https://doi.org/10.1016/j.seta.2019.04.010

This is the Pre-Published Version.

An Analysis on the Effectiveness and Determinants of the Wind Power Feed-in-Tariff Policy at China's National-Level and Regional-Grid-Level

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Abstract

Wind Feed-in-Tariff (FIT) policy has been implemented in China since 2005. This paper aims to examine the effectiveness of the current wind FIT policy at a national-level, and to investigate the determinants of wind power development at a regional-grid-level. The determinants include substitutable fuel (coal consumption), economic development (GDP per capita), residential electricity price and efficiency of an economy (electricity intensity). It is found that the determinants on wind power development show great differences among six regional grids. It is also found that it is urgent to reform the wind FIT policy, especially segmented wind FIT policies rather than a national consolidated one should be considered for different regional grids.

Keywords: Feed-in-tariff; wind power generation; policy design elements; policy reformation.

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1. Introduction

The wind power development in China has been witnessed a rapid and stable increase over the past decades. The main reason is attributed to the enactment of various price policies and non-price policies. The non-price policies include the target-based regulatory policies, mandatory access to grid policies, and cost sharing arrangement, etc. The price policies include a series of subsidizing policies, funding and tax preferential policies to support investors, enterprises and R&D development, etc. Among the different policies, the Feed-in-Tariff (FIT) policy is regarded as the most influential policy to stimulate the wind power development in China by numerous researches [1–7]. However, these studies are based on content analysis and the effectiveness of wind policies are analysed from a descriptive and informative way. Empirical analysis in this area is very few under the Chinese context with only one from the literature[8]. Zhao et al.'s study has employed a panel data regression model to evaluate the effectiveness of price policies and non-price policies on wind power development. No related empirical studies could be found on explicitly analysing the FIT policy for sake of its effectiveness.

Currently, the FIT wind power policy design in China is determined by wind resource distribution [9]. Annual average effective wind energy density (ρ) and annual cumulative hours (H) of wind speed of 3-20 m/s are two indicators for wind resource classification [8]. The National Development and Reform Commission (NDRC) has stipulated four wind resource areas within the nation (namely Category I, II, III, IV), and a higher FIT is provided to relatively poor wind resource areas while a lower FIT is provided to relatively rich wind resource areas (Table 1and Table 2). Promoting the development of wind energy in poor wind resource areas is extremely important in China, because the centre-load of electricity consumption areas are clustered mainly in Category IV, thus the adoption of wind power in these areas could positively release the burden from the supply side.

Category	Before 2009	2009.8.1 to 2014	2015	2016	2017	2018
I	Desulfurized coal-fire power price + less than 0.25	0.51	0.49	0.47	0.44	0.40
II		0.54	0.52	0.50	0.47	0.45
III		0.58	0.56	0.54	0.51	0.49
IV		0.61	0.61	0.6	0.58	0.57

Table 1, Onshore Wind FIT prices (yuan/kWh) [10–14]

Administrative areas included
Category I: Inner Mongolia autonomous region except: Chifeng, Tongliao, Xing'anmeng, Hulunbeier; **Xinjiang uygur autonomous region**: Urumqi, Yili, Karamay, Shihezi
Category II: Hebei province: Zhangjiakou, Chengde; **Inner Mongolia autonomous region:** Chifeng, Tongliao, Xing'anmeng, Hulunbeieeat r; **Gansu province**: Zhangye, Jiayuguan, Jiuquan
Category III: Jilin province: Baicheng, Songyuan; **Heilongjiang province**: Jixi, Shuangyashan, Qitaihe, Suihua, Yichun, Daxinganling region, **Gansu province except:** Zhangye, Jiayuguan, Jiuquan, **Xinjiang autonomous region except**: Urumqi, Yili, Changji, Karamay, Shihezi, **Ningxia Hui autonomous region**
Category IV: Other parts of China not mentioned above

Table 2. Administrative areas included in four Categories [9].

In china, the 31 provinces, autonomous regions and municipalities are divided into 6 regional power grids [15]. China has two state-owned grid companies, namely State Grid Corporation of China (SGCC) and China Southern Power Grid Corporation (CSG), respectively. SGCC provides power for 26 provinces/autonomous regions/municipalities including North China Grid (Beijing, Tianjin, Hebei, Shanxi, West Inner Mongolia and Shandong), Northeast China Grid (East Inner Mongolia, Liaoning, Jilin and Heilongjiang), Central China Grid (Henan, Hubei, Hunan, Jiangxi, Sichuan and Chongqing), East China Grid (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian) and Northwest China Grid (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet), CSG covers the remaining 5 provinces in South China Grid (Guangdong, Guangxi, Yunnan, Hainan and Guizhou).

Although the FIT policy has played a critical role in stimulating the rapid development of wind power generation over the past ten years, the capacity factor of wind farms is quite low since the wind curtailment phenomenon in China is rather severe, and a large amount of wind power could not be accommodated to the demand side [16–18]. Under this circumstance, it was suggested that the FIT policies should be reformed [19]. In this research, a partial adjustment model was applied to analyse the determinants of wind power installed capacity. Based on investors' perspectives, it is found that the power demand factor does not significantly affect the location choice of wind farms by investors, but the governmental subsidies have large effect on such a choice. However, based on a variable intercept model to evaluate the effectiveness of China's wind power policy, it is found that power demand has significant effect on the increase of wind power capacity [8]. What's more, the current wind policies have hindered the further development of wind power and more flexible wind policies should be implemented by government based on adjusting on-grid wind power price, renewable energy trading price across regions and supplementary service price related to wind power generation [8]. The wind energy developments and policies in China were reviewed in ref. [6]. It is found that wind curtailment problem is not taken account into the design of FIT policy, because it would impede achieving the target of wind power capacity. However, ignoring this problem would continuously aggravate the wind curtailment problem. It is undoubtable that the reasons for severe wind curtailment problem are miscellaneous, such as technical aspect, institutional aspect and R&D aspect [20–22]. As the improvement of these aspects requires constantly policy support and long-term observation, the policy reform is considered a straightforward, sophisticated and vigorous aspect to alter all the aforementioned aspects. It is clear to find that all stakeholders involved in the wind power industry only concern about their own interests. The grid companies attribute severe wind curtailment problem to state grid of not constructing sufficient transmission lines. However, the state grid is also in a dilemma because obtaining approval on transmission line construction from the government is complicated and sluggish [21]. Obviously, the current FIT policy could not satisfy various considerations, and should be reformed by changing the environment of economy, energy and politics in China.

Therefore, this paper aims to investigate the effectiveness of current FIT policy on stimulating the cumulative installed wind capacity and annually added wind capacity from Year 2005 to Year 2016, and to identify the influential determinants on wind energy development except from FIT and wind resource potential. Besides, considering that the six regional power grids and the four categories of wind resource in FIT policy demonstrate inconsistent classification of administrative areas, this paper will study the effectiveness of FIT policy on different power grids. To achieve the specific aims, this paper therefore includes the following objectives: 1) examine whether the wind farm location is crucial to the development of wind energy, that the rich wind resource regions are more favourable and advantageous for investors' consideration; 2) explore whether distinguishing the FIT prices after Year 2009 is effective in improving the wind energy development in poor wind resource areas with relatively higher subsidy level; 3) identify the influential determinants in improving wind energy development by adding control variables in the regression model. It should be noted that these objectives are conducted both at the national-level and at the regional-level, and the dependent variables are cumulative wind installed capacity as well as annually added wind capacity. To achieve objective 1) and 2), two hypothesises are created as follows:

Hypothesis a): Wind capacity increases if wind farms are constructed in regions of rich wind resource

Description of Hypothesis a): Although the FIT price in Category I, II and III are relatively lower than that of Category IV, since the wind resource are abundant, these regions are still attractive and thus the wind energy development is rather significant;

Hypothesis b): Wind capacity increases if wind farms are constructed in regions of higher FIT prices.

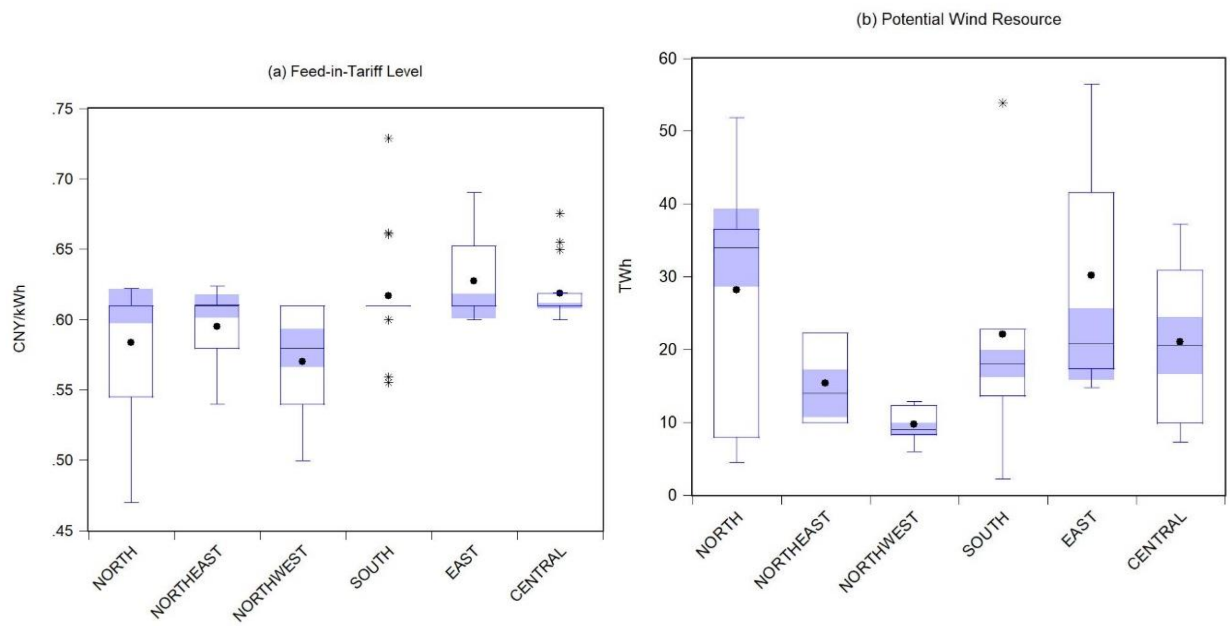
Description of Hypothesis b): Although the wind resource in Category IV is not as abundant as in Category I, II and III, since the FIT price is relatively higher in Category IV than others, it is favourable to investors, thus, the development of wind energy in Category IV is significant.

2. Data Collection

The datasets of cumulative wind installed capacity (in MW) and annually added wind installed capacity (in MW) are collected from Chinese Wind Energy Association [23]. The datasets of national and regional coal consumption (in million tons), gross domestic product (GDP in 100 million yuan), population (in 10,000 person), electricity consumption (in 100 million kWh) are collected from the Statistical Year Book China (National Bureau of Statistics of China, 2017). The datasets of average residential electricity sale price are collected from the State Electricity Regulatory Commission [25]. In this study, the original datasets were further translated into per capita form. Electricity intensity (in kWh/yuan) and GDP per capita (yuan) are two derived datasets. The national-level datasets are summarized in Table 3, and the regional-grid-level datasets are depicted in boxplots in Figure 1. The boxplots illustrate the minimum, maximum, mean, median values, as well as the median 95% confidence in shading areas, first quartile and third quartile.

	Minimum	Maximum	Mean	S. D.	Obs.
FIT price (yuan/kWh)	0.47	0.7292	0.6017	0.0399	368
Wind resource (TWh)	2.30	56.50	21.76	15.2458	360
Coal consumption (million tons)	3.32	409.27	124.16	93.4538	330
GDP per capita (yuan)	5376.46	118127.60	36118.14	22443.61	372
Electricity price (yuan/MWh)	337.85	648.17	505.124	61.7042	335
Electricity intensity (kWh/yuan)	0	0.5205	0.1152	0.0750	372

Table 3. Descriptive Statistics on Variables at National-level



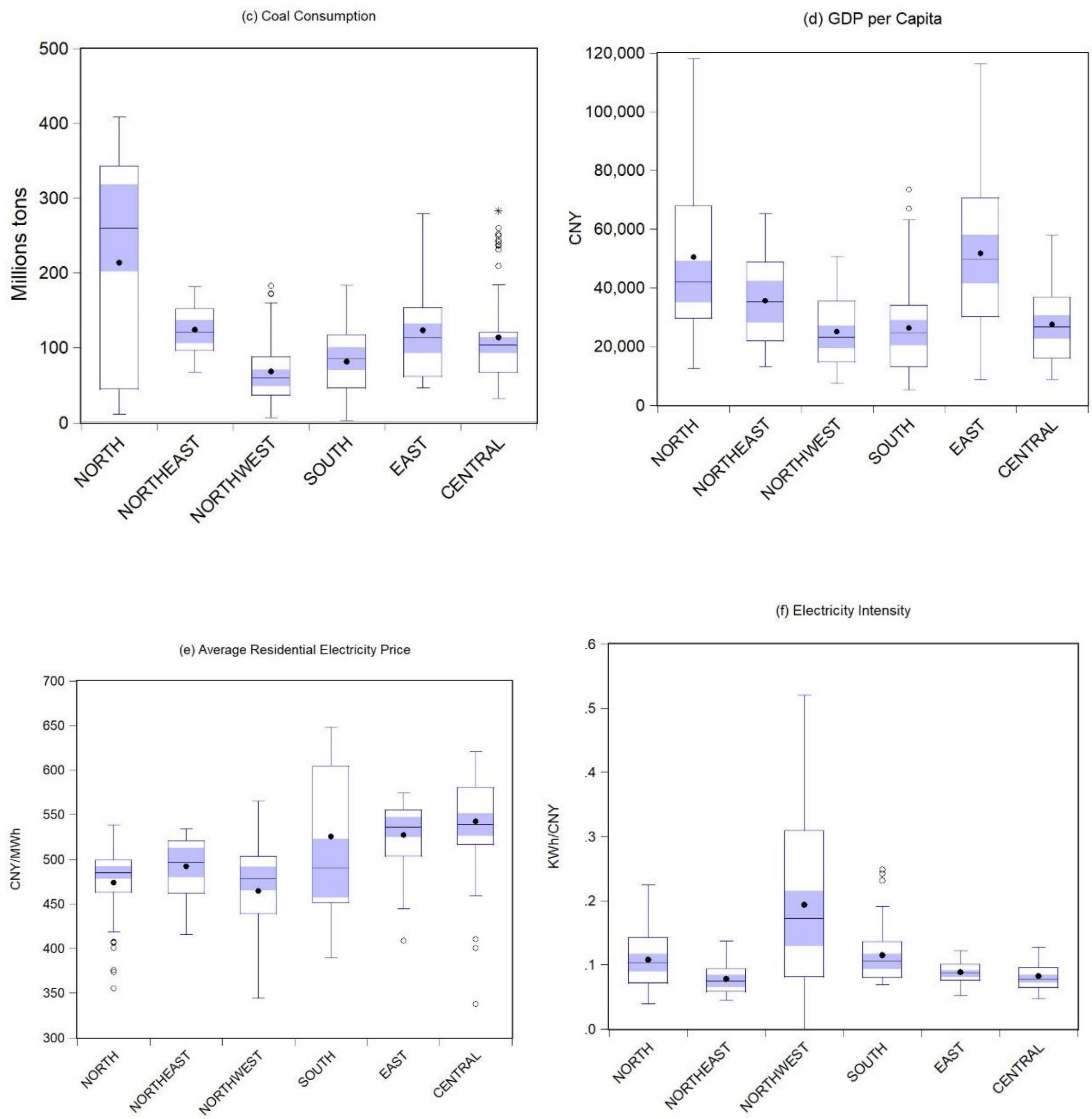


Figure 1. Data description in boxplots at six regional-grid-level

2.1. Dependent Variables

Cumulative installed wind capacity and annually new-added wind capacity are two common dependent variables for assessing the wind policy effectiveness used by other researchers. As stated by these researchers, the cumulative installed wind capacity and the growth of wind capacity reflect the level of wind development in specific regions [26–28]. In this study, the long-term and short-term wind power development trajectories were illustrated by the cumulative wind installed capacity and annually added wind capacity, respectively.

2.2. Independent Variables

The FIT prices and wind resource potentials are two crucial factors in wind energy policy design, thus their efficacies are important to be assessed. The effectiveness of price policies and non-price policies on stimulating the wind development in China is assessed in ref. [8]. FIT policy has been selected to represent the price policy and *Renewable Energy Law* as well as *Medium and Long-term Development Plan of Renewable Energy* are selected to represent target-based non-price policy which also signify the Government's willingness to promote wind energy [8]. However, no relevant researches have focused on the variation and classification of FIT policy for a concrete analysis on the rationality of policy design elements, although some empirical and theoretical researches have concluded that FIT policy is much more significant on promoting wind energy development than non-price policies [29,30]. Therefore, verifying the hypothesis a) and b) is a crucial step to increase the policy confidence or to figure out underlying policy defects. This study uses dummy variables to distinguish the high/low FIT price and the rich/poor wind resource of datasets. To eliminate the nearly colinear matrix problem, the benchmark of high/low FIT price is set as the average FIT prices over 2005 to 2016 in 31 provinces, municipalities and autonomous regions. Thus, the dummy variable to categorize high/low FIT price is defined as:

D_1 = 1 for FIT is equal to or higher than 0.6017 yuan, and 0 otherwise;

For categorizing rich/poor wind resources, the dummy variable is defined as:

D_2 = 1 for regions in Category I, II and III, and 0 otherwise.

2.3. Control Variables

2.3.1. Coal Consumption

Nowadays, coal-fired power accounts for 75% of the total power generated, among which around 30% are for residential use [31]. Since wind resource is intermittent, completely substituting coal is difficult at present, but the penetration of wind power could alleviate the dependency on coal [32]. The cross-price elasticity is found to be positive in [33] when substituting coal by renewable energy. Therefore, this study chooses the amount of coal consumption to capture the energy substitution variable.

2.3.2. GDP per capita

It is stated in [30] that the economic performance is an influential factor to affect the power demand, and the argument about the development of wind energy is associated with economic growth is supported by some studies [33–35]. Therefore, it is rationale to include economic factor as a control variable to evaluate the effectiveness of FIT policy. However, In the Chinese context, a causality relationship analysis by [36] indicated that the increase in electricity consumption in China would stimulate the increase of GDP, but not vice versa. [37] have conducted an econometric assessment to evaluate the effect of wind power generation on local economy from year 2005 to 2011, and proved that the additional installation of 1MW wind capacity would stimulate more than 2200 RMB in GDP per capita, which is consistent with [36]. The indicators of economic performance applied by researchers usually consist of GDP growth rate, GDP per capita, income elasticity and employment rate. This paper employs GDP per capita as the indicator due to the consideration of the large amount of population in China.

2.3.3. Average Residential Electricity Price

Residential tiered electricity pricing (RTEP) mechanism has been formally adopted by China since 2012, and the price adjustment is influenced by the Government regulation, grid companies, power companies as well as end users [38]. The electricity price consists of pool purchase price, transmission and distribution price and retail power price, and it is divided into three tiers in China of which the first tier guarantees the most basic electricity demand from a household [39]. The SERC has issued the report entitled *"Annual Electricity Price Execution and Settlement Briefing"* and adopted the unit of "yuan/kkWh" to measure the average residential electricity price in different regions. The same unit of "yuan/MWh" is also adopted in the present study. Several studies have showed the impact of on-grid wind power accommodation on the electricity price in some countries. [40] indicated that due to the increase of wind power accommodation, the electricity price would decrease whereas the electricity price volatility would increase in the US. [41] analysed the data of electricity market in Poland, the UK, France and Italy and concluded that the low penetration of wind power during winter periods would double or triple the electricity price. [42] suggested to utilize the low marginal cost effect of wind power to induce the merit order in Australian electricity market, and justified that the increase of wind power on-grid would lower the electricity price. The similar conclusions have been drawn by [43] in Germany and [44] in Denmark. However, in China, whether wind power accommodation and electricity price is statistically correlated remains a doubt, thus this paper has done a pioneering work on investigating whether the correlation exists or not.

2.3.4. Electricity Intensity

Energy intensity is a term used to describe the energy efficiency of a country's economy [45]. Convergence analysis is usually conducted to study the energy intensity among a set of countries, and authors could provide policy implications or forecast future energy consumption, but the mechanism attributed to energy intensity is rather complex [46]. Nevertheless, as a sub-strand of energy intensity, electricity intensity is a much less diverse term and has drawn attention by some researches, and it is measured by the ratio of electricity consumption to the total power generation [47,48]. In addition, wind energy is usually harvested for electricity generation. Therefore, this study employs electricity intensity rather than energy intensity as a control variable.

3. Methodology

3.1. Panel Data Regression Model

One national-level dataset and 31 regional-level datasets are collected in this study. As aforementioned, the 31 datasets will be divided into six groups with accordance to the power grids. A panel data regression model is more appropriate than the pooling model because the fixed sample is observed over time rather than randomly picking up. The formula of a general panel data regression model is developed as follow:

$$WC_{it} = \alpha_i + \beta D_{it} + \gamma X_{it} + \varepsilon_{it} \quad (1)$$

Where i = 1, 2, 3….N and denotes the cross sectional individuals being observed; t = 1, 2, 3 … T and denotes the time period; WC_{it} represents the cumulative wind installed capacity and annually added wind installed capacity, D_{it} represents a K-dimensional vector of independent variables, it should be noted that at nation-level the dummy variables are used as aforementioned to verify two hypothesises, but at the region-level, we used the logarithm value of wind resource to and original value of FIT prices to avoid the collinearity problem. X_{it} denotes a K-dimensional vector of control variables; $\beta\ and\ \gamma$ are $K \times 1$ coefficient vectors of independent variables and control variables, respectively; and the slopes are independent of i and t; α_i denotes the regional entity intercepts and ε_{it} denotes the error which varies over i and t.

Furthermore, based on the general formula (1), this paper takes the natural logarithm value of some datasets and the expanded formula is expressed as equation (2). Equation (2) is developed to examine hypothesis (a) and (b) at a national-level.

$$WC_{it} = \alpha_i + \beta_1 D_{1it} + \beta_2 D_{2it} + \gamma_1 lnCoal_{it} + \gamma_2 lnGDP_{it} + \gamma_3 lnElectricity_{it} + \gamma_4 Intensity_{it} + \varepsilon_{it} \quad (2)$$

Whereas at regional-grid-level, the dummy variables are invalid to be used in the model, thus the true value of FIT prices and wind resource potential estimations are used. The model is then expressed as equation (3):

$$WC_{it} = \alpha_i' + \beta_1' FIT_{it} + \beta_2' lnWind_{it} + \gamma_1' lnCoal_{it} + \gamma_2' lnGDP_{it} + \gamma_3' lnElectricity_{it} + \gamma_4' Intensity_{it} + \varepsilon_{it}' \quad (3)$$

In the above equations, $FIT_{it}, Wind_{it}, Coal_{it}, GDP_{it}, Electricity_{it}\ and\ Intensity_{it}$ denote the true value of FIT prices, wind resource potential estimations, coal consumption, GDP per capita, average residential electricity price and electricity intensity in i individuals over time t. The datasets of FIT_{it} and $Intensity_{it}$ have not be converted into natural logarithm form because the true value is less than 1. The prime symbol is used to differentiate the coefficient represented in regional-grid-level from national-level.

3.2. Hausman Test

The Hausman Test [49] is applied to determine whether a random-effect model or a fixed effect model should be used. The null hypothesis of the Hausman test is the appropriateness of random effect model, but if the p-value is less than 0.05, the null hypothesis should be rejected thus the fixed effect model is more appropriate. The Hausman test suggested either fixed-period-effect model or random-period-effect model for different datasets of panel models in this study

(Table 4.). The main difference between these two effect models is, the fixed-period-effect model emphasizes on the specific effect of each year, whereas the random-period-effect model emphasizes on the variation among year groups [50].

	Model I (Dependent variable: Cumulative wind capacity)				Model II (Dependent variable: Annually added wind capacity)			
i	Test summary	Chi-Sq.	Chi-Sq. d.f.	Prob.	Test summary	Chi-Sq.	Chi-Sq. d.f.	Prob.
Nationwide	Two-way random	0	5	1	Period random	9.745534	7	0.2035
North	Period random	0	6	1	Period fixed	14.505772	6	0.0245
Northeast	Period random	0	6	1	Period fixed	58.414302	6	0.0000
Northwest	Period random	0	6	1	Period fixed	39.052971	6	0
South	Period Random	0	6	1	Period random	9.169133	6	0.1643
East	Period fixed	26.800098	6	0.0002	Period random	0	6	1
Central	Period fixed	18.109697	6	0.0060	Period random	8.740990	6	0.1887

Table 4. Hausman Test Results

4. Results and Discussions

The results of panel data regression with the dependent variable of cumulative wind installed capacity and annually added wind installed capacity, respectively are summarized in Table 5. and Table 6. According to the results, conclusions and discussions could be drawn as follows:

4.1. At national-level: Hypotheses a) and b) are proofed

Statistically, significant positive effect of FIT price and wind resource is found on stimulating both the cumulative and annually added wind installed capacity at the national-level. In other words, the increase of wind installed capacity at the national level is associated with a higher FIT price at the benchmark of 0.6017 yuan/kWh, and is also associated with the location of wind farms that are constructed in areas with rich wind resource (Category I, II and III). This finding could verify the doubt of whether the design of FIT policy is effective and rational, that the classification of four wind resource areas and the FIT price has successfully facilitated the wind power development. Investors are motivated by the tangible and foreseeable profits, so constructing wind farms in rich wind resource areas is risk-hedging and has become their primary alternative in deciding whether to invest or not. However, without distinguishing into four-tier FIT prices, the wind power development in southern China and eastern China could hardly be facilitated, and the heavy burden in the load centre of electricity consumption regions could not be alleviated. Indeed, according to the data extracted from the China Statistic Yearbook, the poor wind resource areas such as Yunnan (7970 MW), Guizhou (3785 MW) and Guangdong (3537 MW) in South China grid, Jiangsu (6080 MW) and Fujian (2509 MW) in East China grid, as well as Hunan (2824 MW) and Hubei (2473 MW) in Central China grid have been promoted effectively. This policy design could release the electricity consumption burden in the poor wind resource areas, because according to China Statistical Yearbook 2016 (data accessible up to year 2015), these areas are the central loads of electricity consumption in China in year 2015, which are clustered in North China grid (25.2%), East China grid (23.8%), Central China grid (17.4%) and South China grid (16.7%). Oppositely, the abundant wind resource areas share only less than 17% of the national total electricity consumption (with Northwest China grid of 10.6% and Northeast China grid of 6.3%).

	Nationwide	North	Northeast	Northwest	South	East	Central
Constant	-244.111*** (55.996)	-2.184 (7.000)	-14.620*** (1.557)	-70.327*** (7.171)	-0.395 (8.916)	35.498*** (9.420)	-24.047** (9.151)
FIT price	0.563*** (0.103)	-6.117** (2.604)	-3.143** (1.264)	-7.287** (3.202)	2.504 (2.893)	12.862 (8.642)	-1.136 (4.809)
Wind resource	2.199*** (0.410)	0.776 (0.842)	-0.941* (0.488)	1.789 (1.334)	1.364 (1.274)	-0.499 (1.616)	0.080 (0.535)
Coal	0.263 (0.222)	2.284*** (2.604)	3.507*** (0.520)	-1.585*** (0.581)	-2.369 (1.411)	0.676 (1.124)	0.416 (0.710)
GDP per capita	2.495*** (0.500)	2.872*** (0.652)	0.125 (0.218)	4.343*** (0.794)	8.545*** (1.417)	1.298 (1.167)	1.544 (1.226)
Electricity price	0.169 (1.198)	-3.682 (2.571)	5.146*** (0.779)	21.851*** (0.794)	-13.043*** (4.541)	-17.943*** (3.562)	6.713*** (2.010)
Electricity intensity	0.446 (1.107)	-8.974** (3.759)	-10.953*** (1.403)	3.902*** (0.829)	14.848** (5.675)	8.105 (20.946)	1.988 (10.701)
Obs.	300	60	30	50	50	50	60
Model	Panel EGLS	Panel EGLS	Panel EGLS	Panel EGLS	Panel EGLS	Panel least squares	Panel least squares
R-Sq.	0.756	0.702	0.947	0.709	0.793	0.842	0.889
Adj. R-Sq.	0.750	0.668	0.933	0.668	0.764	0.772	0.851

Table 5. Model I estimation results (Dependent variable: cumulative wind installed capacity)

	Nationwide	North	Northeast	Northwest	South	East	Central
Constant	-278.547*** (45.647)	77.018*** (16.633)	5.262 (8.913)	-31.246* (16.397)	14.890 (12.403)	46.855*** (10.763)	-33.836** (14.190)
FIT price	0.568*** (0.172)	-2.665 (3.140)	-3.896 (6.169)	-20.013*** (5.699)	0.967 (3.955)	-5.185 (4.068)	-10.781* (6.376)
Wind resource	1.554*** (0.241)	-1.057 (1.175)	4.166 (2.343)	0.060 (1.560)	2.303 (1.701)	0.573 (1.593)	1.469* (0.803)
Coal	1.092*** (0.121)	3.461*** (1.067)	-5.001 (3.388)	-1.913 (0.858)	-2.205 (1.857)	1.398 (1.105)	-0.090 (1.022)
GDP per capita	0.770** (0.322)	-2.813** (1.253)	-1.352 (1.158)	0.662 (1.831)	6.243*** (1.184)	0.783 (1.020)	0.850 (1.392)
Electricity price	0.518 (1.177)	-23.763*** (4.832)	3.977 (3.546)	16.090*** (4.400)	-14.904** (5.918)	-17.044*** (3.894)	13.893*** (4.131)
Electricity intensity	2.547*** (0.848)	-24.333*** (5.902)	9.212 (13.433)	2.340** (0.955)	4.795 (7.678)	-29.252 (18.458)	-20.430 (13.633)
Obs.	267	54	27	45	45	45	51
Model	Panel EGLS	Panel least squares	Panel least squares	Panel least squares	Panel EGLS	Panel EGLS	Panel EGLS
R-Sq.	0.614	0.842	0.909	0.892	0.579	0.699	0.678
Adj. R-Sq.	0.603	0.785	0.802	0.841	0.512	0.651	0.634

Table 6. Model II estimation results (Dependent variable: annually added wind installed capacity)

4.2. At regional-level: the effects of FIT price and wind resource potential are alleviated

According to Table 5 and Table 6, it is found that by comparing to the national-level, the effects of FIT price and wind resource potential are alleviated at regional-grid-level. In addition, they are not all significant in every regional grid. In particular, there is no significant effect of FIT price and wind resource potential on both the cumulative and annually added wind installed capacity in South China grid and East China grid. As for others, the negative effect (significance level of 5%) of FIT price on the cumulative wind installed capacity is found in North China grid, Northeast China grid and Northwest China grid, which means that the increase of cumulative wind installed capacity is associated with the decrease of FIT price. However, the negative effect of FIT price is only found on the annually added wind installed capacity in Northwest China grid (significance level of 1%) and slightly on the Central China grid (Significance level of 10%). As for the wind resource, although it has a significant effect on the national-level of wind installed capacity, the effect on the regional-level is extremely slight (significance level of 10%), and could only be found on the cumulative wind installed capacity in Northeast China grid and annually added wind installed capacity in Central China grid.

4.3. Effects of Control Variables

4.3.1. Coal consumption

The results from Table 5 and Table 6 indicate that coal consumption is a crucial determinant in North, Northeast and Northwest China Grids. This conclusion can be explained by the following reasons. First, the urbanization process is witnessed a regional divergence across China, as the use of coal is gradually replaced by electricity in more urbanized areas, whereas the Northern regions are still coal-dominated consumption pattern [51]. According to the data of the Statistical Yearbook China, the coal consumption continued to increase from 2638.65 million tons to 4364.54 million tons during period 2005 to 2012, and started to slightly drop to 4254.76 million tons in

2015. Over the past years, the grid share of coal consumption was gradually decreased in most of the regional grids except North China grid and Northwest China grid, with the share of coal consumption increased from 34.97% to 35.06% and 6.67% to 12.39%, respectively. Especially for North China grid, the effect of coal consumption is positively significant on both cumulative and annually added wind installed capacity. Second, the dissemination of other renewables such as nuclear power and hydro-power plays a vital role as substitutional energy in Central, Southern and Eastern China. The Three Gorges Hydropower Station is the largest hydropower station in China and it accounts for 52.3% of the country's total hydropower installed capacity [52], and the electricity is mainly sold to Central China grid, South China grid and East China grid. As for the nuclear power plant, it is said that by 2020, China's nuclear power plant will be responsible for 6% of the national energy capacity [53].

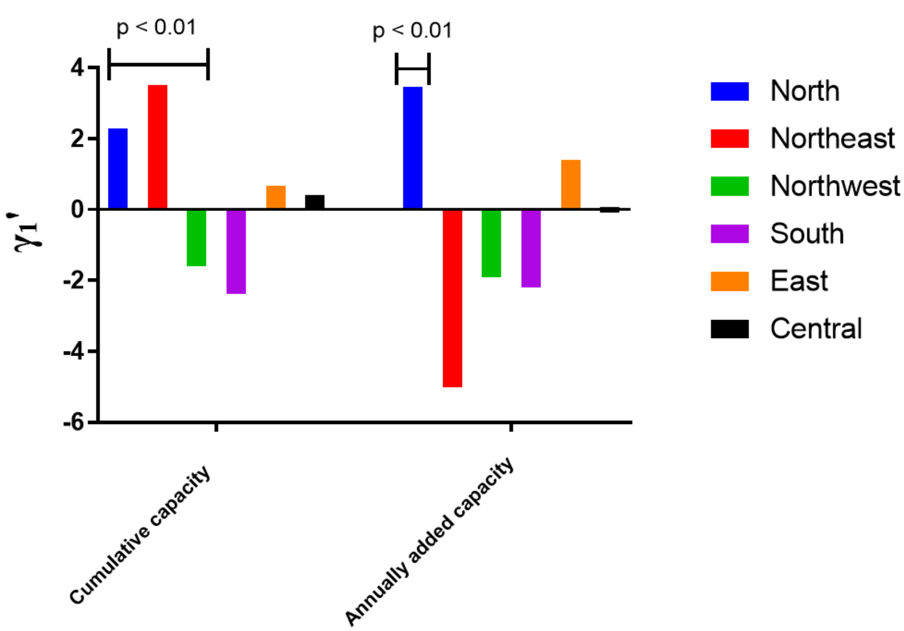


Figure 2. Magnitude, sign and significance level of the coefficient of coal consumption.

The magnitude, sign and significance level of the coefficient of coal consumption are illustrated in Figure 2. It is surprising to find that the effect of coal consumption shows positive sign on wind installed capacity in North China grid and Northeast China grid, which implies that their increase of wind installed capacity is associated with the increase of coal consumption. There are two reasons. First, the wind curtailment rate in China is severe. In year 2014, about 6.8% of wind generation was curtailed although that was an improvement compared to past years. However, the wind curtailment problem was getting more severe in year 2015 and 2016, in which 13.8% and 14.5% of wind generation was abandoned, respectively. The wind curtailment rates are extremely severe in Hebei, Inner Mongolia, Gansu, Xinjiang, Liaoning, Jilin and Heilongjiang, and most of them are the leading regions in terms of installed capacity and wind resource potential. By contrast, the wind curtailment rate in Germany is 0.7% in year 2012, and is less than 3% in Ireland, Italy and Spain in year 2013 [54]. Second, the construction work of grid power connection is still lagging behind. The inconsistency between wind power generation and grid power planning results in difficulty of wind power accommodation, thus, a large amount of wind power is abandoned by wind farms. The most severe regional grids are Northwest China grid (44413 GWh), North China grid (36498 GWh) and Northeast China grid (15851 GWh) cumulated from year 2013 to 2016 [55]. Therefore, it is evident to conclude that the wind energy application efficiency in China is rather low, and the wind power is insufficient to satisfy the increasing demand in Northern regions, thus the statement of "the increase of wind installed capacity is associated with the increase of coal consumption in Northern regions" is to some extent reasonable. However, it should be noted that this association is statistically-based, given that sociological research has found that the substitution of one natural resource for another often does not happen as anticipated because of political and economic factors [56].

4.3.2. GDP per Capita

From Table 5 and Table 6, it can also be seen that GDP per capita is an important determinant in North, Northwest and South China regions. The GDP per capita reflects the regional household income characteristics and population characteristics. [57] indicates that a raising income plays a vital role in energy transition process, families with a higher household income are more insensitive to fuel price and more willing to substitute traditional fuel energy with modern ones. In addition, GDP per capita could also reflect household population characteristics, the elderly is converged in regions with lower energy transition process, and normally they are vulnerable groups without enough capacity to make a living, thus the economic feasibility of choosing cleaner energy is weakened [58]. Besides, [59] states that rural households are affordable to purchase appliances which requires specific energy resource. Regional income inequality and convergence study has indicated that seven east-coastal provinces including Shanghai, Tianjin, Jiangsu, Zhejiang, Guangdong, Shandong, and Fujian, as well as Inner Mongolia are converging into high-income regions, whereas others are low-income regions [60]. The datasets in this study suggests Beijing (118,127[1]), Shanghai (116,440), Tianjin (114,503), Jiangsu (96,747) and Zhejiang (84,528) are the top five regions regarding GDP per capita, whereas Shanxi (35,443), Tibet (34,786), Guizhou (33,127), Yunnan (30,996) and Gansu (27,587) are the least economically developed regions. Therefore, it is found that the North China, Northwest China and South China are relatively under developed and thus more sensible to energy transition.

[1] Numbers in the bracelets are in unit of yuan per capita

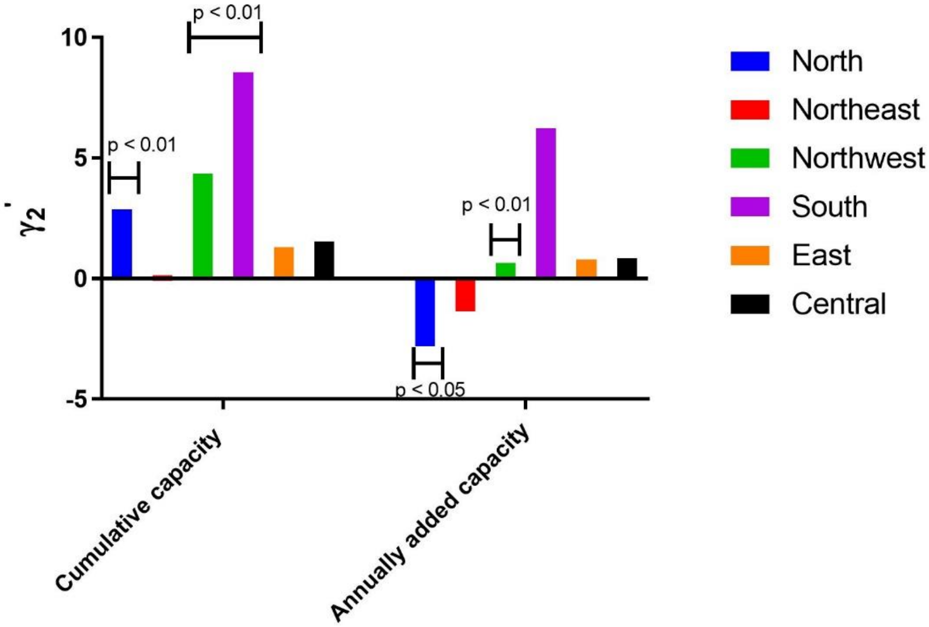


Figure 3. Magnitude, sign and significance level of the coefficient of GDP per capita.

The regression results suggest positive effects of GDP per capita on wind installed capacity in North China grid, Northwest China grid and South China grid (Figure 3), which implies that in these regional grids, the increase of wind installed capacity is associated with the increase of GDP per capita. This is because that economic performance is correlated with power consumption [61–63]. In the Chinese context, different types of causal relationship between power consumption and GDP are found by different researches [64] concluded that in long-term, unidirectional causal relationship from power consumption to GDP is found in eastern, central and western regions in China. However, [65] indicated that the causal relationship diversifies between eastern and western China, in eastern China, a unidirectional causal relationship is found from power consumption to GDP, whereas in western China, a bidirectional relationship is found. In other words, the economic growth is associated with the increase of power consumption, and wind power development is associated with the economic growth.

4.3.3. Average Residential Electricity Price

The effect of average residential electricity price reveals great regional differences. The panel regression results indicate negative effects of electricity price on both cumulative and annually added wind installed capacity in East China grid and South China grid, on newly added wind installed capacity in North China grid; the results also indicate positive effects of electricity price on both cumulative and annually added wind installed capacity in Northwest China grid and Central China grid, on cumulative wind installed capacity in Northeast China grid. It is found that the effect of electricity price indicates great regional difference on wind installed capacity. In East China, South China and North China grids, the increase of wind installed capacity is associated with the decrease of the electricity price (Figure 4), which is met with the expectation by studies mentioned in Section 2.3.3.

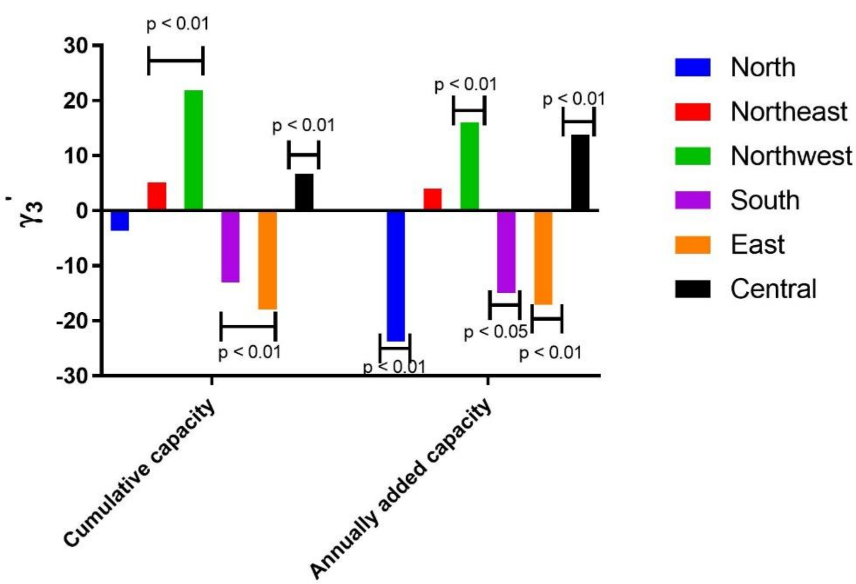


Figure 4. Magnitude, sign and significance level of the coefficient of average residential electricity price.

However, as illustrated by Figure 4, it is interesting to find that in Northwest China, Central

China and Northeast China grids, the increase of wind installed capacity is associated with the increase of electricity price. This paper explains the differences by the following reasons. First, the influential factors affecting the RTEP design in China are the users, the power companies and the Government, whereas the Government regulation plays the most crucial role on the electricity pricing [38]. The users' effect is reflected by the leveraged price design of RTEP which effectively maximizes the effect of demand side, the power companies' effect is reflected by the basis of costs incurred in power generation, transmission and distribution. The effect of renewable energy on the electricity price is not significant, and the necessity for reforming electricity market to assist the integration of wind power is considered a burning issue, because unless the FIT policy, the current electricity price level fails to reflect regional difference in China [38,66,67]. Second, the wind farm capacity factors in the Northwest China, Central China and Northeast China grids are estimated the lowest three compared to other grids, according to the datasets of this paper, the average wind capacity factor over year 2013 to 2016 in these three grids are 11.1%, 11.6% and 15.3%, respectively; whereas the grids of the highest wind capacity factors are the East China grid (18.9%) and the North China grid (17.2%). This to some extent could prove that the efficiency of wind power connected to grid is rather insufficient and low in those three grids, therefore the influence of wind power on the electricity price design remain ambiguous and insignificant. Third, other than RTEP, there exists other residential electricity pricing mechanisms in China, such as time-of-use (TOU) and real-time electricity price (RTP), in East China, South China and North China grids, most of the regions implement the combination of mixed electricity mechanisms; nevertheless, in Northwest China, Central China and Northeast China grids, most of the regions rely solely on the RTEP mechanism. Thus, under the single electricity pricing mechanism, the allocation of power resources are not as efficient as the combined mechanism [38].

4.3.4. Electricity Intensity

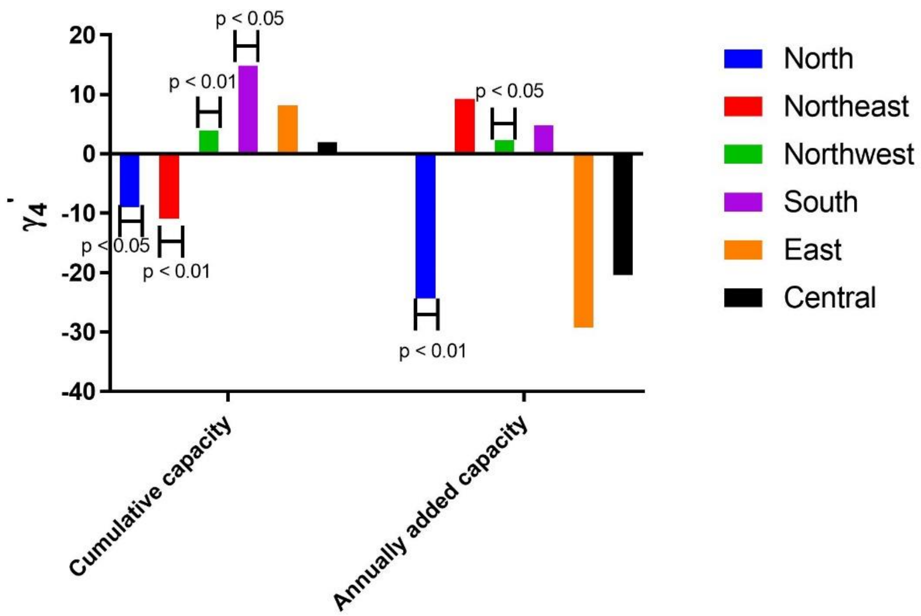


Figure 5. Magnitude, sign and significance level of the coefficient of electricity intensity.

As shown in Figure 5, the effect of electricity intensity on cumulative wind installed capacity is significant outside East and Central China grids, but the effect of electricity intensity is weakened on the annually added wind installed capacity, that is significant only in North and Northwest grids. Negative effect of electricity intensity on wind installed capacity is found in North grid and Northeast grid, which implies that the increase of wind installed capacity is associated with the decrease of electricity intensity in these two grids. However, positive effect of electricity intensity on wind installed capacity is found in Northwest grid and South grid, which indicates that the increase of wind installed capacity is associated with also the increase of electricity intensity in these two grids. Electricity intensity reflects the energy efficiency of regional economy, and it is expected that a lower electricity intensity depicts a more energy efficient economy [68]. In China, the highest electricity intensity regions are clustered in North and Northwest grids, e.g., Ningxia (0.3659)[2], Qinghai (0.3238), Gansu (0.1944), Guizhou (0.1741), Shanxi (0.1698), Xinjiang (0.1541), Inner Mongolia (0.1455) and Hebei (0.1267), whereas the lowest electricity intensity regions are clustered in East and Central China grids. However, the results suggest adverse effect of electricity intensity on wind installed capacity in North and Northwest grids. The most influential determinants of electricity intensity in China are considered the substitution effect, besides, the budget effect which refers to the electricity tariff and the technology effect which expresses the imported technology for primary power generators, are proved as having only little effect on electricity intensity [69]. Substitution effect is found as the driven effect on electricity intensity which represents the neutralization of the capital cost, labour cost and the energy price, the increase of electricity intensity is associated with the increase of labour cost, whereas is associated with the decrease of capital cost and energy price. In [70], it presented that industry agglomeration feature changes through eastern China to western China, that is from capital-intensive industry to labour-intensive industry. The labour-energy substitution effect as well as the capital-energy substitution effect are considered the crucial factors to explain the changing trend of electricity intensity. Substituting labour with energy in China will raise electricity intensity, because the energy price is controlled to remain low by the government. On the contrary, substituting energy with capital yields the decline in electricity intensity in eastern China and central China, whereas will trigger the raise in electricity intensity in western China [71].

5. Conclusion and Implication

This paper has evaluated the effectiveness of wind FIT policy in China with respect to the

[2] Numbers in the bracelets are in unit of kWh/yuan, and represent the average value over 2005 to 2016.

development of cumulative wind installed capacity and annually added wind installed capacity from Year 2005 to 2016. By raising a doubt that whether the classification of wind resource areas and FIT prices is reasonable and effective or not, this paper came up with two hypothesises: a): Wind capacity increases if wind farms are constructed in regions of rich wind resource; b): Wind capacity increases if wind farms are constructed in regions of higher FIT prices. A panel data regression model was employed, and the dependent variables are cumulative wind installed capacity and annually added wind installed capacity, as they depict long-term and short-term wind development trajectory, respectively. The independent variables are wind resource and FIT price, and dummy variables are applied when assessing the effectiveness of FIT policy at national-level, whereas at regional-level, the logarithm value of wind resource and the original value of FIT price are used to avoid collinearity. Control variables include average residential electricity price, coal consumption, GDP per capita and electricity intensity. The test results have proved that both hypothesises are valid at the national-level, but at the regional-level, the results indicate huge differences and could be concluded into four aspects: 1) coal consumption is an important determinant in regions located in North, Northeast and Northwest China grids; 2) economic performance is an important determinant in regions located in North, Northwest and South China grids; 3) the effect of electricity price indicate great regional differences; 4) the effect of electricity intensity is significant outside regions located in East and Central China grids.

Currently, the wind FIT policy in China is classified into four categories based on the distribution of wind resource, and this policy design is proved as effective to promote the rapid development of wind power generation. However, the rapid development phenomenon is seemed to be a feature of renewable energy development at the starting stage in China, problems related to severe wind curtailment and regional wind power grid connection are exposed along with the wind power development, and these problems have revealed that after the starting stage, the current FIT wind policy is no longer appropriate and optimal for the maturing stage without taking regional differences into account. Thus, the most significant contribution of this paper is to figure out the determinants on effectively improving wind installed capacity by regional grids. The regional differences are reflected by taking the amount of coal consumption, GDP per capita, electricity price and electricity intensity as control variables into consideration, and the current wind FIT policy should be reformed, while a more adaptive, sophisticated and flexible wind FIT policy is necessary to be proposed to fit with the regional features and differences.

Two policy implications are suggested by this paper. First, the design elements of wind FIT policy should not be constrained to the same factors at national-level, regional differences should be included. To reform wind FIT policy, it is suggested to establish a tailor-made policy mechanism to fit with the using pattern of coal or other electricity generation energies, the development degree of economy, the electricity price in a specific market and the energy efficiency of an economy. The reformed wind FIT policy is therefore recommended to be segmented into six sub-policies particularly aiming to North China grid, Northeast China grid, Northwest China grid, South China grid, East China grid and Central China grid. For instance, for the North China grid, the crucial determinants of promoting cumulative installed wind capacity are regional coal consumption, regional GDP per capita and regional electricity intensity, thus the reformed FIT price especially for North China grid should consider neutralizing these three elements together with the wind resource potential. Moreover, wind power storage technology is recommended to be integrated with wind farm, thus the wind curtailment problem could be positively alleviated.

Besides, the optimization of FIT price needs to be precisely adjusted by referring to different payoff structures. In other researches, the structures are not restrained to the form of providing a fixed price per unit electricity produced by wind energy, other payoff structures such as a guaranteed minimum price plus a portion of market upside or a certain premium based on the top of the electricity spot price are suggested by [72] and [73]. However, these two works are formulated for improving and optimizing the FIT design in the Irish context and a generalized world context, so the application of other forms of FIT price mechanism in the Chinese context should be carefully studied and investigated to figure out a most appropriate approach.

Acknowledgement:

Miss Zhang acknowledges the PhD studentship offered by the **Ng Wing Hong Laboratory for Sustainable City, Department of Building and Real Estate, the Hong Kong Polytechnic University.**

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