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Mix and match: Configuring different types of policy instruments to develop successful low carbon cities in China

Wenting Ma [a, b], Martin de Jong [b, c], Mark de Bruijne [a], Rui Mu [d, *]

[a] Department of Multi-Actor Systems, Faculty of Technology, Policy & Management, Delft University of Technology, Jaffalaan 5, 2628 BX, Delft, the Netherlands
[b] Rotterdam School of Management & Erasmus School of Law, Erasmus University Rotterdam, Burgemeester Oudlaan 50, 3062 PA, Rotterdam, the Netherlands
[c] Institute for Global Public Policy, Fudan University, Shanghai, 200433, China
[d] Faculty of Humanities and Social Sciences, Dalian University of Technology, Dalian, 116024, China

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ABSTRACT

Local governments in China actively promote low carbon city pilots to respond to the challenges of climate change mentioned in the Sustainable Development Goals, including building sustainable cities and communities, and taking climate action. However, relatively little is known about the actual implementation of programs to achieve sustainable cities, especially how combinations of policy instruments are deployed in the realisation of low carbon cities. First, this study contributes to the literature in policy studies by identifying how four types relevant to carbon city development, hierarchy, market, network and information based ones, can be combined in policy mixes and play out in the effective realisation of low carbon cities in other countries. Second, this framework is used to map the application of policy instruments in China's 35 low carbon pilot cities. This study uses fuzzy set qualitative comparative analysis to explore which configurations of policy instruments are in use and assesses their effects on low carbon city construction. It thus builds a bridge between theory on policy instruments, their combinations and low carbon city development. The presence of hierarchical policy instruments appears to be a necessary condition for low carbon city development and their use prevails. Market-based and network-based instruments complement hierarchical instruments but do not suffice in themselves. Applying hierarchical instruments and market-based instruments together tends to hamper the effect of network instruments and information instruments, whereas network instruments appear to be interchangeable with information instruments. Network governance in China's low carbon city development is still comparatively underdeveloped.

1. Introduction

Climate change has become a serious global challenge which increasingly affects people's quality of life and work. According to an EU based Research Centre, China is still the world's largest CO_2 emitter with power generation and industrial combustion contributing most to its fossil CO_2 emissions (Crippa et al., 2019). In 2016, China's central government proposed the *Work Plan for the Control of Greenhouse Gas Emission during the 13*th *Five-Year Period* as its national policy for climate change (SC, 2016). Local climate action especially aims to be an effective response to Sustainable Development Goal 11 (sustainable cities and communities) and SDG 13 (climate action) (Griggs et al., 2013; Hák et al., 2016). In response to these policy goals, Chinese local governments have changed their policy orientation and adapted more sustainable development models under the eco-city and low carbon city labels (Dong et al., 2017; Fu and Zhang, 2017; Lu et al., 2020; Ma et al., 2020). Local governments are exploring new pathways to achieve more sustainable forms of industrial development (de Jong et al., 2018; Yu, 2014). Developing Low-Carbon Cities (LCC) is an urban development strategy that is frequently used by Chinese local governments to reduce fossil fuel and energy consumption and achieve a decarbonised mode of industrial development (Cheshmehzangi et al., 2018; De Jong et al., 2015).

Some scholars claim LCCs are an effective strategy to reduce

* Corresponding author.
E-mail address: ruimu@dlut.edu.cn (R. Mu).

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carbon emissions (Belloso, 2011; Rius Ulldemolins, 2014), which constitute a key element in the realisation of the SDGs (Gupta and Vegelin, 2016; Huang et al., 2017). However, other scholars claim that this popular city label is merely a tool that is employed by local governments to greenwash their doubtful industrial traces (de Jong, 2019; Ma et al., 2019; Schuetze and Chelleri, 2016). Scholars have conducted ample research on low carbon cities, such as low carbon economy (Bridge et al., 2013), low carbon tourism (Zhang, 2017), and examples such as Shenzhen International Low Carbon City (de Jong et al., 2013; Khanna et al., 2014; Zhan and de Jong, 2018). However, thus far little attention was paid to the policy instruments that have been adopted by local governments to implement low carbon city policies, and how effective these policy packages have been.

A variety of low carbon policy instruments such as carbon taxes and clean innovation have been adopted to reduce greenhouse gas emissions and build low carbon cities (Huang et al., 2016; Kammerlander et al., 2020). Some scholars claim that low carbon instruments are helpful to support low carbon governance (Wang and Chang, 2014). They believe that specific low carbon policy instruments can reduce carbon emissions (Ekins et al., 2017; Kammerlander et al., 2020; Nissinen et al., 2015). Specifically, low carbon instruments can be classified into different types. For example, regulation instruments include applying forced power to close enterprises with high energy consumption and emission of pollutants (Liu et al., 2017). Carbon trade policy, the use of financial subsidies, tax incentives and differential pricing measures can be considered market-based instruments (Henstra, 2016). Government policies targeting the disclosure of data about environmental pollution can be seen as information-based instruments, while measures to strengthen cooperation among organisations and thus promote environmental restoration are network-based ones. In order to take effect, however, combinations or mixes of such policy instruments are required.

Some scholars discuss the selection of policy tools, the application of individual policy tools, and the effects of individual policy tools in environmental governance and low-carbon city construction. Examples include the target responsibility system and carbon trading in low carbon cities (Khanna et al., 2014; Lo, 2014; Stead, 2018; Wang and Chang, 2014). Low carbon policy instruments can be packaged in different ways to reduce carbon emissions and deal with climate change (Ekins et al., 2017; Nissinen et al., 2015). The configurations and combinations of policy instruments can be expected to have an impact on urban low-carbon development (Filippini et al., 2014; Khan, 2013). However, the extant literature focuses on the application of a single type of policy instrument in the analysis of low carbon city development; little attention is paid on the effectiveness of combinations of policy instruments.

To address this knowledge gap, this article investigates *what low carbon policy instruments are selected and adopted by low carbon cities in China. What is the effectiveness of different combinations of low carbon instruments in terms of environmental sustainability?* To answer these questions, this study presents 35 of China's low carbon pilot cities as a research sample and applies a fuzzy set qualitative comparative analysis (fsQCA) to explore how low carbon policy instruments are packaged. It also assesses their relative effectiveness in promoting sustainable development.

Section 2 reviews key literature on low carbon city evaluation and categorises low carbon policy instruments. It presents a detailed explanation of low carbon instruments, including their functional characteristics and application mechanisms. Furthermore, this section proposes a framework for mapping low carbon policy instruments. This framework is used to collect data in the empirical part. A brief description of low carbon pilot cities in China is presented in Section 3. Research methodology, data collection and data processing strategies are explained in this section. Section 4 shows the results of the analysis in this study through fsQCA. It examines the relationship between the low carbon policy instrument configurations and the low carbon performance of low carbon cities. A sensitivity analysis is conducted to assess the impact of other factors. Section 5 presents a discussion of the research findings and compares these with experiences in other countries. Section 6 provides the conclusions of this study.

2. Literature review on low carbon city evaluation and low carbon policy instruments

2.1. Literature on low carbon city evaluation

When scholars discuss low-carbon cities and identify their special features, they mention low carbon production, low carbon consumption, low carbon energy use and low carbon technologies as vital elements for assessments (Wu et al., 2016; Zhang, 2018). These elements are influenced by different policies. These in turn may be influenced by macro aspects such as level of urban economic development, city size, energy mix, quality of urban infrastructures, mobility patterns, resource consumption, adoption of environmental policies (Jia et al., 2012; Tan et al., 2017) and energy consumption transportation and buildings (Huang et al., 2012; Zheng, 2012).

For evaluation purposes, Tan et al. (2017) suggest using a comprehensive method based on a weighted sum model to evaluate policy effectiveness in low carbon cities, while others use specific indicators to assess low carbon levels, such as carbon emission efficiency (Zeng et al., 2019) and CO_2 equivalents (Fan et al., 2011). Many scholars study the performance of low-carbon cities by developing an evaluation index of low-carbon cities (Wu et al., 2016). AHP (Analytic Hierarchy Process) is a widely adopted method to develop low-carbon index systems (Duan et al., 2016). Some cities were selected to test the indicator system, such as Lanzhou and Dalian (Duan et al., 2016; Zhang et al., 2012). In addition, some scholars established a three-layer low-carbon city evaluation index system to calculate low carbon scores (Yang et al., 2011; Zhou et al., 2015). In all of these studies, single case studies are used as a research method to assess the performance of low carbon cities. Multiple case study analysis and large-sample assessments of the performance of low carbon cities are rare.

2.2. Literature on low carbon policy instruments

Fig. 1 shows the literature review process that was undertaken to develop a low carbon instrument framework for this study. A keyword search was conducted to examine core journals in urban planning, environmental science, public governance and other relevant disciplines from the Scopus platform and the downloaded database. Google Scholar and Web of Science were also checked as complementary resources. The keywords used in the literature research include environmental policy instruments, low carbon instruments, hierarchical instruments, authority, regulations, fiscal instruments, environmental information disclosure and network governance, etc. Irrelevant literature was eliminated by reading the title, keywords, and abstract after which the remainder of the documents were used for in-depth study. Especially influential and frequently cited articles were Cheshmehzangi et al. (2018), Wang (2014), Lo (2014), Safarzadeh et al. (2020), Napp et al. (2014), Henstra (2016), Grubb et al. (2020), Blazquez et al. (2018), Nissinen et al. (2015) and Böcher (2012).

The result of the above procedure is a categorisation of low carbon instruments into hierarchy-based, market-based, network-based instruments and information-based instruments. Within

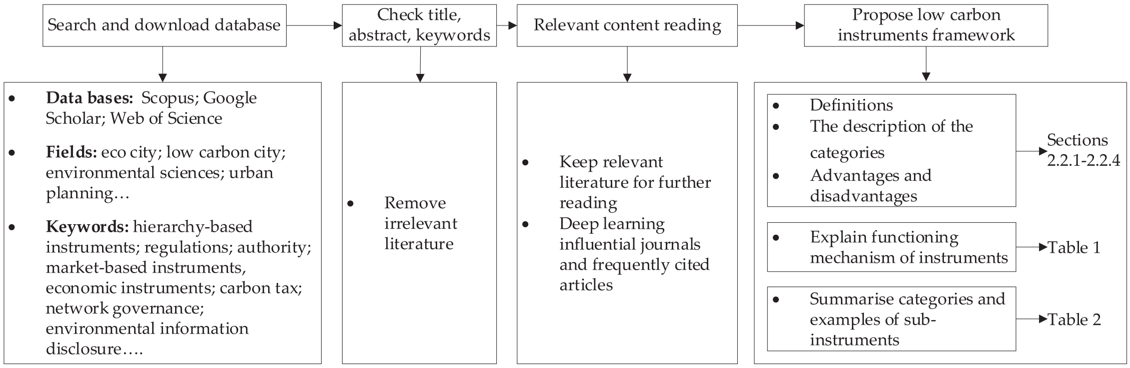

Fig. 1. Literature review process for identifying classification and listing low carbon instruments.

the four classes of policy instruments for low carbon city development 16 instruments were identified. The resulting classification is described in Table 1 and includes a description of the different government roles, resources and incentives in use and the diversity in relationships underlying these instrument classes. Specific examples of the different types of low carbon policy instruments can be found in Table 2. The definitions, characteristics, merits and disadvantages of the identified classes of instruments are discussed in more detail in sections 2.2.1 to 2.2.4.

2.2.1. Hierarchy-based instruments

Hierarchy-based policy instruments (HBIs) are conventional top-down policies applied by governments. Target groups have to follow requirements and reach goals set by government (Howlett et al., 2009; Peters, 2013). The hierarchy-based instruments are specified in laws or regulations and provide governments with legal and administrative powers (Howlett et al., 2009; Wang and Chang, 2014) to develop and enforce policies which seek to restrain or specify certain behaviour (i.e. cap of emissions (standards), or requirement of use of specific technology standards for production) (Liu and Qin, 2016).

Hierarchical governance is the most robust and influential form of external governance (Knill and Tosun, 2009). The application of hierarchical methods, however, forces government to incur higher administrative costs to cope with conflicts and resistance (Peters, 2013). The effectiveness of the instruments are very much dependant on monitoring and sanctioning of the performance of target groups. In case of violation, target groups can be punished. Hierarchical instruments include laws and regulations, target responsibility and supervision and oversight systems. These regulatory instruments are widely applied in the energy, industry restructuring and economic domains. Hierarchy-based instruments and their related administrative measures continue to be favored policy instruments by local Chinese governments in the pursuit of the development of low carbon cities (Khanna et al., 2014; Liu and Qin, 2016).

Some scholars believe that hierarchy-based instruments such as regulation are an efficient response to the environmental crisis (Blazquez et al., 2018) and provides government with a powerful tool to implement low carbon cities and successfully reduce carbon emissions (Wang and Chang, 2014). The centralised and top-down character would allow for improved cooperation and collaboration among different policies and government departments (Peters, 2013). Compared with economic instruments, such as subsidies or tax incentives, regulations are more prescriptive (Park, 2015). Critics claim that top-down regulation and policies are too rigid, hierarchical control is often inflexible which inhibits innovation, produces economic inefficiency and so actually hinders rather than stimulates the development of a low carbon economy (Blazquez et al., 2018; Song and Lu, 2009; Wang and Chang, 2014).

2.2.2. Market-based instruments

Market-based instruments (MBIs) apply economic or financial measures to reduce or eliminate negative externalities from pollution and promote clean production processes (Stavins, 2003). Many national governments, including those of Brazil and South

Table 1
Categorisation of different classes of low carbon policy instruments.

	Incentive	Government role underlying use of policy instruments	Relationship between government and target groups	Type of resources in use
Hierarchy-based instruments	Performance measurement; Punishment and reward	Policy goal formulation and subsequent monitoring and oversight	Vertical: Top-down Government: commander Other actors: implementer	Administration power; Political capital;
Market-based instruments	Competition and price	Facilitation and regulation of markets	Vertical; Government: instruments provider Other actors: receiving party of instruments	Economic resource
Network-based instruments	Resource interdependency	Facilitation and coordination of resources in policy networks	Horizontal; Government: facilitator, organiser and coordinator Other actors: participants The network distance between the target group and the government is different.	Develop and apply organisation resource
Information-based instruments	Learning	Knowledge sharing via communication	Horizontal; Government: information provider Other actors: information consumers Information instruments can also be interactive.	Knowledge

Table 2
Low carbon policy instruments framework.

	Different types of low carbon policy instruments	Description	Examples	References
Hierarchy-based instruments (X1)				
1	Regulations	A regulatory policy that is imposed by a local government on the policy target population and that involves sanction measures if noncompliance is found.	e.g. environmental laws and regulations e.g. emission permits e.g. industrial and technology standards e.g. energy efficiency standards	(Jenkins, 2014; Liu et al., 2017; Wang and Chang, 2014)
2	Target responsibility system	The target responsibility system sets targets for different levels of governments and departments, to reduce major pollutants, decompose the targets for pollutant emission control, and links the performance of pollutant emission control on specific indicators to leaders' career promotion (Zhang and Hao, 2020).	e.g. strengthen accountability	(Lo, 2014; Zhang et al., 2010)
3	Supervision and oversight	Higher-level governments adopt measures to supervise local companies and to promote policy implementation.	e.g. strengthen supervision	Zhang et al., (2010)
Market-based instruments (X2)				
4	Tax incentives	Applying tax mechanisms such as 'deferrals, deductions, credits, exclusions or preferred rates, contingent on some act' (Howlett et al., 2009) to achieve energy conservation and reduce emissions. Tax incentives include positive and negative incentives.	e.g. reduce new energy vehicle purchase tax e.g. financial punishment	(Fankhauser et al., S., 2010; Snyder, 2015; Wang and Chang, 2014)
5	Pricing incentives	Applying pricing mechanisms to achieve energy conservation and reduce emissions.	e.g. low electricity price e.g. fuel prices	Bongardt et al. (2010)
6	Financing preferential policies	Clean producers or projects can obtain bank loans at an interest rate below the market rate.	e.g. easy loans from state-owned banks e.g. green loans (clean enterprises obtain more favorable loan interest rates and loan policies)	Huang et al. (2016)
7	Competition-based government sponsorship	Governments distribute the general revenues to provide grants, subsidies and adopt procurement behaviours to make the producers offer a clean good, service or behaviour.	e.g. government grants e.g. government subsidies e.g. government procurement	(Laes et al., 2018; Wang et al., 2015)
8	Carbon trade policy	The use of carbon trade policy as an instrument for achieving significant reductions in carbon emissions (Dong and Whalley, 2010).	e.g. tradeable emissions allowances e.g. establish a market mechanism for carbon emissions	(Snyder, 2015; Tyler and Cloete, 2015)
Network-based Instruments (X3)				
9	Ad hoc taskforce	Organising professional working groups to promote departmental coordination and strengthening departmental linkages.	e.g. establish a special leading group and work promotion group e.g. establish a special joint meeting system for promoting work	(Bulkeley and Kern, 2006; Khanna et al., 2014; Nakamura and Hayashi, 2013; Stelling, 2014)
10	Public-public partnerships	Cooperation between two or more public or nongovernmental organisations which provides public services and activities.	e.g. participation from state-owned enterprises, power companies, coal and mining companies e.g. participation from NGOs	(Cheshmehzangi et al., 2018; Liu et al., 2015; Wang and Chang, 2014)
11	Public-private partnerships	Cooperative institutional arrangements between public and private sector actors to obtain a wide interest (Hodge and Greve, 2007).	e.g. encourage private participation, including individuals and private firms	(Britton and Woodman, 2014; Hodge and Greve, 2007; Khanna et al., 2014; Roy et al., 2013)
12	Voluntary participation	Government measures which seek voluntary participation of organisations to serve the goal of low carbon building.	e.g. voluntary measures e.g. family and community	(Howlett et al., 2009; Moloney et al., 2010; Oikonomou et al., 2010)
Information-based Instruments (X4)				
13	Public information campaigns	Information can be communicated and released by the government through public service advertising (Howlett et al., 2009).	e.g. publish low carbon information through news media, etc. e.g. advertising measures e.g. low carbon labelling e.g. public information diffusion	(Oikonomou et al., 2010; Wang and Chang, 2014)
14	Exhortation and education	Government adopts efforts to influence the preferences and actions of societal members with the hope that behaviour will spontaneously change in a desired manner (Stanbury and Fulton, 1984).	e.g. advocate and encourage low-carbon life e.g. public education e.g. conduct and organise low carbon activities e.g. government exhortation or suasion	(Moloney et al., 2010; Shen et al., 2018)
15	Public consultation	Government use of temporary bodies to gather information and advice about an issue (Howlett et al., 2009).	e.g. the use of outside experts e.g. advisory committees e.g. consultation of citizens	Howlett et al., (2009)
16	Open government data	Releasing and disclosure of public sector information as open data to all kinds of actors, ranging from companies to non-governmental organisations, from developers to simple citizens (Vetrò et al., 2016).	e.g. establish an environmental information sharing mechanism and platform e.g. environmental information disclosure	(Wu et al., 2011; Zhang et al., 2010)

Africa, apply market-based instruments, such as emission trading and carbon taxes (Milhorance et al., 2020; Tyler and Cloete, 2015). The EU also favors market-based instruments to tackle climate change problems (Laes et al., 2018). MBIs influence polluters via economic signals and are based on competition and the price mechanism (Blazquez et al., 2018). In the application of this family of instruments, governments use markets, prices, tax incentives, green loans and other supportive policies to encourage enterprises to implement environmentally desirable behaviour (Knill and Tosun, 2009; Snyder, 2015). Governments can use tax revenues from polluting enterprises to finance sustainable policies. Besides, other financial instruments (taxes, fines) can also be used to weaken undesirable behaviour. Normally, market-based instruments include tax incentives, pricing incentives, financing of preferential policies, competition-based government sponsorships and carbon trade policies (Blazquez et al., 2018; Park, 2015; Wang and Chang, 2014). Applying MBIs also requires some forms of regulatory intervention (Finon, 2019). Like the hierarchical instrument family, the financial instrument family ensures a vertical pattern in the relationship between government and industries. MBIs have lower administrative costs and allow for more flexibility over traditional hierarchical command and control approaches (Baeumler et al., 2012). MBIs allow different firms to make different adjustments according to their business structures (Song and Lu, 2009). However, some scholars argue that market-based policy tools drain public financial resources, while others argue that carbon trading encourages rather than decreases pollution (Blazquez et al., 2018). At the same time, some subsidies are economically inefficient and stimulate unsound environmental practices, such as overconsumption of energy (Blazquez et al., 2018).

2.2.3. Network-based instruments

Applying network-based instruments (NBIs) implies looser forms of governance, strengthening the participation from public and private actors such as enterprises, NGOs, voluntary organisations and citizens in policy making, and obtaining support from different stakeholders (Khan, 2013). Because of its legitimacy and implementation capacity, network governance has emerged as a new and increasingly popular governance model to respond to the challenges of climate change (Khan, 2013; Nochta and Skelcher, 2020). The relationship between government and other actors is more even-handed. In pursuit of a low carbon cities, (local) governments play the role of network facilitator, organiser and coordinator (Khan, 2013). However, target groups are legitimate and important participants in these networks. Cooperation among actors in the network is based on mutual resource dependence (Lu, de Jong, & ten Heuvelhof, 2018). Communication and cooperation within departments can promote project implementation (Peters, 2013). Network governance has sometimes been accompanied by environmental information exchange, the introduction of market forces and participation of communities and voluntary organisations (Nochta and Skelcher, 2020). An explicit role of allocation, as well as effective coordination of policy activities within the public departments and private actors are a necessity for any low carbon effort and a fundamental step for low carbon city development (Nochta and Skelcher, 2020). Governments also use authority to stimulate the development of network coordination (Tenbensel, 2018). Sweden is one of the countries where network governance for low carbon city transitions is successfully deployed (Khan, 2013). Network governance may provide an effective mode of urban governance in which the hierarchical effect is absent (Nochta and Skelcher, 2020). Some supporters believe that private participation in offering social and economic services offers more flexibility. Others state that involvement of voluntary organisations also promotes community spirit and social cohesion (Howlett et al., 2009). However, it also raises potential governance issues in terms of equity, efficiency and accountability (Shen, 2015). Financing arrangements and inefficient operations also cause administrative challenges to quangos and voluntary associations.

2.2.4. Information-based instruments

Information-based instruments are based on knowledge transfer and public learning (Büchs et al., 2018; Esmark, 2009). Governments release information aimed at persuading and influencing people's preferences and actions (Howlett et al., 2009). For example, local governments widely advocate low-carbon life and low-carbon traveling to the public (Büchs et al., 2018). Public information campaigns, exhortation and environmental information disclosure are normally adopted in low carbon governance (Nakamura and Hayashi, 2013; Palm and Lantz, 2020; Stelling, 2014). Information-based instruments (IBIs) are considered the least coercive of all policy instruments and require low levels of hierarchical control (Carley, 2011). Instead, there is an almost horizontal relationship between the (local) government and other actors. Governments function as hubs of information which in turn are provided to other actors; the other actors receive and take in this information. Information instruments can also be interactive, with two-way communication and information flowing (Bemelmans-Videc et al., 1998). From the perspective of resource application, information tools are considered relatively efficient (Howlett et al., 2009). Information diffusion and sharing improve project coordination (Peters, 2013). Information-based instruments put pressure on polluters to improve their environmental performance (Napp et al., 2014). IBIs are more accurate in influencing specific target groups and obtaining particular responses (Palm and Lantz, 2020). At the same time, different ways of presenting information will also affect the public's understanding and thus effective policy implementation, such as providing general or personalised information (Büchs et al., 2018). The disadvantage of information-based governance is that information disclosure may not change policy and behaviour automatically or immediately (Tyler and Cloete, 2015). Environmental information tools usually have the characteristics of a short implementation cycle and low effect (Laes et al., 2018). Besides, some organisations may be unwilling to share information due to privacy and safety motives (Peters, 2013).

2.2.5. A low carbon policy instrument framework

Table 2 provides a more detailed overview of the various types of policy instruments used in the various classes of low carbon policy and shows to what different instrument categories they belong. This study modifies certain elements in the low carbon policy instruments framework and adds some missing ones based on a through reading of the literature on policy instruments and policy packages, climate change, energy and environmental governance (Ekins et al., 2017; Henstra, 2016; Milhorance et al., 2020; Nissinen et al., 2015; Wang and Chang, 2014; Zhou et al., 2018). The framework will be used when collecting data and analysing the empirical evidence in Section 4.

3. Method

3.1. Low carbon pilot cities in China

In 2008, the Ministry of Housing and Urban-Rural Development (MOHURD) and World Wildlife Fund (WWF) jointly launched "Low Carbon City" pilots in Shanghai and Baoding. In 2010, National Development and Reform Commission (NDRC) issued the "*Notice on Launching Pilot Work in Low-carbon Provinces and Low-carbon Cities*", and identified Guangdong, Liaoning, Hubei, Shaanxi, Yunnan as pilot provinces to develop low carbon cities. Tianjin,

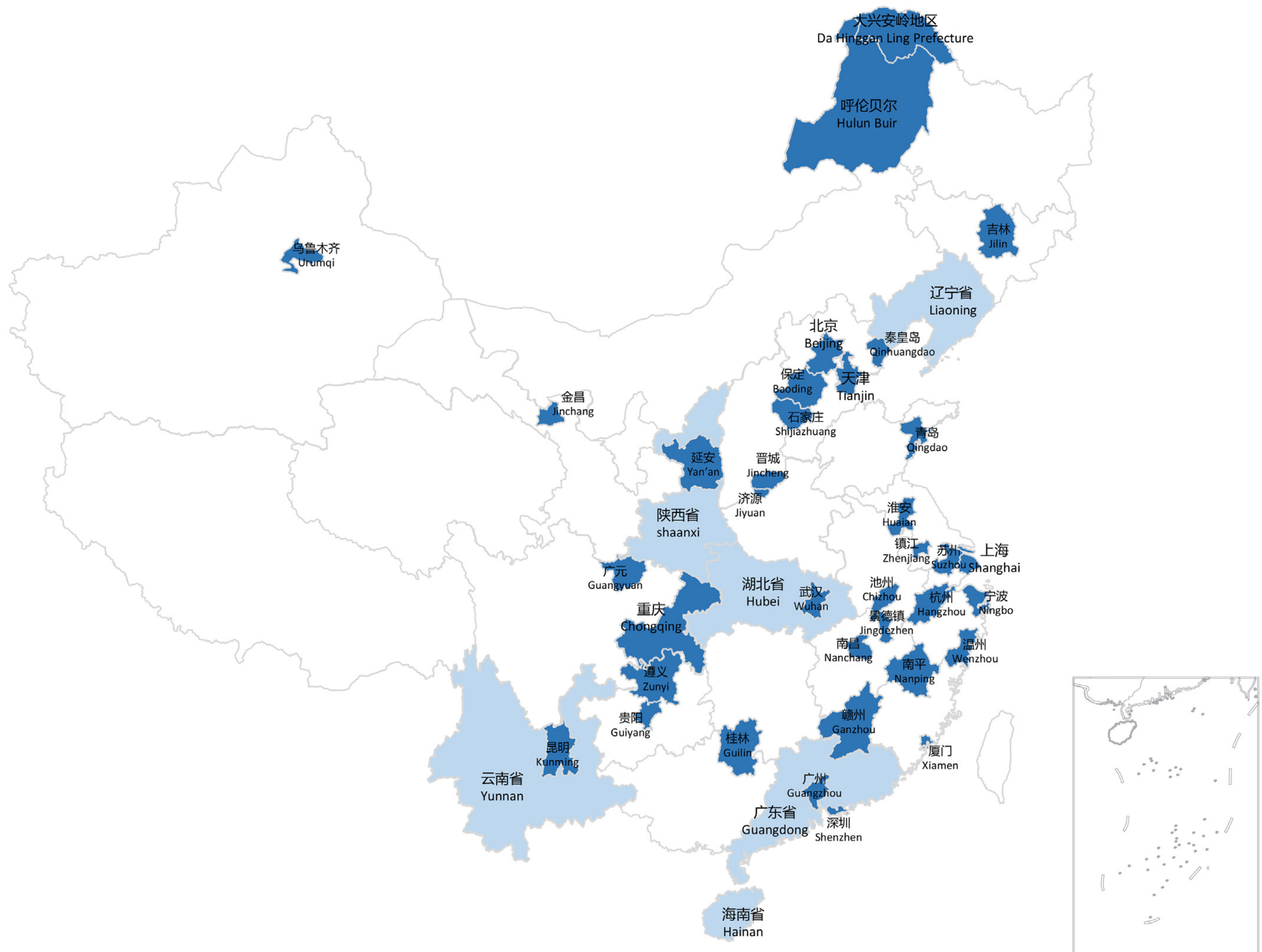

Fig. 2. Distribution of 1st and 2nd batches of Chinese low carbon provinces and cities.

Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding were identified as the first batch of eight national low carbon city pilots in China (Appendix A, Table A1). Subsequently, in 2013 NDRC proposed 28 cities and one province as a second batch, and 45 cities as a third batch in 2017. Anno 2020, China has 81 low carbon pilot cities and six low carbon pilot provinces in total (NDRC) (Appendix A, Table A1).

The first and second batches of low carbon cities announced in 2010 and 2013 of which implementation can now be studied and selected for this study. Since the information on the low carbon effectiveness of Huaian could not be obtained, this city was discarded. Consequently, 35 low carbon pilot cities were selected as research sample, representing the various types of cities in China, including megacities, medium and small-sized cities of all tiers (4 "First-tier" cities, 6 "New First-tier[1]" cities, 8 "Second-tier" cities, 6 "Third-tier" cities and 5 "Fourth-tier" cities, 5 "Fifth tier cities" and 1 "sub-prefectural city[2]") (YICAI, 2020). Fig. 2 shows the location of the sample of low carbon cities. The cities are located in different provinces, ranging from the eastern shore to inland areas. Key social, economic and environmental indicators for each city (Table 3) were collected from the 2018 Statistical yearbook of each city, and the countries' China City Statistical Yearbook 2018 (NBoS, 2018) and supplemented by data from the Air Quality Index Ranking (Tianqi, 2020).

3.2. Method: fuzzy-set qualitative comparative analysis (fsQCA)

This study aims to explore the causal relationship between different types of low carbon policy instrument configurations being applied in China's low carbon cities and their effectiveness in terms of sustainability performance. The Qualitative Comparative Analysis method (QCA) proposed by Ragin (2000) is used. The method claims the outcome (dependent variable Y) is the result of the combined effects of several relevant factors (multiple independent variables X1, X2,...) (Mu et al., 2018), in our case different low carbon policies. The combination of factors is called a "configuration". The sample-size of 35 low carbon cities satisfies QCA's requirement for a small- to medium-sized sample set (Schneider and Wagemann, 2012).

Specific fsQCA was used to perform the fuzzy-set analysis. Two main indicators (consistency, coverage) were used to observe the fit between the fsQCA model and the empirical data (Schneider and

[1] New first-tier cities refer to cities that have developed at a high speed in recent years. Their development is weaker than the original first-tier cities, but stronger than second-tier cities.

[2] A sub-prefectural city is officially considered to be a county-level city.

Table 3
Key economic and social information of low carbon pilot cities (2018).

No.	Cities	Population (10^4 persons)	GDP per capita ('000 RMB)	Industrial structure (1/2/3 as GDP) (in %)	City level	Air quality rank (2020.08.05)
1	Beijing	2171	129.0	0/19/81	First-tier	208
2	Shanghai	2418	126.6	0/31/69	First-tier	158
3	Shenzhen	1253	183.5	0/41/59	First-tier	8
4	Guangzhou	1450	150.7	1/28/71	First-tier	41
5	Hangzhou	947	135.1	2/35/63	New first-tier	102
6	Chongqing	3075	63.7	7/44/49	New first-tier	139
7	Tianjin	1157	119.0	1/41/58	New first-tier	201
8	Suzhou	691	162.4	1/48/51	New first-tier	207
9	Wuhan	1089	123.8	3/44/53	New first-tier	181
10	Qingdao	929	119.4	4/41/55	New first-tier	47
11	Kunming	685	76.4	4/39/57	Second-tier	172
12	Ningbo	597	124	3/52/45	Second-tier	48
13	Xiamen	411	118	1/41/58	Second-tier	40
14	Shijiazhuang	1088	54.9	7/45/48	Second-tier	107
15	Nanchang	546	89	4/52/44	Second-tier	53
16	Wenzhou	825	65.9	2/40/58	Second-tier	52
17	Guiyang	480	74.5	4/39/57	Second-tier	114
18	Baoding	936	32.8	10/42/48	Second-tier	116
19	Zunyi	625	44.1	15/45/40	Third-tier	80
20	Guilin	534	52.0	6/34/60	Third-tier	26
21	Ganzhou	981	32.4	12/43/45	Third-tier	27
22	Urumqi	351	79.9	1/30/69	Third-tier	272
23	Qinhuangdao	313	52.4	6/35/59	Third-tier	126
24	Zhenjiang	319	126	4/49/47	Third-tier	178
25	Nanping	268	60.7	17/43/40	Fourth-tier	24
26	Jilin	415	55	10/36/54	Fourth-tier	78
27	Jingdezhen	167	50.7	1/45/54	Fourth-tier	89
28	Yan'an	226	69	9/59/32	Fourth-tier	204
29	Chizhou	162	52.3	9/50/41	Fourth-tier	94
30	Guangyuan	301	30.1	15/45/40	Fifth-tier	258
31	Hulun Buir	253	50	22/29/49	Fifth-tier	38
32	Jincheng	234	58	4/53/43	Fifth-tier	281
33	Jinchang	47	56.4	7/55/38	Fifth-tier	136
34	Da Hinggan Ling Prefecture	43.9	34.1	48/10/42	Fifth-tier	–
35	Jiyuan	73	87.6	3/65/32	–	198

Wagemann, 2012). Consistency explains the extent to which the empirical evidence confirms the assumed relations in the model (Schneider and Wagemann, 2012, p.141). Coverage shows how many cases are covered by the specific solution (a specific policy configuration). Both indicators have values between 0 and 1. The higher the value, the higher the reliability of the calculated results. QCA models are generally considered to yield high reliability outcomes if the value of the two indicators is above 0.5 (Mu et al., 2019).

3.3. Data collection and calibration

To identify what policy instruments are used in low carbon city pilots to reduce carbon emissions, city policy documents were reviewed. In the Chinese context, local government websites are traditionally regarded as one of the most important and authoritative sources of information of local city government policies.

As a first step, official municipal government websites where all policies are promulgated were visited and scanned for relevance to low carbon city development. All titles of policies and documents covering low carbon city development, such as (low carbon) plans, (industrial) development and production policies were subsequently downloaded. A variety of policy documents including laws, regulations, notices, and measures related to low carbon city construction provided a detailed descriptions of low carbon policies and measures between 2010 and 2019 referring to the requirements of low carbon development announced by China's National Development and Reform Commission in 2010 (NDRC, 2010). Data was collected from the year the city was first identified as a low-carbon city pilot until 2019 as this was the last year of which full data could be obtained for the various indicators.

As a second step in the data collection, the low carbon instrument framework as described in Section 2.2 was used to identify the different types of low carbon policy instruments in each low carbon pilot city. Specifically, the full text of policies were screened and the descriptions of the application of low carbon instruments for each policy on each city in each policy were subsequently recorded. For example, in 2018, Beijing issued the '*Notice on adjusting and improving the fiscal subsidy for the promotion and application of new energy vehicles*'. In this policy, Beijing claimed to provide financial subsidies to encourage the purchase and use of more sustainable vehicles. Furthermore, Beijing set up a hotline and reporting platform to supervise the development, safe operation and subsidising of new sustainable vehicles. Therefore, Beijing's policy to stimulate sustainable vehicles was recorded as being composed of the instruments 'supervision and oversight' and 'competition-based government sponsorship'. All documents were checked applying the principle that as soon as the instrument is mentioned, it is recorded as "1" - no matter how many times it is subsequently mentioned. The results of this step and the list of

Table 4
Description of variable calibration.

Variable	Set membership			
	0	0.33	0.67	1
Y (low carbon effectiveness)	If LCC score is 60–69	If LCC score is 70–79	If LCC score is 80–89	If LCC score is greater than and equal to 90.
X1 (Hierarchy-based instruments)	There are no hierarchy-based instruments.	Only one type of hierarchy-based instrument was adopted.	Two types of hierarchy-based instruments were adopted.	Three types of hierarchy-based instruments were adopted.
X2 (Market-based instruments)	No or only one market-based instrument has been adopted.	Two types of market-based instruments were adopted.	Three or four types of market-based instruments were adopted.	Five types of market-based instruments were adopted.
X3 (Network-based instruments)	No or only one network-based instrument has been adopted.	Two types of network-based instruments were adopted.	Three types of network-based instruments were adopted.	Four types of network-based instruments were adopted.
X4 (Information-based instruments)	No or only one information-based instrument has been adopted.	Two types of information-based instruments were adopted.	Three types of information-based instruments were adopted.	Four types of information-based instruments were adopted.

policy instruments are shown in Table A4 (Appendix A).

In 2019, the Institute of Urban Development and the Environment of the Chinese Academy of Social Sciences (CASS) released the '*Report on the Evaluation of China's Green Low Carbon City*'. Each city was evaluated based on the result of 15 macro level low carbon city assessment indicators (among them low carbon industries, low carbon energies, low-carbon lifestyle, resource and environment, low-carbon policy and innovation). The specific evaluation index system and scoring rules for low-carbon cities are shown in Table A2 (Appendix A). Since this method is reliability and scientific soundness, the CASS ratings were adopted as indicator of the effectiveness of the low carbon city policy instrument configuration study. The scores of each city are shown in the right column in Table A4 (Appendix A).

In the calibration process, each instrument item is assigned a score to indicate its performance. The value of the variable in the fuzzy set is between 0 and 1. In order to express qualitative differences more accurately, four value-fuzzy sets were adopted to determine the value of the variable as 0 and 0.33, 0.67 and 1. Correspondingly, both the condition variables and the outcome variables were divided into four groups. The CASS evaluation rates low-carbon cities on a five-point scale, including scores of 90 points or above, 80 to 89 points, 70 to 79 points, 60–69 points, and below 60 points. Since none of the cities scored below 60, the low-carbon cities could be divided into four groups according to their low carbon results in the CASS evaluation. In calibrating the conditions, this study focused particularly on the application of diverse classes of sub-instruments by city governments (Yang et al., 2018). Multiple policy instruments that reinforce and complement each other improve policy implementation effectiveness (Bengston et al., 2004). The diversity of sub-instruments can be an indicator to assess the effectiveness of low carbon city development. Corresponding scores were assigned to each group both in conditions and outcome. The detailed description of the calibration of outcome and conditions is offered in Table 4. The results of the calibration are shown in Table A3 (Appendix A). The fsQCA 3.0 software is applied for data analysis and processing. Results are presented in Section 4.

4. Findings

4.1. Results

The goal of this study is to examine the use and relative effectiveness of the four categories of low carbon instruments discussed in Section 2 in terms of environmental performance. The intermediate solution in Table 5 presents the outcome of the calculations. A consistency requirement of 0.75 was selected (Schneider and Wagemann, 2012). More than 76.8% of the empirical result is consistent with the path term, meaning that the outcome (low carbon city construction) is normally present for the cases that display the produced paths. The coverage score for the entire solution pattern is quite high. Actually, 95.3% of the sustainability performance is explained by one or more of the four paths. The solutions in this study show strong consistency and coverage, which are necessary to evaluate the fitness situation of the overall QCA model.

The fsQCA identified four paths (policy instrument configurations). The first path is "X1*X2*~X3". It consists of a combination of hierarchy-based policy instruments and market-based policy instruments, without network-based instruments. The second path (X1*~X3*X4) combined hierarchy-based and information-based policy instruments, without network-based instruments. Some cities (Guiyang, Guilin, Nanping, Da Hinggan Ling Prefecture, and Hulun Buir) are covered not only by path 1 but also by path 2. It means these cities choose path 1 and path 2 to construct their low carbon cities. These cities are almost all small cities or prefecture-level municipalities.[3]

The third path (X1*X2*X4) consists of hierarchy-based policy instruments, market-based policy instruments and information-based policy instruments. Unique coverage indicates the extent to which the outcome is simply explained by each policy configuration. The higher the unique coverage, the lower the overlap between the different policy configurations (i.e. the more diverse the application of specific policy instruments). Path 3 is perfectly consistent and uniquely explains 54.23% of the sample set in terms of sustainability performance. Table 5 shows that the policy configuration is employed in most cities in this sample, especially large ones (all megacities and most capital cities).

The fourth path (X1*~X2*X3*~X4) entails hierarchy-based and network-based policy instruments, in the absence of market- and information-based instruments. Only Suzhou employed the combination of policy instruments.

Based on the above, the examination of necessary conditions (a condition is defined as necessary if it must be present for an outcome to occur) demonstrates that hierarchy-based instruments are necessary for low carbon city development because this condition is included in all paths. Therefore, the overall path for successful low carbon construction can be rewritten as (according to Boolean logic language, logical AND is written with a "*" and logical OR is written as a "+"):

[3] A **prefecture-level municipality** (Chinese: 地级市) is an administrative division of the People's Republic of China (PRC), ranking below a province and above a county.

Table 5
Solutions for successful low carbon city development.

	Configurations	Consistency	Raw[a] coverage	Unique[b] coverage	Cities
Path 1	X1*X2*~X3	0.850613	0.362643	0	Guiyang, Guilin, Nanping, Da Hinggan Ling Prefecture, Ningbo, Hulun Buir
Path 2	X1*~X3*X4	0.925307	0.394487	0.0318441	Guiyang, Yan'an, Guilin, Nanping, Da Hinggan Ling Prefecture, Hulun Buir
Path 3	X1*X2*X4	0.780008	0.904943	0.5423	Beijing, Shenzhen, Guangzhou, Hangzhou, Tianjin, Qingdao, Shijiazhuang, Xiamen, Guilin, Kunming, Chongqing, Guangyuan, Shanghai, Nanchang, Wuhan, Guiyang, Nanping, Jingdezhen, Da Hinggan Ling Prefecture
Path 4	X1*~X2*X3*~X4	0.900302	0.141635	0.0161597	Suzhou
Solution coverage: 0.952947					
Solution consistency: 0.768494					

[a] The raw coverage refers to how much of the outcome is covered by each of these paths.
[b] The unique coverage means how much of the outcome is covered only by a specific path.

$$X1^{*}\ (X2^{*} \sim X3 + \sim X3^{*}X4 + X2^{*}X4 + \sim X2^{*}X3^{*} \sim X4) \rightarrow \text{successful low carbon development} \quad (1)$$

Formula (1) is the overall path of this model. It indicates that successful low carbon construction requires building on the presence of hierarchy-based instruments, but also that hierarchy-based instruments need to be supported by other types of instruments, which are therefore complementary.

4.2. Interpretation

All cities in this research sample adopted three types of hierarchy-based instruments (See Table A4 (Appendix A). In addition to the local policies, Chinese national government also issued laws and action plans for the prevention and control of atmospheric pollution in recent years. For example, in 2007, the State Council issued *China's National Plan on Climate Change* followed by *the Action Plan for Prevention and Control of Atmospheric Pollution* and *The Three-Year Action Plan to Win the Battle for Blue Skies* in 2013 and 2018 respectively. In 2015, *the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution* was published. As a response, local governments have come out with their relevant action plans on climate governance. In this sample, 30 cities adopted such comprehensive plans to deal with climate change. A variety of measures were applied in these comprehensive policies, especially regulatory measures.

Path 1 consists of hierarchical (X1) and market-based instruments (X2) and requires the absence of network-based instruments (~X3). Guiyang, Guilin, Nanping, Da Hinggan Ling Prefecture, Hulun Buir, and Ningbo chose this combination. This solution is normally used to reduce high pollution, eliminate backward production and update polluting equipment. Governments use this combination to tackle pollution problems with coercive measures and offer subsidies to companies that have suffered losses from upgrading equipment or closing down outdated capacity. For example, Hulun Buir issued a notice on decentralized coal-fired boilers and implemented renovation of furnaces and grids in 2014. In 2015, Ningbo published '*Opinions on Promoting the Elimination and Renovation of the City's High Pollution Fuel Boilers*'. In 2017, Da Hinggan Ling Prefecture released two policies about the encouragement of elimination of "yellow label" vehicles. In these three policies, the governments needed to achieve the goal of carbon reduction by dispersing coal-fired boilers, restricting the use of "yellow label" vehicles, phasing out and upgrading high-pollution fuel boilers. Meanwhile, special funds were used for subsidies, grants and price incentives to promote the implementation.

The second path combined hierarchy-based policy instruments (X1) and information-based policy instruments (X4), with the absence of network-based instruments (~X3). In 2018, State Council published the '*Notice on the Three-year Action Plan for Winning the Blue Sky War*'. Subsequently, local governments also issued corresponding planning documents, such as Da Hinggan Ling Prefecture, Hulun Buir and Yan'an. These plans present ideas how to strictly control pollution, close down backward production, deepen industrial treatment and develop new energy sources. They also propose strengthening environmental information disclosure and persuading the public to enjoy a low-carbon life. In addition to taking strict control and pollution control measures, Guiyang actively promotes energy-saving weeks and national low-carbon days in the whole city and for units at the district level, all through publicity. On the one hand, Guiyang uses the official microblog and WeChat public platform to publicise knowledge related to national energy conservation. On the other hand, Guiyang encourages saving energy and reducing consumption in the office and organises an online knowledge contest on garbage classification of public institutions.

Path 3 was selected by most cities, especially large cities and capital cities. These cities are normally successful in improving their low carbon performance. This solution appears effective and an acceptable path for Chinese cities. To be specific, in addition to taking strict control measures, subsidies are most frequently adopted to respond to various environmental problems, especially in megacities. To encourage the use of sustainable vehicles, cities such as Beijing and Chizhou employ tax exemptions. Many cities promote new sustainable vehicles via subsidies, including Beijing, Shanghai, Hangzhou, Tianjin, Suzhou, Wuhan, Nanchang, Qingdao, Ningbo, Ganzhou, and Jincheng. Other cities such as Shanghai, Tianjin, Qingdao, Shijiazhuang and Hulun Buir also provide subsidies to renewable clean energy. In 2011, Hangzhou municipality improved the subsidy standard for the relocation of industrial enterprises and required enhancement of the transparency in providing environmental information for these enterprises. Other subsidies are provided to eliminate 'yellow label' cars and deal with the exhaust of heavy diesel trucks, such as in Wuhan, Suzhou, Wenzhou, Baoding, Jincheng, Zunyi and Da Hinggan Ling Prefecture. These governments also publicise the dangers of highly polluting technologies. Besides, governments use other economic instruments, such as grants in Beijing, Shanghai, Nanchang and Wuhan to promote energy conservation, emission reduction, and green transformation. In 2016, Beijing issued a loan preferential policy to replace light-duty gasoline cars. Ningbo set a charging service price of public charging piles for new energy electric vehicles in 2018. Carbon trade policies were adopted by some large cities in their low carbon governance, including Beijing, Shenzhen, Tianjin, Xiamen and Hangzhou. In this policy mix, market policy tools are extensively used, while regulation policies are a compulsory means to reach a certain goal. Financial tools provide economic support for this goal, and information tools are auxiliary tools in these policy combinations.

Path 4 is an alternative solution to low carbon city construction. Suzhou selected this solution. On the one hand, Suzhou has released a large number of strict measures to ban the discharge of fireworks, delimit the urban areas to prohibit the use of high-emission non-road mobile machinery, expand and adjust the forbidden zone for high-pollution fuel, and eliminate the old motor vehicles. On the other hand, Suzhou set up a number of special leading groups to coordinate the implementation of these activities. For example, in 2016, a working group on banning fireworks was established. In 2017, Suzhou set up energy conservation demonstrations in public institutions. Suzhou is among the cities that established a network governance structure.

4.3. Sensitivity analysis

The results in this study could be affected by some controlling variables, which were also considered. Table 3 summarises the key economic and social information for each low carbon pilot city in 2018, including population level, economic output, industrial structure, city level, and environmental (air quality) condition.

In general, cities with large populations emit more carbon dioxide, and their governments will invest more in the reduction of carbon emission than smaller cities. All megacities of more than 10 million people indeed adopted lots of instruments. Except Baoding, all of them perform well in low carbon city construction. Cities with populations under 2 or 3 million perform less well. Some of them cannot be retraced in our paths, such as Chizhou, Jincheng, Jinchang and Jiyuan. Therefore, it can be assumed that population size as such does not affect the application of policy instruments.

Normally, cities with good economic conditions can invest more financial resources in controlling carbon emissions. Wealthy cities such as Beijing, Shanghai, Shenzhen, Guangzhou and Hangzhou adopt a wide variety of instruments, including market-based ones, and obtained very fine effectiveness. These are all mega or large cities and experiencing deep urban transformation. Cities with less favorable economic conditions such as Ganzhou, Yan'an and Da Hingan Ling adopt fewer instruments and do not obtain such positive emission indicators. It is thus tempting to conclude that economic conditions of cities influence the adoption of low carbon policy instruments and influence policy effectiveness.

A city's industrial structure affects both the government's low-carbon policy input and its effect. The proportion of secondary sector production in some cities (manufacturing and mining) is still high. For example, Qingdao, Ningbo, Shijiazhuang, Baoding and Jiyuan adopted many different low carbon policy instruments. Shijiazhuang is Hebei's capital city, Qingdao and Ningbo are vice-provincial cities with enough urban governance capability and transformation readiness to build low carbon cities. They also have strong industrial bases and economic conditions and adopt many different instruments. So did Baoding and Jiyuan. However, their low carbon city construction effectiveness in these five cities is not apparent, as they experience difficulties in adjusting their industrial structure in the short term. It can thus be concluded that industrial structure seriously affects low carbon performance.

Governance capacity affects the ability or willingness to implement low-carbon policy instruments. Smaller and administratively less powerful third, fourth or fifth-tier cities such as Ganzhou, Zunyi, Zhenjiang, Yan'an, Jinchang, and Chizhou did not adopt low carbon policy tools although their secondary industry constituted a major share of their production. These cities released few documents and adopt few low carbon policy instruments. Except for Zhenjiang, all these cities are small and located in China's central or western regions, facing relatively weak economic conditions. In China, the classification of city levels can reflect the cities' governance capability. Apparently, their industrial structure impels them to prioritise their economy and accept high pollution levels.

Cities with good environmental background conditions, especially those in forested areas, generally do not seem to need strict governance measures but obtain well low carbon performance. Xiamen and Guilin are examples. Therefore, the environmental factor also affects the research results to a certain extent.

5. Discussion

The identification and comparison of four configurations of low carbon policy instruments via fsQCA and the empirical evidence regarding their application in low carbon cities makes it possible to engage in a discussion about their impact of various configurations in China and compare these findings with what else known from experiences elsewhere in the world.

Hierarchy-based instruments are widely adopted by local governments in China's low carbon pilots and according to the fsQCA could be considered a necessary condition to reduce carbon emissions. However, in themselves, hierarchical low carbon policy instruments are insufficient. Other classes of policy instruments need to be employed by local governments alongside them to reduce carbon emissions and thus achieve the low carbon city policy goals. The widespread use among municipal governments of hierarchical measures such as command and control and mandatory tools in low carbon city policies confirms the findings of previous studies (Wang et al., 2015; Zhang and Wang, 2017). The explanation for these findings is relatively straightforward. China is one of the largest carbon emitters worldwide (Shuai et al., 2018) and a variety of environmental problems have accompanied its rapid economic development (Gilley, 2012; Lo, 2016). Chinese governments introduced a variety of pollution control measures in recent years in an attempt to reduce carbon emissions. An important regulation is the carbon dioxide emission performance requirement for major generation groups (Liu et al., 2017). Regulatory instruments are thus widely applied in local environmental and energy policies, to achieve emission goals and satisfy mandatory requirements. These include eliminating outdated production and reducing pollution sources (enterprises and equipment), and a strengthening of inspections (Li and Taeihagh, 2020). The use of this class of policy instruments to achieve low carbon policy goals is also consistent with previous studies which found that mandatory measures are in line with China's top-down management characteristics in the early stages of low-carbon city development (Wang et al., 2013). Furthermore, the hierarchical policy tools are relatively simple to deploy by local governments and require little coordination.

Previous research claimed that the use of market-based instruments in Chinese cities was inadequate and weak (Khanna et al., 2014; Wang et al., 2013). Some scholars believe that market-based instruments such as carbon taxes, carbon trading, carbon offsets and energy performance contracting (EPC) played a very limited role in China's local low carbon governance (Wu, 2011). In comparison with other developing countries, China seems to adopt more hierarchical policy measures to achieve low carbon goals, whereas for example India, relies more on market-based policy instruments (Kedia, 2016). Actually, many OECD countries have also recently adopted economic instruments, such as emission trading schemes (Hashmi and Alam, 2019). Besides, Portugal implemented carbon tax in 2015 (Doshi, 2018). Singapore has operated the Carbon Pricing Act (CPA) and its accompanying regulations from 1 Jan 2019 (NEA, 2020). Chile planned to implement tax legislation in 2017, while South Africa expected to adopt carbon price scheme (Doshi, 2018). However, this study shows that market-based low carbon policy instruments in the form of pricing and tax incentives for new energy automobile and energy-saving industries, are adopted by some mega Chinese cities, provincial capital cities, and some rich prefecture-level cities. For example, Shenzhen implemented carbon emission trade schemes in 2012 and Tianjin introduced a similar scheme in 2013. The application of more market-based instruments is consistent with China's shift towards a more competition-oriented pattern of societal and urban development in recent years. Since the reforms and opening up in 1978, the national government has actively encouraged competition in the economic development of cities (Wu and Zhang, 2007). Large cities appear more capable in applying market-based instruments than smaller ones. Megacities are thus in a better position to direct a sustainable urban transformation and can muster their resources to achieve reduce carbon emissions.

Market- and network-based instruments do not seem to be utilised concurrently in China's low carbon city pilots. Market-based policy instruments are typically straightforward subsidy-schemes and deployed in a simple pattern with few requirements for interdepartmental cooperation. The application of market-based instruments thus restricts the functioning of network-based instruments. Strong competition-oriented policy instruments directly affect the redistribution of resources and benefits (Juhola and Westerhoff, 2011), which in turn, reduces the motivation for interdepartmental collaboration. Conversely, powerful state intervention and strong coordination hinder the development of markets and competition (Lo, 2016). Therefore, it is unlikely for market- and network-based policy instruments to coexist in one policy configuration. Since market-based policies are simple to apply and require little cooperation, they are more widely accepted by local governments, especially the adoption of government sponsorship (see Appendix A, Table A4).

Network governance is only used to overcome organisational barriers that arise from the application of hierarchy-based policy instruments. Chinese cities typically set up special leading working groups and systems of joint meetings to organise and coordinate activities and promote mandatory policy objectives. Setting up a special leading group reflects the focus of local governments on the implementation of a project. On the other hand, voluntary afforestation programs among local governments are a widely used method for participation in low-carbon development, since it easier to implement than other instruments (Grubb et al., 2020; Safarzadeh et al., 2020). However, underdeveloped network governance, insufficient government-enterprise interactions, limited participation from private sector actors and environmental NGOs still hamper low carbon city development. This finding is consistent with previous studies indicating that network governance in China's low carbon city pilots is still underdeveloped (Lo et al., 2018; Lo, 2016). Private actors lack the motivation and capacity to become involved in the development of activities to reduce carbon emissions (Lo, 2016; Shen, 2015). In contrast, in Western cities, such as those in Sweden, network governance is amply utilised to mobilise private actors and put climate issues on the top of the local political agenda (Khan, 2013). The city of Berlin involved the private sector in the development of policies to actively reduce their carbon footprint (Reusswig et al., 2020). Participation of private firms, communities, voluntary organisations have become important elements in European urban governance (Nochta and Skelcher, 2020).

In the process of policy portfolio selection, information-based policy instruments are favored over network-based policy instruments in China's low carbon city pilots. On the one hand, information-based instruments can be used to exchange information and stimulate and communicate desired forms of public behavior. Peters (2013) claims that information diffusion can promote coordination among departments. Governments prefer to deploy hierarchical policy instruments alongside a limited set of information-based policy instruments, leading essentially to 'one-way communication'. Governments prefer to use regulation and information as a combination of policy instruments to reduce complexity and minimise costs and the use of valuable resources (Li and Taeihagh, 2020; Palm and Lantz, 2020). Thus, information-based policy instruments are especially favored by small and prefecture-level cities although they are universally employed by all low carbon city pilots as complementary instruments in all policy instrument configurations. When using information-based policy tools Chinese governments generally employ information-based instruments to publish general information in attempts to influence and persuade public behaviour. However, a UK study concluded that personalised and focused information activities could be more effective in influencing behavioural change (Büchs et al., 2018). In other words, variety and focus in the application of information-based policies in China's low carbon city pilots is still open to improvement.

6. Conclusions

In China, as elsewhere, low carbon city development aimed at reaching SDG11 and SDG13 has been taken up full-swing. In this contribution, an analysis was conducted to examine the impact of combinations of low carbon policy instruments on low carbon city construction.

The findings indicate that China's low carbon city pilots primarily employ hierarchical policy instruments to reduce carbon emissions. An analysis of the policy configurations shows their application to be a *sine qua non*, but insufficient in itself for a satisfactory outcome. Combinations of hierarchy-based instruments and other instruments, on the other hand, seem to increase the effectiveness of low carbon city policies. Hierarchical policy instruments seem to co-exist primarily with market-based policy instruments. Both types are widely adopted in efforts of urban governments to reduce carbon emissions, particular in mega cities. Network governance, on the other hand, requires collaboration and trust among organisations and these tend to be weakly developed in Chinese cities, especially participation of the private sector. Information-sharing is a fourth category of policy instruments which can be used in combination with any of the three previous types.

While the use of hierarchical instruments is crucial and makes a very significant contribution to the development of low-carbon cities and can be considered the cornerstone of the system, the use of market-based instruments has also risen. Their combined deployment has consequently become a key feature in the policy mix among many forward-looking low carbon cities in China. Network-based and information-based instruments, however, are underused. Part of the explanation may lie in the rising popularity of the more competition-driven market-oriented instruments which sit uncomfortably with network-based instruments, which rather require cooperation. There appear to be restrictions in the combinations of instruments that can be adopted in the chosen configuration. Information-based instruments, on the other hand, can be used in combination with any of the other categories but their application is still open to improvement in the Chinese context. A deeper analysis of the factors that can explain the level of progress made in achieving low-carbon development points at the relevance of a city's industrial structure, its economic conditions, its governance capacity and its willingness to transform. In line with these features, local governments can choose specific configurations of policy instruments that suit their characteristics and levels of ambition in terms of sustainable development.

This study is the first comprehensive study to identify and map configurations of policy instruments at a theoretical level, empirically apply them to low carbon city development and relate urban government choices to policy impact emerging across a wide range of cities. The patterns that emerge are robust but obviously typical of the Chinese cities that had been selected. It has been shown that chosen configurations will presumably be markedly different in cities outside China, but no systematic research has been conducted on that topic thus far and it would be worthwhile in future to engage in such studies.

Mentioning a number of limitations in this study is due. First of all, it made use of second-hand data in existing official documents provided by Chinese authorities; future research could mitigate potential bias adding supplementary use of other sources of qualitative information such as semi-structured interviews or field observations. A second limitation rests in the relatively crude form of 'measurement' of the use of policy instruments. This study merely checked presence or absence of instruments in use as derived from mentioning of these policies in documentation. This method cannot ascertain the proportional use of policy instruments, nor establish its relative weight. Further study is required to assess to what extent specific policy instruments influence carbon emissions and contribute to low carbon city development. Finally, as became obvious above, this contribution only examined configurations of policy instruments in Chinese cities. In further research, more thorough cross-national comparisons can be made highlighting both national institutional and other specificities and the potential for cross-national and cross-city lesson-drawing.

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CRediT authorship contribution statement

Wenting Ma: Conceptualization, Data collection, Formal analysis, Writing - original draft. **Martin de Jong:** Validation, Formal analysis, Supervision, Writing - review & editing. **Mark de Bruijne:** Formal analysis, Writing - review & editing. **Rui Mu:** Conceptualization, Validation, Formal analysis, Supervision, Funding acquisition, Writing - review & editing.

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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Appendix A. Supplementary data

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