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Examining the Experiences and Challenges of Haze-Fog Governance in China

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Abstract

With the rapid development of industrialisation and urbanisation, China is facing the challenge of severe HF (Haze-Fog) pollution. This essay compares the advantages and disadvantages of China's HF management and summarizes the important lessons China can teach the rest of the world about applying this tactic. China's capabilities in the digital economy, National Innovation Demonstration Zones, and urban innovation systems are examined in this article, along with its shortcomings in information mechanisms and pollution sources. This essay also summarizes China's achievements, particularly regarding local autonomy. The essay goes on to say, however, that China is probably going to be under more pressure to manage HF in the future, both in terms of long-term solutions and the economy.

Keywords

Haze-Fog Control, Digital Economy, National Innovation Demonstration Zones, Local Autonomy

1. Introduction

This essay focuses on the HF governance strategy that has emerged in China in recent years. The aim of this essay is to analyse and summarise the valuable lessons that this strategy can offer to other cities around the world, and what the challenges are for the future, by comparing the strengths and weaknesses of the HF strategy in its concrete implementation. Firstly, the essay summarises the background and reasons for the development of the HF Control strategy. It then discusses in detail how China's strengths in the digital economy, the National Innovation Demonstration Zones and the urban innovation system are reflected in the strategy, and how the strategy's weaknesses in terms of information mechanism and pollution sources are discussed. Based on the strengths analysed, the essay also summarises China's successes in governing HF. In comparison,

the essay also discusses the challenges that China may face in future governance from a negative point of view as well as the impacts on cities and societies.

2. Background for HF Control

In recent years, especially after 2003, hazy weather, which is characterized by PM 2.5 (Pessay Matter 2.5), has become a major pollution concern in the cities of eastern China due to the fast industrialization and urbanization of the region as well as the heavy consumption of fossil fuels (see **Figure 1**). Low visibility and high FPM (Fine Particulate Matter) concentrations are characteristics of HF (Fu & Chen, 2017). It will therefore result in weather with visibility of less than 10 km in cities with relative humidity levels of 80%. The eastern provinces of China, which are highly industrialized, economically developed, and densely populated, are the primary locations of severe air pollution (Yu et al., 2018). Additionally, since the construction sector is one of the biggest generators of dust in China, it is mostly to blame for HF pollution (Wang & Watanabe, 2019). Nevertheless, just 29.3% of China's 338 prefecture-level cities have complied with the new ambient air quality criteria, according to the 2017 China Ecological Environmental Status Report (Huang et al., 2019). Meanwhile, outdoor PM2.5 may be a factor in approximately a million of China's annual premature deaths (Zhang et al., 2020). As a result, the Chinese government has put in place several renewable energy policies, emission reduction laws, and environmental standards to address the problems caused by haze in China.

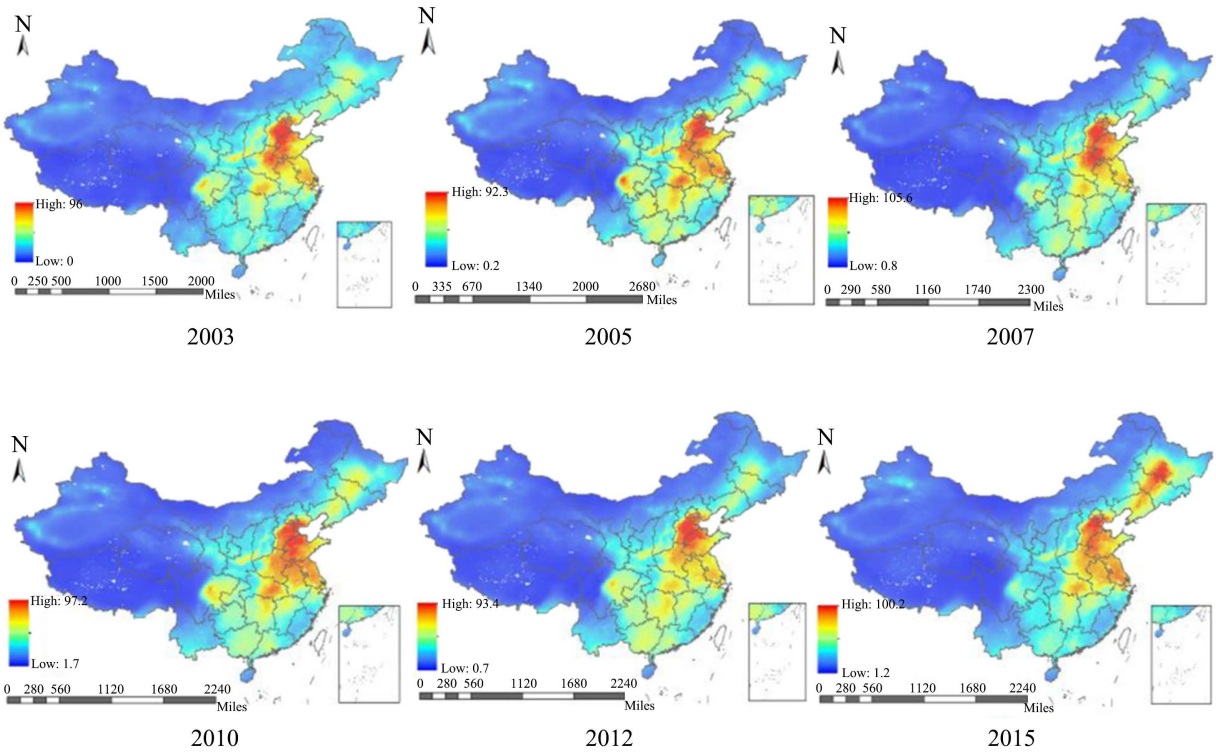

Figure 1. Comparison of annual distribution of PM2.5 concentration in eastern provinces in China in 2003, 2005, 2007, 2010, 2012 and 2015 (Dong et al., 2020).

3. Advantages and Potential Disadvantages of HF Control

3.1. Strengths Demonstrated in HF Control

3.1.1. Digital Economy Development

In the process of China's response to HF pollution, the government attaches great importance to the development of the digital economy. This is mainly because the digital economy has a more significant inhibitory effect on HF pollution in China's resource-based cities, especially eastern cities, and large cities. According to **Figure 2**, the government has also formulated a very detailed digital economy and HF pollution mechanism, which includes direct influence (Solid lines represent impacts that have already occurred), promoting technological innovation and optimization of resource allocation efficiency (Dotted lines represent impacts that are possible but have not yet occurred). As one of the advantages of the strategy, the development of China's digital economy mainly reduces HF pollution by promoting technological innovation and optimizing resource allocation (Che & Wang, 2022). On the one hand, the growth of the digital economy has also allowed several projects to broaden their scope of collection, primarily due to the ability of environmental protection levies to gradually raise tax rates (particularly those about air pollution). By stepping up oversight, collecting environmental protection levies, and addressing unresolved environmental issues, the Chinese government has strengthened environmental oversight. Concurrently, the Chinese government has intensified the scrutiny of heavily polluting businesses and closely monitored businesses that consume a lot of energy and produce a lot of pollution (Li & Deng, 2021). However, the benefits of the digital economy have also contributed to the rise in popularity of digital finance, and the government has taken advantage of this development to foster local innovative capacities and lessen pollution to some degree. The influence of digital finance on HF pollution is progressively growing as regional innovation capacities enhance (Wang et al., 2022).

3.1.2. National Innovation Demonstration Zones

China has also proven that the establishment of national independent innovation demonstration zones is greatly beneficial to HF pollution control (Che & Wang, 2022). First, in the National Independent Innovation Demonstration Zone, in addition to routine monitoring of smog, the government will also strengthen on-site measurements of photochemical smog, biomass burning particulate matter and ship emissions in the zone, especially in key industries (power

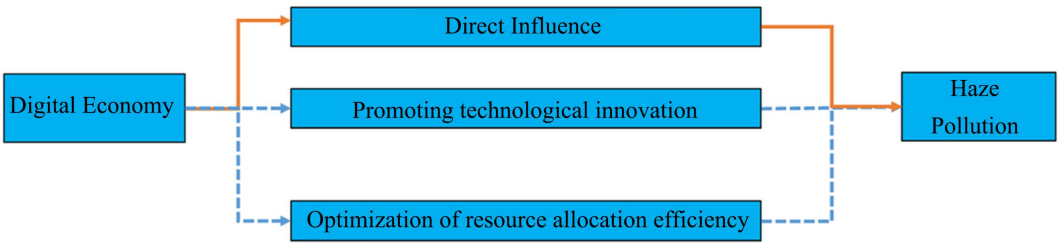

Figure 2. Mechanism analysis of digital economy and HF pollution (Che & Wang, 2022).

plants, cement plants, incineration plants, etc.) emission characteristics and source intensity (Fu & Chen, 2017). This not only facilitates data collection but also improves multi-departmental linkage in the same region, thereby continuously improving HF control. Since China's HF pollution has spillover and regional characteristics. Consequently, the region's coordinated HF control mechanism needs to be strengthened and brought together. By doing this, it will be possible to prevent resource waste brought on by inadequate information exchange, improve communication and coordination between local tax departments and environmental protection agencies, and strengthen the collection of data on environmental pollutants (Li & Deng, 2021). Second, this benefit reinforces the spatial spillover effect of policies about non-core development areas and truly gives non-core development areas full rein to play the radiating and leading role. It also encourages the coordination of non-core development areas in urban policy, science and technology, environmental governance, etc. therefore encouraging the control of urban HF (Liu et al., 2022).

Moreover, the establishment of the demonstration area has led to the improvement of EREHC (Environmental Regulation Efficiency of HF Control). Economic level, industrial upgrading and opening can promote the improvement of EREHC, while energy structure, energy quality and EREHC are negatively related. In central China, the level of science and technology investment is positively correlated with EREHC, which is mainly due to the establishment of demonstration zones in central cities. In comparison, in eastern and western China, the level of science and technology investment is not positively correlated with EREHC (see **Figure 3**). Therefore, the demonstration control enhanced the

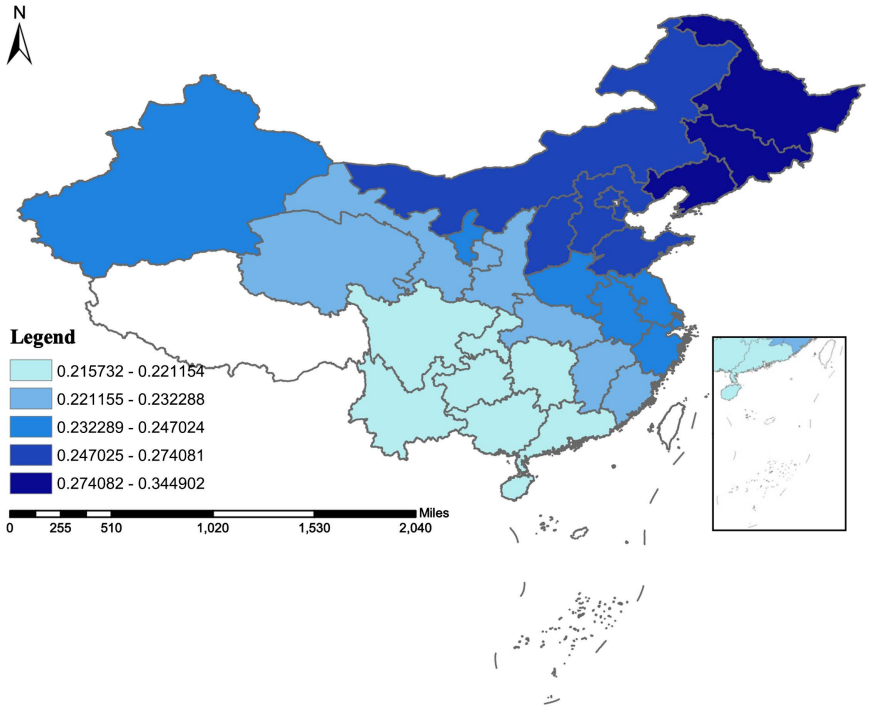

Figure 3. Effect of economic level on EREHC in China (Dong et al., 2020).

policies on scientific and technical innovation and raised funding for these fields. China's central and local governments swiftly compiled and started promoting the experience of building the demonstration zone nationwide, strengthened policy promotion, dynamically optimized and adjusted policy plans, and fully allowed the nation's independent innovation as the demonstration zone's policy scope gradually expanded. The demonstration area's benefit has an impact on HF control. Furthermore, the government plans to set up research facilities within the demonstration region to carry out methodical investigations into the production mechanism of atmospheric HF, forecast and warning models, pollution management technologies, environmental monitoring equipment, and remote sensing monitoring. More innovation in atmospheric environment science and technology research can also be fostered by doing this, as demonstrated by the Beijing-Tianjin-Hebei space stereo observation system and the regional atmospheric environment Research Excellence Innovation Centre (Dong et al., 2020).

3.1.3. Improving the Urban Innovation System

A complete urban innovation system is also an advantage that the Chinese government embodies in the process of controlling smog. First, from the perspective of the innovation environment, the improvement of the innovation system includes promoting the transformation of urban industries and the cluster development of high-tech industries, thereby improving the important mechanism for urban HF control. Most local governments in China have also taken measures to improve the innovation environment in NIIDZ (National Independent Innovation Demonstration Zone) cities (Liu et al., 2022). In addition, from the perspective of industrial structure, the secondary industry is positively related to HF pollution. The tertiary industry can effectively reduce HF pollution, but the emission reduction effect is not significant. Therefore, while China is improving industrial agglomeration, it is also actively supporting secondary industry enterprises and scientific research institutions to carry out high-quality innovation activities, thereby promoting urban HF control. The government often guides the transformation and upgrading of urban industries, increases support for high-tech industries, and curbs urban HF pollution from the source.

Furthermore, the low percentage of funding allocated to science and technology has resulted in a persistently low rate of carbon conversion, which is harmful to the advancement of HF management due to the ongoing release of carbon dioxide. To attain greater levels of innovation and faster rates of urbanization, the Chinese government has therefore also enhanced the carbon emission process. Most of the cities in the eastern provinces are dedicated to creating a headquarters economy, which is typified by financial services and R & D (Research and Development) consulting services, with an emphasis on the development of resident and high-end producer services. As an example, most cities in the western provinces are dedicated to supporting the clustered development of advanced manufacturing industries, including new materials and energy, to

achieve coordinated development of both traditional kinetic energy transformation and new kinetic energy cultivation (Zhao et al., 2020). Hence, the creation of the carbon emission mechanism has significantly enhanced the city's innovation system. Additionally, the practice of fostering and growing the high-tech and tertiary industries has aided in the advancement of the urban economy and has sped up the transformation of scientific research findings. The overall mechanism of HF joint prevention and management has been enhanced via market application.

3.2. Possible Deficiencies in HF Control

3.2.1. Uncertainty about the Formation Mechanism of HF

The Chinese government's control of HF pollution may also cause great uncertainty in the formation mechanism of HF weather. This is primarily because currently available atmospheric chemistry mechanisms do not yet provide a quantitative understanding of them (Fu & Chen, 2017). In China's governance, many atmospheric governance processes are nonlinear, because field measurements show that fine particulate matter suddenly increases in the initial stage of high frequency, which may also be attributed to many physical and chemical processes occurring simultaneously, such as gas and Interfacial chemical reactions between liquids. In the meantime, the uncertainty of this formation mechanism will correspondingly increase the public's risk perception of the HF problem, which may also threaten the sustainable development of Chinese society. Although the government has promulgated relevant policies and regulations, the formation of the mechanism has still brought adverse effects, especially in China's key polluted areas (Wang & Watanabe, 2019).

Moreover, as HF pollution continues to intensify in those areas, the public's environmental awareness and environmental demands have surged, strongly demanding that the government fulfill its environmental governance responsibilities. These public perceptions are largely influenced by factors such as knowledge, attitudes, health status, and expectations for government management. At the same time, because cognition is also affected by economic activities, the external characteristics of HF pollution and the ambiguity of environmental governance make environmental governance face the risk of 'Market Failure' under the market mechanism (Wu et al., 2021).

3.2.2. Control of Pollution Sources

However, due to China's geographic location and the uncertainty of its emission intensity, some of the government's approaches to controlling pollution sources are also impractical, especially for sources of VOCs (Volatile Organic Compounds). Therefore, source-specific control strategies are still an area that needs to be further adjusted. Firstly, in the management of HF in the urban environment, we find that local sources are contributing more to NO_2 (Nitrogen Dioxide) rather than SO_2 (Sulfur Dioxide). Therefore, the government's strict control targeting NO_x emissions should be an effective measure to reduce particulate

matter pollution in the future (Pan et al., 2016). And it is undeniable that NO_x may come from both power plants and transport sources. Second, in the prevention and control of pollution sources with VOCs, the government has not clarified the formation mechanism of urban HF and the distribution of pollution sources. Therefore, there are no quantitative statistics on the urban pollution sources found so far. However, to address the serious air pollution problem in China, the government needs to adopt more comprehensive control strategies for multiple pollutants and emission sources at the local and regional levels (Huang et al., 2019). Therefore, source control of organic compounds has become a major challenge that the government needs to address urgently.

Meanwhile, some local studies have discovered that the concentration of pollution sources may be positively connected with secondary sectors in cities and that urban energy consumption—particularly the use of coal—has emerged as a key channel to produce organic compounds (see **Figure 4**). The association between sources of HF pollution and organic molecules is unclear due to regional variations and energy consumption. The impact of scientific and technological advancements on the avoidance of HF pollution is currently obscured by the low level of commercialization of these breakthroughs. This essay recommends that in the future, environmental regulations should be strengthened, and energy agglomeration should be guided more rationally by the government (Zhao et al., 2020). To contribute to the decrease in the production of organic compounds, the government should also raise the bar for energy innovation and economic openness. Furthermore, the present local governments are vying for foreign investment to achieve energy innovation as well as scientific and technological advancements. This is encouraging pollution and distorting the factor market, which eventually results in a sharp rise in the number of environmental pollution sources (Zhang & Li, 2018). The mitigation of VOCs, NH_3, SO_2 and NO_x precursors is ultimately aimed at reducing PM 2.5. Therefore, the government also needs to find and apply more effective tools and methods to combat HF pollution in future source control.

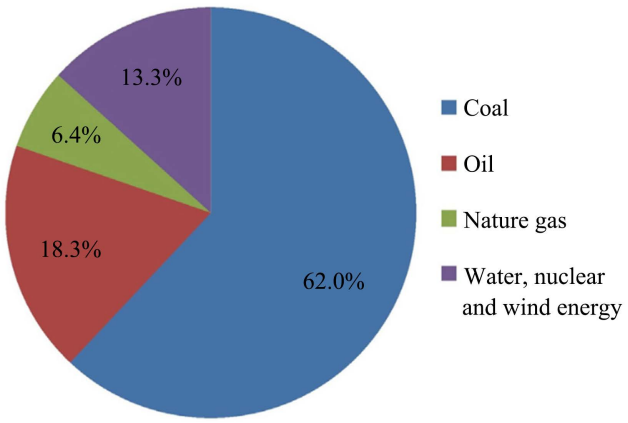

Figure 4. Chinese Energy consumption structure in 2016, included coal, oil, natural gas and water, nuclear and wind energy (Huang et al., 2019).

4. Successful Experience and Future Challenges Brought by HF Control

4.1. Successful Experience

4.1.1. Digital Economy

In recent years, the digital economy has had a significant dampening effect on HF pollution, as well as an even more significant dampening effect on HF pollution in large-scale cities. The first thing worth recognising is the policy experience. On the one hand, the government encourages enterprises to follow the path of innovative development (especially heavy industry and chemical enterprises) by strengthening investment in technological innovation and improving relevant legal measures. On the other hand, the government also pays attention to the necessity of an inter-city innovation linkage mechanism and gives full play to the intermediary mechanism of technological innovation (Wang et al., 2022). But to create a dynamic and unique digital economy policy, the government also considered the heterogeneity of digital finance and HF pollution, given the nonlinear impact of technological innovation on HF pollution. Additionally, the government has established digital finance a technology tool to help each region lower their HF "Hardware" levels. As a result, there is a large regional spillover impact of the digital money feature with HF pollution. For example, when developing pertinent policies and measures, China's first-tier megacities—non-regional cities like Beijing and Shanghai—have strengthened the reach of digital finance throughout their respective regions and, at the same time, have broken down the barriers associated with HF management between regions, thereby enhancing the effective role of digital finance in the environment.

Additionally, China has integrated big data, cloud computing, and artificial intelligence research, development, and application into its governance framework. Additionally, the government has boosted its funding for digital financial inclusion and Internet development. By increasing the size of the digital economy, the government has, on the one hand, consolidated the benefits of applying digital technology. However, to improve regional administration and HF management, the government has stepped up efforts to establish the National Big Data Comprehensive Experimental Zone. By combining the benefits of experimental zones and dividends, resource-based cities are seeing a decrease in their reliance on natural resources as well as a decrease in opposition to the use of technology in the environmental sector (Che & Wang, 2022). Nonetheless, the efficacy of HZ governance may be impacted by issues with mishandled development and poor administration. The government must acknowledge the influence of digital money on HF pollution promptly and maximize its ability to reduce HF pollution.

At the same time, this essay suggests that the government should strengthen the intermediary role of technological innovation in the future (see **Figure 5**). And the government will gather more in small cities in the future city types. In small cities, the development of a digital economy still needs to improve the level

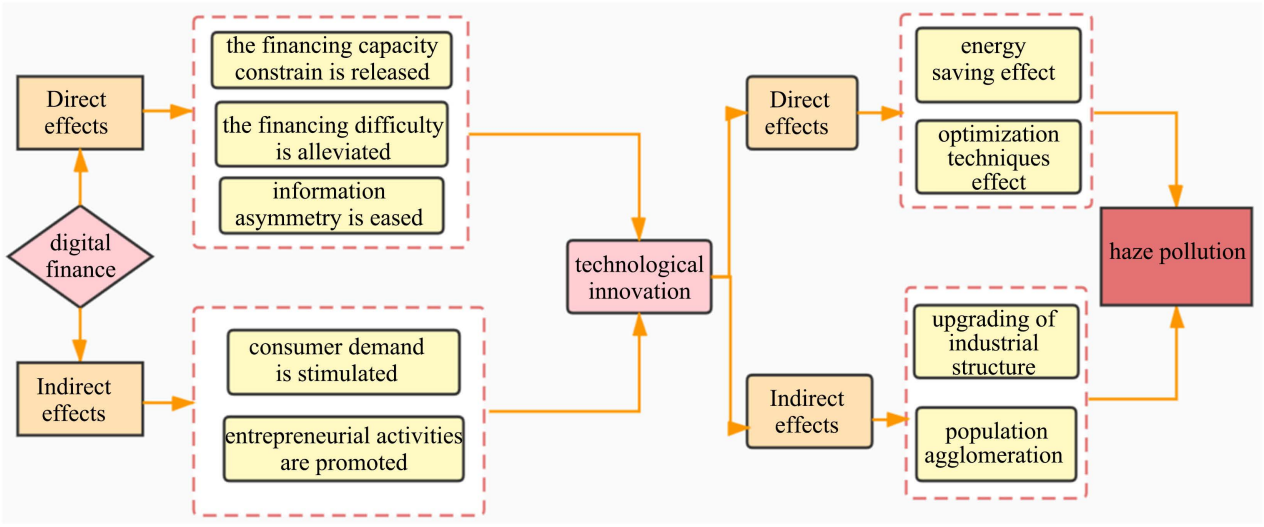

Figure 5. Analysis of the mechanism of the impact of the development of the Chinese government's digital finance on HZ pollution (Wang et al., 2022).

of economic greening in the future, and the level of improvement needs to withstand the robustness test, such as the DID model, control the interference of the environmental policy, and so on. Furthermore, small cities should build application infrastructures and digital network systems in line with their strengths and characteristics, to improve network coverage and informatisation, and to provide strict legal support for the improvement of the crude economic growth mode.

4.1.2. Local Autonomy

In contrast to the relative centralisation of central government power in the implementation of other strategies, the Chinese government has developed a more synergistic capacity and comprehensiveness of local autonomy in the governance of the HZ. On the one hand, localities have developed the concept of win-win governance. The government not only promotes a regional synergy model of cross-regional environmental governance to enhance the synergistic governance capacity of each locality. Furthermore, the government will establish a new information-sharing platform and information notification system from the perspective of the region as a whole and improve the communication mechanism between the synergistic entities in each region. At the same time, the cross-regional synergistic governance of environmental pollution is realised by strengthening the integration of cross-regional relevant laws and regulations (Zhang & Li, 2018). However, based on a win-win situation, local governments also have enough synergistic ability to choose a cooperative strategy (implementing environmental policies simultaneously as agreed) or a non-cooperative strategy (not implementing environmental policies in time). Hence, it is possible that a high degree of synergistic capacity could lead to a spatial diffusion phenomenon where local HF pollution spreads from high to low concentrations, thus allowing non-cooperative parties to steal environmental benefits. This implies that HF

pollution from non-cooperative parties in regional governance will gradually spread to cooperative parties (Zhang & Li, 2018).

Yet, in recent years, Chinese local governments have prioritized implementing a comprehensive top-level design in the governance process, which gives them numerous options for addressing HF pollution. In addition to developing eco-cities and accelerating green urbanization, the government will logically design intra- and intercity transportation networks to lower car emissions and dust from construction. Regarding energy, the government has persisted in imposing green taxes, such as resource and environmental taxes, to govern and restrict energy consumption. As time goes on, communities tend to spend more money on education to raise the standard of living for residents, raise environmental consciousness, and develop talented individuals who can benefit society. Additionally, local governments will frequently boost the environmental access requirements for businesses entering the National Innovation Demonstration Zones in conjunction with them. In addition, a municipal-level pollution emission penalty mechanism will be established by the local district government, reinforcing the oversight and penalties associated with pollutant emissions (Gan et al., 2021).

4.2. Future Challenges

4.2.1. Economic Disadvantages to Governance

Although the Chinese government has had many successful experiences in developing the digital economy, this essay is concerned that some of the government's economic practices may also be detrimental to HF management. Firstly, under the influence of spatial factors, economic development may have more inhibitory effects on the process of haze management. This is mainly because population size, foreign direct investment and secondary industries all add to HF pollution. Therefore, future cities need to plan and adjust their industrial structure in the long run, such as phasing out conventional sectors that are mostly happened in heavy industries and have high resource consumption. Furthermore, it is essential to enhance funding in the field of research and technology in order to enhance and streamline the development of eco-friendly technical advancements. At the same time, the government should pursue high-quality economic development and improve the R & D system of green technology to reduce the negative impact of spatial factors (Gan et al., 2021).

Moreover, corporate factors may also need to obtain strong control to improve regulation. While government regulation is an important part of the functioning of a market economy, proactive regulation of pollution by firms is central to solving environmental problems (Zhang et al., 2020). However, firms are more likely to consider the accumulation of their benefits as well, which seems to run counter to regulating pollution. This essay suggests that in the future, the government should implement more market-incentivised environmental regulation and use market mechanisms to coax firms into technological innovation. At the same time, the massive introduction of foreign firms into China will also

hinder the government's efforts to combat HF pollution. Therefore, the government also needs to reduce foreign entry into the pollution management effect by improving the regulation of the system, and its regulatory role is also generally realized mainly through economic development (Gou et al., 2017).

Thirdly, future high-quality economic development may also have unfavourable technological factors for governance. The development of a high-quality economy may adversely affect the assessment and improvement of existing HF forecasting systems (Fu & Chen, 2017). However, consider that air pollutants can travel over long distances. Therefore, analysing the adverse effects of economic development conditions on technology requires more detailed studies, such as the addition of hourly meteorological data and the exploration of multiple economic-technological relationships (Zhang et al., 2020). In past studies, China has mainly applied the WRF-Chem and RAQMS models to analyse the source identification of fine particulate matter, the potential economic effects, and the complex interactions between the economy and climate. In the future, the government may also need to build on this foundation and vigorously develop atmospheric HF monitoring technologies. Meanwhile, the government could also do more to develop technologies that can reduce emissions of fossil fuel gases (e.g., SO_2) in line with the high-quality transformation and development of the economy.

Finally, fiscal factors have also become an unfavourable factor for economic development in combating HF, which is particularly evident in local implementation. From 2013 to 2018, local fiscal decentralisation is more likely to inhibit HF pollution, and the effect of government innovation preferences on HF pollution is insignificant (Yin et al., 2022). This is mainly due to the increasing number of barriers that hinder factor mobility between regions. In the future, it may be more necessary for the government to use appropriate market instruments to introduce factors into enterprises or regions with higher production efficiency, and to adopt strict entry standards for some highly polluting enterprises, to ultimately achieve the goal of climate governance (Zhang & Li, 2018). Moreover, this essay encourages the establishment of a diversified local government assessment mechanism. This can motivate local governments to actively fulfil their ecological protection responsibilities and achieve the harmonious development of ecology and economy.

4.2.2. Lack of Long-Term Response Measures

Although the current management of HF in China has developed to a certain extent, the government's planning for the future is still insufficient, especially the lack of long-term countermeasures. It should be noted that regional HF may not be an environmental problem unique to China. It occurs in almost all densely populated as well as rapidly developing industrial areas, in both developed and developing countries (Chameides et al., 1999). Therefore, the first thing that the Chinese government lacks is how to cope with the ecological problems exacerbated by the growing population. In addition, it has not consi-

dered projections that China's demand for food will grow rapidly in the coming decades, as well as concerns about whether it will be able to meet the growing demand by increasing agricultural productivity. Secondly, local government competition may not only contribute directly to increased HF pollution but also exacerbate it by distorting local factor markets, a problem that is more pronounced in central and western China (Zhang & Li, 2018). But long-term measures to deal with this problem are lacking.

At the same time, there is greater uncertainty about the problem of factor markets at high spatial and temporal resolution. Uncertainties in the mixed-receptor models used by some governments can also affect the accuracy of identifying sources of severe HF pollution and optimizing emission control options for targeted areas (Yu et al., 2018). In response to this problem in the market, this essay suggests that localities can refer to the HFLTS (Hesitant Fuzzy Linguistic Term Sets) approach in formulating measures, mainly in the group decision-making process where the fuzzy information controlling the decision is not representative of the important group decision-making information. The government needs to be aware that while mandatory temporary suspension of most urban and peripheral emission sources is an effective but costly short-term air pollution control measure, developing a long-term crisis response remains a challenge, especially in curbing severe urban HF events regularly.

Furthermore, when it comes to disposing of fossil fuels, the Chinese government still lacks a long-term solution. The government must recognize that China's fast economic growth and intensive agro-cultural production are driving up fossil fuel consumption, which will eventually result in high emissions of air pollutants and other environmental issues like acid rain. Moreover, China can become a global hotspot for nitrogen deposition in the future due to the significant amount of NH_3 emissions from the rise in agricultural output. The government must create longer-term solutions for each of these issues to address them later (Liu et al., 2019).

5. Conclusion

In conclusion, China has achieved a certain degree of positive results in the governance of HF in recent years, especially in the development of the digital economy and local autonomy. To solve this environmental pollution problem, China attaches great importance to the positive disincentive effect of the digital economy on China's resource-based cities (especially in the eastern part of the country) and has a successful experience in developing the digital economy. China believes that the government should increase investment in technological innovation and emphasise the need for inter-city innovation linkages. Furthermore, the government ought to support the advancement and use of smart technologies like artificial intelligence, cloud computing, and big data. China, meantime, has its special perspectives on local autonomy. China values local cooperation in the government process more. Moreover, in addition to a tho-

rough top-level design, the central government has built a cross-regional governance model. However, this essay also concludes that China's economy might hurt the country's governance system in the future. Economic growth can make managing haze more difficult rather than easier. The primary causes of this are the rise in investment and population. Furthermore, it is yet unclear how well-developed businesses and the government contribute to hazy governance. In the meantime, financial considerations are now seen negatively when it comes to municipal governance. Furthermore, China's current preparations for future governance are insufficient, particularly regarding the absence of long-term remedies.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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