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Development of China's Photovoltaic Industry: Stylized Facts, Difficulties, and Prospect

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Abstract: With the target to achieve national carbon emission peak levels by 2030 and carbon neutrality by 2060, China has diverted a large portion of its resources on the development of renewable energy. As one of the most important domestic renewable energy industries, the photovoltaic industry grows at a rapid pace over the last decade. The essay illustrates the outlook of the photovoltaic industry in China at current in the perspective of industrial achievements and China's position in the global market. Through a comprehensive analysis, the challenges of stagnating core technology, imbalance between surging demand and limited supply as well as the dearth of human capital are highlighted. Aiming at a fully-fledged solar energy market in the future, specific suggestions for PV firms and the government will be given. According to the three problems, expansion strategy is advised for firms: expansion of production scale; expansion of recruitment range; and expansion of technology application. Synchronously, the government is proposed supporting policies including fiscal support, academic support and technological support.

Keywords: China, development, photovoltaic, industry, renewable energy

1. Introduction

As the frequency of climate change continues to rise [1], there has been increasing concern about the impact of growing economic activity on the environment in recent years. The development of renewable energy verifies that the protection of the environment and the pursuit of economic prosperity are not necessarily a zero-sum game, as it provides an opportunity for countries to reduce their reliance on traditional energy sources that contribute to carbon emissions. Among various forms of renewable energy, solar energy is given more importance than most of the others. According to the World Bank, the sharply decreased installation cost has reduced the price of solar photovoltaic (PV) modules by 80%, while the global installed capacity has dramatically increased by nearly 600 GW over the past decade [2]. This great change in the solar power sector is not only due to an increased amount of investment in the photovoltaic industry but also the intrinsic property of solar radiation -- a free good with no opportunity cost, a completely free resource available everywhere.

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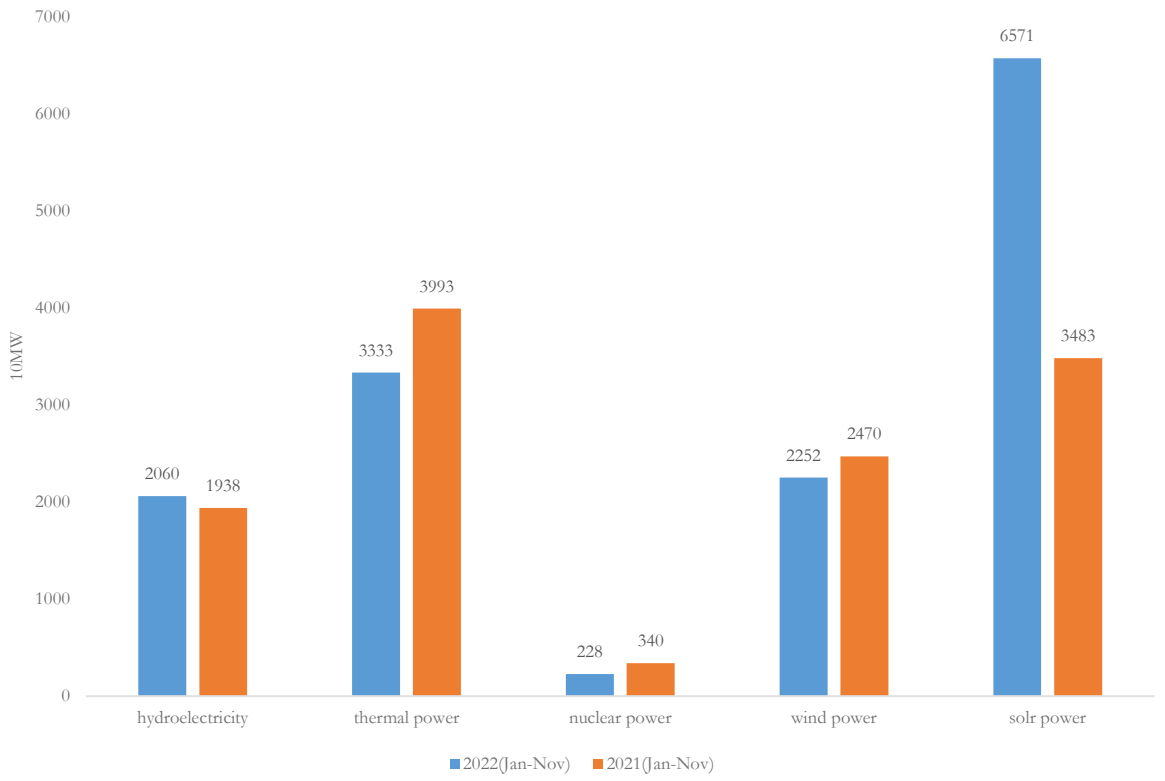

Figure 1: Installation capacity of electricity generation in 2021(January to November) and 2022(January to November).

Data source: National Energy Administration
Photo credit: Original

China, one of the world's biggest economies, has caught up from behind in the PV industry. With a new national carbon emission scheme rolled out in September 2020 aimed at achieving peak levels by 2030 and carbon neutrality by 2060, the country has formulated specific programs to reach its target. The transformation of the domestic energy structure is a crucial strategy involving an expanded demand for clean energy. Total consumption of renewable energy is expected to reach 25% by 2030, according to the 14th Five-Year Plan [3]. As shown in Fig. 1, solar power accounted for nearly half of the total increase in installation capacity, excluding the last month of 2022, and went far beyond that during the same time period in the previous year.

The surge in photovoltaic installation capacity last year reflects a robust expansion in the domestic PV industry in 2022. According to official data [4], the total output value of the industry surpassed 1.4 trillion yuan. This expansion is attributed to both swelling domestic demand, driven by efforts to attain the "30·60" Target, and extended overseas demand, with PV exports offering competitive prices that are favored by international buyers. During the first half of 2022, the gross export value of all PV products amounted to $25.9 billion, representing a 113% year-on-year increase. The export volume of PV modules, one of the main PV products, reached 78.6 GW, which is 74% higher than the previous year. The vast majority of this demand comes from buyers attracted by the comparatively low prices in the global market. As Lin Boqiang, head of the China Institute for Studies in Energy Policy at Xiamen University, pointed out, China is now the leader in the world's photovoltaic race, taking advantage of its equipment manufacturing [5]. Increased productivity due to technological innovation and reduced unit costs of PV modules, owing to economies of scale brought about by the

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cluster effect of firms, has substantially reduced the overall cost of industrial production, making it possible to launch PV products at lower prices while maintaining better quality.

However, the source of external demand for PV products has different components from earlier years. The share of demand for PV module exports from China taken by the European market exceeded 50% in 2022 [5]. Facing high production costs triggered by the pandemic-disrupted global supply chain, most countries are experiencing fetters on the supply side, with Europe being one of the hardest hit regions. The price of traditional energy has also been inflated, as Europe continuously imports a considerable amount of liquefied natural gas from Russia. Solar energy is therefore serving as a substitution and boosting demand for China's exported PV products. Additionally, Europe is expected to struggle to refill its natural gas inventory, a large portion of which has been depleted due to the latest cold winter [1]. As a result, the price of natural gas is expected to remain high, leading to a persistent trend of increasing overseas exports of PV products by switching demand to cheaper solar power.

Despite the current prosperity in the domestic photovoltaic industry, there are insidious problems together with emerging opportunities. The PV industry is facing a dilemma where there is a noticeable imbalance between soaring demand and insufficient supply. Although the disruption of the global supply chain triggered by the pandemic and Russia's invasion of Ukraine has increased the demand for solar energy, the price of raw materials for PV modules has also climbed, especially for metals. Exorbitant energy costs have caused numerous smelters to close and reduced production of refined metals [1]. In addition to the obstruction from expensive raw materials, the shortage of human capital is not in line with the surging demand for manpower with related expertise [6]. Accompanied by the stagnation of technological progress, the enhancement of production capacity has been further hindered. The root of the problem is therefore revealed to be supply-side deficiency.

With the objective of improving the imbalance between supply and demand and safeguarding sustained construction of the domestic photovoltaic industry, the key problem of supply deficiency is fully analyzed in Section 2 from three aspects: raw materials, labor, and technology. In Section 3, policy suggestions for the government and business proposals for private PV firms will be explained in detail.

2. Difficulties Confronted by Domestic PV Industry

2.1. Hiking Price of Raw Materials

The global supply chain has been considerably disrupted by the restrictions imposed during the pandemic and by Russia's invasion of Ukraine. Transport costs have increased due to tightened transportation capacity and prolonged delivery times, which have hindered the usual international freight process of commodities. The commodity price, including energy, agriculture, and metals, has been measured by an index that uses January 2022 as the base month, as shown in Fig. 2. Metal prices have risen persistently since the initial outbreak of the pandemic in 2020, peaking in the first half of 2022. Although the price began to fall after reaching its peak, resulting from weakening demand with globally slowing growth last year, the current price level still remains high, above the pre-pandemic level.

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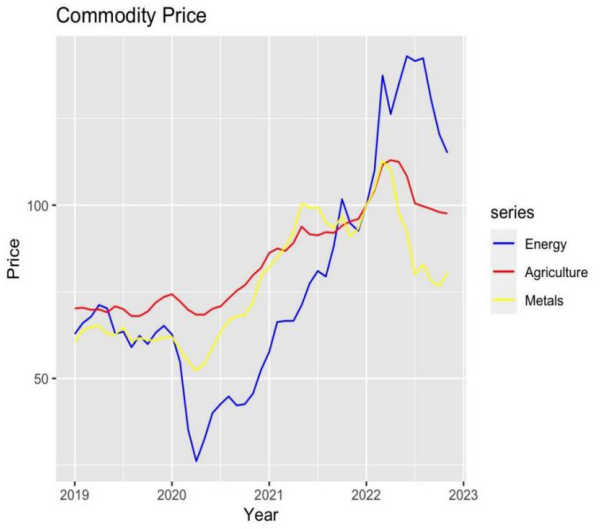

Figure 2: Commodity price of metals, agricultural products and energy from 2019 to the end of 2022.

Data source: Bloomberg
Photo credit: Original

Photovoltaic panel components mainly depend on aluminum, zinc, and steel as the main raw materials. However, due to the skyrocketing energy prices, the situation of most metal suppliers has deteriorated due to the skyrocketing production costs. As a second-level player in the supply chain, firms in the photovoltaic industry inevitably face a pulled-up price of metals required in the production process. Cost-related pressure is also applied to the production of photovoltaic modules, which are another category of the most common PV products. Since the beginning of 2021, the price of silicon, the most important raw material for PV modules, has continued to rise till the end of that year. Fig 3 shows the fluctuations in silicon prices over the decade. The general price level of silicon stayed low and steady before 2021. Following the drastic spike in 2021, the price eventually declined. However, the overall price level in the post-pandemic period is significantly higher than before.

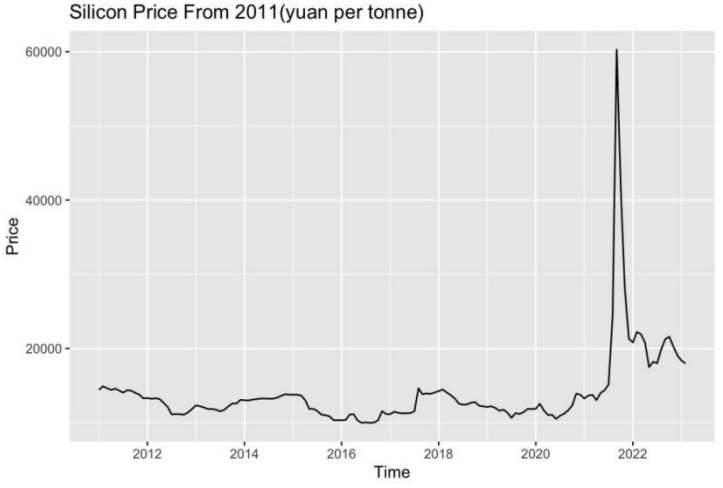

Figure 3: Silicon price from January, 2011 to February, 2023.
Data source: PV_InfoLink
Photo credit: Original

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The energy price shows no sign of a massive reduction this year and is projected to intensify the pressure on the global supply chain. Exports from Russia are anticipated to remain significantly lower than before the start of the Russia-Ukraine War, while the competition for natural gas will remain intense due to Europe's efforts to restore its inventory [1]. Meanwhile, crude oil prices are expected to moderate to $88/bbl on average this year, which is $4/bbl lower than the previous expectation [7]. Nonetheless, the amount of oil production could frustrate the metal producers because the OPEC+ members stick to their production agreement, producing less than enough to reach the target. The shortfall of OPEC+ oil production is displayed in Fig 4.

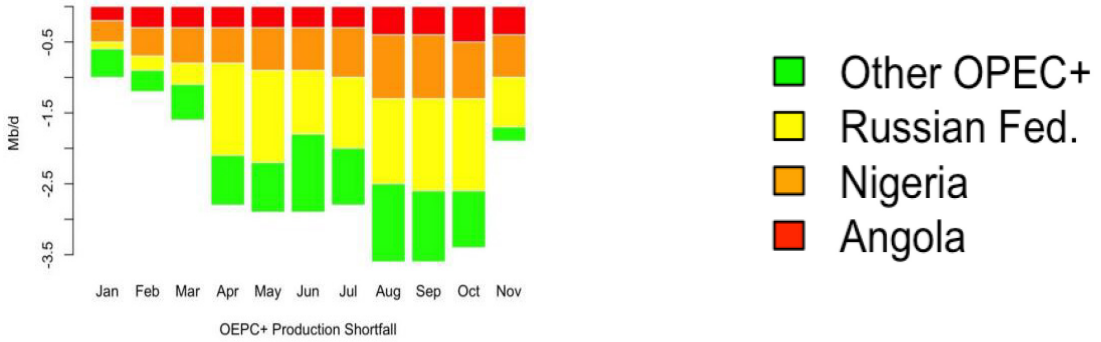

Figure 4: OEPC+ production shortfall from January to November in 2022.
Data source: IEA (2022a)
Photo credit: Original

Consequently, despite the recently relieved global supply chain pressure shown in Fig 5, the burden on the supply side of the PV industry is projected to remain relentlessly heavy compared to that of a few years ago. The high price of raw materials for the PV industry is a warning bell of the imbalance between supply and demand.

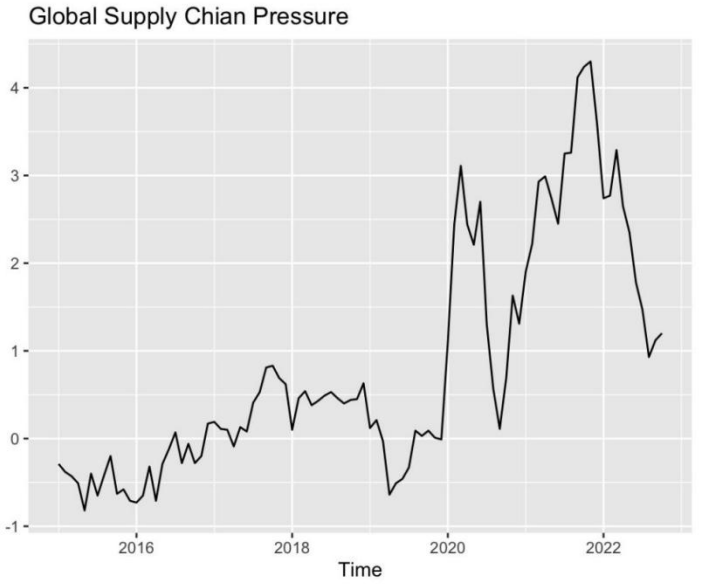

Figure 5: Global supply chain pressure over years.
Data source: Federal Reserve Bank of New York
Photo credit: Original

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2.2. Lack of Human Capital

With the trend of strong growth in 2022, China's photovoltaic industry has achieved a total output value of more than 1.4 trillion yuan, owing to heated demand for solar energy [4]. The demand for photovoltaic products creates a derived demand for human capital in the labor market. However, there is an acute imbalance between the supply of high-quality labor force that can be employed in the domestic PV sector and the excessive demand from firms, including both start-ups and tycoons in the industry. Currently, about 2.5 million people are employed in the domestic PV industry, and an increase of 220,000 is projected in the next three years [8]. The average increase in human capital per year is supposed to be at least 70,000 people, which well outpaces the increase in talents from qualified universities of around 15,000 people a year [8].

A feeble incentive for undergraduates to enter the PV industry is one of the main reasons for the softened labor supply. Suffering from pandemic-related restrictions, China's urban unemployment mounted to 6.1% in April 2022, according to the National Statistics. Although the urban unemployment rate was assuaged to 5.5% by the end of the year, the risk of job losses is still high in the labor market [9]. Due to greater uncertainty, undergraduates are more inclined to accept a job in the public sector with greater security. Jobs offered by the photovoltaic industry are relatively less stable due to frequent fluctuations within the industry, and are therefore more likely to be an inferior choice for most undergraduates who are looking for job opportunities. Only 4% of undergraduates are employed in private firms in the energy and electricity sector, exerting considerable recruitment pressure on businesses [8].

An incomplete training system is another important reason for the current imbalance of supply and demand in the labor market [10]. Courses for further education in universities are commonly designed to be applied to the energy sector as a whole but lack specialized branches, particularly those focusing on the PV sector. Choice teaching materials and textbooks are highly deficient in further courses, which is a universal problem in China's higher education. Some existing resources for study are on the brink of being out of date, as technology changes rapidly in the PV industry. Additionally, scholars often find it difficult to obtain academic results because equipment used in experiments and research tends to be expensive [9].

Furthermore, the geographical distribution of talent is inconsistent with the distribution of the PV industry. A superior education system is built on the base of prosperous economic development. China, a gigantic economy with indubitable influence on the world, however, is not growing equally in every inch of its territory. Gini coefficients of China have consistently been higher than the alarming level of 0.4 in recent years, as illustrated in Fig. 6. The high value of Gini coefficients reflects a large extent of inequality in the country. As a result, human capital with the capability to cluster in the Yangtze River Delta, where the education level is enhanced by more dynamic economic activity [10]. Nevertheless, the PV industry is in the process of transferring to western areas such as Yunnan Province, Sichuan Province, and Xinjiang Province, where the supply of suitable human power is rather sparse.

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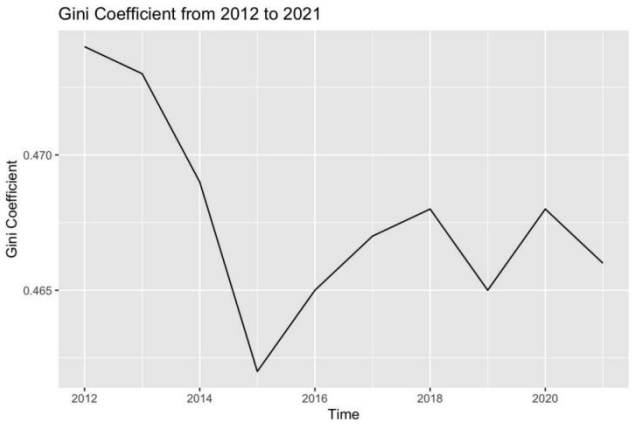

Figure 6: Gini coefficients of China from 2012 to 2021.
Data source: National Bureau of Statistics
Photo credit: Original

2.3. Stagnation of Core Technology

Albeit China's PV industry has already introduced a host of advanced technologies from abroad, the progress in the core technology appears somewhat sluggish. The core technology of the PV industry mainly involves three sections: the cutting technique of silicon slices, the refinement method of the polycrystalline silicon raw material, and the architectural application of the solar system. For the refinement of raw polycrystalline silicon material, physical and chemical refining are the two main approaches used in the PV industry. Currently, over 80% of polycrystalline silicon production firms worldwide adopt an improved chemical refining technique called the Siemens method [11]. Additionally, the Siemens method is the most prevalent method used by the domestic PV industry since it is more mature compared to others. However, there still appears to be a significant gap between the standard technical level and the level achieved by the domestic industry. Moreover, there is a lack of channels for importing metals, exacerbating the scarcity of metals available to the domestic PV industry. The lagging technology results in a combination of high energy loss and low marginal return in the industrial process. The average energy loss in the foreign production of polycrystalline silicon is approximately 125kWh/kg, which is merely half that of the domestic production [2].

If there is a breakthrough in the core technology, the cost of polycrystalline silicon would significantly decrease. However, many photovoltaic companies concentrate more on scaling up production instead of technological progress and product quality optimization. In the short term, economies of scale with lower unit costs can be achieved by expanding production scale, allowing for greater potential profits for firms. However, in the long run, low unit costs relying on economies of scale are not enough to withstand the fierce competition in the PV industry since the barrier of entry has become comparatively low in recent years.

3. Suggestions towards a Solid Growth

3.1. Time for the Government to Take Action

In order to ease the supply-side pressure incurred by high raw material costs, subsidies should be provided for PV firms, especially small and medium-sized firms without an extended production scale to realize economies of scale. Reduction in production costs brought by the provision of subsidies for

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start-up businesses could ensure steadier development processes for the firms and make it easier for these firms to gain a foothold in the industry. Injection of new firms into the industry will further stimulate competition, forcing existing firms to pay more attention to technology improvement and scientific research to remain competitive in the market.

In spite of the zooming demand for talents with photovoltaic expertise in the labor market, few training policies related to the solar power sector are mentioned among existing policy proposals for the photovoltaic industry [12]. Primarily, the government is supposed to invest more in teaching resources in universities, including enhanced teaching levels and up-to-date teaching materials imported from abroad. Extra subsidies should be given to university laboratories to lessen the equipment costs for research and experimentation. The convenience brought by social media benefits the fast spread of information and slashes the extent of information asymmetry. Bolstered publicity of the importance of supporting the renewable energy sector will hopefully encourage more talents to enter associated industries. Regulations of the labor market are needed to suppress the default of labor contracts. There is a close relationship between high labor turnover rates and an unregulated contract system constructed by the work agency in the PV industry. The average time of employment is barely half a year in the PV sector, while an extra fee of 8 yuan has to be paid to the work agency for candidate introductions [10]. Labor market disorder drives the recruitment cost for PV firms to a higher level.

Although China's PV industry has become the world leader attributed to strong growth over the years, China could be struck off its current position if the technology remains stagnated within the domestic industry. To maintain its place as a global leader, investment should be made into the development and research of progressive technology, especially a better refining technique. Production efficiency will thereby be optimized, enabling lower production costs for PV businesses. On a global scale, the competitiveness of domestic PV products will then be fortified with lower prices charged while better quality is delivered.

3.2. For Individual PV Firms -- Keep Aggressive and Progressive

External economies of scale, owing to the cluster effect, can help individual PV firms cut production costs substantially. Determining the exact industrial position will help businesses cooperate more effectively with upper and lower firms adjacent in the industrial chain. To strengthen the coherence between suppliers and manufacturers, firms may increase their geographical links so that production efficiency can be ameliorated by slashing delivery costs. With the trend of large photovoltaic and silicon production factories moving towards western areas, smaller PV firms ought to seize the chance and try to promote geographical mobility.

Utilizing the intelligence and capabilities of talents generates sizable profits and builds competitiveness for PV firms. PV businesses are strongly recommended to cooperate directly with universities. Theoretical knowledge can thereby combine with industrial practice, avoiding the divorce of theory learned by university students in the textbook from realistic operation in the industrial process. In this way, talents with both systematic theory basis and practical experience are introduced into businesses, effectively improving productivity. In addition, expanding the range of recruitment beyond the domestic labor market can offer PV firms diversified choices of talents around the world [12].

Barriers for producers to enter the PV industry are relatively lower than other high-tech industries. Most startup firms formulate their business plan with the salient objective to enlarge the production scale. Although several years ago, production scale expansion was an incisive strategy for most PV firms, this running measure now does not work as well as it did in the early years. Since greater potential profit has goaded an increasing number of firms to enter the industry, competition is ignited. Merely expanding production capacity without technology innovation puts small and medium firms

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at a huge risk of being eliminated from the race. Thus, PV firms must always be alert to being stagnated and emphasize more on technology refreshment. Only firms that are both aggressive and progressive enough are able to stay competitive in this consistently changing industry.

4. Conclusion

Demand for domestic PV products is projected to remain robust for at least the next two years, owing to elevated fossil fuel energy prices last year. A series of negative global supply shocks have led to a favored demand side, while at the same time inhibiting supply-side capacity. Though the trend of growth in the domestic PV industry is tenacious in the next few years, the problem of imbalance is still lurking: the imbalance of limited supply and much too vigorous demand in the final product market; the imbalance between soaring demand for talents and a dearth of human capital supplied in the labor market; and the mismatch of the need for technology advance and businesses' intention of expansion.

Proposals directed against the predicament of imbalance are given from perspectives of both the government and individual firms, mainly supporting the supply side of the domestic PV industry. Green economic development is the basis of the transformation from high-speed development into high-quality development of China's economy. It is impossible to dispatch the development of renewable energy from the attempt to achieve sustainable economic growth. With joint efforts of the government and private firms, the future growth of the domestic photovoltaic industry is expected to become more solid and stable in the hope of promoting this year's economic recovery as well as a further step towards the 30·90 carbon emission target.

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