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Analysis of Feed-in tariff policies for solar photovoltaic in China 2011-2016

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Abstract

In 2011 China initiated policies to promote the adoption of solar photovoltaic (PV) using feed-in tariff (FIT) policies. Since then the PV domestic market expanded substantially. In the past six years, the FIT policies were updated (adjustment of tariff levels, division of three FIT regions, setting of installation quotas) to address emerging problems such as PV waste, explosive installation, unbalanced spatial distribution. This paper aims to investigate the historical development and implementation of FIT policies in China from 2011 to 2016. The tools of net present value (NPV)/ internal rate of return (IRR), learning curve and the system dynamics are employed to show the degree of economic incentives of FIT policies, to understand the learning rate of centralized PV systems, and to study the dynamic mechanism of the FIT system. We conclude that in the near term the tariff levels should be adjusted more frequently to keep NPV/IRR values in the range of 8% – 12%, and a tight quota combined with the deployment of ultra-high voltage (UHV) lines should be continued for the provinces with severe PV waste.

Keywords: Feed-in tariff (FIT); solar photovoltaic (PV); system dynamics; net present value (NPV); internal rate of return (IRR); learning curve.

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1. Introduction

The Chinese government set as a target that by the end of 2020 non-fossil energy should account for at least 15% of national primary energy consumption [1]. The motivations behind this target include dealing with climate change and other environmental problems, improving competitiveness in the field of new energy technologies and promoting national energy security. Solar photovoltaic (PV) is a promising technology to meet that goal.

In China, policies for solar PV were started in 1990s [2]. In the early stage, the China's PV policies mainly focused on R&D (research and development) and product popularization and application stage [3, 4]. The central authority invested in R&D mostly through 863 Programs, 973 Programs and Key Technologies R&D programs [5]. As Lei, et al. [6] pointed out that investment in China PV was mainly focused on manufacturing and application, insufficient in R&D. Because of technology transfer from western countries to China, large European market and low resource costs (labor, land and material resources), China's PV industrial activities started to replace western production capacity [7]. Since 2007 the production of Chinese PV cell has topped the world [3]. However, the development of domestic PV market was really slow, only 140 MW of cumulative installation in 2008 [4]. After 2008, the policies were gradually transferring from supply-side policies to demand-side policies to expand domestic market. In 2009, the central authority initiated the Solar Roofs Program and the Golden Sun Demonstration Program and by 2012 these two programs supported a total capacity of 3423.2 MW [5]. The central authority also sponsored two rounds of public tender for solar power projects in 2009 and 2010 with a total capacity of 290 MW, which aimed to test the benchmark price of domestic PV power generation [8]. Those programs promoted the domestic adoption of PV technology. In July, 2011, in order to deal with the severe manufacturing capacity surplus and the deteriorating international market, China started implementing feed-in tariffs (FIT) policies, marking a new era in the development

of solar PV. FIT policies are instruments designed to attract investment in solar PV generation by offering long-term guaranteed purchase prices to generators for selling their electricity to the grid. With the stimulus of long term guaranteed tariffs, the domestic market expanded rapidly, reached a total of 77 GW cumulative installation in 2016 [9]. Today China is a dominant global player in the PV supply chain, including manufacturing of silicon, ingot, wafer, cells and modules [10].

In China, the development of solar PV has experienced two phases. In the initial phase (2011 – 2013) the domestic PV market was suddenly stimulated by the FIT policies. However, most capacities were installed in the western area of highest resource endowment. In the second phase (2014 – 2016), the rapid expansion continued, but combined with serious waste of PV electricity (see PV waste rate in Table A.5). The PV waste was mainly because most PV power generations located in the less developed western area and no long-distance transmission line existed to connect the solar resource centers to the consumption centers in the central and eastern provinces. In this phase, the FIT policies were updated by setting three FIT regions to encourage investments in the eastern and central China. The quota instrument was introduced to control the PV waste in the western China. Therefore tariffs and quotas worked together to contribute to a balanced spacial deployment, to control PV waste and to contain policy cost. Fig. 1 shows the annual new installation of centralized and distributed power generations. As in China most PV power generations come from centralized systems, our study mainly focus on centralized PV power generations which usually have a capacity of at least 20 MW.

This paper aims to investigate the historical development and implementation of FIT policies in China from 2011 to 2016. We study the economic incentives of FIT policies of seven representative provinces from 2011 to 2016 by calculating NPV/IRR values. We reveal the facts that the policy incentives were increasing in the past 6 years and the quota instrument failed to control the actual instal-

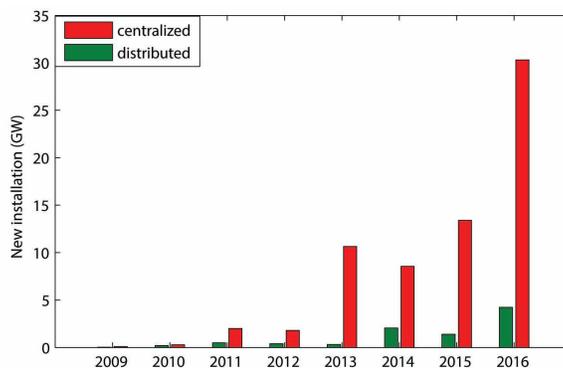


Figure 1: Annual new installation of centralized and distributed PV systems in China [11, 12, 9].

lations in the past 3 years. A system dynamics approach is adopted to explain the mechanism behind these two facts. It incorporates economic approach and technology learning curve to show the dynamic interactions between FIT policies (tariff and quota) and other import factors such as NPV/IRR values, PV technology progress, PV waste and cumulative installation. Finally, our analysis shows that in the near term the central authority should adjust the tariff levels of three FIT regions more frequently to keep NPV/IRR values in the range of 8% – 12%, and a tight quota combined with the deployment of ultra-high voltage (UHV) lines should be continued for the provinces with severe PV waste.

The paper is organized as follows: Section 2 gives a thorough literature review. Section 3 introduces the FIT policies in China. Section 4 describes the methods and data collection. Section 5 shows the historical NPV/IRR values and dynamic mechanism of the FIT system. The last section gives conclusions.

2. Literature review

Worldwide, FIT policies have been the most implemented policy to stimulate the deployment of PV technology [13]. The FIT policies guarantee fixed prices and long contractual periods, which lowers the perceived risks for investors.

Compared with other policy mechanisms such as renewable portfolio standard (PRS), FIT policies are more efficient to increase the capacity and stimulate R&D input to reduce costs [14]. However, FIT policies may inhibit a healthy market competition by giving preferential treatment to certain technologies and increase financial burden on taxpayers [15].

In previous studies, Hoppmann, et al. [16] investigated the evolution of Germany's FIT policies and shown how the characteristics of socio-technical systems affect policy interventions. Gao, et al. [17] developed a step-by-step guidance for late and prospective FIT comers to fine-tune their scheme. For the evaluation of the FIT policies, the economic approaches had been widely adopted. For example, Jenner et al. [18] used economic approaches to assess the success of the FIT policies in 26 European Union countries. Callego-Castillo et al. [19] investigated the effects of FIT policies on wholesale electricity markets and the effects of FIT policies in increasing taxpayer's burden. Ahmad et al. [20] and Shahmohammadi et al. [21] used system dynamics approach to evaluate the impacts of FIT policies on solar PV investments and the generation mix in Malaysia. Also the tool of learning curve is usually adopted to represent the technology progress which is a key component in the optimal FIT models [22, 23].

Focusing on the PV development in China specifically, Huang et al. [7] presented an overview of how China became a world leader in solar PV. Kayser [24] pointed out the risk factors that inhibit demand-driven PV market development. Hui et al. [25] identified that high generation costs and inadequate grid transmission capacity impede the development of clean generation technologies. Zhang et al. [26] proposed a real option model for evaluating PV investment under uncertainty. For the FIT policies specifically, Ouyang et al. [27] calculated the levelized cost of electricity of solar PV for the year of 2011 and compared with corresponding feed-in tariffs. Wang, et al.[28] studied the effects of FIT policies on China's upstream and downstream PV firms. Lin et al. [29] demon-

strated a method to combine FIT policies with emissions trading scheme for a cost-effective climate policy package. Li et al. [30] calculated the annual return on investment and payback period of integrated PV greenhouses systems. Rodrigues et al. [31] calculated the NPV, IRR and payback period of residential PV systems for the year of 2015. However, to our best knowledge so far no one has calculated a series of historical NPV/IRR values of different areas in China for centralized PV system and investigated the dynamic mechanism of FIT system. In this paper, we assess the strength of FIT policies of seven representative provinces from 2011 – 2016 by calculating NPV/IRR values. Moreover, a system dynamics approach incorporating economic approach and technology learning curve is used to show the dynamic interactions of between FIT policies (tariff and quota) and other factors such as investment profits, technology progress and PV waste.

3. The PV FIT system in China

Usually, the elements of FIT policies include: tariff levels, the degression mechanism of tariffs, contract duration and (soft or hard) cap. Compared with the major FIT countries in Europe such as Germany, Spain and Italy, there are several differences in China. As China is a huge country and the distribution of solar resource is highly uneven, the central authority set three FIT regions where areas with higher irradianations will get lower tariff levels. There is no automatic degression mechanism in China and the period of tariff adjustment, almost 30 months, is much longer than other countries. Also the quota instrument in China is different from the hard cap in other major FIT countries (see the detailed analysis in the results section).

3.1. Tariff levels

In July 2011, the National Development and Reform Commission (NDRC) announced a nationwide FIT policy for the development of solar PV. It stated

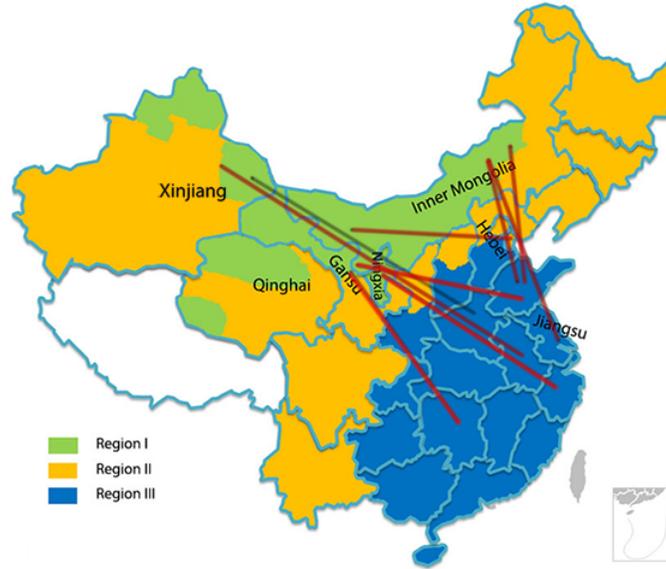


Figure 2: Three FIT regions and the UHV lines(gray line is in operation, red lines are under construction).

that (1) non-bidding projects approved before 1-7-2011 and starting with operation before 31-12-2011 will enjoy a tariff of 1.15 CNY/kWh¹; and (2) projects approved after 1-7-2011 or approved before 1-7-2011 but starting with operation after 31-12-2011 will get a tariff of 1 CNY/kWh [32]. In Aug. 2013, the NDRC issued the "Notice on the role of price lever in promoting the healthy development of the PV industry" [33]. PV power generation was categorized into either distributed or centralized systems. Concerning centralized power generation, the whole country was further divided into three regions, based on solar resource distribution (see Fig. 2. Tibet is an exception, not included in FIT regions.). The tariff were set at 0.9, 0.95 and 1.00 CNY/kWh for Region I, II and III respectively, for projects approved after 1-9-2013 or projects approved before 1-9-2013 but in operation after 1-1-2014. Particularly, it stated that in principle the feed-in tariffs will be guaranteed for 20 years. In Dec. 2015,

¹Exchange rate: 7.30 CNY/EURO, 6.89 CNY/USD, in Nov. 2016.

the updated policy was issued, the "Notice on Perfection of Policy Regarding Feed-in Tariff of Power Generated by Off-Shore Wind and Solar PV" [34], which reduced the tariff levels to 0.80, 0.88 and 0.98 CNY/kWh for Region I, II and III respectively, for projects approved after 1-1-2016 or projects approved before 1-1-2016, but in operation after 30-6-2016. The tariffs are actually paid by the industrial and commercial users by adding renewable surcharge into the electricity price. Currently, the renewable surcharge is 0.019 CNY/kWh [35].

3.2. Installation quota

In 2013, there was an explosive growth of new installation. These new projects were mainly installed in western China such as Xinjiang, Gansu, Inner Mongolia, Qinghai and Ningxia where the ability to absorb renewable energy is limited and they are far away from the load centers of the eastern and central China. In order to curb the crazy installation, contain policy cost and control the potential waste of PV electricity, in Aug. 2013, the National Energy Administration (NEA) introduced installation quota (or caps) [36]. From 2014 onward, the NEA set installation quotas for each province [37, 38, 39, 40]. Whereas in 2014 the NEA specified quotas for distributed and centralized systems, from 2015 onward the NEA only issued total quotas for each province, the latter being free to split that quota between distributed and centralized systems. Usually, these quotas should be realized within one year. The new installation above the quota will not be supported by feed-in tariffs anymore. Such instrument also appeared in other major FIT countries such as Germany, Spain and Italy, after they experienced dramatic growth in PV from 2007 to 2008 [17].

3.3. Tendering

In June 2016, the NEA issued installation quotas for eight PV leading technology bases. They are specialized industry parks located in the provinces of Hebei, Shanxi, Inner Mongolia, Anhui and Shandong, with a total capacity of 5.5 GW

[40]. According to the legislation, these quotas must be allocated to projects by tendering, and only the most competitive enterprises were eligible to participate the bidding. Moreover, the main products such as modules, inverters, and so forth, should be purchased preferentially from manufactures identified as the "top runner"². The tendering scheme can stimulate PV technology innovation and avoid that uncompetitive enterprises survive financially depending on government policies. Moreover, it provides a way of soliciting prices from a wider array of developers. The bidding prices can be used as a guide to set reasonable tariff levels. A similar trend from FIT policies to tendering has happened in other countries such as Australia [17].

4. Methods and data

Three tools are used in this paper: NPV/IRR, learning curve and system dynamics. NPV/IRR is used to show the economic incentives of FIT policies. Learning curve is used to derive the learning rate of centralized PV power systems and to predict the system prices of 2015 and 2016 which are the inputs to calculate NPV/IRR values of 2015 and 2016. The system dynamics approach incorporating NPV/IRR and learning curve is adopted to conceptually show the dynamic mechanism of the FIT system.

4.1. Economic framework

The economic analysis of supported tariff levels is performed by calculating the NPV and IRR of the investment. NPV is the sum across all future years of the difference between revenues and costs, discounted to account for time preference and IRR is the discount rate that makes NPV zero. They are both

²The central authority sponsored the top runner plan in 2016 which made a concrete indexes for module, inverter and other PV components [41]. For example, it stipulated that the conversion efficiency of monocrystalline and polycrystalline modules should be more than 17% and 16.5% respectively. There is no extra subsidies for enterprises that are identified as top runner, but it can improve enterprises' brand value.

measures of the expected profitability of an investment decision, the former is extensive/absolute and the latter intensive/relative. They are defined as follows (notice that IRR is defined implicitly):

$$NPV = -SP + \sum_{t=1}^T (E_t \cdot p_t - O\&M_t - TAX_t)/(1+r)^t \quad (1)$$

$$0 = -SP + \sum_{t=1}^T (E_t \cdot p_t - O\&M_t - TAX_t)/(1+IRR)^t \quad (2)$$

In the previous expressions T (year) is the lifetime of a PV system; SP (CNY/kW) is the system price or installation cost (the sum of permit fee, overheads, module, inverter, control system, rack, wire and other components); E (kWh/kW) is the annual PV electricity output; p (CNY/kWh) is the feed-in tariff or electricity price; $O\&M$ (CNY/kWh) are the operation and maintenance costs; TAX (CNY/kWh) are the taxes including value added tax (VAT) and income tax; r is the discount rate.

We make the following assumptions:

- The lifetime is assumed to be 25 years [27].
- The annual PV electricity output is mainly determined by the irradiation hit on the tilted angle plane annually (I , kWh/m²), the performance ratio (PR)³, the system degradation factor (DF)⁴. We assume that $PR = 0.81$ and $DF = 0.993$ [42], and assume that the PV systems are fixed-axis systems. Annual PV electricity output is calculated as $E_t = I[kWh/m^2]/1[kW/m^2] \cdot 1[kW] \cdot PR \cdot DF^t$ ⁵.

³The performance ratio is the ratio of the actual energy production connected to the grid to theoretical energy production.

⁴System degradation factor is the percentage of initial capacity that is still functional in year t .

⁵ The PV energy production per kW_p equals peak sunshine hours multiplied by actual capacity, and the peak sunshine hours equal to $I [kWh/m^2]/1 [kW/m^2] = I$ h, as peak power of PV module is tested under a constant irradiation of 1kWh/m².

- The discount rate is assumed to be 6% [42]⁶.
- Operation and maintenance costs change over time. We assume that in the first 5 years *O&M* are 0.2% of the system price, in subsequent 7 years they become 0.5%, and beyond that date they rise to 1% [27].
- Taxes include: value added tax (VAT) (with a rate of 17%); income tax (with a rate of 25%). PV generators enjoy several tax reductions: 50% reduction in VAT; income tax exemption in the first three years; and 50% reduction in the subsequent three years [27]. For simplicity we assume that in the first 6 years generators do not pay any VAT, as the VAT which was paid at the time of purchasing the equipments for initial installation can be deducted in the coming years.
- All the electricity produced by PV power generations will be purchased by the grid company.

4.2. Learning curve

A learning (or experience) curve [43] expresses the cost reduction of a technology as a function of cumulative production or installed capacity, which is used as a proxy for the accumulated experience gained through learning-by-doing. The equation of a learning curve is written as:

$$C_t = k \cdot CUM_t^a \quad (3)$$

where *CUM* is cumulative production or installed capacity of the technology, *C* is the unit cost of the production or of the installed equipment, and both *k* and *a* are parameters. This formulation implies that for each doubling of cumulative production or installation the unit cost drops by the percentage $1 - 2^a$, called the learning rate. The learning curve is a simple but powerful tool to model technological progress and to inform policy decision [44, 45, 43]. Bhandari et

⁶ It is a little above the current five-year loan interest rate 5.4%.

al. [46] showed the learning rate of PV system is 10% in Germany and 20% worldwide.

4.3. System dynamics

System dynamics (SD) is a conceptual tool developed in the 1950s by Forrester [47]. In this methodology, the dynamic behaviour of the system is assumed to be a result of interconnected web of feedback loops. Feedback loops represent connections between variables with causal links. They are of two types: positive (also known as reinforcing) and negative (also known as balancing). Positive feedback loops enhance or amplify the feedback of information. Negative feedback loops are goal seeking and tend to resist change in the system. This approach is used to analyze energy policies [7, 16]

In the FIT system, the tariff levels, installation quotas, new installations, technology progress, NPV/IRR values, policy cost, the waste of PV electricity, government attitudes and other components nexus form a complex system. Based on experts' reviews, study of import regulations, analysis of historical data, calculation of NPV/IRR values and derivation of learning rate of PV system, we establish the causal loop diagrams as shown in Fig. 6.

4.4. Data collection

We choose Xinjiang, Gansu, Inner Mongolia, Qinghai, Hebei and Jiangsu as seven representative provinces, as the new installation in these seven provinces accounted for 94.5%, 80% and 69% of national new installation in 2013, 2014 and 2015 respectively. Fig. 2 shows the locations of these provinces on the map. Installations and quotas of seven representative provinces are shown in Fig. 4. Figure A.8 shows the distribution of irradiances of these provinces (note that some provinces have counties belonging to different FIT regions). The national average system prices (i.e., the installation cost of PV), from 2011 to 2016, are shown in Table A.1 (the system prices of 2015 and 2016 are estimated using

learning curves). The system prices for seven representative provinces in 2013 and 2014 are shown in Table A.2 ⁷. As the system prices of seven provinces in years of 2011, 2012, 2015 and 2016 are unknown, we assume the system price of each province in those years to be equal to the national average price. The purchase prices of PV electricity during the first 20 years of its life time (or feed-in tariffs) are provided in Table A.3, split by geographical region. In the last 5 years of its life time the purchase prices are the same as that of coal-fired electricity, shown in Table A.4. Note that the start date of new tariffs are 1-7-2011, 1-1-2014 and 1-7-2016 respectively. We assume the tariff is 1.15 CNY/kWh in 2011, as most projects were installed before 1-7-2011 to obtain the higher tariff. In 2016, actually a part of the projects was supported by the old tariffs. However, for the purpose of simplicity we assume the new tariffs as the tariffs for all in 2016. We also assume that in the future the prices of coal-fired electricity are the same as the prices in 2015.

5. Results

We start by showing two facts: the increasing NPV/IRR values and the failure of quota instrument. Then we investigate the underlying mechanism behind these two facts. Finally we answer the question how should FIT policies adapt in the near term, and discuss the challenges in the medium and long term.

⁷Note that in 2013 and 2014 all provinces' system prices were within a 6.3% range of the average except Gansu, which was respectively 9.22% and 17.72% higher, and Jiangsu, which were 15.64% and 9.49% lower. The lower system prices of Jiangsu are attributed to its developed PV industry, and the higher system prices of Gansu in 2013 and 2014 may be caused by its dramatic increase in installation.

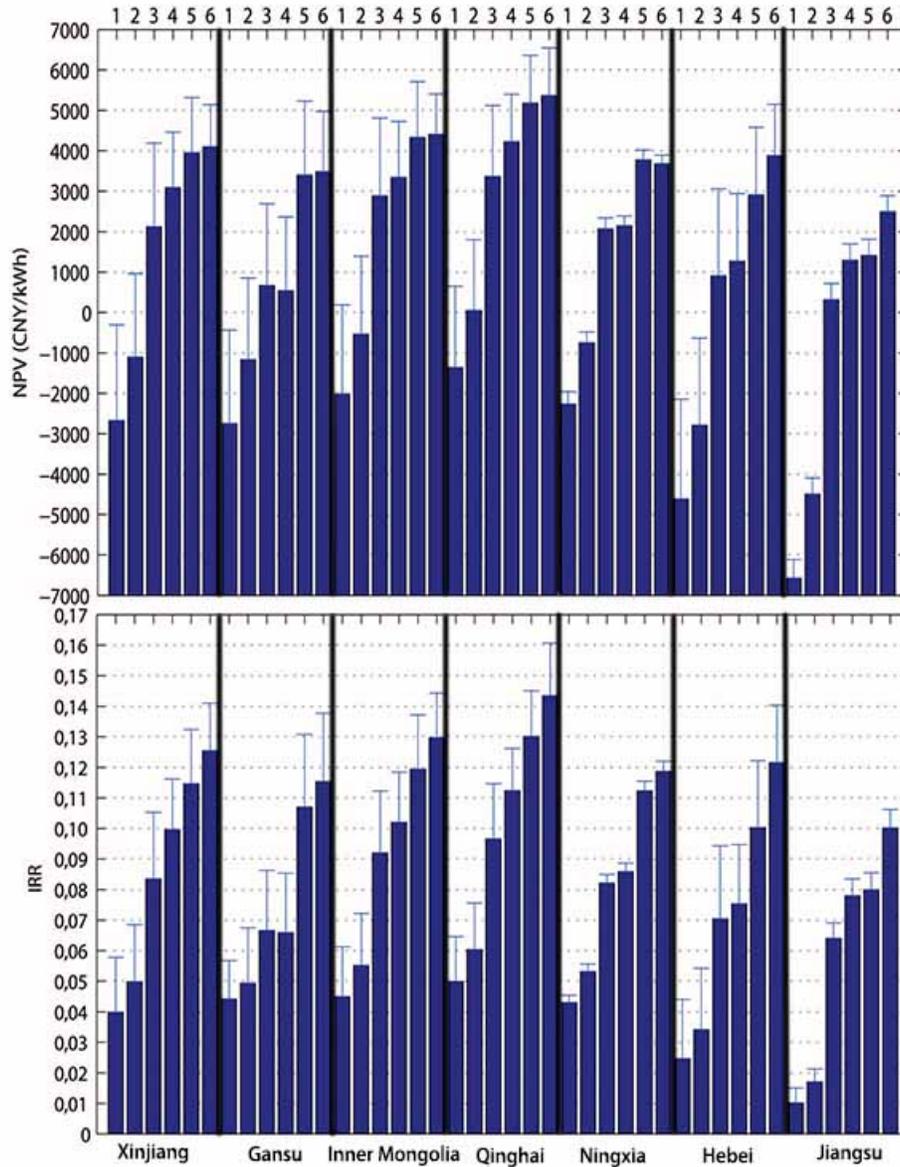


Figure 3: The NPV/IRR levels of seven representative provinces, from 2011 to 2016. It shows the maximum value and 75% percentile value as most installations located in sites with high NPV/IRR values. Number sequence "1 2 3 4 5 6" represents the years of "2011 2012 2013 2014 2015 2016".

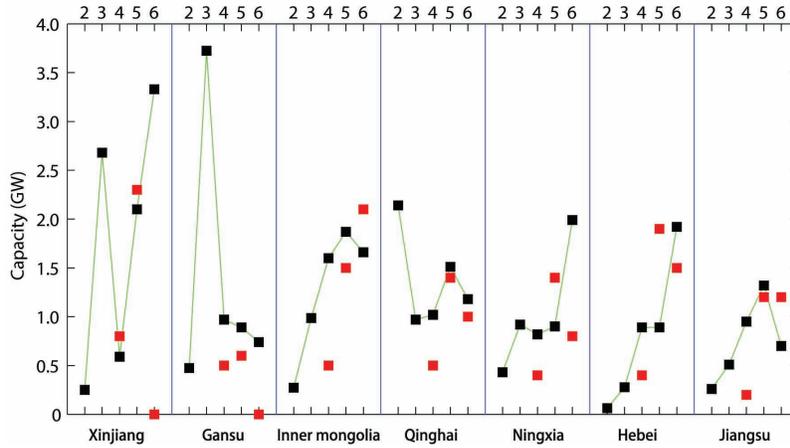


Figure 4: The installations and quotas of seven representative provinces, from 2012 to 2016 [9, 11, 37, 38, 39, 40]. Number sequence "2 3 4 5 6" represents the years of "2012 2013 2014 2015 2016". Red points are quotas and black points are installations. Note that the installation in 2012 is the cumulative installation, others are new installations.

5.1. Two facts

Setting the right tariff levels is a real challenge. Higher NPV/IRR levels attract a wider range of investors but may result in financially less efficient projects and increasing policy cost. While conservative NPV/IRR levels may not be sufficient for market expansion and limit the scope of technology only to those who operate very efficiently [23]. Fig. 3 shows the NPV/IRR values of seven representative provinces from 2011 to 2016. As we can see, in the initial year the NPV values are below zero for most places, which implies the tariff level was insufficient ⁸. In the past 6 years, the central authority adjusted the tariff levels three times (with the start dates of new tariffs at 1-7-2011, 1-1-2014 and 1-7-2016 respectively, see Table A.3). Every adjustment inhibited the rapid growth of NPV/IRR values. However, in 2013 and 2015 when tariff levels were unchanged, the NPV/IRR values increased rapidly. In 2016 the NPV values of the five western provinces (except Qinghai) were slightly declined, but the IRR

⁸With negative NPV values there were still 2 GW installed in 2011, which is mainly because investors were eager to buy tickets to enter this new field.

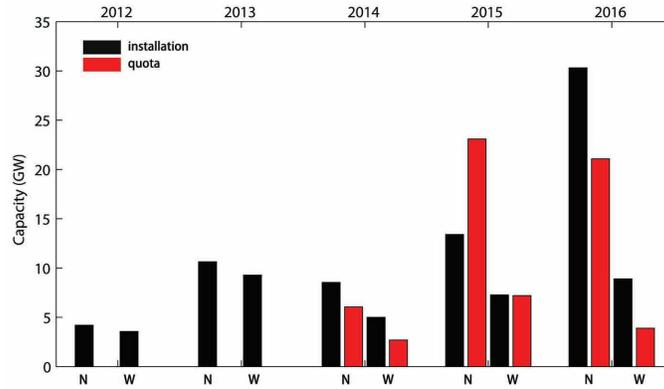


Figure 5: The total installation and quota nationwide and in the western provinces respectively. 'N' represents national and 'W' represents the five western provinces.

values were continued to grow.

Stimulated by the growth of NPV/IRR values, the PV domestic market expanded dramatically, as shown in Fig. 4 and 5. In 2014, the quota instrument was introduced to control the explosive growth of installation in the five western provinces and to obtain an balanced distribution of installation over the western, central and eastern China. However, by observing Fig. 5 we find that the quotas and actual new installations were inconsistent. The new installation in the five western provinces were almost twice more than the quota in 2014, which forced the central government to greatly improve the quota in 2015. Although no quota was allocated to Xinjiang and Gansu in 2016, there were about 3.3 GW and 0.7 GW installed in Xiangjiang and Gansu respectively. All these imply that the quota instrument cannot control the new installation effectively. The uncontrolled installation in the five western provinces made the PV waste in this area getting increasingly severer (see PV waste rate in five western provinces in Table A. 5).

5.2. The mechanism of FIT

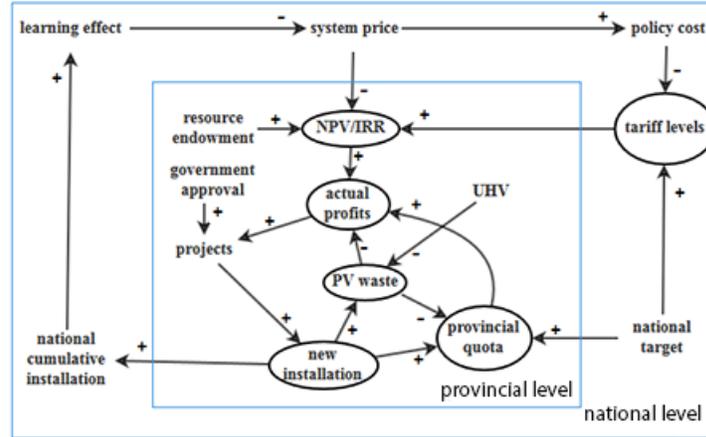


Figure 6: Dynamic interactions between FIT policies and other factors. The cycled elements are the emphasized elements.

Fig. 6 shows the dynamic interactions of different factors in the FIT system. By this systemic view, we seek to explain the increasing of NPV/IRR values and the forces that make local government can ignore the quotas set by the central government. The NPV/IRR values are determined by tariff level, system price (i.e. installation cost) and resource endowment (solar irradiation). Higher NPV/IRR values trigger installation expansion which leads to learning effect or learning-by-doing (LBD) which means the system price declines by a constant percentage with each doubling of cumulative installation. Learning effect is an important factor in triggering technological progress [45]. As shown in Fig. 7, for centralized PV power system in China we find that the learning rate is 16.5%, this is, the national system price will decrease at a rate of 16.5% when cumulative installation doubles. If tariff levels keep unchanged, the NPV/IRR values will rise dramatically as a result of the falling system price (see what happened in 2013 and 2015 in Fig. 3). Hence the central authority has to reduce the tariff level periodically to keep NPV/IRR values at a reasonable range. Observing Fig. 5 and NPV/IRR values of Hebei and Jiangsu in Fig. 3 from

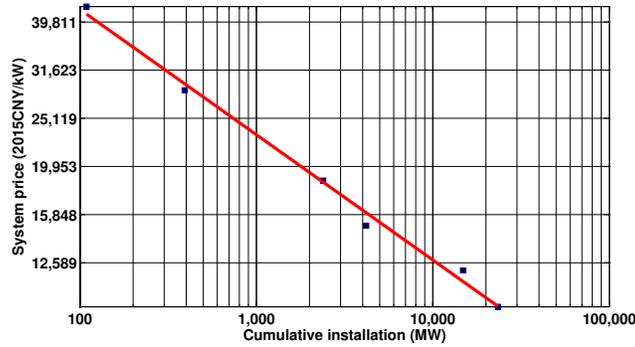


Figure 7: Learning curve for centralized PV system in China with learning rate 16.5%, $R^2 = 0.994$.

2011 to 2015, although the central authority issued more and more quotas for the central and eastern China, the NPV/IRR values were insufficient to stimulate installations in this area. The increasing of NPV/IRR values in the past 6 years was mainly due to i) the reduction of tariff levels did not catch up with the falling system prices, as the uncertain nature of technological progress and very limited cumulative data in early years; ii) the central authority wanted to provide a higher NPV/IRR to further stimulate the expansion of domestic PV market, particularly in the central and eastern China.

In the years of 2012 and 2013, almost all installations located in the five western provinces as higher NPV/IRR values than other areas. However, as the less load demand and the absence of long-distance transmission lines to connect to the central and eastern China, the waste of PV electricity in these five provinces became the most concerned problem (see PV waste rate in Table A.5). It compelled the central government to introduce the quota instrument to curb the crazy installation and the severe PV waste in the five western provinces. A project without quota will not get any feed-in tariff. At the same time, the central authority greatly slashed tariff levels in Region I and Region II (see Table A.3), but the five western provinces still had higher NPV/IRR values than

provinces in the central and eastern China (see Fig. 3). Although the quota is set by the central government, the local governments are the ones to approve projects and allocate the quota. To attract more investments for the purpose of GDP growth, local governments usually approved more projects than their provincial quota. Moreover, they allocated the quota on a first installed first served basis, which forced developers to construct generations quickly to grab the limited quota. For those failed to obtain quota, they can wait in line for the next year's quota. Hence the quota instrument is not a hard cap. It only affects the developers' cash flow and extends the payback year. It seems that the high NPV/IRR values in the five western provinces made project developers willing to take the risk of PV waste and the loss caused by (temporarily) missing the quota. Another factor that greatly impacts the FIT policies is UHV (ultra-high voltage) transmission lines. Currently, one UHV lines is into operation and eight UHV lines are under construction (see Fig. 2) for the development of renewable energy [48]. For example, the Jiuquan (Gansu) – Hunan transmission line is a ± 800 kV HVDC with a transmission capacity of 8 GW over a distance of 2413 km. It will be in operation in 2017. It is expected that when these UHV lines connect to the load centers, the problem of PV waste in five western provinces will be greatly solved, and a large amount of quota will be issued to them to fully exploit the UHV lines. That is the reason why Gansu and Xinjiang installed 0.74 GW and 3.3 GW in 2016 respectively, totally ignoring their zero quotas and severe PV waste rates, 30.45% and 32.23% in 2016 respectively.

5.3. The FIT in the near future

In this subsection, we mainly attempt to answer two questions, how to adjust the tariff levels, and how to set the quota in the near term. Firstly, in the past 6 years the period of tariff adjustment is quite long, almost 30 months, which led to the rapid increase of NPV/IRR values in the year of 2013 and 2015 when tariff levels were unchanged while system price was falling. Hence a more frequent adjustment of tariff levels, at least once every year, should be adopted. Secondly, what is an appropriate NPV/IRR value? As shown in Fig. 4, a sudden

installation growth was happened in the five western provinces in 2013 (except Qinghai ⁹), and in Hebei in 2014, while the corresponding IRR values were approximately in a range of 8% – 12%. Although Jiangsu is a special province with its own province-level feed-in tariffs ¹⁰, the NPV/IRR values of Jiangsu can represent the eastern provinces and some central provinces. In 2016, for the first time, the installation in the central and eastern China suddenly surpassed that in the five western provinces (see Fig. 5), while the corresponding IRR values were approximately in a range of 10% – 11% (IRR values of Jiangsu). Hence we believe that the IRR values of 8% – 12% are reasonable and sufficient to stimulate the installation expansion. The central authority should adjust frequently the tariff levels of three regions to keep IRR values in the range of 8% – 12%. It implies the current NPV/IRR values in the five western provinces are quite high and there is a large room to cut down the current tariff levels in Region I and Region II.

In the near term, a tight quota for the five western provinces is necessary. Although it did not effectively control the installation, without quota the situation will be even worse (see Fig. 4 the crazy installations in 2013 when no quota was

⁹In May 2011, prior to the time of national FIT, Qinghai announced its provincial FIT that projects into operation before 30-9-2011 can obtain a tariff of 1.15 CNY/kWh. Such a strategy attracted the investments from the whole country and led to about 1 GW installation in 2011 and 2012 respectively. The province-level tariff of Qinghai was stopped when the central authority announced national FIT policy.

¹⁰Jiangsu is the only province in China who implements the province-level tariff. It started its provincial tariff in 2009, with 2.15 CNY/kWh, 1.7 CNY/kWh and 1.4 CNY/kWh feed-in tariffs for centralized power generation in 2009, 2010 and 2011 respectively [49]. In 2012, it continued to provide 1.3 CNY/kWh, 1.25 CNY/kWh, 1.2 CNY/kWh and 1.15 CNY/kWh feed-in tariffs for new installations in 2012, 2013, 2014 and 2015 respectively [50]. This explains why a province with poor solar resource and lower NPV/IRR values still has a huge amount of PV power installed. Compared to national 20-year feed-in tariff, the duration of Jiangsu's tariff is unclear. This is the reason why provincial tariff is not considered in calculation of NPV/IRR of Jiangsu.

set). Moreover, with the reasonable IRR values, 8% – 12%, the thrilling effect of quota will be amplified, and both local government and project developers will be more cautious. Ofcourse, the setting of quota should be associated with the process of UHV lines deployment. Once a UHV line is constructed, more quotas should be issued for the corresponding provinces. In the 13th national plan (2016 – 2020) [48], volume target of at least 62 GW was set. Interestingly, only in 2016 34.54 GW (30.31 GW centralized power generations, 4.23 GW distributed systems) was realized [9]. We argue that such installation speed will continue in the coming years as currently the PV electricity only account for 1% of total electricity production [9], and the status of PV waste in the western area will be greatly changed when several UHV lines in operation in 2017, 2018 and 2019. Although the increasing of installation volume will inevitably increases the policy cost which is finally burden by industrial and commercial users, there is still a room for the renewable surcharge as currently the surcharge is only 0.019 CNY/kWh [35].

5.4. Discussion

In this paper, the system dynamics approach is used to study the interactions between different factors. It incorporates economic approach and technology learning, quantifying the relationship between NPV/IRR, system price, tariff levels and resource endowment and the relationship between system price and national cumulative installation. However, not every relationship is quantified in Fig. 6. For example, we cannot calculate the actual profits affected by the limited quota and the risk of PV waste because of insufficient data. And the setting of tariff levels is also affected by the national target, or the ambition of the central authority, which cannot be measured. However, this approach does give us an insight into the mechanism of FIT system. The PV waste is mainly due to i) lack of long-distance (2000 km to 5000 km) transmission lines to connect solar resource centers to load demand centers; ii) the conflict with conventional non-flexibility generations. In the near future, the PV waste caused by the absence of transmission lines will be greatly solved by the deployment of

UHV lines. However, with penetration of PV electricity and highly variability of weather-based energy, the conflict with conventional generations will become increasingly severe. Hence in the medium and long term, in order to promote the development of PV technology we should go beyond the FIT policies. It is essential to improve the grid's system-wide flexibilities to accommodate a high level of weather-based renewable energy [51]. A free electricity market to motivate generators to provide flexibility services will also be a key in this energy transition. Currently, the central authority is trying to promote the reform of electricity market, direct power-purchase for large users, to replace the market of fixed prices set by the government [52]. Finally, a very important question is when the PV electricity will be competitive. Based on our economic framework, to meet 0.36 CNY/kWh – 0.40 CNY/kWh the system prices should be driven down to 5300 CNY/kW – 5900 CNY/kW ¹¹, which requires about 190 GW – 290 GW cumulative installation by the learning rate of 16.5%. That means there is still a long way to go before we achieve grid parity of generation side.

6. Conclusions

The FIT policies have successfully stimulated PV domestic market. In 2016 the new installation has reached 33GW accounting for about 40% of world new installation. However, there are some side effects accompanied with PV expansion such as PV waste. In the past six years the central authority was updating FIT policies by setting three FIT regions, reducing tariff levels and introducing quota instrument to promote sustainable development of solar PV.

In this paper, we have shown the historical NPV/IRR values of seven representative provinces in the past six years, studied the dynamic mechanism of FIT system, and evaluated the performance of FIT policies (tariff and quota).

¹¹The equation (1) is used to calculate system price by setting $NPV = 0$, $p = 0.36(0.40)$ [27, 42].

We have revealed that the NPV/IRR values supported by feed-in tariffs were increasing in the past six years, and that the quota instruments failed to control the actual installation. In the near term, the central authority should adjust the tariff levels more frequently, at least once every year, to keep the IRR values in the range of 8%–12%. Although the quota instrument failed to control the installation, a tight quota combined with the deployment of UHV lines should be continued for provinces of severe PV waste.

As pointed in section 5.4, in order to promote renewable energy development we should go beyond the FIT policies. In the medium and long term, the variability of weather-based renewables will be the key factor in energy transition. The impact of variable renewable energies on the grid system and the flexibility requirement in balancing the supply and demand to cope with high penetration renewables will be our future research topics.

Appendix A.

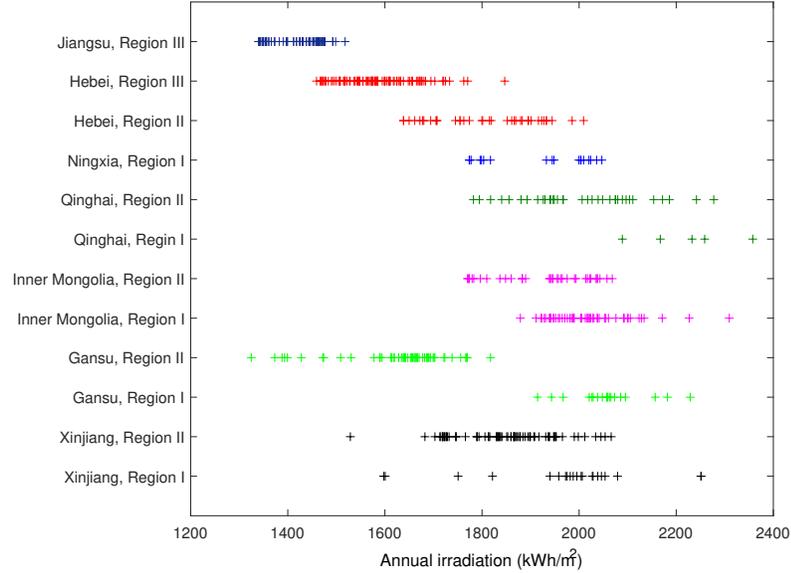


Figure A.8: The distribution of annual irradiation of Jiangsu, Region III (65 counties), Hebei, Region III (37 counties), Hebei, Region II (104 counties), Ningxia, Region I (18 counties), Qinghai, Region II (35 counties), Qinghai, Region I (5 counties), Inner Mongolia, Region II (37 counties), Inner Mongolia, Region I (54 counties), Gansu, Region II (54 counties), Gansu, Region I (19 counties), Xinjiang, Region II (78 counties), Xinjiang, Region I (21 counties). Note that the figure shows the irradiation hit on an inclined panel at the optimal angle instead of an horizontal surface. Data are collected from www.pvtrade.cn.

Time	2009	2010	2011	2012	2013	2014	2015	2016
New installation (MW)	108	283	2000	1800	10638	8550	13410	30310
Cumulative installation (MW)	109	392	2392	4192	14830	23380	36790	67100
System price (CNY/kWh)	35000	25000	17500	14788	12214	10243	–	–
System price (2015CNY/kWh)	42780	28720	18650	15030	12140	10200	9070**	7775 **

Table A.1: Installations and system prices of centralized PV system [11, 53, 54]. ** are the values estimated using learning curve.

Province	2013	2014
Xinjiang	11772	9933
Gansu	13178	11957
Inner Mongolia	11582	10065
Qinghai	11684	10038
Ningxia	12184	10715
Hebei	11303	10724
Jiangsu	10179	9193

Table A.2: System prices of seven representative provinces in 2013 and 2014, in unit of 2015CNY/kWh [11].

	2011	2012	2013	2014	2015	2016
Region I	1.15	1.00	1.00	0.90	0.90	0.80
Region II	1.15	1.00	1.00	0.95	0.95	0.88
Region III	1.15	1.00	1.00	1.00	1.00	0.98

Table A.3: Tariff levels of 3-region from 2011 to 2016 (include VAT), in units of CNY/kWh. Note that the start date of new tariffs are 1-7-2011, 1-1-2014 and 1-7-2016 respectively. We assume the tariff is 1.15 CNY/kWh in 2011, as most projects were installed before 1-7-2011 to obtain the higher tariff. In 2016, actually a part of projects supported by the old tariffs.

Xinjiang	Gansu	Inner Mongolia	Qinghai	Ningxia	Hebei	Jiangsu
0.2620	0.2978	0.2772	0.3247	0.2595	0.3497	0.3780

Table A.4: Prices of coal-fired electricity in 2015 (include VAT), in units of CNY/kWh [35].

	Xinjiang	Gansu	Inner Mongolia	Qinghai	Ningxia
2015	26%	31%	–	3%	7%
2016	32.23%	30.45%	–	8.33%	7.15%

Table A.5: The waste rate of PV electricity [55, 56]. Usually the waste rate should be controlled below 5%.

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