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Co-evolution mechanism of policy mix and institutional context of renewable electricity consumption in China

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ABSTRACT
China, as the world's largest renewable energy market, has set ambitious energy transition goals. However, challenges in renewable power consumption, notably curtailment of renewable electricity, arise due to unclear alignment between both these policies and the institutional context, as well as that between policy instruments and their objectives. Building on policy feedback theory, this study developed a systematic analytical framework to examine the co-evolution of the policy mix for China's renewable electricity consumption and its interactions with the broader political and social systems. We also identified that utilization targets were crucial for increasing power grid connectivity of renewable energies. This study emphasizes the need for enhanced coordination among key stakeholders in renewable energy market, clearly defined consumption responsibilities, and a shift toward market-oriented mechanisms. Additionally, this study suggests a strategy aligning renewable energy growth with grid infrastructure development and regulatory power plants and resources. This could shed lights on the pathway towards China's 2030 carbon peak and 2060 carbon neutrality goals.

KEYWORDS
Renewable electricity consumption, energy transition, policy feedback, evolution mechanism, China.

1 Introduction

1.1 Technology transfer studies

Renewable energy, developed and utilized mainly through conversion to electricity, has become an important direction for global energy transition and source of energy consumption. China has been the world's largest renewable energy market, with the largest installed hydropower, wind power, and photovoltaic (PV) power generation capacity. In 2021, China's total renewable electricity consumption was equivalent to 750 million tons of standard coal, accounting for 14.2% of its primary energy consumption[1]. However, China must meet ambitious renewable energy development targets, as well as to address the significant challenge of increasing renewable energy consumption to achieve its carbon dioxide peaking and carbon neutrality goals[2–5].

Although China has adopted numerous renewable electricity policies over the past two decades, current research regarding these policies is often problem-oriented and largely inadequate to systematically reveal the interrelationships between the adopted policy instruments for renewable electricity consumption and their policy objectives. As renewable energy is consumed across various sectors of the power system, problem-oriented policy-making approaches often result in the formulation of distinct policies. This leads to a lack of systematic understanding in the electricity consumption policy framework. As a result, it is difficult to identify the dynamics of the policy evolution, which is useful to inform the development of future policies.

The policy mix framework, which is defined as complex arrangements of multiple goals and means that normally developed over many years, offers significant advantages in policy evolution analysis. Firstly, the policy mix framework emphasizes the interactions and synergistic effects between different policy instruments. This comprehensive analysis enhances the overall efficacy of policy interventions, preventing conflicts and overlaps between policies. Secondly, by examining the applicability and effectiveness of different policy tools in specific contexts, the policy mix framework supports policymakers in adjusting and optimizing the combination of policies in response to societal and environmental changes. This flexibility and adaptability are particularly crucial for addressing rapidly changing global challenges. Finally, the policy mix framework allows policymakers to consider multiple objectives simultaneously, such as economic growth, social equity, and environmental sustainability, and to ensure balance and coherence among these goals through carefully designed policy combinations. This approach aids in achieving more comprehensive and sustainable policy outcomes. Therefore, it is essential to employ a policy mix analysis framework for a systematic understanding of policies concerning the consumption of renewable electricity.

Currently, the renewable electricity consumption policy mix is continuously adjusted in response to evolving issues. As situations for renewable energy electricity consumption change, it necessitates that the policy mix interacts with the institutional context. The relationship between renewable electricity consumption policies and the institutional context is also unclear. Therefore, studying the policy feedback of renewable electricity consumption can help scholars better understand the relationship between policy mix and the institutional context and provide a reference for subsequent research on consumption policy mix

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based on carbon dioxide peaking and carbon neutrality goals. Furthermore, because the process of renewable electricity consumption involves complex interrelationships among various actors, encompassing political, economic, technological, and resource-related issues, policy research from a single perspective has struggled to understand the dynamics and mechanisms underlying the evolution of renewable electricity consumption policies. Given these points, this study proposes a systematic analytical framework that utilizes policy feedback theory to integrate the study of policy mixes with political and socio-technical aspects within the same framework to uncover key factors and the mechanism of policy evolution.

1.2 Research on renewable electricity consumption policies

Firstly, an important direction for consumption policy research is to promote cooperation among main entities, with a focus on constructing renewable power plants and distributing consumption rights and responsibilities. In particular, the relationships between different entities in terms of consumption responsibility should be clarified to avoid unnecessary power curtailment[6], and the minimum guaranteed annual utilization hours for each province should be generated consistent with the divisions established in the climate change goals[7]. In addition, the top-down planning of renewable energy development may lead to institutional misdirection which, in turn, reduces efficiency, and the failure to reconcile the consumption responsibilities with the construction power aggravates consumption challenges[8–12]. For example, local governments tend to promote local electricity consumption, employment, and tax revenue by building inter-provincial barriers. However, this approach hinders national-level efforts to address consumption challenges and enhance environmental efficiency by facilitating inter-provincial electricity trading[12–15]. Moreover, gaps in expertise and conflicts of interest across sectors constrain the resolution of consumption challenges. Therefore, renewable energy planning should be integrated with grid planning[16–18]. The fragmentation of authority under the State-owned Assets Supervision and Administration Commission also directly confers extremely strong bargaining power to grid companies and energy groups[19]. The renewable portfolio standard can promote renewable electricity consumption and mobilize power supply companies to identify optimal consumption modes on their own initiative[20, 21]. Quota allocations must reflect reality, and only a combination of incentives and assessments can effectively promote consumption, but this is confronted with challenges such as physical constraints and regulatory resistance[22, 23].

As can be seen, promoting the coordination of rights and responsibilities of different entities is an important research direction. The consumption policy system is not yet able to effectively mobilize all entities within the power system, and their consumption responsibilities remain unclear[24, 25]. Some renewable power plant investors continue to expand their investments to maximize long-term benefits despite worsening power constraints[26, 27]. Because taxation policies have failed to spur renewable electricity consumption, local governments stimulate renewable energy development by granting subsidies[13, 15]. The original renewable energy subsidy policy did not effectively encourage grid and ancillary service providers to participate[28]. Therefore, the cost-sharing of renewable energy integration must reflect the geographic location and motivate different entities to participate in consumption progress and create incremental electricity demand to promote consumption through renewable electricity alternative trading and the direct purchase of electricity[16, 17, 29, 30].

1.3 Co-evolution of policy feedback and policy mix

Since the 1970s, scholars have increasingly investigated the influential role of policy feedback in policy change. For example, studies have suggested that social learning is a part of policy feedback, meaning that policymakers study and learn from the successes and failures of particular initiatives[31]. Moreover, policy networks and policy communities engage in policy-oriented learning based on existing belief systems, which is a key factor in policy change[32]. The knowledge and experience of policy feedback are diffusive, and successful and unsuccessful policy experiences are diffused in policy organizations to help policymakers better address problems[33]. Policy feedback can be broadly summarized as a process in which policymakers actively or passively learn new knowledge and methods from the policy process itself or from the policy context to improve policies and align them with their beliefs.

In the field of energy transition, policy feedback research has focused on economic interest structure, technology mix, and the interaction between the political system and energy transition policies in the energy system[34]. Early policy feedback studies confirmed the importance of institutional context and historical scenarios. For example, energy and nuclear crises can contribute significantly to energy policy adjustments in countries, but policy feedback outcomes also vary according to the characteristics of the institutional structure across polities[35, 36]. Due to the high costs of supportive renewable electricity policies and the resulting conflicts of interest, the collision of interest groups in the political system can significantly affect the achievement of low-carbon energy transition goals[34]. Different types of macro systems, including politics, political economy, and social systems, also shape different policy feedback effects and can influence the choice of policy scenarios[37].

It was initially believed that policy feedback can be divided into two main effects—resource effect and explanation effect[38]—and these effects impact different entities, including the government, interest groups, and the public. Policy mix is an important topic in policy feedback research, including top-down policy mix changes and the bottom-up effects of specific policy instruments[39, 40]. The concept of policy mix can be separated into policy mix form and policy mix context. The former includes policy strategies and policy instruments, and the latter mainly includes factors such as implementation settings and target groups[41]. In policy mix form research, the theoretical framework of policy feedback can be applied to the study of a single policy instrument to investigate how the policy instrument design reinforces or constrains different effects[42]. The policy mix form could also be affected by policy feedback in a particular country or region. For example, a policy mix designed for sustainable transition must focus on long-term incentives and overcome weakening political support over time[43]. Comparative studies on the evolution of similar policy mixes across countries have found that renewable electricity policy mix may be modified for different reasons in different countries due to different technological conditions[44, 45].

Energy transition policy mix plays an important role in promoting the diffusion and progress of renewable energy technologies, which also implicates the interaction between policy mix and institutional context. So far, the direct and indirect effects of energy transition policy feedback have not been adequately studied, especially regarding the co-evolution mechanisms of institutional context and energy transition policy mix. Therefore, this study proposes a systematic analytical framework that integrates the co-evolution of policy mix and institutional context based on policy feedback to explore key factors and change dynamic.

2 Theoretical framework, data, and methodology

This study establishes an analytical framework to systematically elucidate the co-evolution mechanisms between the institutional context and the renewable electricity consumption policy mix. First, the initial policy mix stems from the prevailing institutional context (see Figure 1). Then, the implementation of the policy mix leads to progressively strengthened policy feedback. When this policy feedback accumulates to a certain level, it alters the institutional context of the policy mix. In turn, the evolution of the institutional context necessitates corresponding adjustments to the policy mix, including modifications to the policy mix form and policy mix context. Then, the new policy mix continues to generate new policy feedback on the institutional context.

2.1 Institutional context of renewable electricity consumption policy mix

The analytical framework proposed in the literature[46] considers the national energy transition a co-evolution of three major systems: systems of political actions, techno-economic systems, and socio-technical systems. Building on the framework proposed in the literature[46], this study argues that these three systems constitute the institutional context of the renewable electricity consumption policy mix. In particular, this study refines the influencing factors involved in this framework by examining the low-carbon transition in the electricity sector and uncovers each system's key primary and secondary variables[8, 11, 19, 47–51], as shown in Table 1.

As can be seen in Table 1, for systems of political actions, ideologies represent the positioning of the policy mix within the country's overall institutional system and influence the strategic direction of the policy mix. The policy mix should be designed according to ideologies made by the systems of political actions. For example, the spatial mismatch between the renewable generation stations and major electricity users is the cause of the consumption challenges, due in part to the unbalanced renewable energy resources throughout China's vast territory and China's top-level energy strategy design[8–11]. Political interest represents the willingness of different entities to support the policy mix and influences its successful introduction and implementation. Institutional capacity represents institutions' ability to implement the policy mix and influences its design form and implementation settings.

For techno-economic systems, as shown in Table 1, the energy supply and demand is decided by spatial differences, and is also constrained by grid structure. The policy mix addresses the challenges of such spatial and temporal heterogeneity of supply and demand. For example, in northwest, north, and northeast China where consumption challenges are more severe, a large-scale installed electricity capacity far from the power consumption center has been developed due to energy development strategy and other factors; therefore, long-chain and large-scale power transmission projects are underway. The combination of above factors can lead to serious renewable electricity consumption challenges[52, 53]. To avoid these challenges, policy studies suggest considering consumption situation as a precondition in renewable energy development planning. Studies assessing renewable energy development plannings have concluded that consumption condition is an essential prerequisite for large renewable energy bases[49]. The term "consumption market" in Table 1 refers to whether different entities can participate flexibly in consumption affairs with price signals as benchmarks, which determines the flexibility of the policy mix in regulating consumption resources.

Lastly, for socio-technical systems, the term "technological base" in Table 1 refers to the power system's technical structure at the time of policy instrument development. Changing this technical structure means breaking a strong path dependence. Meanwhile, "regimes and niches" refers to the adaptability of management systems to the penetration of renewable electricity technologies and the ability of the government and the market to provide a niche for renewable electricity technology innovation. In short, they determine the starting point of the policy mix path. Next, the resource endowment constraint stems from the distribution structure of fossil and renewable energy resources nationwide. A resource endowment rich in coal but with limited oil and gas constrains China's technology options in the energy transition process and, in turn, the transition path choice of the policy mix. "Technology deployment" refers to the technologies deployed to promote renewable energy penetration, and it constrains the path choice of the policy mix similarly to the resource endowment constraint in the absence of significant innovation in technology conditions. "Market capacity" refers to the ability of appropriate types and scales of technology deployments to yield reasonable

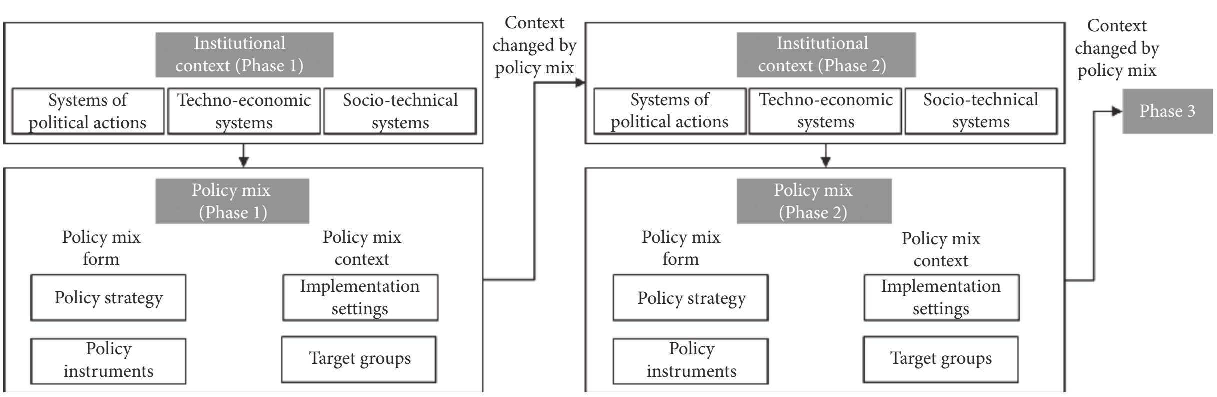

Fig. 1 Analytical framework for co-evolution mechanism of institutional context and renewable electricity consumption policy mix.

Table 1 Main contributing factors of institutional context.

Core areas	Primary factors	Secondary factors
Systems of political actions	Ideologies	Macro development orientation
		Climate change goals
		Strategic emerging industries
	Political interests	Political will to participate in energy consumption
		Political resources for the participation of different entities
	Institutional capacity	Division of responsibilities between central and local governments
		Allocation of responsibilities and authority between provinces and departments
		Cross-regional and cross-departmental coordination capabilities
		Definition and allocation of renewable energy consumption responsibilities among multiple stakeholders
		Energy-saving and energy transition policies and market management systems
Techno-economic systems	Energy flows and market	Renewable energy development pattern
		Grid structure
		Energy demand structure
	Consumption market	Green electricity market trading mechanism
		Ancillary service market
Socio-technical systems	Technological base	Power system based on coal power and its operation management standards
	Regimes and niches	Coal-dominated power system operation and management system
		Renewable energy development management system
	Resource endowment constraint	Rich in coal but with limited oil and gas
		Uneven spatial distribution of renewable energy resources
	Technology deployment	Output prediction technology
		Construction or modification of regulatory power plants
		Advanced power system operation technology
		Regulatory resource technology
	Market capacity	Payback capacity for renewable energy development
		Payback capacity for regulatory power plants and resources

returns, as the policy mix must facilitate the formation of a reasonable cost recovery mechanism in the market. Given the existing power system operation management system, the dispatching system still primarily adopts a planned-based model that accommodates fossil energy. However, annual coal power unit plans are often rigid. Therefore, power must be sent to the grid in accordance with economic costs. An appropriate ancillary service compensation mechanism must be established to stimulate the flexibility retrofitting of coal power units[28, 30, 54–56].

2.2 Policy mix for renewable electricity consumption

Policy mix research has various research paths and could be applied in various policy levels[41, 57–61]. Building on the policy mix research framework proposed in the literature[41], this study establishes a policy mix for renewable electricity consumption with China as an example, including policy mix form and policy mix context. The former includes policy strategies and policy instruments, and the latter includes factors such as implementation settings and target groups[41]. Policy strategies are the strategic goals and scenarios to be achieved by policy instruments in a certain timeframe and are normally determined top-down by the institutional context where they occur, but factors such as bottom-up feasibility can also influence their formulation. As shown in Table 2, policy strategies include ensuring the construction of renewable power plants, reducing waste of renewable electricity, and promoting the development of the renewable energy industry. On the other hand, policy instruments represent the collective policy means adopted by the government to implement policy strategies. They can be classified in different ways, including by supply and demand and by nature[62, 63]. This study classifies policy instruments as regulatory, incentive, and voluntary participation instruments.

Next, policy mix context refers to the environment of the policy mix, including implementation settings and target groups. Implementation setting refers to the implementation setting of policy instruments, including the timing and pacing of implementation, the collection of monitoring information, etc. As shown in Table 3, the implementation settings of the renewable electricity consumption policy mix mainly include consumption monitoring, planning management, development pace control, and strengthened supervision of policy implementation. Target groups usually refer to groups affected by policy instruments whose participation influences a policy's effectiveness, and these groups change as policy instruments are adjusted. The target groups of the renewable electricity consumption policy mix include central government authorities, local governments, investors in renewable power plants, power grid enterprises, enterprises related to regulatory plants, electricity users, energy

Table 2 Policy mix classification for renewable electricity consumption by organizational forms.

Classification	Name of policy instrument	Description of policy instrument
Policy strategies	Ensure the construction of renewable power plants A1	Address the institutional and technical barriers that restrict the construction of renewable power plants.
	Reduce waste of renewable electricity A2	Avoid investment waste and impose a target utilization rate for renewable power plants.
	Promote the development of renewable energy industry A3	Promote the technology penetration and cost reduction of renewable energy.
Policy instruments: regulatory type	Priority dispatching system B1	In power system operations, renewable energy is prioritized as long as grid safety is not compromised.
	Renewable power utilization target B2	Full-amount guaranteed purchase system: Purchasing in full amount the on-grid electricity at the Feed-In Tariff. The amount should be as much as possible until affecting the safety of the power system. Full guaranteed purchase system: Mandatory purchases on-grid electricity of specified generating hours of renewable power.
	Grid integration services for renewable power plants B3	Guaranteed grid integration: Power grid enterprises shall conclude grid connection agreements with all renewable power plants, in which the grid provides guaranteed grid integration services within the planned scale. Market-oriented grid integration: Renewable power plants that not covered in the planned scale, could conclude grid connection agreements as long as they could construct required regulate projects.
	Renewable portfolio standard B4	Renewable energy consumption guarantee mechanism: provincial minimum percentage targets for renewable electricity consumption. The mechanism sets two targets, one for total renewable energy consumption and one for non-hydro renewable energy consumption. Dual control over the amount and intensity of energy consumption: Renewable electricity beyond the target of renewable energy consumption guarantee mechanism can be exempt from consumption energy-saving assessment, and the utilization of renewable electricity can be exempt from energy-saving assessments once specific targets are met.
Policy instruments: incentive type	Incentivize the utilization of renewable electricity C1	Promote renewable power plants participate market-based trading: Allow renewable power plants to sell electricity directly to customers to boost utilization hours. Direct trading of green power: Allow renewable power plants to sell electricity and green power certificates directly. Implement renewable energy alternative trading: Renewable power plants can buy utilization hours from coal-fired plants.
	Cross-regional allocation of renewable electricity C2	Increase trans-regional power transmission capacity: Plan and build more high-voltage trans-regional power transmission routes. Increase the share of renewable electricity in trans-regional power transmission routes: Establish a mechanism to regulate the benefits of cross-provincial power transmission and receiving, and promote cross-provincial transactions.
	Promote the application of local consumption technology C3	Promote the penetration of electrification technology: Promote internal grid building at the provincial level and electricity substitution, demonstrate hydrogen production with electricity in severe provinces.
	Promote system regulate ability C4	Promote the utilization rate of existing regulate ability: Improve the power generation forecasting capability of renewable energy power plants, renewable energy and regulatory power plants to optimize operational cooperation to the fullest extent. Promote the regulate ability of regulatory resources on demand side: Execute user demand-side management and develop auxiliary service market. Change the time-of-use electricity price mechanism to fit the characteristics of renewable power generation. Promote the development of energy storage: Require new renewable power plants to be equipped with energy storage facilities. Accelerate the construction of pumped-storage power stations.
Policy instruments: voluntary participation type	Encourage green power consumption D1	Encourage user-side green power consumption: Provide incentives and guidance for green power consumption, and promote voluntary subscription of green power certificates.

Table 3 Renewable electricity consumption policy mix implementation settings.

Type	Content
Consumption monitoring E1	Improve the appraisal and supervision of different sectors in accommodating power generated from renewable energy.
Planning management E2	Control the pace of renewable energy development in the provincial annual development plans of provinces; increase or decrease quotas of renewable power plants issued in the current year according to the consumption status.
Development pace control E3	Delay the development of renewable power plants in regions facing significant consumption challenges until these issues are resolved.
Strengthened supervision of policy implementation E4	Address problems in the implementation of consumption policies through interviews, penalties, requirements for rectification, coordination for solutions, etc.

storage, and the public.

2.3 Methodology and data collection

We apply this study's proposed theoretical framework to analyze the evolution of the policy mix for non-hydro renewable electricity consumption in China, mainly wind and photovoltaic (PV) energy. In China, renewable electricity consumption policy and other policies such as renewable energy subsidies constitute the renewable electricity policy system, which is an important policy mix for the country's low-carbon energy transition. Since the enactment of the Renewable Energy Law in 2005, renewable energy has developed rapidly, causing China to become the market with the largest installed capacity in the world. However, this large-scale renewable energy installed capacity also poses significant challenges for the coal-based power development and management system while creating and amplifying the waste of investments in renewable power plants. For this reason, China has been monitoring consumption challenges and creating and improving consumption policies for the past 20 years.

This study first establishes the policy mix for renewable electricity consumption with a coding method to induce and derive a coding theory based on empirical information[41, 42]. Coding is a widely used research methodology in the social sciences as well as energy and environment policy analysis[64–67]. For the different types of policies in the data, we identified the contents related to the proposed policy mix and conceptualized them as open codes, as shown in Table 1. Next, we categorized the open codes into axial codes and then into selective codes for login.

In addition, we thoroughly reviewed and compared all policy documents issued by legislative bodies, the central government, and relevant departments from May 1997 to August 2022 aimed at promoting the maximum utilization of wind and solar power in the electricity system. We extracted a total of 209 policy documents related to the renewable electricity consumption policy mix. In the open coding process, we conceptualized and categorized the content of the original materials by continuously asking questions and inducing findings around government management issues, relevant entities, responsibility delineation, and management mechanisms to refine initial concepts and open categories. To minimize the impact of the researchers' subjectivity and bias, the open categories were formulated to extract as much original information from the policy documents as possible. The final generated coding results then underwent saturation testing by experts in the field and, ultimately, were condensed into 69 open categories.

In the second step, we conducted in-depth, one-on-one interviews with 13 individuals who were directly involved in the research or formulation of the renewable electricity consumption policy mix, including policymakers and expert scholars, to explore the evolutionary relationship between the policy mix and the institutional environment. Table A1 in Appendix displays the institutional information of the interviewed experts. Representing the perspectives of different government departments and professional backgrounds, the interviewed experts provided a broad and differentiated view on the policy transitions related to renewable electricity consumption. During the interviews, experts were first asked to introduce the main circumstances and evolution of the renewable electricity consumption policy mix, including stage-specific milestones, strategic shifts in the mix, and the use of policy instruments, as well as the implementation settings and adjustments for the target groups. Subsequently, the experts discussed the main influencing factors and mechanisms by which the renewable electricity consumption policy mix affects the political action, techno-economic, and socio-technical systems. In this process, the researchers did not provide the established theories and analytical frameworks to the experts but instead incorporated the experts' research into the theoretical and analytical framework after the interviews. Based on the interview findings, this study organized and refined the coding results, which are shown in Table 4.

Table 4 Number of codes by stage.

Stage	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	C4	D1	E1	E2	E3	E4
1	10	0	1	0	24	19	0	1	4	0	3	0	2	2	0	0
2	1	13	17	10	29	62	5	26	41	25	74	3	55	19	33	14
3	0	4	5	0	3	7	6	4	3	3	18	4	6	6	1	3

To gain a more detailed understanding of the mechanisms underlying policy evolution, this study expands the data in Table 4 by year. This approach allows for a dynamic analysis of the evolution of different policy codes and helps to summarize the dynamics of policy evolution. However, this method of data presentation has certain limitations in supporting the research. Firstly, due to the varying number of policies issued each year, the coding of policy documents may be overly concentrated in certain years, such as the formulation year of the Five-Year Plans for renewable energy development. Secondly, as this study found that stage divisions are not aligned with calendar years, key conferences or decisions could represent significant turning points in policy evolution. Therefore, the data for the pivotal years dividing different stages are not delineated by calendar years. For instance, the data for 2011 includes the number of policy document codes up to March 2012, and the data for 2020 reflects similar variations. This makes it difficult to accurately depict policy evolution by analyzing the absolute number of codes.

Consequently, this study groups all codes according to three aspects: policy strategy, policy instruments, and implementation settings. The percentage of codes under each category is then presented by group. By analyzing the changes in these percentages, we can examine the trends in policy evolution. Specific details can be found in Table 5. The analysis of changes in the percentage of different codes allows us to understand the evolution of various types of policy mixes.

Table 5 reveals the evolution of policy instruments for renewable energy consumption. First, the introduction and withdrawal of different policy strategies indicate the changes in policy strategies over time. For example, ensuring the construction of renewable power plants was the sole policy strategy in stage 1, but it ceased to be a strategy in stage 2. Secondly, policy strategies

Table 5 Percentage of codes in different categories displayed by year.

Year	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	C4	D1	E1	E2	E3	E4
2007	100%	-	-	-	57%	29%	-	7%	7%	-	-	-	-	-	-	-
2008	-	-	-	-	25%	63%	-	-	-	-	13%	-	-	-	-	-
2009	100%	-	-	-	80%	20%	-	-	-	-	-	-	-	100%	-	-
2010	100%	-	-	-	43%	43%	-	-	14%	-	-	-	-	-	-	-
2011	50%	-	50%	-	30%	50%	-	-	20%	-	-	-	67%	33%	-	-
2012	25%	25%	50%	9%	9%	73%	-	-	-	-	9%	-	25%	50%	-	25%
2013	-	100%	-	5%	15%	51%	-	-	8%	5%	15%	-	58%	8%	17%	17%
2014	-	17%	83%	-	8%	48%	-	8%	12%	-	24%	-	50%	31%	19%	0%
2015	-	-	100%	9%	6%	11%	-	9%	23%	9%	34%	-	57%	14%	14%	14%
2016	-	83%	17%	4%	11%	4%	-	14%	14%	14%	38%	2%	42%	21%	37%	0%
2017	-	33%	67%	2%	13%	9%	2%	16%	18%	13%	22%	4%	38%	17%	38%	8%
2018	-	60%	40%	2%	7%	15%	5%	10%	17%	12%	32%	-	38%	8%	31%	23%
2019	-	33%	67%	-	18%	27%	18%	9%	9%	-	18%	-	50%	-	25%	25%
2020	-	-	100%	-	8%	25%	-	8%	25%	8%	25%	-	47%	-	33%	20%
2021	-	80%	20%	-	8%	16%	11%	3%	8%	11%	39%	5%	50%	25%	-	25%
2022	-	-	100%	-	-	8%	17%	25%	-	8%	25%	17%	-	75%	25%	-

influence the introduction and withdrawal of policy instruments and also affect the proportion of each policy instrument. For instance, in stage 1, regulatory policy instruments aimed at promoting grid openness were the primary tools. Lastly, the implementation settings are also adjusted according to the policy strategies. For example, in stage 2, where the issue of curtailment was severe, strengthening regulation and even controlling the pace of development became crucial. Moreover, the content of the same policy instrument may also evolve over time. For instance, the full-amount purchase system was adjusted to a full guaranteed purchase system. Although these two policy instruments are essentially the same, the control target for power station utilization rates changed from 100% to 95%. Similarly, the non-discriminatory grid integration was adjusted to guaranteed grid integration and market-oriented grid integration. These evolutions in policy instruments cannot be effectively displayed in Table 5. To address this limitation, this study has created Figure 2 to provide a more comprehensive presentation of the policy evolution.

Figure 2 reveals that policy instruments can be categorized not only by type but also by the factors they regulate. Through a comprehensive analysis of interviews and coding data, this study identifies that renewable energy consumption policy instruments primarily control three factors of the power system: renewable energy power stations, the grid, and regulatory power plants and resources.

For renewable energy power stations, policy instruments focus on controlling consumption target of renewable energy electricity and the regional average utilization rate target of power stations. For the grid, policy instruments concentrate on guaranteed grid integration and promoting cross-regional allocation. For regulatory power plants and resources, policy instruments aim to ensure the effective utilization of existing regulation capacity and the development of additional regulatory capacity. The proportion of these policy instrument combinations changes across different stages according to shifts in policy strategies.

3 Results

3.1 The evolution of renewable electricity consumption policy mix

Although the documents concerning consumption can be traced back to the Interim Provisions on the Basic Construction Management of New Energy Projects issued by the National Planning Commission in 1997, there were only a few relevant documents before 2005. However, the government has increasingly emphasized consumption management following the enactment of the Renewable Energy Law. In our research, we found that the evolution of renewable electricity consumption policies can be divided into three stages, as shown in Figure 2: the first is the opening of the electricity system to ensure the grid connection of renewable energy (2005–2012.3); the second focuses on containing the low utilization rate of renewables and promoting utilization rate of regulatory power plants and resources (2012.3–2020.9); and the third is the acceleration of the development of renewable power plants (2020.9–Present). Notably, the division of these stages is consistent with the actual reality. After a guarantee system for the grid operation of renewable energy was established in the first stage, the annual installed capacity of renewable power plants rapidly increased. However, the average utilization hours of the power plants exhibited a trend of volatility and decline in the second stage until the establishment of a comprehensive monitoring mechanism for consumption led to a rebound in utilization hours. In the third stage, the marketization development mechanism has accelerated the rebound of consumption utilization hours, as shown in Figure 3.

3.1.1 First stage: optimize socio-technical system to achieve high-standard utilization rate targets

In the first stage, the consumption policy mix was implemented as a part of the institutional context when renewable energy development was still in its infancy. The strategic vision of the

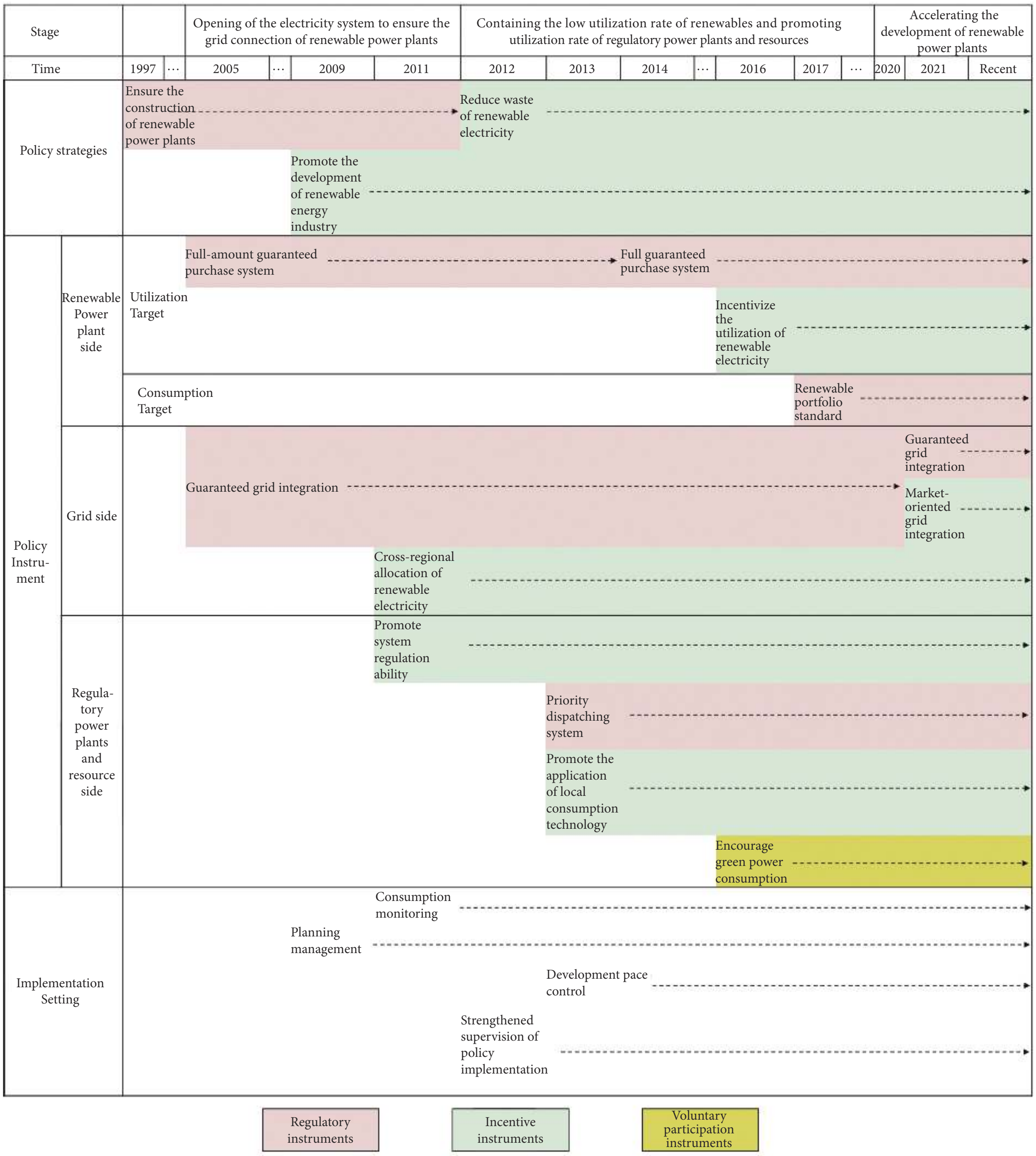

Fig. 2 Evolution of renewable electricity consumption policy mix.

political action system called for the acceleration of the development and utilization of renewable energy, promoting the proliferation of renewable energy technologies and industries. Renewable electricity consumption policies were then formulated and adjusted in accordance with these requirements. Meanwhile, although renewable power plants, represented by wind power, began to develop rapidly with the enactment of the Renewable Energy Law, this potential for development was not fully unleashed, as the socio-technical system became a key barrier to the grid connection and power generation of renewable power plants. In particular, because China's previous electric power construction and management system had not considered the construction or operational characteristics of wind and solar renewable power plants, there were significant institutional obstacles to the construction and operation of non-hydro renewable power plants, restricting the large-scale development of renewable power plants overall.

To build a policy system that ensures the smooth development of renewable power plants, solving the difficulties of grid connection for renewable power plants became the core policy strategy of this stage. Accordingly, the adjustments to the renewable electricity consumption policy instruments in the first stage were dedicated almost entirely to ensuring the construction and grid connection of renewable power plants. Regulatory policy instruments were continuously issued and improved to promote the fair opening of the grid and ensure the consumption of

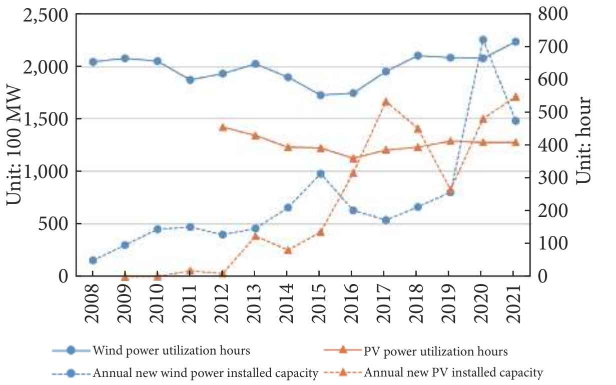

Fig. 3 New annual installed capacity and average annual utilization hours of wind and PV from 2008 to 2021 (Source: China Electricity Council).

renewable electricity by the power system. Among the factors related to the grid connection capacity of renewable power plants was a full-amount guaranteed purchase system that required that all electricity generated by grid-connected renewable power plants be purchased with the responsibility for purchasing to be explicitly borne by the grid companies. In addition, the power system was required to provide integration services to renewable power plants, with grid companies bearing the responsibility for constructing the corresponding grid infrastructure. The first stage also saw the application of incentive-based policy instruments, with few voluntary policy instruments being implemented. Overall, the policy strategy for the renewable electricity consumption policy mix was very clear, although it did not consider the promotion of renewable electricity consumption through the cross-provincial allocation of electricity. The implementation settings of the policy mix were also relatively simple, focusing on monitoring problem situations and managing project planning through regulatory oversight. The policy mix has significantly accelerated the deployment of wind power plants, from 49.9 MW in 2008 to 129.57 MW in 2012. In that same time period, PV power station is negligible due to high cost.

3.1.2 Second stage: optimize socio-technical system to enhance the utilization rate

In the second stage, renewable power plants, including PV power plants, initially achieved large-scale development, propelling China to become the world's largest renewable energy market. Expanding the application scale of renewable energy to promote the development of the renewable energy industry remained the strategic vision of the political action system in the second stage, and the rapid growth of the grid connection capacity and high utilization rate of renewable power plants were important supports for such development.

However, this rapid increase in grid connection capacity and high utilization rate became unsustainable. Because resource conditions differed across regions, renewable energy development between regions varied significantly. Some areas faced difficulties with grid connections and the large-scale curtailment of renewable electricity, a situation primarily caused by the lack of local consumption for renewable energy electricity, the inability to allocate renewable energy across regions, and the inadequate regulation capacity of the power system. These difficulties imply that multiple factors, including the energy supply and demand layout of the techno-economic system and the technological deployment and market capabilities of the socio-technical system, restrict the consumption of renewable energy electricity. Therefore, building on the policies from the first stage, the policy transitions in the second stage focused on promoting cross-regional electricity allocation and exploiting the regulation capacity of the power system.

In particular, in the second stage, the policy strategy shifted from ensuring the construction of renewable power plants to reducing the waste of renewable energy electricity. Special implementation plans were introduced for regions with severe consumption issues, followed by the gradual establishment of a comprehensive consumption-monitoring system covering the entire process of planning, construction, and operation and centered around a quota system. Among the factors related to grid-connected renewable energy stations, the full-amount guaranteed purchase system was adjusted to a full guaranteed purchase system given the high cost of implementation, and electricity beyond the guarantee was encouraged to be consumed in the market under green consumption initiatives. Additionally, policies ensuring the fair opening of the grid were also utilized to solve institutional problems hindering the grid connection of distributed power plants. With the shift from a full-amount guaranteed purchase system to a full guaranteed purchase system, binding utilization targets were established to ensure the development of the renewable energy industry. Given this context wherein both local governments and investors were pushing to advance the development of renewable energy, ensuring the achievement of utilization targets became a prerequisite for the development of renewable power plants in this stage. In addition, technical standards were strengthened to be more binding, emphasizing the power-forecasting capabilities of renewable power plants.

Despite optimizing operational cooperation to the fullest extent, policymakers found that it remained insufficient to fully maximize renewable electricity consumption in terms of regulatory power plants and resources. Thus, a series of policy instruments based on incentives and voluntary participation were introduced to further exploit the regulatory power plants and resources of the power system, including, for example, promoting the construction of a regulation capacity and the application of local consumption technologies tailored to the characteristics of renewable energy generation. Direct trading of green power or renewable energy alternative trading were also introduced, encouraging fossil fuel power plants to cede generating space to renewable power plants.

Regarding implementation settings, the government established a consumption monitoring system to track different regions' renewable energy utilization rates and enhanced departmental collaboration to alleviate the difficulties in coordinating various related factors. In addition, special regulatory efforts were undertaken to limit the blind development of renewable power plants by controlling the pace of development. The target group for the policy mix was further expanded in this stage, with renewable power plants assuming certain responsibilities as established in the technical standards, and regulatory power plants and resources began to participate extensively in the consumption of renewable energy electricity. The policy mix has reversed the downtrend of the utilization hours after 2015. At the meantime, the deployment of renewable power plants remains at high speed in the second stage.

3.1.3 Third stage: optimize system of political actions to diversify the means of achieving utilization targets

In the third stage, China has continued to be the world's largest renewable energy market; renewable energy technologies have achieved significant development and have gradually moved away from subsidies, and they possess the capability for market-oriented development. In addition, the utilization rate of renewable energy has gradually improved nationwide in the third stage, with both wind and PV utilization hours having halted their decline and rebounding. With the introduction of the dual carbon goals, the low-carbon transition of energy has become an important strategic vision. The nation has advanced two initiatives regarding the development work of renewable energy: promoting the large-scale, high-proportion, market-oriented, and high-quality development of renewable energy; and consolidating and enhancing the core competitiveness of the renewable energy industry. In particular, accelerating the increase in the grid connection capacity of renewable power plants in a market-oriented manner has become an important policy adjustment direction.

Furthermore, regulatory policy instruments have become more inclusive, and while guaranteed grid integration have been retained, the constraints on the grid connection capacity of renewable power plants are loosening. Some projects can obtain development quotas through market-oriented means, but these projects are typically required to invest designated amounts in supporting grid infrastructure and regulatory power plants and resources. Such actions are dedicated to helping the locality meet renewable energy utilization rate targets. However, the consumption management for distributed power plants is relatively lax, as they are generally not included in the utilization rate assessment targets. In addition, the issue of unclear responsibilities among multiple entities has been clarified through the quota system, with renewable electricity consumption responsibilities allocated among all relevant entities, and the government has proposed exploring ways that the public can participate more actively in renewable electricity consumption activities.

In terms of implementation settings, there is an increased emphasis on strengthening policy enforcement supervision in this stage. The central government strengthens systematic management through mechanisms such as joint meetings and monthly scheduling to promote effective coordination during the construction of centralized power plants like renewable energy bases. In addition, the target group for renewable electricity consumption policies has been further expanded, enabling electricity users to participate directly in renewable electricity consumption through specially arranged green-power trading markets, and the continuous improvement of the electricity market has allowed regulating resources to participate more broadly in the consumption of renewable energy electricity. The deployment of renewables is further accelerated. Comparing with 2019, annual new installed capacity of wind is increased three times in 2020. Annual new installed capacity of PV has recovered from the influence of subsidies removement in 2020.

3.2 The mechanism of renewable electricity consumption policy evolution

3.2.1 Mechanism one: utilization-target policy instruments effectively promote increased grid connection capacity for renewable power plants

Utilization targets are important indicators to ensure the progression of renewable energy development, and they regulate the utilization rate of renewable power plants as early as 1999. It was proposed that, grid intergration and operation departments must allow the nearest grid connection and purchase all the electricity provided. The full-amount guaranteed purchase system is an important regime to guarantee the utilization rate of renewable power plants, creating an effective niche for renewable energy development. Although these policy instruments are designed to achieve a 100% ultilization target, the full purchase of renewable electricity entails high economic and technical implementation costs. As the scale of renewable energy power stations expands, the nation has attempted to promote electricity grid connection through priority dispatching rights. The implementation of this priority dispatching rights system has advanced the shift from full-amount to full guaranteed purchase systems, encouraging direct and substitute transactions of renewable energy to maximize grid connection. The full guaranteed purchase system, or ultilization target, specifies the purchased volume and corresponding electricity prices for renewable power plants, providing stable expectations for their development. With advances in renewable energy technology and cost reduction, various entities such as local governments and companies have tended to actively increase the grid connection capacity of renewable power plants. In short, utilization targets form the foundational policy instrument for the long-term rapid growth of the grid connection capacity of renewable energy power stations.

3.2.2 Mechanism two: keeping the grid connection capacity of renewable power plants within reasonable limits

Because utilization targets determine the generation volume of renewable power plants, stable revenue expectations help advance the construction of renewable power plants. In the future, the government will take action to increase utilization rates, even in cases of temporary underutilization, as all built renewable power plants are guaranteed by ultilization target policy instruments. To improve the investment efficiency of these plants, the completion of utilization targets is considered when constraining or regulating the growth of grid connection capacity within a region. Since the second stage, the central government has adjusted the annual regional renewable energy development scale to reflect actual consumption, even changing regional renewable energy planning. Furthermore, the growth of the grid connection capacity of renewable energy power stations is monitored and managed through graded early warnings of curtailment, thereby linking utilization targets and renewable energy development management. Because utilization targets are monitored regionally, precise measures tailored to local conditions can be implemented. For example, in 2016, the worst year for curtailment, areas with severe curtailment were prohibited from increasing new project scales. Lastly, in the third stage, given the regional imbalance of low versus high utilization targets in the west and east, respectively, the scale of renewable energy development has further tilted toward regions with higher completion rates of utilization targets.

3.2.3 Mechanism three: accelerating the development of supporting grid infrastructure and regulatory power plants and resources through utilization targets

Due to the high demand for the development of renewable energy power stations, utilization targets can incentivize local governments, energy companies, and other entities to actively participate in accelerating the development of supporting grid infrastructure and regulatory power plants and resources and resources. In the first stage, local governments and energy companies were firm supporters of the fair opening of the grid. The second stage aimed to ensure the fair opening of the grid and promote the use frequency of facilities related to renewable electricity consumption within the power system. Furthermore, as utilization targets enabled increased control over the scale of renewable power plants, local governments and energy companies actively began to participate in promoting renewable electricity consumption, including special projects for nearby consumption and incentives for societal green energy consumption. Additionally, for regions with high renewable energy penetration, the demand for peak adjustment capabilities in the power system increased. It is essential to implement policy instruments that enhances the income of regulatory power plants and resources while improving the forecasting accuracy of renewable power plants, in order to increase the flexibility of the power system.

In the third stage, although the existing regulatory power plants and resources have been fully contemplated, it still could not fulfill the strong growing demand of renewable power plants; therefore, it becomes possible to promote the development of regulatory power plants and resources in a market-oriented manner. Policymakers tried to establish and improve ancillary markets to promote the flexibility necessary for renewable penetration. Besides promoting grid development, promoting the cross-regional allocation of renewable electricity is also an important direction for enhancing renewable electricity consumption. In particular, regions with high renewable energy penetration face severe curtailment issues. On one hand, the speed of renewable energy development exceeds planning expectations, and power planning can fail to adjust in time, leading to a lack of transmission lines. Additionally, the existing trans-regional power transmission routes transfer low proportions of renewable energy electricity. Therefore, the government is building collaboration mechanisms to reduce departmental and inter-provincial barriers, promoting the linkage between renewable energy planning and various related plans, and increasing the proportion of renewable electricity in trans-regional power transmission routes.

The regulatory process emphasizes not only responsibility but also the construction of mechanisms conducive to achieving policy strategies. While grid connection responsibilities were defined in the first stage, grid connection construction was also included in the subsidy scope. The second stage focused on improving the subsidy mechanism for auxiliary services, encouraging renewable power plants to participate in market-based transactions on top of guaranteed purchases. In the third stage, quota systems assess consumption proportion indicators to specify the consumption responsibility of multiple entities, establishing incentive indicators within the quota system to motivate local consumption of renewable energy. Ensuring that policy execution aligns with policy strategies is a focus of regulation. Management in the first and second stages mainly prioritized special regulations for prominent issues, such as priority dispatching and grid connection guarantees. The third stage began the transition to comprehensive regulation that promotes renewable electricity consumption. Approaches to ensuring policy execution are very flexible, including dispatching organizations for interviews in regions with prominent curtailment issues, encouraging cross-regional consumption negotiation mechanisms, confirming that renewable energy generation project construction is progressing as expected with monthly scheduling mechanisms, or even imposing time-limited corrections or administrative penalties for illegal and non-compliant behaviors.

Furthermore, special projects are implemented to improve the severe renewable electricity consumption utilization rate situation in some regions; for example, developing renewable electricity consumption capacity is an important condition for increasing the grid connection capacity of renewable power plants. In the second stage, nearby renewable electricity consumption projects began to be explored in a decentralized manner, with distinct regional characteristics highly related to the local resource environment and industrial structure. For example, the exploration of wind power clean heating projects starting in 2013 mainly involved constructing special clean heating loads and supporting projects and organizing special electricity transactions. Moreover, the state has continuously expanded methods to consume nearby loads, including special hydrogen production, data centers, and other loads gradually incorporated into nearby consumption. In promoting green energy consumption, the government has established a linkage mechanism between renewable electricity consumption and energy dual control assessments. On the user level, exploring multi-part pricing and promoting subsidy-free green certificate transactions are ways to encourage users to actively participate in green energy consumption.

4 Discussion: evolution dynamic of electricity consumption policy mix

The renewable electricity consumption policy mix continuously modifies the institutional environment and co-evolves with it. The entire evolution process focuses on realizing the ideology of the political action system. This ideology, which is part of the national strategic vision, is closely tied to the policy mix. While the core ideology remains constant, its focus can shift. In this case, the ideology centers on the development of renewable energy. However, when renewable industries and management mechanisms are not mature enough to support this development, the focus shifts to promoting the growth of renewable energy industries. Consequently, the policy strategy for renewable electricity consumption aims to ensure the construction of renewable power plants and foster the development of renewable energy industries.

Many of the documents reviewed for this study discuss the policy strategies of the renewable electricity consumption policy mix, involving the National People's Congress, the State Council, and relevant departments. To this point, policy strategies are conceptual, and related content is reflected in various policy documents such as relevant legislation and amendments, renewable energy development planning, documents on the determination and adjustment of relevant indicators, and documents on the balancing of departmental responsibilities.

Policy instruments are primarily formulated and adjusted by the economic and energy regulatory departments, which introduce policy instruments in response to key issues in policy strategy implementation, initially focusing on regulatory tools. From the second stage onward, incentive-based policy instruments have been gradually strengthened; currently, regulatory policy instruments primarily emphasize the clarification of responsibilities and promote consumption through incentive-based and voluntary policy instruments. With the advancement of renewable energy technology, the impact of voluntary policy instruments is increasingly significant. The policy mix emphasizes timely detection and action to avoid the worsening of consumption problems through implementation settings, including controlling the pace of development and strengthening policy enforcement. In the third stage, promoting market-based consumption has become the core objective, and more target groups are being included as the penetration rate of renewable electricity increases; this has caused a shift from prioritizing the grid connection of power plants and the full amount of electricity on the grid to active participation in consumption by multiple entities, which has gradually clarified and reinforced the responsibilities for consumption. As can be seen, the co-evolutionary mechanism between the institutional environment and the renewable electricity consumption policy mix has distinct co-evolutionary characteristics. In particular, policy strategies are formulated and adjusted to align with the strategic vision of the political action system, and the policy mix promotes the realization of this strategic vision by adjusting relevant factors in the institutional environment, as shown in Figure 4.

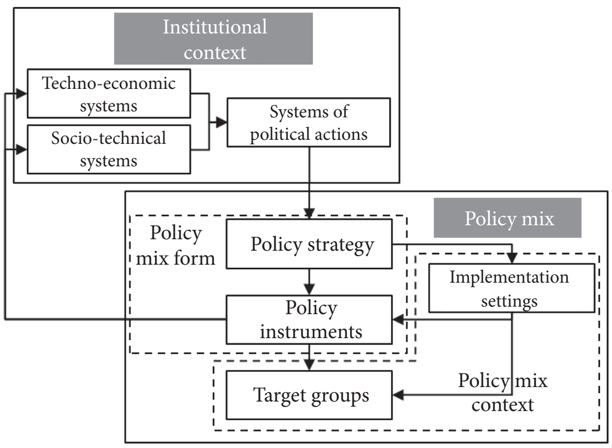

Fig. 4 Co-evolutionary mechanism between institutional environment and renewable electricity consumption policy mix.

The renewable electricity consumption policy mix is influenced by multiple strategic visions, including addressing climate change, developing strategic emerging industries, and overcoming resource and environmental constraints. In turn, the implementation of the policy mix changes the penetration rate of renewable energy and promotes technological diffusion, altering the boundaries of consumption issues while also facilitating cost reduction. This transforms the energy supply and demand structure of the techno-economic system and the technological foundation of the socio-technical system, thereby realizing the strategic vision of the political action system. Indeed, promoting the development of the renewable energy industry always occupies an important position in the political action system. Despite the rapid development and maturation of the renewable energy generation industry, the government continues to promote industrial development that aligns with the strategic vision of renewable electricity consumption policies. In the first and second stages, the strategic vision prioritized changing relevant factors in the institutional environment through policy to promote the development of the renewable energy industry, with energy transition and energy security being relatively secondary. As a result, the institutional environment changed with the continuous implementation of policies, and the political action system adjusted its strategic vision according to the institutional environment. In the third stage, the focus of the strategic vision has shifted from promoting the development of the renewable energy industry to an energy transition aimed at addressing climate change.

The core of the renewable electricity consumption policy mix is the policy strategy, which is directly determined and adjusted by the strategic vision. After clarifying the policy strategy, related policy instruments are formulated by taking into account factors in the institutional environment that are unfavorable to the realization of the strategic vision. Importantly, the design of and adjustments to renewable electricity consumption policy instruments must conform to the policy strategy and consider the political and economic interests of target groups as much as possible.

Renewable electricity consumption policies tend to design policy instruments that address the balance of responsibilities and incentives. As a representative example, the construction and operation of grid connection facilities initially lacked clear responsibilities, funding sources, and regulatory mechanisms. Then, in 2006, grid companies were explicitly tasked with grid connection project construction, while also being allowed to collect grid connection fees through electricity pricing. A series of measures were then implemented to ensure and strengthen enforcement. Ultimately, after clarifying the responsibilities for grid connection projects and the funding sources for subsidies, renewable energy entered a fast track of development.

However, policy instruments are not necessarily balanced in terms of responsibilities, especially when certain interest structures need to be adjusted through them. For example, the lack of grid management regulations once hindered the development of distributed power plants until the Interim Measures for the Management of Distributed Generation clarified the related responsibilities in 2013, providing the conditions for rapid development. Policy instruments also focus on leveraging policy synergies, such as encouraging investment in regulatory power plants and resources in exchange for renewable energy station development quotas and encouraging market transactions for electricity beyond full guaranteed purchase systems to reduce local energy consumption costs.

It is undoubtable that the policy instruments have been thoughtfully designed and adjusted by policymakers. Initially formulated by the Renewable Energy Law, these instruments are continually refined through a problem-oriented approach. This approach primarily aims to address the consumption challenges arising from the increasing penetration rate of renewables. However, with the significant shift in the institutional context due to policy feedback, especially after Dual Carbon Goals, the problem-oriented approach may no longer be sufficient to tackle upcoming consumption challenges. Systematic policy reform is required to address the challenges under new circumstances. For instance, accelerating the growth of renewable power plants necessitates more power grid infrastructure and regulatory power plants and resources. Although recent policy mixes have been improved to alleviate the associated cost increases, they still fall short in scientifically controlling the technology mix and related incremental costs.

Meanwhile, the government progressively optimizes implementation settings starting with key issues, which are crucial entry points for constructing the regulatory system of the renewable electricity consumption policy mix. To this point, the government aims to maintain management intensity while maximizing the congruity of policy mix and strategy. As early as 2009, the National Energy Administration established the National Wind Power Information Management Center (later, the National Renewable Energy Information Management Center) to strengthen the monitoring of renewable energy development, mainly to manage renewable energy surcharge funds. Following the establishment in March 2013 of the requirement to strengthen industry process management, in 2015, the National Renewable Energy Information Management Center began conducting consumption monitoring, starting with the informatization management of renewable energy generation projects and including lifecycle-related information, annual scale management, and the coordination and progress of grid connection projects, which covers the entire process of the consumption guarantee system. Since 2015, this information has been published as the National Renewable Electricity Development Monitoring and Evaluation Report. Furthermore, the scope of the target groups for the renewable electricity consumption policy mix has always been controlled to minimize the difficulty and cost of policy implementation. However, as renewable energy develops rapidly, more groups need to be mobilized for renewable electricity consumption to continuously expand the scope of target groups, which reflects the diffusion from the generation side to the consumption side. In the first stage, the target groups were mainly renewable energy stations and the grid. In the second stage, regulatory power plants and resources were included, and in the third stage, the consumption side has been more broadly incorporated.

Phasal and regional characteristics are also important features of the co-evolutionary mechanism. To this point, the adjustment of interests in the policy mix shows clear phasing, first clarifying the institutional obstacles to the grid connection of renewable energy stations and then expanding the scope of consumption management to address the increasingly severe and widespread consumption issues caused by the physical constraints of the power system. Regionally, due to differences in renewable energy resource endowments and other reasons, different regions present different techno-economic conditions at the same technical level. Because there are significant regional differences in the consumption of renewable energy electricity, policy instruments and implementation settings highlight regional heterogeneity.

The mechanism to alleviate the cost of renewable electricity consumption also continues to be optimized and adjusted. In the first stage, this mechanism was primarily based on national regulation. The regulation capacity of the power system was provided mainly by the existing regulatory power plants and resources within the system, with the state bearing the construction costs of the supporting grid infrastructure. In the second stage, more incentive factors were incorporated into the alleviation mechanism. Policies guided the existing regulatory power plants and resources to take on regulation capacity and encourage renewable energy stations to share costs, with the state continuing to bear the construction costs of the supporting grid infrastructure. In the third stage, the alleviation mechanism has gradually shifted to market mechanisms. As the regulation capacity of the internal regulatory power plants and resources approached exhaustion, policies were adjusted so that new renewable energy stations now actively bear the costs of the required regulatory power plants and resources, with the state continuing to bear the construction costs of the supporting grid infrastructure. Although the alleviation mechanism is continually optimized, clearly, electricity users always bear the actual costs of renewable electricity consumption.

5 Conclusion and policy implications

5.1 Conclusion

This study systematically investigates the co-evolution mechanism of policy mix for renewable electricity consumption and institutional context and proposes a corresponding analytical framework, ultimately concluding that policy feedback encompasses different influencing factors and mechanisms in the co-evolution process. Focusing on China, we collected and analyzed 209 national-level policy documents with a coding research method to extract common characteristics and conducted expert interviews to explore the factors and mechanisms of this co-evolution.

While different stages have prioritized different mechanisms of change, all have been based on the progressive improvement of management levels through policy strategy. The underlying mechanism of the first and second stages of the renewable electricity consumption policy mix was to ensure and promote the development of the renewable energy industry, while the third stage has shifted toward accelerating the increase in grid connection capacity for renewable power plants in a market-oriented manner. Although the strategic vision served by the policy strategy is constrained by resource endowments, technological conditions, and institutional capabilities, the implementation process changes these physical and practical constraints, and more mature conditions, in turn, alter the strategic vision. Secondly, adjusting the structure of interests through policy instruments can help resolve institutional path-dependency issues and prevent excessive adjustments to the existing policy mix. Finally, changes in implementation settings facilitate the supervision and control of the policy instrument execution process, enabling the government to understand the implementation status of the policy mix, and thus ensure that the effects of the policy instruments adhere as much as possible to the policy strategy.

The evolution mechanism of the changes in renewable electricity consumption policies reveals the internal drivers and directions of policy development as well as how these changes respond to technological progress, market demand, and environmental challenges. Firstly, utilization-target policy instruments have played a key role in promoting the growth of grid connection capacity for renewable power plants. By establishing a full-amount guaranteed purchase system and priority dispatching rights, policymakers have provided stable expectations and clear profit margins for renewable energy development, thereby effectively incentivizing the construction and grid connection of renewable power plants. Secondly, with the rapid growth in the grid connection capacity of renewable power plants, policymakers have begun to focus on the reasonable control and optimized management of grid connection capacity, for example, achieving utilization targets in coordination with renewable energy development to avoid resource waste and system operation risks. This precise, regionally differentiated strategy reflects the flexibility and adaptability of policies. Third, to support the consumption of renewable energy electricity, policies have continued to promote the development of supporting grid infrastructure and regulatory power plants and resources; this indicates that as renewable energy development progresses, the flexibility and regulation capacity of the power system increasingly become key factors. Moreover, the gradual improvement of the regulatory process and the advancement of special projects further promote the effective consumption and utilization of renewable energy. By constructing mechanisms conducive to the realization of policy strategies, emphasizing the quality of policy execution, and promoting green energy consumption, policymakers encourage all sectors of society to actively participate in and support renewable energy while ensuring the consumption of renewable energy electricity. Overall, the evolution mechanism of renewable electricity consumption policy reflects policymakers' ongoing search for balance and optimization while addressing complex challenges.

5.2 Policy implications

This article analyzes the systemic evolution of consumption policy mix and its interactions with political and social systems to provide the following insights for future research on renewable electricity consumption policies. Firstly, the co-evolution of the institutional context plays an important role in determining the strategic goals of the consumption policy mix. As renewable generation technologies become increasingly sophisticated, the policy strategy of the consumption policy mix may be influenced by other institutional contextual factors. Secondly, although the consumption policy mix system has initially allocated and consolidated consumption responsibilities, the choice of indicators still suggests end-of-pipe governance. Therefore, a more reasonable assignment of responsibilities is required, especially as the penetration rate of renewable energy increases. Furthermore, the scope and complexity of the consumption policy mix will continue to grow, and the governmental management system of energy consumption must consider involving more entities in consumption actions and establishing a better incentive mechanism. Lastly, market-oriented mechanisms will become increasingly important, and the use of market-oriented means will be a lasting trend under the guideline that those who benefit should shoulder the responsibility. In particular, the market-oriented consumption of renewable energy is expected to gain importance with the continuous improvement of the electricity market.

Consumption policy mix is a comprehensive and complex public administration issue. Given the goals of carbon dioxide peaking and carbon neutrality, consumption policy mix research will remain active for the foreseeable future. Despite possible limitations such as subjectivity in the research methodology, many theoretical and practical issues still need to be studied. Firstly, although the goals of carbon dioxide peaking and carbon neutrality have transformed the institutional context of the consumption policy mix, the key influencing factors and impact mechanisms remain unclear. Given the lack of data after 2020, this issue is not thoroughly analyzed in this paper. Secondly, this study focuses on national-level policy texts, leaving the evolution of local consumption policy mix unexplored. Moreover, the interaction between central government and local governments could affect the policy evolution. This issue also need to be discussed in the future. Finally, the evaluation and evolution dynamic of consumption policy mix remains a promising avenue for future research, as analyses of the dynamic behind the formulation of various policy instruments have so far been inadequate.

Appendix

Table A1 Interviewee information.

Interviewee	Affiliation of interviewees	Number of interviewees	Employment status
Government officials and experts	National People's Congress, China	2	Employed
	Development Research Center of the State Council, China	1	Employed
	Energy Research Institute of Academy of Macroeconomic Research, China	1	Employed
Industry experts	China Electricity Council, China	1	Employed
	Chinese Photovoltaic Industry Alliance, China	1	Employed
Renewable investors	LONGi Green Energy Technology Co., Ltd., China	1	Employed
	China National Nuclear Corporation, China	1	Employed
Researchers	Tsinghua University, China	3	Employed
	Renmin University, China	1	Employed
	North China Electric Power University, China	1	Employed

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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