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# Photovoltaic supply chain coordination with strategic consumers in China

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ABSTRACT

In the context of global climate change, the solar photovoltaic (PV) energy has regained its attention by many governments. The purpose of this paper is to study the coordination mechanisms of the photovoltaic supply chain considering the strategic consumers' behavior under the government's subsidy policies and its impact on the decisions of supply chain stakeholders. A centralized decision model and a revenue sharing contract coordination model for PV supply chain with strategic consumers are respectively formulated and discussed. Using the coordination model and the statistics from the development report of PV industry in the world during 2008–2012, the PV supply chain with monocrystalline modules of 72 solar cells for general power system solutions is analyzed. The analysis has found that revenue sharing is a good coordination mechanism for PV supply chain in the presence of the strategic consumers; while setting a low discount rate and the reduction of modules and assembling costs can increase the utilization of PV systems and the benefit of PV supply chain. The results suggest that governments should set appropriate subsidy policy to encourage PV industry development; the polysilicon module suppliers should enhance the relationship with PV assembler to achieve better coordination and adapt their capacity investment plan and manufacturing schedule to customer demands; in the presence of strategic consumers, the PV assemblers should set appropriate discount rate and share the information with key suppliers to optimize inventory and retail price decision to achieve better coordination; and the strategic consumers should enhance the utilization of PV system to increase their electrical outputs.



## 1. Introduction

Solar energy, a green and clean energy, has regained the worldwide attention in the context of the global climate change. In the past 15 years, the development and utilization of solar photovoltaic energy are progressing very fast [1]. Many large-scale photovoltaic energy programs have been initiated and developed in more than 40 developed nations. The cost in the *photovoltaics industry* (PV industry) has also decreased by twofold in the past 30 years; by the mean time, the industry scale has increased dramatically.

High-purity polysilicon is a key component for the photovoltaic system. Due to its bottleneck on polysilicon purification technology, Chinese government has set an industry policy to encourage the development of PV industry. In the past 10 years, the photovoltaic technology industry in China has leapfrogged to an important industry sector. However, under the government's subsidy policy, the overcapacity and oversupply in the photovoltaic industry have become a problem now. Due to the incentive for quick profits, some manufacturers did not invest in the advanced polysilicon purification and assembly technology, which has led to the high production cost of the photovoltaic system. Most of PV products made by Chinese manufacturers are sold to foreign markets.

As the debt crisis in Europe deepens, European countries have tightened their fiscal spending and reduced the subsidies for PV industry causing the rapid shrinking of PV market. In February 2011, for example, German government revised the solar energy subsidy policy to reduce PV pool purchase price such that the price remains the same only when the installed PV capacity is less than 3.5 GW, or else, the PV subsidy will be reduced by 3% for each additional 1 GW of the installed PV capacity. Due to this impact, SolonSE became the

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first bankrupted solar energy company in Germany. In May 2011, Italy approved a national solar energy subsidy bill for PV power. The annual subsidy fund is within the range of 6 billion to 7 billion Euros, and the subsidy is linked to the installed capacity. In October 2011, Solarworld and the other six PV product companies in the United States made an appeal to the anti-dumping and countervailing investigations on photovoltaic cells, components and other solar energy products that Chinese exports to the U.S. In November 2011, the British government announced that it will cut 50% of the solar energy industry subsidy, which will undoubtedly hurt the UK solar energy PV industry. Suffering from the 311 earthquake, the demand for PV products has slowed down in Japan, which used to be the second largest market of PV products. As the total PV installed capacity in the European market accounted for more than 70% of the world's PV installed capacity, a braking of this important engine has a huge impact on the PV industry in China.

Due to the profit-driven nature of the private capital and the unpractical industry policies of some local governments, the situation of over investment and excess capacity has evolved in China PV industry in only a few years. PV product manufacturers in China were less than 100 in 2008, now this number has already exceeded by 500. By the end of 2011, a total of 67.4 GW had been installed, sufficient to generate 85 TWh/year [2]. The overall production capacity in China has reached 30 GW–40 GW, on the contrary, the global PV demand is only 20 GW–40 GW during 2012–2013 [2]. Apparently, PV industry in China is facing a serious oversupply situation, and the effective strategies for the coordination mechanism between the upstream and downstream enterprises with the right government industry policy are in great need.

Many recent literature have investigated the market and economy of PV industry. Keirstead [3] studied the behavioral responses to photovoltaic systems in the UK. Davies et al. [4] studied the market value of solar PV supply chain integration. Mills et al. [5] investigated the impact of retail rate structures on the economics of the commercial photovoltaic systems in California. Türkaya et al. [6] conducted an economic analysis of the grid-connected hybrid energy systems with solar and wind energy. Macintosh et al. [7] studied the public benefits in solar subsidies of the residential photovoltaic rebate program in Australia. Zhang et al. [8] researched the impact of subsidy policies on the diffusion of photovoltaic power generation. Oh et al. [9] studied the promotion support strategy of PV uses for residential houses in Korea. Hart [10] investigated the market evolution process and regulation of PV electricity in New Jersey. Mitscher et al. [11] studied the economic performance and policies for the grid-connected residential solar photovoltaic systems in Brazil. Grau et al. [12] compared policies of PV industry in Germany and China. Zhao et al. [13] presented the status and prospects of the photovoltaic market in China. Huo et al. [14] presented the current status and governmental interventions of the PV industry development in China. Rigter et al. [15] studied the cost and optimal feed-in tariff for small scale photovoltaic systems in China. Sivaraman et al. [16] investigated the economic performance of the grid-connected PV in California and Texas.

With the increased R&D expenses, new PV products are constantly launched and sold at the full price and older versions of PV products are sold at the discounted price. A customer normally chooses between ordering a newly launched PV product at full price or waiting until its being outdated to buy at a markdown price, whose behavior is called a strategic consumer behavior or a forward-looking consumer behavior [17]. Obviously, the customer behavior has an important impact on the optimal operations management of PV supply chains.

More recent literature have looked into how the supply chain pricing and inventory management impact the behaviors of strategic consumers. Su [18–20] and Su and Zhang [21,22] researched the inter-temporal pricing with strategic consumers' behavior and consumer stockpiling, the impact of commitment on supply chain performance in the presence of strategic consumers' behavior and the optimal pricing in the presence of speculators and strategic consumers. Yin et al. [23] studied an inventory management and optimal markdown pricing policy in the presence of strategic consumers. Liu et al. [24] studied the impact of strategic capacity rationing on early purchases. Cachon and Swinney [25] investigated the relationship among the rapid production, enhanced design, and strategic consumers' behavior. Cachon and Lariviere [26], Wang et al. [27] and Chick et al. [28] have conducted researches on the coordination mechanisms of supply chains. However, very few researches can be found on the coordination in the photovoltaic supply chain.

Most of the researches focus on the impact of strategic consumers' behavior on the pricing and inventory management of the conventional products' supply chains. However, the impact of strategic consumers' behavior on the coordination in a PV supply chain is still scarce, and the impact of the government's subsidy policies on PV supply chain coordination with strategic consumers' behavior is also scarce. Therefore, the purpose of this paper is to construct a coordination mechanism for the photovoltaic supply chain considering the strategic consumers' behavior under the government's subsidy policies and study the impact of the government's subsidy policies and strategic consumers' behavior on the coordination decisions of PV supply chain stakeholders.

## 2. Photovoltaic supply chain system overview and graphic notation

In a PV supply chain, the solar modules (or panels) are the core component of a solar photovoltaic system or station. The solar modules are manufactured by solar module suppliers, with complex manufacturing process of polysilicon purification, ingot molding, wafer slicing, cells manufacturing and panel/module producing. The solar modules together with batteries, controllers, inverters and trackers are then assembled to solar photovoltaic systems by photovoltaic assemblers. Finally, those solar photovoltaic systems (include the Building Integrated PV station, the grid-connected PV system, etc.) are sold and installed for the customers in the market.

Photovoltaic supply chain is very different from the other consumer or industrial goods supply chains. Firstly, a PV system generates the power from the solar energy and reduces the consumption of fossil fuel, which contributes to the energy conservation and Green House Gas (GHG) emission reduction. Secondly, PV supply chains are capital- and technology-intensive with very high entry barrier. Thirdly, the solar energy market size is still very small and the market pricing based on the production costs is difficult and hard to compete with existing utility providers. Thus, the purchasing decision of end users relies on the promotional pricing supported by the government subsidy policies. Finally, the construction and operation of a PV supply chain are not possible without the government's appropriate industry and facilitation policies.

In a PV supply chain, there are major and minor players. Major players include PV assembler, solar modules suppliers and strategic consumers. Minor players are common component suppliers. PV assemblers include companies like Trinasolar, Canadian Solar, and JA solar and et al.; solar modules suppliers include companies like GCL, Yingli solar, and LDK and et al.; inverters are supplied by companies like SMA, KACO, Ingeteam, Siemens, Sungrow and Guanya Power and et al.; controllers are supplied by companies like Max Electronic, Sunway Power, Temaheng Energy and Sanjing Electric and et al.; batteries are supplied by companies like