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Distributional justice in Chinese Solar Photovoltaic Power Development under Feed-in Tariff Scheme

Bo Bai
School of Environment and Energy
Peking University Shenzhen Graduate School
Shenzhen, China
bobai@pku.edu.cn

Junping Ji
School of Environment and Energy
Peking University Shenzhen Graduate School
Shenzhen, China
Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory
Berkeley, USA
jackyjjp@gmail.com

Xiaoming Ma*
School of Environment and Energy
Peking University Shenzhen Graduate School
Shenzhen, China
maxm@pkusz.edu.cn

Abstract—To promote the development of solar photovoltaics, dozens of countries implemented Feed-in-Tariff (FiT) Scheme in succession. However, accompanied with the increasing installed solar capacity, the issue of unequal distribution of the subsidies also arises due to its implementation. In China, a large number of solar PV stations concentrate in the more developed areas, which means that these areas could get more subsidies from the central government, whilst the burden is borne by all the electricity consumers. In 2014, China launched the Photovoltaic Poverty Alleviation Project (PPAP) to construct solar PV stations for the poor, indicating that the poor can also enjoy the subsidies derived from FiT Scheme. This paper is intended to illustrate the distributional justice of FiT subsidies in mainland China, so as to fulfill the gap of empirical studies in this field. What’s more, whether the implementation of the PPAP could enhance energy justice and become a reference for other countries is also discussed. The results suggest that the distribution of per capita subsidy was increasingly even during the past five years. However, the per area subsidy is significantly correlated with the local economic development, which is inseparable from the provincial preferential policies. As for the PPAP, it can improve the distributional justice to some extent but the impact is slender at current stage.

Keywords—justice; feed in tariff; Photovoltaic Poverty Alleviation Projects; subsidy; provincial

I. Introduction

Ever since global warming was proposed by some scholars in 1800s, increasing amount of attention has been paid to the issue of climate change, which is mainly attributed to the overuse of conventional fossil energy. To tackle with global warming as well as the depletion of traditional energy, countries around the world have set developing renewable energy sources as one of the national strategies. Solar energy gains great attention for its flexible location as well as widespread availability. Moreover, as the technology matures, the costs of photovoltaic (PV) systems have plunged sharply, dropped by 81% from 2010 to 2017. So far, solar energy has become the third largest RES in terms of installed capacity, which is inseparable from various supportive policies, among which the Feed-in-Tariff (FiT) Scheme is regarded as the most effective one [1,2].

The FiT Scheme is a policy mechanism aimed at promoting the deployment of renewable electricity generation technologies, usually solar PV panels and wind turbines. It's a performance-based incentive, which offered long-term government-specific prices for each output from the eligible renewable electricity generation stations to guarantee the profitability of investors. The Chinese government proposed the first solar FiT Scheme standard in 2011, by the end of 2018, seven adjustments have been made. In 2013, the government differentiated the subsidy for LSPV and DSPV. For large-scale solar photovoltaics (LSPV), China is divided into three resource areas according to the local solar resources and construction costs, and different resource areas execute different benchmark feed-in tariff, so the subsidy of LSPV is the difference between benchmark feed-in tariff and benchmark electricity price for desulfurization coal. For distributed solar photovoltaics (DSPV), the central government grants a subsidy of 0.42 CNY/kWh for each output from distributed solar PV projects. The subsidy for each solar PV project derived from FiT Scheme would last for 20 years. The adjustments after 2013 all followed this regime, but the subsidy amount kept decreasing. While accompanied with the rapid development of solar photovoltaics, the issue of energy injustice emerged due to its implementation.

Fig.1. shows the deployment of solar PV stations in China. Even though the solar irradiation is richer in the western region, the eastern provinces/municipalities (P/Ms) still possess the highest installed capacity based on the provincial data. In 2017, the annual GDP in east of China exceeded 32112 billion CNY, while there is only 4659 billion CNY in the northwestern area. That is, the more developed areas may enjoy higher FiT subsidies from the central government. Besides, the P/Ms where the installed capacity of distributed solar photovoltaics (DSPV) over 40% are concentrated in the eastern part. The main reason is that for DSPV, the “self-consumption first, then surplus feeds back into the grid” mode

dominates, which requires both self-consumption demand and capital accumulation. Meanwhile, large-scale solar photovoltaics (LSPV) tends to locate in the remote areas where the cost of labor and land rental are relatively low. Be that as it may, generous subsidies provided by the local government including both provincial and municipal in the eastern China, especially in Jiangsu and Zhejiang Province, still attracts a number of LSPV projects.

Thanks to the introduction of FiT Scheme, the profitability of investing solar PV systems is quite promising in China. The subsidies from the central government are already enough to get positive net present value [3], while some local governments subsidies are also considerable. Moreover, with proper operation and maintenance, the annual output of solar PV systems is relative stable since the local solar irradiation level has limited change in each year [4], and the consumption of generated electricity is guaranteed by the State Grid Corporation of China and the China Southern Power Gird, both of which are giant state-owned corporations. Thus, investing solar PV projects is at low-risk with considerable payback.

Nevertheless, the cracking benefits aforementioned can only be enjoyed by the renewable electricity generator holders, while the costs of the subsidies derived from FiT Scheme are equally bore by every electricity user, which is known as renewable energy surcharges contained in electricity tariff. In other word, FiT Scheme could redistribute wealth between consumers and producers [5]. Therefore, the eastern areas possess more installed solar capacity than the western region, which may further exaggerate the unbalanced regional development.

When the developed P/Ms were busy with introducing local subsidies to promote the development of solar energy, on 11th October, 2014, the National Energy Administration (NEA) and the State Council Leading Group Office of Poverty Alleviation and Development (CPAD) issued *the Notice on Implementation of Photovoltaic Poverty Alleviation Project* (PPAP), indicating that the provinces with lots of impoverished counties can also enjoy the benefits derived from solar PV systems. The PPAP refers to using the revenue derived from solar PV systems to help the poor by distributing subsidy to the impoverished households with annually minimum 3000 CNY/household. PPAPs get funded from the government in the form of both the initial investment capital support and solar Feed-in Tariff subsidy. Usually, the central government provides a part of the initial investment and later FiT subsidies, and local governments together with some enterprises fund the remaining.

Fig. 1. The provincial installed capacity of solar photovoltaics systems in China in 2018

Data Source: National Energy Administration

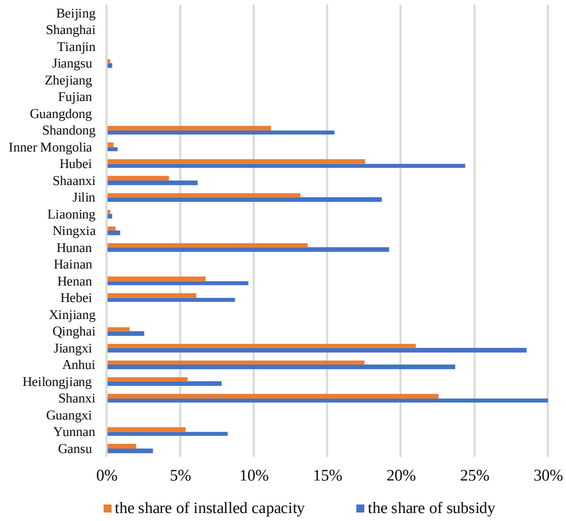

Fig. 2. The proportion of poverty alleviation PV stations to the total solar PV stations in each P/M

Solar PV projects have several attractive features, which makes them to be a qualified poverty alleviation project in the poor rural areas in China. Firstly, as just mentioned, its profitability is promising. Secondly, in China, the impoverished areas usually enjoy large empty land and high solar resources, except for some southwestern areas. Solar PV stations have fewer requirements on the natural environment, except for abundant solar insolation [6], and the location of solar PV stations is more flexible [7] compared with hydro power or wind power. Thirdly, the remaining impoverished people is either lived in extremely poor regions with harsh substantial environment and fragile ecology, or lack of the ability to work. Solar PV stations require limited labor input during its operation. Last but not least, developing solar photovoltaic energy has been one of the main strategies in response to the energy shortage as well as environmental degradation. The rapid development of the photovoltaic industry has accounted for overcapacity in China, and PPAP could form new market to absorb this overcapacity and help the industry get further developed [8].

Ranking by the per capita GDP from the highest to the lowest, Fig.2 shows the proportion of PPAPs in each P/M in terms of the total amount of subsidies and the installed capacity. Shanxi, Jiangxi and Hubei top the list which means that PPAPs contribute considerably on the way to the development of solar energy in these areas. While for the more developed areas, the contribution of PPAP is little. Moreover, the subsidies for PPAPs are higher than the normal PV stations, and the installed capacity of PPAPs is still increasing. Therefore, its implementation may promote energy justice during this energy transition in China.

Despite serious concern over the solar FiT Scheme, there is little empirical evidence to illustrate the distribution of subsidies especially from the regional perspective. What's more, whether the implementation of PPAP could enhance the energy justice and can become a reference for other countries. Thus, this paper is intended to fulfill this gap by recognizing the distributional justice of FiT Scheme in China from a provincial perspective. Unlike the fuel subsidy or carbon emission quota, which are usually measured by the per capita amount to evaluate the distribution equality. The FiT subsidies do not arise from people's activity, but it's for the generated electricity. There are two major production factors of the solar PV stations namely solar irradiation and land, except for the PV module and auxiliaries. Solar irradiation is required to convert into electricity power, while land is used to allocate the PV module. Some people may argue that the subsidies would flow to people at the end anyway. Therefore, in this paper the distributional justice of FiT subsidies in mainland China would be discussed from two aspects, namely per capita subsidy and per area subsidy.

Discounted cashflow model is employed to calculate the total subsidies. The per capita subsidy inequality is measured with the help of Gini coefficient, and regression analysis is introduced to further investigate the per area subsidy justice. Apart from Guizhou, Chongqing, Sichuan where the solar irradiance is very poor, and Tibet where the nationwide FiT Scheme is not applicable, the rest 27 mainland P/Ms are included as the research subjects. The results show that from 2013 to 2018, the distribution of per capita subsidy is more and more evenly. Besides, the per area subsidy is significantly correlated with the local economic development. PPAP can mitigate the distributional injustice during the energy transition to some extent with proper initial investment capital structure. However, when the initial capital of PPAPs is mainly in the form of enterprises participation, conversely, PPAPs would exaggerate the income gap.

II. Literature Review

Several classic tenets of energy justice have been proposed, namely distributional, recognitional and procedural justice [9]. Distributional justice argues that both the burden and benefits should be equally allocated, which dominated justice theory for a long time. Recognition justice emphasizes the equal recognition among various groups without any prejudice or discrimination, while procedural justice concerns the equitability of process and elements during the decision making procedure[10].

Some scholars have already argued that the FiT Scheme could lead to distributional injustice, since the RES surcharges are equally borne by all the electricity consumers while the benefits are enjoyed by the equity holders of the solar PV projects who usually tend to be the rich with sufficient investment capital [11]. As a consequence, the majority of subsidies flow to the rich people, which might further aggravate the income gap and deeply mattered to the claim of distributional injustice [12]. However, few literatures discuss the provincial level justice brought by the FiT Scheme, especially caused by the uniformly subsidy from the central government. Some literatures evaluate the justice from the postal level, and point out that the distribution of benefits tends to gather in higher income areas, but still based on the case of capital cities level [13,14].

There are a variety of principles or values can be used as a basis for distributional justice, such as equity, equality and needs, each of which is associated with different social contexts and psychological orientations [15]. When fostering or maintenance of enjoyable social relations is the common goal, equality is the dominant principle of distributive justice. While when economic productivity is a primary goal, equity dominants [16]. Thus, either the measurement of equity or equality can shed light on the quantitative analysis of energy.

By proposing equity index, [17,18] evaluate energy policy with the consideration of distributional justice. Logistic regression is employed when there are plenty of data. At community level, [19] discusses the energy justice in UK in terms of the onshore wind and solar farms deployment. [20] analyzes distributional justice of wind power development in Swedish, and finds that the areas where highly educated population are concentrated tend to reject windmill proposals. Gini coefficient is widely accepted as a classic measurement of inequality, which is bounded between 0 to 1. It's initial proposed by Corrado Gini in 1912 to gauge the economic inequality, usually measuring income distribution among a population. The traditional Lorenz curve plots the cumulative percentage of population as the x-axis versus cumulative percentage of income as the y-axis. Later in 1997, the Gini index is introduced to measure the inequality of carbon dioxide emissions among countries [21]. More recently, Gini index has been extended more widely in energy studies, from the equality of energy consumption [22,23] and fuel subsidies [24,25], to the equitable allocation of renewable portfolio standards [26]. The energy Lorenz curve employs the same horizontal axis, while the cumulative percentage of energy consumption distribute along the vertical axis. However, few literatures employ Gini coefficient to measure the distribution of the subsidies derived from the FiT Scheme.

III. Material and Methods

A. Gini Coefficient

With the help of Lorenz curve, Gini coefficient can be calculated easily as a numerical measurement of inequality. In this paper, the Lorenz curve is depicted with the horizontal axis representing cumulative population of provinces and the cumulative percentage of subsidies are lying along the vertical axis. Subsidies are in ascending order by per capita subsidy within each P/M to ensure that the slope of Lorenz curve follows monotonical increase. Gini coefficient equals twice the area enclosed by the perfect equality line and Lorenz curve, which can be formulated as follow:

$$Gini = \sum (Y_i + Y_{i+1})(X_{i+1} - X_i) \quad (1)$$

Where $Gini$ is the Gini coefficient based on the FiT subsidies. X_i is the ratio of cumulative population by P/M i to the total amount of population, and Y_i is the quantile of subsidies received by P/M i. The larger the Gini coefficient is, the severer the inequality issue is.

The calculation of subsidies adopts the discounted cashflow method to reveal the time value and investment risk, since the subsidies derived from FiT last for 20 years. Generally, the total FiT subsidies of each P/M including both DSPV and LSPV, thus:

$$Subsidy_i = \sum_1^{20} \frac{sub \cdot E_i \cdot \alpha_i + (fit_i - edc_i) \cdot E_i \cdot (1-\alpha_i)}{(1+r)^n} \quad (2)$$

Where $Subsidy_i$ is the total subsidy received bu P/M i. sub is the subsidy for each output from DSPV. E_i is the annual amount of electricity power generated from solar PV stations in P/M i. α_i refers to the share of installed DSPV capacity. fit_i is the feed-in tariff for each output from LSPV. edc_i is the local electricity price for desulfurization coal. r is the discounted rate to convert all the future cash flows into the present value.

The total annual electricity output is determined as follows:

$$E_i = C_{pv} \cdot PSH_i \cdot e \cdot \eta_{pv} \quad (3)$$

Where C_{pv} is the installed capacity of PV systems. e is the overall loss factor for PV array which is set to be 18%. η_{pv} is the degradation rate of PV module that introduces only a small change of around 0.7%/year.

B. Pearson Correlation

Aside from population related inequality, the Pearson correlation analysis is employed to evaluate the relationship between the level of regional socioeconomic development and per area subsidy received from the central government. GDP per capita is chosen as the indictor for socioeconomic status of each P/M. The reason why we use per capita GDP instead of total GDP is that the scale of each P/M varies a lot, thus the total GDP could not reflect the real status of socioeconomic development.

To make the indicators (subsidy per area and GDP per capita) more comparable, max-min normalization is employed to keep the range of all the indicators between 0 to 1:

$$z_k = \frac{(x_k - \min(x))}{(\max(x) - \min(x))} \quad (6)$$

where z_k refers to the k[th] normalized data of the indicator, and x_k refers to the original data. min and max are the minimum and maximum value of that indicator.

C. Data Collection

The provincial installed solar capacity is collected from the NEA website, and the installed capacity of PPAP in each P/M is listed in the Photovoltaic Poverty Alleviation Projects' Subsidy Catalogue of Electricity Tariff Surcharges for Renewable Energy issued on 20th March 2019 by the National Development and Reform Commission (NDRC), the NEA, the CPAD and the Ministry of Finance of the People's Republic of China. So far, the qualified PPAPs locate in 22 P/Ms. Due to the poor solar irradiation condition, Sichuan, Chongqing, Guizhou are excluded as the objective implementation provinces. Thus, only 27 P/Ms are included in this research. The benchmark electricity price for desulfurization coal in each P/M is collected manually from each Provincial Development and Reform Commission or Provincial Price Bureau. GDP per capita is collected from the National Bureau of Statistics.

The yearly average insolation data of 814 cities in 27 provinces/municipalities in mainland China (except for Tibet) is collected from NASA, and the arithmetic mean within each province is calculated as the provincial insolation data. For PPAP, according to the Suggestions on the Implementation of Accelerating the Construction of Energy Development in Poverty Areas and Push Forward the Work on Poverty Alleviation unveiled on 24th December 2015, the qualified location to implement PPAP should satisfy minimum 1100 utilization hours on average in recent years. By screening the insolation data of no less than 1100 utilization hours, 737 cities are left. Still, we take the arithmetic mean within each province as the provincial insolation data.

The FiT Scheme subsidies of solar PV stations follow the subsidy standard implemented in that year when the solar PV stations put into operation.

IV. Results

Starting from 2013, the installed capacity of solar PV stations in China has soared dramatically. At the very beginning, the deployment of solar PV stations was very concentrated, and the development give priority to LSPV. By the end of 2013, the installed capacity of Gansu, Qinghai and Xinjiang accounted for over 59% of the total installed capacity in China, all of which enjoy high solar irradiation. The province with the highest per capita subsidy was Qinghai, which ups to 7155.16 RMB/cap, while the per capita subsidy for Heilongjiang is only 2.92 RMB in 2013.

As the subsidy for DSPV became attractive, accompanied by the promotion of "self-consumption first, then surplus feeds back into the grid" mode, DSPV gradually gained great popularity. Unlike the LSPV, of which the profitability largely depends on the local insolation level. DSPV benefits a lot from self-consumption, which is highly related to the local electricity price. Therefore, the deployment of solar PV stations began to aggregate in the P/Ms where the socioeconomic status is more developed for both higher electricity demand and retail price.

Fig.3 reveals the provincial equality of subsidy distribution. From 2013 to 2018, the distribution of subsidies among P/Ms was getting more evenly. The Gini coefficient almost reduced by half over the past five years, decreasing from 0.854 to 0.447. The most important reason which results in the increased equality is the promotion of DSPV. Differing from LSPV of which all the generated electricity is fed back into the grid, there is considerable proportion of electricity directly consumed for DSPV. Therefore, the location of DSPV must accompany with electricity demand, which is highly correlated to the number of populations, so the per capita subsidy is more equally distributed.

What's more, the implementation of PPAP also promote the overall equality to some extent. As shown in Fig.4, without PPAP, the Gini coefficient is 0.462, compared with 0.447 for the current overall Gini coefficient. In other word, the implementation of PPAP reduced the distributional inequality by 3.2% in 2018, and the installed capacity of PPAP accounts for 6% of the total.

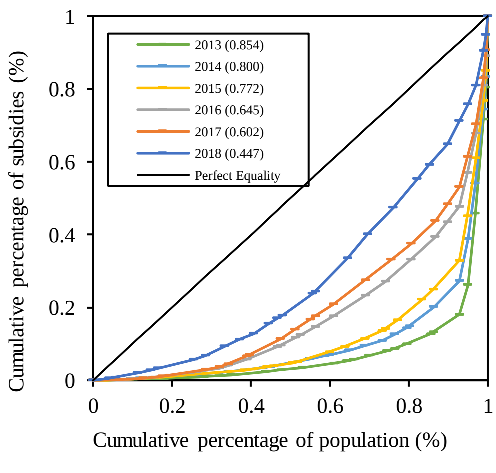

Fig. 3. Lorenz curve of provincial subsidies derived from solar FiT Scheme with population on X axis, from 2013 to 2018 (Gini coefficients are in the parentheses).

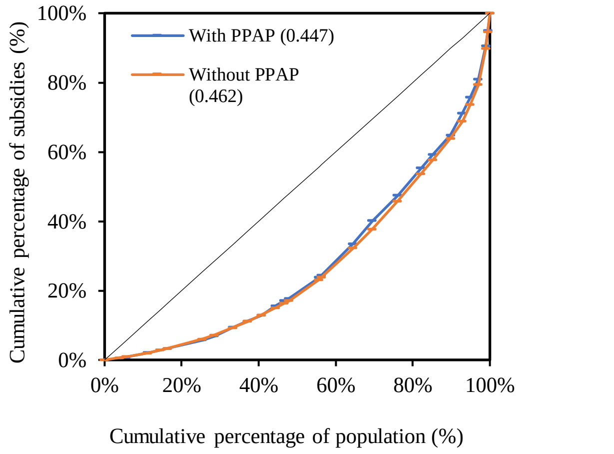

Fig. 4. Lorenz curve of provincial subsidies derived from solar FiT Scheme with population on X axis, in 2018 (Gini coefficients are in the parentheses).

However, the majority of installed solar PV systems in China do not need to be allocated in the densely populated places. By the end of 2018, 71% installed capacity of solar PV stations is in the form of LSPV. For LSPV, the best deployment choices are actually the places with high insolation level and massive cheap spare land.

If the solar PV systems are uniformly deployed across China, which means that the per area installed capacity is the same in each P/M, the subsidies distribute to each P/M would mainly depend on the local solar insolation level. However, Fig.5 shows a positive correlation between per area subsidy and per capita GDP. Even though that some places like Qinghai, Gansu enjoys splendid solar resources, the per area subsidy is still very low. On the contrary, Shanghai, Jiangsu and Zhejiang top the list in terms of per area subsidy.

It's true that the more developed areas tend to have higher electricity demand, but it is not suitable to give more subsidies from the central government to the more developed areas, especially when the relatively poor P/Ms contribute a higher proportion of their GDP. Solar PV systems actually can be viewed as factories, and the production is electricity. Moreover, like other products, the electricity can be transferred to other places. Usually, the factory with lower cost and higher efficient can make more profits, and therefore enjoys better development. However, the developed P/Ms distribute local subsidies to promote the development of local solar PV, which directly result in the sharply increased installed solar PV capacity. At the same time, the central subsidy also flows to these developed areas.

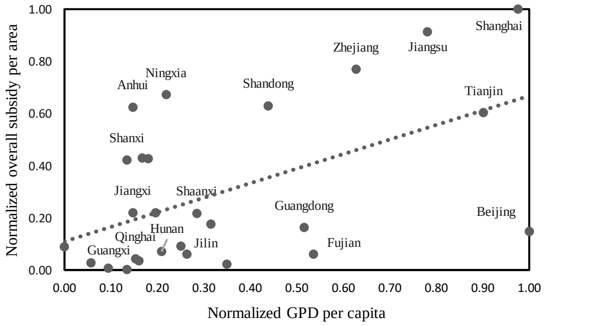

Fig. 5. The normalized GDP per capita against the over subsidy per area

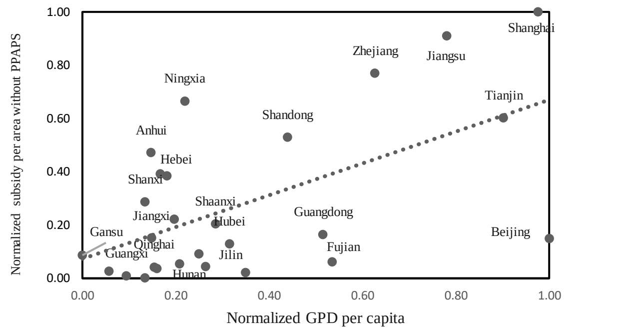

Fig. 6. The normalized GDP per capita against the normalized subsdiy per area without PPAPs

By separating PPAPs from the ordinary solar PV stations, Fig.6 shows the correlation between per area subsidy and per capita GDP when there is no PPAPs. The slope of the trend line is slightly larger in the exclusion occasion. Besides, the Pearson correlation results listed in Table I also show that when there is no PPAPs, the correlation coefficient between per capita GDP and per area subsidy is higher and more significant. Thus, the implementation of PPAP have weaken the relationship between per area subsidy and per capita GDP.

TABLE I. THE CORRELATION BETWEEN PER CAPITA GDP AND FSI

	FSI without PAPSs	FSI with PAPSs
per capita GDP	0.580***	0.528**

Note: ***p≤0.01, **p≤0.05, *p≤0.1

V. DISCUSSION

The above analysis is on the condition that all the subsidies belong to the local government or the impoverished families. However, the current initial investments of the existing PPAPs consist of considerable proportion of external capital, namely bank loads and enterprises' capital for equity participation. Therefore, we collect detailed PPAPs information in 12 representative provinces to further investigate the effectiveness of PPAPs under the different capital structure.

The initial investment capital structure varies a lot across different P/Ms. The proportion of external capital in Hainan province ups to 89.30%, while only 36.8% in Hubei province. In terms of the proportions of donations, in all P/Ms, it is pretty low with maximum of 4.00% in Liaoning. Given the abovementioned capital structure, we evaluate the economic performance of PPAP in each province by the net present value, payback period and the total net cash flow to the local government and the poor. Our results show that the economic performance of Shanxi, Xinjiang and Liaoning is the best for both NPV and the overall economic performance, while Jiangxi is the lowest. However, the payback period and discounted payback period is the shortest in Hainan, which is due to the little government support at the beginning.

It seems like a good thing at first sight, since even the government contributes nothing at the beginning, there are still some impoverished households can get subsidies from PPAP. However, this rather little government input also results in considerable income flowing to the enterprises, which mainly comes from the FiT subsidies, represented by the case of Hainan. The total subsidies under FiT Scheme from the central government to PPAPs in Hainan is 12132.52 CNY, while only 5973.19 CNY belongs to the local government and impoverished households over its lifetime. Thus, when the enterprises capital of PPAP is extremely high, the effectiveness of PPAP is nullified, since the subsidies from central government flows to the enterprises' pocket. Moreover, the distribution of solar PV enterprises is mostly gathered in the developed eastern coastal cities, which may further enlarge the regional economic development gap.

VI. Conclusions

This paper discusses the energy justice issue derived from the development of solar energy in mainland China from a provincial perspective. Both the distribution of per capita subsidy and per area subsidy are illustrated. The results show that from 2013 to 2018, the Gini coefficient based on the subsidies was keeping decreasing, which means that the distribution of per capita subsidies among P/Ms was getting more even. The promotion of DSPV is the most important reason for this, and the implementation of PPAP also help to some extent. Without the implementation of PPAP, the economic benefits of FiT subsidies from the central government is correlated with the local GDP per capita at 1% significance level, with 0.580 correlation coefficient. With the implementation of PPAP, this correlation becomes weaker, for both higher significance level and lower correlation coefficient. Taking the capital structure of PPAP into consideration, we find that the economic performance of PPAP could be highly affected by the capital structure of initial investment. When the external capital is extremely high, like Hainan, the effectiveness of PPAP is nullified, since the subsidies from central government flows to the enterprises' pocket.

Based on our results, there are several policy suggestions. Firstly, as the economic viability of solar PV station is obvious, the government should cancel the FiT subsidy, especially in the P/Ms with considerable local subsidies, so as to promote the development of solar energy in the more insolation abundant areas which usually gathered in the less developed areas. Secondly, the proportions of donations in all P&M are very low, and all of them are less than 4%. The government should take some measures to foster the enthusiasm of enterprises to take part in charitable activities. Thirdly, the implementation of PPAP can promote energy justice during the energy transition to some extent, and thus government should put more efforts to promote the development of solar PV in qualified poor areas.

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