The efficiency of the solar PV industry and determinants of competitiveness

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Graduate School of Fisheries and Environmental Sciences Nagasaki University, Japan

Tiantian Zhang

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Chapter 1 General introduction

1.1 Introduction

Energy is the convertible currency of technology (Dincer, 2000). Without energy, the entire fabric of society as we know it would collapse. In the course of human development, the struggle for energy began with the Industrial Revolution. Due to the non-renewable nature of traditional fossil fuels, relying solely on traditional fossil-fuel energy sources is no longer sufficient for the economic development of countries. New alternative energy sources will be the main driver of competition among countries in the future.

Solar energy is one of many new alternative energy sources. It is clean, non-polluting, and renewable, advantages which have become one of the positively developed goals in various countries. Human utilization of solar energy is mainly divided into solar thermal conversion and solar photovoltaic (PV) conversion, thus forming two major industries: the solar thermal industry and the solar PV industry (Hosenuzzaman et al., 2015a; Ismail et al., 2022). This paper focuses primarily on examining the solar PV industry.

In this study, the solar PV industry includes silicon mining, crystalline silicon purification, PV manufacturing technology, solar cell production, PV module installation, and PV power. For governments, the ultimate goal of a vigorous solar PV industry is to actively and effectively convert PV technology into PV power, because PV power is an essential energy source that can relieve the pressure caused by the scramble for energy.

In 1839, French physicist Edmond Becquerel discovered the PV effect, by directly converting light energy into electricity (Green, 2002). In 1877, the first solar cell was manufactured, proving the PV effect (Lesourd, 2001), which could be applied to real life. In 1954, a solar cell with a PV conversion efficiency of 6% was manufactured at the Bell Laboratories in the USA. This research result was a significant advance in PV power technology. Due to the cost of generating PV power, it did not formally enter real-life until after 1975 (Maycock, 1995). In 1985, photoelectric conversion efficiency of solar cells progressed, with a single crystal silicon conversion efficiency equal to about 20% and a multicrystalline silicon conversion efficiency equal to about 16% (National Renewable Energy Laboratory, 2021).

Meanwhile, the cost of raw materials for the solar PV industry has been significantly reduced under market promotion. Since 1990, Japan and Germany have become the leading countries in developing the solar PV industry (Jacobsson et al., 2004; Watanabe et al., 2000). Since 2000, the Chinese PV industry has been significantly influenced by the German PV market, which has attracted Chinese PV companies to enter the European PV market. The Chinese PV industry has entered a rapid growth period, with more than 50% of the world's PV modules coming from China in 2011 (Yu et al., 2016). Affected by the economic crisis in 2008, the development of the solar PV industry was seriously hampered, and the European debt crisis began to erupt in 2011; European PV market demand was low, and European PV power capacity decreased from 22.4 GW in 2011 to 17.2 GW in 2012 (Najafi et al., 2015).

In 2012, the USA imposed tariffs on Chinese imports of PV products, and then the European Union began imposing anti-dumping duties on Chinese imports of solar panels and PV modules (Wang et al., 2018). The Chinese government relied on a feed-in tariff scheme to stimulate the development of the local PV market, which helped the domestic PV industry overcome the difficulties caused by anti-dumping actions in the USA and Europe (Zhang and He, 2013a).

As of 2021, China, Germany, Japan, the USA, and European countries have made the solar PV industry proliferate over the past decades. PV incentives, PV technology innovation, PV market development, and improvement of the PV industry supply chain have had a significant positive impact on the implementation of affordable PV power.

Renewable energy's share of the global electricity supply reached 28.6% in 2020, the highest level on record, with solar PV and wind each accounting for about one-third of the total 2020 renewable electricity generation growth (IEA, 2021). Solar PV power uses semiconductor materials to convert sunlight into electricity (Alcántara-Avila et al., 2015; Ashok Kumar et al., 2020). Specifically, the solar PV power system consists of solar cells, batteries, inverters, chargers, discharge controllers, solar tracking control equipment, and other systems (Jin et al., 2011). Due to its pollution-free, environmental protection, renewable solar PV power is one of the most developed energy conversion methods (Wang and Sueyoshi, 2017).

Meanwhile, declining fossil fuel savings and rising greenhouse gas emissions have intensified researchers' concerns in the field of solar PV power. According to the latest data released by the IEA, Data and statistics (2019), the worldwide solar PV power reached 680,952 GWh in 2019, indicating that the solar PV power sector has a relatively well-developed scale in countries like the USA, China, India, and the European Union. However, there are relatively few studies on how to effectively evaluate solar photovoltaic industry power efficiency (PVE) among these countries, and PV power analysts have not strongly promoted the term PVE. To achieve the goal of effectively evaluating PVE, we must first define the term. PVE is defined differently from that in power generation systems, meaning that it cannot be defined as the ratio of output power to input power; it should be defined as the effectiveness of input and output factors in the PV sector, which cannot be assessed by a simple formula and requires a combination of multiple methods of analysis (Yi et al., 2019). Although this definition is concise and vague, it provides a valuable reference for evaluating PVE.

Due to the importance of the impact of solar PV power in addressing climate change and achieving sustainable development, the vast majority of economies recognize the significance of assessing the PVE. In particular, it has strong practical implications in accelerating the energy transition and reducing carbon emissions, thus providing stakeholders and policymakers with more scientific evaluation criteria; for example, investment in the global renewable energy sector has grown from less than $50 billion per year in 2004 to approximately $300 billion per year in recent years, with solar PV power attracting 46% of global renewable energy investment between 2013 and 2018 (IRENA, 2020).

Under the pressure of the rapidly increasing energy production capacity required to cope with the growing energy demand, deal with energy use challenges, and promote sustainable economic development, many provinces in China are increasingly fostering sustainable energy development. Although solar photovoltaics account for a small portion of the renewable energy flow, the Chinese government is currently paying attention to its economic potential. For example, as of July 2021, various provinces have announced their energy plan targets during the 14th Five-Year Plan (2021–2025) and 16 provinces have clearly announced a newly increased scale of photovoltaic plans during this period (see Appendix A). This indicates that the Chinese government is increasingly aware of the importance of the effective development of the solar photovoltaic industry in solving the energy supply shortage among provinces (The Central People's Government of the People's Republic of China, 2021). The solar photovoltaic sector includes silicon mining, crystalline silicon purification, manufacturing technology, wafer cutting, battery production, module installation, and power generation. For many local governments, solar photovoltaics are an essential energy source and a valuable channel for transferring more productive and innovative technologies. In the process of transitioning to a global clean energy system, the Chinese government has been vigorously promoting the development of photovoltaic power generation and creating a favorable environment for the renewable energy industry, especially the solar photovoltaic industry. Renewable energy has attracted most of the world’s attention, which will significantly promote market competition and a safe and efficient electricity market transition (IEA, World Energy Outlook, 2019). To this end, understanding the determinants of competitiveness in the Chinese photovoltaic industry and clarifying the relative importance of these determinants will provide a standard for policymakers to prioritize policies and actions.

The scale of China’s photovoltaic industry is growing, and practitioners within this industry are interested in the effectiveness of various factors that aim to make this sector attractive. However, studies that clarify the relative importance of the determinants of the photovoltaic industry’s competitiveness are still limited.

1.2 Purpose

If changes in the power efficiency of the PV industry were not effectively assessed and relied solely on market behavior, the development of the solar PV industry would be affected by many unfavorable factors, such as technology and capital. Therefore, this study aims to ensure the effectiveness of the power efficiency of the PV industry and the support of national PV policy orientation, improve the competitiveness of PV enterprises, and guide the development of the PV industry.

1.3 Treatise structure and content

The non-renewability of traditional fossil fuels and the increase in greenhouse gas emissions have intensified researchers' interest in the solar PV industry. This paper consists of six chapters.

Chapter 1 describes the solar PV industry's development process, including the PV industry's development opportunities, the PV effect, and the emergence of the PV industry among countries. Then, the purpose and significance of the research of this paper are described.

Chapter 2 explains why solar PV power efficiency (PVE) is essential for combating climate change and attaining sustainable development. Therefore, the great majority of economies are interested in estimating the relevance of PVE within China's renewable energy sector, and the significance of the solar PV sector has become more apparent. Numerous Chinese provinces have embraced numerous solar PV industry development strategies.

Chapter 3 investigates PVE and its affecting elements for 26 nations for 2000 to 2020. It utilizes a three-stage data envelopment analysis based on economic dimensions by considering socioeconomic, technological innovation, and external environmental variables. In particular, gross capital formation (% of GDP), labor, solar PV installed capacity, the cumulative number of solar PV patents, PVG, the proportion of urban population in total population, GDP per capita, and carbon dioxide emissions are the variables. It assesses PVE for 26 countries based on economic dimensions and discusses policy recommendations. First, the results indicated that the PVE of the 26 nations was 0.762, which leaves substantial opportunity for improvement. The PVE of high-income nations was greater than that of non-high-income nations. Second, increased GDP per capita and decreased carbon dioxide emissions also increased PVE. The proportion of urban population in total population also affected PVE. Third, the influence of external environmental factors on PVE differed across nations. Twenty-six nations had a greater average PVE in stage 3 than in stage 1, demonstrating that external environmental factors might contribute to an underestimation of PVE.

Chapter 4 uses the diamond model and the analytic hierarchy process to clarify the relative importance of the solar PV industry's determinants. Twenty-two factors were evaluated in six categories (the factor condition; the demand condition; firm strategy, structure, and rivalry; related and support industries; government; and chance). It focuses on analyzing the determinants of the competitiveness of the Chinese PV industry. In addition to the factor condition, the findings indicated that the demand condition, firm strategy, structure, and rivalry had a significant impact on the growth of China's solar sector. The data also showed that conventional issues, such as labor costs and land acquisition, were essential to the growth of the solar PV industry.

Chapter 5 collects and organizes the successful experiences of PV industry power policies in the USA, Germany, and Japan. It also draws valuable insights from them to improve PV industry power policies in other countries.

In Chapter 6, the paper's main conclusions are given, along with the shortcomings of this paper and prospects for future research.

Chapter 2 Literature review

Considering the two purposes of this paper, we subdivide the previous studies into two categories: efficiency and determinants of competitiveness.

2.1 Studies on efficiency

Reviewing the academic literature on efficiency assessment, we found that DEA models have been widely applied to assess efficiency in different countries and fields (Balitskiy et al., 2016; Bian et al., 2016; Martínez-Molina et al., 2016; Moya et al., 2016).

Chien and Hu (2007) analyzed the impact of renewable energy at the national level on the technical efficiency of 45 economies during 2001–2002 through DEA, which included three different inputs: labor, capital stock, energy consumption, and a single output: real GDP. Zhou and Ang (2008) proposed several DEA-type linear programming models for evaluating energy efficiency on an economic scale, with the benefit of models that consider the effects of undesirable outputs and changes in energy structure. Six DEA-based performance assessment models have been proposed for a sample of Chinese coal-fired power plants to ameliorate the dual impact of undesired output and uncontrollable variables (Yang and Pollitt, 2009). Welch and Barnum (2009) applied the DEA program to examine the economic and environmental trade-offs between the different types of fuels used in a plant, which minimizes carbon emissions and cost inputs. Wang et al. (2012) used multiple DEA-based models that consider desirable and undesirable outputs and a joint production framework with energy and non-energy inputs to assess the total factor performance of 26 regions in China. A two-stage environmental network DEA model was used to compare the efficiency performance of China's power system. The results show that clean energy-cased forms of power generation significantly impact environmental efficiency performance and should be extended enormously to the power generation sector (Bai-Chen et al., 2012).

Aranda-Usón et al. (2012) estimated production frontiers for four industrial sectors in Spain through a stochastic frontier production function model and analyzed the degree of inefficiency of each. Chen et al. (2015) used a Bayesian stochastic frontier model to analyze the efficiency of 27 fossil fuel-fired power generating companies in China and drew different policy implications based on their results. Another study examined the productivity and efficiency of wildland firefighting efforts using a stochastic frontier and identified the determinants of inefficiency (Katuwal et al., 2016). Matsumoto et al. (2020) applied DEA window analysis and the global Malmquist-Luenberger index to assess 27 European Union countries' environmental performance. Matsumoto and Chen (2021) used DEA to measure the industrial eco-efficiency of Chinese provinces and Tobit regression to explore the determinants of eco-efficiency. Yi et al. (2019) combined DEA and Tobit regression to evaluate the efficiency of photovoltaic power generation in China and analyzed the determinants affecting efficiency. Wu et al. (2018) proposed an improved three-phase DEA model to assess the performance efficiency of photovoltaic poverty alleviation projects and to explore the influencing factors. First, the Pearson correlation coefficient and super-efficiency analysis were combined to screen for unreasonable variables and outliers. Then, a bootstrapping algorithm was used to optimize the DEA model to achieve effective correction of deviations. Finally, potential environmental variables were extracted and further validated by Tobit regression to provide a more comprehensive reference and support for managers. By examining these models, we found that the performance efficiency obtained by using the DEA model was affected by environmental factors and error terms, which cause inefficiencies. Because DEA has non-parametric and linear programming characteristics, we surmised that these characteristics make the DEA model unable to capture the effects of the external environment and statistical errors.

As Norton et al. (2007) pointed out, many decision-making units (DMUs) operate under site characteristics that are significantly different from those experienced by other DMUs, and these differences may affect their efficiency ratings. It would be unfair to focus only on efficiency ratings and ignore differentiating factors among DMUs. To address the impact of differentiation, researchers have summarized in detail how environmental impacts can be removed from DEA so that efficiencies can be reasonably assessed (Avkiran, 2009; Avkiran and Rowlands, 2008; Camanho et al., 2009; Muiz, 2002; Tsutsui and Tone, 2007). The three-stage DEA model is the most prevalent (Sun et al., 2019; Wang et al., 2017; Zhang, Liu et al., 2017; Zhao, Zhang et al., 2018; Zhao, Zhao et al., 2018; Zhao et al., 2019). The essential purpose of the three-stage DEA model is to adjust the data based on input slack or output slack to balance the competitive environment. **Table 2-1** summarizes representative studies using a three-stage DEA model to assess energy performance.

As mentioned, DEA models, especially the three-stage DEA model, are an assessment method established in many studies.

Table 2-1 Summary of energy performance measurement using three-stage DEA.

Author	Topic [a]/Time period	Method [b]	Input variables [c]	Output variables [d]	Environment variables [e]
Lu et al., 2013	China's regional EE, 2010	Three-stage DEA	Labor, capital stock, provincial total energy consumption	Local GDP	Local coal consumption, climate conditions in major cities, regional per capita GDP, local output value of tertiary industry
Honma and Hu, 2014	TFEE scores for 47 regions across Japan, 1996-2008	SFA, DEA	Regional GDP, labor, capital stock	Energy	Manufacturing industry share, chemical industry share, iron and steel industry share, non-ferrous metals industry share, non-metallic mineral products industry share, pulp, paper, and paper products industry share, service activities share, wholesale and retail trade industry share
Chen, Liu et al., 2016	EE of China's regional construction industry, 2003-2011	Three-stage DEA, DEA-DA	Energy, labor, capital, construction machinery and equipment	Energy-utilizat ion	Energy consumption structure, industrial development level, industrial open degree, industrial scale structure, market ownership structure, market industry structure, market specialization-division structure, technological innovation
Cai et al., 2017	EE in China, 2010-2014	Three-stage DEA	Capital stock, labor force, energy, carbon emissions	GDP of each province	Economy structure, energy structure, urbanization rate, foreign trade

Jia et al., 2017	UE in Chengdu city, 2015	Three-stage DEA	Built-up land area, total investment in fixed assets, non-agricultural payrolls	Non-agricultural GDP, urbanization rate, total retail sales of social consumer goods	Locational factor, government revenue of total GDP, total amount of water resources
Zhang, Liu et al., 2017	Industrial eco-efficiency in China, 2005-2013	Three-stage DEA	Industrial net value of fixed assets, industrial annual employees, annual industrial energy consumption, industrial SO_2 emission	Gross industrial output value	Ratio of pollution charge to industrial value added, numbers of granted patents, GDP per capita, output value of heavy industries
Wang et al., 2017	US solar PV power plants, 2010	Modified three-stage DEA	Nameplate capacity, PV panel area, insolation, daylight hours	Net generation	Latitude, elevation, cloud amount, temperature, precipitation, wind speed
Zhao, Zhang et al., 2018	TFEE in BRI countries, 2015	Three-stage DEA	Carbon emissions, energy, capital, labor	GDP	Energy structure, degree of international trade, industrialization degree

Zhao, Zhao et al., 2018	OE of Chinese provincial electricity grid enterprises, 2016	Three-stage DEA	The amount of employees, the fixed assets investment, the 110 kV and below distribution line length, the 110 kV and below transformer capacity	The electricity sales amount, the amount of consumers, the line loss rate	GDP per capita, the proportion of the second industry added value in GDP, urbanization rate
Zhao et al., 2019	Provincial EE of China, 2008-2016	Three-stage DEA	Total amount of employees, total investment on fixed assets of the whole society, total energy consumption	GDP of every province divided by SO_2 emissions amount	Economic structure, energy consumption structure, urbanization process, technical innovation lever
Zhang and Chen, 2021	EE in RCEP countries, 2000-2015	Modified three-stage DEA	Capital stock, labor, energy consumption	GDP of each country, CO_2 emissions	Urbanization level, energy consumption structure, merchandise trade, government efficiency, tourism income

Notes: [a]: EE: energy efficiency; TFEE: total factor energy efficiency; TE: technical efficiency; UE: urbanization efficiency; PV: photovoltaic; BRI: Belt and Road Initiative; OE: operational efficiency; RCEP: Regional Comprehensive Economic Partnership.

[b]: DEA: data envelopment analysis; BCC: Banker, Charnes and Cooper (1984) published the BCC model; Three-stage DEA: the first stage is BCC-DEA model, the second stage is stochastic frontier analysis (SFA) model, the third stage is BCC-DEA model; DEA-DA: DEA-discriminant analysis; SBM: slacks-based measure; Modified three-stage DEA: the first stage is SBM-DEA model, the second stage is SFA model, the third stage is SBM-DEA model.

[cde]: GDP: gross domestic product.

2.2 Studies on determinants of competitiveness

Most previous studies have used the diamond model method to find important determinants. For example, Tsai et al. (2021) assessed the competitiveness of Taiwan’s solar photovoltaic industry based on six dimensions of the diamond model (i.e., firm strategy; government, structure, and rivalry; demand condition; chance; factor condition; and related and support industries). Luo et al. (2021) assessed the photovoltaic industry and its influencing factors using the diamond model. Zhao et al. (2021) constructed a system dynamics model to analyze the impact of research and development investment on China’s photovoltaic power generation industry. Shao and Fang (2021) used a spatial econometric model to assess the performance of government subsidies and evaluate the photovoltaic industry based on the spatial dependence among regions. Xu et al. (2020) constructed an energy–economy–environment integrated model to explore China’s solar photovoltaic power optimal development path from 2018 to 2050. Dögl et al. (2012) used modified versions of the diamond model and applied them to technical analysis of the renewable energy industry in countries such as Germany, India, and China to help policymakers provide environmental support and standards of action. Fang et al. (2018) conducted a quantitative analysis of the competitiveness of the renewable energy industry in countries such as the Group of Twenty using the modified diamond model, which revealed the driving forces of the renewable energy industry and provided a policy analysis framework for policymakers based on each country's resources and competitive advantages. Xiao (2016) used the six elements of the diamond model to analyze the impact of each factor on the competitiveness of China's photovoltaic industry. Jiao (2013) analyzed the existing problems of China's solar photovoltaic industry using the diamond model as well as qualitative and quantitative methods from the industrial chain, market, trade, policy, and other aspects. Sun (2017) conducted a diamond model comparison analysis of China, the USA, Germany, Japan, and four other countries, identifying the competitiveness gap in the solar photovoltaic industry's international trade and providing suggestions for the development of China's solar photovoltaic industry. In addition, the modified diamond model was used to analyze the influence of the international market share of China's photovoltaic industry, the revealed competitiveness index, and the trade specialization index (Ji, 2014). The results show that China's photovoltaic industry is overly dependent on the international market and the domestic photovoltaic market requires further development (Ji, 2014). Based on the diamond model's four significant factors, Chen (2010) analyzed the policy and corporate strategic factors of international competitiveness and revealed two categories of main factors, macro-environmental and microeconomic, affecting the international competitiveness of the photovoltaic industry. As an improved version of the diamond model, the gear model was used to critically analyze the significant determinants of the photovoltaic power industry's competitiveness in China (Zhao et al., 2011). The results emphasize establishing a complete photovoltaic power generation industry chain and improving independent innovation, government policies, financial incentives, and other measures. Although these studies provide crucial empirical evidence, they also have a limitation. Most of them show the policy's influence as a determinant of the photovoltaic industry, which ignores the relative priorities of other determinants in the photovoltaic industry chain. Thus, research on the relative importance of different influencing factors in the competitiveness of the photovoltaic industry is clearly lacking. This limitation is mainly due to the unavailability of data. In addition, many provinces have implemented multiple support policies in parallel, which makes it difficult to assess the relative importance of each factor.

Chapter 3 Evaluating solar photovoltaic industry power efficiency based on economic dimensions for 26 countries using a three-stage data envelopment analysis

3.1 Methodology and data

3.1.1 Overall summary of the three-stage DEA model

The traditional DEA models used to analyze efficiency scores tend to ignore slack variables and thus produce biased evaluation results due to radial and angular reasons (Cooper et al., 2007). The three-stage DEA model avoids this bias compared to the traditional DEA model and eliminates the influence of external environmental variables and statistical noise on the results. Therefore, we used the three-stage DEA model developed by Fried et al. (2002). The constructions of the model were divided into three parts (**Fig. 3-1**). We used traditional DEA (BCC based on the input perspective; that is, a linear equation of variable returns to scale based on input orientation) model to obtain the initial efficiency scores in the first stage. In the second stage, we considered the three categories that affect the efficiency score (external environmental variables, statistical noise, and management inefficiencies)—that is, the effects of these three categories on the slack variables—separating the effects of external environmental variables and statistical noise through the SFA model to obtain the adjusted inputs. In the third stage, the analysis of the first stage was repeated to obtain new efficiency values. Compared to the efficiency values of the first stage, the new efficiency values removed the effects of the external environment and statistical noise.

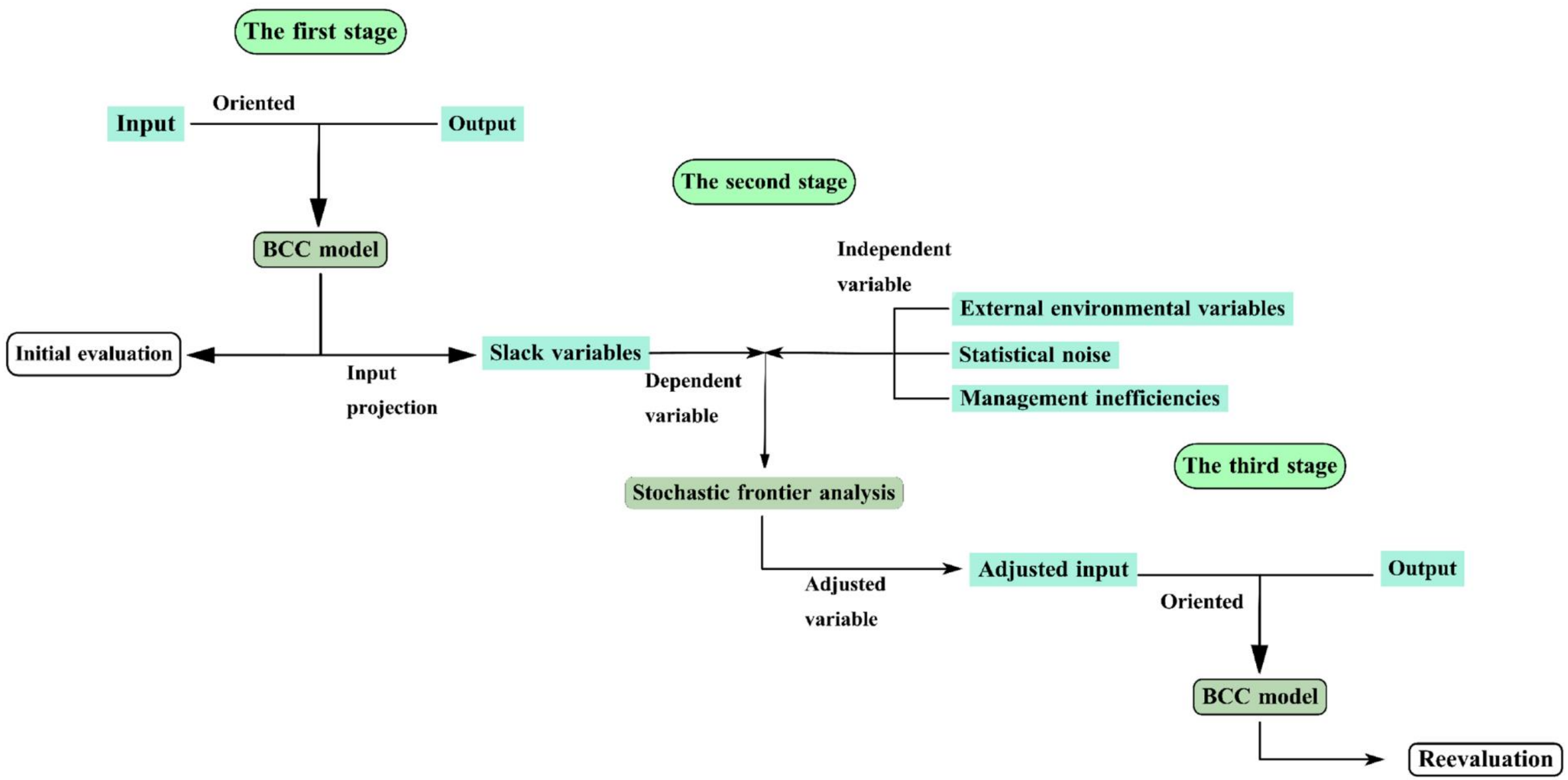

Fig. 3-1 A framework of a three-stage data envelopment analysis model.

3.1.2 First stage: The initial DEA PVE evaluation

The initial PVE evaluation was performed using conventional DEA, where efficiency was assessed as the ratio of the total output of the decision-making unit (DMU) to the punch input, accomplished by aggregating an endogenous weighting scheme for the input and output data. Either orientation was allowed, and we decided to use an arbitrary input orientation for uniformity.

Banker, Charnes, and Cooper (1984) developed the variable returns-to-scale envelopment form a linear program (Cooper et al., 2007):

(3-1)

$$\min_{\theta,\ \lambda} \quad \theta$$

$$\text{subject to } \theta x_{\circ} - X\lambda \geq 0$$

$$Y\lambda \geq y_{\circ}$$

$$e\lambda = 1$$

$$\lambda \geq 0,$$

where $x \geq 0,\ x \neq 0$ are DMU's $M \times 1$ vector of inputs, $X = [x_{1,\ldots,} x_J]$ are $M \times J$ matrix of input vectors in the comparison set, $y \geq 0,\ y \neq 0$ are DMU's $S \times 1$ vector of outputs, $Y = [y_{1,\ldots,} y_J]$ are $S \times J$ matrix of output vectors in the comparison set, λ is column vector with all elements non-negative, e is row vectors with all elements equal to 1. There are J DMUs in the comparison set; this imposes a convexity condition on allowable ways in which the comparison set for each DMU, the data of the DMU being evaluated are subscript "∘", and the DMUs are solved J times.

The optimal solutions to the envelopment form linear program (3-1) provide an initial PVE value θ evaluation for each DMU. The optimal solutions are represented by $(\theta,\ \lambda,\ s^{-},\ s^{+})$, where s^{-} and s^{+} represent the input excesses and output shortfalls, respectively. If $\theta = 1$ and have no slack $(s^{-} = 0,\ s^{+} = 0)$, then we call them efficient; otherwise they are inefficient.

However, through (Avkiran and Rowlands, 2008; Fried et al., 2002), we found that using DEA to assess PVE was influenced by three different phenomena: the efficiency with which management organizes solar PV power, the characteristics of the external environment in which solar PV power are conducted, and some non-human uncontrollable random effects. The first phenomenon belongs to internal factors, and the second and third phenomena belong to external factors. To separate the effects of these phenomena on the PVE, the model must be stochastic; however, the DEA model used in the first stage is deterministic, which means that this cannot be done within the framework of 3.1.2, so we need to resort to 3.1.3 to do so.

3.1.3 The second stage: Decompose the first stage slacks by using stochastic frontier analysis (SFA)

We determined the presence of inefficiency in the first stage by looking at two types of slack: input overload and output underload. However, there are two other factors, external environmental variables and statistical noise, that have an impact on slack. To decompose the slack in the first stage into these three factors, we used SFA. In the second stage, we distinguished the effects of managerial inefficiency and statistical noise by regressing the observable external environmental variables and the mixed error term, which allowed the independent variable (external environmental variables), the unilateral error component (managerial inefficiency), and the symmetric error component (statistical noise) to influence the slack due to the SFA's advantage of asymmetric error terms (Fried et al., 2002).

We use SFA regression for separation; however, there are multiple approaches regarding the selection of the dependent variable, and we refer to the Fried et al. (2002) for an explanation of the selection of the dependent variable, as seen in **Fig. 3-2**, Regarding the kinds of dependent variables, we can either interpret all input excesses s^- and output deficiencies (output shortfalls) s^+ as dependent variables or only s^- as dependent variables. Of course, both approaches are feasible, but considering that we are calculating the results from the input perspective in stage 1, we prefer to interpret only s^- as of the kinds of dependent variables compared to the output perspective. Regarding the number of dependent variables, we can either evaluate each input excess as the dependent variable in each individual SFA regression or stack all of them as the dependent variable in a single SFA regression. The former has the advantage of capturing the different effects that all of the independent variables (external environmental variables) have on each dependent variable (input excess); the latter has the advantage of creating a greater degree of freedom and broader estimation statistics; again, both methods are feasible, but, on balance, the advantages of the former in terms of flexibility are far outweighed by the sacrifice of degrees of freedom. Therefore, regarding the selection of the dependent variable, we chose each input excess as the dependent variable for the individual SFA regression.

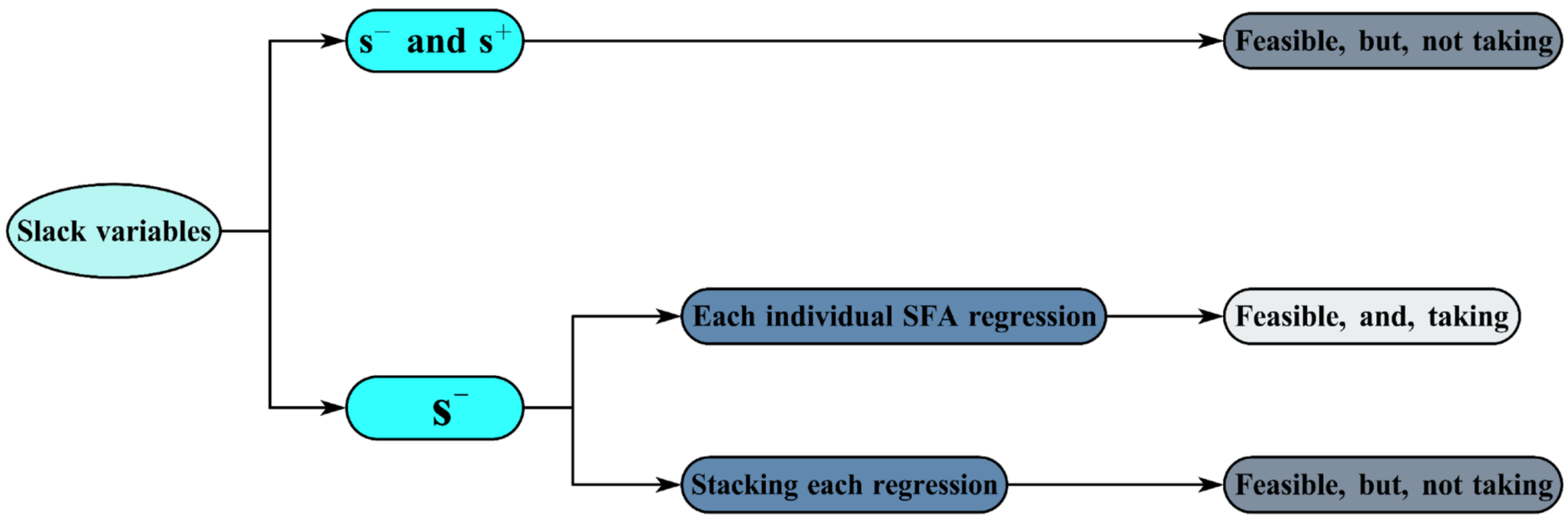

Fig. 3-2 Selection of dependent variables for SFA regression.

For each input slack s_{mj}, we defined the following:

(3-2)

$$s_{mj} = x_{mj} - X_m\lambda$$

$$s_{mj} \geq 0$$

$$m = 1, \ldots, M$$

$$j = 1, \ldots, J,$$

where s_{mj} denotes the *j*th DMU using the *m*th input in the slack of stage 1, $X_m\lambda$ is the optimal projection of x_{mj} on the output vector y_j.

For each individual SFA regression, we used the following form of interpretation:

(3-3)

$$s_{mj} = f^m(z_j; \beta^m) + v_{mj} + u_{mj}$$

$$Z_j = \left[Z_{1j,\cdots,}Z_{Q_j}\right]$$

$$m = 1, \ldots, M$$

$$j = 1, \ldots, J,$$

where Q denote the number of observable, Z_j are external environmental variables and the independent variables in the SFA regression model, β^m denote the parameter vectors, $f^m(Z_j;\, \beta^m)$ denote the deterministic feasible slack frontiers, $(v_{mj} + u_{mj})$ are the mixed error terms.

In this study, regarding the type of SFA regression, we chose the stochastic cost frontier type (Kwan and Eisenbeis, 1995), and we assumed that v_{mj} represented statistical noise (random factors) and $u_{mj} \geq 0$ represented managerial inefficiency, and in the SFA regression model, they represented the effect of statistical noise on input slack variables and the effect of managerial inefficiency on input slack variables, respectively.

We made distribution assumptions for v_{mj} and u_{mj} separately, assuming that v_{mj} obeyed normal distributions, i.e. $v_{mj} \sim N(0, \sigma_{vm}^2)$, assuming that u_{mj} obeyed normal distribution truncated at zero point: $u_{mj} \sim N^+(\mu^m, \sigma_{um}^2)$. Then, we were able to use the likelihood ratio to test the existence of u_{mj}. That is, if the original hypothesis of the existence of u_{mj} being not rejected in the SFA model by the likelihood ratio test, then there is no need to use SFA regression, and Tobit regression can be used directly (Fried et al., 2002).

In the stage 2 SFA regression, we obtained parameter estimates, such as $(\hat{\beta}^m, \hat{\mu}^m, \hat{\sigma}_{vm}^2, \hat{\sigma}_{um}^2)$ the size and direction of each, reflecting the different effects from each source. Next, we adjusted the DMUs' inputs by the parameter estimates to accommodate the adverse effects from different environmental changes and random noise. The aim is to level the playing field before repeating the DEA analysis (Fried et al., 2002). To avoid the negative impact of excessive downward adjustment (negative values are contrary to realistic DMU activity), we refer to Fried et al. (2002) and uniformly use upward adjustment to benefit all DMU input values after adjusting them to a relatively favorable environment and relatively beneficial random noise as much as possible.

We constructed the DMU-adjusted input formula as follows:

(3-4)

$$x_{mj}^{A} = x_{mj} + \left[max_j\{z_j\hat{\beta}^m\} - z_j\hat{\beta}^m\right] + \left[\max_j\{\hat{v}_{mj}\} - \hat{v}_{mj}\right]$$

$$m = 1, \dots, M$$

$$j = 1, \dots, J,$$

where x_{mj}^{A} represent the adjusted input quantity, x_{mj} are the original input quantity, $\left[max_j\{z_j\hat{\beta}^m\} - z_j\hat{\beta}^m\right]$ and $\left[\max_j\{\hat{v}_{mj}\} - \hat{v}_{mj}\right]$ denote the adjustment of DMU to the same external environment and the same nonanthropogenic state, respectively. Therefore, the amount of upward adjustments $\left[max_j\{z_j\hat{\beta}^m\} - z_j\hat{\beta}^m\right] + \left[\max_j\{\hat{v}_{mj}\} - \hat{v}_{mj}\right]$ are relatively small for DMU with a relatively poor external environment or nonanthropogenic relatively unfavorable DMU. In contrast, the amounts of upward adjustments are relatively large for DMU with a relatively beneficial external environment or nonanthropogenic relatively favorable DMU.

Next, we separated the statistical noise v_{mj} and the management inefficiency u_{mj} separately to achieve Eq. (3-4). We referred to Jondrow et al. (1982) to separate the mixed error term in Eq. (3-3), and we derived the estimation equation for statistical noise:

(3-5)

$$\hat{E}\left[v_{mj} \mid v_{mj} + u_{mj}\right] = s_{mj} - z_j\hat{\beta}^m - \hat{E}\left[u_{mj} \mid v_{mj} + u_{mj}\right]$$

$$m = 1, \dots, M$$

$$j = 1, \dots, J,$$

We found $\hat{E}\left[v_{mj} \mid v_{mj} + u_{mj}\right]$ depending on $\hat{E}\left[u_{mj} \mid v_{mj} + u_{mj}\right]$, where $z_j\hat{\beta}^m$ are the estimation of each environment variable can be calculated from the estimation of the parameter β^m, and Eq. (3-2) provides s_{mj}; therefore, in order to implement Eq. (3-5), we need to derive $\hat{E}\left[u_{mj} \mid v_{mj} + u_{mj}\right]$.

As Jondrow et al. (1982) used stochastic production frontier, that is, the mixing error term are $(v_{mj} - u_{mj})$; however, we used stochastic cost frontier, that is, the mixing error term are $(v_{mj} + u_{mj})$, thus, we can refer to Jondrow et al.'s (1982) methodology of derivation to isolate the estimation formula for the management inefficiency:

(3-6)

$$\hat{E}\left[u_{mj} \mid v_{mj} + u_{mj}\right] = \frac{\hat{\sigma}_{um}\hat{\sigma}_{vm}}{\sqrt{\hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2}} \left[\frac{\phi\left\{\frac{\left(\hat{v}_{mj} + \hat{u}_{mj}\right)\frac{\hat{\sigma}_{um}}{\hat{\sigma}_{vm}}}{\sqrt{\hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2}}\right\}}{\Phi\left\{\frac{\left(\hat{v}_{mj} + \hat{u}_{mj}\right)\frac{\hat{\sigma}_{um}}{\hat{\sigma}_{vm}}}{\sqrt{\hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2}}\right\}} + \frac{\left(\hat{v}_{mj} + \hat{u}_{mj}\right)\frac{\hat{\sigma}_{um}}{\hat{\sigma}_{vm}}}{\sqrt{\hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2}} \right]$$

$$\hat{\sigma}_m^2 = \hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2$$

$$\hat{\gamma} = \frac{\hat{\sigma}_{um}^2}{\hat{\sigma}_{um}^2 + \hat{\sigma}_{vm}^2},$$

where $(\hat{v}_{mj} + \hat{u}_{mj})$ denotes the estimated value of the mixed error term, ϕ denotes the probability density function of the standard normal distribution, and Φ denotes the cumulative distribution function of the standard normal distribution.

3.1.4 Third stage: Repetition of the first stage's operation

We obtained the adjusted inputs, which are x_{mj}^A, through the analysis of the second stage. The output of the third stage remained the same as the output of the first stage, after which we repeated the evaluation of the first stage and obtained the evaluation of the DMU of the third stage. Compared with the initial DMU of the first stage, the DMU value obtained in the third stage cleared the impact of the external environment and statistical noise.

3.2 Input and output variables

We used data from 26 countries for 21 years (2000–2020) to assess PVE. This study was based on the economic dimension to assess PVE. The most commonly used variables regarding a country's economic activity: capital and labor force. Capital and labor are usually used as input variables in the production function of the economic model (Matsumoto et al., 2020; Octaviano et al., 2014; Zhang et al., 2014). Topcu et al. (2020) analyzed 124 countries with different income levels between 1980 and 2018 using a panel vector autoregression method and found that gross capital formation (% of GDP) positively affected economic growth in high-income countries. However, it had a negative effect in low-income countries. Onyinye et al. (2017) and Satti et al. (2014) found a bi-directional relationship between gross capital formation and economic growth. Considering that the direction of the impact of gross capital formation on economic growth is different in different income countries, we chose gross capital formation as one of the input indicators. We know from World Development Indicators that labor is the supply of labor in an economy used to produce goods and services, and it includes people who are employed, people who are unemployed but looking for work, and first-time job-seekers. These three groups of people have different directions of influence on economic growth, so we chose labor as an input indicator. The cumulative number of solar PV patents is used as a proxy for technological innovation in solar PV power, which is crucial in addressing energy security, access, and climate change. The basic elements of the solar PV power system contain PV panels, cables, hard disks for mounting or fixing, inverters, chargers, discharge controllers, batteries, and other components (Hosenuzzaman et al., 2015b), and in this study the total amount of all basic elements is represented by solar PV installed capacity. solar PV installed capacity and solar PV power are the most basic indicators of solar photovoltaic power efficiency. Therefore, we chose solar PV installed capacity, the cumulative number of solar PV patents, gross capital formation, and labor as input variables, and solar PV power as the output variable. **Table 3-1** summarizes all the variables and sources used for the three-stage DEA.

Table 3-1 All variables were used for the three-stage DEA models and their data. sources [e].

Type	Variable (unit)	Model	Data source
Input	solar PV installed capacity (MW)	BCC-DEA	BP [a]
	The cumulative number of solar PV patents (numbers)	BCC-DEA	IRENA INSPIRE [b]
	Gross capital formation (% of GDP)	BCC-DEA	World Bank [c]
	Labor (population)	BCC-DEA	World Bank
Output	solar PV power (GWh)	BCC-DEA	IEA [d]
Environment variables	The proportion of urban population in total population (%)	SFA	World Bank
	GDP per capita ($)	SFA	World Bank
	Carbon dioxide emissions (million tons)	SFA	BP

Notes: [a]: BP's Statistical Review of World Energy (https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html)

[b]: IRENA INSPIRE (http://inspire.irena.org/Pages/patents/Patents-Search.aspx)

[c]: World Development Indicators (https://databank.worldbank.org/reports.aspx?source=world-development-indicators#)

[d]: International Energy Agency (https://www.iea.org/data-and-statistics/data-browser/?country=WORLD&fuel=Electricity%20and%20heat&indicator=SolarGen)

[e]: For periods for which data have not been published, these countries have zero sources of data for that period.

3.3 External environmental variables of PVE

External environmental variables in different countries may affect the PVE of that country. An extensive literature review shows that the proportion of urban population in total population, GDP per capita, and carbon dioxide emissions all affect PVE.

The proportion of urban population in total population has an essential impact in terms of energy resource structure and lifestyle, and as urbanization accelerates, it affects different types of power consumption (Bao and Xu, 2019; Lantz et al., 2021; Sheng et al., 2017).

GDP per capita: It is used to measure the level of economic development of different countries, and the level of economic growth determines the country's ability to invest in solar PV power infrastructure development, which can affect PVE (Cicea et al., 2014; Lyeonov et al., 2019; Simionescu et al., 2019).

Carbon dioxide emissions: Countries with more significant carbon emissions have more responsibility for reducing carbon emissions and achieving sustainable development. They also have relatively greater expectations for non-fossil-fuel energy generation, which will also increase the level of attention to solar PV power, and more government policies and researcher input will influence PVE (Bilan et al., 2019; Cerdeira Bento and

Moutinho, 2016; Xu et al., 2018).

3.4 Results and discussion

This section first summarizes the results of each phase and then compares and analyzes the results of the first and third phases.

3.4.1 The first stage: Initial PVE results

In the first stage, we calculated the PVE for 26 countries from 2000 to 2020 using the BCC-DEA model, and the results are shown in **Table 3-2**. It shows the PVE scores over 21 periods for the 26 countries evaluated. The overall characteristics of these countries between 2000 and 2020 show fluctuations, rising, and then falling, or falling and then rising, where the overall average PVE score is 0.762, indicating that there is still much room for improvement in these 26 countries. The average PVE in these countries reached a maximum value of 0.906 in 2020 and a minimum value of 0.686 in 2007. The average PVE score has been fluctuating around 0.8 for the five years from 2000 to 2004 and has been decreasing for the four years from 2004 to 2007, the fact that the global financial crisis of 2007–2008 had a significant impact on the economy and on energy.

According to Bartlett et al. (2009), the financial crisis has increased the PV industry's costs and reduced investments in the PV industry. The type of PV investment and the duration of the PV investment directly affected the PV installations, resulting in a significant decrease in PV demand and, ultimately, a decline in PVE scores. PVE started to rise slowly in 2008, indicating that the countries have been making different efforts in the development of PVE since 2008.

Our analysis from the perspective of 26 countries shows that firstly, from 2000 to 2020, the average PVE score of Belgium, Denmark, Greece, Italy, Portugal, Sweden, United Kingdom, Israel, Egypt, and the Philippines has exceeded 0.8. Second, countries such as Canada, Mexico, the US, Austria, France, Germany, Spain, Morocco, Australia, India, and Japan have performed poorly, with scores below the average. Third, China and South Korea have average scores of 0.463 and 0.536, respectively, much lower than other countries.

Table 3-2 PVE for the first stage from 2000 to 2020.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
CAN	0.836	0.848	0.836	0.800	0.764	0.726	0.697	0.686	0.679	0.717	0.645	0.598	0.584	0.593	0.586	0.603	0.698	0.623	0.628	0.633	0.660	0.688
MEX	0.657	0.699	0.697	0.684	0.657	0.663	0.634	0.617	0.596	0.603	0.602	0.587	0.571	0.605	0.621	0.581	0.569	0.606	0.540	0.731	1	0.644
USA	0.608	0.623	0.631	0.628	0.607	0.598	0.608	0.639	0.655	0.754	0.740	0.647	0.669	0.728	0.818	0.857	0.865	0.997	0.980	0.998	1	0.745
AUT	0.751	0.753	0.769	0.737	0.749	0.754	0.760	0.730	0.731	0.776	0.772	0.728	0.724	0.724	0.730	0.728	0.722	0.720	0.717	0.733	0.758	0.741
BEL	1	1	1	1	0.927	0.880	0.869	0.841	0.797	0.876	0.823	0.781	0.818	0.845	0.855	0.852	0.840	0.853	0.899	0.919	1	0.889
CZE	1	1	1	1	1	0.725	0.707	0.660	0.662	0.713	0.685	0.773	0.731	0.705	0.703	0.714	0.695	0.695	0.704	0.700	0.702	0.775
DNK	1	0.996	0.989	0.996	0.977	0.969	0.944	0.945	0.949	0.990	1	0.993	0.995	1	1	0.992	0.990	0.981	0.994	0.982	1	0.985
FRA	0.739	0.739	0.754	0.748	0.721	0.698	0.672	0.639	0.627	0.655	0.599	0.537	0.578	0.576	0.591	0.606	0.630	0.644	0.676	0.706	0.748	0.661
DEU	0.579	0.601	0.652	0.654	0.652	0.633	0.593	0.559	0.557	0.653	0.632	0.667	0.793	0.831	0.877	0.928	0.906	0.888	0.987	0.952	1	0.742
GRC	1	0.827	1	0.774	0.815	1	0.788	0.762	0.818	1	0.958	1	1	1	1	1	0.988	1	0.969	1	1	0.938
ITA	0.795	0.787	0.755	0.755	0.744	0.744	0.717	0.690	0.640	0.658	0.583	0.667	0.907	0.982	0.992	1	0.951	1	0.924	0.951	1	0.821
NLD	0.870	0.831	0.866	0.868	0.871	0.862	0.837	0.759	0.785	0.827	0.829	0.809	0.813	0.763	0.758	0.597	0.620	0.594	0.567	0.586	1	0.777
PRT	0.748	0.746	0.779	0.852	0.816	0.821	0.829	0.801	0.762	0.834	0.818	0.889	0.980	1	0.965	0.959	0.954	0.904	0.855	0.843	1	0.864
ESP	0.658	0.655	0.633	0.604	0.583	0.558	0.525	0.484	0.464	0.754	0.757	0.825	0.891	0.910	0.890	0.878	0.864	0.890	0.820	0.659	0.904	0.724
SWE	0.934	0.916	0.939	0.933	0.926	1	0.867	0.806	0.803	0.913	0.837	0.806	0.835	0.824	0.786	0.752	0.735	0.700	0.679	0.678	0.663	0.825
CHE	0.957	1	1	0.923	0.915	1	0.810	0.817	0.774	0.710	0.744	0.678	0.702	0.714	0.693	0.701	0.702	0.715	0.729	0.745	0.773	0.800
GBR	0.879	0.879	0.869	0.871	0.868	0.843	0.815	0.788	0.818	0.916	0.851	0.811	0.772	0.728	0.678	0.711	0.747	0.744	0.770	0.777	0.825	0.808
ISR	1	1	1	1	1	0.949	0.937	0.897	0.931	0.963	0.927	0.843	0.835	0.854	0.846	0.864	0.867	0.849	0.831	0.952	1	0.921
EGY	1	1	1	1	1	1	0.900	0.817	0.766	0.862	0.858	0.925	0.891	1	1	1	1	1	1	1	1	0.953
MAR	0.761	1	1	0.689	1	0.660	0.645	0.591	0.514	0.558	0.565	0.528	0.526	0.532	0.558	0.580	0.552	0.546	0.513	0.570	1	0.661
AUS	0.677	0.735	0.705	0.664	0.636	0.625	0.622	0.619	0.595	0.567	0.522	0.482	0.450	0.468	0.470	0.506	0.558	0.673	0.740	0.848	1	0.627
CHN	0.411	0.385	0.377	0.344	0.326	0.337	0.341	0.336	0.321	0.298	0.291	0.319	0.374	0.404	0.430	0.524	0.522	0.581	0.826	0.978	1	0.463
IND	0.585	0.572	1	0.513	0.422	0.396	0.390	0.346	1	0.345	1	0.744	0.722	1	0.641	0.778	0.963	0.801	0.881	0.903	1	0.714
JPN	0.475	0.487	0.517	0.521	0.521	0.516	0.518	0.526	0.526	0.581	0.574	0.558	0.566	0.603	0.686	0.747	0.822	0.911	0.901	0.927	1	0.642
PHL	1	1	1	1	1	1	1	1	1	1	1	1	1	0.745	0.664	0.638	0.573	0.555	0.535	0.537	0.740	0.857

KOR	0.541	0.556	0.563	0.542	0.528	0.518	0.499	0.491	0.449	0.497	0.466	0.464	0.476	0.492	0.498	0.522	0.534	0.562	0.629	0.665	0.773	0.536
Mean	0.787	0.794	0.820	0.773	0.770	0.749	0.712	0.686	0.701	0.732	0.734	0.718	0.739	0.755	0.744	0.754	0.764	0.770	0.781	0.807	0.906	0.762

As shown in **Fig. 3-3**, the vast majority of countries had a score of 1 in 2020, namely, Mexico, the US, Belgium, Denmark, Germany, Greece, Italy, Netherlands, Portugal, Israel, Egypt, Morocco, Australia, China, India, and Japan, meaning that they reached the production frontier side, with these countries generating more solar PV power and smaller economic burdens with relatively fewer inputs. Compared to countries on the production frontier side, countries such as Canada, Czech Republic, France, Sweden, and the Philippines lagged far behind in 2020, with their relatively low PVE scores and relatively large fluctuations in the time series. The US, China, Japan, and Germany, the four countries of the PVE overall upward trend, were more apparent, and the PVE of Denmark was the most stable, essential remaining at around 1.

According to the World Bank classification, the gross national income per capita in high-income countries is at least $12,376 (Khribich et al., 2021). Of the 26 countries included in this study, 20 are high-income countries (for the classification of countries' income, you can refer to Appendix B), with South Korea having a relatively poor PVE score among the high-income countries. There are two upper-middle-income countries, with only China having the worst PVE scores. There are four lower-middle-income countries, of which Morocco has a worse PVE score.

Looking at the average PVE for each country over the 21 years analyzed, we found that the top 10 countries were mainly from high-income countries: (1) Denmark, (2) Egypt, (3) Greece, (4) Israel, (5) Belgium, (6) Portugal, (7) the Philippines, (8) Sweden, (9) Italy, and (10) the United Kingdom. The solar PV market has grown significantly due to falling installation costs and various government subsidy measures, with most of the growth concentrated in relatively affluent and highly educated, high-income households and lower-middle-income households lagging relatively behind (Barbose et al., 2018; Wolske, 2020). This growth trend is also particularly pronounced in high-income countries, where the proportion of high-income households is relatively pronounced. High-income countries have higher productivity and higher quality of life and are well positioned to reconcile economic development with solar PV power. The two countries at the bottom of the ranking were (25) South Korea and (26) China, and we find in **Fig. 3-3** that the change graph of PVE about South Korea floated at around 0.5 until 2018, with better development from 2019 to 2020. The change graph of PVE for China, which was basically within 0.4 before 2010, may be related to China's crude production model, which is accompanied by redundant PV cost inputs and excessive government support. After 2010, the curve has been moving to the upper right (production frontier), which may be related to the change in production model brought about by the Beijing Olympics and Shanghai World Expo.

Fig. 3-3 The change graph of PVE in the first stage.

3.4.2 The second stage: SFA regression results

We used the slack variables of each of the four input variables in the first stage as the four dependent variables in the second stage. Three external environmental variables, the proportion of urban population in total population, GDP per capita, and carbon dioxide emissions, were used as independent variables. The SFA regression results are shown in **Table 3-3**.

Table 3-3 shows that the value of each LR test of the one-sided error is greater than the critical value of the mixed chi-squared distribution test and passes the 1% significance test, indicating that the SFA model is valid. Each gamma value is greater than 0.5, indicating that management inefficiency is the main factor affecting PVE. It is necessary to use the SFA model to remove the effects of the external environment and statistical noise.

Table 3-3 SFA model parameters and estimation results.

Dependent variable	solar PV installed capacity	The cumulative number of solar PV patents	Gross capital formation (% of GDP)	Labor
Constant term	-4313.26	-13034.16	0.12	1.46×10^{8}
	(-4312.85)***	(-13035.27)***	(5.83)***	(1.42×10^{8})***
The proportion of urban population in total population	18.11	130.55	-3.26×10^{-3}	-2.66×10^{6}
	(14.44)***	(260.63)***	(-4.37)***	(-6.81×10^{5})***
GDP per capita	0.03	1.15×10^{-4}	2.00×10^{-6}	-174.15
	(8.61)***	(0.04)	(3.2)***	(-2.03)**
Carbon dioxide emissions	0.13	0.5	-1.50×10^{-5}	40564.65
	(2.12)**	(45.81)***	(-1.95)*	(17.29)***
Sigma-squared	2.11×10^{7}	7.82×10^{7}	85.55	1.10×10^{16}
	(2.11×10^{7})***	(7.82×10^{7})***	(51.19)***	(1.10×10^{16})***
Gamma	0.9999	0.9999	0.9999	0.7477
	(1.63×10^{5})***	(2.30×10^{6})***	(7.75×10^{6})***	(37.39)***
Log likelihood	-5000.10	-5389.72	-1608.91	-10722.43
LR test of the one-sided error	354.42***	290.59***	128.33***	38.99***

Note: Values in bracket denote t-statistics. *, **, and *** represent significant levels at 10%, 5%, and 1%, respectively.

When we analyze the relationship between the external environment variables and slack variables, we generally determine the positive or negative relationship between them using the positive or negative regression coefficient. The negative regression coefficients indicate that an increase in external environmental variables caused a decrease in slack variables, which increased PVE. The positive regression coefficients indicate that an increase in external environmental variables brings about more input slack, leading to a decrease in PVE. The effects regarding each of the external environmental variables are as follows:

(1) The proportion of urban population in total population has a 1% significant positive or negative correlation with each of the slack variables. That is, as the proportion of urban population in total population increases, the input of solar PV installed capacity and the input of the cumulative number of solar PV patents increase correspondingly, and the input of gross capital formation and the input of labor decrease correspondingly. Among the 26 countries in this assessment, the high-income country group accounted for the majority, and the level of urbanization was relatively high. The corresponding solar PV installed capacity and the cumulative number of solar PV patent developments can develop in parallel with it. Along with

accelerated urbanization, a large amount of solar PV installed capacity and a large amount of the cumulative number of solar PV patents are being put in, resulting in a surplus of inputs, which adversely affects PVE. While the proportion of urban population in total population has grown in quantity, the quality of the urbanization process has received little attention. The large influx of people into the city results in a large labor force; capital and GDP are required to grow in tandem with it, inevitably leading to a shortage of inputs for gross capital formation and labor. At the same time, the urban population's demand for a quality of life with high energy consumption will stimulate an increase in PVE. There is a positive impact on PVE.

(2) GDP per capita: Although all coefficients on solar PV installed capacity, the cumulative number of solar PV patents, and gross capital formation were positive, the effects are insignificant. The coefficient on labor was negative and had a significant effect, indicating that GDP per capita was positively correlated with PVE. The growth of GDP per capita indicates the development of the country's economy, the growth of people's income, and the change in people's lifestyles. As a result, people's access to energy and the way they consume it have essentially changed with the increase in GDP per capita, gradually transforming

from fossil energy generation to renewable energy generation, especially in the solar PV power sector. We know from (Costs IRENA, 2022) that the cost of solar PV modules has fallen by about 90% since the end of 2009, accompanied by falling costs, technological advances, enhanced government deployment, and people's pursuit of a high quality of life has raised the PVE.

(3) Carbon dioxide emissions: The coefficients of solar PV installed capacity, the cumulative number of solar PV patents, and labor were all positive, while the effect on gross capital formation was negligible. This shows that an increase in carbon dioxide emissions increases the inputs of solar PV installed capacity, the cumulative number of solar PV patents, and labor and decreases the PVE. In this analysis, the energy consumption structure varied significantly from country to country, but most of the 26 countries' economics were mainly developed through fossil energy consumption, which emits large amounts of carbon dioxide. Therefore, accelerating the energy mix transition of countries and reducing carbon dioxide emissions will positively impact PVE. In Ren et al. (2020) and Wang et al. (2014), we found that an increase in the cumulative installed capacity of solar PV had a positive effect on carbon dioxide emissions reduction in China, meaning that the active

development of the solar PV power industry will also drive down the sting carbon dioxide emissions and thus increase the PVE. This is also of reference significance in other countries. Therefore, there is a negative correlation between carbon dioxide emissions and PVE.

From this analysis, we can find that external environmental factors affect the PVE of the 26 countries.

3.4.3 The third stage: Adjusted PVE results

We again used the BCC-DEA model to calculate the PVE based on the adjusted input values in the second stage. The results are shown in **Table 3-4** and **Fig. 3-4**.

Table 3-4 PVE for the third stage from 2000 to 2020.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
CAN	0.975	0.975	0.975	0.972	0.971	0.970	0.969	0.968	0.967	0.966	0.965	0.966	0.965	0.965	0.965	0.965	0.971	0.966	0.966	0.966	0.966	0.968
MEX	0.949	0.948	0.948	0.946	0.945	0.943	0.941	0.940	0.939	0.938	0.936	0.934	0.932	0.932	0.931	0.929	0.929	0.927	0.940	0.940	1	0.941
USA	1	1	1	1	1	1	0.999	1	0.998	1	1	1	0.990	0.988	0.983	0.980	0.987	1	0.996	1	1	0.996
AUT	0.998	0.999	0.999	1.000	1	1	1	1.000	1	1	1	1	1	1	1	1	1.000	0.999	1.000	0.999	0.998	1.000
BEL	0.960	0.975	1	1	0.987	0.985	0.994	1.000	1	1	0.992	0.966	0.978	1	1	0.989	0.979	0.978	1	0.992	1	0.989
CZE	0.983	0.983	0.983	0.983	0.983	0.984	0.984	0.984	0.983	0.983	0.984	0.986	0.986	0.986	0.986	0.986	0.986	0.985	0.985	0.984	0.984	0.984
DNK	0.967	0.967	0.967	0.969	0.967	0.966	0.964	0.966	0.998	0.994	1	1	0.979	0.979	0.978	0.961	0.959	0.958	0.959	0.958	0.957	0.972
FRA	0.960	0.959	0.959	0.957	0.957	0.956	0.955	0.953	0.952	0.952	0.950	0.954	0.955	0.958	0.955	0.954	0.955	0.955	0.955	0.956	0.957	0.955
DEU	0.960	0.959	0.957	0.956	0.961	0.968	0.968	0.966	0.966	0.968	0.969	0.972	0.979	0.983	0.988	0.993	0.990	0.991	0.999	0.996	1	0.976
GRC	0.984	0.985	0.984	0.983	0.982	0.983	0.980	0.979	0.979	0.985	0.985	1	1	1	1	1.000	0.998	1	0.996	1	0.992	0.990
ITA	0.976	0.976	0.976	0.976	0.976	0.976	0.976	0.975	0.975	0.975	0.986	0.992	0.996	1.000	0.999	1	0.998	1	0.997	0.998	1	0.987
NLD	0.978	0.977	0.975	0.974	0.974	0.973	0.970	0.965	0.970	0.974	0.975	0.977	0.986	0.984	0.989	0.953	0.956	0.955	0.955	0.954	1	0.972
PRT	1	1.000	1	1	1.000	0.999	0.999	0.998	0.997	0.998	0.998	0.999	1.000	1	0.999	0.999	0.998	0.997	0.996	0.996	0.996	0.999
ESP	0.969	0.969	0.968	0.966	0.966	0.964	0.963	0.963	0.963	0.973	0.973	0.979	0.987	0.989	0.985	0.980	0.978	0.982	0.974	0.960	0.975	0.973
SWE	0.966	0.966	0.966	0.965	0.966	0.965	0.964	0.965	0.966	0.969	0.964	0.969	0.969	0.974	0.965	0.957	0.956	0.955	0.954	0.954	0.953	0.963
CHE	0.981	0.981	0.981	0.981	0.984	0.984	0.986	0.989	0.994	0.992	0.995	1	0.994	0.990	0.990	0.985	0.982	0.983	0.983	0.981	0.979	0.986
GBR	0.968	0.969	0.969	0.975	0.980	0.980	0.978	0.981	0.984	1	0.986	0.968	0.965	0.964	0.961	0.962	0.963	0.961	0.961	0.959	0.959	0.971
ISR	0.957	0.958	0.963	0.981	0.978	0.967	0.966	0.959	0.972	0.999	0.990	0.957	0.955	0.961	0.955	0.959	0.956	0.955	0.953	0.988	1	0.968
EGY	0.994	0.995	0.995	0.995	0.993	0.991	0.992	0.991	0.990	0.989	0.988	0.987	0.989	0.990	0.995	0.990	0.984	0.984	0.985	0.982	0.995	0.990
MAR	0.997	0.992	0.992	0.994	0.989	0.993	0.993	0.993	0.994	0.992	0.992	0.991	0.991	0.990	0.989	0.988	0.988	0.988	0.988	0.987	0.982	0.991
AUS	0.969	0.969	0.968	0.965	0.964	0.963	0.963	0.962	0.964	0.959	0.956	0.954	0.953	0.954	0.953	0.955	0.956	0.961	0.964	0.968	0.981	0.962
CHN	0.604	0.603	0.605	0.612	0.624	0.636	0.643	0.651	0.648	0.654	0.661	0.674	0.678	0.688	0.693	0.708	0.733	0.804	0.975	0.998	1	0.709
IND	0.759	0.752	0.744	0.736	0.727	0.721	0.720	0.720	0.721	0.722	0.722	0.715	0.684	0.592	0.719	0.768	0.879	0.828	0.917	0.950	1	0.766
JPN	0.939	0.933	0.928	0.926	0.923	0.921	0.918	0.917	0.916	0.914	0.915	0.916	0.921	0.925	0.931	0.949	0.962	0.974	0.982	0.989	1	0.938
PHL	0.978	0.974	0.972	0.973	0.972	0.974	0.971	0.969	0.965	0.965	0.960	0.970	0.971	0.969	0.970	0.971	0.971	0.973	0.972	0.971	0.986	0.971

KOR	0.964	0.962	0.961	0.959	0.957	0.954	0.952	0.949	0.947	0.947	0.949	0.950	0.949	0.949	0.948	0.950	0.952	0.955	0.958	0.963	0.970	0.955
Mean	0.951	0.951	0.951	0.952	0.951	0.951	0.950	0.950	0.952	0.954	0.954	0.953	0.952	0.950	0.955	0.955	0.960	0.962	0.973	0.977	0.986	0.957

Overall, after adjusted inputs, the average PVE score of 26 countries is 0.957, reaching the maximum value of 0.986 in 2020 and the minimum value of 0.950 in 2006, 2007, and 2013. The PVE scores were below average, except from 2016 to 2020. From the national level, except for China and India, the adjusted PVE scores all exceed 0.9, which is close to the production frontier side. In particular, the USA and Austria have been on the production frontier side for 13 years and 11 years, respectively. Both China and India are located in the Asian region, with large populations and abundant solar energy resources (Arora et al., 2010). The two countries are facing both energy and environmental pressures to varying degrees, and their governments are working to develop solar PV power to play a role in the future energy power system (Sahoo, 2016; Zhang, Matsumoto et al., 2021). Although the Indian government provides financial support for solar PV power projects, and the cumulative installed capacity of solar PV power in India reached 28.18 GW by March 2019 (MNRE, 2022; Singh, 2009) understands that 1/3 of villages in India's power sector are not connected to the grid, which means about 600 million Indians are not connected to the grid. This leads to an insufficient grid to carry and transport the power generated by solar PV power, which is not conducive to the large-scale popularization of solar PV power grid parity, resulting in India's low average PVE score. However, unlike in India, the development of solar PV power in China has gone through an initial stage and an expansion stage, which are divided in time by 2013 (Zhi et al., 2014). Before 2013, the vast majority of the installed solar PV capacity was installed in the western region, with the support of the Chinese government (Zhang and He, 2013b). Due to the better resource endowment in the western region, solar PV generation capacity has been growing slowly in the initial stage. In **Table 3-4**, we also find that PVE has been growing slowly in the initial stage as well. However, the center of solar PV power in China is different from the center of massive consumption of solar PV power, meaning there is no transmission line to connect the western region with the eastern region effectively (Song et al., 2015), which leads to a serious waste of solar PV power during the expansion stage, where the waste rate of solar PV power in four regions, Xinjiang, Gansu, Qinghai, and Ningxia, reached 32.23%, 30.45%, 8.33%, and 7.33%, respectively, in 2016 (NEA, 2017). In **Table 3-4**, we found that the PVE scores also increased slowly from 2014 to 2016; although it is in the expansion stage, the PVE scores have not increased significantly, and these reasons also lead to the overall average PVE score of China being the lowest among 26 countries.

Fig. 3-4 shows that Austria and Portugal have remained stable on the production frontier for a long time. Fina et al. (2020) and Simoes et al. (2017) reported on the current status of solar PV power in Austria, assessing the deployment of solar PV power and its optimal economic potential in terms of space, time, and shared PV. Regarding economic feasibility, solar PV power is sufficient for large-scale development in Austria. At the same time, the Austrian government is bound to invest technically and economically to achieve at least 9.7 GW of solar PV power by 2030 (Fechner et al., 2016), and therefore, in terms of the development scale, consumption level, and economic efficiency relative to other countries, all these conditions also contribute to the best average PVE score in Austria. Seven countries were Belgium, Germany, Netherlands, Israel, China, India, and Japan, all experienced different degrees and periods of increase, and finally, in 2020, PVE scores all reached 1. China had the most prolonged increase, and India fluctuated relatively more in 2013 and 2016.

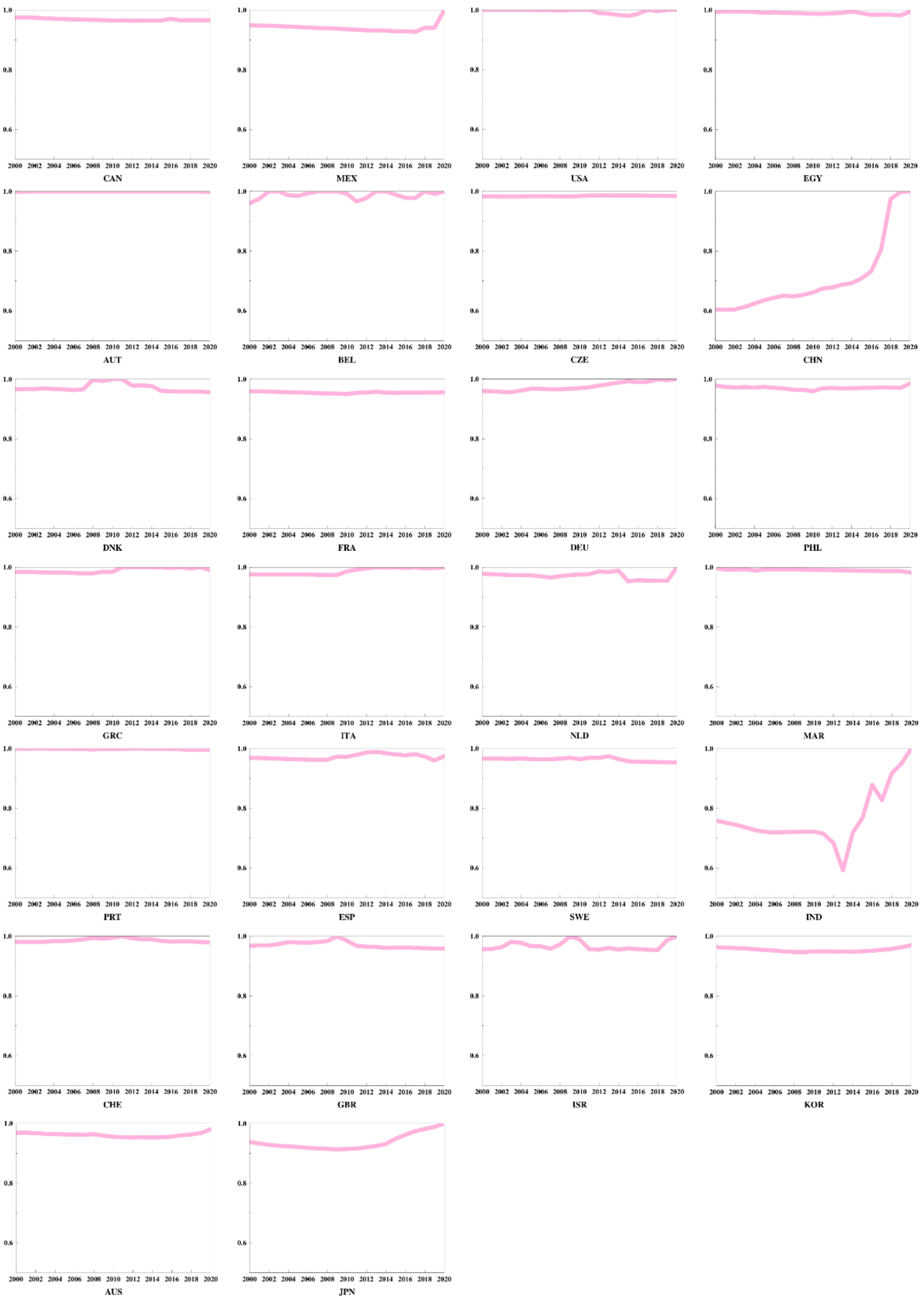

Fig. 3-4 The change graph of PVE in the third stage.

To more accurately analyze the PVE differences between the first and third stages and obtain a more intuitive sense of the changes in PVE scores after excluding external environmental variables, the results of the two stages are compared and analyzed in Section 3.4.4.

3.4.4 Comparison and analysis of the results of the first and third stages

Compared to the results of stage 1, **Tables 3-2** and **3-4** show that the average PVE score for stage 3 increased from 0.762 to 0.957, an increase of 25.5%. This indicates that external environmental variables did not contribute to the PVE in the 26 countries, resulting in underestimating the PVE in the first stage. **Fig. 3-3** and **Fig. 3-4** show that the overall PVE trend for the countries changed significantly. Meanwhile, the PVE scores for non-high-income countries have changed fundamentally, except for China and India.

Fig. 3-5 shows the difference in PVE between stage 1 and stage 3 for the 26 countries. The results for stage 3 were obtained after removing the effects of external environmental variables and statistical noise. We found that almost all countries had generally higher PVE scores in stage 3 than in stage 1. External environmental variables and statistical noise are noncontributing in terms of PVE scores, leading to an underestimation of PVE scores in stage 1, and the reasons for the underestimation are not entirely due to the low level of technology but are related to the relatively poor external environment. Compared with the scores in stage 1, Mexico, Morocco, Australia, Japan, and South Korea had a more considerable increase in PVE scores in stage 3, all exceeding 0.3. This indicates that the external environmental factors in these five countries had a significant negative impact on PVE. The external environment rationing is relatively lagging due to the neglect of external environment development in these countries while vigorously developing their productivity. Based on the results of multiple studies (Ahn et al., 2015; Azeroual et al., 2018; Cancino-Solórzano et al., 2010; Hua et al., 2016; Kousksou et al., 2015; Park et al., 2016; Pischke et al., 2019; Villicaña-Ortiz et al., 2015; Zhu et al., 2020), we found that the energy supply structure of these five countries is highly dependent on fossil fuels and the high dependence on fossil fuel combustion for power generation makes the carbon emissions of these countries relatively high. To achieve the goals of reducing the high dependence on fossil fuels for power generation and lowering carbon emissions, researchers in these five countries generally agree that developing the potential of the renewable energy power generation sector and achieving diversification of the renewable energy generation sector is one of the essential solutions to achieve this goal, including wind power, hydropower, solar PV power, and geothermal power. Among the countries observed during the study period, Mexico, Morocco, and South Korea have lower than average GDP per capita, Japan had higher than average carbon dioxide emissions, and Australia burned fossil fuels to generate 90% of Australia's total electricity (Department of Resources, Energy and Tourism, 2012). In the second stage, we found that PVE was positively correlated with GDP per capita and negatively correlated with carbon dioxide emissions. Thus, the external environment of these five countries was relatively poor overall, and the elimination of external environment variables resulted in a significant change in PVE scores in the third stage. The differences between Greece, Israel, Egypt, and India were relatively small and ranged from 0 to 0.05. The influence of the external environment in these four countries was relatively small.

However, Denmark's score in stage 3 (0.972) was smaller than in stage 1 (0.985), indicating that Denmark's external environment contributes to PVE. Denmark's economic development creates a good external environment. The solar PV power industry structure and renewable energy consumption structure are relatively reasonable. The technology level was relatively high, thus contributing to PVE.

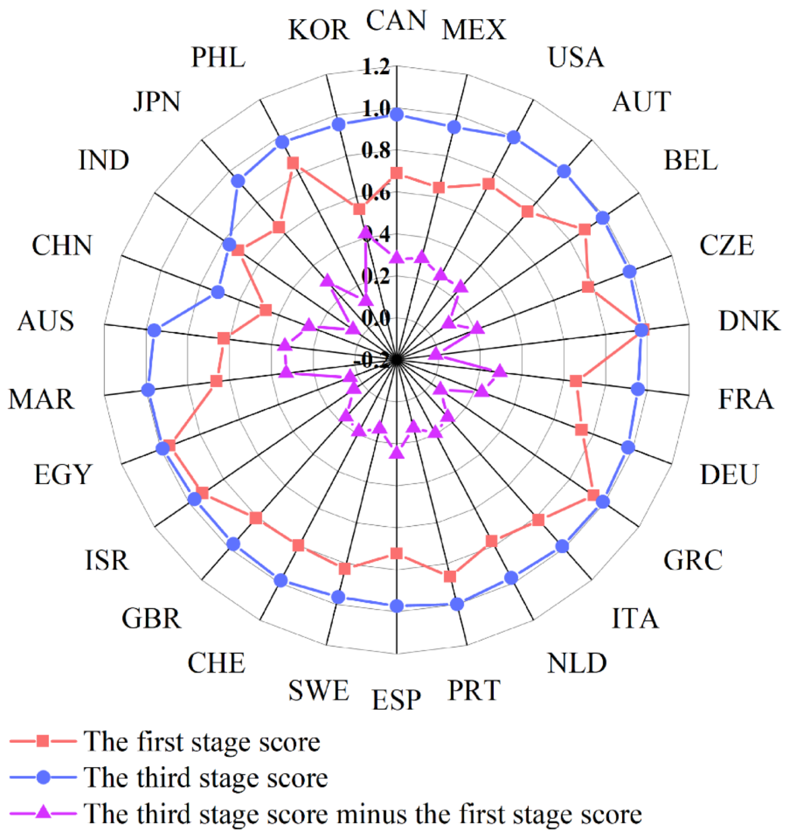

Fig. 3-5 PVE differences between the first and third stages.

Chapter 4 The relative importance of determinants of the solar photovoltaic industry in China: Analyses by the Diamond Model and the Analytic Hierarchy Process

4.1 Methods

The method used in this study is the diamond model (Porter, 1990) (Porter's diamond model theory (Michael Porter diamond model)) and the AHP. These tools are explained separately in the sections below.

4.1.1 The Diamond Model

There are many research methods for investigating solar photovoltaic industrial competitiveness. The diamond model is an effective method for analyzing the competitive advantage of the industry. According to the literature, several studies have used this model to analyze many factors of competitive industrial advantage (Kharub and Sharma, 2017; Stone and Ranchhod, 2006; Wu et al., 2017; Zhao et al., 2009).

The diamond model consists of six parts: factor condition; demand condition; related and support industries; firm strategy, structure, and rivalry; government; and chance. The six parts are introduced below.

(1) Factor condition: This refers to the status of the country in terms of production factors, such as labor, infrastructure, and natural resources (Porter, 1990). In essence, these resources are the cornerstone of value creation and production activities.

(2) Demand condition: This connotes the nature of the home market demand for the industry's product or service (Porter, 1990). Porter (1990) stated that when the domestic demand condition is relatively complex and there are overall expectations for high-quality goods and services, domestic companies are more likely to respond by increasing their production capacity.

(3) Related and support industries: This is the existence or absence of a supply industry in a country that can support the competitiveness of an industry in the global market (Esen and Uyar, 2012). New competitive industries will always be created in related and support industries, and opportunities for information and technology exchange will be provided. The relationship between these industrial clusters is critical to the success of a certain sector within a country (Bakan and Fatma Doğan, 2012).

(4) Firm strategy, structure, and rivalry: Porter believed that corporate strategy, industrial structure, and competition all have an impact on industrial competitiveness (Porter, 1990). The strategy, structure, and competition of enterprises have mastered the intensity of domestic competition. Whether a sector is extremely competitive at home will affect the increase in productivity required for international competition (Bakan and Fatma Doğan, 2012).

(5) Government: The government's position in competition has a great effect because it is directly responsible for improving the well-being of citizens and companies (Porter, 1998).

(6) Chance: Porter considered accidental events to be things that have nothing to do with the national situation (Porter, 1990). Opportunistic events are usually improvements beyond the company's control. Such incidents avoid the advantages of previously constituted competitors and create the potential for new national companies to replace them (Bakan and Fatma Doğan, 2012).

Based on the six aspects of the diamond model, we constructed an analysis framework for the competitiveness of China's solar photovoltaic industry. The specific analysis indicators are shown in **Table 4-1**. The range of the six parts of the diamond model in the photovoltaic industry is outlined in the table. In the Section 4.2, we further refine the impact factors of these six parts.

To clarify the relative importance of each aspect in the analysis framework, we conducted a questionnaire survey with experts in the Chinese solar photovoltaic industry (see Appendix C) and then used the AHP to analyze the relativity of each determinant to finally determine the priority.

Table 4-1 Theoretical framework of the diamond model to evaluate the competitiveness of China's photovoltaic industry.

Factors	Main Method Used in the Literature	Supporting Indicators	Source
Factor condition	The diamond model; a revised diamond model; the diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the Granger causality test; the diamond model and the gear model	Natural resources, scientists, infrastructure, labor cost	Dögl et al. (2012); Fang et al. (2018); Ji (2014); Sun (2017); Xiao (2016); Jiao (2013); Chen (2010); Zhao et al. (2011)
Demand condition	The diamond model; a revised diamond model; the diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the Granger causality test; the diamond model and the gear model	Market size, installed capacity	Dögl et al. (2012); Fang et al. (2018); Ji (2014); Xiao (2016); Jiao (2013); Chen (2010); Zhao et al. (2011)
Related and support industries	The diamond model; a revised diamond model; the diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the Granger causality test; the diamond model and the gear model	Photovoltaic manufacturing, grid construction, supporting firms	Dögl et al. (2012); Fang et al. (2018); Ji (2014); Xiao (2016); Jiao (2013); Chen (2010); Zhao et al. (2011)
Firm strategy, structure, and rivalry	The diamond model; a revised diamond model; the diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the gear model	Industry rules, industry competition, industry environment	Dögl et al. (2012); Fang et al. (2018); Ji (2014); Xiao (2016); Chen (2010); Zhao et al. (2011)
Government	A revised diamond model; the diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the gear model	Government support	Dögl et al. (2012); Fang et al. (2018); Ji (2014); Xiao (2016); Chen (2010); Zhao et al. (2011)

Chance	The diamond model and the revealed competitive comparative advantage index, trade specialization index analysis, and the international market share; the diamond model and the gear model	Industry challenges	Ji (2014); Xiao (2016); Zhao et al. (2011)

4.1.2 The Analytic Hierarchy Process (AHP)

The AHP is an important tool for decision making and determining a set of standards and sub-standards and other multi-standard problems. The AHP was developed by Saaty (1994). Sipahi and Timor (2010) emphasized the importance of the AHP, indicating its suitability for complex social problems that cannot separate intangible and tangible factors. The AHP has been applied in many fields, including studies related to renewable energy (Ghimire and Kim, 2018; Heo et al., 2010; Keeley and Matsumoto, 2018; Mastrocinque et al., 2020; Tsai et al., 2009). However, a small number of studies have used a combination of the diamond model and the AHP to test the relative importance of the determinants of the competitiveness of the solar photovoltaic industry.

First, the determinants or influencing factors determined in the diamond model were brought into the AHP to construct the category parameters in the hierarchical model. In this study, the relative importance of the determinants of the competitiveness of the photovoltaic industry in China was at the top of the hierarchy and broad categories and subcategories were placed below it. The experts then used the 1–9 scale proposed by Saaty (1994) to compare the factors with each other and their influence on the abovementioned six factors (factor condition; demand condition; related and support industries; firm strategy, structure, and rivalry; government; and chance) in the hierarchical structure. The 1–9 scale is explained in more detail in **Table 4-2**. This process systematically transforms pairwise judgments into pairwise matrices.

Table 4-2 Analytic hierarchy measurement scale adapted from (Saaty, 1994).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another, indicating its dominance.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order.
2, 4, 6, 8	For compromise between the above values	Sometimes, one needs to interpolate a compromise judgment numerically.

A factor was divided by the sum of the column formulas of the factors to obtain the normalized matrix, and then the eigenvector was calculated by averaging the factors in the row. The value of each factor represents the weight of importance. In this study, the average value of the experts' evaluation was expressed as the relative importance of each factor.

Next, the consistency of each pairwise comparison matrix was checked to prove that the experts' evaluations are correct, using the common measures of consistency index (*CI*) and consistency ratio (*CR*) (Keeley and Matsumoto, 2018; Luthra et al., 2015; Mastrocinque et al., 2020; Tsai et al., 2009).

CI was calculated according to Eq. (4-1) (Saaty, 1994):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4-1}$$

where n is the number of evaluation factors and λ_{max} is the maximum eigenvalue of the matrix.

CR is defined as follows:

$$CR = \frac{CI}{RI} \tag{4-2}$$

where *RI* is the average value of *CI* obtained from 500 pairs of positive-equivalent comparison matrices, which are randomly generated using a 1–9 scale (Saaty, 1994).

RI values of different matrix orders are shown in **Table 4-3**.

Table 4-3 *RI* values for different *n* (Saaty, 1994).

n	RI
1–2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32

If the *CR* is 0, then the respondents' answers are completely consistent; if the *CR* equals 1, then the answers are completely inconsistent. In general, based on Saaty's suggestion, answers within the range of 0.1–0.15 were acceptable (Saaty, 1994). Based on the steps proposed by Goepel (2013), we combined all the pairwise comparisons that met a *CR* criterion into a decision matrix C_{ij} by using the eigenvector method and the decision matrix C_{ij} combining *m* participants' inputs to obtain the group result (Goepel, 2013). The weighted geometric mean of the decision matrix factors and the pairwise $M \times M$ comparison matrix *A* were used with each expert's weight. The calculation steps are as shown below.

$$C_{ij} = exp\frac{\sum_{k=1}^{m} \omega_k \, ln\, A}{\sum_{k=1}^{m} \omega_k} \tag{4-3}$$

where *k* is participants, ω_k is each expert's weight, and $A = a_{ij(k)}$.

Through Eq. (4-3), we can calculate the relative importance of each factor, which can be compared with one another.

Then, we can calculate the experts' consensus rate by using the Shannon alpha, beta, and gamma entropy (Goepel, 2013). The consensus rate indicator ranges from 0 (no consensus among experts) to 1 (complete consensus among experts).

The consensus rate S is calculated by Eq. (4-4):

(4-4)

$$S = (1/D_{\beta} - D_{\alpha min}/D_{\gamma max})/(1 - D_{\alpha min}/D_{\gamma max})$$

where D_{α} is the average individual decision maker's priority distribution among criteria. D_{β} is a measure of variations of priority distributions among decision makers within the group. D_{γ} is the gamma diversity of order 1 (Goepel, 2013).

The true diversity of order 1 D is given by

(4-5)

$$D = \exp(H)$$

where the Shannon entropy H (Goepel, 2013) can be written as

(4-6)

$$H = -\sum_{i=1}^{m} \rho_i \ln \rho_i$$

where ρ_i is the priorities for criteria i = 1 to m.

The Shannon beta entropy H_{β} can be calculated as follows:

(4-7)

$$H_\beta = H_\gamma - H_\alpha$$

where H_γ is the Shannon gamma entropy and H_α is the Shannon alpha entropy for the priorities of k respondents.

The consensus rate can be calculated for each category and subcategory by these equations.

We used the AHP Excel template (2018) to calculate the relative importance of each factor and the consensus rate between the respondents (experts).

In this study, questionnaires were sent to experts in decision-making positions of Chinese companies in the solar photovoltaic industry. These companies are mainly located in Southwest China, Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Northwest China. The questionnaires were distributed to 24 experts from May 12 to June 30, 2021. The authors directly contacted these experts by telephone, and 24 questionnaires were returned (100% response rate). In each questionnaire, the experts were also asked for their opinions and suggestions on improving China's photovoltaic industry, some of which are shared in Section 4.4.3. Based on the results of the 24 questionnaires, their *CR* values were calculated separately. Of these 24 experts, four were not qualified because their *CR* values were greater than 0.15 (**Table 4-4**).

Table 4-4 Consistency ratio of each category for each respondent.

Respondent	Categories	Factor Condition	Demand Condition	Firm Strategy, Structure, and Rivalry	Related and Support Industries	Government	Chance
No. 1	0.13	0.11	0.10	0.01	0.06	0.09	0.00
No. 2	0.10	0.14	0.07	0.02	0.08	0.07	0.00
No. 3	0.14	0.11	0.11	0.08	0.09	0.04	0.00
No. 4	0.14	0.14	0.08	0.06	0.01	0.12	0.00
No. 5	0.14	0.12	0.10	0.08	0.06	0.12	0.00
No. 6	0.14	0.14	0.04	0.09	0.02	0.09	0.00
No. 7	0.13	0.13	0.09	0.06	0.01	0.12	0.00
No. 8	0.11	0.14	0.10	0.02	0.04	0.08	0.00
No. 9	0.07	0.13	0.07	0.06	0.06	0.13	0.00
No. 10	0.13	0.11	0.03	0.02	0.06	0.14	0.00
No. 11	0.14	0.12	0.06	0.14	0.06	0.11	0.00
No. 12	0.10	0.14	0.03	0.06	0.02	0.11	0.00

No. 13	0.13	0.14	0.12	0.10	0.06	0.11	0.00
No. 14	0.13	0.13	0.07	0.08	0.06	0.09	0.00
No. 15	0.13	0.13	0.07	0.01	0.08	0.12	0.00
No. 16	0.11	0.14	0.12	0.06	0.04	0.11	0.00
No. 17	0.08	0.10	0.07	0.06	0.01	0.04	0.00
No. 18	0.13	0.13	0.09	0.06	0.02	0.07	0.00
No. 19	0.14	0.13	0.05	0.06	0.10	0.05	0.00
No. 20	0.13	0.14	0.08	0.02	0.06	0.10	0.00
No. 21	0.16	0.21	0.32	0.14	0.06	0.14	0.00
No. 22	0.22	0.22	0.01	0.00	0.09	0.09	0.00
No. 23	0.17	0.23	0.01	0.00	0.08	0.08	0.00
No. 24	0.16	0.33	0.17	0.14	0.06	0.13	0.00

4.2 Identifying the subcategories (determinants) based on the six elements of the Diamond Model

4.2.1 Overview

Many factors affect China's photovoltaic industry. These include subsidies for solar technology research and development, incentive policies for purchasing photovoltaic systems, photovoltaic industry policies, photovoltaic enterprise strategies, and operations. We conducted a detailed literature review of the determinants of the solar photovoltaic industry's competitiveness in China.

Based on the theoretical framework (**Table 4-1**) and the literature review, 22 subcategories (determinants) were identified (**Table 4-5**). The following table briefly introduces the definitions of the determinants in each category used in the AHP in this study.

Table 4-5 Summary of the classification of determinants.

Category	Subcategories (Determinants)
Factor condition	F1 natural resources
	F2 mineral resources reserves
	F3 labor cost
	F4 scientific research and technology
	F5 acquiring land
Demand condition	F6 energy supply gap (environmental pressure)
	F7 newly installed capacity for solar photovoltaic power generation (market scale)
	F8 photovoltaic power consumption capacity (local acceptance)
	F9 export volume of photovoltaic products (foreign demand status)
Firm strategy, structure, and rivalry	F10 reasonable and effective development plans for photovoltaic power generation enterprises (a reasonably structured renewable energy development plan)
	F11 interest rate risk
	F12 grid-connected photovoltaic system (external environmental conditions)
Related and support industries	F13 photovoltaic equipment manufacturing
	F14 photovoltaic power station
	F15 tax incentives
Government	F16 policies issued by local governments (policy regulations, local government strategies)
	F17 tax reduction and exemption (exemption of customs duties and import value-added tax)
	F18 financial subsidy intensity
	F19 China’s central government photovoltaic power generation target
	F20 feed-in tariff
Chance	F21 opportunities brought by the 531 Photovoltaic New Deal

	F22 prospects of the photovoltaic industry (low-carbon economy, clean energy)

4.2.2 Factor condition

The factor condition includes natural resources, mineral resource reserves, labor costs, scientific research and technology, and acquiring land.

Natural resources (F1): This refers to the amount of natural resources present in the area. In this study, the term refers to the duration and period of solar radiation (Global Horizontal Irradiation-China, 2019; Liu and Pan, 2012).

Mineral resource reserves (F2): This refers to the resource potential of silicon, which is one of the most important raw materials for the photovoltaic industry (Chen et al., 2016).

Labor cost (F3): This refers to the labor cost of installing, operating, and maintaining solar photovoltaic power generation (Lam et al., 2018).

Scientific research and technology (F4): Scientific research and technology are one of the key factors in the development of photovoltaic power generation projects (Lam et al., 2018; Shubbak, 2019).

Acquiring land (F5): Acquiring land indicates how easy it is to obtain the land required for the development of solar photovoltaic projects (Ji et al., 2019; Zhang, 2018).

4.2.3 Demand condition

The demand condition includes the energy supply gap, the newly installed capacity for solar photovoltaic power generation, the photovoltaic power consumption capacity, and the export volume of photovoltaic products.

Energy supply gap (F6): Conventional power cannot meet the growing power demand. This demand stimulates the rapid development of photovoltaic power generation (Huang et al., 2007; Sheng et al., 2014; Wang et al., 2011).

Newly installed capacity for solar photovoltaic power generation (F7): This is one of the important indicators of the capacity scale in this field (National Energy Board, 2019; China Power News Network, 2018).

Photovoltaic power consumption capacity (F8): This capacity is identified as the local acceptance level of solar photovoltaic power generation projects (Heras-Saizarbitoria et al., 2011; Yuan et al., 2011).

Export volume of photovoltaic products (F9): This reflects the demand situation of related foreign industries, which indirectly stimulates the development of the local photovoltaic industry (Zhu et al., 2021).

4.2.4 Firm strategy, structure, and rivalry

The determinants of firm strategy, structure, and rivalry include reasonable and effective development plans for photovoltaic power generation enterprises, interest rate risk, and grid-connected photovoltaic systems.

Reasonable and effective development plans for photovoltaic power generation enterprises (F10): An enterprise should have a reasonable and effective renewable energy development plan and encourages consistent and stable strategic investment in photovoltaic power generation projects. The more effective the photovoltaic power generation enterprise's strategy, the more dynamic and competitive the industry will be. The strategy, management, and planning of photovoltaic companies play an irreplaceable role in analyzing the competitiveness of the industry (Sun et al., 2016; Zhang et al., 2017).

Interest rate risk (F11): This refers to the loss caused by future interest rate changes in the photovoltaic industry. The interest rate is the price of funds. It refers to the adjustment lever of the money market capital supply and demand relationship. In China, the interest rate is often subject to the management behavior of the central bank (He et al., 2015).

Grid-connected photovoltaic system (F12): A grid-connected photovoltaic system is a trend in the development of the global photovoltaic industry. Combining grid planning with power plant planning and formulating relevant technical standards are more conducive to the promotion and implementation of the photovoltaic industry (Zhang, Xie et al., 2021; Zou et al., 2012).

4.2.5 Related and support industries

The decisive factors for related and support industries include photovoltaic equipment manufacturing, photovoltaic power stations, and tax incentives.

Photovoltaic equipment manufacturing (F13): This refers to the manufacturing industry provided by the photovoltaic industry and related electronic industries that benefit from the photovoltaic industry. These related and support industries will have an impact on the photovoltaic industry (Goodrich et al., 2013).

Photovoltaic power station (F14): Micro-grids, grid energy storage, and smart grids must be developed to ensure the safety, stability, and reliability of photovoltaic power stations (Li, 2015).

Tax incentives (F15): The renewable energy industry policy adopted by the Chinese government provides tax incentives for photovoltaic power generation projects, including tax exemptions and tax reductions (Beyer, 2006). Renewable-energy-related enterprises enjoy tax incentives in terms of equipment depreciation.

4.2.6 Government

The decisive factors of government include policies issued by local governments, tax reduction and exemption, financial subsidy intensity, China's central government photovoltaic power generation target, and feed-in tariff (Bayaliyev et al., 2011; Corwin and Johnson, 2019).

Policies issued by local governments (F16): The photovoltaic industry also relies on local government policies that affect demand prospects. These policies have a clear banner color and accelerate the commercialization of the photovoltaic industry to a certain extent, such as via bidding policies and the renewable portfolio standard (Zhang and He, 2013c).

Tax reduction and exemption (F17): The three major taxes affecting China's photovoltaic industry are value-added tax, customs duties, and corporate income tax. Among them, value-added tax and customs duties are exempted within the prescribed scope and corporate income tax rates vary according to region.

Financial subsidy intensity (F18): The financial department arranges subsidies for special funds for renewable energy, including subsidies for grid power generation projects, independent power generation projects, photovoltaic technology industrialization demonstration projects, and photovoltaic power generation infrastructure construction.

China's central government photovoltaic power generation target (F19): This target can formulate long-term or short-term plans according to the needs and feasibility of different regions in China to provide government commitment indicators for consumers and producers in the photovoltaic industry (Shubbak, 2019).

Feed-in tariff (F20): This policy can provide a fixed long-term price guarantee for local photovoltaic power generation companies (Zhang and He, 2013c).

4.2.7 Chance

The determinants of chance include opportunities brought by the 531 Photovoltaic New Deal and the prospects of the photovoltaic industry.

Opportunities brought by the 531 Photovoltaic New Deal (F21): This deal brings new opportunities to the photovoltaic industry. The photovoltaic industry can be market oriented, and the degree of dependence on government policies is reduced. It also brings heavy losses to some enterprises.

Prospects of the photovoltaic industry (F22): Photovoltaic power generation shows promise in reducing environmental pressure, which is mainly reflected in the environmental capacity of the region and the environmental and social impacts related to the production and consumption of photovoltaic power generation.

4.3 Results

4.3.1 Hierarchical structure

To conduct an AHP, the hierarchical structure was created with the categories and subcategories that were clarified through the literature review (see Section 4.2). The goal of the analysis is at the top of the hierarchy: "Assessing the relative importance of the determinants of the photovoltaic industry." The categories (factor condition; demand condition; firm strategy, structure, and rivalry; related and support industries; government; and chance) come below, and the subcategories or determinants come under the categories. The hierarchical structure is shown in **Fig. 4-1**.

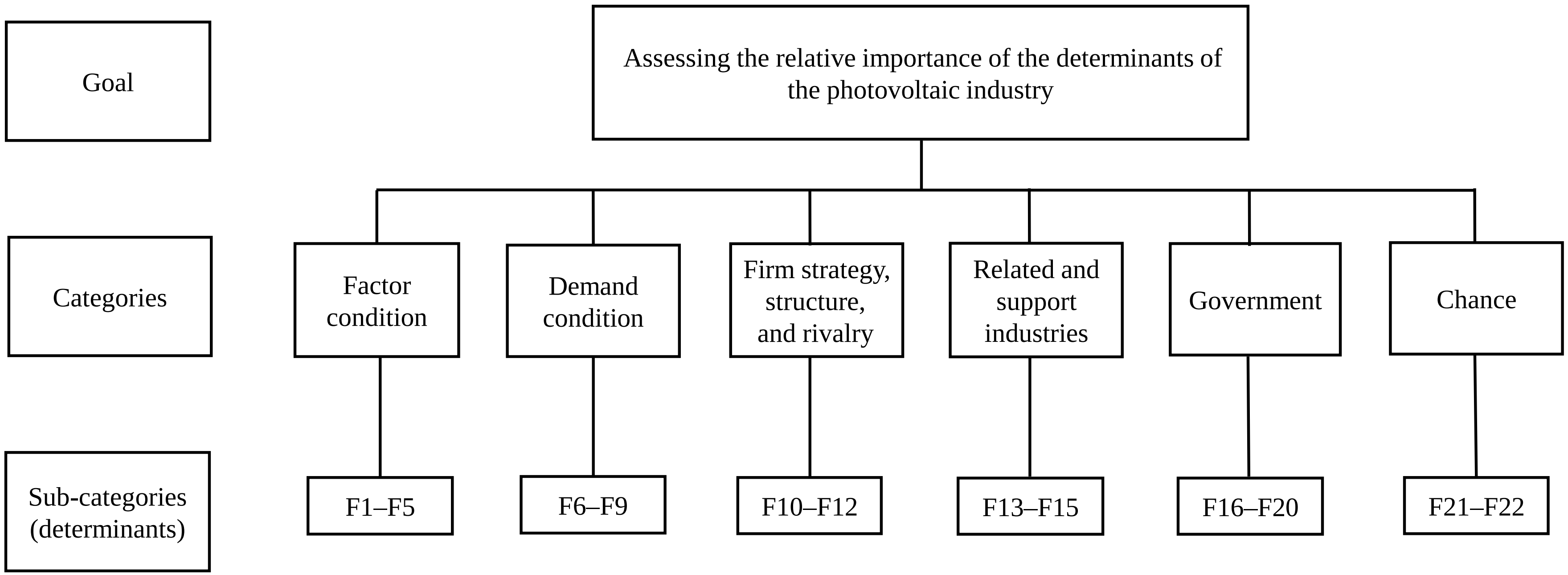

Fig. 4-1 Hierarchical structure. See **Table 4-5** for the definitions of F1–F22.

The respondents initially evaluated the relative importance of the six categories and then the importance of the determinants under each category. The authors calculated the relative importance of each category and determinant based on the respondents' evaluation results.

4.3.2 Relative importance of the six categories

Comparing the six factors (categories), the factor condition was the most important determinant (51.9%; **Fig. 4-2**). Demand condition and firm strategy, structure, and rivalry were 23.6% and 8.9% important, respectively. Government and chance were 4.5% and 7.2% important, respectively, and related and support industries were rated as the least important determinants (3.9%). The consensus rate was 99.0%, indicating a high level of consensus among the respondents.

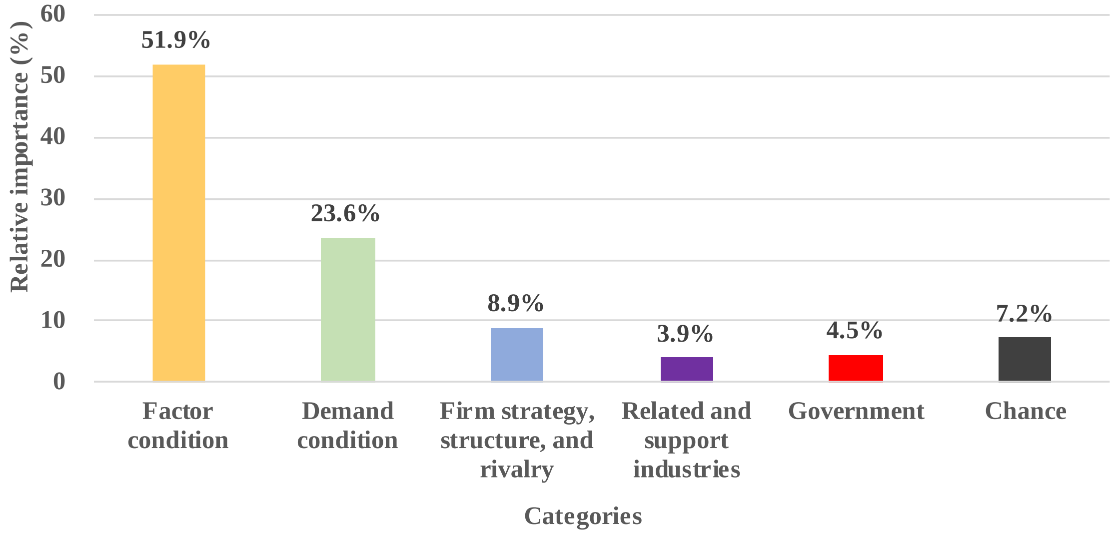

Fig. 4-2 Relative importance of the six categories.

4.3.3 Relative importance of factor condition determinants

The relative importance of factor condition determinants is shown in **Fig. 4-3**. Natural resources were considered the most important determinant (52.5%) of the competitiveness of China's photovoltaic industry. The development of the photovoltaic industry requires solar radiation, and regions with relatively abundant solar radiation resources have priority in the development of the photovoltaic industry. Mineral resources, labor costs, scientific research and technology, and acquiring land were 24.5%, 11.6%, 4.6%, and 6.7% important, respectively. The consensus rate was 99.0%.

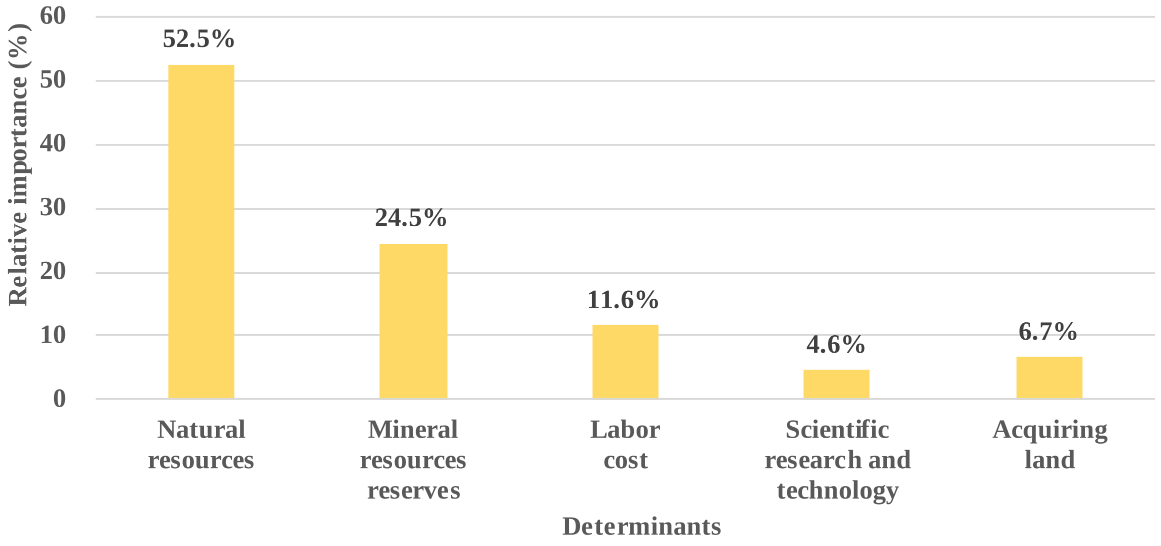

Fig. 4-3 Relative importance of factor condition determinants.

4.3.4 Relative importance of demand condition determinants

The relative importance of the demand condition determinants is shown in **Fig. 4-4**. Respondents believed that the energy supply gap was the most important determinant under the demand condition, with a weight of 59.7%. This is mainly because the traditional energy supply industry cannot meet the growing economic demand, which stimulates and accelerates the development of the photovoltaic industry to a certain extent. The weights of the newly installed capacity for solar photovoltaic power generation, photovoltaic power consumption capacity, and export volume of photovoltaic products were 17.1%, 8.6%, and 14.6%, respectively. The consensus rate was 94.1%.

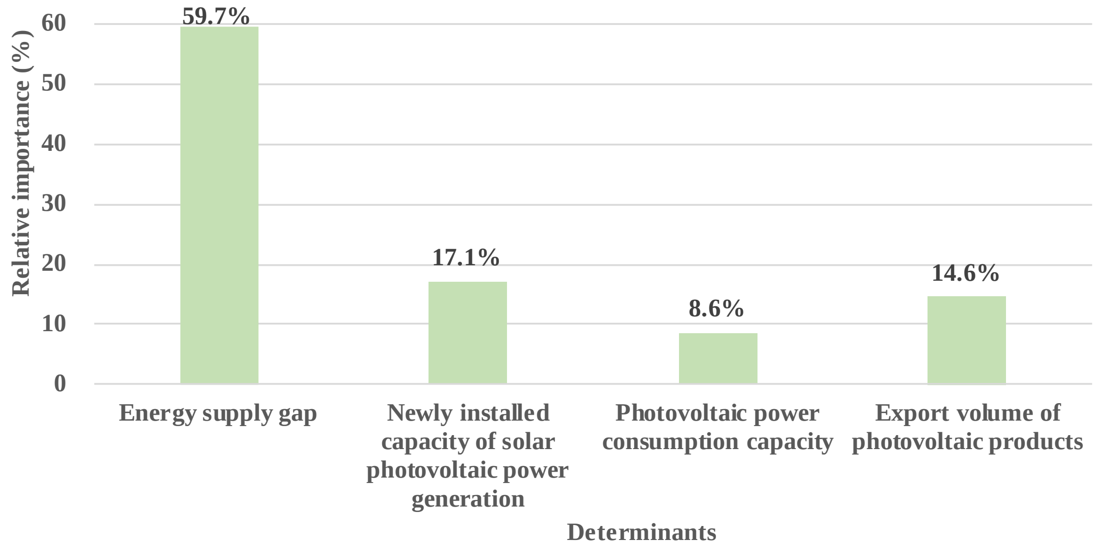

Fig. 4-4 Relative importance of demand condition determinants.

4.3.5 Relative importance of firm strategy, structure, and rivalry determinants

Fig. 4-5 shows the relative importance of firm strategy, structure, and rivalry. Interest rate risk and grid-connected photovoltaic systems were relatively important, at 59.5% and 25.9%, respectively. The weight of reasonable and effective development plans for photovoltaic power generation enterprises was 14.7%. The consensus rate was 94.4%. Respondents generally believed that interest rate risk is the main determinant. The interest rate level of foreign markets and changes in monetary policy will indirectly affect the price of domestic currency and cause losses to the photovoltaic industry.

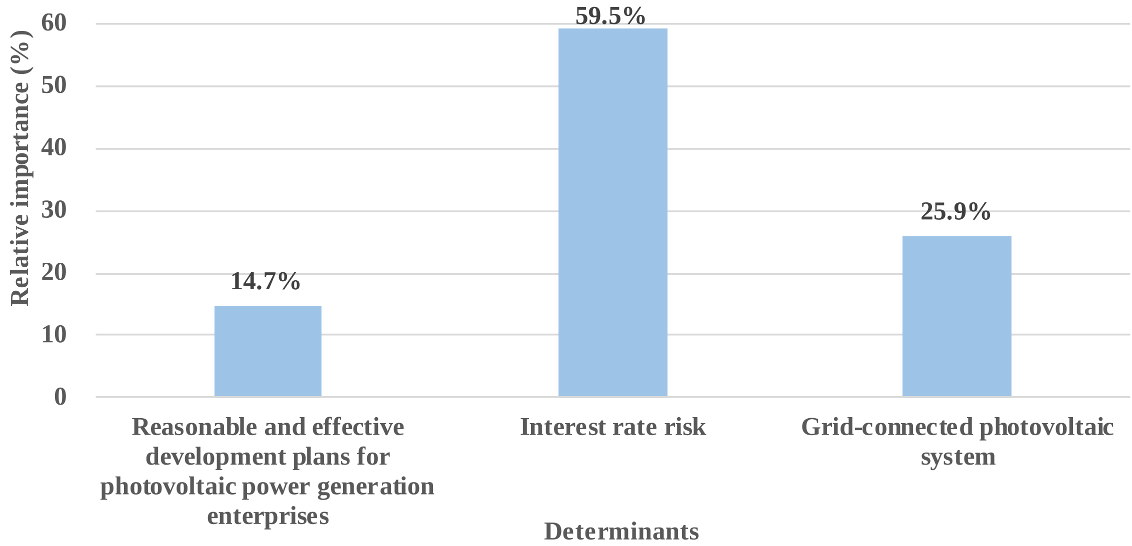

Fig. 4-5 Relative importance of the firm strategy, structure, and rivalry determinants.

4.3.6 Relative importance of related and support industries determinants

The results of the relative importance of the related and support industries determinants (**Fig. 4-6**) show that photovoltaic power stations and tax incentives were very important, at 58.8% and 27.8%, respectively. Experts believed that the role of photovoltaic equipment manufacturing is not so important (13.4%). The consensus rate was 95.7%.

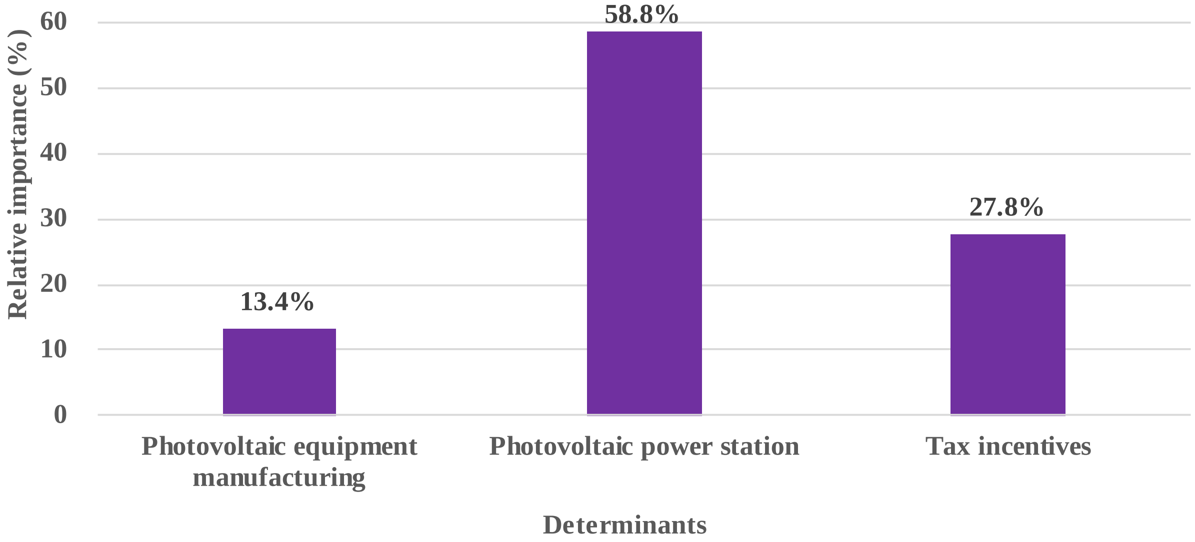

Fig. 4-6 Relative importance of the related and support industries determinants.

4.3.7 Relative importance of government determinants

Fig. 4-7 shows the results of government determinants. In China's photovoltaic industry, policies issued by local governments were rated as the most important factor (57.2%). Tax reduction and exemption was 19.8% important. Financial subsidy intensity, China's central government photovoltaic power generation target, and feed-in tariff account were less important, at 6.5%, 6.3%, and 10.1%, respectively. The consensus rate was 98.9%.

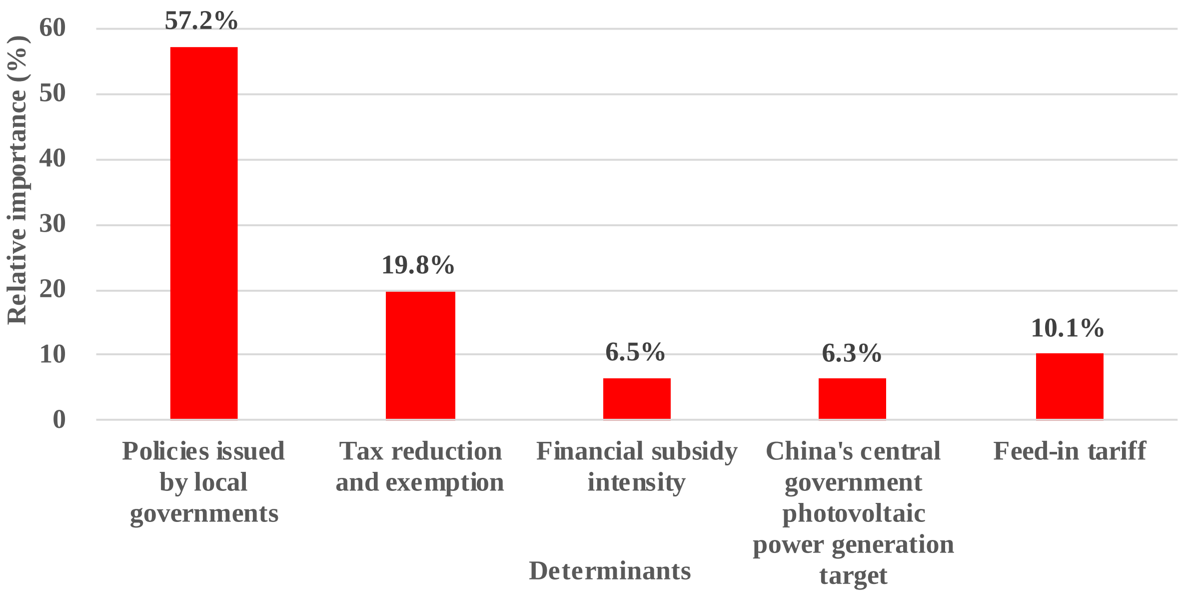

Fig. 4-7 Relative importance of government determinants.

4.3.8 Relative importance of chance determinants

Fig. 4-8 shows the results of chance's determinants. Experts generally believed that the prospects of the photovoltaic industry are very important, with a weight of 86.0%. However, opportunities brought by the 531 Photovoltaic New Deal had a relatively small impact on the industry, with a weight of 14.0%. The consensus rate was 98.5%.

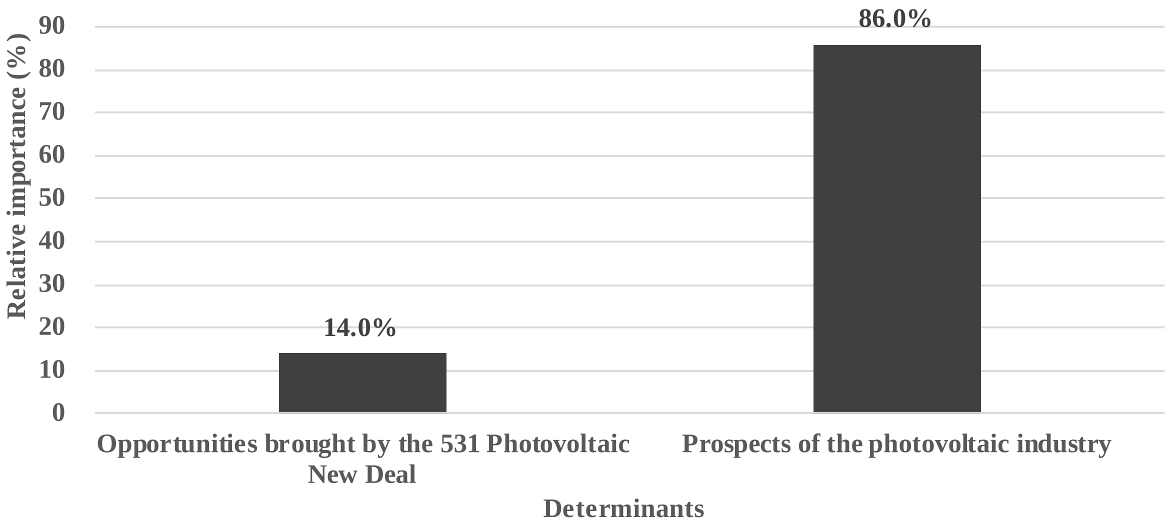

Fig. 4-8 Relative importance of the chance determinants.

4.3.9 Relative importance of all determinants

We multiplied the weight of each subcategory μ_{sub} by the weight of the category μ_c to which the subcategory belongs to calculate the relative importance of each subcategory I_{sub} by Eq. (4-8):

$$I_{sub} = \mu_{sub} \times \mu_c \tag{4-8}$$

For example, the weight of natural resources (52.5%) is multiplied by the weight of the factor condition (51.9%), which makes the relative importance of natural resources in all determinants 27.25%.

Fig. 4-9 shows the final results of all subcategories. Natural resources had the highest weight among all determinants (27.25%), followed by the energy supply gap (14.03%), mineral resources reserves (12.72%), prospects of the photovoltaic industry (6.19%), labor cost (6.02%), interest rate risk (5.36%), newly installed capacity for solar photovoltaic power generation (4.02%), acquiring land (3.48%), and export volume of photovoltaic products (3.43%). This result highlights the determinants important for improving the development of China's photovoltaic industry and the priorities among them.

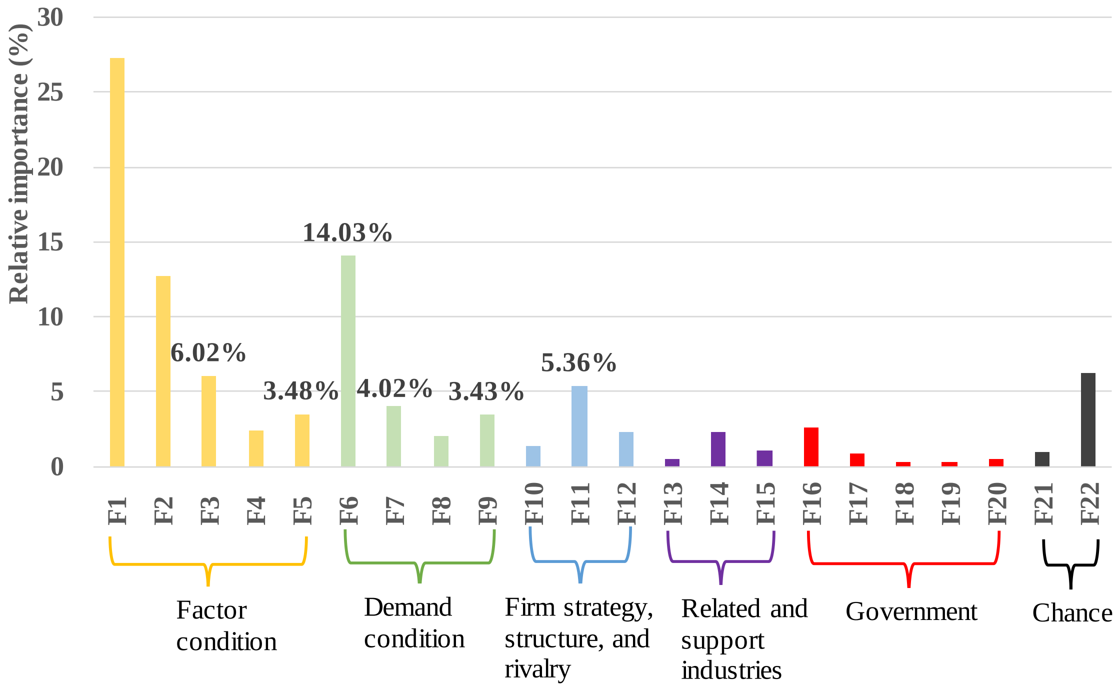

Fig. 4-9 Relative importance of all determinants (see **Table 4-5** for the definitions of F1–F22).

4.4 Discussion

This section presents a detailed discussion of the key determinants of the competitiveness of China's photovoltaic industry. Although natural resources, mineral resources reserves, and prospects of the photovoltaic industry are important factors, they are not discussed here. Regions with good resource endowments have relatively greater potential for development. Natural resources and mineral resources reserves are necessary conditions for the development of the photovoltaic industry; their importance is unquestionable; so it will not be discussed. This questionnaire survey was conducted only among experts in the photovoltaic industry. Considering the singularity of the questionnaire field and the commonality among experts in the same industry, the relative importance of prospects of the photovoltaic industry cannot represent the entire prospects of the photovoltaic power generation industry in China; it only represents the views of experts in the photovoltaic industry on its prospects. Therefore, the importance of prospects of the photovoltaic industry is not the subject of discussion here. The discussion below is conducted in the following order: energy supply gap (14.03%); interest rate risk (5.36%); labor cost (6.02%); acquiring land (3.48%); newly installed capacity for solar photovoltaic power generation (4.02%); and the export volume of photovoltaic products (3.43%).

4.4.1 Energy supply gap and the development of China's photovoltaic industry

According to the China Electric Power Yearbook (2018), solar energy generation has increased significantly more than other types of energy generation (**Fig. 4-10**), of which the largest increase, in 2017, was 75.29%. The growth rate of thermal power generation was negative (−1.68%) in 2015. Although the growth rate of thermal power generation was positive in 2016 and 2017, it was relatively small. This indicates that the Chinese government vigorously developed wind and solar power generation, among which the development of solar power generation was the most significant.

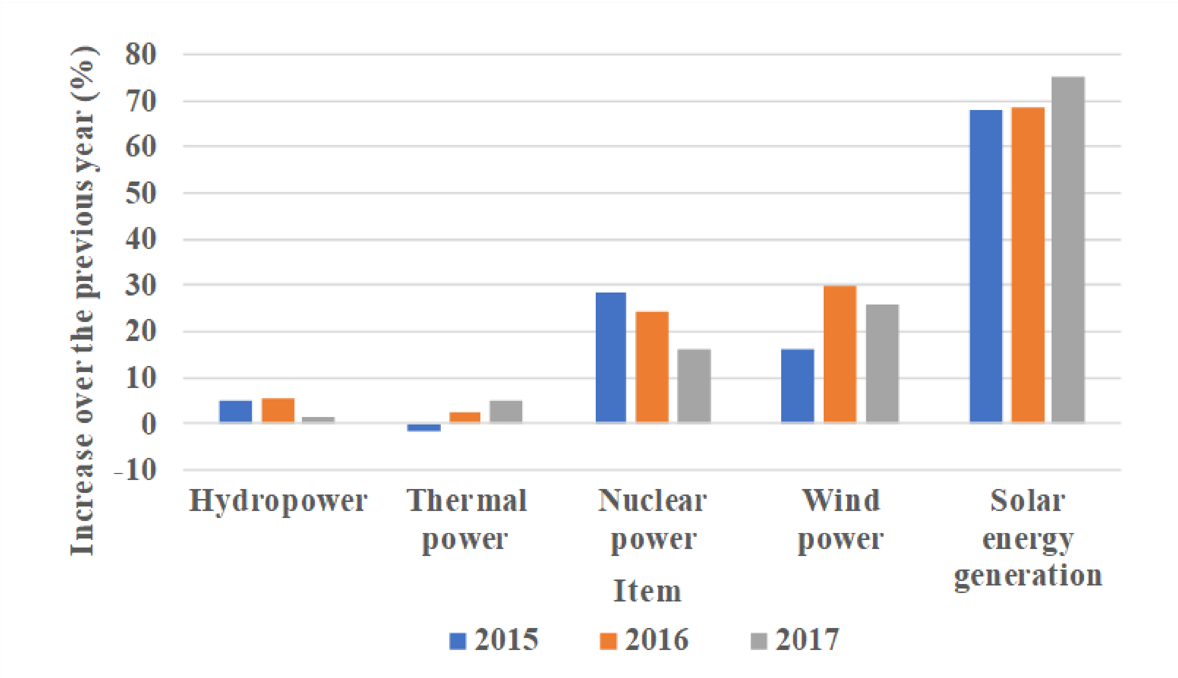

Fig. 4-10 Power generation growth rate in China data from (China Electric Power Yearbook, 2018).

4.4.2 Interest rate risk and the development of China's photovoltaic industry

Interest rate risk will have an impact on the future photovoltaic industry. In China, interest rates play a role in regulating the supply and demand of money in the money market (He et al., 2015; Jia, 2004). Considering that the photovoltaic industry requires long-term investment and returns, decision makers in this industry will be discouraged in regions with relatively high interest rate risk for financial institutions (Lardy and Guo, 2013). Interest rate risk will not only affect the future returns of photovoltaic projects but also increase the initial financing costs. From a macroeconomic perspective, to accelerate the development of China's photovoltaic industry, it is necessary to maintain a stable currency environment.

4.4.3 Labor cost and acquiring land

The level of labor cost is an important determinant of the competitiveness of China's photovoltaic industry (**Fig. 4-9**). According to the China Industrial Statistics Yearbook (2020), the average number of workers required for photovoltaic equipment and component manufacturing and solar power generation was 31.7 million in 2017 and 28.79 million in 2020. The total investment income of photovoltaic equipment and component manufacturing and solar power generation was 1.15 billion yuan in 2017 and 2.624 billion yuan in 2020. The ratio of the average number of workers to the total investment income was approximately 3 million people/billion yuan in 2017 and 1 million people/billion yuan in 2020. Hence, the decrease in the total average number of workers was accompanied by an increase in total investment income. In other words, a reduction in labor costs will help increase the investment income of the photovoltaic industry. According to the opinions of the 20 experts in the questionnaire, the ways of reducing labor costs can be roughly divided into three categories: technological innovation, power grid transformation, and improvement of equipment manufacturing capacity. Other measures may also be used to reduce labor costs in the photovoltaic industry.

Although the relative importance of acquiring land was quite low, at only 3.48%, acquiring land is a slow and unclear process in China (Xing, 2020). This mainly refers to unclear land ownership and restrictions on land purchase. Therefore, to develop China’s photovoltaic industry, national, provincial, and local authorities need to coordinate with each other and set up a special department to establish a fast track for purchasing land for use in the photovoltaic industry. This will not only attract potential investors but also provide a basic guarantee for the development of the photovoltaic field.

4.4.4 Newly installed capacity for solar photovoltaic power generation

Solar power generation includes photovoltaic, photochemical, light induction, and photobiological power generation methods. Thus, photovoltaic power generation is only one of them. According to the latest data released by the China Electric Power Yearbook (2018) and the Qianzhan Industry Research Institute (2018), the newly installed capacity for photovoltaic power generation in 2017 was 53.06 GW and the newly installed capacity for solar power generation was 53.41 GW in 2017. In the newly installed capacity for solar power generation, photovoltaic power generation accounted for 99%, which indicates that 99% of the newly installed capacity for solar power generation in 2017 came from photovoltaic power generation. Thus, the newly installed capacity for photovoltaic power generation in 2017 can be considered equal to the newly installed capacity for solar power generation. The value of the newly installed capacity for solar power generation by region in 2017, provided by the China Electric Power Yearbook (2018), was used to calculate the proportion of newly installed capacity for solar power generation in each province (equal to the proportion of newly installed capacity for photovoltaic power generation) in **Fig. 4-11**. **Fig. 4-11** indicates that the proportion is lower in the west and higher in the east. The pink area represents more than 5% of the proportion of newly installed capacity for photovoltaic power generation, and these are mainly concentrated in these areas. Electricity consumption in these areas has increased rapidly over the years, and the demand for energy is relatively high (Cheong et al., 2019). Traditional energy supplies cannot meet the increasing energy demand. Therefore, leaders of the photovoltaic industry and photovoltaic policymakers should prioritize the development of the photovoltaic industry in the central and coastal areas. This will not only solve the problems caused by insufficient local traditional energy supply but also improve the exports of photovoltaic products and increase local economic sources.

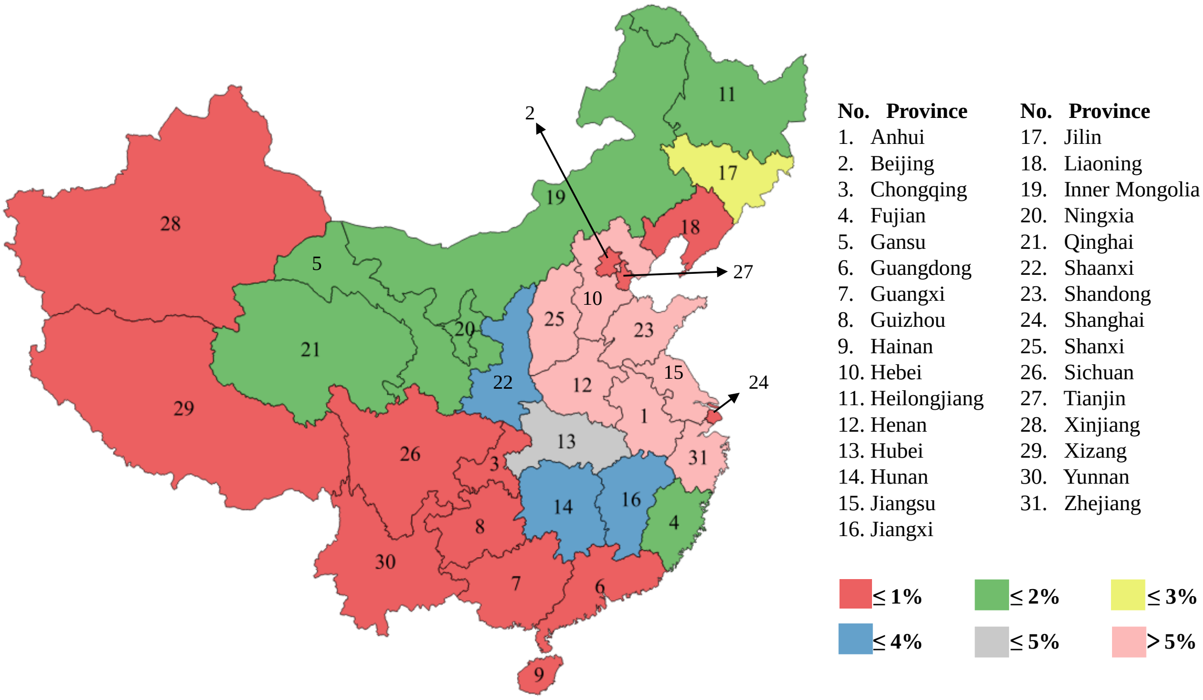

Fig. 4-11 Proportion of newly installed capacity for photovoltaic power generation by region in mainland China in 2017.

4.4.5 Export volume of photovoltaic products

According to the latest statistics from the China Photovoltaic Industry Association (2020) and Jiang et al. (2020), in 2019, China's photovoltaic product exports were USD 20.78 billion. The newly installed capacity of overseas photovoltaics was 85 GW, an annual increase of 37.7%. This shows that the demand for photovoltaic products in overseas markets has increased. As shown in **Fig. 4-12**, the export volumes of silicon wafers, solar cells, and photovoltaic modules were 27.3 GW, 10.4 GW, and 66.6 GW and the export values were USD 2 billion, USD 1.47 billion, and USD 17.31 billion, respectively. The China Photovoltaic Industry Association (2020) and the Qianzhan Industry Research Institute (2018) have identified the main reasons for the increase in the export volume of photovoltaic products. As the capital, technology, cost, and other aspects continue to increase, some overseas photovoltaic companies are slowly withdrawing from the market under the dual pressures of cost increase and profit reduction. This has led to a further concentration of foreign photovoltaic markets in the Chinese market. The photovoltaic markets of many countries, such as the Netherlands, Vietnam, Japan, India, and Australia, choose to import silicon wafers, solar cells, and photovoltaic modules directly from China.

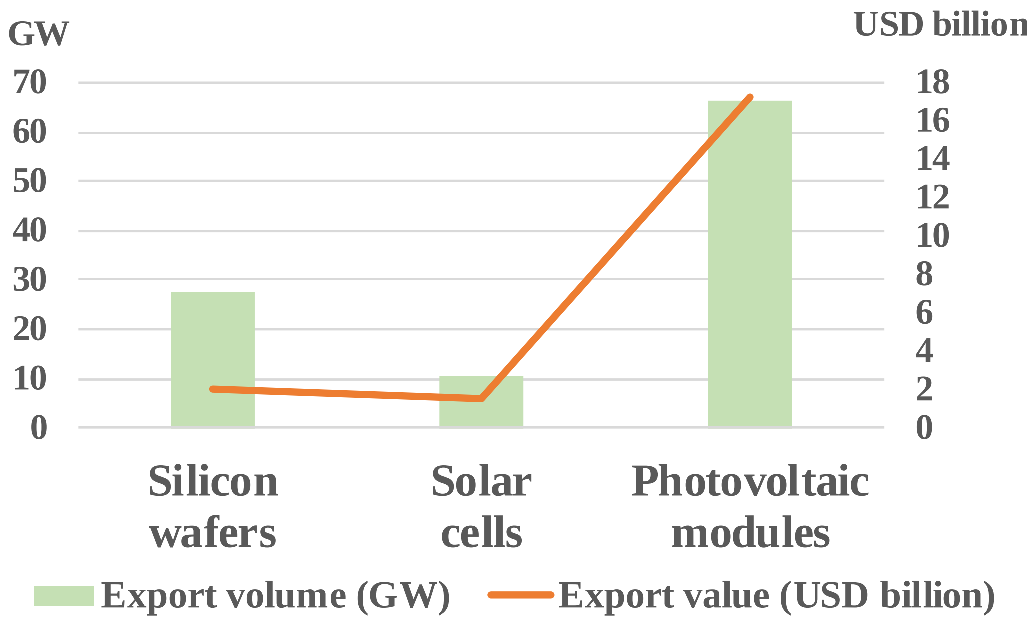

Fig. 4-12 Export volume (GW) and export value (USD billion) of China's main photovoltaic products in 2019 data from (China Photovoltaic Industry Association, 2020).

Chapter 5 Discussion

The contents of this chapter summarize the successful experiences of the PV industry in the USA, Germany, and Japan regarding power efficiency, from which policy insights can be obtained to improve the competitiveness of PV industries in other countries.

5.1 Summary and characteristics of PV industry power policies in the USA, Germany, and Japan

According to the results of the PVE score in stage 3, for both the mean and median of the evaluated period, the USA was ranked in first position among the subjects of this evaluation, coupled with the fact that the USA is one of the birthplaces of PV technology and PV industry in the world. Therefore, the USA was selected as a representative of PV industry power from which experiences and inspiration can be drawn.

PV industry power has a vast investment scale along with technology-intensive, capital-intensive, and high-cost characteristics.

Reliance only on their strength is very difficult to develop. Therefore, government departments are needed to support the policy orientations to promote the sustainable development of PV industry power. Thus, USA PV industry power efficiency scored well because of the active role played by the USA government in the PV industry power process and the use of relevant policies as an essential means of regulation in promoting the sustainable development of USA PV industry power.

In 1992, the USA government began implementing the Energy Policy Act, which gave states or municipally owned or non-profit PV industry electric utilities a tax credit of 1.5 cents per kilowatt-hour for 10 years (October 1, 1993, to December 30, 2003). In 2004, the tax credit was increased to 1.8 cents per kilowatt-hour. In 2005, the USA government announced amendments to the Energy Policy Act to provide a 2-year, 30% tax credit for residential use of PV systems. In 2008, the USA government allocated USD 467 million to promote the use and development of solar energy. The USA Department of Energy provided USD 535 million in loan guarantees for companies related to the PV industry. In 2010, the USA government began implementing the Ten Million Solar Roofs Act to promote the rapid development of the USA PV market in the next decade. In 2016, the SunShot Initiative was introduced to reduce the cost of solar power by 50% between 2020 and 2030, with the USA Department of Energy providing funding to reduce costs further and accelerate the PV industry's growth.

The above collation shows that the USA had all kinds of complete systems and complete bills, and the USA federal government and state governments used market mechanisms to develop PV industry power rapidly. The USA used tax incentives to promote investment in PV projects and attract investors. In addition, the USA financial market also provided loan guarantee channels to facilitate the financing of PV projects. All these measures promoted the development of PV industry power.

The USA PV industry power was characterized by measures such as tax incentives and loan subsidies to attract venture capitalists to the market. In addition, the USA state government developed a renewable energy portfolio standard, with particular attention to the fact that the standard was required to be enforced and its clearly defined quotas for PV power. This standard effectively promoted the development of PV power plants.

Germany is one of the big countries in PV power. Germany accounted for 6.8% of the world’s PV power in 2019. The formation of Germany’s colossal PV market also depended on government departments' policy support.

In 2000, Germany issued the Renewable Energy Act, which subsidized the PV feed-in tariff and required grid companies to acquire the PV feed-in tariff fully. In 2004, Germany amended the Renewable Energy Act to subsidize PV at 0.457 euros per kilowatt hour for 20 years. In 2010, Germany passed an amendment to the PV grid entry subsidy, which increased the incentives for medium-sized and small-scale rooftop PV installations. 2014 saw the unanimous adoption of the German Renewable Energy Reform Plan. In addition to implementing policies and regulations, the German government actively implemented financial support and tax incentives to promote the development of the PV industry for power. For example, commercial PV systems in Germany were exempt from a 19% value-added tax, and investors were offered different types of interest and loan amounts. Germany developed its PV technology and market mainly through government procurement, capital investment, regulatory control, and financial support.

The German PV industry for power was characterized by a policy focused on attracting investors and long-term incentives. Germany did not use refunds or direct subsidies to incentivize the application of PV. The establishment of long-term development mechanisms guided the healthy development of PV industry power.

As one of the leading countries in PV power, the Japanese government has paid more attention to the research and development of PV power technology. The Japanese government promoted PV technology innovation by introducing financial subsidies and establishing research and development institutions.

In 1994, the Japanese government enacted a subsidy policy for PV residential installations, which covered 45% of the initial installation cost of PV systems. However, this policy was discontinued in 2005, and in 2003, the Japanese government introduced the Renewable Energy Portfolio Standard. This standard required utilities to use renewable energy sources (which included a specific percentage of electricity generated from PV). The standard also set a target of achieving 1.35% of national electricity from renewable energy sources by 2010. To achieve this goal, in 2009, the Japanese government reinstated its subsidy policy for PV, giving a 50% subsidy on the installation cost of PV as well as a low-interest loan policy. In 2011, the Japanese government passed the Electricity Company Purchase of Renewable Electricity Act, designed to achieve a minimum of 20% of energy from renewable sources by 2030.

Japan’s PV industry power was characterized by a relatively successful promotion of the public's acceptance of PV power. Through the development of the PV housing market, installation of PV power systems in public buildings and schools, and issuance of consumption points for energy-saving products and green power certificates to the public, the concept of PV power and energy conservation and environmental protection has taken root. In addition, the Japanese government has transformed the subsidies given to PV companies into subsidies for consumers who use PV products.

By summarizing and organizing the experiences of the PV industry in the USA, Germany, and Japan, the following common points can be found: First, government policy support. These countries adopted a mandatory power company acquisition PV policy to protect the PV industry investment. For example, the German government implemented a preferential fixed tariff to acquire a PV feed-in tariff through the feed-in tariff law. The Japanese government twice used the price of electricity to buy back the excess electricity generated by PV power equipment. Second, tax incentives support. These countries enacted numerous tax incentives to promote the development of the PV industry. For example, the USA enacted and implemented a 30% tax credit for PV projects. The German government exempted companies with commercial PV systems from the 19% value-added tax. Third, financial security. These countries provided financial guarantees to accelerate the development of PV industry power through the construction of PV projects, PV technology research and development, and PV product sales. For example, the German government subsidized the PV feed-in tariff. The Japanese government enacted a system of subsidies for installing PV power for residential use.

5.2 Insights from PV industry power efficiency in USA, Germany, and Japan

The above summary and analysis of PV industry power in the USA, Germany, and Japan can give many insights from their development.

PV industry power is capital and technology-intensive, and the advancement of PV technology is essential to achieve grid parity for PV power. Research and development in PV industry power technology require close cooperation between government departments, PV enterprises, and research institutes and strong financial support from government departments. Only by improving PV technology can some aspects of PV power achieve simultaneous development of independent research, development, and commercialization, for example, grid-connected inverters, stand-alone power generation systems, and PV cells.

Establish a long-term mechanism for PV industry power and realize the marketization of PV tariffs. Government subsidies cannot achieve the long-term development of PV industry power alone. It is necessary to establish a renewable energy department to adjust the management system and pricing mechanism of PV tariffs according to the difference in light and the cost of transporting electricity to different regions. This can be achieved by establishing a predictable regulatory mechanism, narrowing the difference in revenue of PV projects, mobilizing the competitiveness of PV enterprises, and achieving the sustainable development of PV industry power.

Encourage the installation and use of PV systems by small businesses and the general public. The popularity and development of small-scale PV equipment in hospitals, universities, and government institutions can be incentivized so that the general public and small PV businesses can benefit from a subsidy policy.

5.3 Suggestions for improving power in the PV industry for other countries

To ensure the effectiveness of the PV industry's power efficiency, based on the successful experience of PV industry policies in the USA, Germany, and Japan, we propose recommendations and measures to guide the sustainable development of the PV industry in terms of technology research and development, fiscal policy and long-term development.

An increase in investment in PV industry technology research and development is essential to encourage independent innovation and improve the competitiveness of PV enterprises. The process of PV enterprise technology research and development needs scientific equipment, laboratories, and other hardware facilities. This process will produce taxes and create resilience in PV enterprises of research and development. Therefore, some policies can be set to reduce the research and development costs of PV enterprises in terms of technology research and development.

Examples of policies include the establishment of PV technology research centers, a PV industry talent training system, and a value-added tax rebate policy and tax incentives to reduce the burden of advancing funds to PV enterprises and the pressure of the capital operation of enterprises.

Tax policy for the PV industry should focus on tax relief for end users of PV products and tilting tax subsidies downstream of the PV industry. In regard to personal income tax, preference should be given to PV technicians; in terms of business tax, exemptions should be given to small and medium-sized enterprises engaged in PV equipment technology development-related services; in terms of import and export tax, subsidies to PV industries should be appropriately adjusted, taking into account international information and domestic conditions and hedging the risks to PV industries caused by foreign factors.

By taking demand as a guide, power can be returned to the PV industry via a long-term mechanism that promotes its sustainable development. A return-on-investment channel can be established for PV industry power by measuring the power output and sales of PV power plants. Because the unpredictability of PV power will impact the traditional power grid, while establishing the return mechanism, the profit distribution should be appropriately increased to the power grid enterprises to drive the enthusiasm for PV industry power. In addition, government departments should accelerate the construction of power grids and improve transmission capacity.

Chapter 6 Summary and conclusion

PV industry power has received significant attention from governments in the initial stages of development and has gradually grown to be one of the new power methods in various countries. The achievements of each country are apparent. However, the effectiveness of the PV industry power should be maintained to ensure that the PV industry policy can be fully implemented and to improve the competitiveness of PV enterprises in the sustainable development of the PV industry power in each country.

This paper describes the PV industry power efficiency results for 26 countries from 2000 to 2020 and the evolution of its influencing factors to report the current status of PV industry power in the evaluated countries. The empirical results showed that the PV industry power efficiency in high-income countries was higher than that in non-high-income countries. The PV industry power efficiency was positively correlated with GDP per capita and negatively correlated with carbon dioxide emissions. China's most recent PV industry power efficiency was at the lowest level among the evaluated subjects.

In addition to analyzing the results of the PV industry power efficiency in the assessed countries, this paper reports the relative importance of the determinants of the competitiveness of the Chinese PV industry. As research subjects, it took PV companies in Southwest China, Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Northwest China. In addition to the determinants of the factor condition (e.g., natural resources and mineral resource reserves), the determinants of the demand condition and firm strategy, structure, and rivalry were proven to be of relative importance.

Based on the current situation of PV industry power in high-income countries, this paper also analyzes in detail the content of PV industry power policies in the USA, Germany, and Japan. Further, it concludes on the effect that PV industry's power policies can play. The successful experiences of PV industry power policies in the USA, Germany, and Japan were collected and organized, and valuable inspirations for improving PV industry power policies in other countries were obtained. Suggestions and measures are proposed for technology research and development, financial and taxation policies, and the long-term development of the PV industry to guide the industry's sustainable development.

The data on PV industry power is not yet perfect, which made it challenging to discuss more research methods in the study of specific issues. In addition, due to the complexity of economic phenomena and the author’s lack of econometrics, this paper was inevitably flawed in the writing process.

Some practical aspects of this study still need to be improved and addressed in future research. First, undesirable outputs should be considered when selecting output variables. It is also relevant to analyze the impact of undesirable outputs on PV industry power efficiency in the process of PV power development. The specific variables need to be analyzed in future studies. Second, only three environmental variables were chosen in this study. Other variables, such as the proportion of renewable energy consumption in total final energy consumption and sulfur dioxide can be introduced in future studies. Third, other methods, such as the three-stage SBM-DEA model, can also measure PV industry power efficiency (Lin et al., 2020). Fourth, the development of the PV industry in different provinces of China was not uniform. This study was an overall assessment of the relative importance of China's PV industry determinants. However, the results were not necessarily applicable to all provinces. The development of different provinces needs further comparative analysis. Fifth, this research was conducted in China. Therefore, it is necessary to explore other countries. Nevertheless, it should be noted that the same method can also be applied to other countries.

Reference

Ahn, J., Woo, J.R., Lee, J., 2015. Optimal allocation of energy sources for sustainable development in South Korea: Focus on the electric power generation industry. Energy Policy 78, 78–90. https://doi.org/10.1016/j.enpol.2014.12.023

Alcántara-Avila, J.R., Sillas-Delgado, H.A., Segovia-Hernández, J.G., Gómez-Castro, F.I., Cervantes-Jauregui, J.A., 2015. Silane Production through Reactive Distillation with Intermediate Condensers, Computer Aided Chemical Engineering. Elsevier. https://doi.org/10.1016/B978-0-444-63577-8.50018-8

Aranda-Usón, A., Ferreira, G., Mainar-Toledo, M.D., Scarpellini, S., Llera Sastresa, E., 2012. Energy consumption analysis of Spanish food and drink, textile, chemical and non-metallic mineral products sectors. Energy 42, 477–485. https://doi.org/10.1016/j.energy.2012.03.021

Arora DS, Sarah Busche, Shannon Cowlin, Tobias Engelmeier, Hanna Jaritz, Anelia Milbrandt, et al., 2010. Indian renewable energy status report: background report for DIREC 2010 (No. NREL/TP-6A20-48948). National Renewable Energy Lab. (NREL), Golden, CO (United States).

Ashok Kumar L., Indragandhi V., Uma Maheswari Y., 2020. Chapter 9-PVSYST. Softw. Tools Simul. Electr. Syst. 349–392. https://doi.org/10.1016/b978-0-12-819416-4.00009-0

Avkiran, N.K., 2009. Removing the impact of environment with units-invariant efficient frontier analysis: An illustrative case study with intertemporal panel data. Omega 37, 535–544. https://doi.org/10.1016/j.omega.2007.10.002

Avkiran, N.K., Rowlands, T., 2008. How to better identify the true managerial performance: State of the art using DEA. Omega 36, 317–324. https://doi.org/10.1016/j.omega.2006.01.002

Azeroual, M., El Makrini, A., El Moussaoui, H., El Markhi, H., 2018. Renewable energy potential and available capacity for wind and solar power in Morocco towards 2030. J. Eng. Sci. Technol. Rev. 11, 189–198. https://doi.org/10.25103/jestr.111.23

Bai-Chen, X., Ying, F., Qian-Qian, Q., 2012. Does generation form influence environmental efficiency performance? An analysis of China's power system. Appl. Energy 96, 261–271. https://doi.org/10.1016/j.apenergy.2011.11.011

Bakan, İ., Fatma Doğan, İ., 2012. Competitiveness of the industries based on the Porter's diamond model: An empirical study. Int. J. Res. Rev. Appl. Sci. 11, 441–455.

Balitskiy, S., Bilan, Y., Strielkowski, W., Štreimikiene, D., 2016. Energy efficiency and natural gas consumption in the context of economic development in the European Union. Renew. Sustain. Energy Rev. 55, 156–168. https://doi.org/10.1016/j.rser.2015.10.053

Bao, C., Xu, M., 2019. Cause and effect of renewable energy consumption on urbanization and economic growth in China's provinces and regions. J. Clean. Prod. 231, 483–493. https://doi.org/10.1016/j.jclepro.2019.05.191

Barbose, G., Darghouth, N., Hoen, B., Wiser, R., 2018. Income Trends of Residential PV Adopters: An analysis of household-level income estimates.

Bartlett, J.E., Margolis, R.M., Jennings, C.E., 2009. Effects of the Financial Crisis on Photovoltaics : An Analysis of Changes in Market Forecasts from 2008 to 2009 (No. NREL/TP-6A2-46713). National Renewable Energy Lab. (NREL), Golden, CO (United States).

Bayaliyev, A., Kalloz, J., Robinson, M., 2011. China's Solar Policy: Subsidies, Manufacturing Overcapacity & Opportunities. Available: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.226.1981&rep=rep1&type=pdf. Accessed June 20, 2012.

Beyer, S., 2006. Environmental Law and Policy in the People's Republic of China. Chinese J. Int. Law 5, 185–211. https://doi.org/10.1093/chinesejil/jmk002

Bian, Y., Hu, M., Wang, Y., Xu, H., 2016. Energy efficiency analysis of the economic system in China during 1986-2012: A parallel slacks-based measure approach. Renew. Sustain. Energy Rev. 55, 990–998. https://doi.org/10.1016/j.rser.2015.11.008

Bilan, Y., Streimikiene, D., Vasylieva, T., Lyulyov, O., Pimonenko, T., Pavlyk, A., 2019. Linking between renewable energy, CO2 emissions, and economic growth: Challenges for candidates and potential candidates for the EU membership. Sustain. 11, 1–16. https://doi.org/10.3390/su11061528

Cai, Y., Xiong, S., Ma, X., 2017. Energy efficiency measures in China: A three-stage DEA analysis. IOP Conf. Ser. Earth Environ. Sci. 61. https://doi.org/10.1088/1755-1315/61/1/012056

Camanho, A.S., Portela, M.C., Vaz, C.B., 2009. Efficiency analysis accounting for internal and external non-discretionary factors. Comput. Oper. Res. 36, 1591–1601. https://doi.org/10.1016/j.cor.2008.03.002

Cancino-Solórzano, Y., Villicaña-Ortiz, E., Gutiérrez-Trashorras, A.J., Xiberta-Bernat, J., 2010. Electricity sector in Mexico: Current status. Contribution of renewable energy sources. Renew. Sustain. Energy Rev. 14, 454–461. https://doi.org/10.1016/j.rser.2009.07.022

Cerdeira Bento, J.P., Moutinho, V., 2016. CO2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. Renew. Sustain. Energy Rev. 55, 142–155. https://doi.org/10.1016/j.rser.2015.10.151

Chen, W., Hong, J., Yuan, X., Liu, J., 2016. Environmental impact assessment of monocrystalline silicon solar photovoltaic cell production: A case study in China. J. Clean. Prod. 112, 1025–1032. https://doi.org/10.1016/j.jclepro.2015.08.024

Chen, X.Y., 2010. Researching on the International Competitiveness of the Solar Industry. Ph.D. Thesis, Nankai University, Tianjin, China.

Chen, Y., Liu, B., Shen, Y., Wang, X., 2016. The energy efficiency of China's regional construction industry based on the three-stage DEA model and the DEA-DA model. KSCE J. Civ. Eng. 20, 34–47. https://doi.org/10.1007/s12205-015-0553-3

Chen, Z., Barros, C.P., Borges, M.R., 2015. A Bayesian stochastic frontier analysis of Chinese fossil-fuel electricity generation companies. Energy Econ. 48, 136–144. https://doi.org/10.1016/j.eneco.2014.12.020

Cheong, T.S., Li, V.J., Shi, X., 2019. Regional disparity and convergence of electricity consumption in China: A distribution dynamics approach. China Econ. Rev. 58, 101154. https://doi.org/10.1016/j.chieco.2018.02.003

Chien, T., Hu, J.L., 2007. Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. Energy Policy 35, 3606–3615. https://doi.org/10.1016/j.enpol.2006.12.033

China Electric Power Yearbook, 2018. Available: https://data.cnki.net/trade/Yearbook/Single/N2019060101?z=Z025. Accessed August 13, 2021.

China Industrial Statistical Yearbook, 2020. Available: https://data.cnki.net/yearbook/Single/N2021020054. Accessed August 13, 2021.

China Photovoltaic Industry Association, 2020. Available: https://bg.qianzhan.com/trends/detail/506/200908-da3e9ade.html. Accessed August 13, 2021.

China Power News Network, 2018. China's newly installed photovoltaic power generation capacity ranks first in the world for 5 consecutive years. Hydropower Stn. Des. 34, 104.

Chung, T.W., 2016. A Study on Logistics Cluster Competitiveness among Asia Main Countries using the Porter's Diamond Model. Asian J. Shipp. Logist. 32, 257–264. https://doi.org/10.1016/j.ajsl.2016.12.010

Cicea, C., Marinescu, C., Popa, I., Dobrin, C., 2014. Environmental efficiency of investments in renewable energy: Comparative analysis at macroeconomic level. Renew. Sustain. Energy Rev. 30, 555–564. https://doi.org/10.1016/j.rser.2013.10.034

Cooper, W.W., Seiford, L.M., Tone, K., 2007. Data Envelopment Analysis. Springer, Boston, MA.

Corwin, S., Johnson, T.L., 2019. The role of local governments in the development of China's solar photovoltaic industry. Energy Policy 130, 283–293. https://doi.org/10.1016/J.ENPOL.2019.04.009

Costs IRENA (International Renewable Energy Agency), 2022. Available: https://www.irena.org/costs. Accessed April 16, 2022.

Department of Resources, Energy and Tourism, 2012. Energy White Paper

2012, Australia's Energy Transformation. Department of Resources, Energy and Tourism.

Dincer, I., 2000. Renewable energy and sustainable development: A crucial review. Renew. Sustain. energy Rev. 4, 157–175. https://doi.org/10.1016/S1364-0321(99)00011-8

Dögl, C., Holtbrügge, D., Schuster, T., 2012. Competitive advantage of German renewable energy firms in India and China An empirical study based on Porter's diamond. Int. J. Emerg. Mark. 7, 191–214. https://doi.org/https://doi.org/10.1108/17468801211209956

Esen, S., Uyar, H., 2012. Examining the competitive structure of Turkish tourism industry in comparison with diamond model. Procedia Soc. Behav. Sci. 62, 620–627. https://doi.org/10.1016/j.sbspro.2012.09.104

Fang, K., Zhou, Y., Wang, S., Ye, R., Guo, S., 2018. Assessing national renewable energy competitiveness of the G20: A revised Porter's Diamond Model. Renew. Sustain. Energy Rev. 93, 719–731. https://doi.org/10.1016/j.rser.2018.05.011

Fechner, H., Mayr, C., Schneider, A., Rennhofer, M., Peharz, G., 2016. Technologie-Roadmap für Photovoltaik in Österreich. Berichte aus Energie-und Umweltforschung, 15, 2016.

Fina, B., Auer, H., Friedl, W., 2020. Cost-optimal economic potential of shared rooftop PV in energy communities: Evidence from Austria. Renew. Energy 152, 217–228. https://doi.org/10.1016/j.renene.2020.01.031

Fried, H.O., Lovell, C.A.K., Schmidt, S.S., Yaisawarng, S., 2002. Accounting for environmental effects and statistical noise in Data Envelopment Analysis. J. Product. Anal. 17, 157–174. https://doi.org/10.1023/A:1013548723393

Ghimire, L.P., Kim, Y., 2018. An analysis on barriers to renewable energy development in the context of Nepal using AHP. Renew. Energy 129, 446–456. https://doi.org/10.1016/j.renene.2018.06.011

Global Horizontal Irradiation-China, 2019. Available: https://solargis2-web-assets.s3.eu-west-1.amazonaws.com/public/flyers/36dd721927/Solargis_maps-2019-05-17_GHI-China-web.pdf.

Accessed August 23, 2021.

Goepel, K.D., 2013. Implementing the analytic hierarchy process as a standard method for multi-criteria decision making in corporate enterprises—a new AHP excel template with multiple inputs. Proc. Int. Symp. Anal. Hierarchy Process 2, 1–10. https://doi.org/10.13033/isahp.y2013.047

Goodrich, A.C., Powell, D.M., James, T.L., Woodhouse, M., Buonassisi, T., 2013. Assessing the drivers of regional trends in solar photovoltaic manufacturing. Energy Environ. Sci. 6, 2811–2821. https://doi.org/10.1039/c3ee40701b

Green, M.A., 2002. Photovoltaic principles. Phys. E Low-Dimensional Syst. Nanostructures 14, 11–17. https://doi.org/10.1016/S1386-9477(02)00354-5

He, D., Wang, H., Yu, X., 2015. Interest rate determination in China: Past, present, and future. Int. J. Cent. Bank. 11, 255–277. https://doi.org/10.2139/ssrn.2398801

Heo, E., Kim, J., Boo, K.J., 2010. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. Renew. Sustain. Energy Rev. 14, 2214–2220.

Heras-Saizarbitoria, I., Cilleruelo, E., Zamanillo, I., 2011. Public acceptance of renewables and the media: an analysis of the Spanish PV solar experience. Renew. Sustain. Energy Rev. 15, 4685–4696. https://doi.org/10.1016/J.RSER.2011.07.083

Honma, S., Hu, J.L., 2014. A panel data parametric frontier technique for measuring total-factor energy efficiency: An application to Japanese regions. Energy 78, 732–739. https://doi.org/10.1016/j.energy.2014.10.066

Hosenuzzaman, M., Rahim, N.A., Selvaraj, J., Hasanuzzaman, M., Malek, A.B.M.A., Nahar, A., 2015a. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. Renew. Sustain. Energy Rev. 41, 284–297. https://doi.org/10.1016/j.rser.2014.08.046

Hosenuzzaman, M., Rahim, N.A., Selvaraj, J., Hasanuzzaman, M., Malek, A.B.M.A., Nahar, A., 2015b. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. Renew. Sustain. Energy Rev. 41, 284–297. https://doi.org/10.1016/j.rser.2014.08.046

Hua, Y., Oliphant, M., Hu, E.J., 2016. Development of renewable energy in Australia and China: A comparison of policies and status. Renew. Energy 85, 1044–1051. https://doi.org/10.1016/j.renene.2015.07.060

Huang, M., He, Y., Cen, H., 2007. Predictive analysis on electric-power supply and demand in China. Renew. Energy 32, 1165–1174. https://doi.org/10.1016/J.RENENE.2006.04.005

IEA (International Energy Agency), 2019. Data and statistics, IEA. Available: https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=Electricity%20and%20heat&indicator=SolarGen. Accessed April 16, 2022.

IEA (International Energy Agency), 2019. World Energy Outlook 2019. Available: www.iea.org/weo. Accessed August 23, 2021.

IEA (International Energy Agency), 2021. Renewable Power, IEA, Paris. Available: https://www.iea.org/reports/renewable-power. Accessed April 16, 2022.

IRENA (International Renewable Energy Agency), 2020. Global Landscape of Renewable Energy Finance 2020, International Renewable Energy Agency, Abu Dhabi. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_GLREF_2020_Methodology.pdf. Accessed April 16, 2022.

Ismail, M.I., Yunus, N.A., Mohamed Kaassim, A.Z., Hashim, H., 2022. Pathways and challenges of solar thermal utilisation in the industry: ASEAN and Malaysia scenarios. Sustain. Energy Technol. Assessments 52, 102046. https://doi.org/10.1016/j.seta.2022.102046

Jacobsson, S., Sandén, B.A., Bångens, L., 2004. Transforming the energy system-the evolution of the German technological system for solar cells. Technol. Anal. Strateg. Manag. 16, 3–30. https://doi.org/10.1080/0953732032000199061

Ji, J., Tang, H., Jin, P., 2019. Economic potential to develop concentrating solar power in China: A provincial assessment. Renew. Sustain. Energy Rev. 114, 109279. https://doi.org/10.1016/J.RSER.2019.109279

Ji, S.D., 2014. Evaluation and Improvement of China's Photovoltaic Industry Competitiveness Based on the Modified Diamond Model—Comparative Analysis of China's Photovoltaic Industry and Some Countries. Master's Thesis, Northwest University, Xi'an, China.

Jia, Q., 2004. Evolution of China`s Monetary Policy Theory and Practice Since Reform and Opening UP. Ph.D. Thesis, Fudan University, Shanghai, China.

Jia, S., Wang, C., Li, Y., Zhang, F., Liu, W., 2017. The urbanization efficiency in Chengdu City: An estimation based on a three-stage DEA model. Phys. Chem. Earth 101, 59–69. https://doi.org/10.1016/j.pce.2017.05.003

Jiang, H., Jin, Y., Ye, X., Qiang, Y., Li, J., Han, P., 2020. Review of China's

PV Industry in 2019 and Prospect in 2020. Sol. Energy 3, 14–23.

Jiao, L., 2013. The Research on the International Competitiveness of Solar Energy Photovoltaic Industry in China. Master's Thesis, Beijing Linye University, Beijing, China.

Jin, H., Qin, L., Hao, C., Wang, L., Jiao, F., 2011. The study and exploration of a new generation of photovoltaic energy storage system. Energy Procedia 12, 986–993. https://doi.org/10.1016/j.egypro.2011.10.129

Jondrow, J., Knox Lovell, C.A., Materov, I.S., Schmidt, P., 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. J. Econom. 19, 233–238. https://doi.org/10.1016/0304-4076(82)90004-5

Katuwal, H., Calkin, D.E., Hand, M.S., 2016. Production and efficiency of large wildland fire suppression effort: A stochastic frontier analysis. J. Environ. Manage. 166, 227–236. https://doi.org/10.1016/j.jenvman.2015.10.030

Keeley, A.R., Matsumoto, K., 2018. Relative significance of determinants of foreign direct investment in wind and solar energy in developing countries – AHP analysis. Energy Policy 123, 337–348. https://doi.org/10.1016/j.enpol.2018.08.055

Kharub, M., Sharma, R., 2017. Comparative analyses of competitive advantage using Porter diamond model (the case of MSMEs in Himachal Pradesh). Compet. Rev. 27, 132–160.

Khribich, A., Kacem, R.H., Dakhlaoui, A., 2021. Causality nexus of renewable energy consumption and social development: Evidence from high-income countries. Renew. Energy 169, 14–22. https://doi.org/10.1016/j.renene.2021.01.005

Kousksou, T., Allouhi, A., Belattar, M., Jamil, A., El Rhafiki, T., Arid, A., Zeraouli, Y., 2015. Renewable energy potential and national policy directions for sustainable development in Morocco. Renew. Sustain. Energy Rev. 47, 46–57. https://doi.org/10.1016/j.rser.2015.02.056

Koutavarapu, R., Tamtam, M.R., Myla, C.R., Cho, M., Shim, J., 2021. Enhanced solar-light-driven photocatalytic properties of novel Z-scheme binary BiPO4 nanorods anchored onto NiFe2O4 nanoplates: Efficient removal of toxic organic pollutants. J. Environ. Sci. (China) 102, 326–340. https://doi.org/10.1016/j.jes.2020.09.021

Kwan, S.H., Eisenbeis, R.A., 1995. An analysis of inefficiency in banking: A stochastic cost frontier approach. Working Paper, Working Papers in Applied Economics, Federal Reserve Bank of San Francisco.

Lam, L.T., Branstetter, L., Azevedo, I.L., 2018. A sunny future: expert elicitation of China's solar photovoltaic technologies. Environ. Res. Lett 13, 34038. https://doi.org/10.1088/1748-9326/aaab70

Lantz, T.L., Ioppolo, G., Yigitcanlar, T., Arbolino, R., 2021. Understanding the correlation between energy transition and urbanization. Environ. Innov. Soc. Transitions 40, 73–86. https://doi.org/10.1016/j.eist.2021.06.002

Lardy, N., Guo, F., 2013. Financial Reform Policies for Rebalancing Economic Growth. China Financ. Rev. 2, 18–38.

Lesourd, J.B., 2001. Solar photovoltaic systems: The economics of a renewable energy resource. Environ. Model. Softw. 16, 147–156.

https://doi.org/10.1016/S1364-8152(00)00078-5

Li, X., 2015. A Review on Energy Management, Operation Control and Application Methods for Grid Battery Energy Storage Systems. CSEE J. Power Energy Syst. 1, 1–15. https://doi.org/10.17775/CSEEJPES.2019.00160

Li, Y., Zhang, Y., Wang, J., Fan, Y., Xiao, T., Yin, Z., Wang, T., Qiu, J., Song, Z., 2022. Enhancement of solar-driven photocatalytic activity of oxygen vacancy-rich Bi/BiOBr/Sr2LaF7:Yb3+,Er3+ composites through synergetic strategy of upconversion function and plasmonic effect. J. Environ. Sci. (China) 115, 76–87. https://doi.org/10.1016/j.jes.2021.05.036

Lin, X., Zhu, X., Han, Y., Geng, Z., Liu, L., 2020. Economy and carbon dioxide emissions effects of energy structures in the world: Evidence based on SBM-DEA model. Sci. Total Environ. 729, 138947. https://doi.org/10.1016/j.scitotenv.2020.138947

Liu, Y.J., Pan, T., 2012. Spatial Simulation of China's Land Surface Solar Radiation Resources. J. Nat. Resour. 27, 1392–1403.

Lu, B., Wang, K., Xu, Z., 2013. China's regional energy efficiency: results based on three-stage DEA model. Int. J. Glob. Energy Issues 36, 262–276.

Luo, Z., He, J., Hu, S., 2021. Driving force model to evaluate China's photovoltaic industry: Historical and future trends. J. Clean. Prod. 311, 127637. https://doi.org/10.1016/j.jclepro.2021.127637

Luthra, S., Kumar, S., Garg, D., Haleem, A., 2015. Barriers to renewable/sustainable energy technologies adoption: Indian perspective. Renew. Sustain. Energy Rev. 41, 762–776. https://doi.org/10.1016/J.RSER.2014.08.077

Lyeonov, S., Pimonenko, T., Bilan, Y., Štreimikiene, D., Mentel, G., 2019. Assessment of green investments' impact on sustainable development: Linking gross domestic product per capita, greenhouse gas emissions and renewable energy. Energies 12. https://doi.org/10.3390/en12203891

Martínez-Molina, A., Tort-Ausina, I., Cho, S., Vivancos, J.L., 2016. Energy efficiency and thermal comfort in historic buildings: A review.

Renew. Sustain. Energy Rev. 61, 70–85. https://doi.org/10.1016/j.rser.2016.03.018

Mastrocinque, E., Ramírez, F.J., Honrubia-Escribano, A., Pham, D.T., 2020. An AHP-based multi-criteria model for sustainable supply chain development in the renewable energy sector. Expert Syst. Appl. 150, 113321. https://doi.org/10.1016/j.eswa.2020.113321

Matsumoto, K., Chen, Y., 2021. Industrial eco-efficiency and its determinants in China: A two-stage approach. Ecol. Indic. 130, 108072. https://doi.org/10.1016/j.ecolind.2021.108072

Matsumoto, K., Makridou, G., Doumpos, M., 2020. Evaluating environmental performance using data envelopment analysis: The case of European countries. J. Clean. Prod. 272, 122637. https://doi.org/10.1016/j.jclepro.2020.122637

Maycock, P D., 1995. Photovoltaic technology, performance, markets, cost and forecast: 1975-2010. United States.

MNRE (Ministry of New and Renewable Energy), 2022. Solar Energy, Gird Connected. Available: https://mnre.gov.in/solar/solar-ongrid.

Accessed April 16, 2022.

Moya, D., Torres, R., Stegen, S., 2016. Analysis of the Ecuadorian energy audit practices: A review of energy efficiency promotion. Renew. Sustain. Energy Rev. 62, 289–296. https://doi.org/10.1016/j.rser.2016.04.052

Muiz, M.A., 2002. Separating managerial inefficiency and external conditions in data envelopment analysis. Eur. J. Oper. Res. 143, 625–643. https://doi.org/10.1016/S0377-2217(01)00344-7

Najafi, G., Ghobadian, B., Mamat, R., Yusaf, T., Azmi, W.H., 2015. Solar energy in Iran: Current state and outlook. Renew. Sustain. Energy Rev. 49, 931–942. https://doi.org/10.1016/j.rser.2015.04.056

National Energy Board, 2019. China's photovoltaic power generation construction and operation in the first quarter of 2019. Sol. Energy 6, 79.

National Renewable Energy Laboratory, 2021. Best Research-Cell Efficiencies: Crystalline Silicon Cells. Available: https://www.nrel.gov/pv/assets/pdfs/cell-pv-eff-crysi-rev211214.pdf.

Accessed April 16, 2022.

NEA (National Energy Administration), 2017. Report on new energy grid-connected operation in the northwest region in 2016. Available: http://www.nea.gov.cn/2017-01/19/c_135996630.htm. Accessed April 16, 2022.

Norton, R.N., Sexton, T.R., Silkman, R.H., 2007. Accounting for site characteristics in DEA: Leveling the playing field. Int. Trans. Oper. Res. 14, 231–244. https://doi.org/10.1111/j.1475-3995.2007.00583.x

Octaviano, C., Paltsev, S., Gurgel, A.C., 2014. Climate change policy in Brazil and Mexico: Results from the MIT EPPA model. Energy Econ. 56, 600–614. https://doi.org/10.1016/j.eneco.2015.04.007

Onyinye, N., Idenyi, O., Ifeyinwa, A., 2017. Effect of Capital Formation on Economic Growth in Nigeria. Asian J. Econ. Bus. Account. 5, 1–16. https://doi.org/10.9734/ajeba/2017/36075

Painuly, J.P., 2001. Barriers to renewable energy penetration: A framework for analysis. Renew. Energy 24, 73–89.

https://doi.org/10.1016/S0960-1481(00)00186-5

Park, S.Y., Yun, B.Y., Yun, C.Y., Lee, D.H., Choi, D.G., 2016. An analysis of the optimum renewable energy portfolio using the bottom-up model: Focusing on the electricity generation sector in South Korea. Renew. Sustain. Energy Rev. 53, 319–329. https://doi.org/10.1016/j.rser.2015.08.029

Pischke, E.C., Solomon, B., Wellstead, A., Acevedo, A., Eastmond, A., De Oliveira, F., Coelho, S., Lucon, O., 2019. From Kyoto to Paris: Measuring renewable energy policy regimes in Argentina, Brazil, Canada, Mexico and the United States. Energy Res. Soc. Sci. 50, 82–91. https://doi.org/10.1016/j.erss.2018.11.010

Porter, M.E., 1990. The Competitive Advantage of Nations. Harv. Bus. Rev. 68, 73–93.

Porter, M.E., 1998. The Adam Smith address: Location, clusters, and the “new” microeconomics of competition. Bus. Econ. 33, 7–13.

Ren, F. rong, Tian, Z., Liu, J., Shen, Y. ting, 2020. Analysis of CO2 emission reduction contribution and efficiency of China’s solar photovoltaic industry: Based on Input-output perspective. Energy 199, 117493. https://doi.org/10.1016/j.energy.2020.117493

Saaty, T.L., 1994. How to Make a Decision: The Analytic Hierarchy Process. Inst. Manag. Sci. 24, 19–43.

Sahoo, S.K., 2016. Renewable and sustainable energy reviews solar photovoltaic energy progress in India: A review. Renew. Sustain. Energy Rev. 59, 927–939. https://doi.org/10.1016/j.rser.2016.01.049

Satti, S.L., Farooq, A., Loganathan, N., Shahbaz, M., 2014. Empirical evidence on the resource curse hypothesis in oil abundant economy. Econ. Model. 42, 421–429. https://doi.org/10.1016/j.econmod.2014.07.020

Shao, X., Fang, T., 2021. Performance analysis of government subsidies for photovoltaic industry: Based on spatial econometric model. Energy Strateg. Rev. 34, 100631. https://doi.org/10.1016/j.esr.2021.100631

Sheng, P., He, Y., Guo, X., 2017. The impact of urbanization on energy consumption and efficiency. Energy Environ. 28, 673–686. https://doi.org/10.1177/0958305X17723893

Sheng, Y., Shi, X., Zhang, D., 2014. Economic growth, regional disparities and energy demand in China. Energy Policy 71, 31–39. https://doi.org/10.1016/J.ENPOL.2014.04.001

Shubbak, M.H., 2019. The technological system of production and innovation: The case of photovoltaic technology in China. Res. Policy 48, 993–1015. https://doi.org/10.1016/J.RESPOL.2018.10.003

Simionescu, M., Bilan, Y., Krajňáková, E., Streimikiene, D., Gędek, S., 2019. Renewable energy in the electricity sector and gdp per capita in the European Union. Energies 12. https://doi.org/10.3390/en12132520

Simoes, S., Zeyringer, M., Mayr, D., Huld, T., Nijs, W., Schmidt, J., 2017. Impact of different levels of geographical disaggregation of wind and PV electricity generation in large energy system models: A case study for Austria. Renew. Energy 105, 183–198. https://doi.org/10.1016/j.renene.2016.12.020

Singh, A., 2009. A market for renewable energy credits in the Indian power sector. Renew. Sustain. Energy Rev. 13, 643–652. https://doi.org/10.1016/j.rser.2007.10.011

Sipahi, S., Timor, M., 2010. The analytic hierarchy process and analytic network process: An overview of applications. Manag. Decis. 48, 775–808. https://doi.org/10.1108/00251741011043920

Song, D., Jiao, H., Fan, C. Te, 2015. Overview of the photovoltaic technology status and perspective in China. Renew. Sustain. Energy Rev. 48, 848–856. https://doi.org/10.1016/j.rser.2015.04.001

Stone, H.B.J., Ranchhod, A., 2006. Competitive advantage of a nation in the global arena: a quantitative advancement to Porter's diamond applied to the UK, USA and BRIC nations. Strateg. Chang. 15, 283–294. https://doi.org/10.1002/jsc.770

Sun, J., 2017. Research on the international trade competitiveness of China`s solar photovoltaic industry. prices Mon. 12, 32–36. https://doi.org/10.14076/j.issn.1006-2025.2017.12.07

Sun, J., Ruze, N., Zhang, J., Zhao, H., Shen, B., 2019. Evaluating the investment efficiency of China's provincial power grid enterprises under new electricity market reform: Empirical evidence based on three-stage DEA model. Energies 12. https://doi.org/10.3390/en12183524

Sun, M., Zhang, P., Gao, C., Ji, J., Ampimah, B.C., 2016. Study on the mutual influence between enterprises: A complex network perspective of China's PV enterprises. J. Renew. Sustain. Energy 8. https://doi.org/10.1063/1.4971452

The AHP Excel template, 2018. Available: https://bpmsg.com/new-ahp-excel-template-with-multiple-inputs. Accessed August 23, 2021.

The Central People's Government of the People's Republic of China, 2021. Available: http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm. Accessed August 23, 2021.

The Qianzhan Industry Research Institute, 2018. Available: http://www.aikosolar.com/news/84.html. Accessed August 13, 2021.

Topcu, E., Altinoz, B., Aslan, A., 2020. Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation. Resour. Policy 66, 101622. https://doi.org/10.1016/j.resourpol.2020.101622

Tsai, P.H., Chen, C.J., Yang, H.C., 2021. Using Porter's Diamond Model to Assess the Competitiveness of Taiwan's Solar Photovoltaic Industry. SAGE Open 11. https://doi.org/10.1177/2158244020988286

Tsai, S., Rawson, D.M., Zhang, T., 2009. Development of cryopreservation protocols for early stage zebrafish (Danio rerio) ovarian follicles using controlled slow cooling. Theriogenology 71, 1226–1233. https://doi.org/10.1016/j.theriogenology.2009.01.014

Tsutsui, M., Tone, K., 2007. Separation of uncontrollable factors and time shift effects from DEA scores (No. 07–09). National Graduate Institute for Policy Studies.

Villicaña-Ortiz, E., Gutiérrez-Trashorras, A.J., Paredes-Sánchez, J.P., Xiberta-Bernat, J., 2015. Solar energy potential in the coastal zone of the gulf of Mexico. Renew. Energy 81, 534–542. https://doi.org/10.1016/j.renene.2015.03.068

Wang, D.D., Sueyoshi, T., 2017. Assessment of large commercial rooftop photovoltaic system installations: Evidence from California. Appl. Energy 188, 45–55. https://doi.org/10.1016/j.apenergy.2016.11.076

Wang, H., Wang, J., Feng, Z., 2018. The economic effects of anti-dumping and anti-subsidy policies among China, the U.S. and the EU: the photovoltaic industry. Singapore Econ. Rev. 63, 513–534. https://doi.org/10.1142/S0217590817400136

Wang, K., Wei, Y.M., Zhang, X., 2012. A comparative analysis of China's regional energy and emission performance: Which is the better way to deal with undesirable outputs? Energy Policy 46, 574–584. https://doi.org/10.1016/j.enpol.2012.04.038

Wang, Y., Gu, A., Zhang, A., 2011. Recent development of energy supply and demand in China, and energy sector prospects through 2030. Energy Policy 39, 6745–6759. https://doi.org/10.1016/J.ENPOL.2010.07.002

Wang, Y., Zhou, S., Huo, H., 2014. Cost and CO2 reductions of solar photovoltaic power generation in China: Perspectives for 2020.

Renew. Sustain. Energy Rev. 39, 370–380. https://doi.org/10.1016/j.rser.2014.07.027

Wang, Z., Li, Y., Wang, K., Huang, Z., 2017. Environment-adjusted operational performance evaluation of solar photovoltaic power plants: A three stage efficiency analysis. Renew. Sustain. Energy Rev. 76, 1153–1162. https://doi.org/10.1016/j.rser.2017.03.119

Watanabe, C., Wakabayashi, K., Miyazawa, T., 2000. Industrial dynamism and the creation of a "virtuous cycle" between R&D, market growth and price reduction. The case of photovoltaic power generation (PV) development in Japan. Technovation 20, 299–312. https://doi.org/10.1016/S0166-4972(99)00146-7

Welch, E., Barnum, D., 2009. Joint environmental and cost efficiency analysis of electricity generation. Ecol. Econ. 68, 2336–2343. https://doi.org/10.1016/j.ecolecon.2009.03.004

Wolske, K.S., 2020. More alike than different: Profiles of high-income and low-income rooftop solar adopters in the United States. Energy Res. Soc. Sci. 63, 101399. https://doi.org/10.1016/j.erss.2019.101399

Wu, Y., Xiao, X., Song, Z., 2017. Competitiveness analysis of coal industry in China: A diamond model study. Resour. Policy 52, 39–53. https://doi.org/10.1016/j.resourpol.2017.01.015

Wu, Y., Ke, Y., Zhang, T., Liu, F., Wang, J., 2018. Performance efficiency assessment of photovoltaic poverty alleviation projects in China: A three-phase data envelopment analysis model. Energy 159, 599–610. https://doi.org/10.1016/j.energy.2018.06.187

Xiao, L., 2016. Research on International Competitiveness of China PV Industry. Master's Thesis, Hainan University, Haikou, China.

Xing, W., 2020. Analysis On the System of "Collective Ownership of Rural Property". Ph.D. Thesis, China University of Political Science and Law, Beijing, China.

Xu, M., Xie, P., Xie, B.C., 2020. Study of China's optimal solar photovoltaic power development path to 2050. Resour. Policy 65, 101541. https://doi.org/10.1016/j.resourpol.2019.101541

Xu, X.L., Chen, H.H., Feng, Y., Tang, J., 2018. The production efficiency of renewable energy generation and its influencing factors:

Evidence from 20 countries. J. Renew. Sustain. Energy 10. https://doi.org/10.1063/1.5006844

Yang, H., Pollitt, M., 2009. Incorporating both undesirable outputs and uncontrollable variables into DEA: The performance of Chinese coal-fired power plants. Eur. J. Oper. Res. 197, 1095–1105. https://doi.org/10.1016/j.ejor.2007.12.052

Yi, T., Tong, L., Qiu, M., Liu, J., 2019. Analysis of driving factors of photovoltaic power generation efficiency: A case study in China. Energies 12, 1–15. https://doi.org/10.3390/en12030355

Yu, H.J.J., Popiolek, N., Geoffron, P., 2016. Solar photovoltaic energy policy and globalization: a multiperspective approach with case studies of Germany, Japan, and China. Prog. Photovoltaics Res. Appl. 24, 458–476. https://doi.org/10.1002/pip

Yuan, X., Zuo, J., Ma, C., 2011. Social acceptance of solar energy technologies in China—End users' perspective. Energy Policy 39, 1031–1036. https://doi.org/10.1016/J.ENPOL.2011.01.003

Zhang, C., Chen, P., 2021. Applying the three-stage SBM-DEA model to evaluate energy efficiency and impact factors in RCEP countries. Energy 241, 122917. https://doi.org/10.1016/j.energy.2021.122917

Zhang, J., Liu, Y., Chang, Y., Zhang, L., 2017. Industrial eco-efficiency in China: A provincial quantification using three-stage data envelopment analysis. J. Clean. Prod. 143, 238–249. https://doi.org/10.1016/j.jclepro.2016.12.123

Zhang, P., Sun, M., Zhang, X., Gao, C., 2017. Who are leading the change? The impact of China’s leading PV enterprises: A complex network analysis. Appl. Energy 207, 477–493. https://doi.org/10.1016/J.APENERGY.2017.05.082

Zhang, S., Bauer, N., Luderer, G., Kriegler, E., 2014. Role of technologies in energy-related CO2 mitigation in China within a climate-protection world: A scenarios analysis using REMIND. Appl. Energy 115, 445–455. https://doi.org/10.1016/j.apenergy.2013.10.039

Zhang, S., He, Y., 2013a. Analysis on the development and policy of solar PV power in China. Renew. Sustain. Energy Rev. 21, 393–401.

https://doi.org/10.1016/j.rser.2013.01.002

Zhang, S., He, Y., 2013b. Analysis on the development and policy of solar PV power in China. Renew. Sustain. Energy Rev. 21, 393–401. https://doi.org/10.1016/j.rser.2013.01.002

Zhang, S., He, Y., 2013c. Analysis on the development and policy of solar PV power in China. Renew. Sustain. Energy Rev. 21, 393–401. https://doi.org/10.1016/j.rser.2013.01.002

Zhang, S.T., 2018. Research on the Reform of Rural Collective Land Property Right System from the Perspective of State Control. Ph.D. Thesis, Shanxi University, Taiyuan, China.

Zhang, T., Matsumoto, K., Nakagawa, K., 2021. The relative importance of determinants of the solar photovoltaic industry in China: Analyses by the diamond model and the analytic hierarchy process. Energies 14. https://doi.org/10.3390/en14206600

Zhang, T.H., Xie, M.C., Wang, B.B., Yukita, K., 2021. System Dynamics Simulation of Shared Value of Distributed Photovoltaics and Its Impact on Distribution Network. Autom. Electr. Power Syst. 45, 35–44.

Zhao, C., Zhang, H., Zeng, Y., Li, F., Liu, Y., Qin, C., Yuan, J., 2018. Total-factor energy efficiency in BRI countries: An estimation based on three-stage DEA model. Sustain. 10, 1–15. https://doi.org/10.3390/su10010278

Zhao, Haoran, Guo, S., Zhao, Huiru, 2019. Provincial energy efficiency of China quantified by three-stage data envelopment analysis. Energy 166, 96–107. https://doi.org/10.1016/j.energy.2018.10.063

Zhao, H., Zhao, Huiru, Guo, S., 2018. Operational efficiency of Chinese provincial electricity grid enterprises: An evaluation employing a three-stage data envelopment analysis (DEA) model. Sustain. 10, 1–18. https://doi.org/10.3390/su10093168

Zhao, X., Wei, W., Ling, W., 2021. A dynamic analysis of research and development incentive on China's photovoltaic industry based on system dynamics model. Energy 233, 121141. https://doi.org/10.1016/j.energy.2021.121141

Zhao, Z.Y., Hu, J., Zuo, J., 2009. Performance of wind power industry development in China: A Diamond Model study. Renew. Energy 34, 2883–2891. https://doi.org/10.1016/J.RENENE.2009.06.008

Zhao, Z.Y., Zhang, S.Y., Zuo, J., 2011. A critical analysis of the photovoltaic power industry in China - From diamond model to gear model. Renew. Sustain. Energy Rev. 15, 4963–4971. https://doi.org/10.1016/j.rser.2011.07.057

Zhi, Q., Sun, H., Li, Y., Xu, Y., Su, J., 2014. China's solar photovoltaic policy: An analysis based on policy instruments. Appl. Energy 129, 308–319. https://doi.org/10.1016/j.apenergy.2014.05.014

Zhou, P., Ang, B.W., 2008. Linear programming models for measuring economy-wide energy efficiency performance. Energy Policy 36, 2911–2916. https://doi.org/10.1016/j.enpol.2008.03.041

Zhu, D., Mortazavi, S.M., Maleki, A., Aslani, A., Yousefi, H., 2020. Analysis of the robustness of energy supply in Japan: Role of renewable energy. Energy Reports 6, 378–391. https://doi.org/10.1016/j.egyr.2020.01.011

Zhu, X., He, C., Gu, Z., 2021. How do local policies and trade barriers reshape the export of Chinese photovoltaic products? J. Clean. Prod. 278, 123995. https://doi.org/10.1016/J.JCLEPRO.2020.123995

Zou, X., Li, B., Zhai, Y., Liu, H., 2012. Performance Monitoring and test System for Grid-Connected Photovoltaic Systems. In Proceedings of the 2012 Asia-Pacific Power and Energy Engineering Conference, Shanghai, China, 27–29 March 2012. IEEE: Shanghai, China, pp. 1–4.

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Appendix A

The 14th Five-Year Plan of newly increased photovoltaic scale

Table A-1 The 14th Five-Year Plan of newly increased photovoltaic scale.

Province	Newly Increased Photovoltaic Scale (GW)
Hainan	52
Inner Mongolia	50
Hebei	32.1
Shandong	29.28
Yunnan	25.9
Ningxia	14
Zhejiang	12
Sichuan	10
Jiangsu	9.16
Tibet	8.63
Liaoning	6
Heilongjiang	5.5
Jiangxi	3.24
Gansu	Wind power and photovoltaic power generation installed capacity reached more than 50GW
Guangdong	The installed capacity of wind power, photovoltaic power generation and biomass power generation is about 42GW
Henan	New installed capacity of wind power and photovoltaic power generation reaches 20GW

Sources: https://guangfu.bjx.com.cn/news/20210719/1164401.shtml (accessed on August 23, 2021).

Appendix B

National income classification

Table B-1 National income classification.

Country Name	Country Code	Income Group
Canada	CAN	High income
Mexico	MEX	Upper middle income
United States	USA	High income
Austria	AUT	High income
Belgium	BEL	High income
Czech Republic	CZE	High income
Denmark	DNK	High income
France	FRA	High income
Germany	DEU	High income
Greece	GRC	High income
Italy	ITA	High income
Netherlands	NLD	High income
Portugal	PRT	High income
Spain	ESP	High income
Sweden	SWE	High income
Switzerland	CHE	High income
United Kingdom	GBR	High income
Israel	ISR	High income
Egypt, Arab Rep.	EGY	Lower middle income
Morocco	MAR	Lower middle income
Australia	AUS	High income
China	CHN	Upper middle income
India	IND	Lower middle income
Japan	JPN	High income
Philippines	PHL	Lower middle income
Korea, Rep.	KOR	High income

Sources:
https://databank.worldbank.org/reports.aspx?source=world-development-indicators#
(accessed on August 23, 2022).

Appendix C

Relative importance of determinants of solar photovoltaic industry in China

-Questionnaire-

Introduction

Thank you for your participation in this questionnaire. We have identified you as one of the major experts working on solar photovoltaic industry in China.

In the 14th Five-Year Plan, the Chinese government is increasingly aware of the importance of effective development of the solar photovoltaic industry in solving the shortage of energy supply among local provinces. This study sets out to explore the relative importance of the factors of solar photovoltaic industry in China. At this stage of the research, we have literature review about the Chinese solar photovoltaic industry and identified 22 factors that are broadly categorized into factor condition, demand condition, firm strategy, structure and rivalry, related and support industries, government, and chance. In order to analyze the relative importance of the factors, we kindly ask you to express your perception of the presented factors.

Contact:

Zhang Tian Tian

*Ph.D. Student at Nagasaki University, Japan

Email: bb53419003@ms.nagasaki-u.ac.jp

* **To return the questionnaire, you have the following options:**

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*** In order to fill in please click just above the line**

Confidentiality

Your response will be treated confidential, and the results are used for academic reasons only. Your response will be treated confidentially (name of the interviewee and affiliations are not going to be cited in any publicly available text) and the results are used for academic purposes only.

You may reserve your right to anonymity if you wish to do so.

Instruction

Summary of the introduction:

1. **Please evaluate the relative importance of each factor comparing with another factor using scale 1 to 9.**
2. **If you have any comment on the presented factors, please write in the comment section provided next to the brief explanation of each factor.**

This questionnaire asks you to evaluate relative importance of six categories (factor condition, demand condition, related and support industries, firm strategy, structure and rivalry, government and chance) and factors that constitute each category on a scale from 1 to 9 (equally important to extremely more important than the others) for each of them.

Below is an example of how to answer the question. The example compares the relative importance of criteria A to criteria B when conducting a solar photovoltaic industry in China. If you think factor condition (criteria A) are very strongly more important compared to demand condition (criteria B), then please click "7" on the criteria A side. Likewise, for the second question, if you think chance (criteria B) are moderately more important compared to government (criteria A), please click "3" on the criteria B side.

*Example Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Factor condition	○	○	◉	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Demand condition
Government	○	○	○	○	○	○	○	○	○	○	◉	○	○	○	○	○	○	Chance

In the following pages, first you are asked to compare the broad categories: **factor condition; demand condition; firm strategy, structure and rivalry; related and support industries; government; chance**. And final the factors that constitute the categories. A brief explanation on each category and factor is provided. There is also comment section next to each brief explanation, in which we would greatly appreciate your thoughts/suggestions/ideas with respect to the factors presented.

1. Evaluation of the six Broad Categories

Based on the short description of each category with lists of factors in each category provided below, please make a careful evaluation of which category is more important when conduction solar photovoltaic industry in China.

Category	Brief Explanation	Comment Section
Factor condition	Natural resources, scientists, infrastructure, labor cost	
Demand condition	Domestic market, overall market installed capacity and environmental pressure, local acceptance	
Firm strategy, structure and rivalry	Industry rules, industry competition, industry environment	
Related and support industries	Photovoltaic manufacturing, grid construction, supporting firms	
Government	Legislation, policies, economic incentives and taxes	
Chance	Industry advantages and industry challenges	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Factor condition																		Demand condition
Factor condition																		Firm strategy, structure and rivalry
Factor condition																		Related and support industries
Factor condition																		Government
Factor condition																		Chance
Demand condition																		Firm strategy, structure and rivalry
Demand condition																		Related and support industries
Demand condition																		Government
Demand condition																		Chance
Firm strategy, structure and rivalry																		Related and support industries
Firm strategy, structure and rivalry																		Government
Firm strategy, structure and rivalry																		Chance
Related and support industries																		Government
Related and support industries																		Chance
Government																		Chance

2. Evaluation of factor condition

Category	Brief Explanation	Comment Section
Natural resources	This refers to the duration and period of solar radiation	
Mineral resources reserves	This refers to the resource potential of silicon, which is one of the most important raw materials for photovoltaic power generation	
Labor cost	This refers to the labor cost of installing, operating, and maintaining solar photovoltaic power generation	
Scientific research and technology	It is one of the important key factors in the development of photovoltaic power generation projects	
Acquiring land	How easy it is to obtain the land required for the development of solar photovoltaic projects	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Natural resources																		Mineral resources reserves
Natural resources																		Labor cost
Natural resources																		Scientific research and technology
Natural resources																		Acquiring land
Mineral resources reserves																		Labor cost
Mineral resources reserves																		Scientific research and technology
Mineral resources reserves																		Acquiring land
Labor cost																		Scientific research and technology
Labor cost																		Acquiring land
Scientific research and technology																		Acquiring land

3. Evaluation of demand condition

Category	Brief Explanation	Comment Section
Energy supply gap (environmental pressure)	Conventional power can not meet the growing power demand, the demand in the power market stimulates the rapid development of photovoltaic power generation	
New installed capacity of solar photovoltaic power generation (market scale)	The newly installed capacity of solar photovoltaic power generation is one of the important indicators of the capacity scale in this field	
Photovoltaic power consumption capacity (local acceptance)	This capacity is identified as the local acceptance level, and the local residents' acceptance of solar photovoltaic power generation projects	
Export volume of photovoltaic products (foreign demand status)	It reflects the demand situation of related foreign industries, which indirectly stimulates the development of the local photovoltaic power generation industry	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Energy supply gap (environmental pressure)																		New installed capacity of solar photovoltaic power generation (market scale)
Energy supply gap (environmental pressure)																		Photovoltaic power consumption capacity (local acceptance)
Energy supply gap (environmental pressure)																		Export volume of photovoltaic products (foreign demand status)
New installed capacity of solar photovoltaic power generation (market scale)																		Photovoltaic power consumption capacity (local acceptance)
New installed capacity of solar photovoltaic power generation (market scale)																		Export volume of photovoltaic products (foreign demand status)
Photovoltaic power consumption capacity (local acceptance)																		Export volume of photovoltaic products (foreign demand status)

4. Evaluation of firm strategy, structure and rivalry

Category	Brief Explanation	Comment Section
Reasonable and effective development plans for photovoltaic power generation enterprises (a reasonable structured renewable energy development plan)	An enterprise has a reasonable and effective renewable energy development plan and encourages consistent and stable strategic investment in photovoltaic power generation projects. The more effective the photovoltaic power generation enterprise's strategy, the more dynamic and competitive the industry will be. The strategy, management, and planning of photovoltaic power generation companies play an irreplaceable role in analyzing the competitiveness of the industry	
Interest rate risk	It refers to the loss caused by future interest rate changes in the photovoltaic industry. Interest rate is the price of funds, it refers to the adjustment lever of the money market capital	

	supply and demand relationship. In China, the interest rate is often subject to the management behavior of the central bank. However, monetary policy and the interest rate levels of other countries or regions have changed due to the influence of many factors	
Grid-connected photovoltaic systems (external environmental conditions)	Power generation industry. Combining grid planning with power plant planning and formulating relevant technical standards are more conductive to the promotion and implementation of the photovoltaic power generation industry	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Reasonable and effective development plans for photovoltaic power generation enterprises (a	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Interest rate risk
Reasonable and effective development plans for photovoltaic power generation enterprises (a	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid-connected photovoltaic systems (external environmental conditions)
Interest rate risk	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid-connected photovoltaic systems (external environmental conditions)

5. Evaluation of related and support industries

Category	Brief Explanation	Comment Section
Photovoltaic equipment manufacturing	It refers to the manufacturing industry provided by the photovoltaic industry and related electronic industries that benefit from the photovoltaic industry. These related and supporting industries will have an impact on the photovoltaic industry	
Photovoltaic power station	Micro-grids, grid energy storage, and smart grids must be developed to ensure the safety, stability, and reliability of photovoltaic power stations	
Tax incentives	The renewable energy industry policy adopted by the Chinese government, the tax incentives for photovoltaic power generation projects include tax exemption or tax reduction. Renewable energy-related enterprises enjoy tax incentives in terms of equipment depreciation	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Photovoltaic equipment manufacturing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Photovoltaic power station
Photovoltaic equipment manufacturing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Tax incentives
Photovoltaic power station	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Tax incentives

6. Evaluation of government

Category	Brief Explanation	Comment Section
Policies issued by local governments	The photovoltaic power generation industry also relies on local government policies that affect demand prospects, local government policies have a clear banner color and accelerate the commercialization of the photovoltaic power generation industry to a certain extent, such as bidding policies and the renewable energy portfolio standard	
Tax reduction and exemption	The three major taxes affecting China's photovoltaic industry are value-added tax, customs duty, and corporate income tax. Value-added tax and customs duties are exempted within the prescribed scope, and corporate income tax rates vary according to region	
Financial subsidy intensity	The financial department arranges subsidies for special funds for renewable energy, including subsidies	

	for grid power generation projects, subsidies for independent power generation projects, subsidies for photovoltaic technology industrialization demonstration projects, and subsidies for photovoltaic power generation infrastructure construction	
China's central government photovoltaic power generation target	The photovoltaic power generation target established by the Chinese government, which can formulate long-term or short-term plans for the needs and feasibility of different regions in China to provide government commitment indicators for consumers and producers in the photovoltaic power generation industry.	
Feed-in tariff	It is a policy that can provide a fixed long-term price guarantee for local photovoltaic power generation companies	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Policies issued by local governments																		Tax reduction and exemption
Policies issued by local governments																		Financial subsidy intensity
Policies issued by local governments																		China's central government photovoltaic power generation target
Policies issued by local governments																		Feed-in tariff
Tax reduction and exemption																		Financial subsidy intensity
Tax reduction and exemption																		China's central government photovoltaic power generation target
Tax reduction and exemption																		Feed-in tariff
Financial subsidy intensity																		China's central government photovoltaic power generation target
Financial subsidy intensity																		Feed-in tariff
China's central government photovoltaic power generation target																		Feed-in tariff

7. Evaluation of chance

Category	Brief Explanation	Comment Section
Opportunities brough by the 531 Photovoltaic New Deal	It brings new opportunities to the photovoltaic power generation industry, the photovoltaic power generation industry can be market oriented, and the degree of dependence on government policies is reduced. It also brings heavy losses to some enterprises.	
Prospects of the photovoltaic industry	Photovoltaic power generation shows promise in reducing environmental pressure, which is mainly reflected in the environmental capacity of the region and the environmental and social impacts related to the production and consumption of photovoltaic power generation	

Criteria A	9 Extreme	8	7 Very Strong	6	5 Strong	4	3 Moderate	2	1 Equally	2	3 Moderate	4	5 Strong	6	7 Very Strong	8	9 Extreme	Criteria B
Opportunities brought by the 531 Photovoltaic New Deal	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Prospects of the photovoltaic industry

Comments/Remarks:

If there are any other factors that you think are important to when conduction solar photovoltaic industry in China, please write in this section.

(*Click below to write comments)

Would you like to receive the final results of this study?

Yes:

No:

And finally, thank you very much for your participation.