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Can the new energy demonstration city policy reduce environmental pollution? Evidence from a quasi-natural experiment in China

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A B S T R A C T

The New Energy Demonstration City policy (NEDC) is an important pilot measure to promote the in-depth advancement of the ecology in China. Objectively evaluating its effect on environmental pollution is greatly significant in the development of this policy. The difference-in-differences method and the mediation model are employed to analyze the effect and mechanism of the NEDC on the urban environmental pollution on the basis of 271 cities in China from 2005 to 2016. Results show that the NEDC has significantly reduced environmental pollution. Specifically, the NEDC has significantly reduced approximately 28.83% of exhaust gas emissions and 12.88% of wastewater emissions. The conclusion that the NEDC can significantly reduce environmental pollution is still valid after the endogenous problems have been alleviated and robustness tests have been carried out. The NEDC can also reduce environmental pollution through technological innovation effect, structure effect, and resource allocation effect. The effect of technological innovation is the strongest, followed by resource allocation and industrial structural effect, respectively. Moreover, compared with the western region and small-scale cities, the effect of the NEDC on regional environmental pollution is more significant in the eastern and central regions and medium-sized and above cities. This study provides evidence for China to promote the construction strategy of new energy demonstration city further and improve the construction quality of new energy demonstration city. This article also provides guidance for the promotion of new energy demonstration cities construction and in-depth research and development of new energy technology.

1. Introduction

China has achieved rapid economic growth through industrialization and urbanization. However, the extensive economic development model has caused serious environmental pollution (Sun et al., 2014; Chen, 2015; Tilt, 2019; Ran et al., 2020). According to the 2018 China Eco-Environment Status Bulletin, the proportion of air quality in major cities exceeding the standard reached 64.2% in 2018. The scores and rankings of the 2018 Global Environmental Performance Index (EPI) based on 180 countries and regions show that the comprehensive score of the EPI index of China is 50.74. The EPI ranks 120th, and the air quality ranks 177th, which is the lowest.[2] These results have serious impact on high-quality economic development, government image, public living space even the physical health of China (Peters et al., 2001; Ouyang et al., 2019; Signoretta et al., 2019). Therefore, it is not only one of the main contents of environmental economics research to clarify the factors causing environmental pollution and seek ways to reduce environmental pollution, but also the main focus of the government to formulate environmental policies and improve the quality of economic development. There is no doubt that it is of great theoretical value and policy guiding significance to conduct in-depth research on this issue(Li et al., 2019).

In fact, environmental pollution is closely related to the large-scale use of traditional fossil energy. And, as one of the largest energy consumers in the world, China's energy demand is still growing with the continuous development of China's industry. Such extensive use of fossil fuels is bound to exacerbate environmental pollution problems (Mekhilef et al., 2011). Therefore, it has

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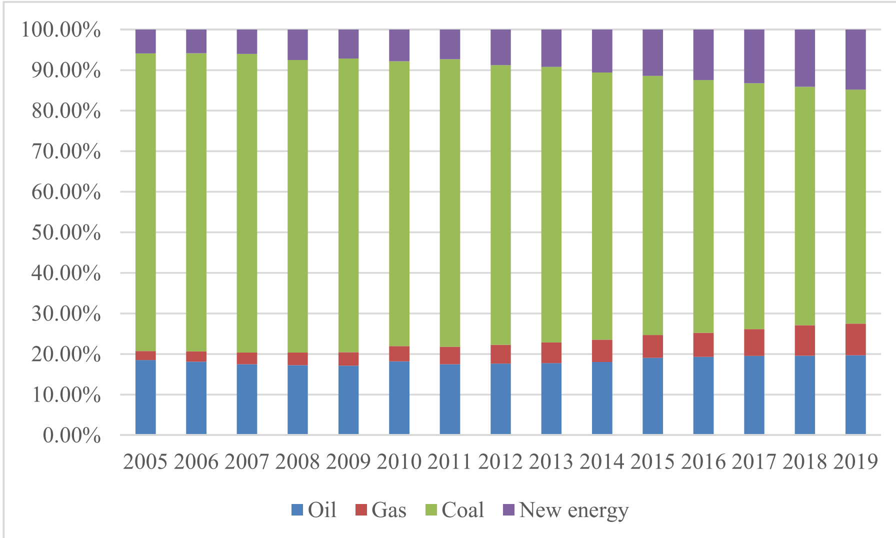

Fig. 1. Changes in energy consumption structure in China from 2005 to 2019.
Note: For simplicity, new energy sources refer to hydropower, nuclear power, wind power, solar power, geothermal power, biomass power, and biofuels. Source: The data come from the BP World Energy Statistical Yearbook (Http: www.bp.com).

been recognized by countries all over the world to solve the problem of environmental pollution through new energy with a large inventory, low pollution, and strong renewable capacity (Zeng et al., 2018). Statistics show that China has been the largest consumer and producer of new energy in the world since2016.[3] According to the National Energy Administration document, the installed capacity of new energy power generation in China reached 794 million kW by the end of 2019, an increase of 9% over the same period the previous year. The installed capacity of new energy generation accounted for 39.5% of the total installed capacity. At the same time, new energy generation reached 2.04 trillion kW·h, which is an increase of approximately 176.1 billion kW·h over the same period in the previous year.[4] With the continuous expansion of the installed scale of new energy, the proportion of new energy applications is also gradually increasing, and the role of new energy in the replacement of clean energy is becoming increasingly prominent. (see Fig. 1).

However, despite the rapid development of new energy in China, fossil energy (coal, oil, and natural gas) still accounts for a high proportion of energy consumption (see Fig. 1). The energy structure dominated by fossil fuels cannot be fundamentally changed in the short term. The environmental problems caused by a large amount of fossil energy consumption cannot be ignored. Therefore, in order to increase the proportion of clean energy in cities, and promote the construction of a resource-conserving and environment-friendly society, the Chinese government has introduced and strictly enforced a series of strategic plans and regulations, such as the Medium - and Long-term Development Plan for Renewable Energy, the Renewable Energy Industry Development Guidance Catalogue, and the Renewable Energy Law and so on (Wu et al., 2018; Sun et al., 2020). Furthermore, the Chinese government put forward the concept of new energy demonstration city (NEDC) on the basis of the 12th Five-Year Plan for Renewable Energy Development. Also, the Chinese government issued the Evaluation Index System and Description of New Energy Demonstration Cities (Trial Implementation), which marks the official opening of the selection of the NEDC.[5] Then, the Chinese government officially established the first batch of 81 pilot cities and 8 industrial parks in2014.[6] The selected cities are expected to create good space capacity for the development of the national new energy industry in the demonstration projects and applications of new energy. These cities are also expected to play a leading role in guiding the optimization and adjustment of the urban energy structure and the reduction of urban pollution in China.[7]

New energy demonstration city, as pilot areas for China to explore energy development paths with Chinese characteristics,

[3] More details at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf.

[4] More details at:http://www.nea.gov.cn/2020-03/06/c_138850234.html.

[5] Among them, NEDC is guided by “clean, efficient, multi-energy complementary, and integrated coordination”. This policy aims to improve energy efficiency, optimize the energy structure, and establish a modern energy system. At the same time, some of its other objectives include promoting the utilization of renewable energy technologies in cities, and conducting demonstrations of diversified new energy utilization technologies; such objectives can foster the sustainable development capacity of cities while improving environmental pollution (Yang et al., 2017; Zhang et al., 2016).

[6] The list of pilot cities and industrial parks includes Changping district in Beijing, Chengde in Hebei, Datong in Shanxi and Hohhot in Inner Mongolia in Heilongjiang, Xuzhou in Jiangsu, Ganzhou in Jiangxi, Zhengzhou in Henan, Xiangyang in Hubei, Guiyang in Guizhou and so on.

[7] For instance, Dunhuang city is rich in new energy resources in Gansu Province.The annual total solar radiation in Dunhuang is 1754k Wh/m2, and the potential installed capacity of photovoltaic power generation is 100 million kW. In 2009, Dunhuang became China’s first national million kilowatt photovoltaic base. In 2011, the Chinese government approved the “Dunhuang New Energy City Development Plan”, supporting Dunhuang City to focus on multiple utilization methods of solar energy and promote the application of various new energy technologies in the city in an orderly manner.The photovoltaic power generation capacity of Dunhuang City in Gansu Province reached 640 million Kilowatts, exceeding the city’s annual electricity consumption for the first time, and achieving 100% new energy power supply in 2015. It is estimated that new energy applications will account for about 28% of the total energy consumption in Dunhuang city by 2020. Chengde City, Hebei Province, as the first batch of new energy demonstration cities, draws on unique natural conditions and vigorously develops new energy industries. The city’s the power generation reached 9.046 billion kW·h, accounting for 49.5% of the city’s total power generation respectively in 2018. By 2020, Chengde City will strive to achieve two million kilowatts of installed photovoltaic power generation, 6.5 million kilowatts of wind power, and 100,000 kW of biomass power generation to form a diverse new energy system.

are important carriers for implementing sustainable development strategies and promoting high-quality economic development in the new era. However, from the perspective of the evolution of new energy policies, the industrially developed countries are at the forefront of the formulation of various new energy development policies, which has played a demonstration role and triggered the change of the world's concept of the traditional energy industry. (Wang et al., 2014; Amado and Poggi, 2012; Xu and Lin, 2018). Many countries have gradually formed a complete policy support system, including strategic drivers, laws, and regulations, to achieve a large scale, in-depth, and sustainable use of new energy resources. Therefore, scholars from various countries have set off a new energy research path. The existing research on the development of new energy mainly includes the following aspects. First, some scholars have studied the prospect and motivation of new energy development (Bloch et al., 2015). They believe that mitigating climate change, increasing the proportion of new energy, and maintaining energy security are the main reasons for countries around the world to promote the deployment of new energy actively (Guerra, 2018; Barthelmie and Pryor, 2014). Second, Some scholars have also studied the factors affecting the development of new energy (Boudri et al., 2002; Alvarez-Herranz et al., 2017; Yousefi et al., 2018). Zhao et al. (2019), Lewis and Wiser, 2007, and Dodd et al. (2018) believe that demand-driven technological innovation, reasonable premium compensation, government intervention, economies of scale, and economic growth are important factors that affect the development of new energy. At present, the focus of new energy research is mainly on the impact of political factors represented by government policies on the development of the new energy industry(Kuik et al., 2019). Moreover, a large number of studies have confirmed the role of new energy development in curbing global warming, reducing pollutant emissions, and bringing negative environmental externalities to fossil energy use (Su and Yu, 2020; Destek and Aslan, 2020; Barthelmie and Pryor, 2014). Therefore, in the process of economic development, countries can optimize the energy structure by improving the efficiency of new energy utilization and the proportion of new energy use, which ultimately reduces environmental pollution. (Vidadili et al., 2017; Karanfil and Omgba, 2019; Sharif et al., 2020). However, due to the late start of China's new energy demonstration city construction and the lack of research on China's new energy demonstration city planning methods, there are few empirical studies on the policy evaluation of China's new energy demonstration cities (Lou, 2014a; Hu, 2015). A few existing studies only focus on policy interpretation, carrying out preliminary discussions on the specific pilot city, and defining the concept of new energy demonstration cities, which lack the universality of policy research. Or most of them have introduced the concept of new energy demonstration city planning, but the research mainly discusses low-carbon city planning, eco-city planning, and zero-carbon city planning, which are related to new energy city planning (Todorović et al., 2012; Khanna et al., 2014; Liu 2014; Peña et al., 2017; Sun et al., 2020). In particular, these studies have not systematically and comprehensively evaluated the effects of the implementation of this policy on curbing environmental pollution. As a result, up to now, the feasibility of a comprehensive policy roll-out has so far been inconclusive.

To this end, as a major institutional arrangement in the field of energy transformation and green development, can the externalities brought about by the policy impact of NEDC alleviate the ecological damage and environmental pollution caused by traditional urbanization? If so, what transmission mechanism does NEDC affect environmental pollution? What are the differences in the policy effects of NEDC on different types of cities (city size, city location)? Answering the above questions will provide some marginal empirical support for policymakers to give full play to the policy effects of NEDC, reasonably improve the energy structure, and promote the coordinated development of the economy and the environment. Therefore, this paper makes an in-depth empirical analysis of the environmental effect of NEDC and tries to clarify the internal mechanism of the impact of NEDC on environmental pollution. On the one hand, it can guide for policymakers to implement the strategic deployment of energy in the future, comprehensively deepen the promotion and utilization of new energy "demonstration zones", and accumulate experience in the development of regional new energy, so as to help achieve the goal of sustainable development. On the other hand, as an important policy tool for the government to promote sustainable urban development, NEDC can also explain the effectiveness of the implementation of the Chinese government's new energy policies to some extent. This provides experience and reference for governments of other developing countries (such as India, Vietnam, and Brazil, etc.) to formulate reasonable new energy-related policies, which has very important theoretical value and practical guiding significance.

The three main contributions of this paper can be summarized as follows. First, the environmental governance effect of the NEDC is evaluated, and the regional and urban scale heterogeneity of the NEDC is analyzed. This exploration provides some factual basis for formulating different pilot policies and gradually popularizing the experience of pilot cities in the later stage. Second, the dataset of prefecture-level cities is used to study the relationship between the construction of the NEDC and environmental pollution. Given the increase of research samples, the research conclusions are more convincing than previous conclusions. Third, considering the potential endogeneity problems in the model, the propensity score matching and difference-in-differences (PSM-DID) method is employed to analyze the governance effects of the construction of the NEDC on environmental pollution and the robustness test. Moreover, the mediating effect and the bootstrap method are introduced to explore the influence mechanism of the NEDC on environmental pollution, which makes the research more in-depth and specific.

The remainder of the paper is organized as follows. In Section 2, the mechanism analysis and research hypothesis of the impact of the NEDC on environmental pollution are introduced. In Section 3, the methodology and data utilized in this study are briefly interpreted. Then, the empirical results are introduced in Section 4. In Section 5, the estimation results are discussed. Lastly, the conclusion and policy recommendations are provided in Section 6. The specific research framework is shown in Fig. 2.

2. Mechanism analysis and research hypothesis

Attaching importance to the development of local new energy is the biggest feature of the construction of the NEDC, which is also the biggest difference from traditional energy planning (Lou, 2014b; Yang, 2017; Li and Guo, 2016). Theoretically, NEDC can promote the development of new energy from several aspects in pilot cities, such as strengthening the guidance of strategic planning, improving the implementation system and supporting policies, accelerating the development of industrial clean technology, accelerating the proportion of new energy consumption, and advocating the concept of new energy consumption and new energy life (Wu et al., 2018; Hu, 2017). This is not only conducive to the pilot cities to establish a diversified new energy development security mechanism and to explore the scientific development mode according to local conditions, but also ultimately it can promote the coordinated development of the environment and economy (Hu, 2015; Geng et al., 2016). Specifically, the NEDC reduces environmental pollution in the following three ways.

First, NEDC can develop new energy sources sustainably and accelerate the substitution of traditional energy sources (Sohag et al., 2015; Wu et al., 2017). In the process of new energy development, pilot cities have taken the initiative to strengthen its R&D and application of new energy technologies (Wang et al., 2020). For example, many pilot cities have set up national new energy technology research centers to support new energy development vigorously and improve their energy efficiency (Hu, 2017). Also, new energy with mature technology and strong market competitiveness, such as solar energy, wind energy, and biogas, is widely used in pilot cities. At the same time, biomass energy with great development potential has been gradually promoted. NEDC realize the diversification and rationalization of the source structure and reduce environmental pollution. Second, NEDC minimizes energy use through intelligent design (Lou, 2014a,b). Different energy use structures are designed for various functional areas of the pilot cities. For example, solar photovoltaic power generation and new energy vehicles are widely used in urban centers with a large population density and a small area (Yang et al., 2017). The suburbs, which are rich in biomass energy resources are located in relatively scattered cities, often use biomass energy, solar energy, decentralized heating, and other types of energy. Thus, these areas have a rational use of energy. Third, the new energy industry plays an important role in promoting urban green development (Shi et al., 2018). Given the high cost of new energy production, the Chinese government not only provides subsidies and tax breaks to producers of new energy products but also provides consumer subsidies and tax rebates to consumers of new energy products (Sun, 2012;Van Der Schoor and Scholtens, 2015). Xie et al. (2021) found that subsidies could significantly improve environmental quality, subsidies scale increased by 1%, environmental pollution would decrease by about 0.15%. In this way, more public and enterprises are encouraged to buy new energy products, promote the development of new energy economy, and ultimately reduce environmental pollution(Liao et al., 2018). In summary, the NEDC can be used as an effective means to optimize the energy structure, improve energy efficiency, and then mitigate environmental pollution. On this basis, this paper proposes the following positive hypothesis:

H1. NEDC has a significant effect on environmental pollution.

If the effect of the NEDC on environmental pollution control exists, what is the pollution reduction mechanism of the pilot policy? How does NEDC achieve environmental governance?

2.1. Technological innovation effect

The impact of the NEDC on environmental pollution is first reflected in the reduction of energy consumption led by technological progress (Li and Guo, 2016). According to the requirements of "Evaluation Index System and Description of New Energy Demonstration City", NEDC needs to continuously explore the optimized combination of new energy and the comprehensive utilization mode of renewable and conventional energy on the basis of innovative new energy development and utilization mode. In this process, the development and utilization of new energy technologies should be applied and innovated constantly.(Xu and Wang, 2014; Hu, 2015). Through the pilot policy to vigorously support technological innovation, which provides a new path choice for the use of urban energy, constitutes the endogenous power of green growth, reduces the dependence of urban economic development on natural resources, and restrains the consumption of traditional energy (Khan et al., 2020). Ghisetti and Quatraro (2017) believe that new energy technology innovation is regarded as the fundamental impetus of green productivity growth. This policy has become the key to solve practical problems such as resource shortage and ecological imbalance in cities (Wu et al., 2018). Moreover, with the enhancement of urban innovation ability, the core competitiveness of the city has also been reshaped, which in turn will promote the city to break the original model of relying on natural resource consumption to obtain a temporary and balanced economic growth, and then seek new growth drivers in continuous innovation, which plays a positive role in promoting environmental governance (Brauni and Wield, 1994; Sun et al., 2019).

Therefore, technological progress is one of the important driving forces for industrial pollution emission reduction and the inevitable result of the NEDC (Alvarez-Herranz et al., 2017 Zhu et al., 2020; Liu et al., 2020). On the one hand, technological innovation promotes the progress of new energy technology. It realizes pollution control from source to end. Lin and Zhu (2019) found that technological innovation can improve the technical level of new energy and promote the production of new energy. Lewis (2010) believes that

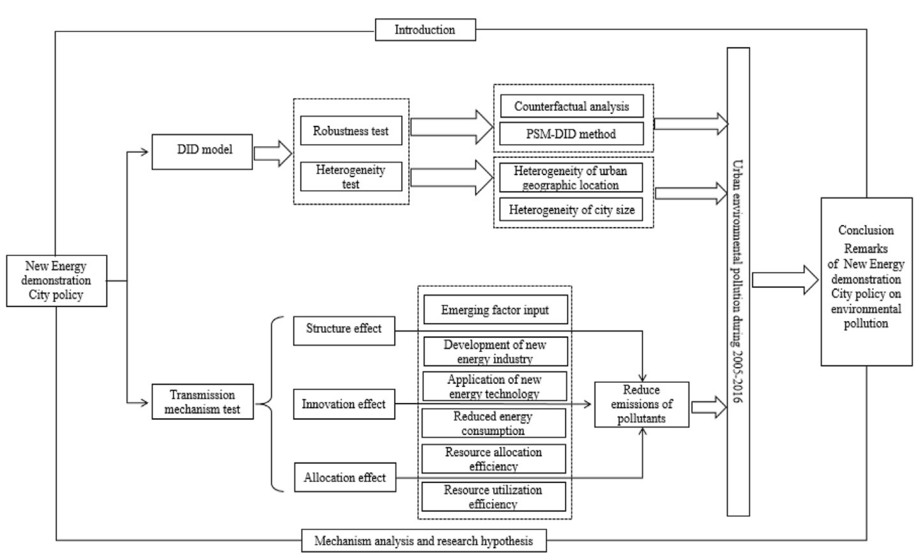

Fig. 2. Research framework.

new energy technology innovation can effectively improve the supply capacity of new energy and meet energy demand. Under the background of the mainstream development of strict environmental control, enterprises apply green technology to all aspects of production, produce environmentally friendly green products. Moreover, they also essentially improve the efficiency of the use of enterprise resources and enhance the level of prevention and control of enterprise pollution (Sezen and Çankaya, 2013). On the other hand, polluting enterprises achieve the substitution of high pollution and high consumption energy by adopting new energy technology that improves the energy efficiency (Kemp and Arundel, 1998), reduce the production cost of enterprises, and increases their profits (Keeble et al., 2005). And, enterprises can further increase the proportion of green clean energy use through new profits (James, 1997; Driessen et al., 2013), and form a closed-loop benign feedback cycle mechanism for clean production (Li et al., 2019; Tilt, 2019).

Finally, NEDC provides a carrier for new energy enterprises to agglomerate and a platform for innovation(Li and Guo, 2016). The combined effect of policy incentives, talent incentives, and infrastructure spillover, can induce enterprise innovation (Park and Lee, 2004; Wu et al., 2017). For example, The implementation of the pilot policy has improved the distribution pattern of urban new energy enterprises. Various factors are more conducive to viewpoints collision and knowledge accumulation in demonstration areas . This will not only accelerate the flow and integration of green technology innovation elements but also produce a synergistic effect to promote the improvement of new energy technology innovation capacity. Moreover, each innovation subject in the pilot area forms a good “industry-university-institute” cooperation model through interaction with other market subjects in the peripheral area, which can speed up technology diffusion and knowledge spillover, and form a linkage effect, so as to achieve a positive coupling between the innovation of new energy technology and the improvement of urban economic quality, and ultimately reduce environmental pollution(Ye et al., 2018). Based on the above analysis, this paper proposes the following hypothesis:

H2. NEDC will further reduce environmental pollution through technological innovation.

2.2. Structural upgrade effect

According to the objectives of the 12th Five-Year Plan of the State Energy Administration, the NEDC should be based on the basic principles of optimizing the energy structure, speeding up the rational upgrading of industries, and increasing the proportion of new energy in urban energy consumption. When new energy demonstration cities were set up, the government induces the industrial development of the pilot cities to focus on new energy through corresponding industrial policies(Wu et al., 2018). Besides, local governments also adjust and optimize the current industrial distribution pattern through spatial planning and factor resetting, to realize the effective utilization of resources (Chen et al., 2019). In the process, the traditional extensive industrial development structure will be optimized, and the industrial subjects will be promoted to concentrate on new energy technology in the demonstration areas, to realize the rational development of the industrial structure. Chen et al. (2019) pointed out that rational industrial spatial layout is particularly important for environmental governance. Therefore, the key to the realistic feasibility of the above goals lies in the coordination of industrial structure changes to achieve a reasonable proportion of industrial structure.

On the one hand, the development model of polluting enterprises is unsustainable from the perspective of industrial development (Acemoglu et al., 2012). Wang et al. (2015) pointed out that most pollsters are reluctant to take the initiative to reduce emissions due to the scale effect of the market and the initial production advantages of non-green technologies. However, the use of fossil energy is restricted by pilot cities, which effectively resolves the risk of existing overcapacity; replaces enterprises with high energy consumption; and guides them to close, stop, merge, and transfer to achieve the maximization of resource utilization (Zheng et al., 2020). On the other hand, NEDC can also provide sustentacular policy support to enterprises with low energy consumption and low pollution, and further foster and strengthen strategic emerging industries such as energy conservation, environmental protection, and new energy, and establish a green industrial system characterized by low pollution and emission. The development model and production management experience of emerging industries not only provide reference for polluting enterprises to adjust production methods, but also produce demonstration and force effect, which will greatly promote the energy transformation of the polluting enterprises to reduce pollution emission and realize green production(Ek and Söderholm, 2010; Guo et al., 2018).

Finally, from the perspective of advanced industrial structure, the promotion and application of new energy technologies are mainly concentrated in technology-intensive industries, most of which discharge less pollution (Kemp and Arundel, 1998). With the gradual optimization and integration of industrial structure to high-tech industries dominated by technologically advanced and knowledge-intensive industries, the advanced industrial structure represented by the green energy industry rapidly promotes the proportion of new energy application (McDowall et al., 2018). In the process of industrial structure upgrading, the added value of products and the effective utilization of resources and space elements are brought up, and the new economic growth point of the city is cultivated, which brings new growth force for the realization of green production in the city. Therefore, pollution emissions are reduced. Based on the above analysis, this paper proposes the following hypotheses:

H3. NDEC will reduce pollutant emissions by upgrading the industrial structure.

2.3. Resource allocation effect

The allocation effect of NEDC on environmental pollution can be explained from the perspective of resource allocation and utilization efficiency. On the one hand, in a well-developed and fully competitive market system, factor resources will continuously flow to enterprises with high efficiency, clean technology, and low energy consumption, and achieve reasonable allocation among various industries (Wang et al., 2020). At the same time, the huge development potential of the new energy market will also attract factor resources to the emerging markets, breaking the original resource allocation pattern (Sun et al., 2020). On the other hand, NEDC will improve factor distortions and further reduce environmental pollution by redistributing factor resources. For example, Dai and Cheng (2016) found that there are serious factor market distortions in various energy industries in China. And such distortions reduce the quality of economic development. Under the fiscal decentralization system, local officials who seek political promotion and participate in the economic competition are more likely to intervene in the factor market , protect the three high industries (namely, high energy consumption, high pollution, and high emission) from elimination, eventually, lead to unreasonable allocation of resources and reduce energy efficiency (Hsieh and Klenow, 2009). However, the inefficient use of energy is an important cause of pollutant emissions (Ryzhenkov, 2016; Tajudeen et al., 2018). Yin et al. (2018) pointed out that compared with efficient factor allocation, low-efficiency industries have more scarce resources, and such industries have no incentives for innovation and industrial up-gradation (Liu et al., 2017).

From the perspective of the NEDC to improve resource allocation efficiency, the technological framework of the NEDC needs to rely on new material industries, such as new energy materials and information materials, which are technology-intensive and low-pollution industries (Sun et al., 2020). Its development will drive the flow and agglomeration of capital, labor, technology, and information to this field (Verbong and Loorbach, 2012), optimize the allocation structure of new energy and traditional industry resources, reduce factor distortion, and improve the allocation efficiency. At the same time, with the help of the pilot policy, enterprises adjust and change the current organizational and business model . Such change allows enterprises to keep close to the market demand and realize the flexible scheduling of production resources (enterprise capital, labor force, and energy). it allows them to improve the efficiency of enterprise resource utilization continuously, avoid the waste of resources, and reduce the discharge of waste pollutants. In addition, the development of the new energy industry forces traditional polluting enterprises to upgrade (Jordaan et al., 2017), which not only promotes the flow of new energy factors to polluting enterprises but also optimizes the resource allocation efficiency of polluting enterprises through the "catfish effect", thus reducing their energy consumption and pollutant emissions (Wu et al., 2020; Sun et al., 2020). Based on the above inference, this study puts forward the following hypothesis:

H4. The NEDC may reduce environmental pollution through the effect of resource allocation.

3. Methodology and data

3.1. Econometric methodology

In 2014, 81 cities and 8 industrial parks were selected as pilot areas for new energy policy, providing a quasi-natural experiment for studying the environmental effects of the construction of NEDC. We used the Difference-in-Differences (DID) method to evaluate the environmental performance of NEDC (Wooldridge, 2001).[8] The basic principle of the DID method is to compare the difference between the control group and the treatment group before and after the implementation of the policy, and then construct the difference-in-differences statistics reflecting the effect of the policy (Shao et al., 2017).[9] Therefore, based on the principle of the DID method, this study constructs two dummy variables: the treatment group dummy variables and the control group dummy variables. The policy pilot cities are regarded as the treatment group, and the nonpolicy pilot cities are regarded as the control group. According to our screening method, the treatment group includes 67 cities, and the control group consists of 204 cities.[10] Besides, the policy shock variable is regarded as du, while the time grouping variable is regarded as dt. du is a dummy variable equal to 1 if a city has a policy on NEDC, and 0 if it does not. Similarly, dtequals 1 in the period after 2014 to reflect the implementation of the NEDC. Finally, the multiplier term *NEDC* is obtained by multiplying *du*and dt. The DID model is set as follows:

$$lnPOL_{it} = \beta_0 + \beta_1 NEDC_{it} + \beta_n CONTROL_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

where i is the city, and t is the year. *lnPOL*is the environmental pollution level, which is expressed by exhaust gas discharge ($lnSO_2$) and wastewater discharge (*lnWATER*). *CONTROL* represents the other control variables that affect environmental pollution, specifically human capital (*lnHUM*), energy consumption (*lnPELE*), economic development level (*lnPGDP*), openness (*lnOPEN*), and population density (*lnPOP*). $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$ are the coefficients. μ_i is the individual fixed effect, δ_t is the time-fixed effect, and ε_{it} is the random perturbation term. This study focuses on the coefficient β_1.

3.2. Variable selection

3.2.1. Environmental pollution level (lnPOL)

In China, pollution mainly comes from industrial pollution, which is divided into solid pollutants, liquid pollutants, and gaseous pollutants in the in-phase state. Therefore, the selection of environmental pollution indicators should also take into account the above three physical forms of pollutants, such as solid industrial soot, solid waste, solid smoke dust, liquid industrial wastewater, gas nitrogen oxides, and gas industrial sulfur dioxide. However, this study uses industrial wastewater emissions and industrial sulfur dioxide emissions as proxy variables of environmental pollution because of the data availability (China has not released prefecture-level city data on the emissions of industrial solid pollutants and industrial gaseous nitrogen oxides).

3.2.2. New energy demonstration city construction

China introduced the concept of NEDC construction in 2012. The pilot project of NEDC was formally established in 2014. Among the 271 city samples involved in this paper, 67 cities have become pilot cities. This study characterizes the state of NEDC construction in the form of dummy variables. The city is defined as 1 during the pilot year and thereafter; otherwise, the value is 0.

[8] The advantages of the DID method are as follows: firstly, the DID method can avoid the endogenous problems when the policy is used as the explanatory variable, which can effectively control the interaction effect between the explained variable and the explanatory variable (Lechner 2011; Moser and Voena, 2012). Secondly, the DID method can not only make use of the exogeneity of the explanatory variables but also control the influence of unobtrusively individual heterogeneity on the explanatory variables (Wooldridge, 2001), so as to obtain an unbiased estimate of the policy effect (Chen et al., 2020). Finally, the traditional policy evaluation method is mainly through the setting of virtual variables for regression analysis; while the DID method is through the establishment of quasi-natural experiments to evaluate the policy, so the DID method is more accurate (Dinardo, 2010).

[9] Specifically, a counterfactual framework is used to evaluate the changes in the observed factors in both cases. If the samples are divided into two groups by an exogenous policy shock (treatment group interfered by the policy and control group not interfered by the policy). In addition, before the policy shock, there is no significant difference between the explained variables of the treatment group and the control group, then we can regard the explained changes of the control group before and after the policy as the situation when the treatment group is not affected by the policy shock (the counterfactual result). Then, by comparing the change of explained variables in the treatment group ($D1$)with the change of explained variables in the control group ($D2$), we can get the actual effect of the policy shock ($DID = D1 - D2$) (Ashenfelter (1978); Lan et al., 2020).

[10] Considering that demonstration cities include prefecture-level cities and county-level cities, the research samples are processed as follows to ensure the robustness of the research conclusions. The new energy demonstration cities with more missing research data are deleted (such as Golmud City, Qinghai Province, Korla City, and the Xinjiang Uygur Autonomous Region). Given that the policy pilot is continuous, the policy pilot of a county (district) can have a great impact on the energy pattern of prefecture-level cities. Therefore, for some prefecture-level cities that only take counties (districts) as pilot areas, this study treats this kind of prefecture-level cities as policy pilot cities (such as Chenggong District of Kunming and Jimo City of Qingdao).

3.2.3. Control variables

To control other factors affecting environmental pollution, this study introduces the following control variables.

(1) Human capital(*lnHUM*). Human capital refers to the knowledge, skills, and labor proficiency condensed on the labor force (Psacharopoulos and Schultz, 1972). The impact of human capital on environmental pollution is mainly reflected in the following two aspects. (1) Higher human capital contributes to the local development of energy conservation and emission reduction technologies, thus promoting the improvement of environmental quality. (2) Areas with high human capital tend to put forward higher requirements for environmental quality, which prompts the local government to implement stringent environmental regulation measures to limit the emission of environmental pollutants. Referring to Sarkodie et al. (2020), we use the number of college students per 10,000 students in each city to measure the regional human capital.

(2) Energy consumption (*lnPELE*). Energy consumption is one of the important factors affecting environmental pollution. Given the dominance of coal power generation in China, the electric power industry is not only one of the most important energy industries but also a key industry with high energy consumption and high pollution. In addition, energy consumption is generally positively correlated with environmental pollution. Limited by the availability of data, energy consumption is measured by per capita power consumption intensity (Vaona, 2013).

(3) Economic development level (*lnPGDP*). The level of economic development of a region can be reflected by per capita GDP, and the problem of environmental pollution is always closely related to economic development (Hao et al., 2019). On the one hand, China has long relied on capital investment to promote economic growth. However, this extensive growth model may have brought a series of environmental pollution problems. On the other hand, when the economy develops to a certain extent, the government also has more sufficient funds to control environmental pollution. Referring to Hao et al. (2019), the economic development level is measured by the actual per capita GDP of each region, and it was deflated by the GDP deflator in 2005.

(4) Openness (*lnOPEN*). The degree of opening up represented by foreign direct investment is the basic factor to be considered in the study of environmental pollution. The existing research mainly forms two viewpoints. First, developing countries take the initiative to lower environmental regulation standards to attract foreign investment to develop their economy and become a "pollution haven" for developed countries (List and Co, 2000). Second, the new technology provided by foreign direct investment is conducive to improving environmental quality and giving full play to the "pollution halo" effect (Letchumanan and Kodama, 2000). Referring to Wu et al. (2020a,b), openness (*lnOPEN*) is measured by the proportion of foreign direct investment used in the GDP.

(5) Population density (*lnPOP*). The rapid migration to the city leads to a sharp expansion of the demand for urban resources, which is embodied in the excessive consumption of energy. At the same time, cities eventually discharge an increasing amount of pollutants into the natural environment given the expansion of production scale and the deepening of industrialization. Following Yi et al. (2020), we use the ratio of resident population at the end of the year to the total area of urban jurisdictions in measuring population density to control the possibility of population pollution.

3.2.4. Mediation variables

(1) Industrial structure effect (*lnIND*). The effect of industrial structure is measured by the ratio of the GDP of the tertiary industry to the GDP of the secondary industry (Wu et al., 2020). The coefficient of the industrial structure is expected to be negative, indicating that the construction of an NEDC has promoted the upgrading of the industrial structure and produced structural effects to reduce environmental pollution.

(2) Resource allocation effect (*lnECO*). The resource allocation effect is expressed by the total factor productivity (Hsieh and Klenow, 2009). The larger the value, the higher the resource allocation efficiency and the stronger the allocation effect. The expected sign coefficient of resource allocation is negative, indicating that the construction of NEDC reduces resource mismatch, improves resource allocation efficiency, and generates allocation effects to reduce environmental pollution.

(3) Technological innovation effect (*lnINV*). The technological innovation effect is expressed by the urban innovation index. This indicator is a comprehensive indicator that can comprehensively reflect all aspects of urban innovation. The advantage of this indicator is to estimate its value through the patent update model. This model overcomes the problem of large differences in patent value and corrects the traditional measurement error caused by the number of patents to measure the level of innovation. The data are derived from the Report on the Innovation of Chinese Cities and Industries by the Industrial Development Center of Fudan University.

3.3. Data sources

In this study, the balanced panel data of 271 prefecture-level cities were selected in China from 2005 to 2016 as the research object. The original data of the selected indicators were derived from the China Statistical Yearbook of Science and Technology, China Statistical Yearbook of Urban Construction, and China Urban Statistical Yearbook. Descriptive statistics of relevant data are shown in this paper (see Table 1).

3.4. Empirical results

3.4.1. Parallel trend test

The premise of using the DID model is that a common trend exists between the treatment group and the control group before the implementation of the policy. We use the Event Study method to verify the parallel trend hypothesis (Wang, 2013). If the parallel trend hypothesis is verified, then the impact of the policy pilot on environmental pollution will only occur after the implementation of the policy. Before the pilot policy is implemented, no significant difference should exist between pilot cities and nonpilot cities. To verify the parallel trend hypothesis, we set the following model on the basis of Model (1).

$$lnPOL_{it} = \alpha + \sum_{j=-4}^{2} \beta_j NEDC_{i,t-j} + \mu_i + \delta_t + \varepsilon_{it} \tag{2}$$

where i is the city, and t is the year. $NEDC_{i,t-j}$ is a dummy variable. When i implements the pilot policy in the $t-j$ year, then the

Table 1
Statistical description of variables.

Variable type	Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	$\ln SO_2$	tons	3252	3.6652	1.0535	−7.6543	6.2073
	lnWATER	million tons	3252	3.8072	1.0332	−2.6593	6.8163
Explained variable	NEDC	–	3252	0.0618	0.2408	0	1
Control variable	lnHUM	–	3252	0.7568	0.5785	0	2.6471
	lnPELE	kw·h/person	3252	6.9808	1.1827	3.5653	11.5600
	lnPGDP	Yuan/person	3252	10.2723	0.7207	8.1098	12.4564
	lnOPEN	%	3252	0.9143	0.6310	0	4.3558
	lnPOP	Square kilometer /thousand people	3252	5.8551	0.6743	2.8461	7.2435
Mediation variable	lnIND	–	3252	3.5747	0.2436	2.1494	4.4467
	lnECO	–	3252	−0.4783	0.3537	−2.3026	0
	lnINV	–	3252	0.9594	1.0258	0	6.5440

Note: "ln" in the table refers to the logarithmic form of the variables.

variable is equal to 1; otherwise, it is equal to 0[11]. In addition, the effect of the current policy pilot period is expressed by β_0; the effect of the first 1 to 4 periods of the policy pilot is expressed by $\beta_{-4}$to β_{-1}. Moreover, the effect of 1–2 periods after the policy pilot is expressed by $\beta_1$to $\beta_2\beta_0 current\beta_{-4}$ $\beta_{-1}pre\_4pre\_1$ β_1 $\beta_2 post\_1pre\_2$. The results are shown in Table 2. Table 2 shows that the coefficients of *pre*_2 to *pre*_4 are not significant (To avoid collinearity, we usually delete the variable *pre*_1). After the policy is implemented, the coefficients of *post*_1 and *post*_2 are significantly negative overall. Thus, the construction of the NEDC has a negative impact on environmental pollution, which means that the parallel trend hypothesis is verified. The DID method is suitable for the assessment of the environmental pollution effects of the construction of the NEDC. At the same time, to show the effect of the parallel trend test more intuitively, this paper presents the dynamic economic effects of policies among different years (see Fig. 3). Fig. 3 shows that the construction of NEDC has a significant role in reducing pollution. Over time, this effect becomes increasingly strong.

3.5. Benchmark regression

This paper uses the DID method to evaluate the impact of NEDC on environmental pollution. The results are shown in Table 3. In Table 3, Models (1) and (3) do not have control variables. Models (2) and (4) are added with control variables for regression. These four models respectively show the impact of the NEDC on waste gas and wastewater emissions. All the estimation results show that whether or not the control variable is added, the NEDC has a significant negative impact on various pollution indicators. Thus, the NEDC significantly reduces the amount of waste gas emissions by approximately 28.83% while also reducing the amount of wastewater emissions by approximately 12.88%.

3.6. Transmission mechanism test

The benchmark regression results above show that the NEDC has significantly reduced urban pollution. What is the mechanism of the NEDC to reduce urban pollution? As explained in the previous theoretical analysis, the NEDC affects the economic development and environmental governance of the city through technological innovation effects, allocation effects, and structural effects. Ultimately, these effects reduce urban environmental pollution. Referring to the analysis ideas of Baron and Kenny (1986), this paper verifies the mechanism by seting up the following measurement model:

Table 2
Parallel trend test-dynamic economic effects.

Variable	(1)	(2)
	$LnSO_2$	LNWATER
pre_4	0.0083	−0.0549
	(0.0615)	(0.0523)
pre_3	0.0926	0.0346
	(0.0805)	(0.0685)
pre_2	0.0230	0.0324
	(0.0805)	(0.0685)
Current	−0.1069	−0.0219
	(0.0805)	(0.0685)
post_1	−0.1558*	−0.1069
	(0.0805)	(0.0685)
post_2	−0.9654***	−0.4701***
	(0.0805)	(0.0685)
Constant	3.6871***	3.8250***
	(0.0157)	(0.0134)
Year effect	YES	YES
Individual effect	YES	YES
Observations	3252	3252
R-squared	0.084	0.027

Note: "ln" in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and10% levels, respectively. Standard error statistics are in parentheses.

$$lnPOL_{it} = \alpha_0 + \alpha_1 NEDC_{it} + \alpha_n X_{it} + \varepsilon_{it} \tag{3}$$

$$M_{it} = \phi_0 + \phi_1 NEDC_{it} + \phi_n X_{it} + \varepsilon_{it} \tag{4}$$

$$lnPOL_{it} = \vartheta_0 + \vartheta_1 NEDC_{it} + \vartheta_2 M_{it} + \vartheta_n X_{it} + \varepsilon_{it} \tag{5}$$

where M is an intermediary variable, which includes the technological innovation effect (*lnINV*), the resource allocation effect (ln*ECO*), and the industrial structure effect (*lnIND*). Formulas (3), (4), and (5) constitute the mediation model. When α_1 is significant in Equation (3), then the significance of ϕ_1 in Equation (4) and ϑ_2 in Equation (5) are observed. If ϕ_1 and ϑ_2 are significant at the same time, then the NEDC affects the environmental pollution in China, with a median effect of $\phi_1 \times \vartheta_2$. At this time, if α_1 is still significant, which means that the intermediary variable is a partial intermediary variable. The NEDC not only directly affects environmental pollution but also affects environmental pollution by affecting the intermediary variable. If ϕ_1 is no longer significant, then the intermediary is a complete intermediary variable. The NEDC has an indirect impact on environmental pollution or other mechanisms of action. Only the intermediary variable has an impact on environmental pollution. Besides, the bootstrap method

[11] $NEDC_{i,t-j}$represents a series of explanatory variables, which include variables *pre*_4 to *pre*_1, *current*, *post*_1, and *post*_2.

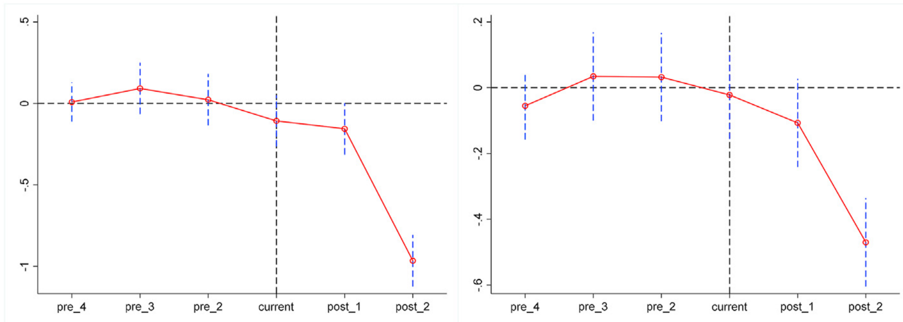

Fig. 3. Parallel trend test.

Table 3
Benchmark regression estimation results.

Variable	(1)	(2)	(3)	(4)
	lnSO$_2$	lnSO$_2$	lnWATER	lnWATER
NEDC	−0.4278***	−0.2883***	−0.1705***	−0.1288***
	(0.0388)	(0.0404)	(0.0325)	(0.0345)
lnHUM		−0.2668***		−0.2335***
		(0.0761)		(0.0650)
lnPELE		0.0408		0.0649**
		(0.0299)		(0.0255)
lnPGDP		−0.1721***		−0.0777***
		(0.0281)		(0.0240)
lnOPEN		0.0570**		0.0315
		(0.0226)		(0.0193)
lnPOP		−0.2714		0.1681
		(0.1698)		(0.1450)
Constant	3.6917***	6.9042***	3.8178***	3.3250***
	(0.0087)	(0.9373)	(0.0073)	(0.8003)
Year effect	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES
Observations	3252	3243	3252	3243
R-squared	0.039	0.084	0.009	0.024

Note: “ln” in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and10% levels, respectively. Standard error statistics are in parentheses.

is used to test the robustness of the mechanism. Then, it provides the proportion of indirect effects. Given the limitation of space, this paper only discusses the influence of NEDC on waste gas pollution. The results are shown in Table 4.

According to Regression (1) in Table 4, the total effect of the NEDC on urban environmental pollution is −0.3879, thus passing the significance level test of 1%, which is consistent with the previous conclusion. Regression (2) is the result of the estimation of the industrial structure of the NEDC, and the empirical results show that the regression coefficient of the NEDC is significantly positive at the 1% level. The NEDC is conducive to the optimization of the industrial structure of pilot cities. Regression (3) is the result of the estimation of environmental pollution by the NEDC and the industrial structure. The regression coefficient of the industrial structure to environmental pollution is also significantly positive at the 1% level. The optimization of industrial structure can effectively reduce urban environmental pollution. On the basis of the above analysis, the NEDC can reduce environmental pollution by optimizing the industrial structure. Its intermediary effect is −0.1004, accounting for approximately 26% of the total effect. The Sobel test and the bootstrap test are significant at the 1% level, indicating that the mediating effect of the structural effect exists significantly. Thus, H3 is verified. Regressions (4)–(5) and Regressions (6)–(7) are the test results of the allocation effect and the innovation effect, respectively. The intermediary effect of the allocation effect is −0.1142, accounting for approximately 29% of the total effect. The intermediary effect of the innovation effect is −0.1409, accounting for approximately 36% of the total effect. H2 and H4 were verified. A comparison of the size of the three intermediary effects shows that the effect of technological innovation is the strongest, followed by the effect od resource allocation and the industrial structural effect, respectively. Therefore, the technological innovation effect and allocation effect of the NEDC have the most effective inhibitory effect on environmental pollution. However, the substitution effect of industrial structure is relatively limited.

3.7. Heterogeneity test

The abovementioned empirical results show a strong global relationship between the NEDC and environmental pollution. However, urban environmental pollution is multisource, multiscale, and has a cross-regional distribution (Oanh et al., 2006). Thus, showing an atypical situation, which is different from or even completely contrary to the global space in the local space, is possible (Zalakeviciute et al., 2018). With the continuous expansion of the urban scale, a large number of people flow from rural areas to cities, resulting in a sharp increase in urban energy consumption, which is likely to worsen environmental quality . Therefore, this paper expands and analyzes heterogeneity from the perspectives of the urban interregional and urban scale, thus further identifying the heterogeneity.

3.7.1. City size heterogeneity

The previous analysis shows that large cities cause economic agglomeration; the efficiency of resource allocation and utilization is correspondingly high, which can reduce environmental pollution (Hao et al., 2020). At the same time, the excessive size of the city can easily produce a crowding effect, which aggravates the problems of urban disease and environmental pollution. Traditional urban development inevitably encounters these two effects. Thus, this article further uses the latest standards in the Notice on Adjusting the Standards for the Division of Urban Size issued by the State Council in 2014 as the basis for classifying cities (population size of less than one million is defined as a small-scale city. A population size between one and three million is defined as a medium-sized city. Meanwhile, a population size of more than three million is defined as a large-scale city). This study also examines the differential impact of the construction of the NEDC on environmental pollution in cities of different sizes. The results are shown in Table 5.

The results show that under the medium-sized city scale, the pollution reduction effect of the NEDC is not significant, which indicates that the environmental control efficiency decreases with

Table 4
Transmission mechanism test.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$lnSO_2$	lnIND	$lnSO_2$	lnECO	$lnSO_2$	lnINV	$lnSO_2$
lnIND/lnECO/lnINV			−0.8730***		−1.0222***		−0.3423***
			(0.0776)		(0.0482)		(0.0307)
NEDC	−0.3879***	0.1151***	−0.2875***	0.1117***	−0.2737***	0.4116***	−0.2470***
	(0.0711)	(0.1581)	(0.0703)	(0.0243)	(0.0669)	(0.0410)	(0.0709)
lnHUM	−0.2844***	0.1874***	−0.1208***	0.1641***	−0.1166***	0.5988***	−0.0794*
	(0.0378)	(0.0084)	(0.0399)	(0.0129)	(0.0363)	(0.0213)	(0.0414)
lnPELE	0.4656***	0.0124**	0.4764***	0.0740***	0.5412***	0.1855***	0.5291***
	(0.0233)	(0.0052)	(0.0229)	(0.0080)	(0.0221)	(0.0131)	(0.0236)
lnPGDP	−0.0216	−0.0473***	−0.0629*	−0.2399***	−0.2668***	0.5017***	0.1501***
	(0.0342)	(0.0076)	(0.0337)	(0.0117)	(0.0341)	(0.0192)	(0.0369)
lnOPEN	−0.0602**	0.0326***	−0.0317	0.0019	−0.0583**	0.0139	−0.0555**
	(0.0285)	(0.0063)	(0.0281)	(0.0097)	(0.0267)	(0.0161)	(0.0280)
lnPOP	0.7010***	0.0493***	0.7440***	0.1018***	0.8050***	0.6815***	0.9343***
	(0.0292)	(0.0065)	(0.0289)	(0.0100)	(0.0278)	(0.0164)	(0.0354)
Constant	−3.1785***	3.5071***	−0.1167	0.7450***	−2.4211***	−9.9722***	−6.5920***
	(0.3409)	(0.0758)	(0.4312)	(0.1164)	(0.3215)	(0.1918)	(0.4534)
Sobel test		−0.1004***		−0.1142***		−0.1409***	
		(0.0164)		(0.0254)		(0.0186)	
Bootstrap (Direct effect)		−0.2875***		−0.2737***		0.2470***	
		(0.0633)		(0.0571)		(0.0645)	
Bootstrap(Indirect effect)		−0.1004***		−0.1142***		−0.1409***	
		(0.0156)		(0.0226)		(0.0253)	
Proportion of indirect effects		26%		29%		36%	
Observations	3243	3243	3243	3243	3243	3243	3243
R-squared	0.204	0.254	0.243	0.169	0.301	0.735	0.233

Note: "ln" in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and10% levels, respectively. Standard error statistics are in parentheses.

the decrease of city size. In addition, the NEDC does not exert its effect. Such circumstances may be due to the lack of a technological base and green technology-related industrial configuration in small-sized cities. The NEDC has a significant pollution reduction effect in large-sized cities. Besides, the pollution reduction effects among the different types of city sizes vary. The inhibitory effect of city size on exhaust gas is strengthened with the increase of city size, whereas the pollution reduction effect of wastewater is the strongest in large cities. On the whole, this conclusion confirms the view that the larger the city size, the stronger the pollution reduction effect of the NEDC. However, various degrees of differentiation in the treatment of different pollutants exist. From this conclusion, crowding and pollution in the process of traditional urban development are easily solved when the urban governance model is changed. The key to the pollution problem is not the size of the city but whether the urban governance model is innovative and progressive.

3.7.2. Heterogeneity of urban geographic location

Several differences in resource endowment, factor allocation, and policy formulation exist in different location cities in China. The regression analysis of the urban sample population may cover up regional differences. Therefore, according to the geographical location of the city, the sample is divided into the eastern cities, a central city, and western cities. The different effects of the NEDC on environmental pollution are verified by group regression. The regression results are shown in Table 6. On the whole, the pollution reduction effect of the NEDC is still significant, but the pollution reduction effect in the eastern and central regions is more significant.

3.8. Robustness test

3.8.1. Robustness test I: test based on the PSM-DID method

This study further uses the PSM-DID method to test the robustness. The method solves the systematic differences in the changing trend between pilot cities and other cities and reduces the estimation error of the DID method. However, before using the PSM-DID method, testing whether a significant difference exists in the average value of covariates between the treatment group and the control group after matching (see Table 7) is necessary. The results in Table 7 show no significant difference in all variables after matching, which proves that the use of the PSM-DID method in this paper is reasonable. Also, the nuclear matching method is used to estimate whether the effect of the NEDC on reducing environmental pollution is robust, and the matching effect of the treatment control group is tested by drawing the kernel density function diagram (see Fig. 4). Fig. 4 shows that the probability density of the tendency score of the treatment and the control group is very close after matching, indicating that the matching effect of this paper is good. Therefore, the feasibility and rationality of the PSM-DID method are further proven on the basis of the common support hypothesis.

Table 8 shows that after using the PSM-DID method, the NEDC still significantly reduces the level of urban environmental pollution, which reduces the total amount of exhaust gas emissions and total wastewater emissions by 30.24% and 10.96%, respectively. No significant difference exists between the results of PSM-DID estimation and the previous DID results. This finding supports the empirical conclusion that the pollution reduction effect of the NEDC is very significant.

3.8.2. Robustness test II: counterfactual analysis

The DID model is used to test the influence of the NEDC on environmental pollution. The premise is that if the pilot city is not affected, the changing trend of pollution in the control group and treatment group will not be the systematic difference with time. Therefore, this study uses counterfactual analysis to test whether the above premise is valid. Specifically, this work selects the period of the unbuilt NEDC (2005−2013) as the research sample period

Table 5
Regression results of heterogeneity of city size.

Variable	(1) $lnSO_2$ Small-sized	(2) $lnSO_2$ Medium-sized	(3) $lnSO_2$ Large-sized	(4) lnWATER Small-sized	(5) lnWATER Medium-sized	(6) lnWATER Large-sized
NEDC	0.0047	−0.1840	−0.3035***	−0.1806	−0.3992***	−0.0894**
	(0.1767)	(0.1365)	(0.0427)	(0.3044)	(0.1094)	(0.0357)
lnHUM	0.0430	−0.6501***	−0.2327***	−0.4427	−0.1939	−0.2207***
	(0.2296)	(0.2363)	(0.0852)	(0.3955)	(0.1895)	(0.0713)
lnPELE	0.0554	−0.0374	0.0247	0.2312	0.0714	0.0189
	(0.0852)	(0.0874)	(0.0350)	(0.1467)	(0.0701)	(0.0293)
lnPGDP	0.1082	−0.0447	−0.1916***	0.4760*	−0.0158	−0.0772***
	(0.1399)	(0.0914)	(0.0312)	(0.2409)	(0.0732)	(0.0261)
lnOPEN	0.1687*	0.0940	0.0373	0.0310	0.0537	0.0135
	(0.0971)	(0.0889)	(0.0235)	(0.1673)	(0.0713)	(0.0196)
lnPOP	2.4523***	1.0501	−0.4261**	0.8737	−0.7183	0.1469
	(0.7360)	(1.0497)	(0.1729)	(1.2677)	(0.8417)	(0.1447)
Constant	−9.6626***	−1.2812	8.2420***	−7.6935	6.8544	3.9066***
	(3.4847)	(5.3573)	(0.9745)	(6.0018)	(4.2954)	(0.8157)
Year effect	YES	YES	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES	YES	YES
Observations	79	531	2633	79	531	2633
R-squared	0.253	0.047	0.107	0.221	0.046	0.026

Note: "ln" in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. Standard error statistics are in parentheses.

Table 6
Regression results of urban geographical location heterogeneity.

Variable	$lnSO_2$ Eastern region	$lnSO_2$ Central region	$lnSO_2$ Western region	lnWATER Eastern region	lnWATER Central region	lnWATER Western region
NEDC	−0.4445***	−0.2126***	−0.1986**	−0.0919*	−0.2165***	−0.0733
	(0.0701)	(0.0574)	(0.0861)	(0.0474)	(0.0584)	(0.0785)
lnHUM	−0.6989***	−0.4590***	0.3227**	−0.2900***	−0.2455*	−0.0738
	(0.1304)	(0.1270)	(0.1432)	(0.0881)	(0.1293)	(0.1305)
lnPELE	0.0360	0.1352**	0.0206	0.0120	0.0595	0.1032**
	(0.0626)	(0.0538)	(0.0450)	(0.0423)	(0.0548)	(0.0411)
lnPGDP	0.0174	−0.2513***	−0.3177***	−0.0132	−0.0063	−0.2459***
	(0.0566)	(0.0398)	(0.0535)	(0.0383)	(0.0406)	(0.0488)
lnOPEN	0.0504	0.0023	0.1503***	0.0280	0.0119	0.0614
	(0.0377)	(0.0361)	(0.0474)	(0.0255)	(0.0368)	(0.0432)
lnPOP	−1.2921***	0.0178	0.8766*	0.0702	−0.0410	1.0802**
	(0.3000)	(0.2116)	(0.4729)	(0.2028)	(0.2154)	(0.4311)
Constant	11.6488***	5.4459***	1.4827	4.1416***	3.804***	−0.9701
	(1.7146)	(1.1814)	(2.4876)	(1.1589)	(1.2028)	(2.2677)
Year effect	YES	YES	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES	YES	YES
Observations	1152	1187	904	1152	1187	904
R-squared	0.110	0.126	0.082	0.024	0.020	0.054

Note: "ln" in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. Standard error statistics are in parentheses.

Table 7
Applicability test of PSM-DID method.

Variable	Unmatched	Mean		%reduct		*t*-test	
	Matched	Treated	Control	%bias	bias	t	p>|t|
lnHUM	U	0.9819	0.7433	39.7	81.5	5.63	0.000
	M	0.9819	1.0262	−7.4		−0.66	0.507
lnPELE	U	7.4149	6.9528	43.0	94.3	5.34	0.000
	M	7.4149	7.4411	−2.4		−0.25	0.799
lnPGDP	U	10.861	10.232	99.8	99.5	12.13	0.000
	M	10.861	10.858	0.5		0.06	0.953
lnOPEN	U	0.9868	0.9114	11.4	27.0	1.63	0.103
	M	0.9868	1.0419	−8.4		−0.83	0.405
lnPOP	U	6.0028	5.8507	23.9	65.7	3.10	0.002
	M	6.0028	6.055	−8.2		−0.83	0.409

and advances the actual new energy pilot time of each prefecture-level city by five years, four years, three years, two years, and one year to construct a counterfactual test. At the same time, NEDC 2009, NEDC 2010, NEDC 2011, NEDC 2012, and NEDC 2013 are used as "pseudo-pilot city" variables instead of to estimate regression. Models (1)–(10) in Table 9 show that the coefficients of NEDC 2009, NEDC 2010, NEDC 2011, NEDC 2012, and NEDC 2013 are positive and negative. However, all of the coefficients fail the significance test. The placebo test results show that the analysis in the above benchmark regression is not caused by other unobservable factors but by the exogenous impact of the NEDC.

4. Discussion

4.1. Discussion for the results of the DID model

Further to the above regression results, we proceed with the following discussions.

Table 3 shows that NEDC can significantly reduce environmental

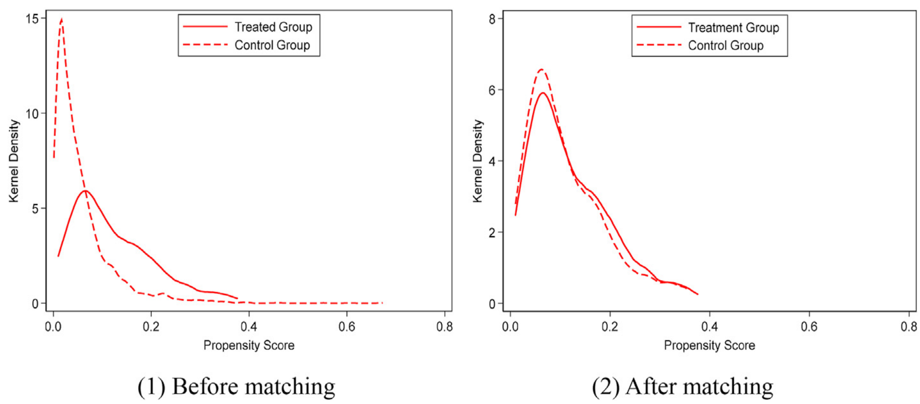

Fig. 4. Kernel density function matching diagram.

Table 8
Analysis of PSM-DID empirical results.

Variable	(1) lnSO$_2$	(2) lnSO$_2$	(3) lnWATER	(4) lnWATER
NEDC	−0.4594***	−0.3024***	−0.1585***	−0.1096***
	(0.0382)	(0.0397)	(0.0315)	(0.0337)
lnHUM		−0.1202		−0.1099
		(0.0818)		(0.0694)
lnPELE		0.0276		0.0397
		(0.0325)		(0.0276)
lnPGDP		−0.2623***		−0.1121***
		(0.0320)		(0.0272)
lnOPEN		0.0473**		−0.0034
		(0.0232)		(0.0197)
lnPOP		−0.2343		0.1686
		(0.1649)		(0.1399)
Constant	3.7522***	7.7111***	3.8968***	3.8826***
	(0.0089)	(0.9243)	(0.0074)	(0.7840)
Year effect	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES
Observations	2830	2821	2830	2821
R-squared	0.054	0.110	0.010	0.023

Note: "ln" in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and10% levels, respectively. Standard error statistics are in parentheses.

pollution in China, which promotes our understanding of the pilot policy. From the current system design of the pilot policy, the setting of various new energy consumption proportion indicators in the pilot cities indicates that the pilot cities focuses more on improving the proportion and efficiency of new energy application and takes the development of clean and low-carbon new energy as the main direction of energy structure adjustment (Wu et al., 2018). In this process, on the one hand, the government takes the elimination of backward and inefficient production capacity, improvement of production efficiency and active fulfillment of social responsibility for environmental products as strategic goals(Yang et al., 2017). On the other hand, driven by policy factors, production enterprises will also take the initiative to research and develop new energy technologies and apply new energy facilities, so as to further increase the proportion of new energy consumption, squeeze the consumption of traditional fossil energy and reduce pollutant emissions. From the perspective of the content of the pilot policy, the pilot cities aim to optimize the energy structure and establish a modern energy utilization system, and promote the application of various new energy products and technologies in urban power supply, energy supply, heating, and building energy conservation (such as the utilization of distributed solar energy in Turpan,[12] the utilization of wind energy and biomass energy in Xingtai City, and the utilization of green electricity in Mudanjiang City, etc) (Yang et al., 2017). Finally, the management system and policy mechanism that adapt to the development of new energy in cities are established to realize the efficient treatment of environmental pollution.

4.2. Discussion for the mediation effect results

NEDC can significantly reduce environmental pollution through technological innovation effect, industrial structure effect, and resource allocation effect respectively.

The technological innovation effect of NEDC is mainly caused by new energy technology progress, which brings good energy-saving and emission reduction effects. On the one hand, the implementation of the pilot policy will tighten the environmental constraints of pilot cities, which will accelerate the R&D, innovation, and application of enterprises in production, environmental protection, and energy-saving technology (Sezen and Çankaya, 2013; Cheng et al., 2014; Lin and Zhu, 2019). On the other hand, to achieve the emission reduction requirements of pilot policies, the technological progress brought by NEDC is conducive to the improvement of pollution prevention and control level, including the ability to reduce pollutant emissions from the source to the entire production process. In particular, the application of clean technology for the effective treatment of pollution industries and important pollution sources, so as to better achieve the goal of reducing the environmental pollution (Driessen et al., 2013).

The structural effect of NEDC mainly lies in the transformation and upgrading of the industrial structure, which improves environmental quality. One possible reason is that unlike traditional industries that rely on capital and labor inputs, the pilot policy will guide urban industries to upgrade and adjust to industries with high technology content, high value-added, low pollution, and low energy consumption (Kemp and Arundel, 1998; McDowall et al., 2018). In the process, industries with high energy consumption and high pollution will be eliminated, and more supportive policies and financial support will be provided to industries with low

[12] For example, in order to implement the new energy demonstration city policy in Turpan, Xinjiang Uygur Autonomous Region, according to its own climate and geographical characteristics, solar photovoltaic energy, solar thermal energy, and other new energy technologies are comprehensively applied to urban building complexes. The survey data shows that the photovoltaic power generation of Turpan was 955 million kW·h in 2018, an increase of 13.1% over 2017. It is equivalent to the reduction of 5253.46 tons of SO$_2$ emissions, 2062.8 tons of dust, 1547.1 tons of nitrogen oxides, and 844,400 tons of CO$_2$. Thus, NEDC can effectively replace fossil fuels, thereby reducing pollutant emissions.

Table 9
Counterfactual analysis.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	$\ln SO_2$	lnWATER	$\ln SO_2$	lnWATER	$\ln SO_2$	lnWATER	$\ln SO_2$	lnWATER	$\ln SO_2$	lnWATER
lnHUM	−0.0811	−0.1539**	−0.0806	−0.1546**	−0.0806	−0.1550**	−0.0807	−0.1550**	−0.0809	−0.1549**
	(0.0730)	(0.0665)	(0.0730)	(0.0665)	(0.0730)	(0.0665)	(0.0730)	(0.0665)	(0.0729)	(0.0665)
lnPELE	0.1080***	0.0940***	0.1087***	0.0942***	0.1093***	0.0947***	0.1081***	0.0951***	0.1068***	0.0943***
	(0.0282)	(0.0257)	(0.0282)	(0.0257)	(0.0282)	(0.0257)	(0.0282)	(0.0257)	(0.0282)	(0.0257)
lnPGDP	−0.0210	−0.0165	−0.0208	−0.0165	−0.0209	−0.0172	−0.0207	−0.0177	−0.0199	−0.0180
	(0.0415)	(0.0378)	(0.0415)	(0.0378)	(0.0415)	(0.0378)	(0.0415)	(0.0378)	(0.0415)	(0.0378)
lnOPEN	0.0026	0.0069	0.0025	0.0068	0.0024	0.0068	0.0026	0.0068	0.0028	0.0069
	(0.0206)	(0.0188)	(0.0206)	(0.0188)	(0.0206)	(0.0188)	(0.0206)	(0.0188)	(0.0206)	(0.0188)
lnPOP	−0.0090	0.2509*	−0.0156	0.2472*	−0.0217	0.2430*	−0.0105	0.2437*	−0.0021	0.2510*
	(0.1605)	(0.1463)	(0.1606)	(0.1464)	(0.1608)	(0.1465)	(0.1607)	(0.1465)	(0.1606)	(0.1464)
NEDC2009	−0.0173	0.0434								
	(0.0365)	(0.0333)								
NEDC2010			0.0049	0.0458						
			(0.0350)	(0.0319)						
NEDC2011					0.0195	0.0497				
					(0.0345)	(0.0315)				
NEDC2012							−0.0088	0.0513		
							(0.0350)	(0.0319)		
NEDC2013									−0.0364	0.0371
									(0.0366)	(0.0334)
Constant	3.3569***	1.9895**	3.3878***	2.0097**	3.4207***	2.0376**	3.3618***	2.0359**	3.3130***	2.0006**
	(1.0650)	(0.9708)	(1.0656)	(0.9712)	(1.0664)	(0.9720)	(1.0663)	(0.9718)	(1.0659)	(0.9718)
Year effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3243	3243	3243	3243	3243	3243	3243	3243	3243	3243
R-squared	0.258	0.099	0.258	0.099	0.258	0.100	0.258	0.100	0.259	0.099

Note: “ln” in the table denotes the logarithmic form of the variables. ***, **, and * indicate significance at 1%, 5%, and10% levels, respectively. Standard error statistics are in parentheses.

energy consumption and low pollution. This will further foster and strengthen strategic emerging industries such as energy conservation, environmental protection, and new energy materials, establish a new energy industry system featuring low pollution and low emissions, and ultimately reduce environmental pollution.

NEDC can reduce environmental pollution through resource allocation effect. In the implementation process of the pilot policy, new energy technology has been widely used in urban transportation, construction, and materials, realizing the low-energy operation of urban logistics, information flow and traffic flow, ultimately reducing the use of traditional fossil energy in production and life, and improving the efficiency of resource allocation (Lou, 2014a). At the same time, the pilot policy will also have crowding-out effect on the three high-tech enterprises (high pollution, high emissions, high energy consumption) (Li et al., 2019). It forces the polluting enterprises to eliminate the backward production capacity in time, transform and upgrade the energy structure (Jordaan et al., 2017), and reduce the distortion of energy structure, optimize the resource allocation of polluting enterprises, and then improve energy efficiency. Also, the pilot policy encourages the continuous flow of factor resources to enterprises with high efficiency and low energy consumption technology (Wang et al., 2020), so that enterprises with high energy efficiency can reasonably allocate enough elements to achieve the purpose of reducing pollution.

4.3. Discussion for the results of city size heterogeneity

On the whole, as the city size continues to expand, NEDC’s inhibitory effect on environmental pollution has gradually increased. We can explain the reasons for the following aspects. First of all, from the perspective of human capital, smaller cities generally have a lower level of economic development, with a serious loss of local talents and fewer talents in the field of new energy (Hong et al., 2020). For larger cities, the level of economic development is higher, and there are more talents in the field of new energy, which provides technical support for the actual implementation of pilot cities and is more conducive to the implementation of pilot policies (Satterthwaite,1997; Duranton and Puga, 2003). Also, compared with smaller cities, larger cities have deeper financial resources and greater support for pilot policies, so they play a more significant role in environmental pollution control. Second, there is a relatively large space for the agglomeration of population and economic activities in big cities (Huang et al., 2013, Wang et al., 2015; Zhu et al., 2020). The implementation of pilot policies is conducive to the formation of agglomeration effects of new energy industries, making energy use more efficient and improving environmental pollution more obvious (Brown and Southworth, 2008; Oliveira et al., 2015; Sun et al., 2020). Finally, with the continuous expansion of the size of the city, residents’ demand for a green environment is increasing, residents’ awareness of environmental protection and public demands are enhanced, and they prefer more green products and services (Ek and Söderholm, 2010; Guo et al., 2018). Given residents’ growing public demands, local governments will also intensify the implementation of pilot policies to provide residents with more public products of new energy and promote the development of new energy technologies in cities (Liao et al., 2018). The environmental governance itself also has economies of scale. The expansion of urban scale will significantly reduce the average cost of environmental governance and improve the regional environmental quality to a certain extent (Dasgupta et al., 2002; Liu et al., 2020).

4.4. Discuss for the results of urban regional heterogeneity

Table 6 shows that the inhibition effect of NEDC on environmental pollution is gradually enhanced from the west to the east. It is not difficult to understand that the eastern and central regions have higher economic levels, relatively early industrial start-up periods and a more mature industrial structure (Wu et al., 2019; Hao et al., 2020). Also, the eastern and central regions have a high level of urbanization and relatively complete infrastructure related to the policy of new energy demonstration cities, which provides a material guarantee for the reduction of environmental pollution (Zhu et al., 2020). At the same time, the high urbanization level also makes the supporting resources and industries related to new energy agglomeration in the eastern and central regions, which is conducive to the better implementation of pilot policy to reduce pollution (Shen and Peng, 2020). After the 18th National Congress of the Party, the model of economic development has gradually changed, and the evaluation index of political achievements has mainly shifted from the competition for GDP to the coordinated development of economy green. The eastern and central regions have enough capital to invest in environmental protection and industrial upgrading to pursue long-term economic benefits to have a strong inhibitory effect on environmental pollution. However, as an underdeveloped region in China, the western regions is restricted by ecological environment carrying capacity, climatic conditions, geographical conditions, and other factors, and there is a big gap in technology, human capital, and capital allocation (Liu et al., 2020). Thus, the role of the NEDC is limited. Finally, the pollution reduction effect of the NEDC in the western region is less than that in the eastern and central regions.

5. Conclusion and policy recommendations

Since China first proposed NEDC in 2012, the rapid development of NEDC has had increasingly significant impacts on the economy, structure, and technology, which has further affected environmental pollution. In this regard, this paper uses the balanced panel data of 271 cities in China from 2005 to 2016 and uses the DID model and the mediation effect model to analyze the effect and mechanism of the NEDC on environmental pollution. On this basis, the heterogeneity of the NEDC on urban environmental pollution is explored. The main findings can be summarized as follows. First, the DID model shows that the implementation of the NEDC can significantly reduce environmental pollution. This conclusion is still valid after endogenous problems and robustness tests are eliminated. Second, the intermediation effect model shows that the NEDC reduces environmental pollution through technological innovation effect, structure effect, and resource allocation effect. The effect of technological innovation is the strongest, followed by the effect of resource allocation and the industrial structural effect, respectively. Finally, the heterogeneity analysis shows that the treatment effect of the NEDC on environmental pollution is significant in eastern and central regions and medium-sized cities. The conclusion of this paper reasonably promotes the construction of demonstration cities and the development of the city with a clean, low-carbon, and comfortable life. On the basis of the above conclusions, this paper puts forward the following policy recommendations:

(1) The selection system of demonstration cities should be further improved by government departments. Through the construction of additional scientific evaluation indicators and the introduction of relevant regulations to strengthen the supervision of the construction quality of demonstration cities, the construction quality of demonstration cities is ultimately improved. At the same time, the promotion of NEDC should be hastened. Cities that have not set up pilot cities should be encouraged to learn from the successful experience of establishing these new cities. The location conditions and existing economic characteristics of these cities should be taken into consideration in the construction of a unique energy system. The number of pilot cities should be increased. Finally, these cities should effectively play the role of demonstration cities in the treatment of environmental pollution.
(2) Policymakers should actively explore the path of diversified environmental governance in pilot cities. Policymakers should continue to adjust and improve the industrial structure of the city. Moreover, they should take energy technology innovation as the guide and accelerate the transformation and upgrading of the production structure of the company. Policymakers should also take the lead to realize the coordinated progress of the energy industry and green development. A pilot exploration of the follow-up large-scale construction of model cities should also be conducted. Besides, policymakers should play the role of a public service provider. It should focus on building an innovative R&D platform and provide an excellent R&D environment for scientific research and innovation. Such platforms can strengthen the training of professionals. Excellent R&D talents from universities and scientific research institutes should also be combined to find human capital support for the R&D and innovation of intelligent technology. Finally, policymakers also need to develop new materials industries vigorously, such as new energy materials and information materials, and encourage the flow and agglomeration of capital, labor, technology, and information to this field. The "catfish effect" should serve as a guide in the optimization of the resource allocation of polluting industries and enterprises, the improvement of their resource utilization efficiency, and the reduction of pollutant emissions.
(3) Large-scale cities can alleviate and eliminate the reverse hindrance of urban disease to the expansion of urban scale by vigorously developing green technology, applying green technology to all aspects of production and life, and improving the efficiency of resource allocation. On the basis of maintaining the original advantages, small- and medium-sized cities should make full use of the dividends of the development of model cities. Moreover, they should give full play to their comparative advantages and apply and develop new energy projects that adapt to the characteristics of urban development. These decisions maximize the efficiency of urban environmental governance and operation. Also, the western region should learn from the advanced experience in the construction of the NEDC in the central and eastern regions. In combination with its actual conditions, the western region should also actively absorb advanced technology from the central and eastern regions to achieve the coordinated development of regional pollution control

behaviors and maximize the pollution reduction effect of the demonstration cities.

(4) Although the above research conclusions are based on China, they also have reference significance for other developing countries in the world (Vietnam, India, Thailand, Myanmar, etc.). For those developing countries in the period of rapid economic development, how to coordinate economic development and ecological protection is a universal and necessary problem.[13] Therefore, policymakers in developing countries can diversify their energy structure by implementing energy demonstration city policies, including biofuels, wind energy, solar energy, and biomass energy. In this way, developing countries can not only solve the problem of energy shortage by increasing the supply of new energy, but also reduce their dependence on fossil fuels and environmental pollution. At the same time, through the implementation of new energy demonstration city policies, relying on the existing technical level, researchers, universities, and scientific research institutions, the developing countries can vigorously develop practical and cheap new energy, improve the technical level of new energy, upgrade the traditional industrial structure, reduce resource misallocation, so as to achieve environmental and economic sustainable development. Besides, new energy demonstration city policies should first be carried out in cities with a large population or a more developed economy. In general, the larger or more economically developed cities have better institutional management, more adequate financial capital, and higher human capital level. This provides a good material basis for the implementation of pilot policies so that the effect of pilot policies can be maximized, such as Hanoi and Ho Chi Minh City in Vietnam, Rio DE Janeiro in Brazil, Mumbai, and New Delhi in India and Bangkok in Thailand in Myanmar, etc.

While the research has important theoretical and practical significance, this study still faces some limitations. First, the indicators for evaluating environmental pollution are not comprehensive. This article only uses gaseous and liquid pollutants, which may cause the research scope to be insufficient, because solid pollutants have not been included in the statistical scope of prefecture-level cities in China. Second, this study only focuses on the situation in China, whereas other countries are not included in the scope of this study. Such exclusion may lead to the lack of the universality of the empirical results. Finally, the relationship between geographical location and environmental pollution is not proven because of the limited research methods. Future studies should further explore the causal relationship among geographical location, NEDC, and environmental pollution.

CRediT authorship contribution statement

Xiaodong Yang: Conceptualization, Project administration, Formal analysis, Writing - review & editing, Data curation, Writing - original draft. **Jinning Zhang:** Writing - review & editing, Validation. **Siyu Ren:** Software, Visualization, Writing - original draft, Writing - review & editing, Formal analysis. **Qiying Ran:** Conceptualization, Methodology, Funding acquisition, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[13] For example, so far, 130 million people are facing power shortages in Southeast Asia. The surge in energy demand puts policymakers under great pressure (Apergis and Gangopadhyay, 2020). In order to combat energy poverty in Southeast Asia, policymakers have formulated a set of complex fossil fuel supply policies to find (long-term) alternative energy sources that balance demand and supply. However, the excessive use of fossil fuels also brings great pressure to the environment. Among them, Vietnam's fossil fuel power generation accounted for 61% of the total electricity supply in 2015 (Clark et al., 2020). And,Vietnam's energy demand increased by more than 10% annually during the period 2013–2019. (Do et al., 2020; Nong et al., 2020).

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