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Policy Analysis on China's PVs Policies from 2012 to 2022: A Content Analysis

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Abstract: ***As an abundant and renewable energy source, photovoltaic solar energy has garnered substantial investments over the past decade, emerging as a pivotal tool in the global effort to decarbonize. In this process, China has transitioned from being primarily an "Original Equipment Manufacturer (OEM)" for Western countries in the photovoltaic industry to a key player in the global photovoltaic landscape. This transformation has significantly reshaped the global supply and demand dynamics for photovoltaic products. This research employs a combination of qualitative and quantitative content analysis methods to categorize and analyze 192 policy documents issued by the central government of China between 2012 and 2022. By scrutinizing policy action areas, policy instruments, and policy targets, this paper elucidates China's nationally led, top-down approach to photovoltaic development. The goal is to offer an overarching perspective on the types and evolution of PV policies implemented by the Chinese central government. This study addresses gaps in knowledge within the realm of Chinese decarbonization and offers pertinent policy recommendations.***

1. INTRODUCTION

The utilization of solar energy by humans has a rich historical precedent, with China emerging as a pivotal contributor to affordable Photovolatic (PV) solar energy since the early 21st century. The invention of the silicon PV cell at Bell Labs in 1954 marked a seminal moment in modern PV technology (Fraas, 2014). For a significant duration thereafter, the United States stood as the global leader in PV technology (G. Nemet, 2019a). However, during the 1980s, following the election of President Reagan, the United States systematically dismantled its PV initiatives, leading to the relocation of the PV design, research, and manufacturing industrial chain to other nations with stronger national support. Japan and Germany notably assumed this mantle (Fraas, 2014). These two countries, through a combination of technology-driven policies and robust domestic market initiatives, played pivotal roles in the global commercialization of PVs from the 1980s into the early 21st century (Yu et al., 2014). China's PV industry had a comparatively late start and initially centered on processing and exporting solar cells and components to Western countries, with core technologies largely imported from abroad (Sun, 2019). The introduction of the PV benchmark on-grid power tariffs scheme by the Chinese government in 2013 played a significant role in spurring the rapid expansion of the industry (Sun, 2019). Between 2012 and 2022, China's cumulative solar installed capacity exceeded 400 GW, constituting nearly 35% of the world's total installed capacity (REN21, 2023b). By 2021, China accounted for over 80% of all stages in solar panel production, including PV modules, cables, inverters, and polysilicon ingots (IEA, 2022b). Furthermore, the number of solar PV patents originating from China has seen a substantial upswing since 2015, with the yearly count surpassing the combined total of worldwide patents filed outside of China (Yap et al., 2022).

Solar PV energy stands out as the most promising replacement for fossil fuels among existing renewable energy sources. This is primarily attributable to the ongoing enhancement in efficiency driven by substantial investments. Notably, solar PV has been the recipient of the highest investments in the renewable energy sector over the past decade. In 2019, approximately 141 billion dollars was channeled into solar energy technology (Fernández, 2023), a figure on par with investments in wind power technology and significantly surpassing those in other renewable energy sources, including geothermal and nuclear energy (Fernández, 2023; IEA, 2022a). This substantial investment has spurred swift technological advancements and a continuous upswing in energy conversion efficiency. As depicted in Figure 1 below, nearly every segment of the PV supply chain has undergone or completed technological upgrades from 2015 to 2020. For instance, prominent PV industry leaders have gradually transitioned from PERC cells to N-type cells, which offer higher potential efficiency. Thanks to these efficiency enhancements resulting from technological progress, the cost of solar PV power generation has been consistently declining. According to the recent Levelized Cost of Energy (LCOE) report published by Lazard (LAZARD, 2023), the average unsubsidized LCOE per megawatt-hour (MWh) for PV power generation plummeted from

$359/MWh in 2009 to $60/MWh in 2023. This cost is notably lower than the LCOE for coal-fired power generation, which stands at $117/MWh (LAZARD, 2023).

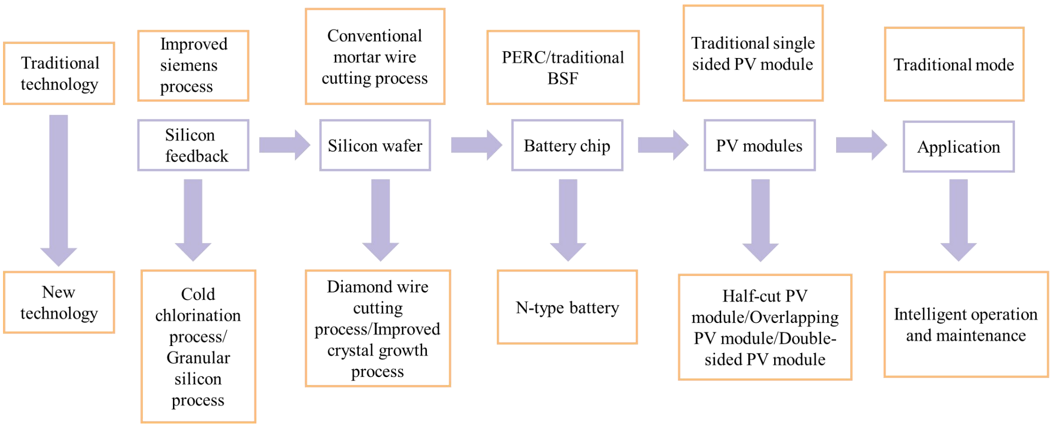

Figure 1: PV Technology Progress and Prospects from 2015 to 2020

The Russo-Ukrainian War, along with the increasing number of nations committing to carbon neutrality targets, has heightened the demand for PV products. Before the conflict, Russian fossil fuels such as crude oil, natural gas, and coal played a significant role in the EU's energy mix (BritishPetroleum, 2022). In response to the war, the European Commission introduced the REpowerEU initiative, aiming to reduce reliance on Russian fuels (Lonergan et al., 2022). Within this initiative, the rapid deployment of renewable energy, with a focus on PV solar energy, is pivotal (EuropeanCommission, 2022). As part of the REpowerEU plan, the EU Solar Energy Strategy aims to bring online over 320 GW of solar PV capacity by 2025, more than doubling the capacity available in 2020 (EuropeanCommission, 2022). Furthermore, an increasing number of countries have introduced carbon peak and carbon neutrality targets in recent years, necessitating the widespread substitution of fossil fuels with renewable energy sources (Shan et al., 2021; Yuan et al., 2022). This trend has spurred the demand for PV solar energy. Over the decade spanning from 2012 to 2022, global cumulative PV capacity witnessed substantial growth (REN21, 2023a) (as depicted in Figure 2).

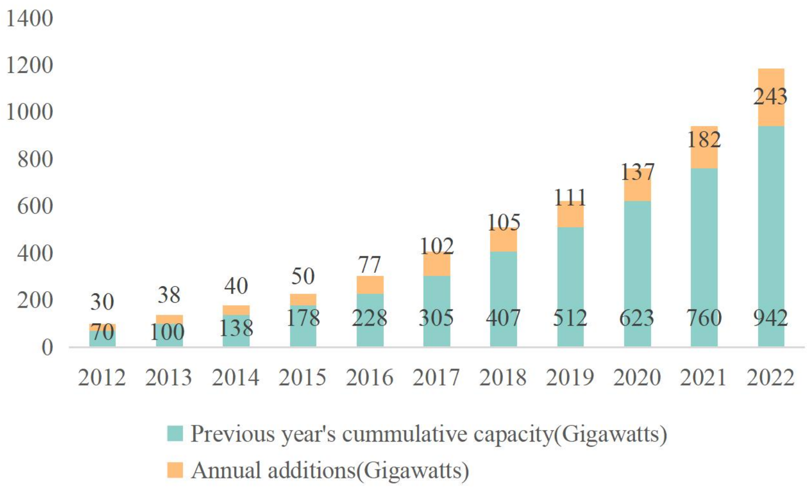

Figure 2: Solar PV Global Capacity and Annual Additions, 2012-2022

With the continuous technological progress of solar energy and its gradual growth as a reliable alternative to fossil fuels, as well as the increasing global demand for solar PV products, paying attention to the development of solar PV is of great significance for decarbonisation and climate change mitigation for all humanity. The solar PV industry holds the potential to play a significant role in achieving these crucial environmental goals for the benefit of all of humanity. Given China's dominant position on both the demand and supply fronts of the solar PV industry, a comprehensive analysis of the policies implemented by the Chinese central government during the most rapid development period of solar PVs in China (2012–2022) can provide valuable insights. This analysis helps address the question of the operational logic underlying Chinese PV industry policies and aids in understanding how the public sector has effectively strengthened decarbonization measures within the Chinese model of decarbonization.

2. LITERATURE REVIEW

Presently, research on China's PV policies can be categorized into two main types. The first type involves the assessment of policy effectiveness from economic, environmental, and social standpoints, leveraging various quantitative analysis methods. In terms of economic benefits, existing literature primarily evaluates the impact of policy changes by calculating economic indicators such as the internal rate of return(Zhao et al., 2019), net present value and simple payback period (Li et al., 2018), and the LCOE (Zhao et al., 2019). Environmental impacts are primarily assessed using the Life Cycle Assessment Method (LCA). For instance, L. Xu et al. (2018) utilize shadow pricing of CO_2 and SO_2 to estimate the environmental costs of solar PV systems throughout their entire life cycle. Fu et al. (2015) conducted a life cycle assessment of China's polycrystalline silicon module PV system, assessing factors such as primary energy demand, energy payback period (EPBT), and environmental consequences like global warming potential and eutrophication across the PV system's life cycle. Xie et al. (2018) conducted a life cycle assessment using the Endpoint Damage Model (CEDM) for impact assessment and established a method for aggregating data into industry-level databases through on-site investigations. Moreover, numerous studies delve into the social benefits of China's PV subsidies and support policies. Research employing a two-stage DEA-Tobit model has demonstrated that government subsidies positively influence the innovation capacity of China's PV industry (Lin et al., 2020). The second type of PV policy research involves reviewing and qualitatively analyzing the development history and policy framework while summarizing policy implementation experiences. For instance, Zhi et al. (2014) categorized China's PV policy instruments into demand-oriented and supply-oriented, analyzing policy evolution history separately from these perspectives. H. Zhang et al. (2018) applied Rothwell and Zegveld's methods to construct a two-dimensional analytical framework for assessing China's PV-based precision poverty alleviation policies. Meanwhile, Zhou et al. (2020) created a two-dimensional framework using policy instruments and the project lifecycle to analyze the content of China's PV application policies from 2005 to 2018. Their analysis also led to recommendations for strengthening demand-oriented policies and enhancing green certificate trading mechanisms.

The existing literature has provided a solid theoretical foundation for this study. However, there are still some shortcomings: (1) There exist few previous policy assessment papers that fully cover the Chinese central government's PV policy during the solar boom period from 2012 to 2022. (2) Many prior studies have primarily focused on assessing the effectiveness of China's PV policies within specific action areas, with limited attention given to the comprehensive PV-related policy documents issued by the Chinese central government. This paper's contributions are primarily manifested in the following three aspects: (1) This paper conducts an analysis of the policy instruments, target subjects, and areas of action within China's PV policies from 2012 to 2022 using a content analysis framework. (2) Utilizing 192 PV-related policies issued by the Chinese central government from 2012 to 2022, it constructs a three-dimensional analytical framework and assesses China's PV policies from each dimension of policy instruments and policy action areas.(3) This paper delves into the policy evolution that occurred during the rapid development of China's PV industry and offers recommendations and references for future development.

3. METHOD AND DATA

3.1 Analysis Framework

In accordance with public policy theory, policymakers should strategically blend various policy instruments based on their alignment with policy objectives, action areas, and the characteristics of policy subjects to create synergistic policy forces that lead to optimal policy outcomes. To address the nuances of the policy system, this paper establishes a three-dimensional analytical framework for China's PV policy system, as depicted in Figure 3. The analysis is conducted using content analysis, a method developed in 1983 and initially employed by the U.S. Office of General Assessment (H. Zhang et al., 2018). Content analysis serves as a technique for processing research samples and extracting qualitative insights from statistical data through statistical analysis methodologies and tools. The application of content analysis involves several critical stages, including the careful selection of a representative dataset, the identification of distinct units of analysis, the formulation of a comprehensive coding scheme, the systematic coding of data, the subsequent quantification of the coded information, and the analysis and interpretation of the results obtained.

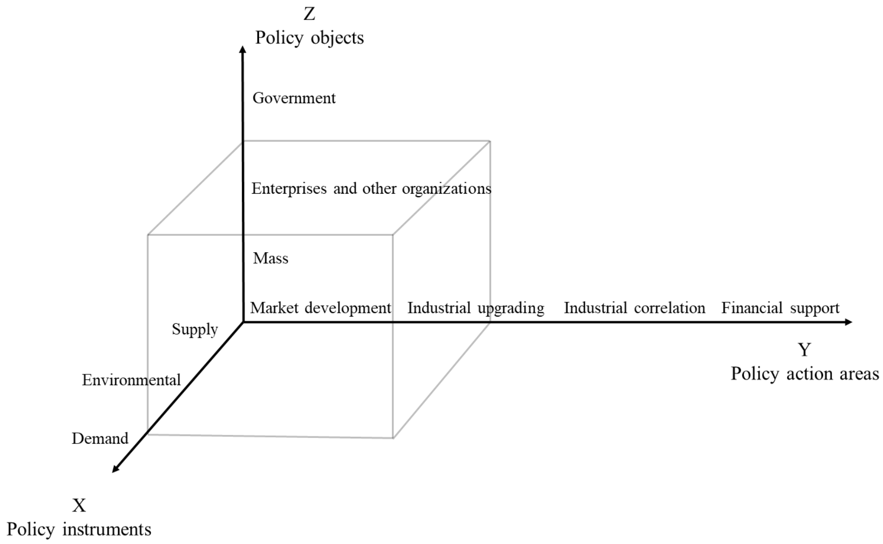

Figure 3: Three-dimensional Analyse framework for PV policies

3.1.1 X Dimension: Policy Instrument Dimension

The policy instrument theory, as put forth by Rothwell et al. (1985), classifies policy instruments into three distinct categories: supply-based policy instruments, demand-based policy instruments, and environmental policy instruments. This categorization of policy instruments effectively showcases the underlying structure of policies by amalgamating policy content and functions. It is widely applicable to the analysis of industry policies. In this paper, we employ this classification method within the policy instrument dimension to provide a clearer illustration of the composition of China's PV policy system.

Drawing upon Zhou et al. (2020) classification of China's PV application policies within the framework of Rothwell and Zegvel's policy instrument analysis, we define supply-based policy instruments as those through which the government directly influences factors of production such as talent, capital, and technology on the supply side to foster the adoption of PV technology. Demand-based policy instruments, on the other hand, are government policies designed to stimulate consumption, investment, and international cooperation within the Chinese PV market by focusing on the demand side. Environmental policy instruments encompass policies established by the government to create a favorable regulatory environment for the PV industry. Building on Y. Zhang et al. (2021) specific classification and nomenclature of China's decarbonization policy instruments, this paper further categorizes supply-based policy instruments into three distinct categories: capital input, information services, and technical support. Demand-based policies are classified into multi-party collaboration, government procurement, demonstration projects, demand-side incentives, and international communications. Environmental policies fall into categories such as target planning, financial support, regulatory control, and tax incentives. Please refer to Table 1 for detailed definitions of these policy instruments. These three categories of policy instruments interact with one another. Supply-based policies stimulate PV applications and open up the market, demand-based policies drive market participation, and environmental regulations provide support for environmental considerations, as illustrated in Figure 4.

Table 1: Policy instrument types, names and definitions

Type of Instrument	Name of Instruments	Definitions
Supply	Capital Investment	Capital investment policy instruments are incentives used by governments to support business creation and development, personal training, and infrastructure construction in the solar supply chain.
	Information Service	Policy instruments related to information services encompass the provision of information and education pertaining to PV technologies,market,opportunities, regulations, and policies. Such information dissemination can occur through various means, including websites, research studies, promotional campaigns, and educational seminars.

	Technology Support	Technical support policy instruments encompass the provision of technical guidance, support for research and development (R&D), and incentives for fostering innovation. These measures are aimed at advancing and enhancing PV technologies.
Demand	Multi-Party Synergy	Multi-party synergistic policy instruments facilitate collaboration among governments, industry, academia, and society to collectively promote research, development, deployment, and application of PV technologies. These instruments may involve the creation of public-private partnerships aimed at fostering knowledge sharing and driving technological innovation in the PV sector.
	Government Procurement	Government procurement policy instruments encourage governments to acquire and incorporate PV technologies into government facilities and equipment. By doing so, governments can act as early adopters of PV technology, effectively stimulating market demand for these technologies.
	Demonstration Project	The demonstration projects policy instrument entails government funding or support for a variety of PV projects with the aim of showcasing the feasibility and advantages of PV technologies. These projects may span various application areas, including residential, commercial, industrial, and public facilities.
	Demand-Side Incentive	Demand-side incentive policy instruments involve providing incentives, subsidies, feed-in tariff (FiT) policies, and other economic incentives to stimulate the adoption of PV technologies in the market. These measures are designed to lower investment costs and enhance economic returns for users, thus encouraging the use of PV systems.
	International Communication	The international communication policy instrument promotes collaboration between governments, enterprises, and research institutions on an international scale, encouraging knowledge exchange and cooperation. Its primary objective is to facilitate the worldwide development and application of PV technologies.
Environmental	Target Programming	Targeted programming policy instruments consist of goals and programs established by governments to provide direction for the development and deployment of PV energy. These targets typically encompass various aspects, such as PV capacity, energy mix ratios, and objectives related to reducing carbon emissions.
	Financial Support	Financial support policy instruments involve providing financial resources in the form of funds, loans, grants, risk-sharing arrangements, financing guarantees, and other financial tools. These measures are implemented to mitigate the financing costs and risks associated with PV projects, making them more financially viable.
	Regulatory Control	Regulatory control policy instruments encompass the establishment and enforcement of regulations, codes, and standards designed to oversee the operations and environmental impacts of the PV industry. This may entail the enactment of laws related to environmental protection, construction regulations, safety standards, and other regulatory measures to ensure industry compliance and environmental sustainability.
	Tax Incentive	Tax incentive policy instruments entail offering tax deductions, tax credits, or other forms of tax benefits for PV projects and PV technologies. These incentives are designed to encourage investors and businesses to embrace environmentally friendly technologies, such as PV systems.

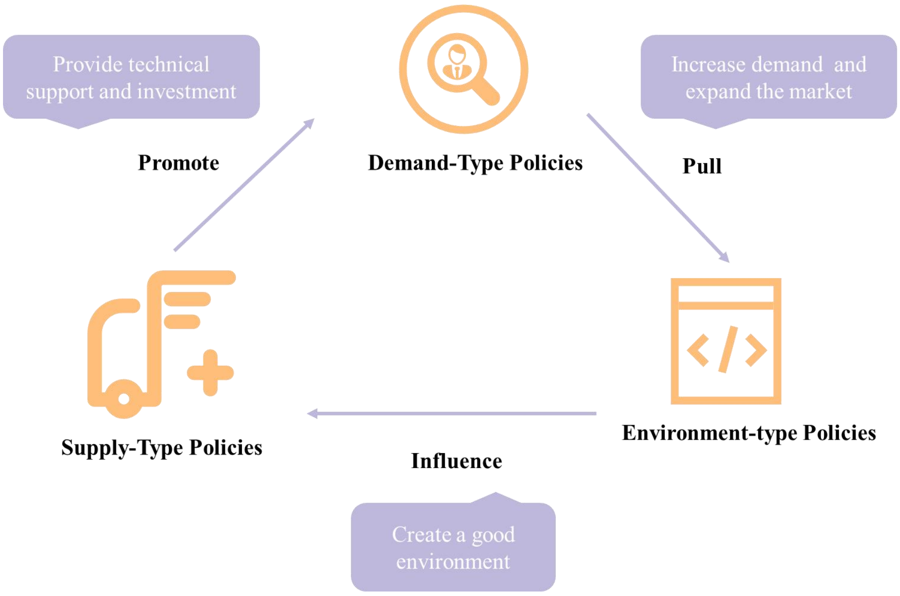

Figure 4: The influences of three policy instruments on PV power applications

3.1.2 Y Dimension: Role-goal Dimension

The development of the PV industry in China represents a long-term strategic initiative by the Chinese government, and PV policies encompass a wide range of aspects, including social benefits, production and consumption, and citizens' daily lives. When viewed through the lens of policy action areas, policies implemented at various stages of the industrial development process have distinct objectives aimed at achieving different goals. S. Zhang (2016) segmented China's distributed PV policy action areas from the latter half of 2012 to the first half of 2014 into four primary categories: scale and registration management, tariff, financing, and financial incentives, market promotion and grid connection, and measurement and settlement. Yang et al. (2018) analyzed the distributed PV and energy storage industry policies introduced by the Chinese central government from 2011 to 2017 and summarized four core policy areas: technology support, management drive, environment protection, and financial support. This paper adopts a classification system inspired by the above-mentioned scholars and key phased planning documents of the Chinese central government, such as The 12th Five Year Plan for Solar Energy Development and The 13th Five Year Plan for Solar Energy Development. The PV policy action areas are divided into four distinct categories: market development, industrial upgrading, industrial correlation, and financial support. These categories are integrated within the Y dimension of the three-dimensional analysis framework. Within this framework, market development primarily revolves around activities such as creating new markets for existing PV products, fostering the emergence of innovative business models, and introducing appropriate regulatory measures for these markets. Industrial upgrading predominantly involves a series of policies that aim to drive technological innovations, establish technical standards in PV-related industries, and chart strategies for future-oriented industrial growth. Industrial correlation, on the other hand, focuses on policies designed to enhance collaboration and synergy among PV supply chain industries, with a specific emphasis on policies that promote the positive societal benefits of the industry, such as poverty reduction, and mitigate its negative impacts, such as environmental pollution. Financial support encompasses a comprehensive set of measures employed by the government to encourage the financial development of the PV industry. These measures may influence both the production side, for example, through partial tax exemptions, and the consumption side, such as offering subsidies for power generation. By scrutinizing these policy action areas, it becomes possible to assess the degree of attention given to each area by prior policy systems, helping to identify gaps and challenges that can guide the formulation and implementation of future policies.

3.1.3 Z dimension: Policy Objects Dimension

When discussing PV policies, policy objects encompass various stakeholders and entities involved in PV policies, each playing distinct yet vital roles in advancing the development and implementation of PV energy. While some environmental researchers have traditionally asserted that strengthening government regulations is one of the most effective means of achieving environmental objectives (Harvey et al., 2018), mainstream economists argue for the minimal role of regulation in decarbonization. They contend that substituting regulation with market mechanisms can enhance efficiency (Fischer et al., 2008). The notion of utilizing market mechanisms to curb carbon emissions is also evident in the international carbon trading provisions of the Paris Agreement (Biber et al., 2016). Given the significant impact of the debate surrounding regulation and market mechanisms on the government's capacity to reduce greenhouse gas emissions, this paper categorizes the policy subjects of the Chinese central government into three groups: government, enterprises and other organizations, and the public, as depicted in Table 2.

Table 2: Policy objects types, and definitions

Type of Policy Object	Definitions
Government	Policies serve different levels of the government
Enterprises and Other Organizations	Policies serve the enterprises and other organizations
Public	Policies serve the public

3.2 Date Source

Data collection for this paper initiated in August 2023, with a focus on primary sources of information sourced from the official websites of China's central government, including the State Council and its subsidiary departments such as the National Energy Administration, and the National Development and Reform Commission. The search parameters included the terms "PV," "PV policies," and "renewable energy policies," utilizing both exact match and synonym expansion methods. The collected documents comprised normative texts with policy implications, including binding opinions, measures, and notices. In total, 192 documents related to the PV field or renewable energy policies impacting the PV sector were systematically gathered, covering the period from 2012 to 2022 (refer to Table 2).

Table 3: Summary of PV policy documents

Serial Number	Title	Issue Department	Issue No.	Issue Date
1	Solar PV Industry "Twelfth Five-Year" Development Plan	Ministry of Industry and Information Technology	National Development [2012] No. 9	2012-02-24
2	PV power plant construction specifications	Ministry of Housing and Urban-Rural Development	GB50794-2012	2012-06-28
3	Notice on Improving the Feed-in Tariff Policy for Solar PV Power Generation	PRC National Development and Reform Commission	NDRC Price [2012] No. 1594	2012-08-01
4	Opinions on Financial Services to Support Distributed PV Power Generation	National Energy Administration	Guoneng Xinneng [2013] No. 312	2013-08-22
5	Several Opinions on Promoting the Healthy Development of the PV Industry	State Council	National Development [2013] No. 24	2013-07-15
6	PV manufacturing industry normative conditions	Ministry of Industry and Information Technology	National Development [2013] No. 24	2013-09-16
7	Notice on VAT Policy on PV Power Generation	Ministry of Finance	Finance and Taxation [2013] No. 66	2013-09-23
…	…	…	…	…
192	Notice on Matters Relating to the Promotion of the Healthy Development of the PV Industry Chain	National Energy Administration (NEA)	DRC Operation [2022] No. 788	2022-10-28

3.3 Research Instrument

The qualitative methodology employed in this research utilized NVivo 12 analysis software. A total of 192 Chinese PV energy policies, disseminated by the State Council of China and its subordinate departments, were collected and subsequently imported into the software for the purpose of proprietary data coding and analysis. The coding process was primarily carried out manually. Initially, the relevant articles in the 192 policy documents were sequentially numbered using a format of "policy number, chapter number, and serial number." Subsequently, the content units of each policy text were classified according to three dimensions: action area, policy instruments, and policy objects, using the previously established three-dimensional analytical framework of the carbon neutrality policy system. The coding procedure is presented in Table 5.

Table 4: Example of a policy content unit coding process

Serial Number	Title	Policy Module Content	Code Number	Policy Instruments	Policy Target	Role Target
91	Matters relating to the promotion of the healthy development of the PV industry chain	Support polysilicon enterprises to strengthen technological innovation and research and development, to enhance the level of automation, digitalization, informationization and intelligence of production lines.	91.5.1	Technology Support	Enterprises and social organizations	Industrial upgrading
92	Measures for the Development and Construction of PV Power Plants	Enhances the comprehensive monitoring of the entire process, from the development and construction to the operation of PV power plant projects.	92.6.19	Regulatory Control	Government	Industrial upgrading
93	The State Council Poverty Alleviation Office on the issuance of the first batch of PV projects for poverty alleviation	In addition to allocating a portion of the government's investment as direct financial support to impoverished households, emphasis is placed on harnessing the labor force of these households to fully realize the comprehensive benefits of poverty alleviation projects.	93.7.12	Financial Support	Public	Industrial correlation

4. ANALYSIS AND DISCUSSION

4.1 X Dimension: Policy Instrument Analysis

In terms of policy instruments (X dimension), there is an imbalance in the distribution of the three types of policies. China's PV policy system predominantly relied on environmental policy instruments, which were used more frequently than demand-based and supply-based policy instruments. The statistical findings for the X-dimension (policy instrument dimension) are illustrated in Figure 5. Out of a total of 838 coded articles extracted from the 192 policy documents, environmental policy instruments accounted for 375, approximately 45%. Demand-based policy instruments amounted to 276, making up around 33%, while supply-based policy instruments were the least common, totaling only 187, or roughly 22%.

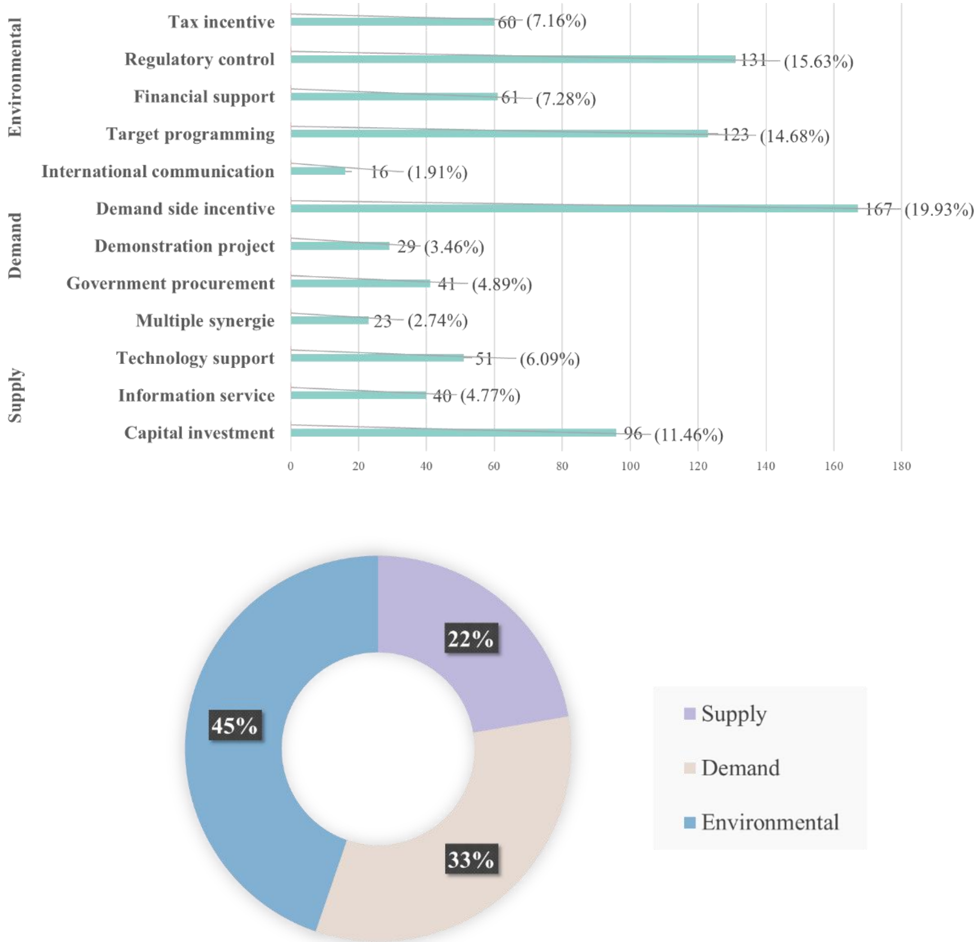

Figure 5: Policy statistics for the dimension of policy instrument

Upon further analysis, it becomes evident that the Chinese government exhibits a preference for three specific policy instruments: demand-side incentives, regulatory control, and target programming. These three instruments account for 19.93%, 15.63%, and 14.68% of the total policy instruments, as depicted in Figure 5. This indicates the government's reliance on demand-side economic incentives and macroeconomic control in shaping PV policies. Target programming, in particular, plays a crucial role in China's industrial development. The government has formulated various long-term plans and technical roadmaps to set guidelines and goals for advancing solar PV energy. Simultaneously, a series of regulations in fields such as environmental protection, PV power station construction, product standards, and fiscal subsidies support the achievement of these objectives. It's worth noting that the lack of forward-looking and reasonable measurement standards in the overall target system has led to multiple revisions of China's solar energy development goals. This has, in turn, affected the stability and credibility of the overall target system (D. Song et al., 2022). On the other hand, the Chinese central government has relatively weaker measures in the areas of international communication (1.91%), multiple synergies (2.73%), and demonstration projects (3.46%). This suggests that China's PV industry has primarily focused on domestic market development during the period from 2012 to 2022 (Zhu et al., 2021). Considering the significant contributions made by international cooperation to China's PV industry, the importance of coordinated actions across different sectors, and the potential for new energy innovation through public sector-supported demonstration projects (Bossink, 2017; Lerman et al., 2021), there is room for the Chinese government to increase its attention to policy instruments in these three areas.

Furthermore, an analysis of the Chinese government's use of the three types of policy instruments over different time periods reveals distinct trends. Between 2012 and 2018, the central government extensively utilized demand-side incentives and environmental policy instruments. These included measures such as low-interest loans for distributed PV users, tax exemptions for PV companies, and large-scale subsidies to reduce the cost of PV system installations. However, the overuse of large-scale subsidies and FiT policies led to issues of overinvestment and fiscal pressure. Moreover, some poor-quality PV plants were established solely to gain access to subsidies (Zhou et al., 2020). During the period from 2012 to 2016, the Chinese government issued 25 regulatory control documents, primarily aimed at governing the construction, operation, and maintenance of PV power generation. These regulations also encompassed policies related to subsidy distribution and market competition. Since 2016, the number of supply policy instruments has increased. This shift can be attributed to the trade war initiated by the United States, which primarily targeted China's high-tech advancements (Fang, 2020). In response to the trade war, the Chinese government expanded policy instruments related to technical support and talent development, successfully addressing technological gaps within the PV industry chain (W. Song et al., 2022).

4.2 Y Dimension: Analysis of Policy Action Areas

The coding results in the Y-dimension (policy action areas) are presented in Figure 3. A total of 787 articles from the 192 policy documents were coded in this dimension. The number of coded policy articles in the area of market development is 181, constituting approximately 23%. In the sphere of industrial upgrading, 202 policy articles were coded, representing around 26%. The policy articles pertaining to industrial correlation total 67, making up approximately 8%. Meanwhile, the policy provisions related to financial support number 337, accounting for about 43% of the total. These statistics reveal that the Chinese central government prioritized financial support during the period from 2012 to 2022 but allocated relatively less attention to enhancing the positive social impacts of the PV industry and fostering coordination among upstream and downstream sectors.

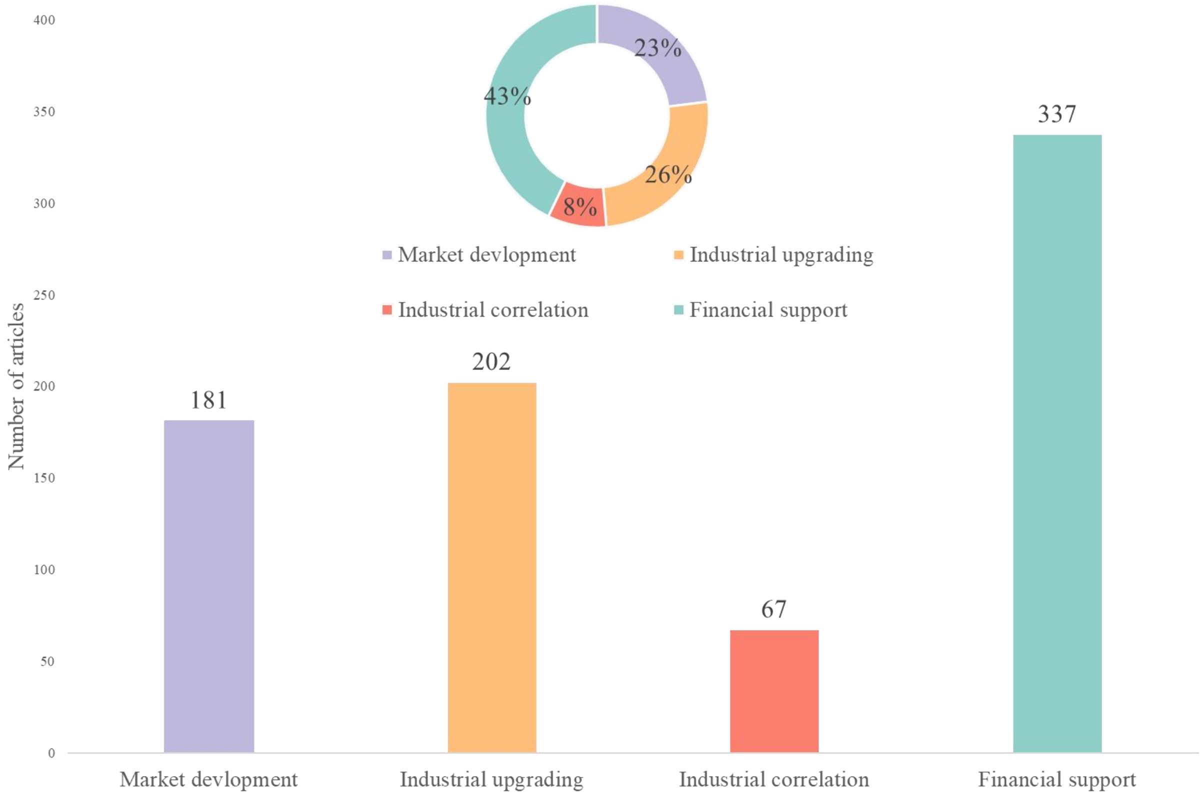

Figure 6: Policy statistics for the dimension of policy action areas

The focus of market development policies has evolved over time. Between 2012 and 2013, when the European Union and the United States imposed anti-dumping and anti-subsidy sanctions on Chinese PV products (Zhu et al., 2023), the primary objective was to develop the domestic market. This aimed to absorb excess capacity while mitigating project development risks and disorderly competition (Huang et al., 2016). As the domestic PV market experienced rapid growth after 2013, the focus of market development policies shifted towards the creation and protection of new business models. This transformation is particularly evident in the distributed PV sector, as policies encouraged stakeholders to develop energy management contract models (EPC mode) and loan custody operation and maintenance models (refer to figures 4 and 5). It is important to note that in 2013, the policy document titled Several Proposals of the State Council on Promoting the Healthy Development of the PV Industry emphasized the significance of expanding into European and American markets. However, in the Action Plan for Innovative Development of the Smart PV Industry (2021-2025) released in 2021, PV product trade with countries along "the Belt and Road" was considered an effective means to deepen international exchanges and cooperation. While the European and American markets have traditionally been crucial for China's PV exports, the shift in China's PV export strategy in response to European and American trade protectionism opens up opportunities for enhanced trade with "the Belt and Road" countries (Zhu et al., 2023).

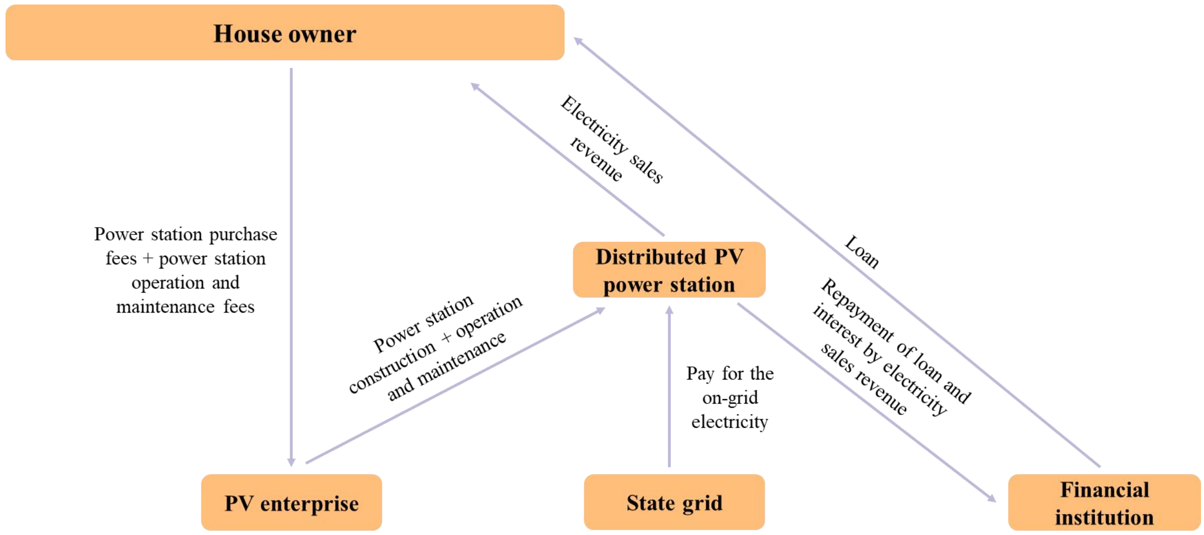

Figure 7: The business model for Loan custody operation and maintenance mode

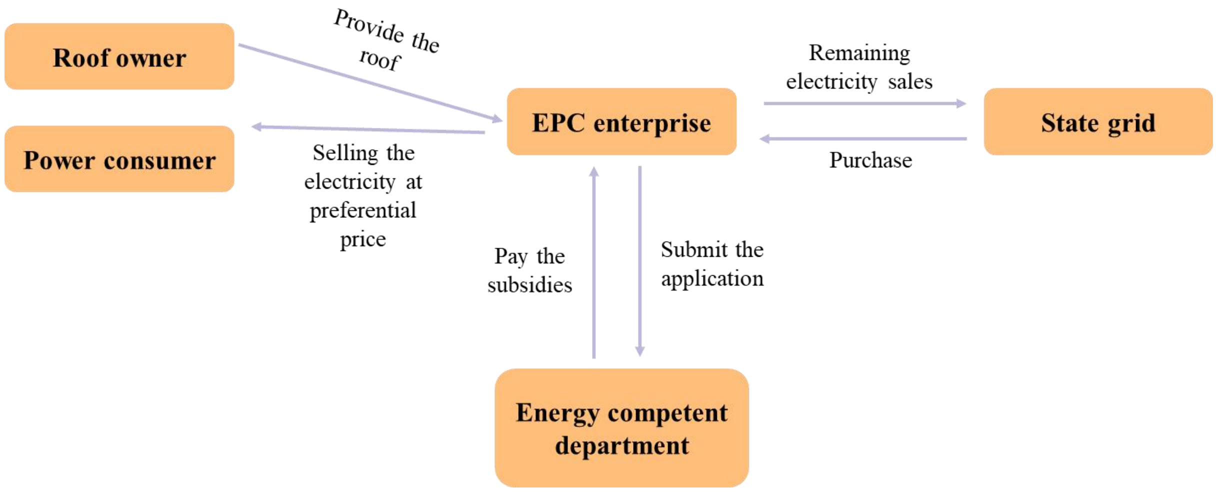

Figure 8: The business model for Energy management contract mode

In the realm of industrial upgrading policies, China has seen substantial public sector investments to bolster research institutions and support enterprise R&D. These investments have been instrumental in aiding the accomplishment of each "five-year plan" mandated by the central government. Initiatives such as the Ministry of Science and Technology's (MOST) National High-Tech Research and Development Plan (863 Plan), the National Basic Research Plan (973 Plan), and the Key Technology R&D Plan of MOST have played a pivotal role in helping China surmount technical challenges in thin-film PVs, crystalline silicon technology, and production equipment (Grau et al., 2012). From 2012 to 2022, the central Chinese government initially concentrated on enhancing polycrystalline silicon and PV cell technologies. Subsequently, the focus shifted towards improving the performance of intelligent PV systems and energy storage systems. The launch of the Top Runner Program by the

Chinese government in 2015 significantly contributed to the advancement of China's PV technology. This program established technical standards for industry producers both upstream and downstream. Producers failing to meet these standards by specified deadlines face penalties, including potential bans on product sales. Concurrently, the Chinese government has actively encouraged PV enterprises to undergo product quality certification. This includes promoting ISO 14067 carbon footprint certification and ISO 14064 greenhouse gas certification, as outlined in the Standard Conditions for the PV Manufacturing Industry published in 2013. These initiatives underscore China's commitment to fostering standardized PV products as international decarbonization tools.

Industrial correlation policies primarily aim to promote positive externalities in the PV industry, discourage negative externalities, and facilitate collaborative development across different sectors within the industrial chain. Two prominent examples of positive externalities stemming from China's PV industry are poverty alleviation and rural revitalization. The Chinese government has placed great importance on applying PV technology in rural areas. As early as 2002, they initiated the Power Transmission to Rural Areas Project to address the electricity needs of residents in remote, unelectrified regions. In recent years, China has progressively promoted programs like PV agricultural greenhouses, PV breeding, and PV sewage purification, as well as the Whole County PV Promotion Program, to continually enhance the social benefits of PVs in poverty alleviation and rural revitalization. Regarding policies that foster the collaborative development of industries, the Chinese government has consistently encouraged cooperation among different sectors in the PV industry's upstream and downstream. The Notice on Promoting the Collaborative Development of the PV Industry Chain, issued in 2022, encourages enterprises to establish long-term cooperation mechanisms with relevant upstream and downstream entities through strategic alliances, long-term contracts, technical collaboration, mutual equity participation, and other means. This inter-industry collaboration helps the PV industry navigate cyclical patterns. Deepening this cooperation mitigates the effects of cyclical fluctuations in orders for PV terminal products on the entire industry chain.

The Electricity Feed-in Law of 1990, introduced in Germany, marked the world's first renewable electricity FiT legislation. This landmark law played a crucial role in driving the growth and expansion of the global PV market (G. Nemet, 2019b). China's FiT policy, established in 2011, stands as a pivotal milestone in the history of China's PV subsidy policy development. Before the implementation of this policy, the Chinese government predominantly supported the domestic PV sector by offering low-interest or interest-free loans to PV enterprises and by directly disbursing financial subsidies to PV projects, with the Golden Sun Project being a prominent example (G. F. Nemet, 2019). Following 2011, the Chinese government introduced a pivotal strategy wherein they categorized resource zones based on the varying levels of solar radiation resources. Subsequently, they established distinct benchmark feed-in tariff prices for each of these resource zones. This innovative approach played a significant role in fostering the expansion of the domestic market for PV energy (see Table 1 and Table 2) (National Energy Administration, 2014). Beyond the implementation of FiT policies, the Chinese government has prioritized the development of the PV industry as a strategic goal. To support and stimulate this sector, they offer an array of incentives, including tax deductions, export rebates, low-interest loans, and access to affordable land (Lin et al., 2020). Starting in 2018, the Chinese government issued the Notice on Matters Related to PV Power Generation in 2018, which provided clear support for the transformation of PV power generation towards a state of being non-subsidized while ensuring affordability in grid access. As a result of these measures, Chinese PV power generation systems have progressively transitioned into the era of subsidy-free grid parity. Over the nine years from 2012 to 2021, the Chinese government systematically reduced the FiT prices and subsidies for PV installations, reflecting a deliberate effort to establish a more self-sustainable PV industry (Hu, 2022)(see table 2).

Table 5: China's solar energy resource richness level

Class	Resource code	Annual total radication (MJ/m^2)	Annual total radication (Kwh/m^2)	Annual average irradiance (W/m^2)
Richest area	I	≥6300	≥1750	≥200
Rich area	II	5040~6300	1400~1750	160~200
Relatively rich area	III	3780~5040	1050~1400	120~160
General area	IV	<3780	<1050	<120

Table 6: Chinese National subsidy policy for PV since 2011

Year Period	Benchmark feed in tariff price for centralized PV station (yuan/Kwh)			Subsidy for distributed PV "self-use first and the rest of the generation to the grid" mode user
	Solar resource area I	solar resource area II	solar resource area III	
2011	1.15	1.15	1.15	-
2012-2013	1.00	1.00	1.00	
2014-2016.5	0.90	0.95	1.00	0.42
2016.6-2017.5	0.8	0.88	0.98	0.42
2017.6-2017.12	0.65	0.75	0.85	0.42
2018.1-2018.5	0.55	0.65	0.75	0.37
2018.6-2019.6	0.50	0.60	0.70	0.32
2019.7-2020.5	0.40	0.45	0.55	Industrial & Commercial Distributed PV station: 0.10/Household Distributed PV: 0.18
2020.6-2020.12	≤0.35	≤0.30	≤0.49	Industrial & Commercial distributed PV station: 0.05/Household distributed PV station: 0.08
2021.1-2021.12	Local electricity pricing for coal-fired power generation	Local electricity pricing for coal-fired power generation	Local electricity pricing for coal-fired power generation	Industrial & Commercial distributed PV station: 0/Household distributed PV station: 0.03

In May 2019, the National Development and Reform Commission issued the Notice on the Improvement of Renewable Energy Power Consumption Guarantee Mechanism. This notice encouraged the integration of the PV industry into the carbon trading market and the green power certificate trading market to assist subsidy-free grid parity projects in achieving fair and reasonable returns. The Chinese Certified Emission Reduction (CCER) program serves as the Chinese equivalent of carbon credits. It entails the recording and registration of greenhouse gas emission reductions by the government, following the provisions of the Interim Measures for the Administration of Voluntary Emission Reduction of Greenhouse Gases. These reductions are measured in "tons of carbon dioxide equivalent." However, the participation of PV power stations in the CCER trading market, particularly distributed PV power stations, has yet to reach a significant scale. This is primarily due to the extended duration required for CCER development transactions to enter the market from project filing and the associated high costs associated with certifying power generation and tradable electricity data (Yao, 2022). Consequently, even though prior studies have extensively evaluated China's distributed PV carbon assets to determine how the carbon market can compensate for users' losses in the electricity market during the grid parity era (Song et al., 2020; X. Xu et al., 2018), there still exist significant operational challenges at this stage.

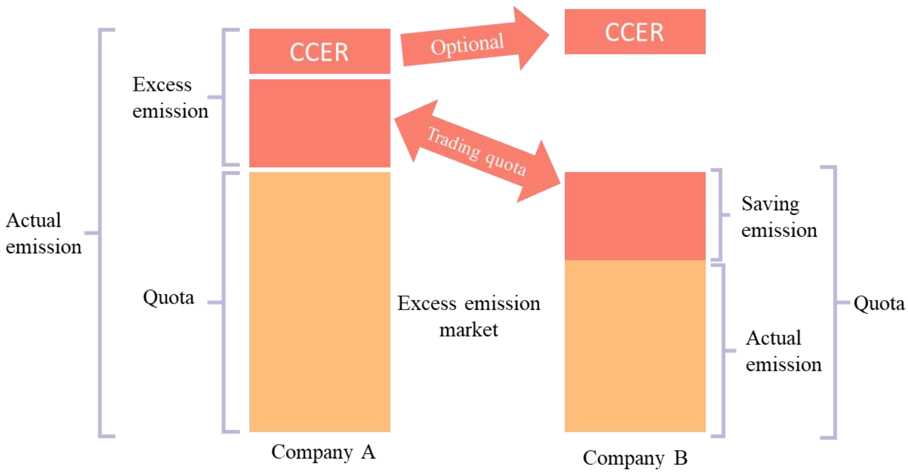

Figure 9: Model map for China CCER carbon trading market

4.3 Z dimension: Policy Object Analysis

When considering the policy objects in the dimension of Z, it's evident that China's PV policy system displays a notable imbalance. As depicted in Figure 8, the majority of policy provisions primarily involve the government, accounting for 52% of the total. In contrast, there are relatively fewer policies that directly engage enterprises and other organizations, comprising 34%, and the public, making up 13%. This distribution underscores the prominent role of the Chinese government as the principal leader, overseer, and policymaker in the realm of renewable energy development. It's essential to highlight that numerous unofficial institutions and organizations in China, such as the China PV Industry Association, often necessitate approval and scrutiny from the Chinese government for their establishment and activities. Moreover, there is a noticeable absence of context for non-governmental organizations (NGOs), scientists, and more extensive social groups in China's core PV policy framework, which signifies the Chinese government's top-down approach to governance and its reliance on regulatory mechanisms.

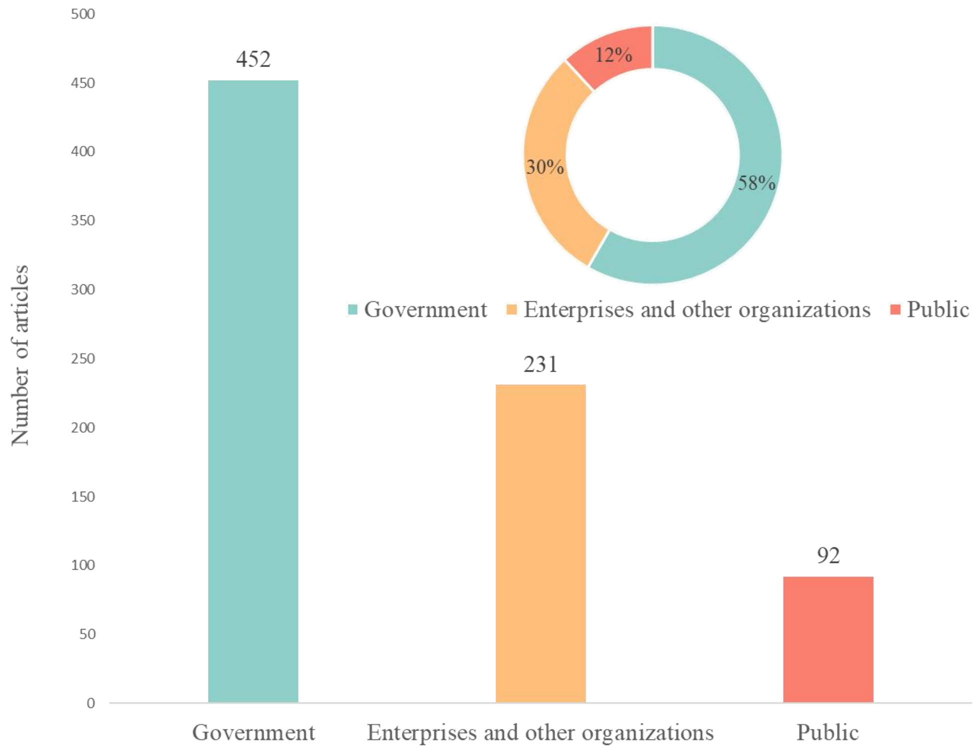

Figure 10: Policy statistics for the dimension of policy objects

5. CONSLUSION AND POLICY RECOMMENDATION

This paper presents a comprehensive systematic review and content analysis of China's central government's PV policies spanning the period from 2012 to 2022. The analysis is conducted across three key dimensions: policy action areas, policy instruments, and policy objects. Overall, during this era of rapid PV development in China, the central government's PV policies have predominantly relied on a plethora of demand and supply-side economic incentives, regulatory measures, and overarching goal-oriented policies. This approach has been employed to construct a top-down, nationally driven strategy for PV development. Interestingly, since the election of the Biden administration and the passage of the Green New Deal Act, even the United States, which has historically been a fervent advocate of neoliberalism, has begun to allocate collective resources towards the pursuit of economic decarbonization and combating the climate crisis through regulatory mechanisms and environmental oversight. In this context, an analysis of China's nationally led decarbonization model offers insights and implications for future collaborations and the strengthening of global decarbonization instruments. Therefore, examining the development model of China's PV industry, characterized by strong government intervention involving substantial public investment funds to drive industrial upgrading and market expansion while reinforcing economic regulation, can serve as a valuable reference for countries urgently seeking to transition from fossil fuel energy to renewable energy for decarbonization and leverage the public sector's role in bolstering decarbonization efforts and climate change mitigation. Based on the conclusions drawn, this paper offers a set of policy recommendations and research directions for further exploration:

Firstly, broaden the scope of policy objects by encouraging greater participation from the scientific, engineering, and media sectors in popularizing PV knowledge and promoting decarbonization instruments. Secondly, enhance international communications by expanding policy instruments related to international communications. Given increased imports of PV products from China by Europe amidst the Russo-Ukrainian War and ongoing trade frictions, the Chinese government should engage in more international exchanges to demonstrate the reliability of its industrial chain and the rationality of its decarbonization model. This can be achieved through various international exchange programs facilitated by universities, research institutions, and commercial exhibitions. Thirdly, it advocates the development of green certificate and carbon trading markets to ensure the effective functioning of the domestic PV market, particularly to compensate for the diminishing returns for non-subsidized and grid-parity PV power stations. Addressing the high entry barriers and non-standard issues for distributed PV power stations participating in these markets is essential, and this can be achieved through strengthened oversight, the establishment of new regulatory branches, and subsidies for data collection. Fourthly, promote innovative application models to expand the market and amplify the social benefits of the PV industry. Encourage and support innovative models like agriculture-PV integration programs that can contribute to social well-being. Finally, address the need for stronger scrapping and recycling regulations. Given the explosive growth in China's PV installations in recent years, there is a pressing need to address the insufficient experience in scrapping and recycling PV power plants. To prevent an increase in the carbon footprint due to improper disposal of PV materials, it is essential to issue more comprehensive environmental and technical regulations and support the development of scrapping and recycling technologies and devices. These recommendations offer a strategic framework for enhancing China's PV industry, fostering international cooperation, and addressing crucial sustainability concerns.

In conclusion, this paper aims to provide essential theoretical support for the Chinese government's efforts to drive the energy transition and work towards achieving the goals of carbon peak and carbon neutrality. However, it's important to acknowledge that there are certain limitations within this paper, which could be addressed in future research endeavors. On one hand, this study exclusively analyzes the PV policies of the central government in China, without taking into account the PV policies of local governments in the country. Many local governments in China have adopted policy instruments and timelines that diverge from those of the central government, leading to regional disparities in China's PV policies. For instance, Zhejiang Province in eastern China continues to provide demand-side subsidies even after national-level PV subsidies and FiT policies have been discontinued. On the other hand, this paper does not bridge the knowledge gaps regarding the interconnections among different policy instruments, action areas, and policy objects. Future research should establish effective cross-analysis methods from various dimensions to delve deeper into the complexities of the policy system and provide a more comprehensive understanding.

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