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Can the cancellation of government subsidies alleviate the phenomenon of overcapacity in the photovoltaic module industry? From a dynamic perspective

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Abstract

The environmental pollution problem stimulates the photovoltaic industry's vigorous development and further promotes the prosperity of the module manufacturing industry. After the cancellation of government subsidies, how the phenomenon of overcapacity that has always existed in the module manufacturing industry will develop is one of the essential issues that we need to consider. This paper constructs a systematic framework to analyze the driving mechanism of government subsidies on overcapacity. Then, a system dynamics model is established to predict the development trend of overcapacity after the cancellation of government subsidies. The result shows that: (i) By 2030, the production capacity will exceed 600 GW in China's photovoltaic module industry, which is about two times that of 2021. Moreover, its price and cost will drop to 0.46 yuan/W and 0.41 yuan/W, which are down 67% and 60%, respectively, compared to 2021; (ii) After the cancellation of government subsidies, the phenomenon of overcapacity will not disappear soon, and it will continue until 2030. In 2030, the production capacity utilization rate will reach 80%, and the phenomenon of overcapacity will disappear; (iii) From the perspective of production factors, the impact of the labor factor on the production capacity is minimal. In the initial stage, technology and capital factors are vital. As the industry matures, the influence of the capital factor will gradually weaken. Finally, we have put forward corresponding policy implications.

Keywords Photovoltaic industry · Government subsidies · Overcapacity · Production capacity · System dynamics

List of symbols

p_t^e PV power price (t)

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p_0^e	Initial PV power price
C_t^e	Annual cost per capacity (t)
C_{t-1}^e	Annual cost per capacity (t-1)
C^o	Operating cost
C_t^i	Initial investment cost per capacity
T_t	Total PV installed capacity (t)
T_0	Initial installed capacity
E	Power generation per capacity
G	Target of installed capacity
s	Subsidy
F	Demand growth
α	Demand growth factor
I	Inflation
β	Inflation factor
K	Cost decline
δ	Cost decline factor
V	Supply growth
γ	Supply growth factor
p_t^{m}	Module price (t)
U	Module demand growth
λ	Module demand growth factor
X	Module cost decline
ϕ	Module cost decline factor
Z	Module supply growth
η	Module supply growth factor
p_0^{m}	Initial module price
a	Module cost learning rate
W^m	Profit of the module manufacturer
PT	Newly added production capacity
D_t	Production capacity (t)
D_0	Initial production capacity
D_{t-1}	Production capacity (t-1)
q	Total demand
R	Return on investment
$A(t)$	Technology investment (t)
NT	Newly added PV installed capacity
m	Investment coefficient
W^e	PV electricity profit
u	Installation awareness
O	Labor
L	Capital
g	Labor factor
k	Capital factor
z	Utilization rate
v	Investment policy
C_0^{m}	Initial module cost
C_t^{m}	Module cost (t)
C_{t-1}^{m}	Module cost (t-1)

PV Photovoltaic
SD System dynamics
ROI Return of investment
kWh Kilowatt-hour
R&D Research and development

Abbreviations

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1 Introduction

Low-carbon energy transformation promotes the explosive growth of the PV application market (Soonmin & Taghavi, 2022; Tao et al., 2022) and then leads to the rapid development of the module manufacturing industry (Yu et al., 2021). As the world's largest PV module manufacturer, China accounted for 77.2% of the global production capacity in 2021 (360doc, 2022). However, compared with other industrial chain links, module manufacturing is characterized by lower technology requirements and a higher profit rate, attracting investors' extensive attention (Peters et al., 2022). Moreover, the PV module segment is at the end of PV manufacturing chain (Alhousni et al., 2022). The module manufacturer directly faces the application market and is more sensitive to market changes (Fonseca et al., 2020).

The subsidy is an essential measure for the government to support the development of the renewable energy industry (Tang et al., 2021). It has three stages in China's PV industry: 2009–2013 is the period of initial investment subsidies (CPGPRC, 2009), 2014–2020 is the period of kWh subsidies (NDRC, 2013), and after 2020, the era of grid parity officially begins (Tengxun, 2021) (Fig. 1). Driven by government subsidies, the PV application market experienced explosive growth in China. However, with falling costs and increasing government financial pressure, the government subsidies gradually declined and were canceled from China's PV market in 2021.

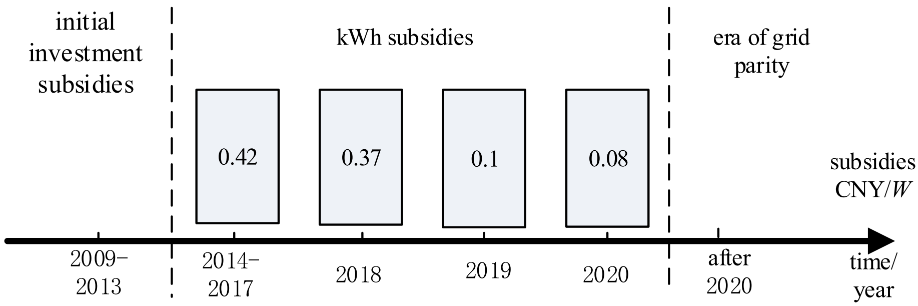

Fig. 1 China's PV subsidies

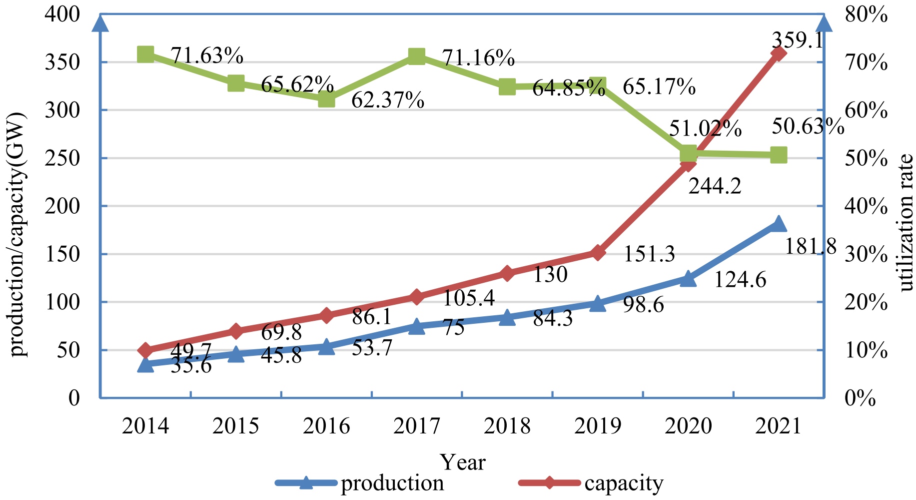

Fig. 2 Development of China's PV module industry

In recent years, China's PV module industry has rapidly increased production and capacity, but the production capacity utilization rate is relatively low (Fig. 2) (CPIA, 2022). Europe and the USA stipulate that overcapacity refers that the utilization rate being lower than 79% (wiki, 2016), which illustrates that it always exists in China's PV module industry. By the end of 2021, the production capacity of China's PV module industry had reached 359.1 GW, while the production amount of 181.8 GW constitutes a utilization rate of only 50.63%, which indicates that there is a phenomenon of severe overcapacity. However, the trend of future expansion persists, and Jiangsu province alone will increase its production capacity by at least 73 GW in the next three years, equivalent to one-third of China's total capacity in 2020 (Adviser, 2022).

The overcapacity phenomenon hinders the industry's development (Lin et al., 2018), which causes serious problems such as the low operating rate of the enterprises, bankruptcy, and unemployment of the workers, affecting social stability and resulting in sharp economic fluctuations (Chen & Liu, 2022). For example, the Wuxi Suntech Group, once the benchmark of China's PV industry, went bankrupt under such circumstances (Zhang, et al., 2016). Therefore, the overcapacity problem needs to be considered in China's PV module industry.

In the early stage of the PV industry, there is already the problem of overcapacity (Yan et al., 2019), and more and more scholars have begun to pay attention to this phenomenon. Wang et al. (2014) pointed out that the domestic PV market might not be able to ease the phenomenon of overcapacity in a short period, and it should take a long time to solve this problem. Wang and Luo (2018) found that there were two types of overcapacity in the PV industry: overall overcapacity and structural overcapacity. They also found that the capacity in high-end industries was insufficient and excessive in mid-to-low-end industries. Liu et al. (2019) illustrated that overcapacity had a severe negative impact on the development of the sector. Tercan et al. (2022) also found that as China's PV industry had become a global leader, there was a severe overcapacity problem. However, they did not analyze the dynamic logic relationship inside the PV system.

Most scholars believed that government subsidies were the main cause of overcapacity (Chen et al., 2021; Tang et al., 2021). They thought government subsidies distorted enterprises' investment behavior, resulting in severe overcapacity (Dong, et al., 2021). However, they only analyzed from a static perspective and did not study the dynamic driving process of government subsidies on overcapacity. Chen and Wang (2022) built an empirical analysis model to investigate the relationship between government subsidies, R&D expenditures, and overcapacity. They found that government subsidies had a positive effect in promoting overcapacity and R&D expenditures. Biondi and Moretto (2015) showed that government intervention greatly impacted the PV industry. They calculated the value threshold between energy prices and energy costs to maximize the net payoff of an investment in a PV system. Hu et al. (2020) built an econometric model to evaluate the impact of policy intensity on overcapacity by using 55 listed PV firms. They thought fiscal subsidy had the most significant positive effect in promoting overcapacity, followed by tax preference and land support. Dong et al. (2021) used panel data regression and counterfactual analysis to rigorously estimate the impact of government subsidy on PV market development. Xiong and Yang (2016) built an empirical model to analyze the effect of government subsidies on China's PV industry. They found that subsidy could maximize the social and economic impacts at the early exploratory stage, and subsidy had little effect on its turnover and aggravated overcapacity of PV supply at the intermediate and mature stages. However, they did not study whether this phenomenon could be alleviated after the government canceled the subsidy.

According to the above literature review, most articles used historical data to conclude that government subsidies were the leading cause of overcapacity from a static perspective. However, China's PV industry is a complex system with a dynamic relationship between various elements. In addition, government subsidies were canceled from China's PV market in 2021. Few articles analyzed whether the phenomenon of overcapacity could be alleviated after the cancellation of government subsidies from a systematic perspective. To fill this research gap, firstly, this paper analyzes the driving mechanism of government subsidies on the overcapacity of the PV module industry. Then, an SD model is established to explore the impact of government subsidies cancellation on overcapacity.

The main contributions of this paper are as follows: (i) The driving mechanism of government subsidies on overcapacity is analyzed in PV module industry. (ii) Whether the cancellation of government subsidies alleviates the phenomenon of overcapacity is researched from the system and dynamic perspectives. (iii) The key factors affecting production capacity are studied, and policy implications are given.

The remainder of this study is organized as follows: Section 2 builds an SD model; Sect. 3 indicates data involved in the model; Sect. 4 shows model validation; Sect. 5 illustrates results and analysis; Sect. 6 presents conclusions and policy implications; and Sect. 7 describes the strengths and limitation of this study.

2 Methodology

2.1 Theoretical framework analysis

According to the theory of supply and demand, as the typically demand-driven emerging industry, the change in market demand leads to the rapid response of the PV module manufacturing industry (Fan et al., 2021). In 2014, the government issued kWh subsidies to promote the development of China's application market (Luan & Lin, 2022). The development of PV industry is a dynamic cycle process, and the theoretical transmission mechanism of government subsidies to overcapacity should first be sorted out to analyze the effect of government subsidies on capacity.

For the market demand side, the domestic installed market is affected by many factors such as ROI, power profit, investment policy, decision preference, investment cost. Among them, the most important is the economic factor (Ma et al., 2021; Pierro et al., 2018; Soler-Castillo et al., 2021), the ROI composed of PV power price, government subsidies, and investment cost is the critical factor (Abedi & Kwon, 2023). In addition, the owner of PV power station reinvests a percentage of the profit (Guo & Guo, 2015), and the changed profit brought by the change of government subsidies also has an impact on the domestic installed market. Therefore, the cancellation of government subsidies impacts the ROI and profit of the domestic market, affecting the domestic demand for installation.

For the module supply side, the development of China's PV module industry is macroscopic and long-term from the industry-wide perspective (Benda & Cerna, 2022). The manufacturer produces the PV module according to the market demand (Rathore et al., 2021). The production function method is a common way to analyze such problems. The expansion of production capacity is influenced by technology, capital, and labor (Xin-gang & Wei, 2020; Zhen et al., 2021), in which the capital partly comes from the profit of the PV module manufacturer (Guo & Guo, 2015). Moreover, due to the existence of trade protection, the tariff directly affects the market share of China's PV module industry in foreign countries, further affecting demand and profit (Zhu et al., 2021). On the other hand, since the production amount of PV modules is almost equal to the total order (CPIA, 2022), the production capacity utilization rate can be derived from total demand and production capacity.

Therefore, the corresponding research framework is shown in Fig. 3.

2.2 SD model

This paper aims to understand the effect of government subsidies on overcapacity in the PV module industry. This research involves two subsystems: the market demand subsystem and the module supply subsystem, including many endogenous and exogenous variables with a complex dynamic relationship between each variable. In the existing research, most scholars studied the problems by using empirical analysis (Liu et al., 2021; Qin et al., 2022; Yang et al., 2022). However, it is difficult to describe the interrelationship and influence mechanism of numerous factors (Song et al., 2021). Therefore, this paper applies the SD method to study whether the cancellation of government subsidies can alleviate the phenomenon of overcapacity in the PV module industry.

SD is a systematic modeling and dynamic simulation methodology for analyzing complex systems. Based on the principle of systems thinking and feedback control theory, SD helps to understand the time-varying behavior of complex systems (Feng et al., 2021). The advantage of this method is that it can qualitatively and quantitatively explain the relationship between the internal structure and the functional state of the system. Combined with the learning curve theory, this method is suitable for studying the phenomenon of overcapacity in the renewable energy industry (Castrejon-Campos et al., 2022).

Based on Fig. 3, Vensim PLE is used to transform the research framework into the causal diagram, as shown in Fig. 4. Here, "+" represents the positive feedback relationship, and "–" indicates the negative feedback relationship.

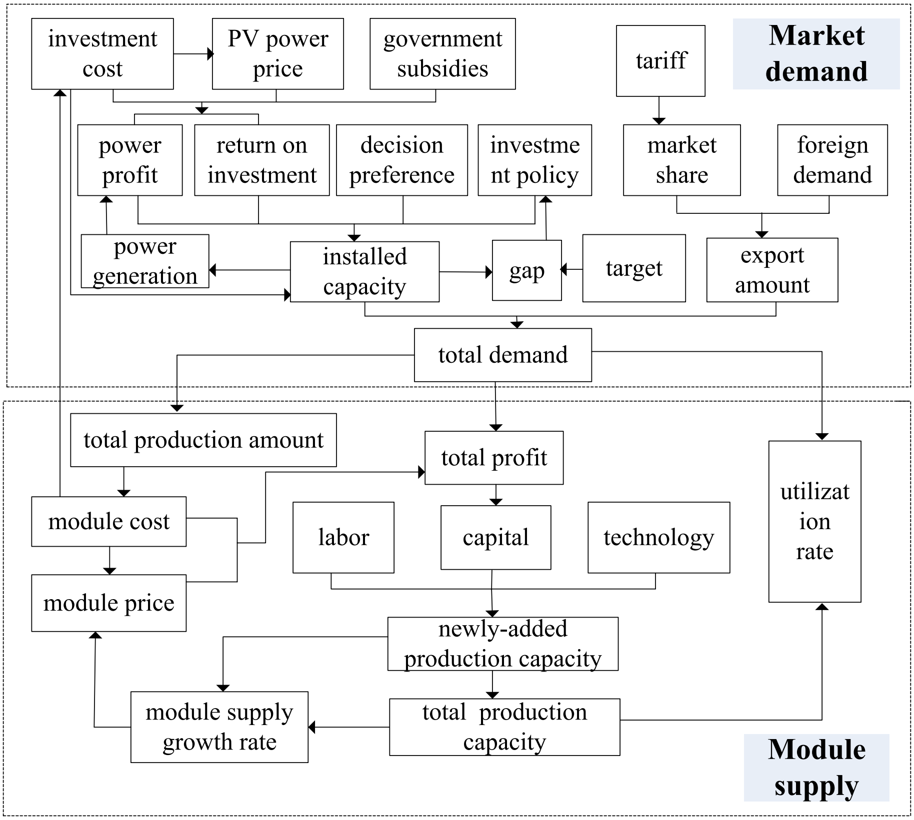

Fig. 3 Research framework

Based on Fig. 4, this part subdivides the system's state, flow rate, and auxiliary variables, and determines the function and logical relationship between them to obtain the SD model for the impact of the government subsidies cancellation on overcapacity, as shown in Fig. 5. Here, the system is divided into two subsystems: the market demand subsystem (shown in blue) and the module supply subsystem (shown in red). The critical impact path is indicated in bold to more intuitively reflect the impacts of the government subsidies cancellation on overcapacity.

(1) Market demand subsystem

The market demand for PV modules involves two parts: domestic and export demand. The cancellation of government subsidies mainly has an impact on domestic demand. The export demand is mainly obtained through the regression of historical data.

PV power price is a state variable, and its influencing factors involve demand, inflation, cost, and supply (Liu et al., 2020). Hence, the corresponding equation is as follows:

$$P_t = P_0 + \int (\alpha F + \beta I - \delta K - \gamma V)dt \tag{1}$$

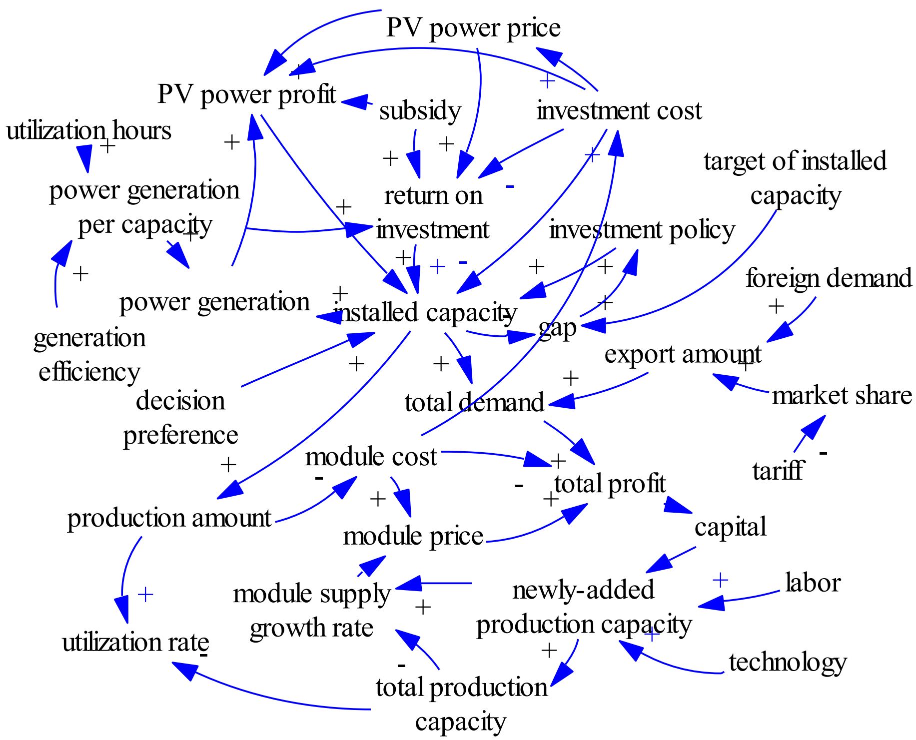

Fig. 4 Causality diagram

Regarding initial investment cost, including modules, inverters, brackets, land, etc. Modules have consistently accounted for about 40% of the total cost in the development of PV industry. Therefore, to simplify the calculation, the initial investment cost is expressed as follows:

$$C_t^i = C_t^m / 0.4 \tag{2}$$

The life of a PV power station is generally 20 years, and the annual cost per capacity can be expressed as follows:

$$C_t^e = C_t^i / 20 + C^o \tag{3}$$

The ROI represents the ratio of annual profit to investment cost, composed of PV power price, government subsidies, power generation per capacity, and cost per capacity. Therefore, the corresponding equation is as follows:

$$R = (p_t + s_t - C_t^e) * E / C_t^e \tag{4}$$

The newly added installed capacity of the domestic PV market is a rate variable, while the total installed capacity is a state variable (Guo & Guo, 2015). Hence, the corresponding equations are as follows:

$$NT = \alpha * (1 + m) * W * u * v * 0.1 / C_t \tag{5}$$

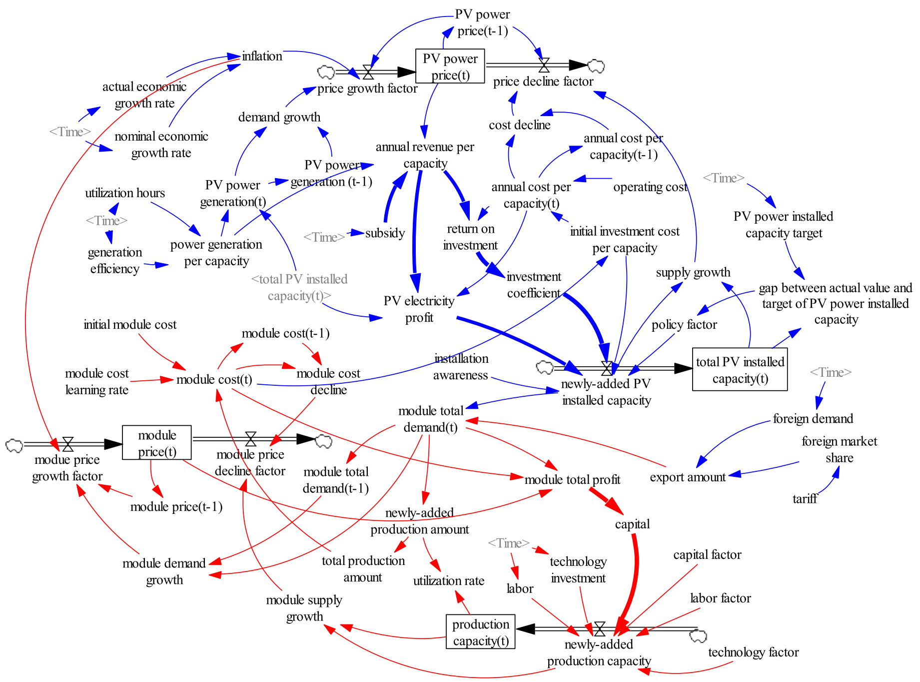

Fig. 5 SD model

$$T_t = T_0 + \int (NT)dt \tag{6}$$

(2) Module supply subsystem

The module price is a state variable, and its influencing factors involve demand, inflation, cost, and supply. Moreover, the module price of the previous year is represented by a delay function. Hence, the corresponding formulas are as follows:

$$P^m_t = P^m_0 + \int (\lambda U + \beta I - \phi X - \eta Z)dt \tag{7}$$

$$P^m_{t-1} = DELAY\ FIXED(P^m_t, 1, 4.6) \tag{8}$$

In Eq. (8), 1 represents that the delay time is 1 year, and 4.6 indicates that the module price is 4.6 yuan /W in 2013.

The learning curve is employed to represent the cost of PV module (Elshurafa et al., 2018). Simultaneously, the previous year's cost is represented by a delay function. Therefore, the corresponding equations are as follows:

$$C^m_t = C^m_0 * T_t^{\ln(1-a)/\ln 2} \tag{9}$$

$$C^m_{t-1} = DELAY\ FIXED(C^m_t, 1, 3.16) \tag{10}$$

In Eq. (10), 1 signifies that the delay time is 1 year, and 3.16 means that the module cost was 3.16 yuan /W in 2013.

The module profit mainly comprises module price, cost, and total demand. The corresponding formula is as follows:

$$W^m = (p_t^m - c_t^m) * q * 10 \tag{11}$$

According to the Cobb–Douglas production function, the production capacity of PV modules is mainly affected by technology, capital, and labor (Encyclopedia, 2015). Among them, technology investment is used to represent the technology level. The higher the investment, the higher the technology level (Su et al., 2022a, 2022b). Furthermore, the production capacity of the previous year is represented by a delay function. Therefore, the corresponding equations are as follows:

$$D_t = A(t) * O^g * L^k \tag{12}$$

$$D_{t-1} = DELAY\ FIXED(D_t, 1, 40) \tag{13}$$

In Eq. (13), 1 expresses that the delay time is 1 year, and 40 shows that the production capacity was 40GW in 2013.

In the PV industry, the obvious manifestation of technological progress is the increase in technology investment (sina, 2021). Therefore, technology investment is used to represent the technical factor.

The ratio of newly added production and capacity obtains the production capacity utilization rate. Hence, the corresponding equation is as follows:

$$z = PT/D_t \tag{14}$$

3 Data

There are more than 60 variables in the model, and the relevant basic parameter settings are shown in Table 1.

About the learning rates of investment cost and module cost, substituting their historical data (CPIA, 2018, 2020b) into Eqs. (2) and (9), respectively. This paper finds that the learning rates of average investment and module cost are 12% and 31%, respectively.

The foreign demand is obtained from the annual report of the China Photovoltaic Association. The yearly share of the foreign market is obtained by the ratio of China's export amount and foreign demand given in the China Photovoltaic Association annual report (CPIA, 2020a).

4 Model validation

In order to ensure that the established SD model can simulate the actual situation more accurately, it is necessary to verify the model. According to the test method of the existing literature (Qudrat-Ullah & Seong, 2010), this paper tests the model. The key variables involve newly added installed capacity, module production capacity, and utilization rate. The statistical data from 2014 to 2021 of these variables is collected to test the validity of the SD model, and the results are shown in Figs. 6, 7 and 8. Due to the specific difference between the simulated virtual system and the actual situation, the error range is set as 10% (Yu & Shi, 2021).

Figure 6 shows that the error range is under control in all years except 2018 and 2020 for newly added installed capacity. In 2018, PV industry published the "531" new policy in China, which caused a short downturn for the domestic PV installed market (chyxx, 2019). In addition, the COVID-19 outbreak seriously impacted all industries, including the PV industry, in 2020 (Nandi et al., 2021; Vaka et al., 2020). Figures 7 and 8 show that the errors of simulation results are controlled within 10% for module production capacity and utilization rate. Therefore, the established SD model is reasonable.

5 Results and analysis

5.1 Results

In this part, the development trend of China's PV module industry is predicted. The results are as follows:

5.1.1 The trend of production capacity

According to the current development situation, the production capacity of PV modules will have a continuous expansion in the future. By 2030, it will exceed 600 GW (Fig. 9). Therefore, to ensure the industry's healthy and stable operation, it is necessary for the government to issue a series of safeguard measures.

The PV module industry's rapid development mainly comes from economics and market demand.

In economics, its price and cost continue to decline despite the decline getting smaller. By 2030, the price and cost will drop to 0.46 yuan/W and 0.41 yuan/W, respectively. Compared to 2021, they are down 67% and 60%, respectively (Fig. 10), which

Table 1 Basic parameter settings

Variable name	Unit	Value	Data source
T_0	GW	15.89	CPIA, (2018)
D_0	GW	42	OFweek, (2014)
f	%	25	Jiaxuan, (2019)
C_0^e	Yuan	1.11	Elecfans, (2016)
r	%	12	CPIA, (2018, 2020b)
C_0^m	Yuan	32	CPIA, (2020b)
a	%	31	CPIA, (2018, 2020b)
α	%	30	Guo and Guo, (2015)
p_0^e	Yuan	0.95	NEA, (2013)
s	Yuan		Zhao and Zhang, (2021)
G	GW		Finance, (2020)
d^f	GW		CPIA, (2020a)
λ	%		CPIA, (2020a)
H	10^8		Ding et al., (2020)

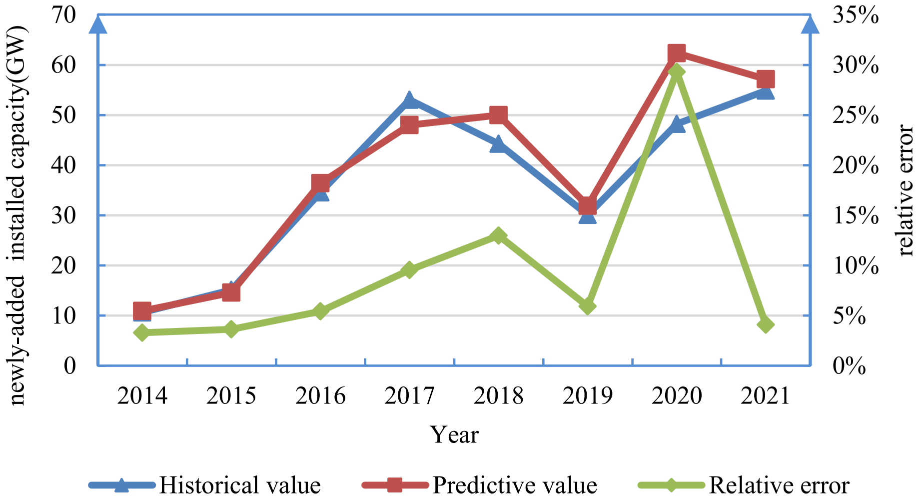

Fig. 6 Newly added installed capacity

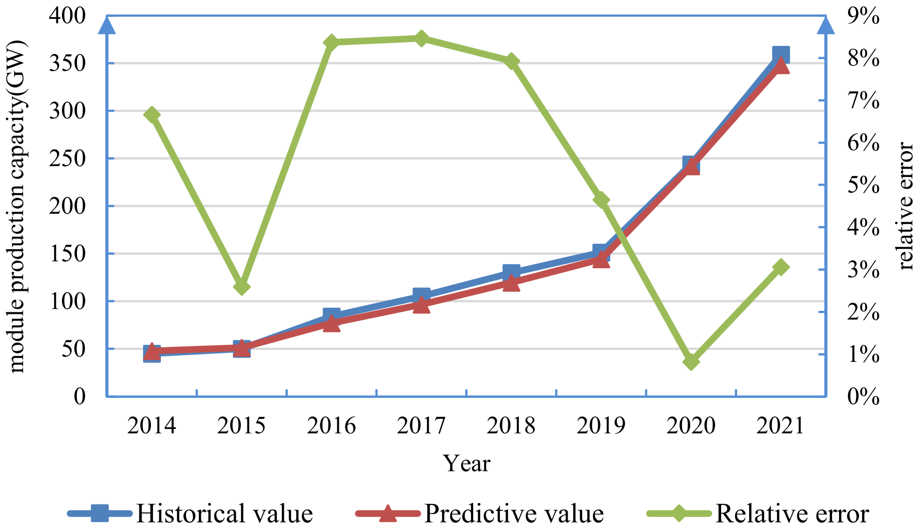

Fig. 7 Module production capacity

will lower the module industry's entry threshold. However, the ROI is still in the range of 31–34% without much change, leading to an inevitable expansion of production capacity. Therefore, to promote China's energy structure from traditional to renewable energy, it is essential to increase R&D investment further to enhance the economic advantages of PV power generation.

In terms of the marketed demand, as a typical market-driven industry, the great demand drives the development of PV module manufacturing. By 2030, China's PV market will have an average annual installed capacity of 70 GW, and the cumulative

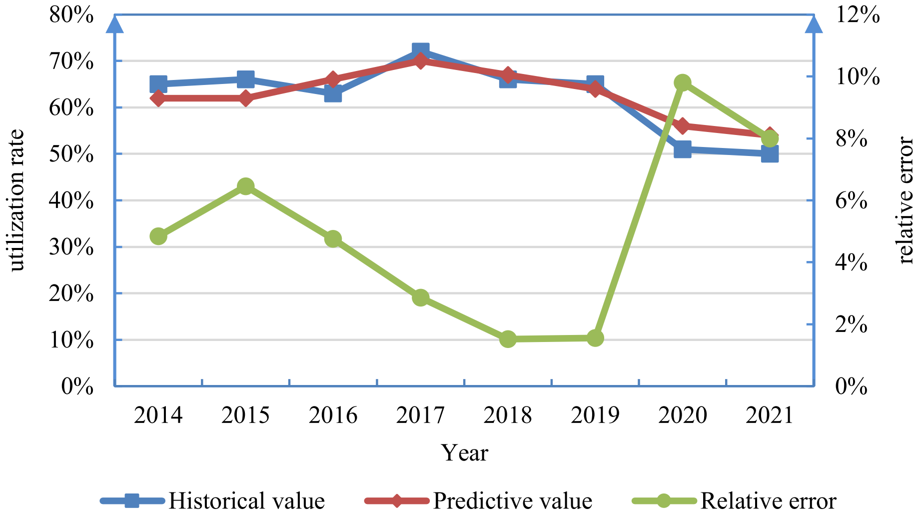

Fig. 8 Utilization rate

installed capacity will be close to 1000 GW (Fig. 11). Therefore, better market prospects will also prompt some investors to enter this industry.

5.1.2 The trend of utilization rate

After the cancellation of government subsidies, the phenomenon of overcapacity in China's PV module industry will not disappear immediately, and the production capacity utilization rate will still be below 80% for a long time. However, this phenomenon will gradually be improved after the government subsidies are canceled, and the utilization rate will reach about 80% by 2030 (Fig. 12), which means that the phenomenon of overcapacity will disappear in this year. This also shows that government subsidies do not entirely cause overcapacity. Other reasons, such as market share and investors' prospects, also lead to overcapacity in the PV module industry. Therefore, if the government wants to relieve this phenomenon as soon as possible, in addition to taking measures from the aspect of government subsidies, they can also take steps from other elements, such as increasing entry barriers and improving product quality requirements.

5.2 Sensitivity analysis

The influence of changes in the parameters, capital, labor, and technology investment, on production capacity is analyzed by fluctuating 20%, respectively.

5.2.1 Effect of capital factor

The capital has a specific impact on the production capacity of the PV module industry. When the capital factor fluctuates by 20%, production capacity also changes by about 20%

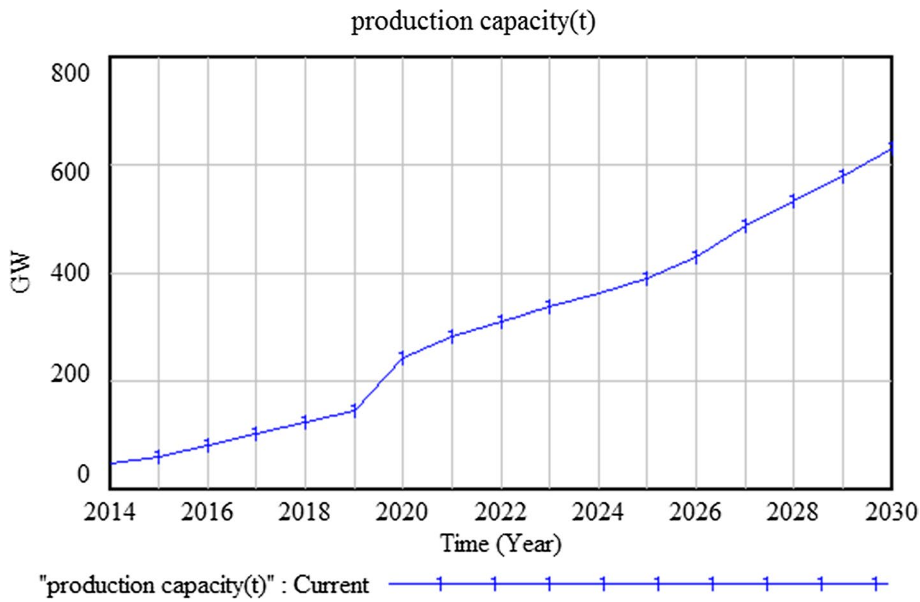

Fig. 9 Production capacity

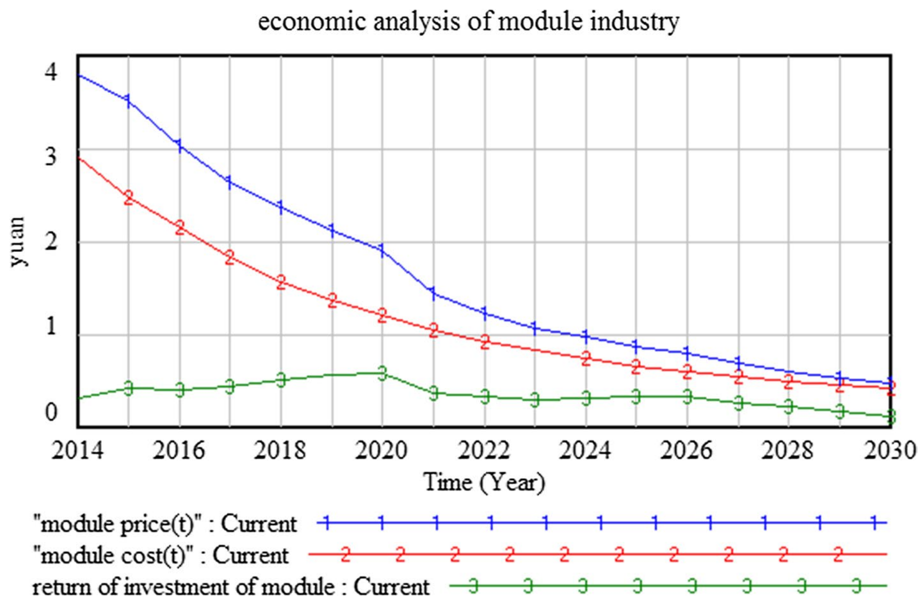

Fig. 10 Economic analysis of module industry

in 2022. As time goes on, it changes smaller, varying by about 5% in 2030 (Fig. 13). This illustrates that with the development of the PV module industry, the sensitivity of production capacity to the capital is getting weaker. It is not difficult to find that in the early stage of industrial development, the enterprise will invest much capital in expanding production to occupy a larger market share, which is consistent with our actual situation (MIIT, 2021). However, as the industry gradually matures, if the company wants to gain a competitive advantage, it needs to focus more on product quality, and the role of capital will gradually weaken. Therefore, in the initial stage, the relevant government can regulate production capacity from the aspect of capital. With the development of the industry, its regulatory effect will gradually weaken.

5.2.2 Effect of labor factor

The change in labor factor also affects the production capacity, but the range of change is minimal in the PV module industry. When the labor factor fluctuates by 20%, the production capacity fluctuates by about 5% in 2022. The sensitivity of production capacity to labor factor diminishes over time, falling to around 3% in 2030 (Fig. 14). To find out its cause, in the initial stage, many workers are required to complete some tasks due to the immaturity of various industry norms and the higher labor costs. However, with the gradual standardization of the industry, intelligence will further penetrate every link of the industrial chain, and the demand for staffing will weaken (Guangfu, 2019; sohu, 2018, 2019). On the whole, the sensitivity of production capacity to the labor factor is minimal. Therefore, if the government controls the production capacity of PV modules from the perspective of the labor factor, they cannot get excellent feedback.

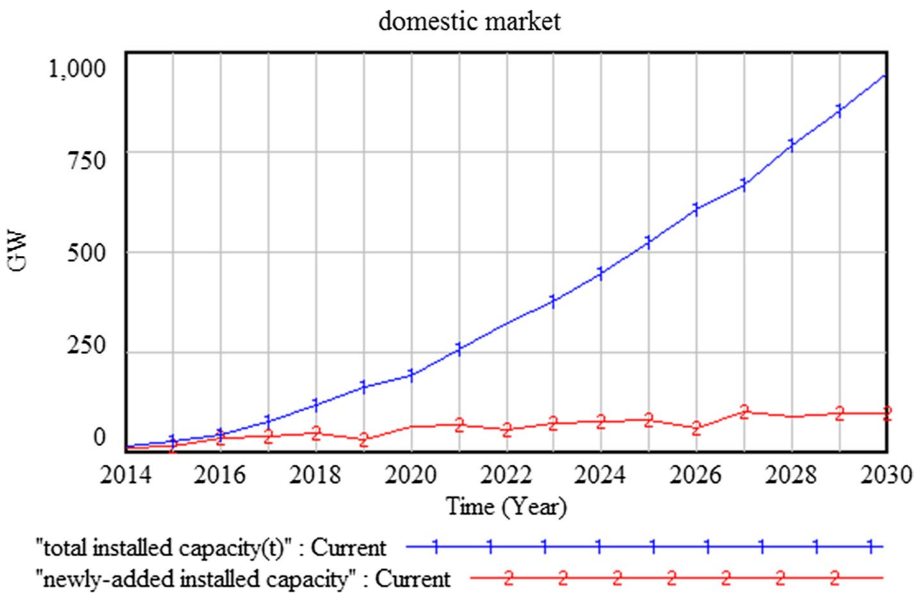

Fig. 11 Marketed demand

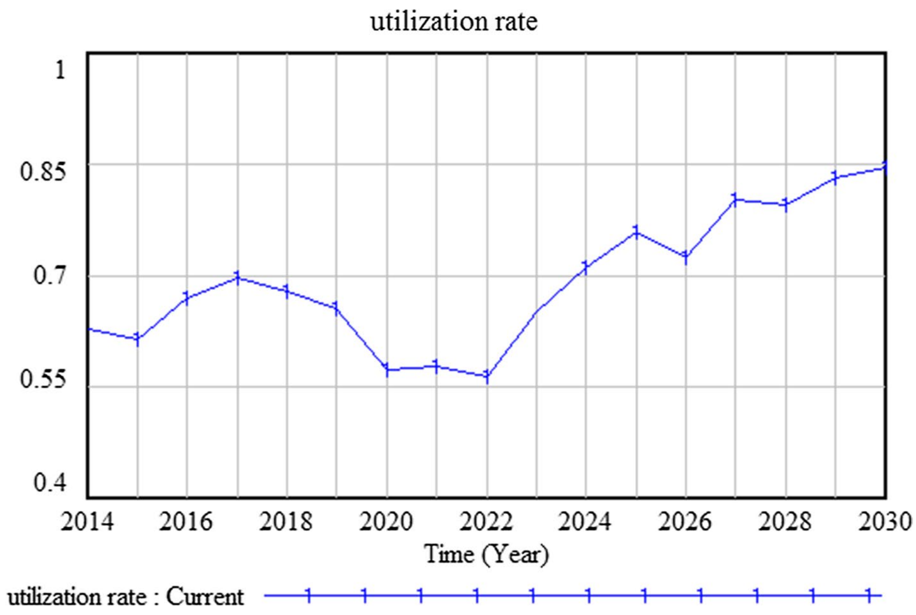

Fig. 12 Utilization rate of production capacity

5.2.3 Effect of technology investment factor

The change in technology investment factor also has a specific impact on the production capacity of the PV module industry. When the technology investment factor fluctuates by 20%, the production capacity fluctuates by about 27% in 2022. With time, it becomes less sensitive, fluctuating by approximately 16% in 2030 (Fig. 15). To find out its cause, the same R&D investment will bring minor technological achievements as the industry matures. Nevertheless, compared with other factors, the impact of technology investment factor on production capacity is still significant in the future. Hence, if the government controls the production capacity from technology investment, they will get an obvious result.

5.3 Further discussion

(1) Although China's PV module industry always has the phenomenon of overcapacity, it still has a great tendency to expand the production capacity in the future, which is consistent with our actual situation (Power, 2022).

(2) Some scholars thought that government subsidies were the main reason for the overcapacity of the PV module industry. After the government subsidies were canceled, this phenomenon could be improved quickly (Corwin & Johnson, 2019; Zhang, et al., 2016), which is somewhat different from our research results. This paper's results show that the phenomenon of overcapacity will not disappear immediately after the cancellation of government subsidies. Still, it will gradually ease until the utilization rate reaches about 80% in 2030, which illustrates that the problem of overcapacity is not entirely caused by government subsidies.

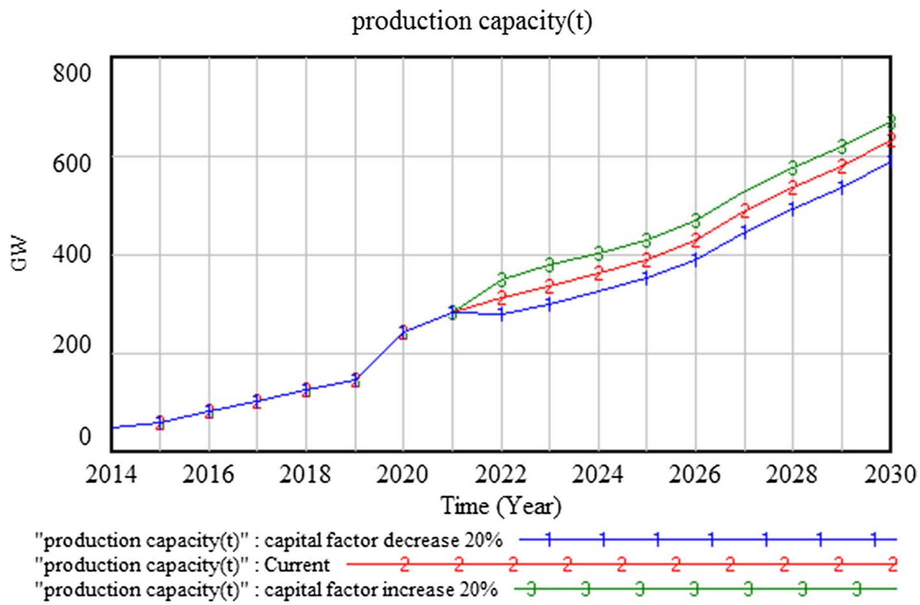

Fig. 13 Effect of capital factor

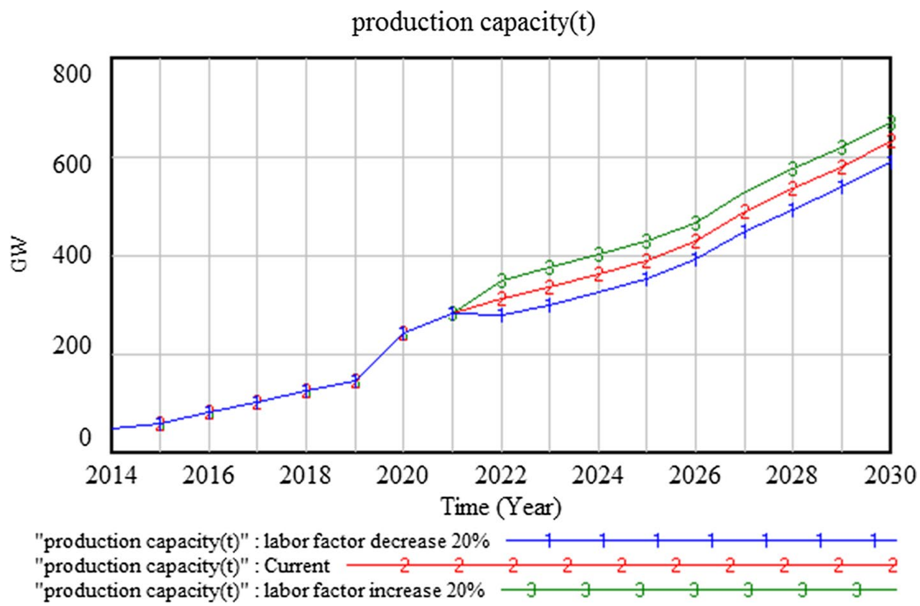

Fig. 14 Effect of labor factor

(3) The sensitivity analysis indicates that compared with the other two factors, the impact of the labor factor on the production capacity has always been minimal. In the initial stage, the influence of capital and technology factors is significant. However, as the industry gradually matures, the impact of the capital factor will become smaller, which is consistent with the actual development of China's PV module industry (Xin-gang et al., 2021).

6 Conclusions and policy implications

How the phenomenon of overcapacity will develop in the future after the cancellation of government subsidies is one of the critical issues we need to consider in the PV module industry. This paper constructs a systematic framework to analyze the driving mechanism of government subsidies on overcapacity. Then, an SD model is established to predict the development trend of overcapacity after the cancellation of government subsidies. The main conclusions are as follows:

(1) By 2030, the production capacity will exceed 600 GW in China's PV module industry. The reason is mainly from two aspects: economics and market demand. On the one hand, its price and cost will drop to 0.46 yuan/W and 0.41 yuan/W, which are down 67% and 60%, respectively, compared to 2021. On the other hand, by 2030, the domestic installed capacity will be close to 1000 GW, an increase of about 2.7 times compared with 2021.
(2) After the cancellation of government subsidies, the phenomenon of overcapacity will not disappear soon, and it will continue until 2030. However, this phenomenon will

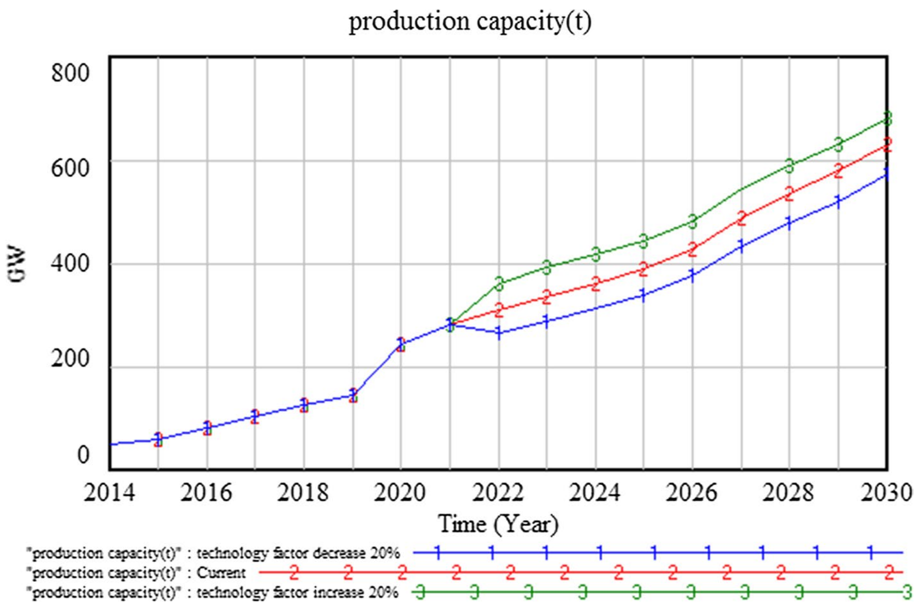

Fig. 15 Effect of technology investment factor

gradually be improved after the government subsidies are canceled, and the production capacity utilization rate will reach about 80% by 2030.

(3) The impact of the labor factor on the production capacity is minimal. In the initial stage, technology and capital factors are vital to it. As the industry matures, the influence of the capital factor will gradually weaken.

Given the above conclusions, this paper proposes the following policy implications:

(1) Both the application and the module manufacturing end of China's PV industry will have good development prospects in the future. The government needs to create a good business environment, such as increasing market openness, shortening tax processing time, and creating a diversified financial system.
(2) The phenomenon of overcapacity will continue for a long time in the future. Therefore, the government can take some measures to accelerate the reduction in overcapacity, for example, eliminating outdated facilities, implementing punitive measures for enterprises with low utilization, and providing incentives for enterprises with high utilization.
(3) To better regulate production capacity, the government must consider different factors at different stages. For example, in the initial stage, they can view the two perspectives of capital and R&D investment. As the industry matures, they should mainly focus on R&D investment.

7 Strengths and limitations

This article has some strengths but also some limitations. The details are as follows:

In terms of the strengths, firstly, this paper constructs a systematic framework to analyze the driving mechanism of government subsidies on overcapacity in the PV module industry. Then, the development trend of overcapacity after the cancellation of government subsidies is analyzed from a dynamic point of view. Finally, the key factors and policy implications for regulating production capacity are given.

In terms of the limitations, the SD model established in this article simulates the PV module system based on historical data. It can only analyze the general development trend of PV module industry and cannot predict significant events, such as major technological changes and the promulgation of crucial policies.

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Data availability All data generated or analyzed during this study are included in this published article, and they are allowed to be cited under reasonable circumstances.

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