	-0.022180738733619726	-0.002786603920914323	-2.278024877241061
Hebei	1	2000	2009	-0.013907119422234548	-0.018524089157631214	-2.8311304962723804
Hebei	2	2009	2024	-0.0317512232841156	-0.007489676879992653	-2.8311304962723804
Heilongjiang	1	2000	2004	-0.006315597952901764	-0.05604871219163646	-11.795084278854645
Heilongjiang	2	2004	2024	-0.026016541570767365	-0.02290570020465879	-11.795084278854645
Inner Mongolia	1	2000	2005	-0.008098344261782043	-0.029531421561323247	-0.8250762273840564
Inner Mongolia	2	2005	2024	-0.04152379187843361	-0.017855964965360613	-0.8250762273840564
Jilin	1	2000	2005	-0.009086502933285301	-0.023732998074291013	-2.000800421265148
Jilin	2	2005	2024	-0.030892794595556692	-0.008555784498504687	-2.000800421265148
Liaoning	1	2000	2005	-0.023832049292538682	-0.031369609689204284	-9.187379873318612
Liaoning	2	2005	2024	-0.037201483192871254	-0.007984359758488272	-9.187379873318612
Shaanxi	1	2000	2009	-0.0056119481759231305	-0.011095420141889824	-0.7931572760236658
Shaanxi	2	2009	2024	-0.044376156899013745	-0.00808307397319817	-0.7931572760236658
Shandong	1	2000	2006	-0.010030835023311313	-0.02123318678229093	-1.6880362941160358
Shandong	2	2006	2024	-0.03445627730589705	-0.00844951780564246	-1.6880362941160358
Shanxi	1	2000	2006	-0.010679485924314502	-0.018777973228689737	-1.1288987774017762
Shanxi	2	2006	2024	-0.04415824809091842	-0.01058029895986449	-1.1288987774017762
Tianjin	1	2000	2007	-0.014611593823699285	-0.02729884523508939	-5.2308290433516484
Tianjin	2	2007	2024	-0.031855067962354676	-0.004189874910873846	-5.2308290433516484
Xinjiang	1	2000	2005	-0.008260457212077332	-0.011285357220886527	-0.48482181279720304
Xinjiang	2	2005	2024	-0.028084358723233397	-0.011273413847563312	-0.48482181279720304

Table 10.5: Showing model output for various parameters, source: author