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Overall review of distributed photovoltaic development in China: process, dynamic, and theories

Alex Hongliang Zhang[1,2] and Selahattin Murat Sirin[3]

[1]Yangtze River Delta Economics and Social Development Research Center, Nanjing University, Nanjing, Jiangsu, China; [2]School of Business, Nanjing University, Nanjing, Jiangsu, China and [3]Ivey Business School, Western University, London, Ontario, Canada

Review Article

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Abbreviations:
CAPEX: Capital Expenditure; CBIRC: China Banking and Insurance Regulatory Commission; CPI: Climate Policy Initiative; DCEP: Desulfurized Coal-fired Electricity Benchmark Price; DPV: Distributed PV; EPC: Engineering Procurement Construction; FIT: Feed-in Tariff; GSP: Golden Sun Projects; IEA: International Energy Agency; IRENA: International Renewable Energy Agency; IRR: Internal Rate of Return; LCOE: Levelized Cost Of Electricity; MIT: Ministry of Information and Technology; MOF: Ministry of Finance; MOST: Ministry of Science and Technology; NDRC: National Development and Reform Commission; NEA: National Energy Administration; NPC: National People Congress; P2P: Peer-to-peer; PBC: People's Bank of China; PV: Photovoltaic; RES: Renewable Energy Surcharge; ROI: Return on Investment; RPS: Renewable Portfolio Standard; UPV: Utility PV

Corresponding author:
Selahattin Murat Sirin;
Email: ssirin@uwo.ca

Abstract

Non-technical summary. DPV systems, typically small to medium-sized solar power installations on buildings, which primarily and directly supply electricity to industrial, commercial, or residential consumers in proximity. DPV is an advocated renewable substation for climate change and energy saving for merits of low installation costs, high energy efficiency, and the ability to provide decentralized power supply. Our research has theoretical significance in explaining and understanding the development and policy evolution of DPV in China and provide valuable suggestions for future industry policies during grid parity.

Technical summary. Since 2021, China has been phasing out its decade-long feed-in tariff policies, reducing the photovoltaic industry's dependency on subsidies. Despite the challenges posed by declining electricity prices and slowdown in economic growth, the authorities continue to prioritize the development of DPV due to its low investment costs, high energy efficiency, and decentralized power supply, and these technologies have already achieved demand-side parity. Driven by this phenomenon, this study examines the trajectory of DPV diffusion and the evolution of related policies over the last decade. It unravels the dynamic mechanism of DPV investment through theoretical analysis and develops a macro model to identify optimal installation strategies and renewable energy proportions. Our findings highlight the increasing role of green energy and suggest that green finance is crucial for stimulating DPV investment in the era of grid parity. The study concludes with practical recommendations for overcoming DPV challenges in China.

Social media summary. DPV has become a prominent renewable energy solution in other countries but not in China. We probe the system dynamics modeling to give explanation and solution during grid parity.

Attachment

Zone I: Ningxia, Haixi of Qinghai, Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang, and Jingchang of Gansu; Hami, Tacheng, Altay, and Karamay of Xinjiang, Inner Mongolia, except for Chifeng, Tongliao, Hinggan League, and Hulunbuir

Zone II: Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Sichuan, Yunnan, Chifeng, Tongliao, Hinggan League, and Hulunbuir of Inner Mongolia, Chengde, Zhangjiakou, Tangshan, and Qinhuangdao of Hebei, Datong, Shuozhou, and Xinzhou of Shanxi, Yulin, and Yanan of Shaanxi, Qinghai, Gansu, and Xinjiang, except zone I

Zone III: Mainland of China except for zone I&II

1. Introduction

Renewable energy technologies are replacing coal and other conventional energy sources as countries provide various incentives to deal with risks associated with the climate change, deteriorating environment, and energy supply security. Photovoltaic technology, a cornerstone of clean-tech investments, has garnered significant interest worldwide. Between 2013 and 2018, PV investments represented a staggering 46% of total global renewable energy investments, far outpacing other emerging energy technologies (IRENA & CPI, 2020). The current trend in investments is marked by a move towards decentralized systems, with distributed renewable energy emerging as a key trend. DPV systems, typically small to medium-sized solar power installations on buildings, exemplify this shift. These systems primarily supply electricity to industrial, commercial, or residential consumers in close proximity, with any surplus power fed back into the grid. In Europe, particularly in Germany, DPV has become a prominent renewable energy solution thanks to its low installation costs, high energy efficiency, and the ability to provide decentralized power supply (Avril et al., 2012; Robert & Florian, 2011).

The evolution of China's DPV sector has been complex and heavily influenced by governmental policies that have undergone several distinct phases. During its early phase, DPV sector briefly flourished under the Golden Sun Project (GSP), which provided initial investment subsidies. As the policies shifted towards the next phase dominated by feed-in tariffs (FIT) and a surge in Utility PV (UPV) investments driven by subsidies, the growth of DPV projects lagged behind. As a response to the decline in initial investment costs of PV technologies (PV capital expenditure – CAPEX), the government drastically cut back on UPV subsidies and aimed to control the uncontrolled expansion of the PV sector. This led to a decline and stagnation in the UPV sector, but simultaneously, DPV sector encountered unparalleled growth opportunities. The government's ongoing subsidies and the reduction in costs significantly accelerated DPV installations until the COVID-19 pandemic (Tang et al., 2021), which created major supply chain problems and investments costs increased again. At the same time, the central government ceased subsidies for new UPV investment and industrial & commercial DPV ventures (NDRC, 2021). Caught between increasing investments costs and declining electricity prices for commercial and industrial users, the diffusion of DPV technologies is encountering several hurdles (Alex et al., 2022). Hence, it has become crucial to identify strategies to navigate through the challenging period of grid parity effectively.

Driven by this phenomenon, the article aims to discuss the trajectory of DPV diffusion over the last decade, untangle the dynamic mechanism of DPV investments, and suggests possible policy recommendations for the future development of DPV during grid parity. We start with covering the factors affecting DPV investments from a micro perspective and explain the twists and turns in the DPV adoption path. Subsequently, we develop a broader model to probe and determine the optimal setup for the diffusion of DPV technologies. We include the business logic of DPV deployment and attempt to understand the evolution of the market. In comparing the strengths and weaknesses of different support policies, we highlight the critical role of green finance in advancing unsubsidized DPV projects at the point of grid parity. Ultimately, we identify a growing trend towards the replacement of conventional energy sources with renewable ones. This leads us to offer evidence-based recommendations for guiding the future growth of DPV and the broader green economy.

Current studies on China's DPV market are insightful, yet often they only address the market's observable trends on a case-by-case basis. The segmented nature of China's PV market is intricate, laden with various practical challenges and theoretical conundrums that require deeper exploration to uncover the fundamental principles and logic driving DPV's evolution (Alex et al., 2022). This research adopts a comprehensive method, scrutinizing the entirety of China's policy support for DPV using dynamic analytical tools over the last decade rather than focusing only on one or two specific periods. Thus, a notable contribution of this paper is to enrich the existing literature on China's renewable energy sector. In addition, we investigate the dynamic mechanisms of DPV development from two perspectives: the micro-level of individual actors and the macro-level of the economic system, providing a comprehensive analysis of driving factors and uncovering the underlying internal logic of DPV growth. Furthermore, through a critical evaluation of policy strengths and weaknesses, we argue that green finance emerges as a crucial strategy to boost DPV investment in the era of grid parity, offering several actionable recommendations to navigate DPV's challenges. The paper proceeds with a review of relevant literature in Section 2, then moves on to detail the landscape of China's DPV market and its principal policies in Section 3. Section 4 is dedicated to theoretical analysis. The concluding Section 5 explores variations in policy and outlines significant policy recommendations.

2. Literature review

Leveraging the benefits of prosumer participation, conservation of land, and alignment with energy demand, DPV has emerged as the leading clean technology globally, leading to a surge in related scholarly articles. The literature primarily concentrates on the forefront of PV adoption, including countries such as Germany, Japan, and the USA. (Lars & Alvar, 2016; Mario, 2013; Sufang, 2016b). Following the introduction of the feed-in-tariff policy in 2011, the market for UPV in China has seen remarkable growth, in contrast, DPV experienced a period of sluggish expansion. This situation has not only affected investors but has also garnered interest from the academic community, prompting researchers to investigate the economic viability and feasibility of investing in DPV within China. To name a few studies, Jiahai et al. (2014) examine the economic aspects of China's DPV using the Levelized Cost of Electricity (LCOE) and conclude that DPV is economically unfeasible in many scenarios. They identify several obstacles contributing to high investment risks: challenges in securing rooftop spaces, complex procedures for grid connections, difficulties in acquiring bank financing, and rigid, unappealing subsidy regimes. These factors significantly explain the sluggish growth of DPV in China during the period. Xingang et al. (2015) analyze the internal rate of return (IRR) and static payback periods for DPV systems across five cities in China, each in distinct resource zones, revealing that FIT policies outperform initial investment subsidies in efficiency. Bing et al. (2017) conducted a comparative study between local consumption DPV and large-scale and long-distance transmission UPV in China and concluded that local consumption schemes can generate cheaper electricity and achieve a higher renewable energy electricity integration ratio, which should be encouraged. Meanwhile, Feng & Tao (2019) investigate the lifecycle impacts of solar power, introducing metrics for energy and carbon investment returns, and argue that DPV is particularly apt for the eastern regions of China, where reducing carbon emissions is a pressing concern. Subsequently, to address the challenges of DPV diffusion in China, experts and scholars have shifted their focus to exploring business models. Fang et al. (2015) provide detailed cost and time breakdowns for DPV project installations, comparing various DPV scenarios and highlighting that industrial and commercial DPV projects with 100% self-consumption are the most advantageous. Yuexia et al. (2019) develop and assess a business model that combines investment and consulting services within the DPV energy system. They suggest that the consumer-to-consumer model not only enhances local energy consumption, environmental quality, and grid safety but also boosts DPV investors' profits while reducing electricity costs for users and government subsidies. Xingang & Zhen (2019) explore DPV grid parity from both the user and generation perspectives through cost-benefit analysis, concluding that DPV offers benefits in self-use and local consumption. Peiyun et al. (2021) evaluate the economic viability of DPV under different business models in three provinces, representing typical resource zones, and demonstrate that peer-to-peer (P2P) trading is the most profitable approach, benefiting both DPV owners and electricity consumers. As China's PV sector moves towards an era without subsidies, academic interest has focused on DPV diffusion under grid parity. Through an analysis that compares the LCOE of DPV systems against the prices of DCEP using cost-crossover methodology, Ying et al. (2020) thoroughly explore the potential for DPV systems to economically replace coal-fired power in 344 prefectural-level cities, concluding that DPV could feasibly substitute for 85.17% of coal-fired plants in China in the near future. Minhui & Qin (2020) delve into both demand-side and supply-side aspects of DPV grid parity on a provincial scale, predicting that DPV is poised to outcompete thermal power in nearly all provinces except for seven by 2025. Additionally, Libo et al. (2021) investigate the dual impact of reducing Feed-in Tariffs and implementing a Renewable Portfolio Standard (RPS) in China, asserting that RPS is a pivotal measure for maintaining momentum towards grid parity after FITs are phased out.

3. An overview of DPV diffusion in China

DPV in China began its journey almost concurrently with Utility UPV in the 2010s. However, unlike UPV's rapid growth, DPV in China followed a less favorable trajectory for an extended period. Recently, as FITs for UPV have been gradually reduced, DPV has seen a surge in development, leading to a significant narrowing of the market disparity between DPV and UPV as presented in Figure 1. The progress in DPV investments has been intricately linked with the changes in China's subsidy policies, which can be segmented into three distinct phases: initial upfront subsidies, consistent generation-based subsidies, and subsequent reductions in these subsidies.

3.1. Initialization phase: upfront subsidy (2009–2012)

Since becoming the world's leading producer of solar PV in 2007 (Sufang et al., 2014), China initiated the Solar Rooftop Plan to lessen the global financial crisis's burden on its economy and to address issues of excess capacity. This initiative introduced demonstration projects and provided fiscal incentives for the adoption of photovoltaic technology (MOF, 2009). By July 2009, the collaborative efforts of the MOF, MOST, and NEA (2009) gave rise to GSP. This program offered financial support, covering 50% of the costs for grid-connected solar projects and 70% for the off-grid projects. Initially, in 2009, the MOF awarded investors a subsidy of 20 CNY/w, which was subsequently reduced to 7-8 CNY/w during 2011–2012 (MOF, 2009; MOF et al., 2012). Such early investment subsidies through the GSP significantly propelled the expansion of DPV technology, resulting in a 250% increase in DPV capacity added by 2011 and a 79% increase in 2012.

GSP assisted Chinese PV companies in weathering their first downturn, shifting their focus from international to domestic markets. Subsequently, China's PV application market began to grow at an unprecedented rate. However, during GSP's implementation, the pitfalls of initial investment subsidies became apparent, including fraudulent activities, delays, and substandard work (Huang et al., 2016). In 2013, the MOF reviewed the fiscal funds allocated for GSP and discovered that 80% of the projects between 2009–2011 failed to meet the necessary requirements, putting 7 billion CNY of subsidies at risk of being retracted (Fengtao, 2013). Following this, the authorities revised the subsidy scheme, concluding the initial investment subsidies and shifting DPV policy towards electricity generation subsidies similar to those for UPV.

3.2. Period of stagnation: fixed generation subsidy (2013–2016)

In August 2013, NDRC (2013) introduced a new FIT policy for UPV projects and specified that DPV would receive a subsidy of 0.42 CNY per kWh, marking DPV's transition into the electricity generation subsidy era. The application and development processes for all PV projects are quite similar; however, unlike large-scale UPV projects, DPV installations are typically smaller, constrained by factors such as rooftop area, roof quality, and building load capacity. Thus, UPV projects, being nearly ten times larger in scale, appeared more attractive to investors than DPV. Additionally, UPV's FIT was comprised of local DCEP and national subsidies, backed by national credit and funded by the state. In contrast, DPV projects, mainly serving prosumers, often rely on tariffs collected from enterprises via EMC mechanisms, associated with business credit. This difference increased the difficulty of tariff collection for DPV, increasing profitability uncertainties (Guoliang et al., 2016), leading banks to downgrade DPV asset ratings and complicating financing (Sufang, 2016a). Moreover, prime rooftop spaces were already taken by earlier GSP initiatives, contributing to a contraction in the DPV market post-2012. Consequently, the newly installed DPV capacity

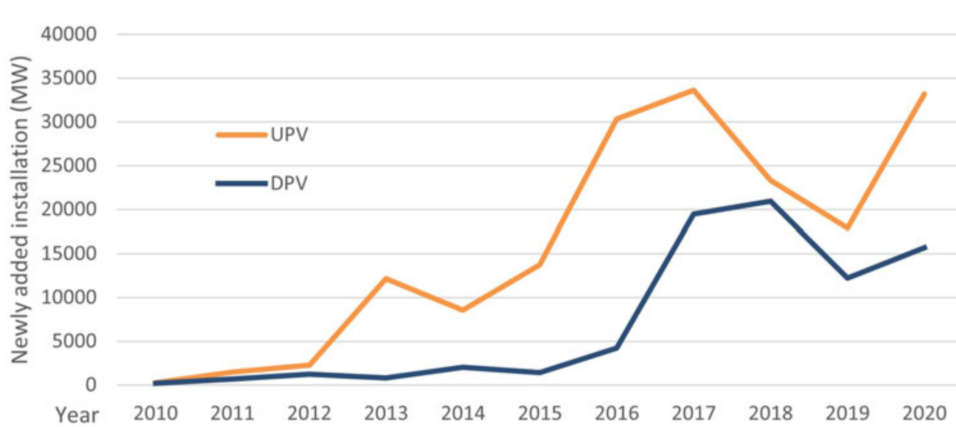

Figure 1. Annual installations of UPV and DPV in China 2010–2020 (*source*: NEA).

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dropped to 801 MW, a 36% year-on-year decrease in 2013. FIT policies have significantly boosted the deployment of UPV, but the growth of DPV experienced a period of decline and stagnation from 2013 to 2016, with DPV's share of total installations dropping from 30–40% to 10–20%. In 2012, NEA (2012) released the '12th Five-Year Plan' for PV development, placing equal emphasis on DPV and UPV. The plan set a goal for each PV project type to achieve a cumulative installation capacity of 10GW by the end of 2015. However, by 2015, the cumulative capacity of DPV was only 6GW, reaching 60% of the planned target and comprising 14% of the total installations. Meanwhile, UPV capacity surged to 37GW, 3.7 times the target, accounting for 86% of the total installations.

3.3. Dynamic era: subsidy reduction (2017–2021)

During the 12th Five-Year Plan period, as UPV expanded rapidly, curtailment and generation restrictions in the northern regions intensified. Consequently, the authorities began imposing quotas to limit the construction of large-scale UPV power stations in areas prone to brownouts (NEA, 2014). At the same time, with a significant decrease in initial investment costs, the FIT rates for UPV began to decline annually starting in 2016. As the diffusion of DPV was failing to meet anticipated goals, the government maintained its subsidies, continuing to support the prosumer DPV model. In 2016, NDRC and NEA (2017a) jointly issued the 13th Five-Year Plan for Energy Development, prioritizing DPV development and setting a target installation capacity of 60GW by 2020.

DPV began to recover and entered a growth phase, with new installations reaching 19.44 GW in 2017, a 4.58-fold increase year-on-year. From then, DPV's share rose from 10% at the close of the 12th Five-Year Plan period to 30–40%, significantly closing the gap with UPV. The 531 PV New Deal (Due to the rapid development of China's PV market and heavy burden of fiscal subsidies, the central government reconsidered and issue a new document to adjust the PV policies in order to improve the quality and efficiency of the whole industry and achieve high-quality sustainable development. Because the document was signed on May 31, it was called the 531 PV New Deal.) in 2018 applied reduced UPV support to expedite the industry's move away from subsidies, which had a substantial impact across the sector. UPV construction declined sharply, with annual installations experiencing a significant drop of 31%. In contrast, DPV shone brightly, not just maintaining its ground but also surging to a record high of 20.96 GW in new capacity for the year, representing 47% of the total annual installations.

With the increase in installation and decrease in CAPEX, the NERC also began to reduce the DPV subsidy. During the 531 PV New Deal, the allowance was initially cut by 0.05 CNY/kWh for DPV, followed by reductions to 0.1 CNY/kWh in 2019 and 0.05 CNY/kWh in 2020 (Figure 2). By 2021, China had phased out the FIT policies for UPV and commercial & industrial DPV projects, leading the PV industry into the grid-parity era (NDRC, 2021). Recently, in alignment with the dual carbon goals of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060, NEA (2021) introduced a county-wide DPV promotion plan to enhance DPV deployment.

4. Methodology, theory and inferences

4.1. System dynamics

System Dynamics was founded at MIT Sloan in 1956 by Professor Jay W. Forrester. This discipline combines the theory, methods, and philosophy needed to analyze the behavior of systems – not only in management, but also in such other fields as environmental

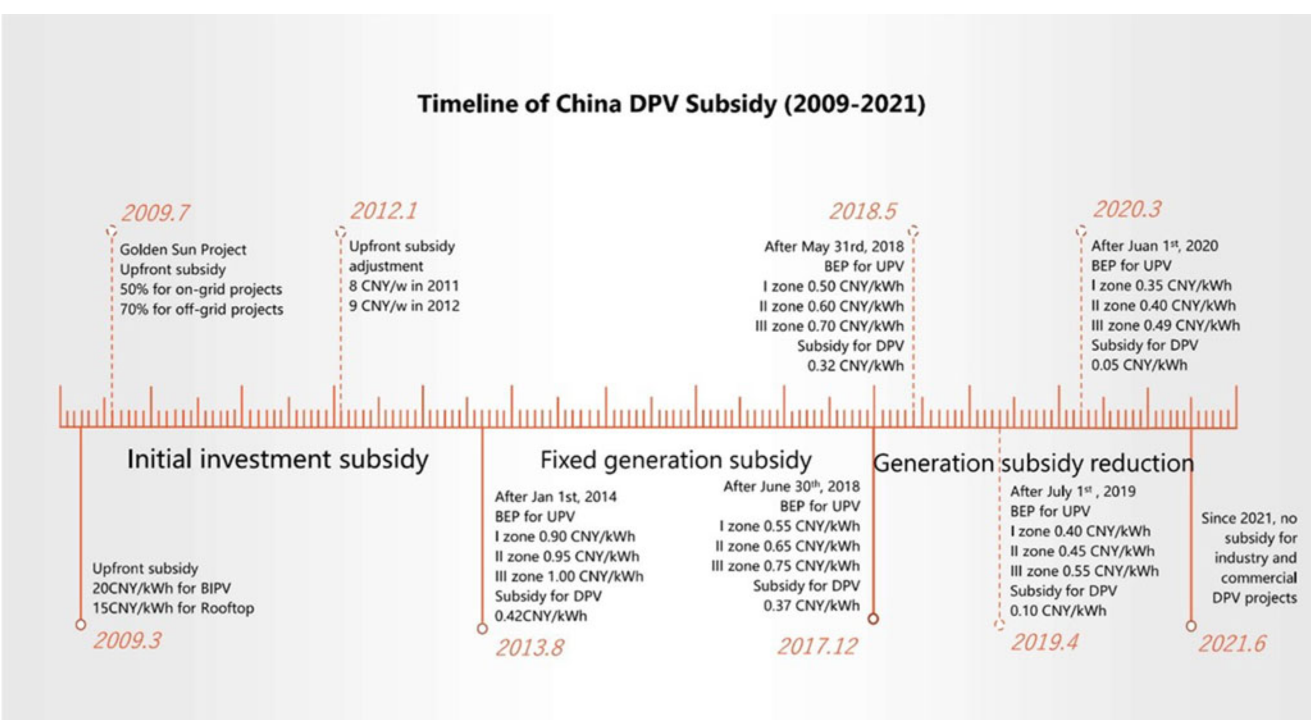

Figure 2. Timeline of China DPV subsidy 2009–2021 (compiled from different sources).

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change, politics, economic behavior, medicine, and engineering (MIT Sloan School of Management website: https://mitsloan.mit.edu/phd/program-overview/system-dynamics). System dynamics is an interdisciplinary approach to the study of the behavior and change of systems over time by building mathematical models to analyze the interactions and feedback mechanisms within systems. System dynamics is becoming a powerful methodology for analyzing and simulating complex social and economic system. Social and economic elements can be simplified into several mathematic variables, and causal relationship can formulize to quantity equations. Using mathematical tools, complexed social and economic relations can be logically analyzed and concluded by deductive reasoning. Regarding economic policy, system dynamics will help researchers and scholars to simulate possible scenarios for different policy initiatives, which can explain economic phenomena, predict possible results and draw valid conclusions for policy makers. Here, we adopt systems dynamics mechanism to assess DPV policies.

Based on the conception of investment return, we analyze DPV projects investment decision mechanism at the firm-level. Similar to other investments, DPV projects should at least satisfy Social Average Investment Yield (SAIY), otherwise investors will refrain from new investments. By micro analysis, we can clearly probe the background of three DPV development periods and understand the diffusion trajectory. Second, relying on government's policy dynamics, we utilize Cobb-Douglas production function to measure DPV policies' benefit, and optimize the equation to gain the best solution. By successively analyzing the variables in the optimization solution, we can infer several meaningful conclusions.

4.2. Micro firm-level perspective

DPV power assets are characterized by notable financial features, such as device standardization, ease of disassembly, and an extended service life. Typically, DPV power stations are capable of providing a return on investment (ROI) exceeding 10%, with a lifespan of over 20 years. The investment in DPV is conducive to securitization, mirroring the attributes of long-term, high-return financial assets. With 70% financial leverage, the return on equity (ROE) can reach 15–20%. DPV projects typically progress from development and construction to grid connection within 6–12 months, making them akin to investment funds capable of generating stable returns within a year. Thus, DPV power stations can be considered as a financial asset: an initial investment recouped annually through electricity income and subsidies. These stations can normally operate for 25 years and receive fiscal subsidies for 20 years. Currently, the quality of photovoltaic products ensures power generation for even longer periods, and operation costs are very low, negligible in our theoretical deduction.

In summary, we posit that the CAPEX for DPV installations is E CNY/w, with an average resource allocation of 1000 (According to China Wind and Solar Energy Resources Bulletin 2022, China's average resource endowment is around 1452.7 hours in 2022. To simplify, the resource endowment are calculated as 1000 in the paper, which theoretically has the same result with using the actual sunshine hours.) hours, and the electricity price is set at P CNY/kWh. Following the one-time initial investment of E CNY, the projected annual revenue in subsequent years is P CNY, assuming the DPV power station operates perpetually. Consequently, the return on investment (ROI) for the DPV station is calculated as P/E, akin to purchasing bonds for E CNY in the initial year and subsequently receiving annual interest of P CNY. During the nascent stages of DPV development, the CAPEX E was significantly high, resulting in a comparatively low ROI (r_g):

$$r_g = P/E \tag{1}$$

Without government subsidies, the initial return on investment (r_g) for DPV projects would be lower than the Social Average Investment Yield (SAIY) (r). Consequently, investors lack the incentive to develop DPV projects, hindering the technology's widespread adoption. Recognizing the low-carbon benefits to society, the government is likely to support the advancement of PV applications. To enhance r_g, authorities might either decrease the initial investment cost (E) through investment subsidies or increase the generation price (P) through generation subsidies. These approaches reflect the distinct phases of DPV policy implementation in China.

4.2.1. Initial investment subsidy

To promote the development of the DPV market, the government provides a certain amount of subsidy S to improve the investment return of DPV so that the ROI of DPV investment can reach or exceed SAIY.

$$r_{g1} = P/(E - S) = r$$

However, the goal of enterprises is to achieve maximum profit. In the early stage of the initial investment subsidy, once the government issues the level of subsidy S, private enterprises tend to increase their return and profits through delay, rent seeking, or shoddy engineering.

① Delay

Considering the learning curve and scale effect, the CAPEX of DPV decreases sharply over time, and the delay in construction reduces the investment cost and enhances the investment profit. We assume that the ROI of DPV investment is only half of the SAIY, namely, $r_g = P/E = ½r$; then, the government considers subsidizing DPV enterprises half of the initial investment: $S = ½E$. Now, the ROI of DPV projects with subsidy $r_{g1a} = P/(E\text{-}½E) = 2P/E = r$, which is equal to SAIY. If the enterprises extend the construction one more year, and suppose that CAPEX will fall by 25% during the period, to 0.75E. Although the income and the subsidy are still the same, but the ROI of the same project doubled.

$$r_{g1b} = P/(0.75E - 0.5E) = 4P/E = 2r$$

This means that enterprises can double their ROI by delaying construction. In 2010, the administration calculated the DPV CAPEX at around 30 CNY/w and subsidized GSP projects at 15 CNY/w, half of the CAPEX. Then, CAPEX declined to 18 CNY/w in 2011, and if a 2010 GSP project completed construction in 2011, the investors would only spend 3 CNY/w by themselves. By 2012, the CAPEX dropped to 11 CNY/w, so the 2010 GSP projects completed by 2012 did not need any private investment; in contrast, they provided a net profit of 4 CNY/w to the developers directly.

② Rent-seeking

According to the GSP program, the CAPEX was 30 CNY/w in 2010, 18 CNY/w in 2011, and 11 CNY/w in 2012, which were all

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higher than the actual market prices at that time. In addition, the DPV cost decreased significantly over time, providing space and opportunities for rent-seeking. If GSP's CAPEX has 20% premium over the actual cost, so the over-subsidy is equivalent to 20%*0.5 = 10% of the actual total investment if the government subsidizes 50% of the exaggerated CAPEX. The 10% subsidy would be converted into a value for rent-seeking. According to IRENA's data, the total investment of a 10MW GSP was 280 million CNY (IRENA. Renewable Power Generation Costs in 2020. Abu Dhabi 2020.) in 2010, and the upfront cost, which is known as road-fee (Road-fee refers to the expense of PV project development, including application fee and compliance documents' cost.), would reach 28 million CNY and occupy 10% of the total investment.

③ Shoddy engineering

Due to the high initial investment subsidy of GSP, as well as the lack of effective and rigorous monitoring of the quality of PV construction, private enterprises might largely cut down the total investment E by using inferior products or shoddy engineering to ensure $E < S$. If so, the investor will obtain a one-time profit S–E through equipment sales or Engineering Procurement Construction (EPC) and no longer care about future operations and revenue (Fang et al., 2015).

Certainly, the authorities also found these issues while implementing GSP policies, modified the policy defects, and slashed the subsidy standards. However, the initial investment subsidy level was still high, and multi-project management was difficult for authorities. Therefore, the GSP did not fully meet the government's expectations. In 2013, the MOF investigated and liquidated the fiscal funds for the GSP during 2009–2011, and found that 80% of projects had not been completed as required. By the end of 2012, only 40% GSP projects finished grid-connections on time.

4.2.2. Insufficient generation subsidies

Learning from the lessons of upfront subsidy, the authority transformed to FITs policy and provided electricity generation subsidy, and subsidized ΔP to improve the electricity price. However, due to the small scale of DPV projects and the risk of tariff collection, ROI of the DPV after the generation subsidy was still lower than that of the SAIY. Furthermore, with the unprecedented growth of UPV and wind power generation, the Renewable Energy Surcharge (RES) was running on financial fumes. The RES fund was the only source to subsidize all renewable energy, and subsidy payments appeared to lag seriously (Jianglong & Jiashun, 2020). After the completion of PV construction, DPV projects would be applied to enter the list of governmental subsidies and wait for two or more years to obtain the first month allowance. Subsequently, enterprises lost enthusiasm and interest in DPV, and eventually, the development of DPV could not meet the government's expectations, and the market stagnated.

$$\text{Government: } (P + \Delta P)/E = r$$

$$\text{Enterprise: } r_{g2} = (q*P + q'\Delta P)/E < r$$

Note: q is the rate of successive tariff collections, q' is the state subsidy availability rate, and $q \leq 1$, $q' < 1$.

4.2.3. Appropriate generation subsidies

Entering the 13th Five-Year Period, after the rapid expansion of the PV industry, especially UPV deployment, the solar PV CAPEX declined sharply. However, the authorities did not reduce the DPV's subsidies, while the UPV tariff was cut down sharply year by year, and the return of DPV projects continued to rise and gradually approached the SAIY.

$$r_{g3} = (q*P + q'\Delta P)/(E - \Delta E) = r$$

where ΔE denotes the reduce of CAPEX

Thereafter, DPV achieved rapid development using the prosumer model: self-use and the remaining electricity sold to the grid. In 2018, under the background of PV subsidy reduction, DPV began to gradually realize grid-parity on the consumer side.

4.2.4. Grid-parity

In 2021, the NDRC declared phasing out the FITs policy and weaned the industry from subsidy reliance. Since 2021, the central government would no longer provide fiscal subsidies for new UPC projects and industrial & commercial DPV projects, and PV's tariff will implement according to local DCEP (NDRC, 2021). To meet the tough dual-carbon targets, incubating and developing DPV remains undeniable during the grid-parity era. How can governments promote and support DPV diffusion through other means? Returning to Eq. (1):

$$r_g = P/E \tag{1}$$

Without the initial investment subsidy and generation subsidy, how can we improve the ROI of DPV, optimize the investment environment, increase the investment enthusiasm of enterprises, and boost the rapid and prosperous development of DPV projects?

Enlarging qualified DPV rooftop

Regarding incremental roofs, there is vast space for DPV development. In 2019, the newly completed construction area in China was more than 4 billion square meters in China. If 5% of the area can be utilized for the installation of DPV, the annual installed capacity will approach nearly 20GW. Improving construction quality and green building standards is conducive to providing more high-quality build surfaces and decreasing the CAPEX, increasing the investment income for DPV projects.

② Green finance policy

The initial investment in DPV is huge and there is a large gap between what private capital can provide. However, private capital can expand investment and enhance yields by leveraging. Today, the share of equity can be maintained at a minimum of 20% of total investment, so the leverage effect is evident in China. Given the ROI of the DPV project r_g, the ROE r_e will be affected by the debt-equity ratio D/E of the capital structure and financing cost r_d (generally $r_d < r_g$). ROE can be interpreted as ROE-added benefits from financing leverage (Peter, 2001):

$$r_g = r_e*E/(E + D) + r_d*D/(E + D) \tag{2}$$

Solving the equation:

$$r_e = r_g + (r_g - r_d)*D/E \tag{3}$$

Therefore, the ROE is also divided into two parts: the project yield r_g, and the effect of financing leverage. Typically, the ROI of DPV power stations is stable and predictable, and green finance can provide preferential interest for large green investments and help DPV enterprises earn higher returns on equity and lower financing costs to stimulate investment.

③ Peer-to-peer trade (P2P)

P2P trade is a more profitable and win-win solution for both DPV owners and electricity consumers, especially by mutual auctions in local microgrids (Zibo et al., 2020). P2P transactions expand the sales range of electricity, improve the self-use proportion of prosumers, reduce the EMC contract risk, and increase the rate of tariff collection q, which raises the final electricity price P for DPV, obtains more generation income, and enhances overall investment income.

Considering the risk of tariff collection, the ROI of DPV note as:

$$r_{g4} = q*P/E \tag{4}$$

The final sales price P of electricity is the weighted average of the higher discount electricity price P_c from power consumers and the lower DCEP of the rest power sold to the grid, and the weight factor is power absorption ratio of consumer c. P2P model will provide more market channels and allow DPV owners sell more electricity to surrounding enterprises with low default risk and high electricity consumption, then make electricity price P and absorption ratio c higher, so as to improve electricity income and investment return (Peiyun et al., 2021).

$$r_{g5} = q*P/E = q*(c*P_c + (1-c)*DCEP) \tag{5}$$

note: DCEP $< P_c$, $c \leq 1$, $q \leq 1$

4.3. Macro social-level perspective

4.3.1 Model and assumption

A country has two types of energy production: low-carbon green energy, represented by DPV, and traditional energy with carbon emissions, represented by thermal coal power. Agents include the government – the decision-maker of energy policies–and energy enterprises – the economic agents. The government aims for green economic growth, which means realizing GDP growth under carbon emission control, and enterprises aim to maximize their investment returns. Using the Cobb-Douglas production function (Cobb & Douglas, 1928),

Green energy production function:

$$\mathrm{F}_g = \mathrm{A}(t)_g \mathrm{K}_g^{\alpha} \tag{6}$$

Traditional energy production function:

$$\mathrm{F}_o = \mathrm{A}(t)_o \mathrm{K}_o^{\alpha} \tag{7}$$

$\mathrm{A}(t)_\mathrm{g}$ and $\mathrm{A}(t)_\mathrm{o}$ are production efficiency, K_g and K_o represent the capital input respectively, and a is the output elasticity of capital $a < 1$. In the early stages, the production efficiency of renewable technology is lower than traditional energy, which means $\mathrm{A}(t)_\mathrm{g}/\mathrm{A}(t)_\mathrm{o}$ is relatively low. Over time, green technologies have improved efficiency, significantly reducing LCOE through the learning effects, while the traditional energy will remain relatively stable. Hence, the ratio of $\mathrm{A}(t)_\mathrm{g}/\mathrm{A}(t)_\mathrm{o}$ will be significantly enhanced over time.

Since 1976, PV modules have maintained a 20% learning curve rate for nearly half a century (Elshurafa et al., 2018), and the cost of PV power generation has decreased rapidly. In China, the LCOE of industrial and commercial DPV decreased from USD 0.182/kWh in 2011 to USD 0.060/kWh in 2020, a decrease of three times (IRENA, 2020), whereas the LCOE of thermal power increased from USD 0.034/kWh to USD 0.056/kWh during the same period (IEA, 2010, 2020), an increase of 1.6 times, which almost approaching the cost of DPV generation.

Green energy can not only provide energy for investors but also increase economic output and reduce carbon emissions. Moreover, an increase in economic output brings additional tax revenues and increase employment; thus, there is also a GDP effect. Here, we assume that the GDP effect of developing green energy is a linear function of its output $T(F_g)$:

$$T(\mathrm{F}_g) = t\mathrm{A}(t)_g \mathrm{K}_g^{\alpha} \tag{8}$$

where t denotes the GDP effect rate of green energy, which is equal to the ratio of the GDP effect to DPV output. The greater the power generation, the greater the GDP effect. Generally, $t > 0$.

Considering the social carbon cost, the spillover effect of DPV power generation is the carbon reduction during power generation, which is proportional to electricity generation. In short, we assume that the spillover social welfare of green energy is a linear function of its output; note S (F_g):

$$S(\mathrm{F}_g) = s\mathrm{A}(t)_g \mathrm{K}_g^{\alpha} \tag{9}$$

where s denotes the social welfare rate of green energy and is the ratio of social benefits to DPV output. In contrast to GDP, social benefit is a relatively subjective factor that is influenced by the social value of carbon dioxide abatement, which will increase with their awareness of environmental protection and low-carbon development. During the early stages, the government and public were not conscious of climate change and carbon emissions, so s could be 0. As climate issues become increasingly serious, tackling global warming gradually becomes the main task of all human beings, and the government and public will have much more pressure on carbon emissions and care more about climate change, which will improve significantly.

At the early stage of green energy, the investment return is lower than that of SAIY and the investment return of traditional energy. Because green energy has a social effect on carbon reduction and the GDP effect, the government is motivated to support green energy under the pressure of carbon targets. The government has two schemes to support renewable energy: fiscal subsidies and green finance.

4.3.2 Fiscal subsidy

Upfront subsidies for the initial investment

The fiscal subsidy scheme can be a one-time subsidy for the initial investment or an electricity generation subsidy during operation. First, we analyze the mode of one-time subsidy for the initial investment and use formula (1) without subsidy first:

$$r_g = P/E \tag{1}$$

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To develop green energy, the government provides a proportion (f) of subsidies for one-time initial investment to improve the ROI of renewable energy to the level of traditional energy, which equals SAIY and the interest rate r, namely:

$$r = P/E(1-f)$$

Solving equation:

$$f = 1 - P/(E*r) \tag{10}$$

The total amount of one-time subsidy equals the total investment in renewable energy (K_g) multiplied by the subsidy ratio f, that is, f^*K_g

From a fiscal point of view, subsidy policies have two main effects: improving GDP and reducing carbon emissions. The government's target is to maximize the earnings of social welfare and the GDP effect minus the cost of subsidies, and we discount the yearly benefit of government to the current period by interest rate r, as follows:

$$Max\ U_f = \sum_{1}^{\infty}(sF_g + tF_g)/(1+r)^n - fK_g \tag{11}$$

where U_f represents the government's policy earnings, t is the GDP effect rate (such as the tax rate), s is the social welfare rate, and $n = 1,2,3\ldots\ldots$

$$Max\ U_f = (s+t)*F_g*\sum_{1}^{\infty}1/(1+r)^n - fK_g \tag{12}$$

Cause $\sum_{1}^{\infty}1/(1+r)^n = 1/r$, therefore

$$Max\ U_f = (s+t)*F_g/r - fK_g \tag{13}$$

Then we bring Eqs (6) and (10) into (13), then work out as follow:

$$U_f = (s+t)/r*A(t)_g K_g^a - (1 - P/(E*r))K_g$$

First order derivative of optimization:

$$\partial U_f/\partial K_g = a(s+t)/r*A(t)_g K_g^{a-1} - (1 - P/(E*r)) = 0 \tag{14}$$

Under optimal conditions, we obtain the solution:

$$K_g^{1-a} = a(s+t)*A(t)_g/(r - P/E) \tag{15}$$

Cause $a < 1$, hence 1-$a > 0$

By successively analyzing the variables in the above formula, we can obtain several primary inferences about the development of green energy, as follows:

1. As the public awareness regarding climate change increases, the evaluation of the social welfare rate s for renewable energy will improve, thus promoting the total investment in green energy.
2. The development of green energy is also affected by national and local attitudes towards GDP t. The more emphasis the administration puts on spurring economic growth, the more green energy investments will be done. The diffusion of green energy will support economic growth, provide additional tax revenues, and create employment opportunities in the future.
3. With the large-scale deployment of new energy, renewable technology will continue to improve production efficiency $A(t)g$, and total green energy production will gradually increase.
4. As global growth is sluggish and the interest rate r in capital market become lower, green energy will embrace new development opportunities, and the economic aggregate of green technology will continue to expand.
5. The development of green energy is also connected with the transformation of the electricity market. With the development of electricity market liberalization and implementation of P2P trade, the proportion of self-consumption for DPV will increase, the final average DPV tariff P will also increase, and the total amount of green energy will further increase.
6. With the development of green energy and technological progress, the CAPEX of green energy E decreases significantly through the learning effects (Neij, 2008; Yue et al., 2021), green energy enters a virtuous cycle, and the total amount of green energy further increases. Meanwhile, the government should adjust and lower its initial investment subsidy to prevent excessive subsidies.

② Generation subsidy

From the fiscal perspective, it is the same for the upfront investment and generation subsidies. Now, we return to formula (1) without subsidy:

$$r_g = P/E \tag{1}$$

To stimulate green energy, the government provides an appropriate proportion of electricity price subsidy p to improve the investment income of DPV to SAIY r, namely,

$$r = P(1+p)/E$$

By solving equation:

$$p = E*r/P - 1 \tag{16}$$

During the operation period, the government needs to subsidize projects according to the annual electricity generation. We still assume that the national average resource endowment is 1000 hours, which means that one watt panel module can generate one kilowatt-hour each year. The annual subsidy is based on the total power generation, which is the equivalent of the installed capacity, and the equal total green energy investment divided by CAPEX E. We multiplied the installed capacity by the electricity price P and price subsidy ratio p and then obtained the total amount of electricity subsidy per year: $p^*P^*K_g/E$.

From the fiscal perspective, the government's target remains to maximize social welfare and the GDP effect minus the cost of subsidies, but there are in the same year. We discount them to the current period by interest rate r, as follows:

$$Max\ U_p = \sum_{1}^{\infty}[(sF_g + tF_g) - \mathrm{p}*P*K_g/E]/(1+r)^n \tag{17}$$

Simplified as:

$$Max\ U_p = [(sF_g + tF_g) - \mathrm{p}*P*K_g/E]/\mathrm{r} \tag{18}$$

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Then bring Eqs (6) and (16) to (18):

$$U_p = [(s+t)*A(t)_g K_g^a - (r - P/E)K_g]/r$$

First order derivative of optimization:

$$\partial U/\partial K_p = [a(s+t)*A(t)_g K_g^{a-1} - (r - P/E)]/r = 0 \tag{19}$$

Under optimal conditions, we obtain the solution:

$$K_s^{1-a} = a(s+t)*A(t)_g/(r - P/E) \tag{15}$$

This is the same as the result for the upfront subsidy, and we can also infer the six inferences. Meanwhile, we suggest that the intensity of FIT subsidies should be adjusted and reduced with the decrease in LCOE.

4.3.3 Green finance

Assumption: The total capital in the energy field is $\bar{K}$, which is constant in a certain period and is distributed between green energy and traditional energy:

$$\mathrm{K}_g + \mathrm{K}_o = \bar{K}$$

$$\mathrm{K}_o = \bar{K} - \mathrm{K}_g \tag{20}$$

The proportion of green energy to traditional energy is k_g. The larger the proportion, the better the development of green energy.

$$k_g = K_g/K_o \tag{21}$$

To support green energy, the government provides green credit with a lower interest rate i_g to encourage low-carbon benefits from green technology. Although traditional energy is still subject to the market interest rate i_t, is isolated from the green finance market. Due to free competition in the financial market, the marginal return on capital of investment is equal to their respective interest rates for traditional energy and renewable energy:

$$i_g = \partial F_g/\partial K_g = aA(t)_g K_g^{a-1} \tag{22}$$

$$i_t = \partial F_t/\partial K_t = aA(t)_o K_o^{a-1} \tag{23}$$

The goal of the government is to maximize the sum of the net output and social benefits and the optimal objective function:

$$MaxU = \mathrm{F}_g - i_g \mathrm{K}_g + S(\mathrm{F}_g) + \mathrm{F}_o - i_t \mathrm{K}_o \tag{24}$$

Bring Eqs (6), (7) (21–24):

$$MaxU = (1 - a + s)A(t)_g K_g^a + (1-a)A(t)_o K_o^a$$

First order derivative of optimization:

$$\partial U/\partial K_g = a(1 - a + s)A(t)_g K_g^{a-1} - a(1-a)A(t)_o K_o^{a-1} = 0 \tag{25}$$

Where we use formula Eq. (20) and $\bar{K}$ is constant, then we bring Eqs. (21) into (25), and obtain:

$$k_g^{1-a} = ((1 + s/(1-a))*A(t)_g/A(t)_o \tag{26}$$

Cause $a < 1$, hence $1 – a > 0$

By successively analyzing the variables in the equation, we can obtain two more inferences about the ratio of green energy as follows:

7. With global awareness of low-carbon enhancement, the social efficiency rate s of renewable energy assessed by the government and public will increase, and the proportion of green energy in application will continue to improve.
8. With the rapid development of green energy and the continuous progress of renewable technology, the production efficiency of new energy $A(t)_g$ will be significantly upgraded compared to the production efficiency of traditional energy $A(t)_o$. The ratio of $A(t)_g/A(t)_o$ will continue to increase, indicating that the proportion of green energy will become increasingly high, and the proportion of green investment in the energy field will be much larger.

As mentioned above, there is a risk of tariff collection for renewable energy, and we modify the formula to

$$F_g = q\mathrm{A}(t)_g \mathrm{K}_g^{\alpha} \tag{27}$$

Notes: q is the ratio of successive tariff collection

The optimal objective function of government changed as:

Solving the equation under optimal conditions,

$$k_s^{1-a} = ((1 + s - a)q/(1-a)*A(t)_g/A(t)_o \tag{28}$$

9. With electricity market reforms and diffusion of P2P trade, we can hedge the risk of tariff collection, which will improve investment income, largely expand green energy investment, and further increase the proportion of green energy.

5. Discussion and policy implications

5.1 Discussion and conclusion

From a macroeconomic perspective, the results of the initial investment subsidy and generation subsidy are similar; however, we can conclude that they still have some significant disparities from the previous micro-level analysis. Compared to the generation subsidy, the initial investment subsidy can directly provide funding support during the construction period, which is conducive to the launch of the DPV market at the beginning. However, when it comes to the project operation stage, initial investment subsidy policies are not conducive to increasing generation efficiency, while generation subsidies will become more effective and valuable.

The generation subsidy subsidizes power generation during the whole operation process, which means good quality PV stations can earn more subsidy and encourages projects' quality control. However, with the expansion of renewable energy, the government's fiscal burden has aggravated. China's FIT subsidy is only undertaken by the RES embodied in retail electricity prices,

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which means that it will ultimately be undertaken by consumers. With more and more renewable projects constructed over last several years, the charge on RES has increased from 0.001 Yuan/kWh in 2006 to 0.019 Yuan/kWh since 2016 (Jianglong & Jiashun, 2020). However, the subsidy gap continues to extend rather than shrink, which exceeded 60 billion CNY in 2018 (Zhang et al., 2020). The generation subsidy policies are unsustainable, and more than 90% of newly installed renewable energy projects during the 13th Five-Year Plan (2016–2020) were not been funded by subsidies in China (NPC, 2019).

Since the investment subsidy initiated the DPV market in China, the generation subsidy standardized and developed the diffusion of DPV. Currently, China's PV enters the grid-parity era without fiscal subsidy, and financial policy will become a new tool for the country to support green energy (NDRC et al, 2021). Compared to fiscal subsidies, green finance can adjust the market through various instruments. In the previous analysis, we found that both a low interest rate r and a high debt ratio D/E can effectively boost the development of green energy. The previous analysis of green finance was based on the assumption of an indefinite duration. All projects, including DPV, have a limited operation period. The length of the loan is also an important factor affecting green projects, and should be matched with the operation period. The longer the loan cycle, the smaller the principal repayment pressure allocated to each year, and the more secure the investment income can cover the cash flow during operation, which makes many more DPV projects with low ROI feasible and profitable.

Our analysis assumes that the condition for using financial leverage is that the project's ROI is larger than the interests ($R_g > R_d$ in Formula 2). Therefore, under the finance policy, the investment returns of the selected green projects should be above zero and higher than a certain level to avoid invalid investments. In addition, institutes such as policy banks or commercial banks can provide professional services and play a major role in risk control during the process of green finance implementation. Green loans not only provide and solve the funding gap of initial investment in green investment but also realize the supervision and control of quality during operation through loan agreements and management in the future. Moreover, case-by-case financing decisions can ensure that policy banks and finance institutions implement green policies flexibly, support appropriate green projects according to local conditions through different financial instruments, and avoid the problem of a one-size-fits-all fiscal subsidy (Table 1).

Above all, the upfront subsidy initiated China's DPV application, and the generation subsidy led the DPV to grid parity. Today, DPV technology will continue to expand its market share, improve the generation proportion, and gradually replace traditional energy with green finance.

Table 1. Comparation of different green policies

Type	Development phase	Advantages	Disadvantages
Upfront subsidy	Initialization phase	Provide startup funding Expanding investment directly and promptly	Delay Shoddy engineering Rent-seeking
FIT policies, generation subsidy	Growing phase	Process control Quality management	Fiscal burden Payment arrears
Green finance	Marketing phase	Filling the funding gap Flexibility Risk control	Need high level of development Mature finance market

5.2. Policy implications

In China, electricity tariff is controlled by government, which can be used as an effective economic tool. To decrease operational costs and boost efficiency for companies during economic downturn, NDRC (2018, 2019) implemented a reduction of 10% in industrial and commercial electricity rates between 2018 and 2019, followed by a 5% cut in 2020–2021 (NDRC et al., 2020, 2021). As a result, the tariff for electricity from DPV projects, which was adjusted in line with these reduced rates, has been on a consistent downward trend. Since 2021, new DPV projects will achieve grid parity, which means those projects no longer qualify for central government subsidies (NDRC, 2021). Despite facing various challenges and uncertainties, the development of DPV in China should not be overlooked due to its advantages in local consumption, power matching, and the potential for high penetration rates. Given these factors, it is essential to continue supporting and encouraging the growth of DPV in China.

5.2.1 Augmenting suitable roof surface

After a decade of widespread adoption and implementation of DPV systems, the availability of qualified and suitable building roofs has significantly diminished. There are few remaining roofs that meet the necessary criteria for structural load capacity and possess clear property rights, making the acquisition of rooftops for DPV projects increasingly challenging. Roof reinforcement to accommodate these systems escalates construction costs and investment risks. Additionally, issues with incomplete roof ownership can hinder government approvals, impact the execution of Engineering, EPC contracts, and complicate financing efforts, thereby inhibiting the spread of DPV technology. To address these challenges, manufacturers should focus on developing lightweight modules, and developers should opt for lighter panels to alleviate the structural load on existing buildings. Legislation should be enacted to delineate the rights of DPV projects on rooftops from those of the underlying properties and to ensure the safety of the PV systems. Effective division of property rights will help protect the DPV owner's interests and guarantee proper operation, which is crucial to bank financing (Guoliang et al., 2016).

In the context of new constructions, enhancing construction quality and adhering to green building standards play a crucial role in providing a durable roof surface, lowering capital expenditure, and boosting the return on DPV investment. Building administrators are encouraged to elevate energy efficiency standards in building construction and promote the installation of DPV systems as a measure to cut carbon emissions. For the design of industrial facilities, it's important to factor in the steel frame structure and roof load capacity to reserve space for PV system installation and ensure adequate load-bearing capabilities, thereby minimizing the need for costly roof reinforcements. The integration of DPV concepts during the planning phase of construction

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is essential. The use of prefabricated PV components that can be installed early in the construction process enhances the efficiency of PV system installation, prevents damage to the building exterior, and supports the widespread adoption of DPV.

5.2.2 Strengthening green finance support

Green finance in China is experiencing rapid growth, yet it is primarily driven by loan financing. As of 2021, the national balance of green loans in both domestic and foreign currencies reached 15.9 trillion CNY, marking a year-on-year increase of 33%, which is 12.7% higher than the growth observed in 2020 and 21.7% above the growth rate for all loans. Specifically, clean energy projects accounted for 4.21 trillion CNY of loans, with an increase of 31.7% (PBC, 2022). Despite this, commercial banks tend to focus on servicing large power stations, such as utility-scale projects and wind farms, leaving most DPV projects to rely on financing from leasing institutions. As a result, the financing channels for DPV remain limited and the cost of financing high (Guoliang et al., 2016).

The government needs to encourage and funnel social capital investment in the DPV market by setting up the DPV industry fund. A DPV green credit system led by policy banks, supported by commercial banks, and participating by financial leasing institutions should be established to support DPV finance for small and medium-sized enterprises through re-lending, specialized guarantee mechanisms, and financial discounts for green credit supporting mechanisms. To improve asset liquidity and broaden financing channels, we can set a trade platform for DPV property rights and build a DPV trading information network. To reduce financial costs, we should encourage green financial innovation, research green financial derivatives, realize the securitization of DPV assets, and support the development of various carbon financial products.

5.2.3 Promoting peer-to-peer energy transaction

In P2P trade, DPV projects can directly sell electricity to nearby energy consumers through a power distribution network, rather than only to roof companies or to the national grid at a low price. In 2017, NDRC and NEA (2017b) issued documents to carry out pilot projects of DPV market-based trading to conduct DPV power transactions with nearby power consumers through P2P transactions. However, P2P policy was not promoted successively because it involves too many shareholders. In 2022, NDRC and NEA (2022) jointly signed a document again to encourage direct transactions between DPV projects and surrounding electricity users to accelerate the construction of a unified national power market system·

P2P transactions help DPV trade power over a wider range and release it from a single buyer, which is conducive to overcoming the two main barriers hindering DPV diffusion: the difficulty of tariff collection and the stability of consumers. Moreover, low-voltage transmission and distribution can improve profitability and raise the electricity price by absorbing nearby and reducing curtailment, which is a win-win solution for both DPV owners and electricity consumers. Electricity trading mechanisms should be improved to facilitate P2P trade (Peiyun et al., 2021).

In this study, we develop a system dynamics model to theoretically analyze the DPV policy and its performance. By extracting and purifying the cause relation of DPV development, we can more straight forward approach the correlations between economic policy and its effect. However, our analyses ignore the difference between long-term and short term and omit the influence of time to energy investment. In future research, we will take time as an influence factor. Moreover, no theory is complete without practical test. Since 2009, DPV policy have been carry out more than a decade in China, and NEA provide provincial DPV installation capacity and data each quarter (Alex et al., 2022). Those deduction and inferences should be testified by empirical analysis tools. Future DPV research can try those approaches and methodologies.

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