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Investigating the financialization of water infrastructure in China: A public policy perspective

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ABSTRACT

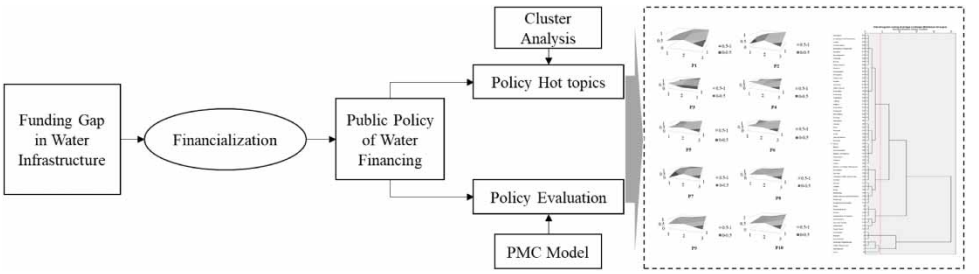
Insufficient funding for water infrastructure has become a notable challenge for China and other developing countries. In light of marketization and globalization, financialization has emerged as a potential avenue to address the financial difficulties. This study employs the PMC index model and cluster analysis method to quantitatively analyze the financialization of water infrastructure in China through a lens of public policy lens. The findings suggest that financialization has become a significant trend in water infrastructure, with public policy playing a critical role in water infrastructure development. This study contributes to the novel possibilities for studying water infrastructure financialization and offers a reference to policymakers and professionals for optimizing water infrastructure development.

Key words: Financialization, PMC model, Public policy, Text mining, Water governance, Water infrastructure

HIGHLIGHTS

- Financing is a key challenge facing global water infrastructure development.
- This study employs the PMC index model and cluster analysis method to quantitatively analyze the financialization of water infrastructure in China through a lens of public policy lens.
- Financialization has become a significant trend in water infrastructure, with public policy playing a critical role in water infrastructure development.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is an essential prerequisite for producing livelihoods, economic growth, and urbanization (Mason, 2022). Water scarcity and a lack of adequate clean water are challenges for many countries around the globe (Dolan *et al*., 2021). The United Nations has listed clean water and sanitation as one of the 17 Sustainable Development Goals (SDG 6). Water scarcity, uneven spatial and temporal distribution, and high pollution are the essential characteristics of China's water resources (Liu & Sun, 2019). The two primary approaches to solving this issue are to enhance the water supply by diverting water resources from abundant to limited areas, as in China's South-North Water Diversion Project, and to improve water use efficiency (Ma *et al.*, 2023). Both strategies require extensive water infrastructure construction. Urban development, economic expansion, and sustainable water development are all facilitated by effective water infrastructure (Neves Alves, 2022). However, the water infrastructure, especially the mega water infrastructure projects, has the characteristics of huge investment, high risk, and substantial public benefit. A major global challenge is how to build a strategy with a sustainable investment and financing for water infrastructure.

For a long time, water infrastructure has mainly relied on government investments and bank loans. The limited government finances have led to, on the one hand, great constraints on water infrastructure construction; on the other hand, the larger investment demand for water infrastructure has also affected government debt (Humphreys *et al*., 2018; Pryke & Allen, 2019; Li *et al*., 2022a). In the context of globalization and marketization, there is a trend of financialization in urban development, which has introduced private capital into infrastructure construction through marketed and diversified financing instruments to address the infrastructure funding gap (Wu, 2022). There has also been a major impact on water infrastructure. Financialization provides an innovative approach to solve the financing problems of water infrastructure (Grafe, 2020). Compared to other infrastructure sectors such as transportation, municipalities, and energy, the practical and theoretical research on water infrastructure financialization is relatively lagging (O'Brien & Pike, 2017).

Prior studies of water infrastructure financialization have focused on the suitability assessment, financing arrangements, financial technology, regulation, and management of financialization (Ahlers & Merme, 2016; Schmidt & Matthews, 2018; Pryke & Allen, 2019; Grafe, 2020). Understanding financialization innovation and evolution from the perspective of public policy remains a key research weakness in water financialization. Public policy as an important tool for the government to intervene in economic activities has been widely used and successfully experienced in many emerging markets and transition countries (Aranguren *et al*., 2017; Acciai & Capano, 2021). Therefore, research on water infrastructure financing based on a public policy perspective not only enriches the existing knowledge body but also promotes water infrastructure development and water governance.

This study aims to address the following question: Is there financialization in China's water infrastructure? How is this financialization reflected in public policy? What is the government's role in water infrastructure financialization through policy instruments? To this end, this study takes China as a typical case, quantitatively analyzes the public policies related to water infrastructure investment and financing by the collecting and text-mining method, and uses the PMC index model and cluster analysis methods to identify the development characteristics and trends. The contributions of this study are multifold. First, the approach presented opens up identifying and evaluating the water financialization through the lens of public policy. Second, this study contributes to debates on financialization and its effects on water infrastructure. Third, this study also enriches the perspective of water policy and water governance research. Finally, this study can help scholars and practitioners around the world further understand water infrastructure financing in China.

The remainder of this article proceeds as follows. Section 2 reviews existing theories of water infrastructure financing. Section 3 describes our methods and data. The findings and discussion are presented in Sections 4 and 5, respectively. Section 6 concludes and provides policy implications.

2. FINANCING THE WATER INFRASTRUCTURE

The single source of funding and lack of sufficient funding for water infrastructure construction is a common challenge facing the world, especially in developing countries (Ahlers & Merme, 2016). The development of water infrastructure, especially mega water infrastructure, is a complicated story in which finance has played a crucial role (Loftus & March, 2016). The design, construction, operation, and contribution of water infrastructure to the effective distribution and management of limited water supplies are all greatly influenced by the financing mechanisms (Grafe, 2020). For an economically, socially, and environmentally sustainable management of water resources, research from numerous nations has demonstrated the crucial need for sustainable water financing (Hilbig & Rudolph, 2019). The infrastructure has traditionally been dominated by public financing, but in recent years, there has been a growing trend toward private finance driven by financialization (Bayliss, 2013). Applying an innovative financing model will be essential to closing the water infrastructure funding gap. Therefore, the rise and spread of financialization in water infrastructure is considered to be a market outcome.

Financialization originated in the economic field and later expanded to urban development, with land, real estate, and infrastructure becoming the main arena of urban financialization (Zhang & Wu, 2022). Financialization is generally manifested by the increasing proportion of financial assets in the national economic system, and the status and role of financial sectors and financial instruments in economic life have become more important (Aalbers, 2020). Financialization describes the process by which financial markets, institutions, and actors increasingly impact how the economy and society are shaped (Christopherson *et al*., 2013). With the acceleration of the globalization process, the gradual formation of a global financial network has emerged (Wójcik, 2018). Over the past few decades, financialization has become widely concerned in academic and policy circles, especially since the 2008 global financial crisis (Li *et al*., 2022b). Financialization separates the use value of resources from the exchange value of financial instruments (Knox-Hayes, 2013). Financialization has given financial players greater power and appears to have moved the center of profit-making from the real economy to a financial economy (Loftus & March, 2015). Financialization is also regarded as part of a broader sustainable transition (Bresnihan, 2016). In addition, some scholars have argued that it has led to greater efficiency and innovation in financial markets, whereas others have claimed that it has produced a system prone to volatility and crises (Fainstein, 2014; Murphy, 2015; Ioannou & Wójcik, 2019). Financialization has also had a significant impact on infrastructure, leading to changes in ownership, finance, and development (O'Neill, 2019). This has been driven by a range of factors, including fiscal austerity, neoliberal policy agendas, and the search for higher returns on investment (Langley, 2018; Grafe & Mieg, 2019). Financialization can lead to greater efficiency, innovation, and access to finance, which can help overcome the funding gap for infrastructure investment (Clark, 2017). Diversified finance can also assist in introducing new management techniques and skills to infrastructure (O'Brien & Pike, 2017). On the other hand, some scholars have argued that financialization can lead to a narrow focus on financial returns, which can lead to the neglect of social and environmental considerations (Grafe & Hilbrandt, 2019; O'Neill, 2019; Li *et al*., 2023).

Water infrastructure financialization has received a lot of attention in recent years. Financialization is a necessary response to the issues of an ageing water infrastructure and fiscal challenges (Bayliss, 2013). It is a global practice for the state to encourage the private sector and capital to participate in water infrastructure (Grafe, 2020). Water market and water infrastructure have generated returns for private investments. At the same time, financial institutions have gained increasing influence in water infrastructure and water governance

(Loftus & March, 2016). Using the example of the Thames Water Desalination Plant in Britain, Loftus & March (2016) examined the effects of financialization on water infrastructure. By focusing on water management, Bayliss (2013) sought to contextualize changes in water delivery within broader financialization tendencies. Based on a case study in San Diego, California, Pryke & Allen (2019) demonstrated how a drinking water infrastructure was transformed into a value asset to meet the needs of institutional investors. Humphreys *et al*. (2018) demonstrated that the current strategies for financing water infrastructure construction do not appear to be highly suitable for small towns.

According to the review above, financialization has emerged as a key area for water infrastructure development. However, the majority of existing research has been devoted to case studies and theoretical analyses, and quantitative analyses from a public policy perspective are lacking, which will be enriched by this research study.

3. MATERIALS AND METHODS

3.1. Research methods

This study is mainly based on a policy text-mining approach, which focuses on two dimensions, namely, the development of financialization in water infrastructure and policy text analysis. The methods in this study include the policy modeling consistency (PMC) index model and textual keyword clustering analysis.

The PMC index model was created by Ruiz Estrada, and its core idea is the 'Omnia Mobilis hypothesis' that everything in the world is interrelated and every variable is equally important (Wang *et al*., 2022). The PMC Index model can integrate the economic and non-economic variables of a policy and unify the scores of a policy into a single index by building a multidimensional model to achieve a comprehensive evaluation of the policy's strengths and weaknesses (Kuang *et al*., 2020). The PMC Index model approach consists of four steps: variable identification and parameter identification, the construction of multiple input–output tables, a PMC Index calculation, and the construction of PMC surfaces. The PMC index model is widely applied in public policy research (Li *et al*., 2021; Li & Guo, 2022).

Cluster analysis is a statistical method. The subject changes of policy text in various periods can be analyzed when the focus of the policy text has been discovered by condensing the co-word relationship among various analysis objects into a limited number of cluster phrases. This study employs the clustering analysis method to identify the key words and policy significance of water infrastructure investment and financing in each stage based on the division of policy development stages to examine the evolutionary trend of water infrastructure financialization.

3.2. Data and processing

The data in this study were obtained from the www.pkulaw.com database and official government websites, including the Water Resources Bureau, Tax Bureau, and Finance Bureau, etc. A total of 68 policies on water infrastructure investment and financing have been obtained since 1978. POST-CM6 was used to analyze the data by word separation and word frequency statistics, excluding policy-specific terms such as 'used for' and 'regulations,' which have no research significance.

4. RESULTS

4.1. Hot topics and the evolution of water infrastructure-financing policies

Based on the 68 policy texts collected and the key events in China's water infrastructure investment and financing, this study divides the development of water infrastructure-financing policies into three phases, namely the emergence phase (1978–2010), the deepening reform phase (2011–2020), and the exploration and innovation

phase (2021–present). The number of policies in each phase varies greatly, with only five policies in the emergence phase, 30 policies in the deepening reform phase, and 33 policies from 2020 to the present. This also profoundly reflects the vigorous development of water infrastructure financialization.

In terms of the selection of a keyword frequency threshold, this study adopts the *g*-index method, in which keywords are arranged by frequency, and if the number of *g* keywords with the same frequency is *n*, and if the sum of the cumulative frequency of *g* keywords is greater than or equal to g^2, and at the same time, the cumulative frequency of $(g+n)$ keywords is less than $(g+n+1)^2$, then the keywords up to the $g+n$ included previous keywords are selected as high-frequency words in the set of phrases. The specific method is shown in the following equation:

$$\sum_{i=1}^{g} Si \geq g^2 \sum_{i=1}^{g+n} Si \leq (g+n+1)^2 \tag{1}$$

4.1.1. The emergence phase (1978–2010)

Since China's reform and opening-up policy in 1978, China's political regime and economic development have entered a new phase. However, for a long time, there has been no special policy to regulate and guide water infrastructure construction. Water infrastructure construction was previously mainly financed by the government's fiscal fund. However, in 1997, the Chinese government issued the '*Measures for Raising and Using the Water Conservancy Construction Fund*' and '*Notice on Further Improving the Establishment of the Water Conservancy Construction Fund*,' which explicitly provided for the raising of funds for water infrastructure construction through the water construction fund, and has been in use ever since.

The results of the cluster analysis of the five water policies at this stage are shown in Figure 1. The Ministry of Finance and the State Council of China were the main policy-making bodies at this time, according to the cluster analysis results, and the government took the lead in funding water infrastructure construction at all levels and in all regions using a top-down approach through the water construction fund. A primary purpose of water infrastructure at this time was to control floods, irrigate crops, and meet the drinking water needs of urban and rural residents.

4.1.2. The deepening reform phase (2011–2020)

The global financial crisis of 2008 brought a great shock to the global economy. In response to the crisis, the Chinese government increased investments in infrastructure as a driver for economic growth. In addition, the Chinese government has accelerated the marketization reform and strengthened the emphasis on sustainable development. These measures have produced a significant impact for water infrastructure development. In particular, market-based financing instruments are beginning to be introduced into water infrastructure and financialization has gained importance.

After 2016, the PPP model began to be promoted in the construction of water projects. According to the database of the PPP Center of the Ministry of Finance, as of December 2022, 323 water PPP projects were implemented in China, covering reservoirs, flood control, irrigation, water diversion, and other sectors. In addition, most of the first round of water construction fund-related policies promulgated by various local governments have lapsed, and governments at all levels have started to update water construction fund policies. The keyword clustering analysis of water infrastructure-financing policies in this period is shown in Figure 2. Topics related to deepening reform and financialization became the focus of the period. During this period, policy design was more complete and rational, with improvement to the existing water construction fund through

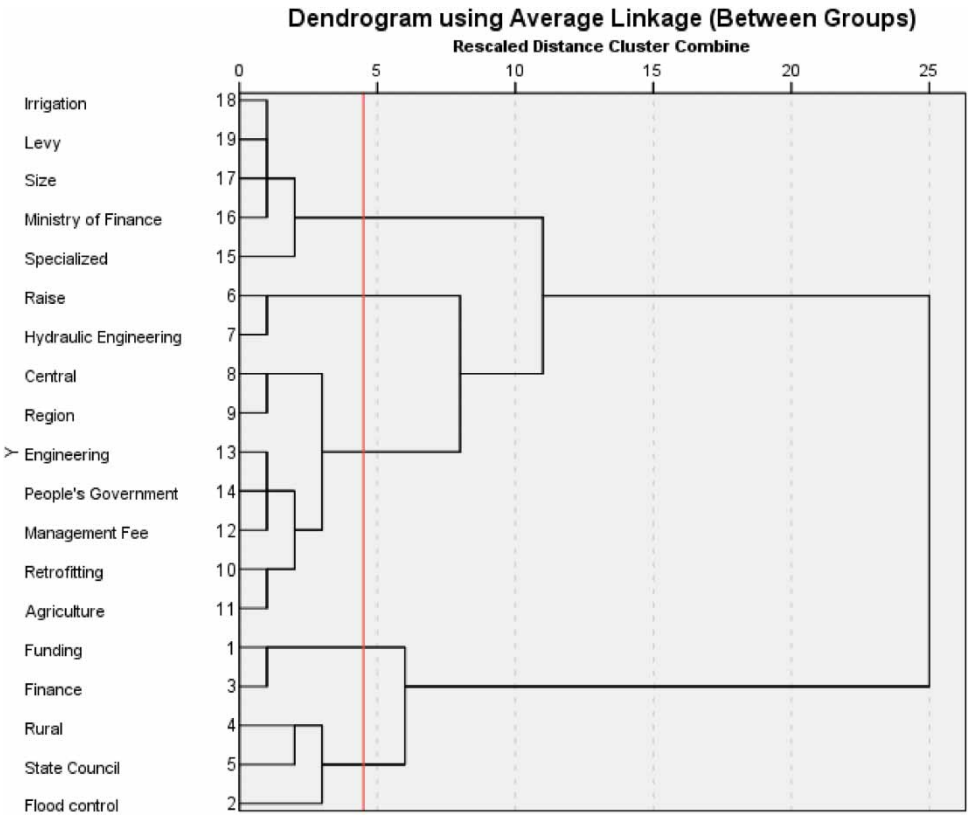


Fig. 1 | Keywords clustering of water infrastructure-financing policy, 1978–2010.

marketized sources of capital being the main content. The policy actors were more diverse, with banks involved in addition to the public sector, such as the Ministry of Finance and Ministry of Water Resources. Agricultural water and flood-control projects are still the key topics of water infrastructure construction. The finance appears frequently, meaning the trend of financialization is becoming more pronounced under financial pressure.

4.1.3. The exploration and innovation phase (2021–present)

The number of water infrastructure investments and financing policies in only three years since 2020 exceeds that of the past 10 years' sums. In 2020, the National Development and Reform Commission of China issued the *Notice on Further Improving the Pilot Work of Real Estate Investment Trusts (REITs) in the Infrastructure Sector*, which launched the pilot of infrastructure REITs. On June 21, 2021, the first nine infrastructure REITs in China were officially listed. The Ministry of Water Resources has also seized the opportunity to actively promote water infrastructure REITs. Infrastructure REITs are an innovative financial instrument that contribute to the financialization of water infrastructure by offering a new source of funding for its construction.

The results of the keyword cluster analysis of water infrastructure investment and financing policies in this period are shown in Figure 3. The majority of the water financing policy information during this period was focused on PPP and REITs, primarily in the form of advice from the government and banks on how to carry out PPP and REITs projects. At the same time, due to the epidemic's effects and the control of local government

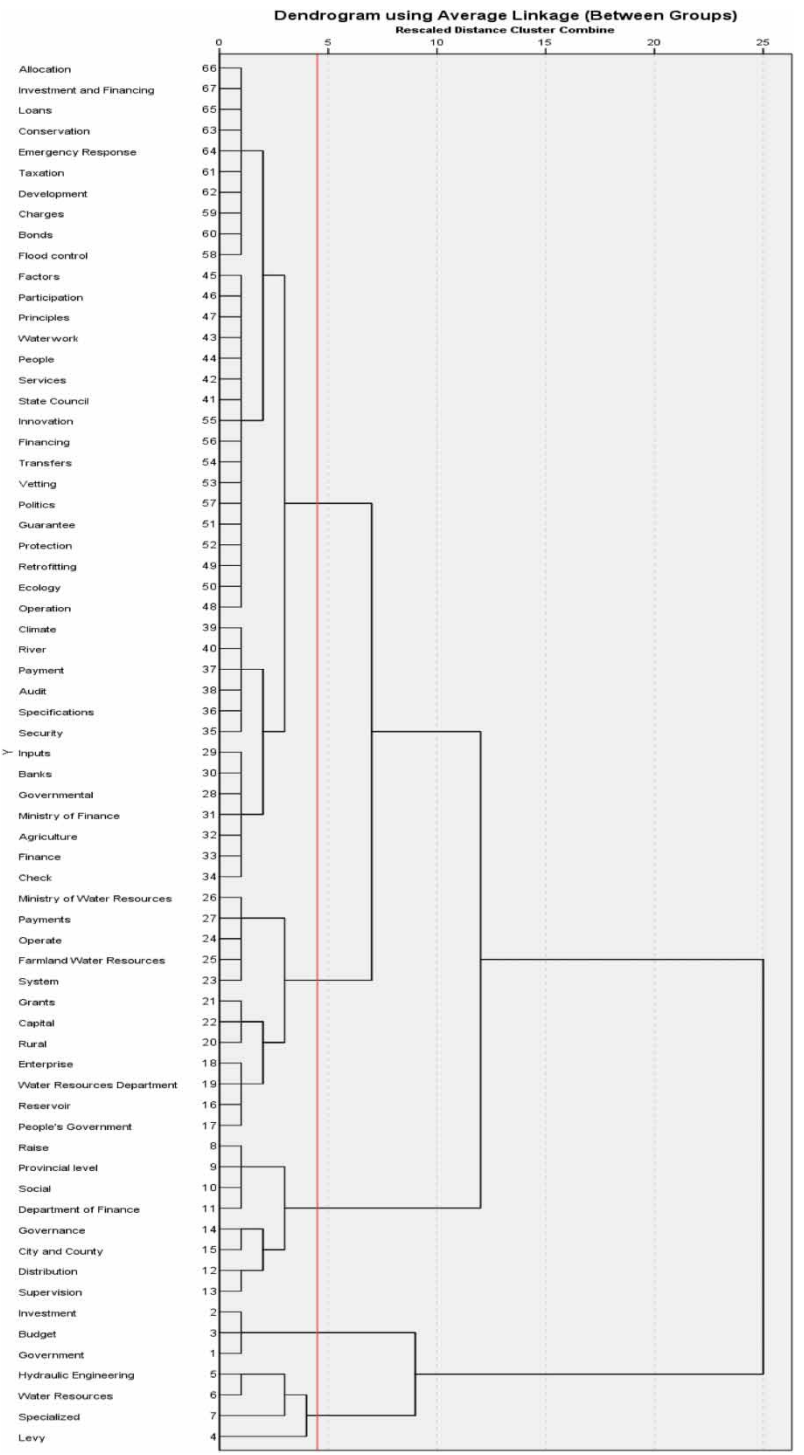


Fig. 2 | Keywords clustering of water infrastructure-financing policy, 2011–2020.

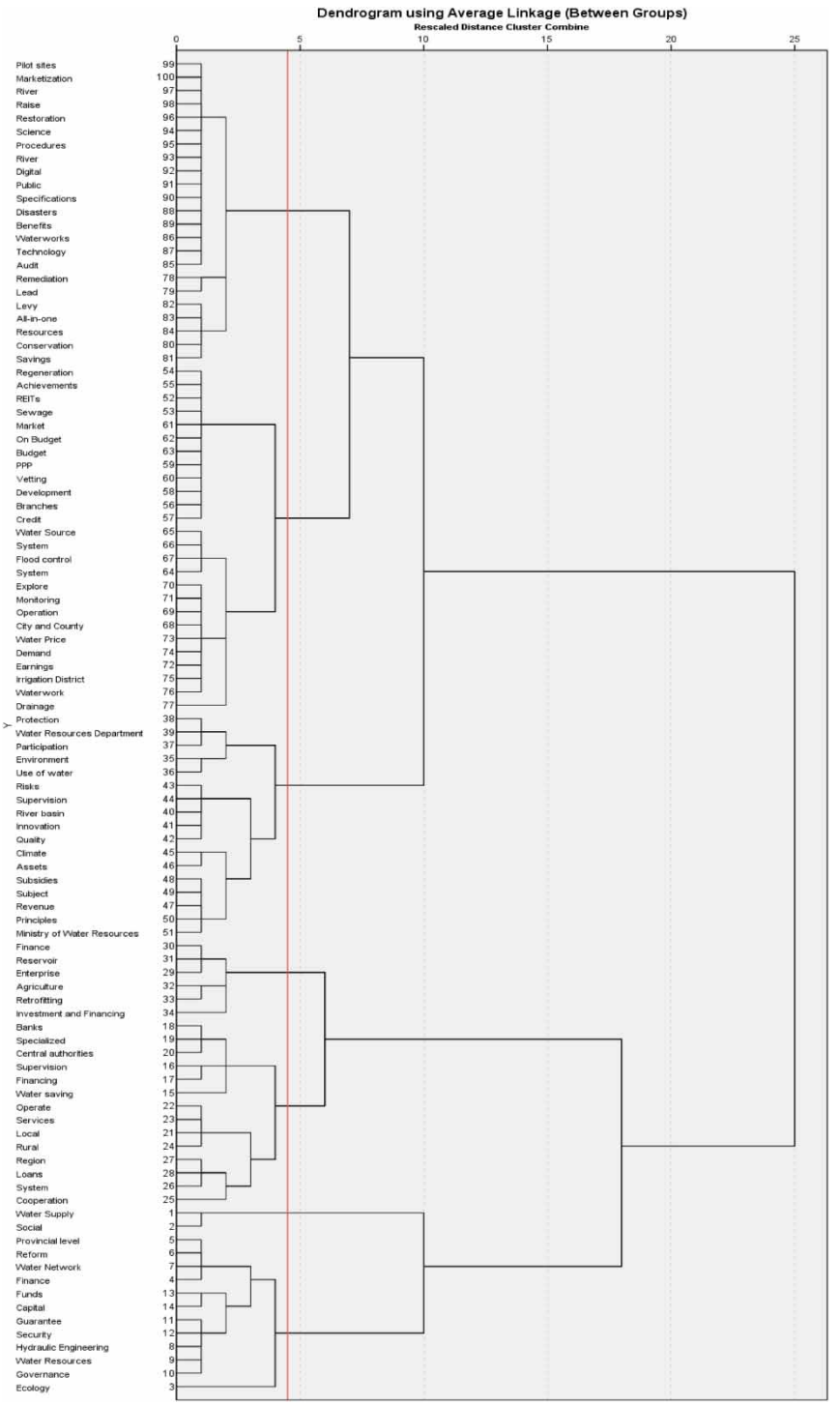


Fig. 3 | Keywords clustering of water infrastructure-financing policy, 2020–present.

debt, some local governments have also implemented measures to lower water construction funds. Policy actors further expanded to public and social organizations. The financial policies and tools in water infrastructure policies increased the frequency of occurrence; therefore, financialization has become the mainstream in water infrastructure policy. Water infrastructure construction has placed greater emphasis on serving urbanization. Water infrastructure construction and financing are more focused on sustainability and ecology.

4.2. Evaluation for key policies of water infrastructure financing

4.2.1. Variable identification and parameter identification

This study selected 10 key policies of water infrastructure investment and financing since 2010, combined with high-frequency keywords to construct an evaluation index system for water infrastructure financialization. The index system consists of two levels, including nine primary variables and 36 secondary variables. The primary variables are policy nature (X1); policy timeliness (X2); policy effectiveness (X3); policy field (X4); policy evaluation (X5); policy function (X6); policy focus (X7); policy coverage (X8); and policy disclosure (X9).

More specifically, policy nature (X1) determines whether the policy has a forecast, descriptive, regulatory, planning, guiding, and supporting role for water infrastructure financialization. Policy effectiveness (X2) is used to evaluate the effectiveness characteristics of the policy text, which is divided into short-term, medium-term, and long-term. Here we define policies that are valid for less than three years as short-term, 3–5 years as medium-term, and five years and above as long-term. Policy effectiveness (X3) is used to distinguish policy levels, which are mainly classified into laws and regulations, administrative regulations, and regulatory documents. Policy field (X4) is a description of policy content, which is divided into five areas: credit, bonds, PPPs, REITs, and the water construction fund, based on key words extracted during data pre-processing. Policy evaluation (X5) aims to measure the strengths and weaknesses of the policy design, including four aspects: clear objectives, detailed planning, scientific programs, and sustainable development. Policy function (X6) is divided into resource allocation, regulation, institutional constraints, guidance, financial services, and mechanism construction, according to the role played by the policy for water infrastructure-financing practice. Policy focus (X7) is a summary of the policy emphasis, including operation, innovation, reform, development, and support. Policy coverage (X8) covers four levels: national, regional, financial institutions, and the public. Policy disclosure (X9) examines whether the policy is open, with no secondary variables. All of the above variables use a binary system, and the secondary variables take the value of 1 when the policy text conforms to the secondary variables, and 0 if otherwise. The policy documents and variable index system are shown in Tables 1 and 2.

4.2.2. Construction of multiple input–output tables

In the PMC index model, the multiple input–output table can store a large amount of data and is a data analysis framework that measures individual factors with multidimensional variables. Each primary variable contains multiple secondary variables and the number of secondary variables is unrestricted, so there is no specific ranking order for the multiple input–output table and only a basic classification of secondary variables. Using a binary system ensures that all sub-variables are given the same weight. The multiple input–output table constructed for the water infrastructure-financing policies in China is shown in Table 3.

4.2.3. PMC index calculation

The calculation of the PMC Index is calculated in two steps. Firstly, the secondary variables are assigned in binary form according to Equations (1) and (2), and the results of the primary variables are obtained from the calculation of the secondary variables according to Equation (3). Secondly, the PMC Index for each sample policy is calculated by summing up the primary variables according to Equation (4). The calculation results are shown in

Table 1 | Key policies of water infrastructure financing.

Number	Policy	Issuing unit	Issuing time
P1	Opinions on Further Improving Financial Services for Water Reform and Development	People's Bank of China, Development and Reform Commission, Ministry of Finance	2012
P2	Opinions on the Implementation of Encouraging and Guiding Social Capital to Participate in the Construction and Operation of Major Water Projects	National Development and Reform Commission, Ministry of Finance, Ministry of Water Resources	2015
P3	Notice on the issuance of Special Administrative Measures for Investment within the Central Budget in the Field of Water	National Development and Reform Commission, Ministry of Water Resources	2021
P4	A guideline on accelerating the construction of provincial water networks	Ministry of Water Resources	2022
P5	Guidelines on Strengthening development financial support to improve water security capability	Ministry of Water Resources, China Development Bank	2022
P6	A guideline on promoting the development of the public–Private Partnership (PPP) model for water infrastructure	Ministry of Water Resources	2022
P7	Guidelines on Policy-based Financial Support for the Construction of Water Infrastructure	Ministry of Water Resources, Agricultural Development Bank of China	2022
P8	Guidelines on Financial Support for the construction of water infrastructure	Ministry of Water Resources, Agricultural Development Bank of China	2022
P9	Opinions on Strengthening Investment and Financing Services for Water Infrastructure Construction	Ministry of Water Resources, People's Bank of China	2022
P10	Guidelines on Financial Support for Water Infrastructure Construction to Promote Water High-Quality Development	Ministry of Water Resources, Industrial and Commercial Bank of China	2022

Table 4:

$$X \sim N[0, 1] \tag{2}$$

$$X = \{XR{:}[0 \sim 1]\} \tag{3}$$

$$Xt\left\{\sum_{j=1}^{n}\frac{Xtj}{T(Xtj)}\right\} \quad t = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, \ldots\ldots, \infty \tag{4}$$

$$\mathrm{PMC} = \left[\begin{array}{c} X1\left[\sum_{i=1}^{6}\frac{X1i}{6}\right] + X2\left[\sum_{j=1}^{3}\frac{X2j}{3}\right] + X3\left[\sum_{k=1}^{3}\frac{X3k}{3}\right] + X4\left[\sum_{l=1}^{5}\frac{X4l}{5}\right] \\ +X5\left[\sum_{m=1}^{4}\frac{X5m}{4}\right] + X6\left[\sum_{n=1}^{4}\frac{X6n}{4}\right] + X7\left[\sum_{o=1}^{7}\frac{X7o}{7}\right] + X8\left[\sum_{p=1}^{4}\frac{X8p}{4}\right] \\ +X9 \end{array}\right] \tag{5}$$

This study draws on Estrada's policy rating scale, which is divided into four levels, including perfect (10–9), excellent (8.99–7), acceptable (6.99–5), and unacceptable (4.99–0). Because the primary variable is 9, the full

Table 2 | PMC model variable settings.

Primary variables	Number	Secondary variables	Number	Secondary variables
X1 Policy nature	X1:1	Forecast	X1:2	Descriptive
	X1:3	Regulatory	X1:4	Planning
	X1:5	Guiding	X1:6	Supporting
X2 Policy timeliness	X2:1	Long-term	X2:2	Medium-term
	X2:3	Short-term		
X3 Policy effectiveness	X3:1	Laws and regulations	X3:2	Administrative regulations
	X3:3	Regulatory documents		
X4 Policy field	X4:1	Credit	X4:2	Bonds
	X4:3	PPP	X4:4	REITs
	X4:5	Water construction fund		
X5 Policy evaluation	X5:1	Clear objectives	X5:2	Detailed planning
	X5:3	Scientific programs	X5:4	Sustainable development
X6 Policy function	X6:1	Resource allocation	X6:2	Regulation
	X6:3	Institutional constraints	X6:4	Guidance
X7 Policy focus	X7:1	Financial services	X7:2	Mechanism construction
	X7:3	Operation	X7:4	Innovation
	X7:5	Reform	X7:6	Development
	X7:7	Support		
X8 Policy coverage	X8:1	National	X8:2	Regional
	X8:3	Financial institutions	X8:4	The public
X9 Policy disclosure	/	/	/	/

score is 9, and the indicators of each grade are in order minus 1, which are perfect (9–8), excellent (7.99–6), good (5.99–4), and poor (3.99–0). The evaluation results of 10 key policies are shown in Table 5. Seven policies are at the excellent level, accounting for 70%, namely P4, P5, P6, P7, P8, P9, and P10, and three policies are at the good level, accounting for 30%, namely P1, P2, and P3. There are no poor policies. The results indicate that the current water infrastructure-financing policies in China are reasonably designed and actively promote water infrastructure financialization.

4.2.4. Construction of PMC surfaces

Constructing a PMC surface is an advantage of the PMC Index model as a policy evaluation method. The policy's strengths and weaknesses can be determined by comparing the policy's primary variables' scores with the average. The calculation method is shown in Equation (5). Figure 4 shows the PMC surfaces for each water infrastructure-financing policy:

$$\mathrm{PMC}_{\mathrm{surface}} = \begin{pmatrix} X_1 & X_2 & X_3 \\ X_4 & X_5 & X_6 \\ X_7 & X_8 & X_9 \end{pmatrix} \tag{6}$$

The surface of the 10 key policies shows that all 10 policies are public policies, so they all have a full score at X9. Ten key policies are all normative documents, so they all score 1 and all score 0.33 at X3. At X2, only P3 has an explicit 5-year time limit, and its score is below the average. At X1, policies P3, P4, P6, and P7 scored above the

Table 3 | Multiple input-output table.

Primary variables	Secondary variables	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
X1	X1:1	0	0	0	1	0	0	0	0	0	0
	X1:2	1	1	1	1	0	1	0	0	0	0
	X1:3	1	0	0	1	1	1	1	1	1	1
	X1:4	0	0	1	1	0	0	1	0	0	0
	X1:5	1	1	1	1	1	1	1	1	1	1
	X1:6	0	0	1	1	1	1	1	1	1	1
X2	X2:1	1	1	0	1	1	1	1	1	1	1
	X2:2	1	1	1	1	1	1	1	1	1	1
	X2:3	0	0	0	0	0	0	0	0	0	0
X3	X3:1	0	0	0	0	0	0	0	0	0	0
	X3:2	0	0	0	0	0	0	0	0	0	0
	X3:3	1	1	1	1	1	1	1	1	1	1
X4	X4:1	1	1	0	1	1	0	1	1	1	1
	X4:2	1	1	1	1	0	0	1	1	1	1
	X4:3	0	1	0	0	1	1	1	1	1	0
	X4:4	0	0	0	1	0	0	0	1	0	1
	X4:5	1	0	0	0	0	0	0	0	1	0
X5	X5:1	1	1	1	1	1	1	1	1	1	1
	X5:2	1	1	1	1	1	1	1	1	1	1
	X5:3	1	1	1	1	1	1	1	1	1	1
	X5:4	0	1	1	1	1	1	1	0	0	0
X6	X6:1	1	1	1	1	1	1	1	1	1	1
	X6:2	0	1	1	1	1	1	1	1	1	1
	X6:3	0	0	1	1	0	0	0	0	0	0
	X6:4	1	1	1	1	1	1	1	1	1	1
X7	X7:1	1	1	1	1	1	1	1	1	1	1
	X7:2	0	1	1	1	1	1	1	1	1	1
	X7:3	0	1	0	1	0	1	0	0	0	0
	X7:4	1	0	0	0	1	1	1	1	1	1
	X7:5	1	0	0	0	1	1	1	1	1	1
	X7:6	1	0	1	1	1	1	1	1	1	1
	X7:7	0	1	0	1	0	0	0	0	0	0
X8	X8:1	1	1	1	1	1	1	1	1	1	1
	X8:2	1	0	0	0	0	1	1	0	0	0
	X8:3	1	1	0	1	1	1	1	1	1	1
	X8:4	1	1	0	1	1	0	1	1	1	1
X9	/	1	1	1	1	1	1	1	1	1	1

average, accounting for 40%. At X4, policies P1, P2, P4, P7, P8, P9, and P10 have scores above the average, accounting for 70%, reflecting that with the development of financialization and the improvement of financial instruments and financial policies, China's water infrastructure financing has expanded from a single resource to multiple resources. At X5, P2, P3, P4, P5, and P6 have above-average scores and full scores, accounting for 60% of the total. The policies that do not receive full scores are those that lack consideration in terms of sustainable development in water infrastructure financing. In X6, X7, and X8, the weaknesses of each policy itself are more prominent. In X6, only P3 and P4 policy scores are higher than the average. X7 has P1, P2, and P3

Table 4 | PMC Index calculation results.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Mean
tableX1	0.50	0.3	0.67	1	0.5	0.67	0,67	0.5	0.5	0.5	0.57
X2	0.677	0.67	0.33	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.64
X3	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
X4	0.6	0.6	0.2	0.6	0.4	0.2	0.6	0.8	0.8	0.6	0.54
X5	0.75	1	1	1	1	1	1	0.75	0.75	0.75	0.9
X6	0.5	0.75	1	1	0.75	0.75	0.75	0.75	0.75	0.75	0.78
X7	0.57	0.57	0.43	0.71	0.71	0.86	0.71	0.71	0.71	0.71	0.67
X8	1	0.75	0.25	0.75	0.75	0.75	1	0.75	0.75	0.75	0.75
X9	1	1	1	1	1	1	1	1	1	1	1
Score	5.92	5.97	5.21	7.06	6.11	6.23	6.06	6.26	6.26	6.06	6.11
Rating	9	8	10	1	5	4	6	2	2	6	–

Table 5 | Rating results of 10 key policies.

Policy	PMC Index	Rating
P1	5.92	Good
P2	5.97	Good
P3	5.21	Good
P4	7.06	Excellent
P5	6.11	Excellent
P6	6.23	Excellent
P7	6.06	Excellent
P8	6.26	Excellent
P9	6.26	Excellent
P10	6.06	Excellent

policy scores lower than the average, and X8 P3 policy scores are lower than the average. This is also a direction where these policies must focus on improvement in their follow-up work and policy design.

5. DISCUSSION

Water infrastructure is a public good and has a strong public interest. In particular, major water infrastructure, such as the South-to-North Water Diversion Project and the Three Gorges Dam, plays an important role in the country and regional development. However, the huge investment in water infrastructure is unaffordable with traditional government funds alone (Humphreys *et al.*, 2018). Financialization through market-based financial instruments to attract diversified capital into water infrastructure is a global trend (Bayliss, 2013).

A systematic review of policies in China shows that there has been an evolutionary process in the financing of water infrastructure, with recent years showing a significant trend toward financialization. Policies related to

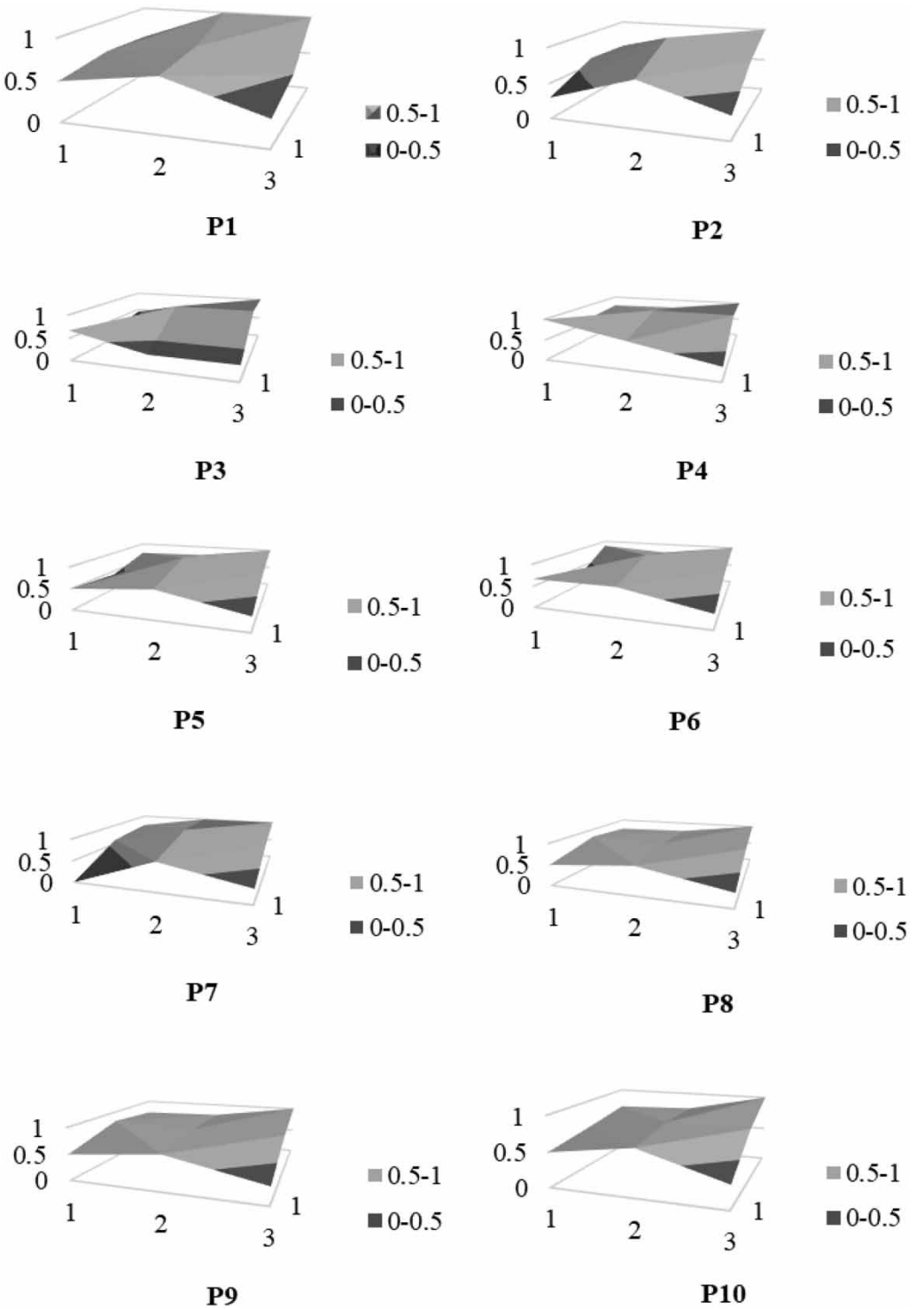


Fig. 4 | PMC surfaces of 10 key policies.

financialization mainly emerged after 2010. In 1997, China started to establish a water construction fund, the mechanism of which was to take 3% of the governmental funds collected by the government (the number of entities paying this fee continued to increase over the next 20 years) and establish a special fund to support water infrastructure construction. At this time, China's water infrastructure investment and financing mechanism has a single subject and a relatively simple and straightforward channel. In 2018, the Chinese government proposed a policy of tax reduction and fee reduction, and the water construction fund stopped collecting for two and a half years before continuing to collect in 2021. However, several developed provinces have reduced the water construction fund's levy, especially Beijing, Zhejiang, and Shandong, who have now stopped the local water construction fund levy. In recent years, the Chinese government has faced great pressure on fiscal revenues due to the impact of multiple factors such as the epidemic, economic transformation, and reverse globalization. The funding gap for water construction in China is prominent, and the need for financialization in water infrastructure is great.

The financialization in water infrastructure is mainly manifested in the application of PPP and REIT models. A PPP is a long-term cooperation based on an agreement between the government and private sector and includes Build–Operate–Transfer (BOT), Build–Transfer–Operator (BTO), Building–Owning–Operation (BOO), and Design–Build–Finance–Operate (DBFO) (Cheng *et al.*, 2016). REITs are equity-based asset securitization mutual funds that originated in real estate (Fuller *et al.*, 2019). In recent years, the Chinese government has expanded REITs to cover the infrastructure sector, including transportation infrastructure, industrial parks, warehousing and logistics, affordable housing, tourism, and agricultural water. REITs can effectively revitalize stock assets, broaden infrastructure-financing resources, and increase the proportion of direct financing (Jin *et al.*, 2022). REITs are suitable for water infrastructure, but are currently in the pilot stage and have no official product listed.

The government and policy have played a leading role in water infrastructure financialization. In the traditional government investment model, there is a single source of funding and no need for specific policies. For addressing the water infrastructure funding gap, governments increasingly need market-based financing and funding sources, which require policies to encourage, attract, and support private finance into water infrastructure. Public policy plays an important role in financialization. For example, China's Ministry of Water Resources has issued policies such as '*Guidance on Promoting the Piloting of Water Infrastructure REITs*' and '*Guidance on Promoting the Development of the Public and Private Partnership (PPP) Model for Water Infrastructure*' to promote the development of the PPP and REITs models. Our analysis of the policies also proves that these policies are highly targeted and reasonable.

Financialization is a complex and dynamic phenomenon. As a development concept and financing means, financialization has gradually expanded to various sectors. The implementation of the UN SDGs, in particular SDG6, requires countries to build a large amount of water infrastructure (Basu & Dasgupta, 2021). According to the latest data for 2020, about 26% of the world's population (2 billion people) do not have access to safely managed drinking water services (Goal 6.1) and about 46% of the population (3.6 billion people) do not have access to safely managed sanitation facilities (Goal 6.2), so there is a need to attract more funding for water infrastructure development through cooperation. Government and policy should play a greater role in financialization and sustainable water development.

6. CONCLUSION

To identify and assess the role of public policies in water infrastructure financialization, this study provides an empirical validation by conducting a policy econometric analysis with China as a typical case. This study systematically analyzes policies related to water infrastructure investment and financing and constructs a policy

assessment index system through the PMC Index model to assess 10 key policies in water infrastructure financing. The POST-CM6 software was used to process the policy texts by word separation and word frequency statistics, and SPSS was used to perform a cluster analysis on this data. The results of the cluster analysis were used to elucidate the process of change in the policy of water infrastructure financing in China.

Faced with the growing fund demand for water infrastructure construction, China's investment and financing policy in water finance is also innovating. This innovation is not only a change in financing methods, but also a series of potential issues, such as the decentralization of governmental authority, expansion of policy actors, and change of development ideas.

Financialization is an important phenomenon in the development of China's infrastructure and it will continue for a period of time. However, there are some negative aspects of financialization, such as over financialization and the contribution to inequality and instability. Water infrastructure financialization must also be integrated into the planning for achieving SDGs so water projects can be developed toward green infrastructure. This study enriches the existing theory of water finance from public policy perspectives. There are two possible directions for further research in the future: on the one hand, to improve the mechanism analysis and theoretical basis of water finance and water infrastructure financialization; on the other hand, water infrastructure financialization can be empirically analyzed based on multi-source data.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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