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The Impact of Government Behaviors on the Transition Towards Carbon Neutrality in the Construction Industry: A Perspective of the Whole Life Cycle of Buildings

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The carbon-intensive economy has dramatically caused global climate changes and profoundly impacted humankind. As one of the largest energy consumers, carbon emissions in the construction industry (CECI) play a crucial role in achieving the carbon neutrality goal. Government behaviors could significantly affect CECI. However, few studies have comprehensively reviewed existing literature regarding the effect of government instruments on triggering carbon reduction. A total of 1,082 papers about CECI from 51 countries/regions were retrieved in this study, while 296 relevant articles on the government behaviors in CECI were collected to conduct further analysis. Based on the bibliometric analysis with CiteSpace, the co-occurrence networks of countries/regions, institutions, keywords and cluster analysis are applied to illustrate the characteristics of previous studies. Furthermore, a research framework has been formulated to review the impact of government behaviors on CECI during the life cycle of buildings. The result indicated that government behaviors could affect CECI through three stages, i.e., material production, construction and operation, which is considered the transmission path of government behaviors towards CECI. Moreover, the findings revealed that government behaviors present the most significant impact on CECI in the following sectors: 1) the green supply chain management and waste recycling in the material production stage; 2) the green building decisions and the adoption of off-site construction in the construction stage; 3) energy conservation behaviors and green retrofit decisions in the operation stage. Finally, this study discusses prior study gaps and provides potential directions for future research.

Keywords: carbon neutrality, carbon emissions, construction industry, government behaviors, whole life cycle

1 INTRODUCTION

Since the early 20th century, carbon-intensive economy has contributed to a 1°C rise in the global average temperature (Rueda et al., 2021), and climate changes caused by carbon emissions have profoundly affected humankind (Yang et al., 2022). As the sector of high energy consumption, the construction industry has contributed quantities of carbon emissions to the world (Lee et al., 2020; Su et al., 2022). Global CO_2 emissions from the buildings sector totaled about 1 billion tons in 2019, accounting for 28% of the world's energy-related carbon emissions, rising to 38% when the construction industry component [the part of the industry used to make building materials such as steel, cement and glass (estimated) is added] is included (IEA, 2021). The Intergovernmental Panel on Climate Change (IPCC) report complied by 278 scientists from 65 countries highlights the magnitude of a comprehensive transformation of the construction industry's emission reduction path (IPCC, 2022). Against the United Nations Framework Convention on Climate Change (UNFCCC), governments worldwide have set respective goals to mitigate carbon emissions. In 2015, the Paris Agreement was adopted by 196 Parties at COP 21 in Paris, a legally binding international treaty on climate change (Paris Agreement, 2015), in which 90 countries have included actions to address building-related emissions or improve energy efficiency in the Paris Agreement. Based on the principle of common but differentiated responsibilities, Chinese government pledged at Paris Climate Conference in 2015 that China would stop increasing its total CO_2 emissions no later than 2030 (Chen J. et al., 2021). Until 2020, 136 countries mentioned emissions reductions in their nationally determined contributions.

An innovative transition to low carbon development in the construction sector is required, which has become a hot topic in the academic and industry community. Developing countries account for 58% of global carbon emissions (Zheng, 2021). Since the last financial crisis, China, as the largest country in the emerging market, has become the world's largest carbon emitter (Wu et al., 2019). Chen et al. (2017a) proved that the CECI consisted of as large as 22.5%–33.4% of the total emissions in China during 1995–2011. To fulfill global responsibility for the green and low-carbon mission, China proposes to achieve carbon peak by 2030 and carbon neutrality by 2060 at the General Debate of the 75th Session of The United Nations General Assembly (Xi, 2020), for which China has set compulsory carbon reduction targets for the construction industry in each province (Wen and Wang, 2020). On account of this, mitigating carbon emissions in the construction industry (CECI) is crucial to achieving the carbon neutrality goal.

The government has played an irreplaceable role in construction carbon reduction with reduced environmental impact (Sunikka, 2006; Ismailos and Touchie, 2017). Government behaviors include law, executive order, reward and compensation (Saka et al., 2021). For industries, the adverse effects of their carbon emissions can be seen as externalities of their economic activities, and there are various ways to internalize the externality of economic activities (Li and Colombier, 2011). In response to this problem in the construction industry, governments typically face a two-step strategy: first, setting environmental targets (e.g., carbon emission mitigation); second, selecting policy tools based on various targets (Stavins, 1996). Policies are a strategic tool for the government to achieve the established goals (Liu et al., 2020), while government policies and market mechanisms can significantly impact technological innovation in construction projects (Wu et al., 2017).

At present, the government has implemented various strategies to reduce CECI. For example, the government has adopted six measures, including regulation-based and direction-based policies, to stimulate green retrofit (Tan et al., 2018). Furthermore, five measures that involve incentives, standards, regulations, guidance and initiatives are implemented to promote off-site construction (Luo et al., 2021). Moreover, some regulations, directives and initiatives have been adopted to intensify the recycling of construction and demolition waste (Kylili and Fokaides, 2017). Government behaviors will clearly affect corporate carbon emissions, and policymakers can influence corporate carbon emissions by adopting environmental regulations and economic incentives (Mahmoudi and Rasti-Barzoki, 2018). Meanwhile, government environmental regulations are essential to eco-innovation in the construction sector (Ortiz et al., 2009; Balasubramanian and Shukla, 2017).

Prior studies have investigated the impact of a single government behavior (such as carbon taxes) on carbon emissions, or focused on the impact of different policies on carbon emissions in a single sector of the construction industry (such as off-site construction). However, extant studies rarely reveal holistic research on the impact of government behaviors on carbon emissions from the perspective of the entire life cycle of buildings. It is argued that more attention should be paid to the indirect carbon emissions of the construction industry (Chen et al., 2017b), which is the most significant contributor. This paper proposes a framework to disclose the impact of government behaviors on the whole life cycle of CECI and reviews the impact of government behaviors on each stage.

This paper is organized as follows: The bibliometric analysis with CiteSpace is presented in **Section 2**. Government behaviors and corresponding transmission paths toward CECI are presented in **Section 3**. **Section 4** investigates the impact of government behaviors in the material production stage. The impact of government behaviors in the construction stage is discussed in **Section 5**, and **Section 6** analyzes the impact of government behaviors in the building operation stage. Finally, concluding remarks, limitations and directions for future research are provided in **Section 7**.

2 BIBLIOMETRIC ANALYSIS

2.1 Methodology and Data Collection

Scientometric analysis is a technology that demonstrates the scientific development process and structure relationship based on the knowledge domain (Trofimenko, 1987). Many software have been developed to conduct a scientometric analysis, such as BibExcel, Ucinet, SCIMAT, VOSviewer and CiteSpace (Shi et al., 2019). Among these, CiteSpace incorporates co-occurrence analysis, evolutionary trend detection and visualization functions to provide a mature approach for bibliometric analysis (Chen, 2006, 2017), which has been widely utilized in

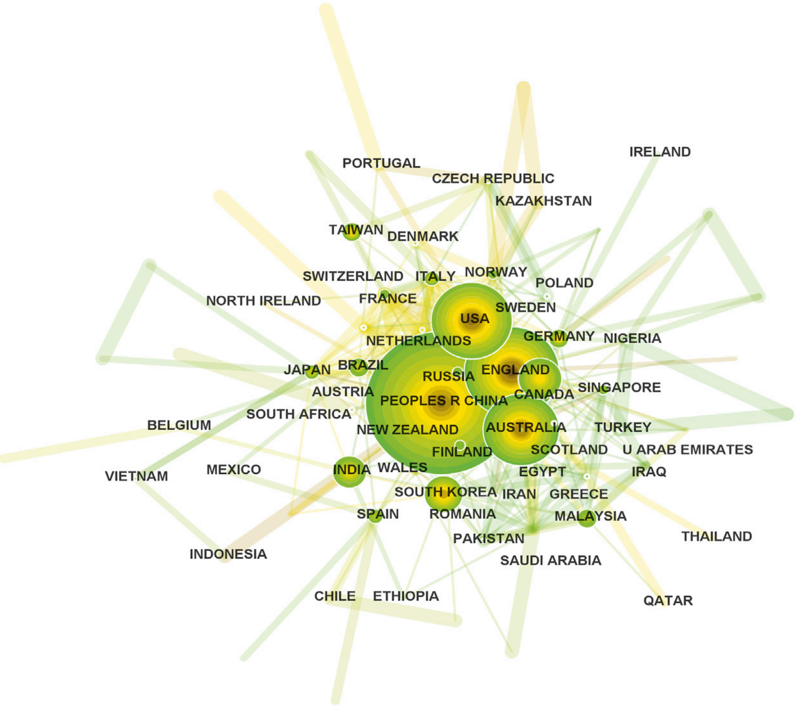


FIGURE 1 | Co-countries/regions network: CECI.

various research fields such as sustainable development (Si et al., 2019; Koondhar et al., 2021; Huang et al., 2022). However, this tool is still less used in the CECI field.

Betweenness centrality and burst strength are two critical indicators in CiteSpace. Betweenness centrality is the ratio of the shortest paths between two nodes to the sum of all shortest paths (Freeman, 1977). Generally speaking, the occurrence of a high betweenness centrality is likely to reveal a transformative discovery (Chen et al., 2009). Citation bursts present keywords repeatedly cited within a specific period (Yu et al., 2017). Burst strength could indicate a sudden change in a citation over a period of time, during which the nodes of high burst strength might be the turning points or milestones in the development of literature themes. This paper used the retrieved result through the core collection database of *Web of Science* (WoS) to conduct a bibliometric analysis.

2.2 Results and Discussion: CECI

This paper conducted two-step bibliometric analyses using different constraints. One step analyzes the existing research on CECI, and the current research on government and CECI is analyzed in another analysis. For the first analysis, the content of string retrieve was set as "TS=("construction industry" AND "carbon emission")". The literature type was set to "journal article" written in English and the database was set to "Web of Science Core Collection" to ensure the quality of our data source. The time span of articles was set as "from 2010-01-01 to 2022-03-05". A total of 1,082 articles were presented according to the above retrieval criteria. The collaboration network of countries/regions captures the contribution network of countries/regions to the body of knowledge of CEIC. **Figure 1** shows that China has the most significant number of publications in all 51 countries, followed by the United Kingdom, the US and Australia, and the topic of carbon emission in the construction sector has been debated among researchers worldwide.

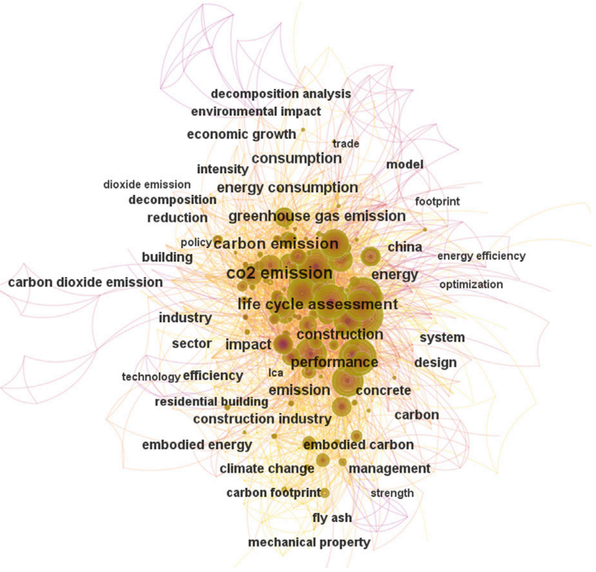


FIGURE 2 | Keywords co-occurrence network: CECI.

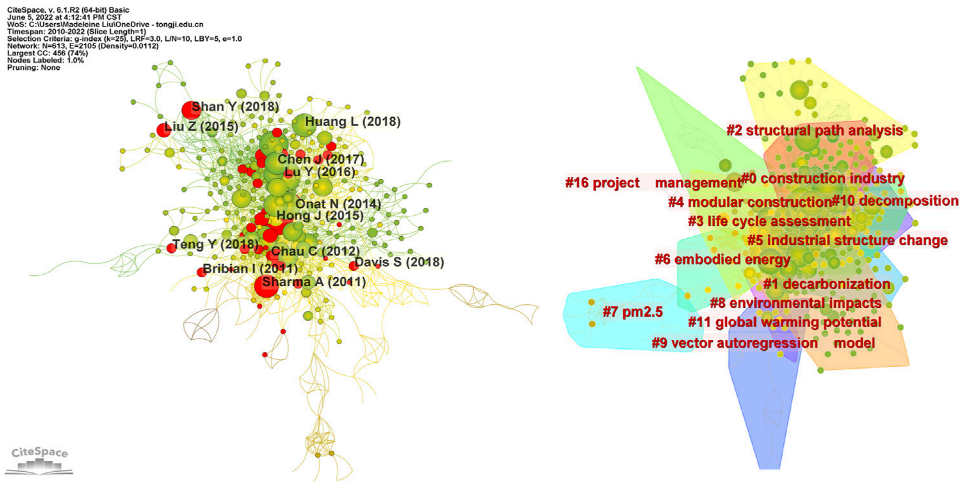
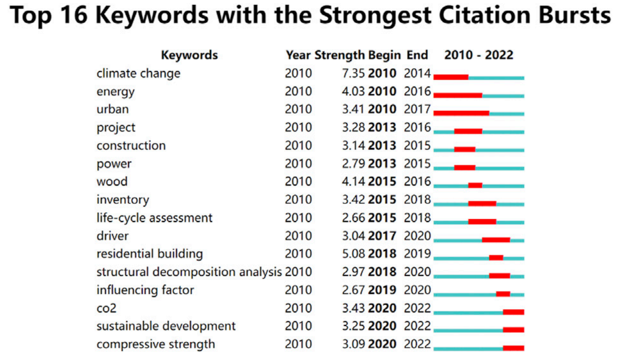


FIGURE 3 | Co-citation network and topic clustering of CECI domains: 2010–2022.

Keywords co-occurrence analysis can demonstrate the keywords that appear most frequently in existing studies and their links, which could help identify the primary topics in the research topic of CECI. The co-occurrence network of keywords is presented in **Figure 2**, which total includes 464 keyword nodes and 2,930 links in prior studies of the CECI field, and the size of each node shows the frequency of keywords appearing. The top five keywords are: CO_2 emission (frequency = 224), carbon emission (frequency = 174), life cycle assessment (frequency = 164), energy (frequency = 119) and construction (frequency = 118).

Figure 3 left-hand presents a co-citation network consisting of 613 nodes and 2,105 links, and the red nodes denote the citation burst, and the color change from brown, yellow to green reflects the time span from past to present (2010–2022). The right side of **Figure 3** demonstrates the cluster analysis of keywords using the Log-Likelihood Ratio (LLR), and thirteen highlighted research clusters were identified. Here, the modularity Q = 0.772 (>0.5), which shows the overall clustering outcomes are significative, while the weighted mean silhouette = 0.878 (>0.8) means that the cluster members have certain similarity and homogeneity. The cluster analysis is an exploratory data mining technique to analyze and identify vital topics, content and interrelationships (Wilks, 2019). The CiteSpace provides access to extract the noun phrases from titles, keywords or abstracts of publications and use them as tags for different groups (Chen, 2006; Si et al., 2019). Among all the clusters, the largest two clusters are #0 (construction industry) and #1 (decarbonization). The former represents the focus of the construction sector on CECI-related research. The cluster "decarbonization" mirrors the decoupling relation between the construction and carbon emissions, and its alternative labels of this cluster include sustainable construction, supply chain, emissions reduction, carbon abatement, carbon mitigation, greenhouse gases, carbon neutrality and so on. For example, the study by Karlsson et al. (2020) indicated that it is technically possible to halve road construction CO_2 emissions with the best available technologies and practices to abate more than three-quarters of the emissions by 2030 and achieve close to net zero emissions by 2045.

The premise of CECI reduction is to clarify the carbon emission source and impact path, which is related to the whole industrial green transition and development. To address this, the research community has carried out a considerable amount of studies to evaluate energy consumption and carbon emissions of the construction sector by different approaches. Furtherly, it has investigated the low-carbon transition of the construction industry, including the cluster #2 (structural path analysis), #3 (life cycle assessment), #4 (modular construction), #5 (industrial structure change), #6 (embodied energy) and #10 (decomposition). For instance, applying the multi-regional structural path and sensitivity analysis model, Chen J. et al. (2022) assessed the structural paths and sensitivity of construction CO_2 emissions in China, India, Japan, Russia, and the United States in 2015. Cluster # 8 (environmental impact) concentrate on 3R (i.e., reduce, reuse and recycling), and keywords labels embody resource recovery, circular economy and waste treatment. For the cluster, Bao and Lu (2021) developed a decision-support framework to plan on-site and


Top 16 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2010 - 2022
climate change	2010	7.35	**2010**	2014	
energy	2010	4.03	**2010**	2016	
urban	2010	3.41	**2010**	2017	
project	2010	3.28	**2013**	2016	
construction	2010	3.14	**2013**	2015	
power	2010	2.79	**2013**	2015	
wood	2010	4.14	**2015**	2016	
inventory	2010	3.42	**2015**	2018	
life-cycle assessment	2010	2.66	**2015**	2018	
driver	2010	3.04	**2017**	2020	
residential building	2010	5.08	**2018**	2019	
structural decomposition analysis	2010	2.97	**2018**	2020	
influencing factor	2010	2.67	**2019**	2020	
co2	2010	3.43	**2020**	2022	
sustainable development	2010	3.25	**2020**	2022	
compressive strength	2010	3.09	**2020**	2022	

FIGURE 4 | Keywords with the most robust citation bursts: CECI.

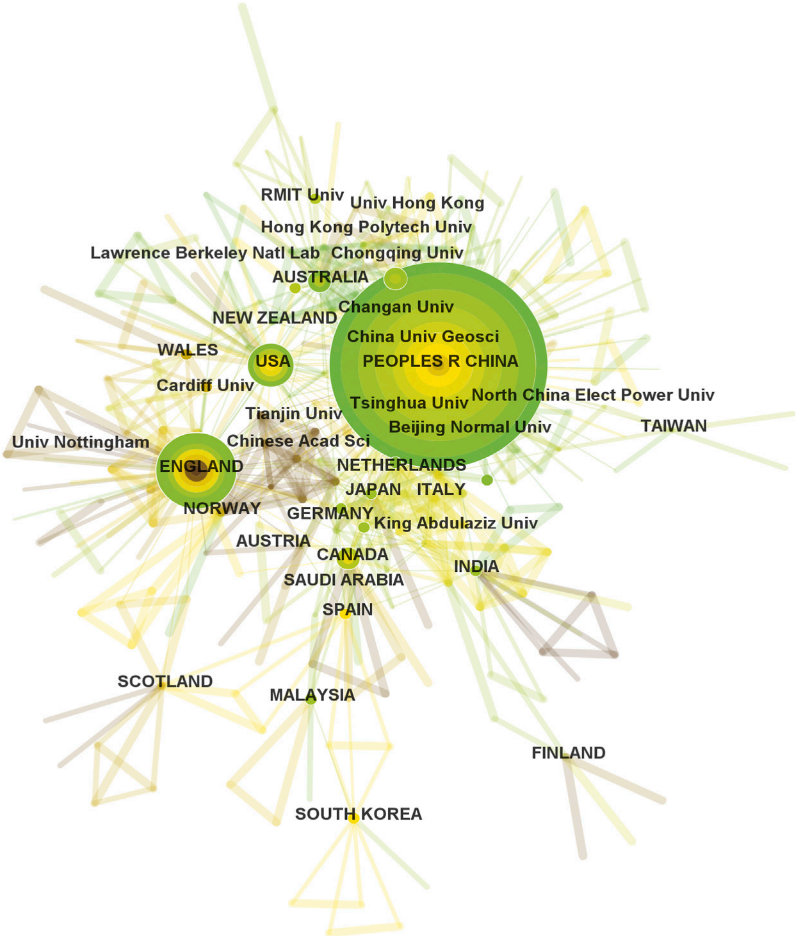


FIGURE 5 | Co-countries/regions and institutions network: CECI and government.

off-site construction waste recycling in the case study of Shenzhen, China.

The keywords bursts in the field of CECI are given in **Figure 4**. Climate change is at the top of the list, with the most robust citation burst of 7.35 from 2010 to 2014. During the 2018–2019 period, the research emphasis on carbon emissions of residential buildings shows an explosive growth (Kneifel et al., 2018; Li et al., 2019). Hotspots in recent years include sustainable development and compressive strength, indicating the construction industry's sustainable transition that incorporates the advancement of techniques and green supply chain management (Ghani et al., 2017; Zhang X. et al., 2022).

2.3 Results and Discussion: CECI and Government

For the second analysis, our keywords for searching included "construction industry" AND "carbon emission" AND "government", and other restrictions are the same as the first time. A total of 296 articles were retrieved, which was greatly reduced compared with the first analysis.

Figure 5 shows the contribution network of countries/regions and institutions to the body of knowledge in the CECI and government perspective. China, the United Kingdom and the United States are still the countries with the largest number of publications in the CECI and government fields, which indicates that research communities from these countries concentrate on the significant roles of government behaviors in carbon reduction action. Active academic communities in Asian-Pacific, European and United States have contributed significantly to the research field on government behaviors of CECI.

Figure 6 shows that in the research field of CECI and Government, impact replaces energy as the top five keywords, and some new perspectives are absorbed, such as innovation and life cycle assessment. Furthermore, there are only three citation bursts in the fields of CECI and government, including management, residential building and design. Though these are not new topics, more microscopic and specific strategy has been discussed in the governmental behavior in this field.

Overall, previous studies have paid attention to governmental behavior in the CECI. Some researchers have tried to reveal the process in specific conditions from various perspectives, such as policy incentives in residential buildings (Ismailos and Touchie,

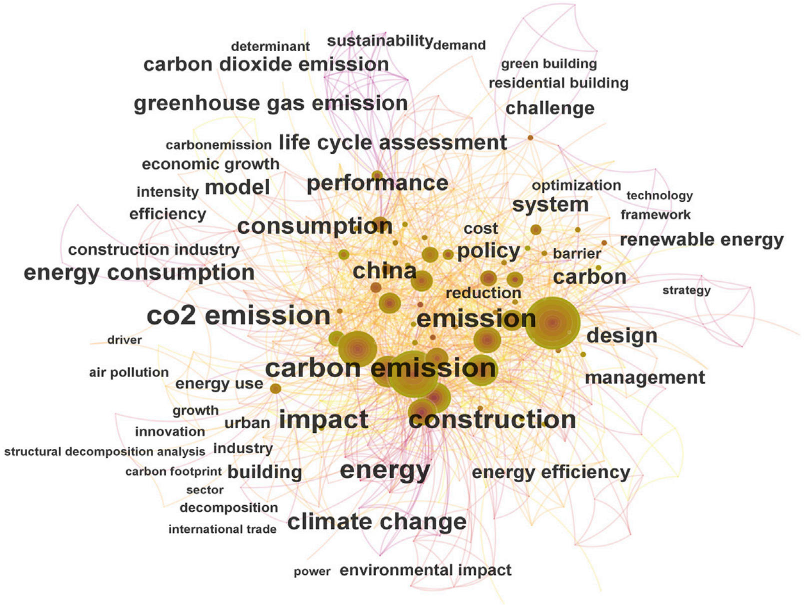


FIGURE 6 | Keywords co-occurrence network: CECI and government.

2017; Huo et al., 2021), carbon reduction in green buildings (Berry et al., 2014; Hope and Booth, 2014), and government role in construction waste recycling (Bao et al., 2019; Bao and Lu, 2020). However, few studies have investigated the government's role in CECI from the life cycle perspective. Thus, a more systematic review of government behaviors in CECI could effectively disclose the influencing path and identify internal barriers, which promote the effectiveness and efficiency of government instruments in carbon reduction in the construction sector.

3 GOVERNMENT BEHAVIORS AND TRANSMISSION PATH

3.1 Government Behaviors

Government can encourage and restrict the construction industry by law, executive order, reward and financial allowance (Saleh and Al-Swidi, 2019). Law and executive orders are compulsory, whereas rewards and allowances are encouraging and voluntary for stakeholders in the construction sector (Saka et al., 2021). Li and Colombier (2011) have divided the governmental tools to regulate energy consumption into two categories, incentives-based instruments and regulatory measures. The former is considered the most cost-effective, while the latter can also contribute to mitigating carbon emissions. Xie et al. (2022) have generalized government intervention into two categories, government support and environmental regulations, and studied their impact on the construction industry separately.

Policy instruments can also be divided into three policy types: supply-side, demand-side, and environmental-side (Wang and Zou, 2018; Xue et al., 2021). In the field of carbon emissions, supply-side policies frequently used by the government include establishing uniform supply standards, increasing training for workers and investing in establishing information platforms. The demand-side policy is a policy tool used by the government to help accelerate innovation by stimulating the demand for innovation. The commonly used demand-side policies include trade supervision and government procurement (Creutzig et al., 2018). Environmental-side policies are always market-based instruments, which could guide the behaviors of stakeholders through market signals released by decision-makers (Wolde-Rufael and Weldemeskel, 2020). Furthermore, in Finland and the United Kingdom, governmental policies can be divided into three categories: economic, regulatory, and soft (Kern et al., 2017). Liu et al. (2020) summarized six types of policies: control, technology, economic incentives, certification, information, and organization and professional.

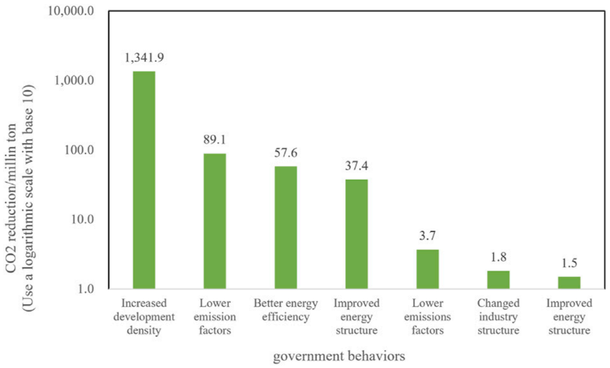


FIGURE 7 | Impact of different government behaviors on CO_2 reduction [The picture is drawn by the authors with data source from Wu et al. (2019)].

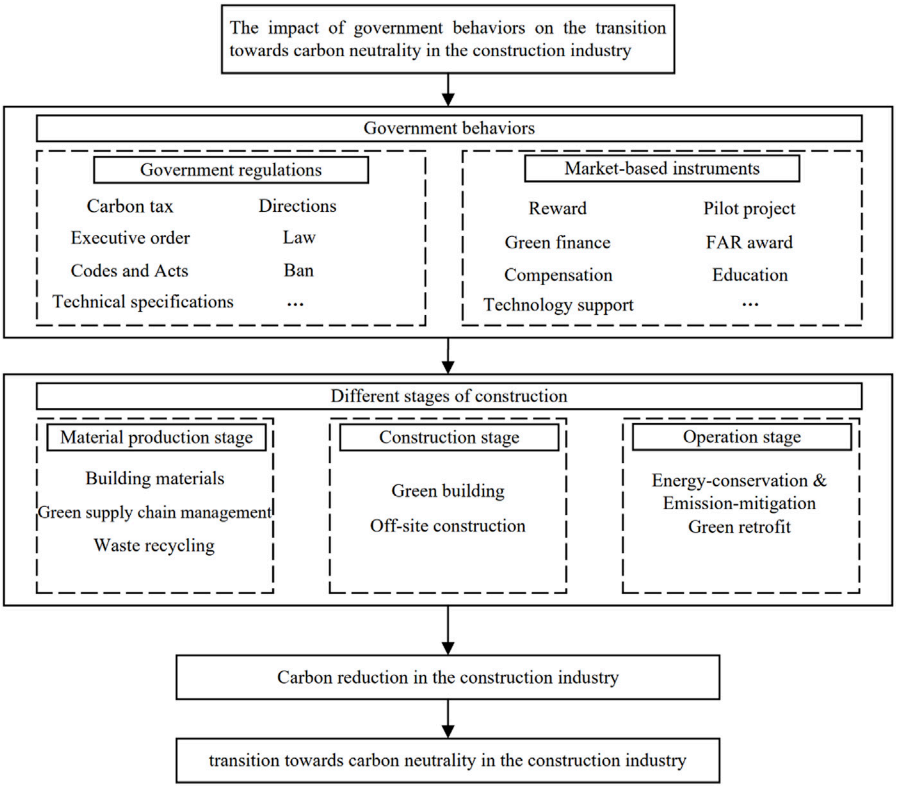


FIGURE 8 | The transmission path of government behaviors towards CECI.

Simultaneously, the effect of different government actions on reducing CECI is different. Environmental-side policies are most frequently adopted by the Chinese government, and "regulation control" and "goal-planning" instruments are the ones most widely applied (Liao, 2016). Ozorhon (2013) probed the response of construction clients to low-carbon building regulations and governmental policies. Wu et al. (2019) investigated the carbon reduction effect of government behaviors and quantified it (**Figure 7**).

This study categorizes government behaviors as government regulations and market-based instruments according to whether they are mandatory or optional. Stakeholders in the construction industry must accept the former but can decide whether to adopt the latter in line with specific market conditions and development strategies.

3.2 Transmission Path

Carbon emissions in the construction industry can be divided into operational and embodied carbon emissions, in which embodied carbon emissions include direct and indirect emissions (Giesekam et al., 2014). Li et al. (2020) summarized it as

$$C = C_D + C_I + C_O$$

where C represents the total carbon emissions of the construction industry, and C_D, C_I and C_O denote the direct carbon emissions, indirect carbon emissions and carbon emissions generated during the building operation, respectively.

Researchers classified the construction sector into various stages to adapt their study focus. Hong et al. (2014) divided construction into three stages: material manufacturing, transportation, and on-site construction, to examine the carbon emissions of the Korean construction industry. Li et al. (2017) have calculated the embodied carbon in the life cycle of a residential building, which is divided into five stages, including materials production, transportation, construction, maintenance, and demolition and disposal. Lu et al. (2018) decomposed the carbon emissions of the construction industry into three stages of material production, construction and operation, and found that the material production stage emits the most greenhouse gases based on empirical research in China. Ruiz and Guevara (2021) disclosed the impact of policies on different stages (design, construction, and operation) of the life cycle of social housing units.

Based on the summary of previous studies, this study proposes that government behaviors can affect CECI *via* exerting impacts on three stages during the life cycle of buildings, including material production, construction and operation, indicating that different stages in the life cycle of buildings are the transmission path towards CECI for government behaviors. Given this context, this study establishes a research framework to analyze the impact of government behaviors on CECI and reviews the impact of each government behavior (**Figure 8**). As

TABLE 1 | Representative literature about government behaviors in the material production stage.

Sector	Policy classification	References	Tools studied
Building materials	Government regulations	Nabernegg et al. (2019) Tangtinthai et al. (2019)	Taxes
		Kylili and Fokaides (2017) Wu et al. (2019)	Legislation and administrative orders
	Market-based instruments	Chen et al. (2022b) Akan et al. (2017)	Technical standards
Green supply chain management	Government regulations	Xie et al. (2022) Zakeri et al. (2015) Halat et al. (2021) Luo et al. (2022)	Environmental regulations Carbon tax
	Market-based instruments	Xie et al. (2022) Zakeri et al. (2015)	Government support Carbon price and carbon trading
Waste recycling	Government regulations	Yan et al. (2014) Kylili and Fokaides (2017) Karlsson et al. (2020) Doust et al. (2021)	Legislative and regulatory change
		Kylili and Fokaides (2017) Di Maria et al. (2018) Hoang et al. (2021)	Taxes
	Market-based instruments	Kylili and Fokaides (2017) Di Maria et al. (2018) Bao et al. (2021) Yu et al. (2022)	Sustainable systems
		Bao et al. (2019) Hoang et al. (2021)	Green government procurement
		Nussholz et al. (2019) Bao and Lu (2021) Wang et al. (2021a)	Guidance and support

the framework shows, government behaviors on CECI embodied in the policy toolkit, industry standards and corresponding behavioral supervision, which could affect construction carbon emissions directly (construction stage) and indirectly (material production and operation stages) through the flow of the life cycle of buildings.

Sections 4, **5** and **6** reviewed prior studies and discussed the governmental impact mechanism of carbon reduction to illustrate the role of government instruments in different stages.

4 MATERIAL PRODUCTION STAGE

In the material production stage, government behaviors can influence CECI through building material production, material supply chain and waste recycling. **Table 1** shows representative research on this topic.

4.1 Building Materials

The production and transportation of building materials generate a large amount of carbon emissions. A process-based life cycle assessment incorporating an extended system boundary indicated that 94.36% of all indirect emissions is caused by the production of building materials, whose transportation accounts for a share of 3.64% (Hong et al., 2015). Wu et al. (2019) used Logarithmic Mean Divisia Index to analyze CECI from the perspective of a life cycle, and found that CECI mainly comes from the manufacturing of building materials and the operation of buildings, which account for 58 and 40%, respectively. In the extraction phase of raw materials, CECI also constitutes the most significant proportion (Gan et al., 2018). In 2017, the construction industry consumed 25% of annual steel production and 75% of cement production in China (Shi et al., 2017).

Government behaviors can indirectly affect CECI by affecting the production and transportation of building materials. By combining a Computable General Equilibrium and a Multi-Regional Input-Output model, Nabernegg et al. (2019) researched Austria's carbon emission policy in the construction sector and found that the government's carbon tax on additional carbon emitted in the building materials production stage performs effectively in reducing carbon emissions. Kylili and Fokaides (2017) proposed that the government could adopt legislation to ensure the sustainable development of building materials. Tangtinthai et al. (2019) believed that the Thai government should introduce environmental taxes on the extraction, processing and disposal of building materials to reduce CECI. During China's 12th Five-year Plan (2011–2015), due to the overcapacity of steel and aluminum, China's carbon emissions from construction raw materials soared from 1.32 billion tons to 2.63 billion tons. Therefore, Chinese government adopted laws and administrative orders, such as Guiding Opinions of the State Council on Resolving Serious Production Overcapacity Conflicts, to optimize the excess capacity upstream of the construction industry and reduce CECI (Wu et al., 2019).

Carbon emissions vary in multiple building materials (Ouyang and Lin, 2015), and carbon cut action could be more targeted. Chen M. et al. (2022), Chen et al. (2022c) found that among all building materials, cement, brick, steel, asphalt felt and lime contributed about 93.1% of the total embodied energy and 95.7% of the total embodied carbon. Furtherly, steel and linoleum were not used much in the construction process but were the primary sources of carbon emissions, while sand and gravel were consumed most but contributed less carbon emissions during construction, so they proposed that government should consider this situation when making decisions. Akan et al. (2017) investigated the measurement of the total greenhouse gas emissions for a tunnel construction project by a Turkish firm, which argued that the government and industry associations could affect the supply chain of the construction industry by promulgating relevant regulations on concrete production technology, thereby indirectly affecting the CECI.

4.2 Green Supply Chain Management

Government behaviors can also mediately affect carbon emissions *via* impact on the supply chain of the construction industry, such as the transportation of building materials and stakeholders in the supply chain. However, previous research merely considered the concept of Green Supply Chain Management (GSCM) in construction (Wibowo et al., 2018), and only 1.39% of all GSCM studies focused on the construction industry (Bhatia and Gangwani, 2021).

The government can promote the implementation of GSCM in the construction industry by means of law and executive orders, and the government's incentives and support also contribute to the application of GSCM. Xie et al. (2022) studied the effect of government support and environmental regulations on GSCM in the construction industry. Generally, environmental regulations focus on command-and-control, whereas government support is market-based and can clarify top-level environmental objectives. Their empirical study found that environmental regulations can exert pressure on stakeholders in the construction industry and, therefore, force them to obey the laws, and government support can promote the execution of GSCM; both support and regulations can indirectly contribute to the reduction of carbon emissions by employing GSCM.

As the carbon emissions of the supply chain network account for an increasing proportion of the impact of global climate change (Wang et al., 2019), carbon price and carbon trading are also applied in supply chain management to promote carbon reduction (Zakeri et al., 2015). The government can influence the supply chain through carbon tax, whereas the design of carbon tax policy and the structure of the supply chain will affect the outcomes of the policy. Luo et al. (2022) used four game-theoretic models to evaluate the impact of carbon tax policy on a closed-loop supply chain. They found that carbon tax policies can encourage producers to invest in technical innovation to reduce carbon emissions when adequately designed, but unreasonable carbon tax policies would perform oppositely. It is argued that the government could encourage low-carbon consumption by subsidizing the demand side to reduce carbon emissions. Halat et al. (2021) investigated carbon tax policy in inventory games of multi-echelon supply chains, and found that the government can affect the supply chain through the carbon tax to reduce carbon emissions. However, for supply chains with a relatively high cooperation structure, an excessive carbon tax will reduce the effect of carbon emission reduction, so a high carbon tax is more effective for decentralized supply chains. Meanwhile, it is notable for the public departments to establish a mandatory regulatory platform and incentive market mechanism for firms' environmental information disclosure (Wang et al., 2022).

4.3 Waste Recycling

Large amounts of construction and demolition waste (CDW) are continuously generated along with construction activities (Akhtar and Sarmah, 2018; Hao et al., 2021). As one of the most extensive waste types, CDW includes wood, bricks, glass, plastics, concrete and steel (Yazdanbakhsh, 2018), whereas only 5%–15% of China's annual 1,500 million tons CDW is eventually recycled (Xu et al., 2019). The main reason for the low recycling rate is the obstacles in the utilization process, and government behaviors are essential to eliminate the barriers to the recycling use of building materials (Nussholz et al., 2019). The government could promote carbon emissions cut by promoting CDW reuse through policy instruments (Liu et al., 2022). Recycling CDW can significantly reduce carbon emissions, which can be seen as a reduction of implied carbon emissions from building materials (Peng et al., 2021). In addition, the last mile problem of sourcing and qualifying waste from discrete sites for central processing needs to be addressed, which could empower the CDW recycling through various intelligent technologies and concerted collaboration from multi-stakeholders coordinated by a determined government (Bao et al., 2021).

The government could exert an impact on waste recycling *via* various instruments. Kylili and Fokaides (2017) classified current policies to enhance the sustainability of building materials into three types: regulations, directives and initiatives. Some measures are critical to reducing CDW, consisting of incentives, sustainable design appraisal systems, tax breaks, and increased stringency of fiscal policies and legislative measures. Wang G. et al. (2021) analyzed the mandatory, incentive and guidance policies separately, and found that guiding policy on carbon reduction exerts the best effect when used singly, and the combination of these three policies shows a superiority effect. Hoang et al. (2021) studied the prospective supply of and demand for CDW recycling plants in Hanoi, and found that government behaviors to internalize externalities are necessary for CDW recycling. Thus, the government could readjust the price of recycled concrete aggregates by imposing raw material taxes, increasing green government procurement, and setting quality standards, thereby increasing the recycling of CDW and reducing carbon emissions. The government can also remove barriers to using circular building materials by encouraging the waste collection

TABLE 2 | Related literature about government behavior on CECI in the construction stage.

Sector	Policy classification	Representative scholars	Main content and viewpoints
Green Building	Government regulations	Steinfeld et al. (2011)	Laws
		Chen et al. (2021b)	Penalty
	Market-based instruments	Olubunmi et al. (2016)	Reward and compensation
		Zou et al. (2017)	
		Yang et al. (2019)	
		Long et al. (2020)	
		Gou (2020)	
		Saka et al. (2021)	
		Kong and He (2021)	
		He and Chen (2021)	
		Qiao et al. (2022)	
		Yang et al. (2021)	Carbon trading market
		Blackburn et al. (2020)	Promotions
		Mustaffa et al. (2021)	
Off-Site Construction	Government regulations	Luo et al. (2021)	Mandatory technical specifications
	Market-based instruments	Luo et al. (2021)	Reward and compensation
		Xue et al. (2021)	
		Yi et al. (2021b)	
		Wang et al. (2021c)	
		Gan et al. (2018)	Pilot project and guidance
		Luo et al. (2021)	

and recovery markets to recycle CDW at a higher value (Nussholz et al., 2019). Doust et al. (2021) considered regulatory change the best way to reduce CDW, and policies should focus more on front-end strategies. Government support and amenable policies can greatly determine the decision-making of on-site and off-site recycling options (Bao and Lu, 2021). The strategy combinations of government instruments could be practical to achieve CDW circular management, including 1) implementing intense governmental interventions, 2) developing a thriving CDW recycling market, 3) introducing advanced recycling technologies, and 4) enacting responsive institutional arrangements (Bao and Lu, 2020).

Generally, four processing methods are often utilized in CDW: recycling after selective demolition, advanced recycling, downcycling and landfilling (Di Maria et al., 2018). Higher quality recycling tends to demonstrate better environmental benefits. When recycling waste, even if this process is feasible, it is necessary to consider whether the carbon reduction resulting from recycling will be offset by carbon emissions from transport processes; if the latter is greater than the former, the environment will continue to be damaged (Vadenbo et al., 2017). Taking the Hong Kong case, Bi et al. (2022) established a combinatorial approach to improve the efficiency of waste collection and transportation and proposed to develop a work dispatch system like Uber or proper vehicle routing algorithms for improving waste collection efficiency and reducing carbon emissions. In addition, the landfill tax can effectively organize the landfill of CDW; meanwhile, other government behaviors are needed to promote the transfer of CDW to higher quality recycling, such as a recycled aggregates quality-certification system and natural aggregates tax increase (Di Maria et al., 2018). After assessing the effectiveness of China's CDW management policy, Yu et al. (2022) proposed that the government should strengthen the information disclosure of CDW generation, landfill and recycling and establish a unified network monitoring platform. Moreover, the government could encourage the introduction of innovative procurement models into the CDW, such as Public Private Partnership (PPP), and it is critical to devise institutions to prevent corruption and opportunistic behaviors during the process (Bao et al., 2019).

In addition to CDW, the government can also reduce CECI by spurring the recycling of other materials to produce building materials. Yan et al. (2014) suggested the government could strengthen the reuse of these sediments by relaxing the legal supervision on the treatment of dredged sediments. The government can encourage the use of them as raw materials to produce controlled low-strength material, and green building materials produced through controlled low-strength material can reduce CECI from building materials production. Karlsson et al. (2020) found that the change in Swedish waste regulation, which puts limitations on the reuse of excavation masses, can help Swedish construction supply chains reach net-zero carbon emissions.

5 CONSTRUCTION STAGE

In the construction stage, government behaviors can impact CECI by affecting the green building decisions and the adoption of off-site construction. **Table 2** presents some representative studies.

5.1 Green Building

Green building has been put forward to mitigate the significant impacts of the building stock on the environment, society and economy (Zuo and Zhao, 2014; Mattoni et al., 2018), and the core of the green building is to save all sorts of resources to the greatest extent and to minimize the pollution throughout the life cycle (Wong and Zhou, 2015). Green building presents multiple benefits to society (Olubunmi et al., 2016), and can significantly reduce CECI during the whole life cycle of the building. Hence, the green building benefits human beings living in harmony with nature and has important strategic significance (Qiao et al., 2022).

Government behaviors could internalize the positive externality of green building and avoid market failure effectively (Olubunmi et al., 2016). Government behaviors, regulation tools and promotions are critical external incentives to develop green buildings (Mustaffa et al., 2021). Gou (2020) proposed that governments can encourage the private sector to engage in green building transition through monetary incentives. The Australian government's energy policies and regulations provide incentives for promoting green buildings in Australia at different levels (Steinfeld et al., 2011). The Chinese government fines buildings that do not comply with green building rules, which could regulate the behaviors of stakeholders and avoid disorderly competition in the industry (Chen L. et al., 2021). Governments can also disseminate the value system of green buildings to the public by establishing green building ecological demonstration zones to enhance public awareness and acceptance (Blackburn et al., 2020). Government behaviors constantly interact with the stakeholders' decision-making in the green building sector (Qiao et al., 2022). Saka et al. (2021) summarized the government's reward and compensation policies to promote the development of green buildings into nine types, and determined that the government can promote the development of green buildings through one policy or a combination of more than one. Furthermore, green building technologies also face some obstacles. The lack of green building loans from banks and the cost of policy incentives are the biggest barriers to be addressed, so the government should pay more attention to the market mechanism when trying to affect the green building industry (Qiao et al., 2022).

Different policies have distinct effects on moving green buildings forward (He and Chen, 2021), and understanding and assessing the policy effectiveness and efficiency could better encourage the green-building initiative in the construction industry (Li Y. et al., 2021). Previous research indicated that the government's market-oriented voluntary incentives have a better effect than mandatory measures such as laws and regulations (Borck and Coglianese, 2009; Saka et al., 2021). When considering the effects of environmental tax, green subsidy and carbon trading market on green building technology separately, the green subsidy policy has a better effect than environmental tax. The proportion of market participants in the carbon trading market is positively correlated with adopting green building technologies, and policy combinations are more effective than individual policy instruments (Yang et al., 2021). Kong and He (2021) divided the green building policies of more than 30 provinces in China into supply-side and demand-side, and they found that compared to demand-side policies (such as housing loans and tax incentives), supply-side policies (such as land policies and floor area ratio incentives) could better promote the innovation of green building technologies. If only government subsidies are considered, the incentive effect of government subsidies to consumers (demand side) is better than that to developers (supply side); and subsidizing both will bring the highest social welfare (He and Chen, 2021). By conducting evolutionary game model, Yang et al. (2019) found that positive policy incentives may have a negative impact on the implementation of green buildings, while negative policies are proven to be effective, so government could adopt user-customized strategies. Olubunmi et al. (2016) explored the incentive effect of the government's external incentives on green building owners, and the evidence suggested that non-financial incentives are more practical in promoting green buildings when compared with financial incentives, thus the government should seek a mechanism that can determine the best level of incentives to promote the progress of green buildings.

Government behaviors vary over time and circumstances. From 2008 to 2012, green building development in China was voluntary by the private sector; In 2013, the central government made the development of green buildings a mandatory requirement for government investment projects through a series of targeted policies, which contributed to an exponential growth in the number of green projects (Gou, 2020). Nevertheless, there were many opportunistic behaviors in the process: some developers falsified data on green grades, and some sellers made false claims about the green performance of their products in order to capture excess profits, which also reduced consumers' willingness to pay (Qiao et al., 2022). In addition, financial subsidies account for more than 50% of the Chinese government's incentive policies for green buildings (Zou et al., 2017), which has put enormous pressure on the national finances. Therefore, the government should adjust its incentive policies to adapt to the market development stage of green buildings and determine the optimal subsidy intensity in line with the actual situation of different stages, which will help the market achieve an optimal equilibrium (Long et al., 2020). More specifically, understanding collaboration networks in construction carbon reduction could be helpful to government agencies for facilitating built environmental transformation and multi-disciplinary collaboration (Wang G. et al., 2021).

5.2 Off-Site Construction

Off-site construction (OSC) originates from manufacturing (Mao et al., 2015), which means that the builder produces a part of the components required for the construction in a controlled environment and then transports them to the construction site for assembly (Yi et al., 2021b). The main advantages of OSC encompass faster construction (Gan et al., 2018), lower cost (Polat, 2008), ability to reduce CECI and construction waste (Mao et al., 2013), and lower labor requirements (Jaillon and Poon, 2008). However, due to market share and technical integration, OSC is currently not widely used. In China, the gross floor area of projects adopting OSC in 2020 is only 630 million square meters, accounting for only 20.5% of annual new buildings (Xue et al., 2021). In order to achieve the carbon neutrality goal, the Chinese government needs to promote the widespread use of OSC through effective policies (Luo et al., 2021). Currently, policymakers worldwide are working to push OSC promotion by developing multiple policies (Weisheng and Hongping, 2012; Guribie et al., 2021). In summary, the current mandatory instruments adopted by the government to promote OSC include legal constraints and mandatory technical specifications, and market-based instruments include floor area ratio (FAR) awards, financial subsidies, land support, financial support, tax subsidies, and pilot project assistance (Jiang et al., 2019; Pham et al., 2020).

Luo et al. (2021) divided the government's policies to promote OSC into five forms: incentives, standards, regulations, guidance and initiatives. In China, regulations are the easiest and most effective way to promote OSC but are often ignored by policymakers; policymakers have created various incentives to promote OSC promotion, whereas they are rarely used because they impose additional financial burdens on governments. Luo et al. (2021) concluded that the Chinese government should further optimize policy tools and provide financial support. Using partial least-squares path analysis, Xue et al. (2021) measured the impact of three types of policies (demand-side, supply-side and environmental) on the implementation of OSC by developers. The result illustrated that environmental policies perform a more significant promotion effect on the implementation of OSC, while supply-side and demand-side policies have no direct effect on the implementation of OSC by developers. Hence, the government should optimize the policy system and implement a combination of mandatory policies and market-based instruments (Xue et al., 2021; Hussain and Lee, 2022).

Using social network analysis, Gan et al. (2018) analyzed 15 types of stakeholders' power status on 13 types of barriers and identified that the government and developers exert the most significant impact on OSC execution. Therefore, the government should take measures to endorse stakeholder collaboration to overcome existing barriers, such as the dominant conventional project processes and the lack of expertise. As a market-based instrument, government subsidies can support the promotion of OSC, and policymakers need to pay attention to the rationality of subsidies (Yi et al., 2021a). Based on a three-stage Stackelberg game framework, Yi et al. (2021b) found that unreasonable government subsidies for OSC would reduce the use of precast concrete in construction and thus increase carbon emissions from transporting precast concrete. Grounded on an evolutionary game model, Wang H. et al. (2021) analyzed the interactive effect of the behaviors of government and developers, and proposed that the government should establish an institutional framework that includes reputational rewards and financial incentives for developers. The government should strengthen public education to mitigate negative perception, and cultivate OSC professionals by guiding school-enterprise cooperation and establishing education bases.

6 OPERATION STAGE

The operation activities of the building mainly include lighting, cooking and the maintenance of heating, ventilation, and air conditioning (HVAC) systems (Fan et al., 2018), which generate a lot of operational carbon (Hacker et al., 2008). In winter, building operation accounts for about 24% of CECI due to coal consumption and power use of buildings (Zhang and Wang, 2016). The contribution of the building operation will increase to 40% if the accommodation and offices on the building site are taken into account (Wu et al., 2019). Wu et al. (2019) argued that CECI mainly comes from the manufacturing of building materials and the operation of buildings, accounting for 58 and 40%, respectively. In China, carbon emissions from building operations increased from 0.67 gigatons in 2000 to 2.11 gigatons in 2018, accounting for 21.9% of China's total carbon emissions (Chen M. et al., 2022). From the experience of China and the United States, government guidance is the most considerable motivation for carbon reduction in building operations (Zhang S. et al., 2022). At the same time, for built roads and other infrastructure, the government should concentrate more on maintenance rather than repair, which will have a better effect on carbon emission reduction (Ruiz and Guevara, 2020).

Government behaviors can impact CECI in the operation stage by affecting energy conservation behaviors and green retrofit decisions. **Table 3** exhibits some representative literature.

6.1 Energy Conservation and Emission Mitigation

Energy-conservation and emission-mitigation (ECEM) are essential to reduce carbon emissions in the operation phase. Government intervention can help ECEM establish structured processes to improve energy use efficiency and raise social awareness (Ruparathna et al., 2016).

The current research on carbon emission reduction of buildings in the operation phase mainly focuses on residential and commercial buildings. Government ECEM strategies in the residential sector include mandatory, information, and economic intensive (Ma et al., 2019b). The mandatory strategy includes formulating energy-saving standards in the residential sector, the information strategy includes energy efficiency labels and stepped electricity prices, and the intensive economic strategy involves special government funds and financial subsidies. Similarly, Azevedo et al. (2013) compared these three energy policies as sticks, tambourines, and carrots. For commercial buildings, it is very effective for local governments to develop a comprehensive energy consumption detection platform and provide necessary administrative and financial support (Li et al., 2022). Ma et al. (2019a) noted that the government's firm and continuous commitment to building energy conservation and emission reduction and the promotion of the large-scale use of renewable energy in civil building operations provide a strong guarantee for the successful implementation of government energy conservation regulations. Coal still accounts for 70% of all energy and other consumption (Xu et al., 2014); therefore, the government can significantly reduce CECI by advocating using clean energy such as natural gas to replace coal (Wu et al., 2019). Government should formulate a more feasible low-carbon or zero-carbon roadmap, promote the electrification of urban and

TABLE 3 | Associated literature about government behavior on CECI in the operation stage.

Sector	Policy classification	References	Main content and viewpoints
Energy conservation and emission mitigation	Government regulations	Yao et al. (2005) Azevedo et al. (2013) Delmastro et al. (2015) Ma et al. (2019b)	Mandatory standards
	Market-based instruments	Azevedo et al. (2013) Ruparathna et al. (2016) Ma et al. (2019b) Wu et al. (2019) Han et al. (2021) Chen et al. (2022a) Zhang et al. (2022a)	Information strategy
		Azevedo et al. (2013) Fan and Xia (2017) Ma et al. (2019b) Li et al. (2022)	Economic intensive strategy
Green retrofit	Government regulations	Tan et al. (2018) Liu et al. (2020) Tan et al. (2021)	Direction-based policies
		Tan et al. (2018) Liu et al. (2020) Tan et al. (2021)	Regulation-based policies
	Market-based instruments	Tan et al. (2018) Iralde et al. (2021) Tan et al. (2021) Kim et al. (2022)	Financial support policies
		Jagarajan et al. (2017) Tan et al. (2018) Tan et al. (2021)	Evaluation-based policies
		Tan et al. (2018) Bobrova et al. (2021) Tan et al. (2021) Alabid et al. (2022)	Knowledge and information policies

rural residential consumption and accelerate electricity decarbonization in society to better develop the decoupling effect in Carbon Kuznets curves to hit the carbon neutrality goal (Chen M. et al., 2022).

The Chinese government introduced a series of building energy standards early in the 1980s, but the implementation of the standards at that time was slow (Yao et al., 2005). Between 2006 and 2015, in the field of residential ECEM, the Chinese government has formulated more than eighty policy documents, over ten relevant codes and acts, and at least fifty mandatory standards, which made remarkable achievements in reducing carbon emissions in China's residential sector (Ma et al., 2019b). The China Act on the Energy Efficiency of Civil Buildings promulgated by the Chinese government in 2008 has made significant contributions to the ECEM of Chinese civil buildings, such as the unprecedented development of the application of renewable energy in the building operation stage (Ruparathna et al., 2016), and the promotion of the establishment of energy conservation policies system of buildings (Han et al., 2021). At the same time, the introduction of the central government's national strategy and financial incentives, such as the "Solar Energy Roof Plan" in 2009 (Fan and Xia, 2017), made the geothermal and solar application areas of civil buildings in China reach 478 and 476 million square meters respectively at the end of 2016 (Ma et al., 2019a). Prior research recommended that the Chinese government continue to implement energy policy within an appropriate policy framework, which will help China reduce energy consumption by 850–4005 PJ in 2030 compared to a scenario where no policy is adopted (Delmastro et al., 2015).

While each country is establishing its policy system for carbon emission reduction in the building operation field, it is also crucial to conduct international technical cooperation RandD and experience sharing sessions on carbon emission reduction in the construction industry (Zhang S. et al., 2022). There are regional differences in the carbon emissions of building operations due to differentiation in economic development levels and climate conditions (Wang Z. et al., 2021), so the government needs to take different carbon emission reduction measures to respond to local conditions when intervening (Li H. et al., 2021). The government has achieved excellent outcomes in promoting technological advances in ECEM, but efforts to help build energy habits and develop low-carbon lifestyles for building users are somewhat inadequate (Ruparathna et al., 2016). The usage behaviors of occupants in buildings will significantly alter building energy consumption and carbon emissions. The government should fully consider the impact of occupant behavior when issuing energy policies, as misunderstood and oversimplified occupant behavior will bring new problems (Hu et al., 2020).

6.2 Green Retrofit

Compared with green buildings mainly oriented to creating increments, green retrofit aims to improve the energy and resource efficiency of existing buildings during the operation phase of the building (Liu et al., 2020). Green retrofit is anticipated to trigger global energy and resource efficiency effectively, thereby reducing carbon emissions (Ruparathna et al., 2017).

Government policies are of great importance for green retrofit (Baldwin et al., 2018), and government behaviors are the pivotal drivers for green retrofit development and carbon reduction (Liu et al., 2020). Many countries have carried out corresponding measures to promote green retrofit, such as the Green Deal in the UK, the Building Retrofit Energy Efficiency Financing scheme in Singapore and the Energy Policy Act in the United States (Liu et al., 2020). Tan et al. (2018) divided more than 500 policies in more than 29 countries worldwide into six categories: direction-based policies, regulation-based policies, financial support policies, organization and professional training policies, evaluation-based policies and knowledge and information policies. It is argued that different policies can play particular roles at different stages.

Direction-based policies, such as plans, directives or frameworks, can provide long-term direction for the market, reflecting the macro trend of market development. Government policies, such as the EU Energy Performance of Buildings Directive 2018/844, demonstrate policymakers' determination to promote the green transformation to industry stakeholders and form the basis of all policies (Liu et al., 2020). Regulation-based policies refer to government laws and regulations. Common evaluation-based policies include government-issued labels and green ratings for projects, such as the Green Building Evaluation Label in China, the Eco-Management and Auditing Scheme in the EU and the Leadership in Energy and Environmental Design (LEED) in the US. The government's assessment helps identify the potential for renovation of old buildings, paving the way to initiating subsequent laws and financial policies (Jagarajan et al., 2017).

Financial support policies, such as government subsidies and tax exemptions, could trigger the action of green retrofit implementers. The investigation of Iralde et al. (2021) on the energy transformation of residential buildings in Spain indicated that government funding currently accounts for only 8% of all necessary investments, far from what is currently available, and the fragmentation and complexity in policy implementation reduce its global impact. In addition, the green loans provided by the government also exert a significant impact on the development of green retrofit. With the increase in supporting interest and carbon tax rates, the government and building owners will take more active actions (Kim et al., 2022).

Organization and professional training policies, such as RandD, are beneficial for developing new green retrofit technologies. Professional industry associations and experienced experts help improve the technical level of green renovation skills (Tan et al., 2018); thus, it is vital to establish an effective green transformation market. Knowledge and information policies can help to increase stakeholder awareness of green retrofit. The government should raise public awareness of the importance of green retrofit in reducing carbon emissions by organizing workshops and training programs with end-user participation to make the public part of the green retrofit decision-making process (Alabid et al., 2022). In the early stages of green transformation decision-making, providing information to homeowners through non-expert networks is essential to advance the decision-making process (Bobrova et al., 2021).

According to the promotion effect of different policies on green retrofit technology, Tan et al. (2021) further divided the six green retrofit policies into three priorities. Among them, direction-based policies, financial support policies and knowledge and information policies are policies at tier one. These policies can directly affect air conditioning and lighting, which account for 40% of a building's total electricity consumption and play the most critical role in reducing CECI.

However, most studies only focus on a single policy and its impact, and studies on the impact of multiple policy combinations are lacking in current research (Liu et al., 2020). There is no one solution fits all (Alabid et al., 2022), so existing policies toward green retrofit do not apply in all cases.

7 CONCLUSIONS AND FUTURE RESEARCH

This study reviewed the CECI research domain and corresponding government behaviors by employing the bibliometric analysis and introducing an analytical framework of the transmission path of government behaviors towards CECI. The result indicated that government instruments affected the CECI through three critical stages and seven key subsystems during the life cycle of construction carbon emissions.

Based on systematic summarization of government behavior on CECI, this paper found several gaps to be addressed in existing studies. First, most studies focus on the impact of a single policy, while few concentrate on the impact of policy combinations on CECI. Moreover, existing research is more about the impact of government behaviors on a particular part of the building life cycle. However, in practice, some government behaviors can affect the whole life cycle of the building. Given these, this paper puts forward some suggestions and prospects for future research.

Firstly, government policies are always characterized by a combination form, including non-exclusive economic incentives and mandatory administrative measures. Compared with a single policy, policy combinations perform excellent superiority. Wang G. et al. (2021) found that the combination of the mandatory, incentive and guidance policies shows tremendous advantages for waste recycling. Saka et al. (2021) summarized the government's reward and compensation policies to promote the development of green buildings into nine types, and proposed that the government can promote the development of green buildings through a combination of different policies. When considering the effects of environmental tax, green subsidies and carbon trading market on green building technology, Yang et al. (2021) found that policy combinations are more effective than individual policy instruments. Liu et al. (2020) proposed that studies on the impact of multiple policy combinations are lacking in prior studies on green retrofit. Therefore, the interaction and connection between different government instruments may need to be considered when exploring the impact, rather than simply applying a so-called mature mathematical model to try to explain the whole picture. The coupling effects of various governmental instruments should be incorporated to maximize their function of carbon reduction in the building sector. Regarding the research methodology, the fuzzy-set qualitative comparative analysis (fsQCA) techniques and Necessary Condition Analysis (NCA) (Ragin and Strand, 2008) could be conducted to investigate the impact path of government instruments.

Secondly, the life cycle of buildings is very long, and many policies may not only affect one stage. For instance, selecting unreasonable low-carbon building materials seems to reduce carbon emissions in the building materials production stage, but it may increase energy consumption and carbon emissions in the construction operation stage. Previous studies have investigated carbon emissions throughout the life cycle of buildings (Hong et al., 2015; Wong and Zhou, 2015; Wu et al., 2019; Ruiz and Guevara, 2020). However, there is less literature focusing on the effects of government behaviors, and the integrative role of government behavior on the CECI is still ambiguous. Therefore, it is valuable to disclose the mechanism for government behaviors in decreasing carbon emissions from the whole life cycle of buildings. Meanwhile, positive and negative performance should be equally noticed in the assessment of policy effectiveness and efficiency, and the negative externality of government behaviors needs more attention, such as dishonest behavior of carbon emission information disclosure in construction companies. More importantly, it needs to consider the multiple stakeholders in implementing the instruments to reduce the transaction cost, such as information disclosure, knowledge sharing and decision-making costs.

Thirdly, intensive work could be utilized in more innovative areas to reduce CECI, including zero energy building (ZEB), megaproject carbon neutrality and community carbon neutrality. More and more researchers have begun to focus on ZEB and passive houses. The passive house is regarded as a critical strategy for the low carbon economy in Europe (Piccardo et al., 2020), and ZEB is an essential pillar in achieving carbon neutrality goals, but its share in existing buildings remains low (Zhang et al., 2021). Concerning the current assessment of the mega project, the technical factor is the most important factor considered. In the future, more attention should be paid to the carbon emissions generated during the construction and operation of the mega project. As the smallest unit of the city, carbon reduction in the community may receive more attention. Infrastructure, application scenarios and lifestyles in communities are the key factors affecting CECI in cities during the building operation stage. At the infrastructure level of the community, the government can influence the installation of photovoltaic power generation devices and the upgrading of building energy efficiency through the establishment of special development funds for building energy efficiency. Meanwhile, the government's advocacy and subsidies can help communities make better use of public building space in the community for roof greening or vertical greening. In terms of application scenarios and lifestyles, influencing the behavior of building occupants can contribute to reducing CECI, but research in this field is currently inadequate (Ruparathna et al., 2016). Moreover, the government should also thoroughly consider the behavior of building users at the micro level when formulating relevant environmental regulations, as misunderstood and oversimplified occupant behavior might cause problems in policies (Hu et al., 2020). Therefore, establishing an effective community low-carbon living system can help reduce CECI. In the future, more research can focus on these fields and contribute to the realization of carbon neutrality goals and the sustainable development of humankind. Furthermore, more international collaboration networks on emerging Frontier technologies and patterns should be summarized and explored to promote the carbon reduction action in the construction industry.

This study attempts to investigate government instruments in the carbon reduction in the construction industry from the whole life cycle perspective by bibliometric analysis and systematic review. However, several limitations in this research should be recognized. First, the study is entirely sourced from the core database of WoS. Though WoS is widely conducted in literature review articles for its authoritative source, some important papers in other databases might be overlooked. Moreover, this study did not exhibit co-author and co-citation networks since prior studies on government behavior in CECI are relatively few and dispersed. Furthermore, the focus of government instruments in CECI could vary from different cultures and regions, which has been ignored in the study. Understanding the characteristic differences in CECI in different regions could help local policymakers formulate appropriate emission reduction policies in the long term. Further study could consider the differentiation among the countries/regions to provide insightful ideas for reducing CECI.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

DT and XG contributed to the conception and design of the study. XG collected the data, analyzed and wrote the first draft of the manuscript. DT and ML wrote the sections of the manuscript. DT provided the funding support for this study. All authors contributed to manuscript revision, read, and approved the submitted version.

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