Measuring the effects of power system reform in Jiangsu province, China from the perspective of Social Cost Benefit Analysis

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Abstract

The paper uses a social cost benefit analysis (SCBA) approach to measure the effects of the power system reform starting from 2015 in Jiangsu province, China. We review the background of Jiangsu power system and summarize the implemented policies since the publication of "Document #9". Then we pick the average industrial and commercial retail price and analyse the sources of price reductions. We show that the nominal industrial and commercial price fell by 21.3% between January 2012 and May 2021. We then analyse the likely overall welfare change facing industrial and commercial customers using SCBA and conclude that there is a permanent gain equivalent to 9.1% lower prices per year mainly because of the reform. This figure is a significantly more positive consumer gain than that calculated in previous SCBAs of electricity reform in other countries.

Keywords

Power system reform (PSR), social cost benefit analysis (SCBA), electricity market, industrial and commercial electricity price

1. Introduction

From the establishment of the People's Republic of China in 1949 to before 2015, the electricity price was strictly regulated. The desire to promote electricity consumption by residential and agricultural customers has led to a lower regulated electricity price for residential and agricultural customers than for

industrial and commercial customers, which is different from the situation in the United States and Europe. Furthermore, under the strictly regulated price mechanism, both electricity price received by generators and the price paid by electricity consumers were set by the government (see Chen et al., 2014).

On one hand, the regulated price mechanism successfully met the increasing load demand and promoted investment in power infrastructure and rapid economic growth in China in the past few decades (Xie et al, 2020). On the other hand, the regulated price mechanism was also controversial because of its association with vertical integration, low generation asset utilization and energy efficiency (Guo et al., 2020) and high electricity prices for industrial and commercial customers due to the lack of competition. To solve these problems, China launched a new round of power system reform in 2015 (the PSR 2015) with the publication of "Document #9" (NDRC, 2015). The Chinese government intended to deregulate the electricity sector, build a competitive wholesale market via power sector reform (PSR) and reduce industrial power prices (Pollitt, 2020).

One of the core elements of the PSR 2015 was pricing mechanism reform. The regulated on-grid price on the generation side was to be replaced by a market-oriented price. The generation companies were to sell electricity by signing bilateral contracts with retail companies and customers or by participating in centralized bidding mechanisms. Moreover, the transmission and distribution price (T&D price) is separated out from the retail price and thus the final electricity price for industrial and commercial customers is no longer to be set by the government. The T&D price was to be subject to periodic review and hence be subject to incentive regulation, driving efficiencies at state owned grid companies. The reform is supposed to promote the competition and increase the efficiency in all parts of the electricity sector.

Another task of the PSR 2015 is to promote the energy saving and environmental protection. The government has already implemented a Renewable Portfolio Standard in 2018 and Carbon Emissions Market in 2021. Moreover, on the 75th U.N. General Assembly 2020, Chinese President Jinping Xi mentioned that "China aims to have CO2 emissions peak before 2030 and achieve carbon neutrality before 2060"[1], also known as the "Dual Carbon Goals" or "30·60 decarbonization goal" for China. The

[1] See https://en.qstheory.cn/2020-09/27/c_541152.htm

"Dual Carbon Goals" implied that the power system in China is going to change drastically from a thermal generation dominated system to a renewable energy generation dominated one in the next few decades.

A large amount of previous literature has focused on power system reforms. Many scholars have undertaken social cost benefit analyses of international electricity reforms in different countries, including UK (Domah and Pollitt, 2001; Newbery and Pollitt, 1997; Newbery, 2016), Brazil (Mota, 2003), Philippines (Toba, 2002, 2007), Chile (Galal et al., 1994), Peru (Anaya, 2010), Mexico (Moshiri and Santillan, 2018), etc.

Xie et al. (2021) completed a review on the 2002 unbundling reform of China and analyzed the efficiency changes between 1999 and 2016. For studies related to the PSR 2015, Zeng et al. (2016) did a comprehensive policy review of "Document #9". In Guo et al. (2020), the authors stated that the four goals of PSR 2015 are increasing generation asset efficiency, decreasing energy consumption and pollutant emissions, developing renewable energy and decreasing industrial electricity prices. Lin et al. (2019) focused on the transition period of market reform and explained the challenges and strategies for it. There were also many papers focused on analysis of the policy (Lei et al., 2018; Lin and Purra, 2019; Zhao et al., 2020) and measurement of PSR 2015 effects including at the national level (Liu, et al. 2019; She et al., 2020; Timilsina et al., 2021) and provincial level (Cheng et al., 2018; Abhyankar et al., 2020; Xie et al., 2020). From the environmental perspective, the effects of power system reform on generation efficiency (Meng et al., 2016), renewable energy consumption (Xu et al., 2018; Zhang et al., 2018) and carbon emissions (Zhou and Zhao, 2021) have also been studied.

Jiangsu is one of the most well-developed provinces in China and has made a remarkable progress on medium and long-term electricity markets (one-month-ahead and one-year-ahead markets) since 2015. To better evaluate the effect of the reform, this paper examines the progress with power market reform beginning in 2012, detailing the emergence of bilateral electricity trading and progress with annual and monthly markets following the No.9 Document of 2015. The study period includes the pre-reform period (before PSR 2015) and the period after the reform (2016 to 2020). The effects of the reform can be visualized by the changing industrial and commercial electricity price trend. However, what we highlight

is the extent to which the effects of the reform came from the introduction of market prices for generation or reductions in regulated network prices and additional charges (such as VAT or renewables subsidies). We want to show the sources of price reductions and the impact of the reform on prices paid to generators and on the transmission and distribution charges received by the grid companies. Having established the sources of the change in prices we go on to evaluate the fall in price relative to different counterfactuals of what might have happened in the absence of reform. This allows us to evaluate the overall effect of reform in net present value terms and to compare these values to previous power sector reform studies.

The major contributions of this paper can be summarized as follows:

1) This paper does a comprehensive review on the power system reform in Jiangsu Province.

2) The paper quantifies and visualizes the effects of the PSR 2015 on the industrial and commercial retail price in Jiangsu Province. The components of the monthly price reduction are calculated.

3) A Social Cost Benefit Analysis (SCBA) is proposed to evaluate the welfare change of the industrial and commercial customers in Jiangsu Province and the calculation result is compared with other power system reforms.

The remainder of the paper is organized as follows. In Section 2, the setting and history of PSR in Jiangsu are introduced. Section 3 summarizes the method of social cost benefit analysis (SCBA) and the decomposition of the retail price. The power market reform effects are explained in detail in Section 4. In Section 5, based on the assumed counterfactuals, the net benefit of the reform is calculated using SCBA. The final section concludes the analysis and provides recommendations for the policy makers in China about the power system reform.

2. Background

2.1.Jiangsu Power System

Jiangsu province is located in the east coast of China next to Shanghai in the Yangzi delta region. By the end of 2020, Jiangsu had the second highest provincial GDP of 10.27 trillion Yuan, which accounts

for more than 10% of the GDP of China, and the third highest GDP per capita (127 thousand Yuan) among all the Chinese provinces (The Paper, 2021). The GDP of Jiangsu (1.61 trillion USD) can ranks 11th on the GDP ranking by Country, close to South Korea (1.64 trillion USD) (see World Bank, 2021). Therefore, Jiangsu is one of the most well-developed and important provinces in China.

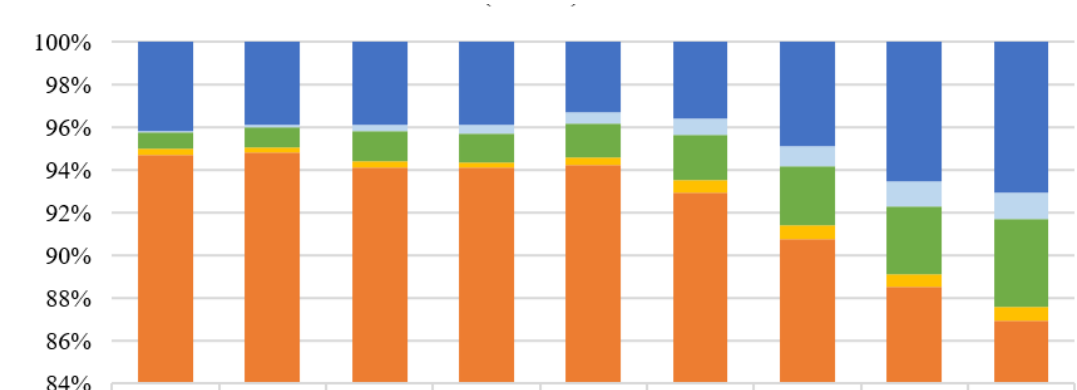
In Jiangsu a "six verticals and six horizontals" 500kV backbone network was built. Through ten 500kV high voltage lines and four 1000kV ultra high voltage lines, an alternating current looped network within the eastern China power grid was formed within Jiangsu, which is closely connected with Shanghai, Zhejiang and Anhui power grids. Jiangsu Power Grid, a subsidiary of State Grid Company of China (SGCC), receives power injected from Sichuan, Shanxi, Inner Mongolia and Hubei through four cross-provincial and cross-regional direct current transmission lines (JSDRC, 2020).

By the end of 2020, the installed capacity in Jiangsu was 136.6 GW: coal-fired power generation is 79.53 GW (58.2% of total generation); renewable power generation is 28.23 GW (20.7%); gas power generation is 16.11 GW (11.8%); nuclear power generation is 5.49 GW (4.0%)[2].

The generation mix of Jiangsu power system is presented in Fig.1. The highlighted grey cells in the table means the data is not available from the statistical data sources and the data are estimated by the trend in the available data. It can be seen that thermal generation accounts for around 90% of total generation every year and has a downward trend, starting at 95% in 2012 and ending at 87% in 2020. Thus, the renewable generation percentage was growing over time.

Fig. 1. Power generation mix in Jiangsu from 2012 to 2020 (TWh)[3]

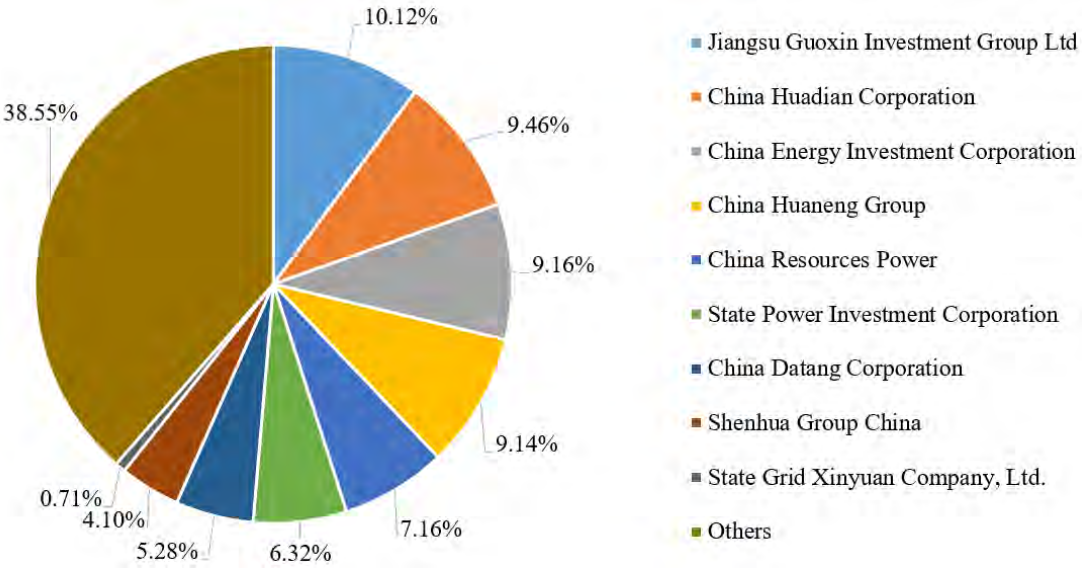
[2] Jiangsu Development & Reform Commission, 2020.
[3] Source: National Bureau of Statistics (National Bureau of Statistics, 2021).



	2012	2013	2014	2015	2016	2017	2018	2019	2020
nuclear	16.24	16.69	16.77	16.62	15.37	17.28	24.22	32.89	35.56
solar	0.20	0.49	1.20	1.98	2.60	3.62	4.62	5.87	6.46
wind	3.01	3.98	6.26	5.67	7.39	10.07	13.52	15.86	20.71
hydro	1.11	1.10	1.12	1.11	1.68	2.75	3.26	3.02	3.16
thermal	366.97	406.87	406.25	405.01	439.73	443.79	447.73	443.90	439.05

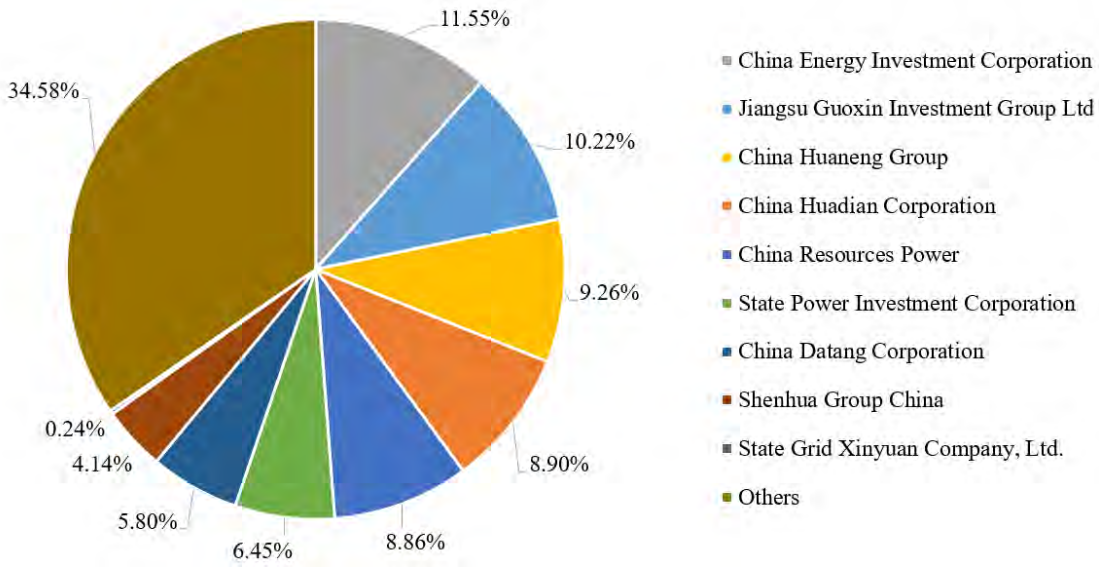
There are a number of power generation companies in the province. The installed capacities at the end of 2020 and the share of total generation output in 2020 of different generation companies are shown in Fig. 2 and Fig. 3 respectively. The largest eight companies are shown and other generation companies are shown as 'Others'. Power generation is diversified.

Fig. 2. Installed capacity of major power generation companies (by 2020)[4]



[4] Source: Jiangsu Power Exchange Center (Jiangsu Power Exchange Center, 2021).

Fig. 3. Share of total generation output in 2020[5]



Because of the strong power grid and the diversity of power generation companies, Jiangsu Province is considered to have better pre-conditions than other provinces for establishing an electricity market (see JSDRC, 2020).

2.2.Implemented Policies of Power System Reform

The Chinese government has implemented a lot of policies since the PSR 2015. Zhejiang and Guangdong, as the forerunners of the electricity market, have already brought down the electricity price comparing to the electricity price in 2012 (Xie et al., 2020 and Pollitt, 2021). Furthermore, Zhejiang and Guangdong were listed as spot market pilot provinces participating the first round of market reform. The spot markets in Guangdong and Zhejiang have both reached the trial operation stage by the end of 2021.

Jiangsu officially started the electricity market in 2016. At present (May 2022), despite the fact that there is still no spot market, Jiangsu has already successfully built a medium- and long- market. These markets involve direct trading between generators and retailers/customers. As a result of this, Jiangsu had the biggest electricity direct trading volume among all the provincial level electricity markets.

[5] Source: Jiangsu Power Exchange Center (Jiangsu Power Exchange Center, 2021)

The implemented national and provincial level policies are shown in Table. 1.

Table. 1 Implemented Policies of National and Provincial levels

Date	National Level Policy	Provincial Level Policy
Mar. 15, 2015	*The Document of Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System ("Document No. 9")* (CCCP and the State Council, 2015)	
Sep. 10, 2015		*Notice on Further Expanding Pilot Work of Jiangsu Electric Power Direct Trading in 2015* (JSRO of NEA, 2015)
Nov. 30, 2015	*Notice on the Issuance of Supporting Documents for the Reform of the Electric Power System* (NDRC and NEA, 2015)	
Apr. 18, 2016		Establishment of Jiangsu Power Exchange Center (China Electric Power News, 2016.)
Oct. 8, 2016	*Enter and Exit Measures for Electricity Retail Companies* (NDRC and NEA, 2016a)	
Dec. 29, 2016	*Basic Rules of Medium- and long-term electricity trading (provisional)* (NDRC and NEA, 2016b.)	
Feb. 28, 2017		*Pilot Scheme of Power System Reform on Retail Side in Jiangsu* (JSDRC and JSRO of NEA,2017a.)
Mar. 29, 2017	*Notice on the Plan for Orderly Liberalisation of Generation and Utilization of Electricity* (NDRC and NEA, 2017.)	
Aug. 11, 2017		*Detailed Rules for Pilot Reform of Retail Side in Jiangsu* (JSDRC and JSRO of NEA, 2017b.)
Oct. 27, 2017		*Construction Scheme of Jiangsu Electric Power Market*

		(JSRO of NEA and Jiangsu Provincial Economic and Information Commission, 2017.)
Oct. 30, 2017		*Medium- and Long-term Electricity Trading Rules of Jiangsu Province (provisional)* (JSRO of NEA and Jiangsu Provincial Economic and Information Commission, 2017.)
Dec. 18, 2017		*Work Plan for Orderly Liberalisation of Generation and Utilization of Electricity in Jiangsu* (Jiangsu Provincial Economic and Information Commission, 2017)
Dec. 20, 2017		*Implementation Scheme of Jiangsu Electricity Market Construction* (Jiangsu Provincial Economic and Information Commission, JSRO of NEA, JSDRC, Jiangsu Provincial Price Bureau, 2017.)
Mar. 23, 2018	*Renewable Portfolio Standard (RPS) and Assessment Methods* (NEA, 2018)	
Jul. 16, 2018	*Notice on Actively Promoting Electricity Market Trading and Further Improving the Trading Mechanism* (NDRC and NEA, 2018.)	
Jul. 24, 2018		*Implementation Scheme of Jiangsu Electricity Market Regulation* (JSRO of NEA and Jiangsu Provincial Economic and Information Commission, 2018)
May. 10, 2019	*Notice on Establishing and Improving the Energy Consumption Guarantee Mechanism (ECGM) of Renewable Energy* (NDRC and NEA, 2019)	
Jun. 20, 2019	*Notice on Relevant Requirements of Fully Liberalizing the Electricity Using Plan for Commercial Electricity Consumers*	

	(NDRC, 2019.)	
Jun. 10, 2020	*Basic Rules of Medium- and long-term electricity trading* (NDRC and NEA, 2020.)	
Dec. 20, 2020		*Construction Scheme of Jiangsu Electricity Spot Market* (JSDRC, 2020)
Jan. 6, 2021		*Medium- and Long-term Electricity Trading Rules of Jiangsu Province* (JSRO of NEA and Jiangsu Provincial Economic and Information Commission, 2021.)
Jul. 16, 2021	Establishment of National Carbon Emission Market (Shanghai Environment and Energy Exchange, 2021.)	
Oct. 12, 2021	*Notice on further deepening the power market reform of coal generation on-grid price* (NDRC, 2021)	

The first monthly centralized bidding pilot work in Jiangsu was carried out on September 13th, 2016. The total trading electricity volume was 5 TWh by direct trading. Three more monthly centralized bidding pilots were completed in 2016. In fact, all the transactions happened in 2016 were only on the generation side, which means that the transactions were only between the generators and the power grid company, and the retailers and costumers was not included in the market. The first monthly centralized bidding completed with the participation of both the generation and retail sides happened on February 24th, 2017.

Construction Scheme of Jiangsu Electricity Spot Market states that Jiangsu is planning to set up the spot market in the period of 2021 to 2023. In April 2021, National Development & Reform Commission (NDRC) and National Energy Administration (NEA) published the *Notice on Further Expanding Pilot Work of Electricity Spot Market Construction* (NDRC and NEA, 2021), which officially listed Jiangsu as one of provinces participating the second round of pilot spot markets.

Another perspective of the power system reform in China is to develop renewable energy generation and to reduce the carbon emissions. The *Renewable Portfolio Standard (RPS) and Assessment Methods* stipulated the proportion of renewable electricity consumption in each province. As mentioned in the

Notice on Establishing and Improving the Energy Consumption Guarantee Mechanism (ECGM) of Renewable Energy, buying green certificates (GCs) is one alternative for meeting the requirements of the RPS. The government is intending to use market-oriented measures, which means building an electricity market coordinated with the GC market and the Carbon Emissions Market, to encourage the renewable energy generation construction and to eventually achieve the "Dual Carbon Goals".

The coal price was never more than 700 Yuan per tonne (equivalent to 101.5 $/tonne[6]) before December 2020 since PSR, but the price started to climb in February 2021. In September and October 2021, the coal price rapidly rose to an unprecedented level – the coal price rose from less than 900 Yuan per tonne (130.5 $/tonne) at the beginning of September to a high point of 1982 Yuan per tonne (287.4 $/tonne) in mid-October before it dropped back to approximately 900 Yuan per tonne at the beginning of November[7]. However, for the marketized part of the electricity sector, the large proportion of coal generation companies had signed bilateral contracts in the annual electricity market at a relatively low price and there was no spot market for them to sell electricity at higher price to reduce their losses, despite the existence of the monthly market with very low volume proportion. For the regulated part of the market, the generation companies sold the electricity at a single price, which is much lower than the unit cost. As a result, for every kilowatt hour of generated electricity, the generation companies would lose money. Most generation companies were facing massive deficits in those months. To solve the problem, the government published the document of *Notice on further deepening the power market reform of coal generation on-grid price*, which expanded the transaction price range of the coal generation electricity price. Moreover, the document cancelled the industrial and commercial regulated retail price and mentioned that all the industrial and commercial customers would have to participate the electricity market. In this case, all the industrial and commercial customers have to face the market price instead of a fixed regulated price. The annual electricity contracts were honoured until the end of 2021. The assumptions made in the SCBA in this paper is based on the industrial and commercial electricity price and volume trends from 2012 to 2020. Therefore, the publication of this document does not affect the market and regulated electricity volume in our analysis.

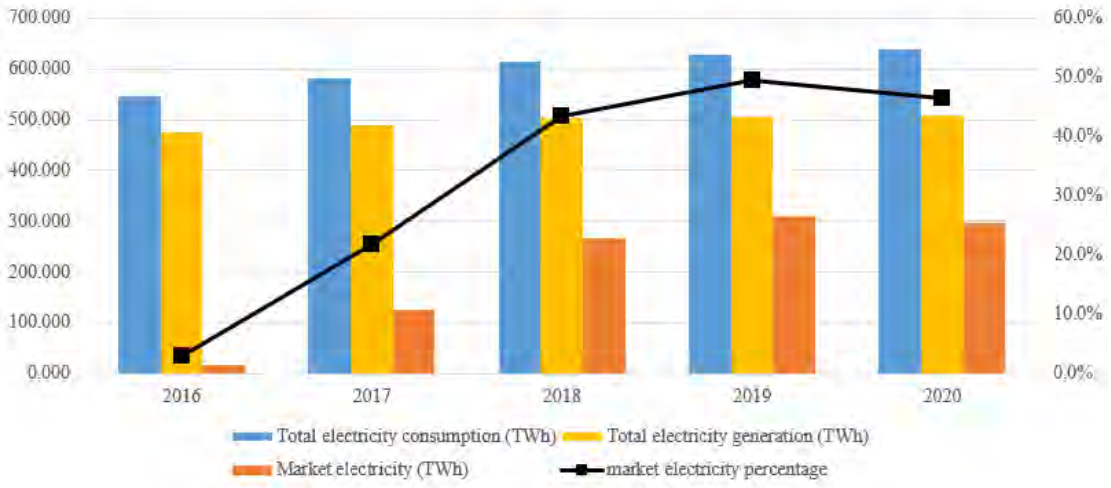
[6] The Yuan to $ average exchange rate in 2020 is 0.145 $, see www.exchangerates.org.uk.
[7] Sina Finance, 2021

2.3.Jiangsu Power Market Overview

As can be seen from Fig. 4, in the past few years, after the establishment of the medium- and long-term electricity market in Jiangsu, the volume and percentage of electricity market trading are both rising. total electricity consumption also exhibits an upward trend, while the market electricity trading volume has a faster growth rate. The market percentage slightly fell in 2020 because of the effects of Covid-19.

What also can be concluded from Fig.4 is that Jiangsu is a net importer of electricity from other provinces and the imported electricity volume is climbing during the past few years as well. In 2020, Jiangsu province consumed 637 TWh of electricity and 20% is imported from other provinces. More importantly, half of the imported electricity are renewable one[8]. It is worth noticing that there is no imported electricity in market electricity, since the imported electricity is considered as one of the boundary constraints of Jiangsu power market.

Fig. 4. Consumed, generated and market electricity volume of Jiangsu[9]



It is worth noticing that almost all market electricity is generated by thermal power generators. This is because the Energy Consumption Guarantee Mechanism (ECGM) for renewable energy (NDRC and NEA, 2019) means that all the electricity generated from renewable generators must be consumed and renewable electricity is a part of "priority electricity generation". The "priority electricity generation" is considered as regulated generation, but not a part of the medium- and long-term electricity market (JSDRC

[8] Jiangsu Power Exchange Center, 2021.
[9] Sources: Beijixing (Beijixing, 2017). Jiangsu Power Exchange Center (Jiangsu Power Exchange Center, 2018, 2019, 2020, 2021)

and Jiangsu Regulatory Office of State Energy Administration, 2021).

At present, Jiangsu medium- and long-term electricity market consists of three main markets – the annual market, the monthly centralized bidding market, the monthly listing market. We collected the transaction records of these three markets and calculated the market electricity volume by month, which is explained in detail in Section 3.2.

3. Method for analysing PSR

3.1. Social cost benefit analysis (SCBA)

In this section, the social cost benefit analysis (SCBA) methodology is described. SCBA is great way of measuring reform impact for a single jurisdiction when the reform has been in progress for a number of years. It has been systematically applied to UK electricity reforms in a series of papers (Newbery and Pollitt, 1997; Pollitt, 1997; Pollitt, 1999; and Domah and Pollitt, 2001).

The analysis aims to assess whether the overall welfare impact measured in terms of social surplus has a positive net present value (NPV). This is equivalent to treating reform as a social investment and assessing whether it has positive value at a societal discount rate. The total welfare impact can include quality and environmental impacts. The NPV can then be split between who receives it in society: namely consumers, producers and the government. Consumers might receive it in the form of lower prices or better air quality; producers in the form of higher profit and the government as fiscal transfers (from dividends/profits in state owned electricity companies, electricity company profit taxes and/or asset sales of privatized electricity companies). Weightings on each of these groups can be altered as thought desirable: one might for instance weight government net welfare receipts at 1, consumers at slightly less than 1 (because electricity consumers are slightly richer than the population as a whole) and private producers at significantly less than 1.

The crucial part of the analysis is to compare the actual and predicted future performance of the reformed industry with an appropriate counterfactual prediction of what might have happened in the absence of reform. The counterfactual might for instance be based on price and cost trends prior to reform.

A reform which delivers a sharp fall in cost against a small annual trend fall in costs prior to reform might be expected to be NPV positive, as long as the costs of reform itself were small or its effects on non-monetary variables (such as air emissions) were non-negative.

The basic formula for measuring the change in welfare as a result of a reform is a variant of the one used by Jones et al. (1990):

$$\Delta W = V_{withref} - V_{withoutref} \quad (1)$$

Where W is the social welfare, $V_{withref}$ is the social value with reform and $V_{withoutref}$ is the social value without reform. The reform is socially worthwhile if $\Delta W > 0$.

When a reform is based on the performance of power generation and network companies, the key source of social value change is a reduction in underlying costs. This can be computed as the difference between costs with and without reform, less the actual reform restructuring costs (which might take the form of redundancy payments or consultancy fees):

$$\Delta W = C_{withoutref} - C_{withref} - RC \quad (2)$$

Where $C_{withoutref}$ is costs without reform, $C_{withref}$ is the costs with reform and RC is the restructuring costs.

Total welfare change is then allocated between different groups (customers, producers and government).

$$\Delta W = \Delta Cust + \Delta Prod + \Delta Gov \quad (3)$$

Where $\Delta Cust$, $\Delta Prod$ and ΔGov represent the welfare change of the customers, producers and government. Customers see their benefits in the form of lower prices, producers higher retained profits and government in terms of more tax revenue or higher dividends from the reformed companies if they are government owned.

In this paper, we look at the welfare change of the industrial and commercial customers, which mainly comes from the electricity price change. Actually, analysing the welfare change of the customers is what we are able to do from the available data. We decompose the electricity price change to try and identify

the part that is due to the market reform and the part that is due to tax and charge changes (e.g. reducing VAT and renewable charges) which are not strictly due to reform. We then assume that the electricity cost is changing in line with the reform induced price change unless we have more detailed information about other factors. In what follows we focus on the consumer price change as the starting point for measuring the total welfare change. We also analyze changes at the generator level to look for fuel cost savings and environmental impacts.

We will not only focus on what actually happened on the welfare change from 2012 to 2020, but also look at the assumed welfare impact from 2021 to an arbitrary convergence date, which is 2030 in our analysis. This method in line with previous studies. To investigate the welfare change, two basic counterfactuals are introduced – one of them is the "pro-reform" case and the other is the "pro-no reform" case. The "pro-reform" case is more favourable to the reform assuming a less favourable electricity sector performance in the absence of reform, while the "pro-no reform" case assumes the unreformed electricity sector would have performed relatively well in the absence of the 2015 PSR. The detailed assumptions of the two counterfactuals will be presented in Section 5.

3.2. Decomposition of the Retail Price

In this sub-section, the goal is to show what has been changing in the retail price. The breakdown of the price has four components – generation price, network charge, value added tax (VAT) and additional charges. After the implementation of electricity market in Jiangsu in 2016, the total electricity consumption can be divided into the regulated part and the market part. The price change in each component are analyzed. According to this partition, the total weighted retail price can be calculated as follows (Xie et al., 2020):

$$p_r = \frac{p_r^R \cdot Q^R + p_r^M \cdot Q^M}{Q^R + Q^M} \tag{4}$$

Where p_r is the total weighted retail price, p_r^R is the weighted regulated retail price, p_r^M is the weight market retail price. Q^R is the total regulated consumption and Q^M is the total market trading volume. The regulated retail price can be formulated as follows:

$$p_r^R = \frac{\sum_i p_{gi}^R \cdot Q_i^R}{(1+t)Q^R} + \frac{p_n^R}{(1+t)} + VAT^R + add \quad (5)$$

Where p_{gi}^R is the regulated generation price for ith generation source type and Q_i^R is the regulated generation volume of ith source type, t is the VAT rate, p_n^R denotes the network charge of the regulated part, add denotes the additions. The total regulated consumption equals the sum of various regulated generation volumes, which means $\sum_i Q_i^R = Q^R$. Since p_r^R is the regulated retail price, which is given, and VAT^R and p_n^R can be calculated as follows:

$$VAT^R = \frac{(p_r^R - add) \cdot t}{1+t} \quad (6)$$

$$p_n^R = \frac{(p_r^R - add) \cdot Q^R - \sum_i p_{gi}^R \cdot Q_i^R}{Q^R} \quad (7)$$

It is worth mentioning that this paper does not consider other kinds of taxes, for example the corporate income tax. The reason is that our study is focusing on the welfare change of the customers. We assume that VAT is not charged on additions.

The market retail price can be expanded as follows:

$$p_r^M = \frac{p_g^M}{1+t} + \frac{p_n^M}{1+t} + VAT^M + add \quad (8)$$

Where p_g^M is the market price on the generation side, p_n^M is the transmission and distribution (T&D) price. p_g^M and VAT^M can be formulated as follows:

$$p_g^M = \frac{p_a \cdot Q_a + p_b \cdot Q_b + p_l \cdot Q_l}{Q_a + Q_b + Q_l} \quad (9)$$

$$VAT^M = \frac{(p_g^M + p_n^M)t}{1+t} \quad (10)$$

Where p_a , p_b , p_l are the market generation price in the annual market, monthly centralized bidding market, monthly listing market respectively. Q_a, Q_b, Q_l are the trading volume of the three markets respectively.

The total market electricity and weighted market price by month are shown in the Fig. 11. The breakdown by month of the annual market trading volumes is not available in the reference materials, so the contribution of annual trading volume to each month is the volume divided by twelve. The price peaks

and valleys of the weighted price are basically affected by the monthly market price fluctuations.

To decompose the total weighted retail price, p_r can be expressed as follows:

$$p_r = \left[\frac{\sum_i p_{gi}^R \cdot Q_i^R}{(1+t)Q^R} \cdot \frac{Q^R}{Q^R+Q^M} + \frac{p_g^M}{1+t} \cdot \frac{Q^M}{Q^R+Q^M}\right]$$
$$+\left[\frac{(p_r^R - add)\cdot Q^R - \sum_i p_{gi}^R \cdot Q_i^R}{Q^R(1+t)} \cdot \frac{Q^R}{Q^R+Q^M} + \frac{p_n^M}{1+t} \cdot \frac{Q^M}{Q^R+Q^M}\right] \quad (11)$$
$$+\left[\frac{(p_r^R - add)\cdot t}{1+t} \cdot \frac{Q^R}{Q^R+Q^M} + \frac{(p_g^M + p_n^M)t}{1+t} \cdot \frac{Q^M}{Q^R+Q^M}\right] + add$$

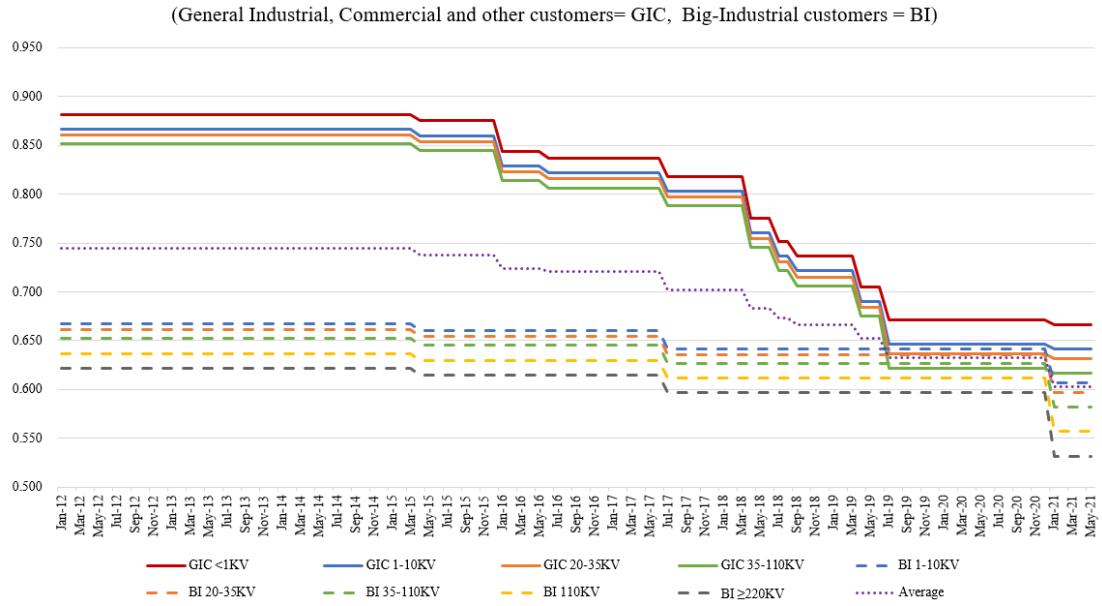
In this equation, the expression in the first bracket is the weighted generation price. The second is weighted network charge. The third one is the weighted VAT.

4. Effects of power market reform

In this section, we try to quantify and visualize the effects of the PSR 2015 on the electricity price.

The regulated retail benchmark electricity price depends on the connection voltage of customers. The voltage level range is from “Below 1 kV” to “220 kV and above”. Fig. 5 shows the industrial and commercial retail benchmark price for different costumer groups and voltage levels. What can be clearly see from the figure is that the price for “general industrial, commercial and other customers” has a much higher price drop from 2012 to 2021 than the one for “big industrial customers”. Xie et al. 2020 takes 35kV retail price of general industrial customers for the analysis because this voltage range is considered to be representative (accounts for 10% of total power consumption). If we use the similar group (35-110kV general industrial, commercial and other customers) for the Jiangsu case, the actual price drop for all industrial and commercial customers will be exaggerated. Unfortunately, the consumption percentages of different groups are not shown in any available sources. Therefore, for the convenience of calculation, we simply take an arithmetic average of all nine groups of retail price for the following analysis (which is the purple dotted line in Fig. 5).

Fig. 5. Industrial and commercial retail benchmark price (regulated retail price)[10]



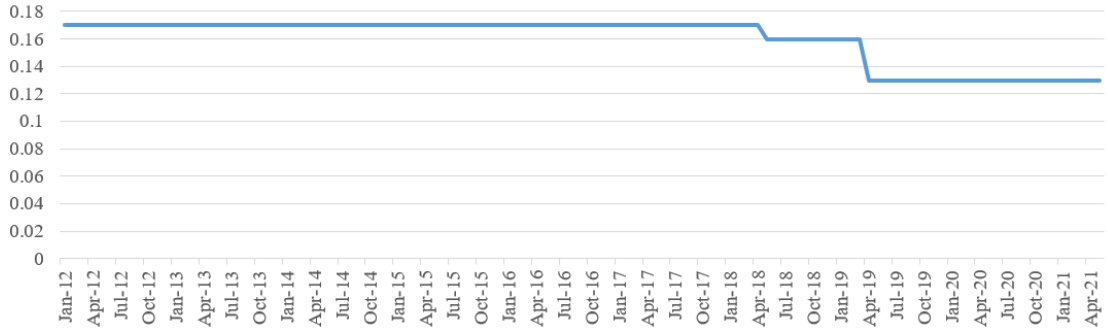
In Section 4.1, the value added tax (VAT) and additions change in retail price is discussed. Since we are focusing on the impact of PSR we should ignore price changes that are due to VAT and additions changes in the SCBA calculation, as these are changes in tax policy. Then, the method proposed in Section 3.2 is used to carefully calculate the price change in the remaining retail price components in Sections 4.2 to 4.4. In order to understand the relationship between price changes and changes in underlying costs we look to understand what might be happening to network and generation revenue, cost and profitability in Sections 4.5 and 4.6. Section 4.5, the revenue of *STATE GRID Corporation of China (SGCC)* is presented. A single anonymous coal generation company in Jiangsu is investigated in Section 4.6 to see what factors have impacted the electricity generation price change during the PSR period. Finally, we look to assess the impact of reform on CO2 and SO2 emissions in Section 4.7. We study the relationship between total electricity generation and coal consumption in order to further calculate the CO2 and SO2 emissions change due to the 2015 PSR in Section 5.

4.1. Value Added Tax and Additions in Retail Price

[10] Jiangsu Provincial Bureau of Price (2011, 2012, 2015a, 2015b, 2016, 2017a, 2017b, 2018a, 2018b, 2018c, 2019a, 2019b, 2021).

The value added tax (VAT) is a significant addition to electricity retail price. The VAT is directly charged to the generation price and network price, which are the components of retail price, in proportion. The VAT has changed twice from 2012 to 2019 which presented in Fig. 6. In May 2018, the VAT rate reduced from 17% to 16%. It dropped again to 13% in April 2019.

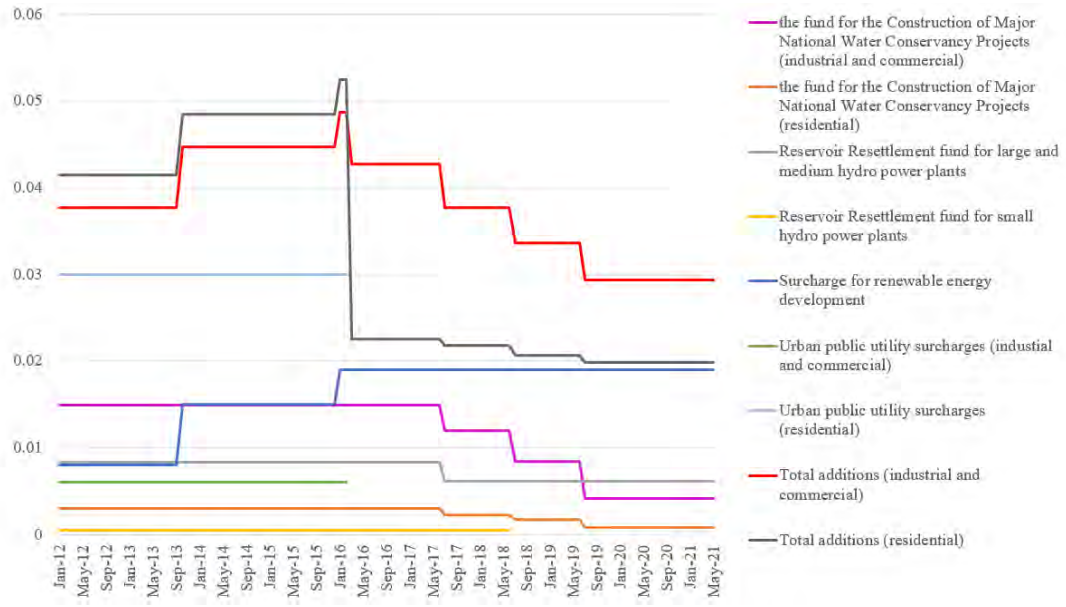
Fig. 6. Value added tax rate change



There are a lot of kinds of additions in retail price for industrial and commercial customers, as well as residential ones. They include the fund for the Construction of Major National Water Conservancy Projects, the Reservoir Resettlement fund for large and medium hydropower plants, the Reservoir Resettlement fund for small hydropower plants, Surcharges for renewable energy development and Urban public utility surcharges. What needs to be clarified is that we cannot definitely say the additions changes are the effect of power market reform, so we exclude this part when calculating the welfare change of the reform in the later section. However, we still need this part to show the retail price components variations.

Fig. 7. Additions changes[11]

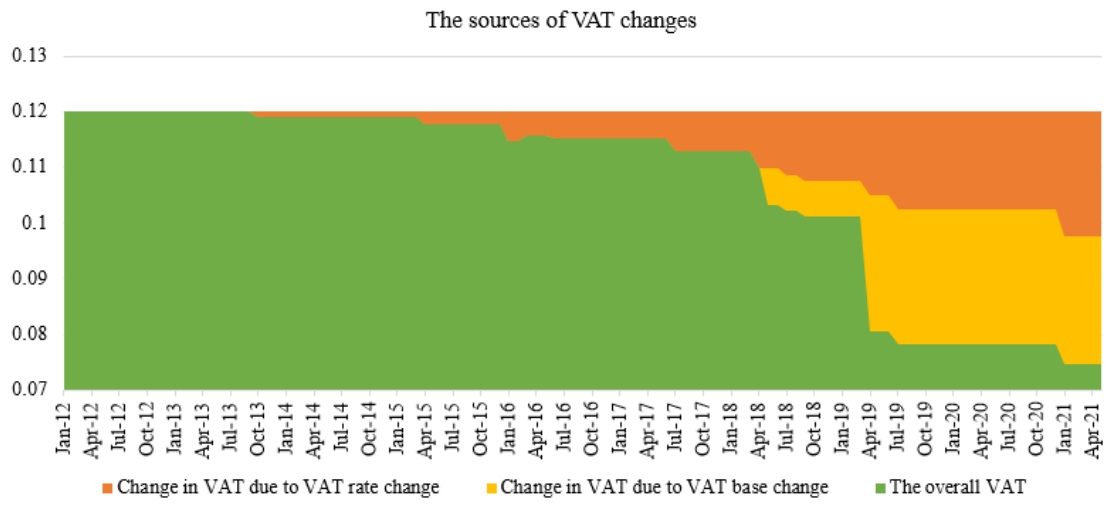
[11] Jiangsu Provincial Bureau of Price (2011, 2012, 2015a, 2015b, 2016a, 2016b, 2016c, 2017, 2018a, 2018b, 2018c, 2019a, 2019b, 2021). National Development & Reform Commission (2013).



The changes of the different additions and their sum are shown in Fig, 7. The urban public utility surcharge was no longer charged to customers in March 2016 and it is updated in the price adjustment document published in June 2016. the Reservoir Resettlement fund for small hydropower plants was abolished in July 2018.

In order to derive VAT from the regulated retail price, additions are subtracted from the retail price and VAT rate is applied to the remaining amount. VAT changes are attributed to two sources, which are the change of the VAT rate and the changes in the VAT base. As can be seen from Fig. 8, the overall VAT is shown in green, while the orange block and yellow block represent the two sources respectively.

Fig. 8. The sources of VAT change



4.2.On-grid Price for different generation types

Before the 2015 electricity reform, all the generation prices from different fuel sources were regulated by the National and provincial Development and Reform Commission. The method of price control has experienced significant regime change. Before 2004, the generation price was subject to a cost of service regulation regime. Different power plants or even different generation units were paid various generation prices. After 2004, China introduced yardstick competition regulation for coal-fired power plants. Each province has separate uniform benchmark generation prices for all the coal-fired generators. These benchmark coal generation prices determine generation costs for the whole electricity system since coal is the major fuel source of China's generation. The same benchmark price control mechanism was implemented for hydro generators from 2004, abolished in 2009 and reintroduced in 2014. There was no specific benchmark price for nuclear generators until 2013, but their price cannot exceed that of coal-fired generators. Wind and solar benchmark generation pricing started at 2009. The only exception is gas-fired power. Since the cost of natural gas is high in China, only rich coastal provinces can afford such relatively clean energy (Xie et al., 2020). The benchmark price for gas generators in Fig. 9 starts at 2015, which is because it is the time of the earliest online document can be traced.

Fig. 9 shows the benchmark prices of different generation types. The provincial power mix is dominated by the coal power as mentioned in Section 2.1. Therefore, the weighted regulated price is most

affected by the coal generation price. The wind and solar power price changes are mainly driven by the subsidy changes. The price of hydropower and nuclear power are set by the government.

The on-grid price of wind power is divided into class I ~ IV, and Jiangsu belongs to class IV (the highest price). The earliest official document for the on-grid price of gas power generation that can be traced was released in 2015. No public document was found on the website before this time point. The price of natural gas remained stable after November 2018. However, due to the high price of natural gas in winter, the on-grid price of gas generation was temporarily increased in winter of 2018 and 2019. The prices of hydropower and nuclear power are set by the government. Due to the difficult operation of small hydropower in Jiangsu, the price of hydropower adopts the on-grid price of coal power. The nuclear electricity in Jiangsu is generated by Tianwan Nuclear Power Plant. The on-grid price of its five units are different, which are listed in the figure. Their starting points are the time points when each officially starts operation.

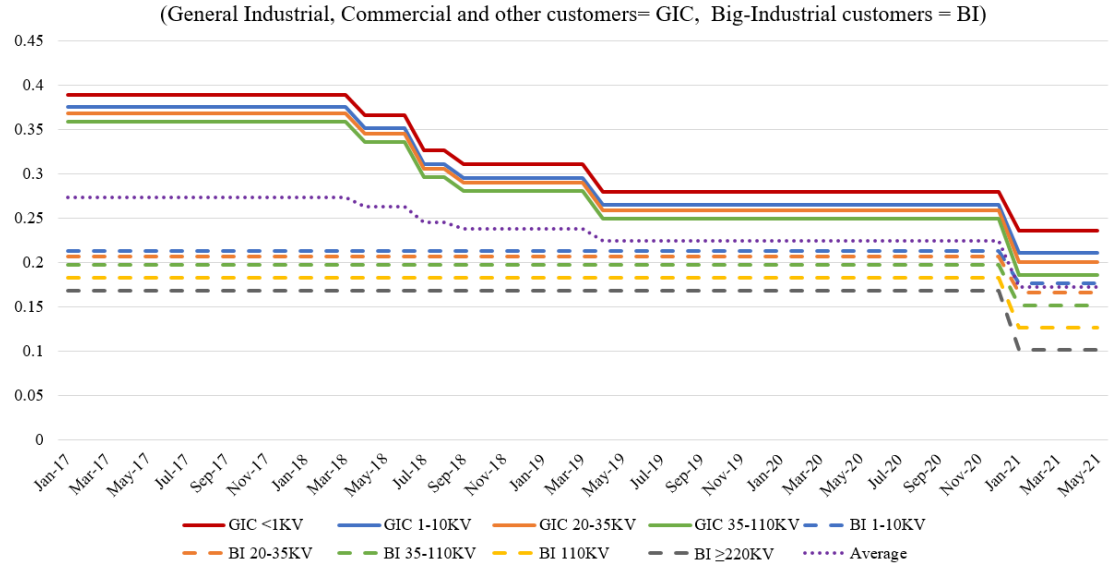
Fig. 9. The on-grid price (regulated generation price) for different types of generation

4.3.Transmission and Distribution Price

In 2017, Jiangsu published "Notice of the Jiangsu Provincial Administration of Commodity Prices on matters related to the transmission and distribution (T&D) prices of the Jiangsu Power Grid in 2017-

2019", which indicated the beginning of charging a transmission and distribution fee. The T&D price is the network charge applied to the electricity supplied via the market. However, as mentioned in Section 2.2, Jiangsu electricity market started in September 2016. For the convenience of the calculation and distinguish the marketized volume from regulated one, the T&D price from September to December 2016 is assumed to be the same as January 2017 for the following analysis.

Fig. 10. T&D price (the network price applies to the market electricity)[12]



As can be seen from Fig. 10, the T&D price had a downward tendency from 2017 to 2019 for all the industrial customers. Initially, the T&D price for was mentioned in the "Notice of the Jiangsu Provincial Administration of Commodity Prices on matters related to electricity price adjustment" (January 2017). The T&D price for big industrial customers only had one drop at the beginning of 2021. For general industrial and commercial customers, in April 2018, the price had the first drop due to the publication of "Notice of the Jiangsu Provincial Administration of Commodity Prices on further reducing general industrial and commercial electricity price" (April 2018). Then, the price fell again in July and September because of the publication of "Notice of the Jiangsu Provincial Administration of Commodity Prices on matters related to reducing general industrial and commercial electricity price" (September 2018). The

[12] Jiangsu Provincial Bureau of Price, 2016a, 2016b, 2017, 2018a, 2018b, 2018c, 2019a, 2019b, 2021. T&D price is the network price for the market electricity. Differently, the network price for regulated electricity is calculated using formula (7) shown in Section 3.2.

price had another reduction in July 2019 with the publication of "Notice of the Provincial Development and Reform Commission on matters related to reducing the general industrial and Commercial electricity price" (May 2019).

4.4.Overall Retail Price

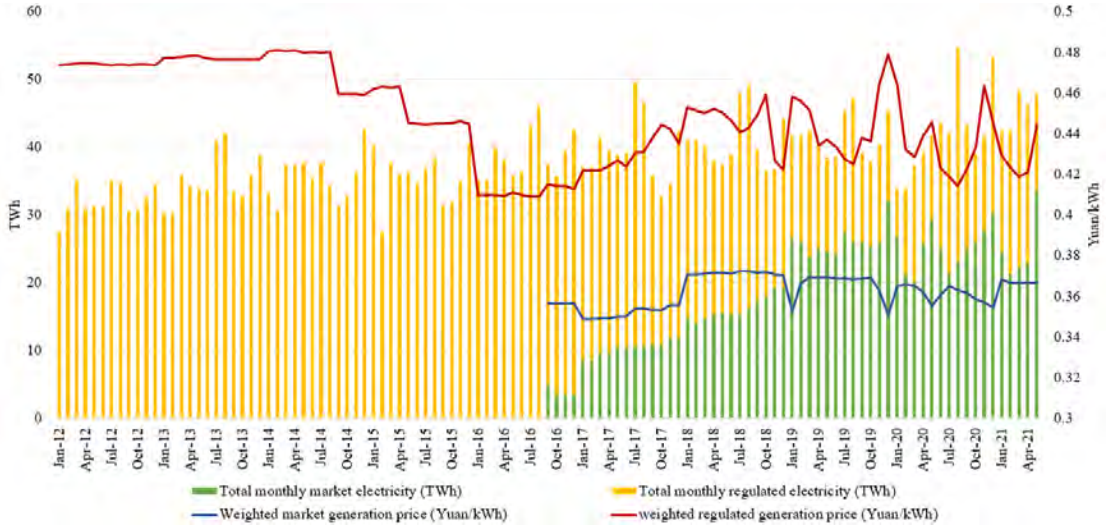
Based on the annual and monthly trading historical data, the monthly market electricity volume and weighted market price are presented in Fig. 11. It should be noted that since the monthly breakdown of the annual market trading volume is not mentioned, the monthly market electricity is calculated by the summation of one-twelfth of the annual market trading volume and the monthly market trading volume. Furthermore, because of the absence of the breakdown of thermal generation, the monthly coal generation electricity volume and the monthly gas generation electricity volume are calculated using their capacity shares (see Table. 2). What needs to be clarified about Table. 2 is that the bold numbers in the grey cells are obtained from online sources, while other numbers are linearly calculated from the available data. Since all the market electricity are generated by coal generators, the regulated generation volume consists of other types of generation and the coal generation remaining outside the market. Therefore, the weighted regulated generation prices are not necessarily accurate but they can reflect the general trend.

Table. 2. Coal and gas generation capacity

	2012[13]	2013	2014	2015	2016	2017[14]	2018	2019	2020[15]
Thermal capacity (GW)[16]	**67.4**	**71.2**	**74.9**	**78.5**	**82.2**	**85.9**	**89.9**	**92.8**	**95.6**
Coal capacity (GW)	**62.4**	64.9	67.4	69.9	72.4	**74.9**	76.4	78.0	**79.5**
Gas capacity (GW)	**5.1**	6.3	7.5	8.7	9.9	**11.1**	13.5	14.8	**16.1**
coal percentage in thermal capacity	92.5%	91.1%	90.0%	88.9%	88.0%	87.1%	85.0%	84.1%	83.2%
gas percentage in thermal capacity	7.5%	8.9%	10.0%	11.1%	12.0%	12.9%	15.0%	15.9%	16.8%

Fig. 11. Monthly electricity volume and weighted generation price

[13] Jiangsu Regulatory Office of National Energy Administration (2013).
[14] Jiangsu Regulatory Office of National Energy Administration and Jiangsu Provincial Economic and Information Commission (2017).
[15] Jiangsu Development & Reform Commission, 2020.
[16] Jiangsu Bureau of Statistics, 2021.



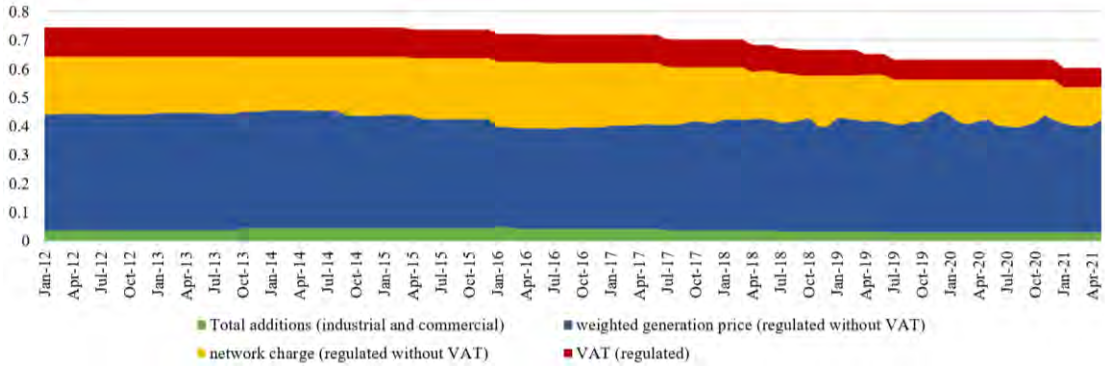
As can be seen from Fig. 11, the weighted market generation price is lower than the regulated one. The market generation price rose in 2018 because of the increasing coal price. The market generation price was relatively stable in 2018 and 2019 except for two low price points in 2019. One possible reason is that the generation companies had already completed their annual profit targets (monthly centralized bidding for January 2019 was completed in December 2018) and they were willing to sacrifice some unit profit for more market share. The weighted generation price fluctuated a lot in 2020 because of the Covid-19 quarantine. There was no electricity traded in the monthly centralized bidding market in March and July 2020, and in the monthly listing market in February and March 2020.

According to the formulas provided in Section 3.2, the following figures can be presented.

Fig. 12. Retail price components variations

(a) Retail price components for market industrial and commercial customers

(b) Retail price components for regulated industrial and commercial customers



(c) Overall retail price for all industrial and commercial customers

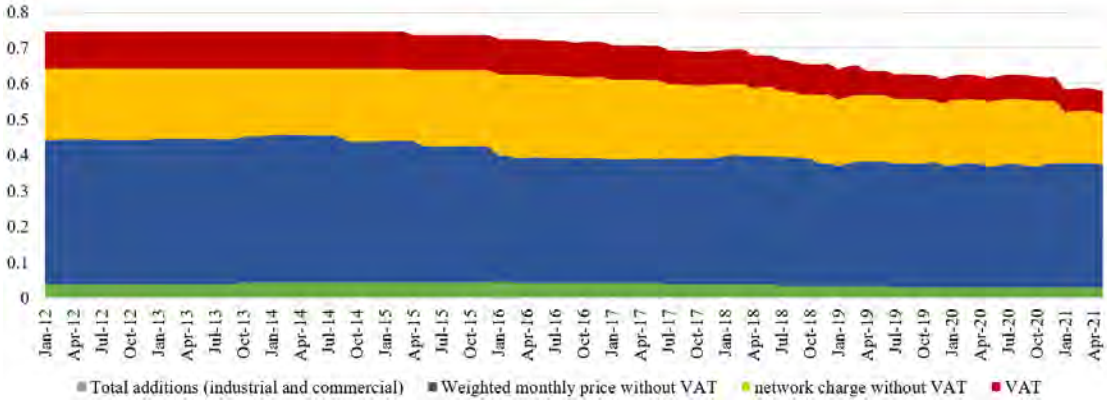
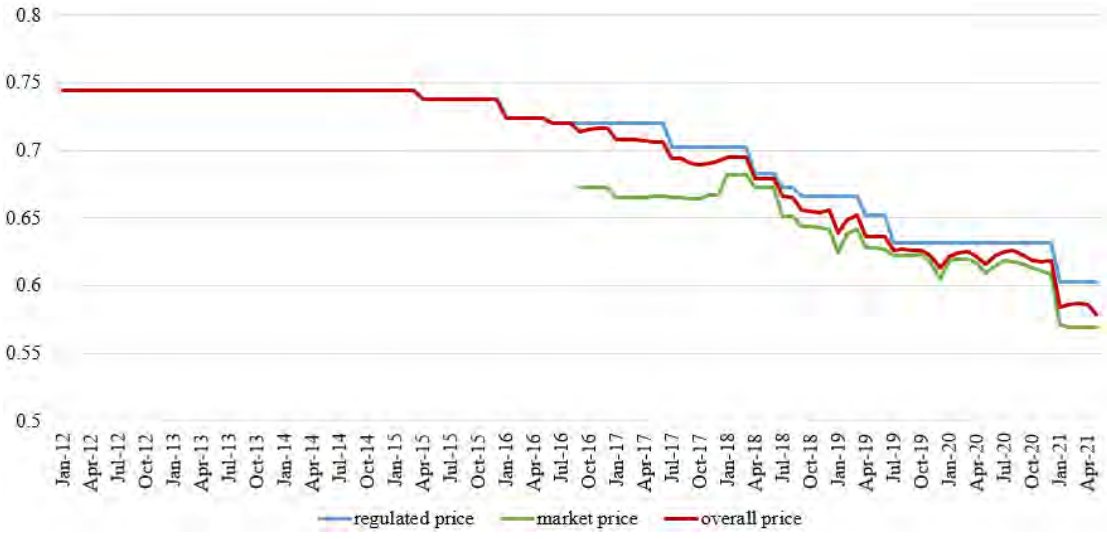


Fig. 13. Regulated, market and overall retail price



The comparison of market, regulated and overall retail price is shown in Fig. 13. It can be seen that all three price curves have downward trends. The market price is lower than the regulated price after the

market is introduced.

To further visually show the decomposition of price reduction, January 2012 is taken as the base case and all the prices from other month are related to it.

For the regulated price change:

$$\Delta p_r^R = \left[\frac{\sum_i p_{gi}^R \cdot Q_i^R}{(1+t)Q^R} - \frac{p_g^B}{1+t}\right] + \left[\frac{p_n^R}{1+t} - \frac{p_n^B}{1+t}\right] + (VAT^R - VAT^B) + (add - add^B) \tag{12}$$

Where p_g^B is the weighted generation price of January 2012, p_n^B is the network charge of January 2012, VAT^B is the VAT of January 2012 and add^B is the total addition of January 2012. Similarly, the market price change Δp_r^M can be achieved.

$$\Delta p_r^M = \left[\frac{p_g^M}{1+t} - \frac{p_g^B}{1+t}\right] + \left[\frac{p_n^M}{1+t} - \frac{p_n^B}{1+t}\right] + (VAT^M - VAT^B) + (add - add^B) \tag{13}$$

With the introduction of the power market reform, the price of the generation power mix, network cost and VAT change to some extent, but since this paper is mainly focusing on the welfare change of customers, we are only looking at the network price and generation price components for the SCBA in Section 5.

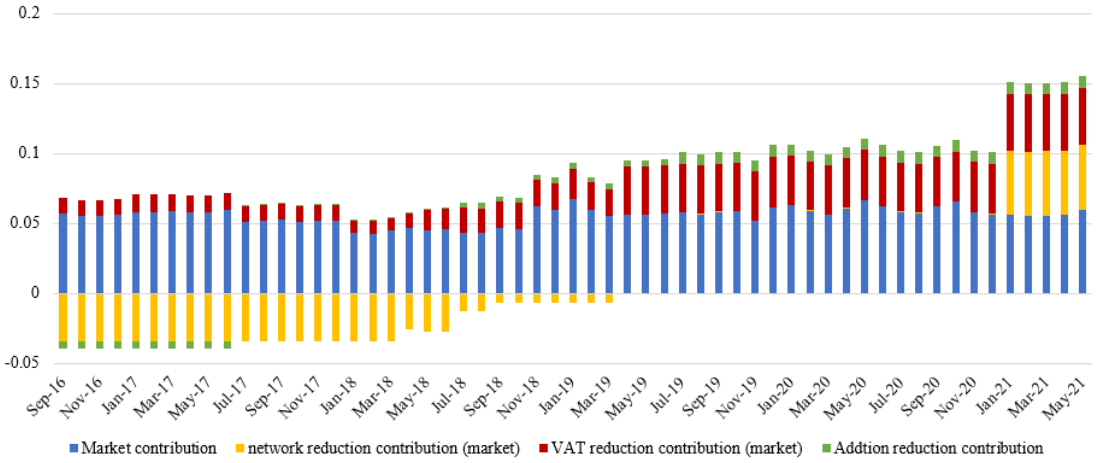
Let α be the proportion of the traded power in the market compared with the total generation, then

$$\Delta p_r = \alpha\left[\frac{p_g^M}{1+t} - \frac{p_g^B}{1+t}\right] + (1-\alpha)\left[\frac{\sum_i p_{gi}^R \cdot Q_i^R}{(1+t)Q^R} - \frac{p_g^B}{1+t}\right] + \left[\frac{\alpha p_n^R}{1+t} + \frac{(1-\alpha)p_n^M}{1+t} - \frac{p_n^B}{1+t}\right] + [\alpha VAT^M + (1-\alpha)VAT^R - VAT^B] + (add - add^B) \tag{14}$$

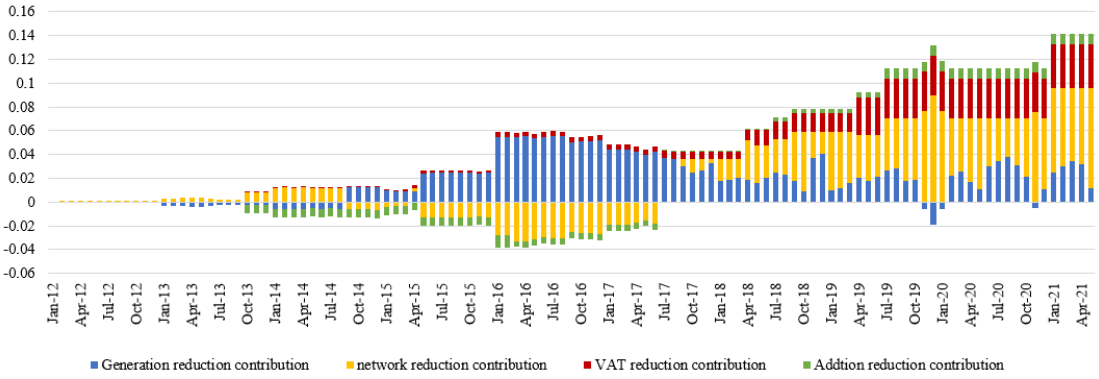
Where first term is the market generation contribution, and the second term is the regulated generation price contribution. The following three terms are network reduction contribution, VAT reduction contribution and additions reduction contribution respectively.

Fig. 14. Components of price changes in retail price

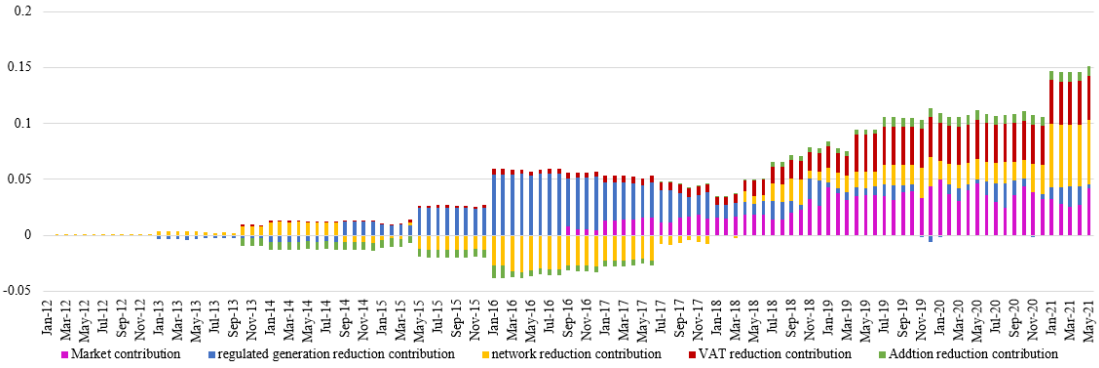
(a) Components of price changes for market electricity volume



(b) Components of price changes for regulated electricity volume



(c) Components of price changes for all industrial and commercial customers



The decline of retail price for market customers was slightly larger than the one for regulated customers (0.155 vs. 0.141yuan/kWh). The main source of the decline of regulated retail price was the

decline of network price (0.085 out of 0.141 yuan/kWh). In the decline of market retail price, the contribution of transmission and distribution electricity price decline was about 0.046 yuan/kWh. The power generation contribution to the electricity price decline was about 0.060 yuan/kWh. The reduction in value-added tax was about 0.041 yuan/kWh.

The regulated weighted generation price has a rising trend after falling. The on-grid price of coal power was lowered to 0.378 yuan / kWh in 2016 and increased to 0.391 yuan / kWh in 2017. This was mainly due to the change of underlying coal price.

Overall, the weighted average price decreased by 0.151 yuan / kWh, equivalent to 21.3% reduction, by May 2021 compared to the price of January 2012. Among the sources of price reduction, the decline of network price accounts for a large proportion, though the contribution of power generation side cannot be ignored.

Xie et al. (2020) also have similar results when analyzing retail price variations in Zhejiang and Guangdong cases. They also find that the largest retail price drop contribution is from the reduction of network price. The market retail price, regulated retail price and overall retail price in May 2021 had dropped 23.6% (Zhejiang 30.4% and Guangdong 30.2% from 2012 to 2019), 19.0% (Zhejiang 26.7% and Guangdong 26.6% from 2012 to 2019) and 21.3% (Zhejiang 27.7% and Guangdong 27.7% from 2012 to 2019) respectively in Jiangsu comparing to January 2012. The generation, network and VAT contribution to the price drop in Jiangsu are 30.3%, 38.1% and 26.1%, which is quite different from the ones in Zhejiang (17.0%, 58.5% and 21.7%) and Guangdong (18.7%, 55.8% and 21.5%). Furthermore, Xie et al. only takes one group of prices (35kV) for the analysis, in which case the price drop could be exaggerated for all industrial customers. It is worth noticing that these price reductions are calculated based on nominal prices, which is different from the real price reductions when including inflation (at 19.6% in the period of 2012 to 2020) in Section 5.

4.5.Revenue of the STATE GRID Corporation of China (SGCC)

The Jiangsu power grid is owned by the State Grid Jiangsu Electric Power Co., LTD (JSEPC), which is a subsidiary of the SGCC. In this section, we try to find evidence of impact on the profit margin change from before and after the PSR 2015. Since the annual audit reports of JSEPC are not available, the annual audit reports and social responsibility reports of SGCC are used as the original data sources.

Table. 3. Datasheet of the SGCC[17,18]

	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020
Operating revenue	Billion Yuan	1877.6	2043.2	2082.8	2061.5	2063.7	2347.0	2547.0	2636.0	2644.5
Operating Profits	Billion Yuan	104.5	66.7	76.8	84.5	83.6	109.3	78.7	76.0	56.6
Electricity Sales	TWh	3254	3523	3469	3451	3605	3875	4236	4454	4578
Total assets	Billion Yuan	2388.3	2570.1	2893.5	3108.7	3404.1	3810.6	3929.3	4155.9	4196.8
Unit electricity income	Yuan/kWh	0.577	0.580	0.600	0.597	0.572	0.606	0.601	0.592	0.578
Unit electricity profit	Yuan/kWh	0.032	0.019	0.022	0.025	0.023	0.028	0.019	0.017	0.012
Gross profit m argin	%	5.55%	3.26%	3.67%	4.08%	3.99%	4.63%	3.07%	2.86%	2.12%

As can be seen from Table. 3, the profitability of SGCC is squeezed during the past few years. The unit electricity income did not have an obvious drop during the early period of the reform. However, if we see Table. 3 combined with Fig. 9 and Fig. 10, the unit electricity profit margin was squeezed as the T&D price and retail price fell in 2018.

4.6.Revenue of a Generation Company

There are several reasons for a generation company to decrease the electricity price. First, if the fuel price falls, the cost of unit electricity generation can be lower. Second, the generation company could upgrade their generation technology to become more efficient, in order to save the fuel. Third, the implementation of electricity market makes the generation company to be more competitive and this might lower its profit margin. The goal of this sub-section is using data from a single anonymous coal generation company in Jiangsu to investigate which of these three factors might at work during the PSR period.

Table. 4 Datasheet of the single anonymous coal generation company

	Unit	2013	2014	2015	2016	2017	2018	2019	2020
Unit coal consumption	kg/kWh	0.2433	0.2462	0.2401	0.2331	0.2439	0.2488	0.2511	0.3227

[17] Annual audit reports: CCDC, 2020; SCH 2019, 2021; SSE, 2014, 2017.
[18] Social responsibility reports: SGCC, 2021.

Unit electricity price	Yuan/kWh	0.3655	0.4137	0.3385	0.3062	0.3231	0.3343	0.3359	0.3289
Unit electricity profit	Yuan/kWh	0.0788	0.0780	0.0971	0.0686	0.0325	0.0256	0.0363	0.0420

Source: Data provided from company to researchers

The revenue of the single anonymous coal generation company is provided and the key information is shown below in Table. 4. As can be seen from Table. 4, there has been no obvious improvement in the efficiency of coal generators. The unit coal consumption is stable from 2013 to 2019, which remains at the level of approximately 0.25 kg/kWh. However, in 2020 the unit coal consumption rose dramatically for this company. A possible explanation for that is the COVID-19 epidemic situation. The load decreased compared with the same period of the previous years and generators operated at a low capacity factor for a long time, reducing their thermal efficiency. Moreover, the profit rate of the power generation company has sharply fallen since the PSR 2015, in line with the fall in the received electricity price. There might be two reasons for this. One is that the implementation of electricity market has had a positive impact, compelling the company to being more competitive (there is a reduction in unit electricity price) so profit margins are compressed. The other reason is rising costs due to staff or fuel costs. We tried to investigate the connection between the unit electricity price trend and the unit coal price trend, but no obvious evidence was found.

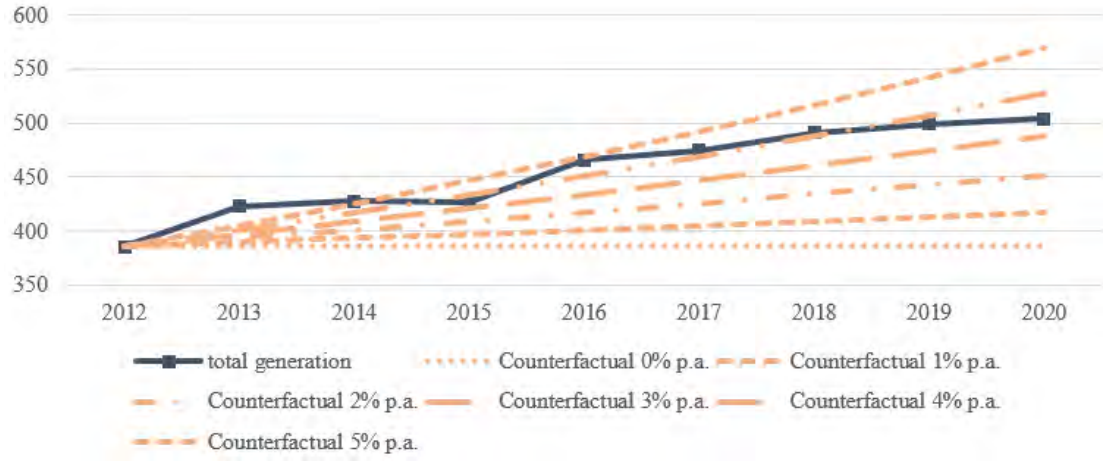
4.7.Energy Consumption and Emissions

In this section, since there is no evidence of cost efficiency improvement in coal generators, we intend to find the evidence of the change of the generation mix and further investigate the environmental effects of the PSR 2015. In this study, the environmental effects are calculated as variations in SO2 and CO2 emissions, which can be calculated by coal consumption change.

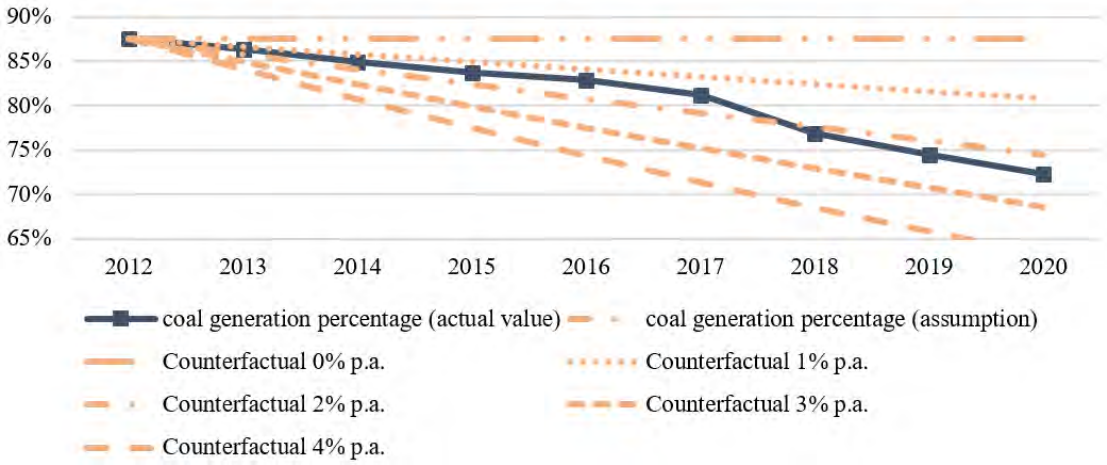
Due to limited source data, energy consumption in the electricity sector is not available. In this paper, the annual coal consumption is calculated based on the total annual electricity generation volume (Fig. 15(a)), coal generation percentage (Fig. 15(b)) and assumed total coal consumption (@0.25 kg/kWh, which is the unit coal consumption from the analysis of Section 4.6).

Fig. 15. The calculation of annual coal consumption

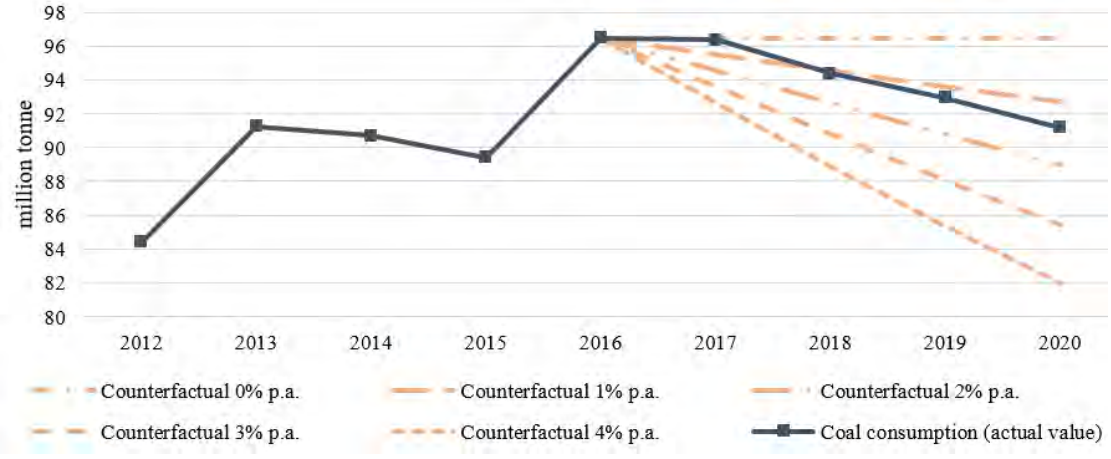
(a) total annual electricity generation volume (TWh)



(b) coal generation percentage



(c) the total coal consumption (@0.25 kg/kWh)



Although the total annual electricity generation increases every year, the coal generation percentage exhibits a downward trend. As can be seen from the figure, annual coal consumption starts to fall since 2016 at the rate of approximate 1% p.a.

Unit CO2 emission is 1.9 kg per kg of coal (UK Data Service, 2018), while Unit SO2 emission is 0.075kg per kg of coal (US EPA, 2018)[19]. The CO2 price used for calculation is 400 Yuan/tonne[20] (The World Bank, 2017) and the SO2 price is 14000 Yuan/ton (Zeng et al., 2018). To simplify the calculation of emissions from coal generation, this paper does not take the change of unit coal emissions and emission prices into consideration. Therefore, the CO2 and SO2 emissions change linearly with the total coal consumption.

5. Social Cost Benefit Analysis Results

For a full social cost benefit analysis (SCBA) actual evolution of costs needs to be compared against a counterfactual of what costs might have been in the absence of reform. Real controllable unit costs are focused on in the analysis that follows. By controllable costs, all costs which are not under the control of the companies have to be excluded, such as those driven by the price of fuel or government property taxes on companies. The actual performance can be compared to a counterfactual which shows that costs fell by, 2%, 4%, 6%, etc. p.a.. We however focus on the industrial and commercial consumer welfare impact because it is the price impact of power market reform that can be observed more easily in China.

In Section 4, we calculated the price reduction component by using the nominal price trends. However, in this section, to do the SCBA, we have to take inflation into consideration. Firstly, the consumer price index (CPI) is use to adjust the weighted generation price and network price without VAT. In this paper, the SCBA base year is set at 2020.

[19] We tried to find the CO2 and SO2 emission coefficient of China, but we can't find any official sources. There exist discussions that the coefficient of China is higher than the ones for UK and US, which are 2.66-2.72 kg CO2 and 0.085 per kg of coal. Since we are doing a conservative SCBA and more unit emissions reductions means more welfare gained, plus we do not want to use unofficial data sources, we use the UK and US coefficient for this analysis.

[20] The World Bank gave the price range of shadow price of CO2 from 2017 to 2030 in the document. The ranges of the price are 37 $/tonne to 75 $/tonne in 2017 and 50 $/tonne to 100 $/tonne in 2030. Both the low and high estimate are monotonically increasing. This paper takes the average of the low and high estimate in 2020 as the CO2 price for calculation, which is 60 $/tonne (approximately 400 Yuan/tonne).

$$\mathrm{RP_N} = \mathrm{NP_N} \times \frac{CPI_{2012}}{CPI_N} \quad (15)$$

Where $\mathrm{RP_N}$ and $\mathrm{NP_N}$ mean the real price and nominal price of the year N, CPI_N means the CPI of the year N (CPI base year 2012, which means $CPI_{2012} = 100$ and is different from the SCBA base year).

For the weighted generation price, the reform starts in 2015. For our base year calculation, the real price from 2012 to 2014 is averaged, because it is necessary to average the weights for all three years instead of giving too much weight to the price in 2014. For the weighted network price, the T&D price is implemented since 2016.

Then, the assumptions of both cases are presented as follows in Table. 5:

Table. 5. Assumption of the two cases

<table>
<tr><th>Pro-Reform</th><th>Pro-No Reform</th></tr>
<tr><td colspan="2">Calculation of coal consumption for both cases:
The historical industrial and commercial electricity consumption volume is used for 2012 to 2020 (Jiangsu Bureau of Statistics, 2021). From 2021 to 2030, it is assumed that the industrial and commercial electricity consumption volume increases 2% p.a.
The total generation volume increases 1% p.a.[21] and the coal generation percentage drops 2% p.a. The total coal consumption is calculated by:
coal consumption = generation volume * coal generation percentage * 0.25 kg/kWh</td></tr>
<tr><td>Assumptions:
The actual data is given for the pro-reform case from 2012 to 2020.
From 2012 to 2020, if there is no reform, it is assumed that the counterfactual network price and generation price will remain the</td><td>Assumptions:
The actual data is given for the pro-no reform case from 2012 to 2020.
The electricity sector experiences a 2% price drop p.a. on the generation price and network price to 2020. By the year of 2030, there will</td></tr>
</table>

[21] The assumption is very conservative about the generation volume growth in Jiangsu Province. Therefore, it is assumed that Jiangsu's import share will increase to meet the growing load demand.

price level before the RPS 2015. Then, the forecast values of pro-reform and the counterfactuals converge at 2030. The assumption for coal consumption counterfactual is that it remains the same from 2016 to 2030.	be no price gap between the forecast price and the counterfactual. For the coal consumption counterfactual, it is assumed that the power grid company and the government keep using policies to reduce coal consumption and made a 1% reduction per year from 2016 to 2030.
Visualisation and calculation: The calculation of cost savings for **Pro-Reform** case is the horizontally shaded area in Fig.16 and Fig. 17. The calculation of coal consumption reduction is the difference between the blue and green line to the "Counterfactual 0% p.a." line.	**Visualisation and calculation:** The calculation of cost savings for **Pro-No Reform** case is the vertically shaded area in Fig.16 and Fig. 17. The calculation of coal consumption reduction is the difference between the blue and green line to the "Counterfactual 1% p.a." line.

The assumptions about the two proposed cases are quite conservative, because the impact of the reform to the generation price and network price is not applied indefinitely and a significant part of the gains are already realized by 2020. It is assumed that the forecasted values and counterfactuals converge by 2030, so that the benefit of the reform is not exaggerated beyond our available data. Since the goal of this assumption is to calculate the benefit of the reform, to simplify the visualization and calculation, the counterfactual line is locked in 2020 and the forecasted line goes up linearly to converge toward the counterfactual line.

Fig. 16. Network price ex VAT, counterfactual assumptions and calculation areas

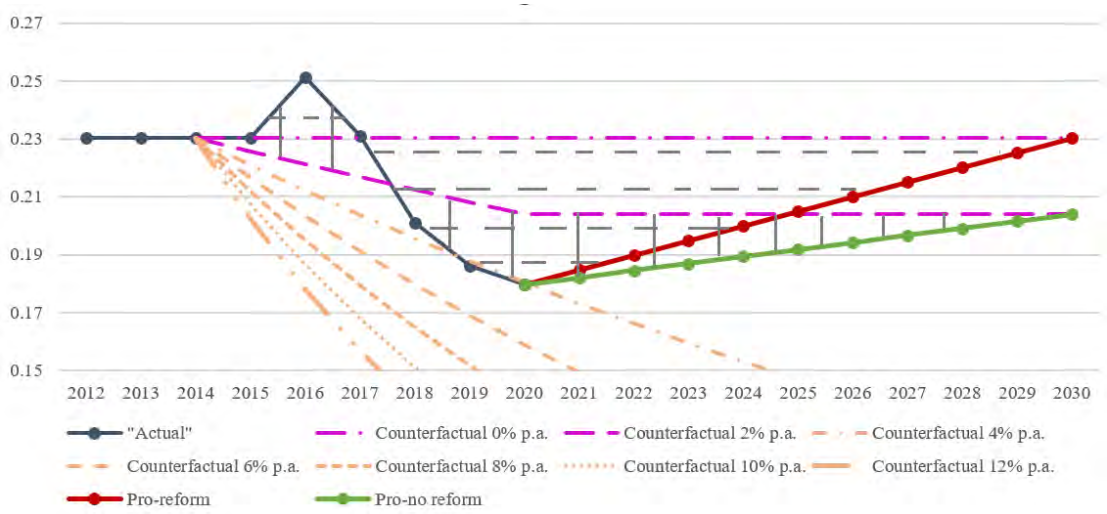


Fig. 17. Generation price ex VAT, counterfactual assumptions and calculation areas

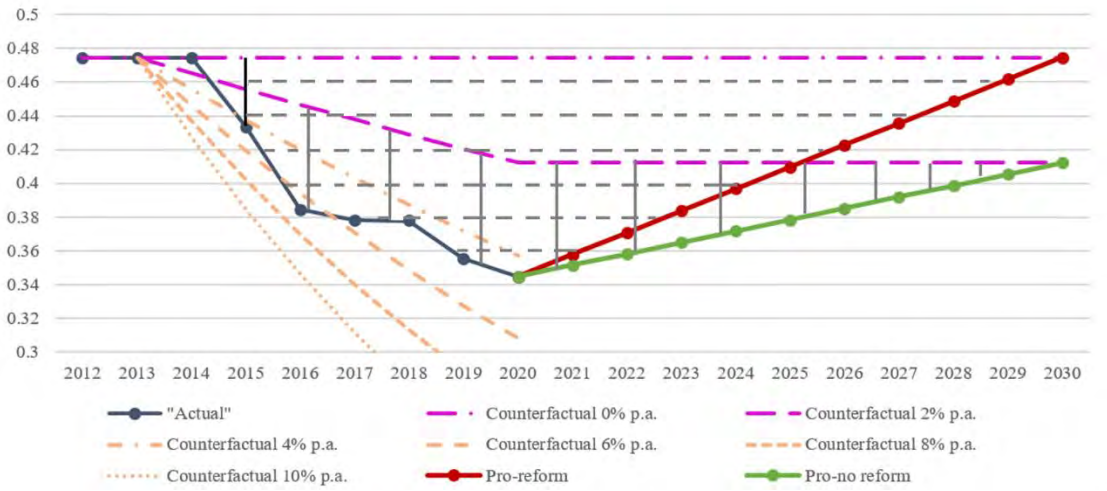


Fig. 18. Coal Consumption (actual value and assumption)

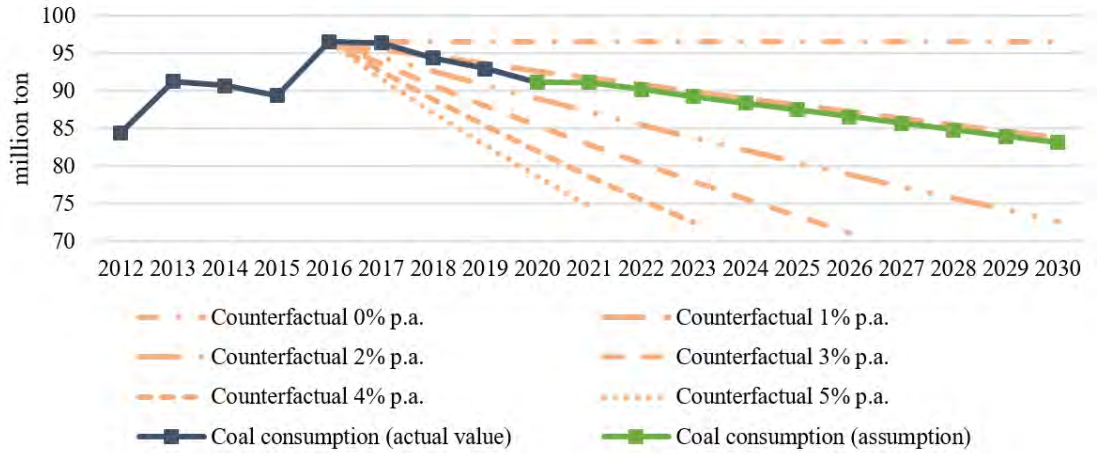


Fig. 19. Industrial and commercial electricity consumption volume

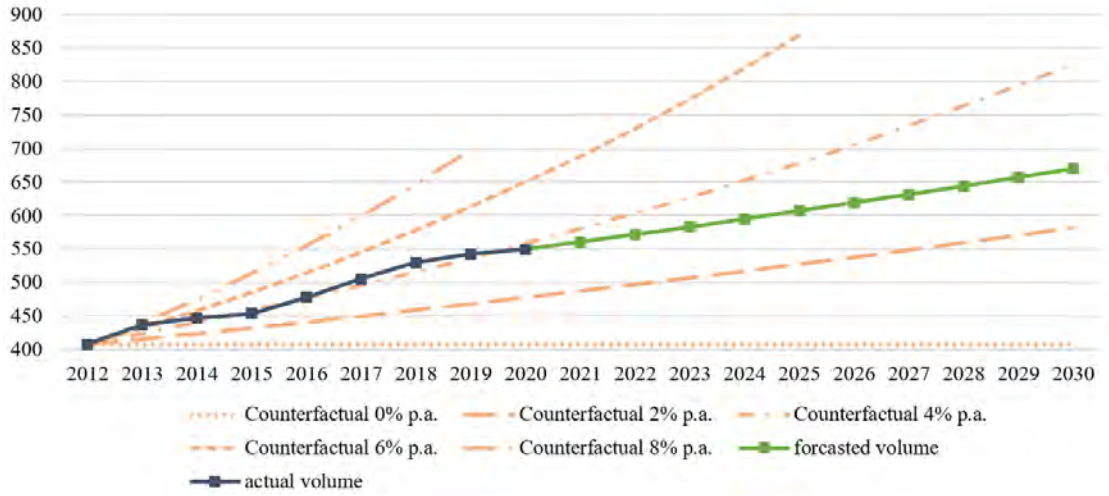


Table 6. Net Benefits of Reform[22]

No	***Discounted To 2020***	***Counterfactual Scenario:***				
	Billion Yuan		*Pro-reform*		*Pro-no reform*	
	Discount Rate		*6%*	*10%*	*6%*	*10%*
1	Fuel Savings Excl. Externalities @ 1000 Yuan / Tonne		82.5	67.7	12.3	10.2
	Externality Savings					
2	SO2 @ 14000 Yuan / Tonne		86.6	71.1	12.9	10.7
3	CO2 @ 400 Yuan / Tonne		62.7	51.5	9.4	7.7
4	Total Externality Benefits	2+3	149.4	122.6	22.3	18.4
5	Reform Costs		-2.9	-2.6	-2.9	-2.6
6	Cost Savings (generation)		615.7	610.1	337.6	337.1
7	Cost Savings (network)		127.1	126.8	20.7	22.0
8	Total cost savings	6+7	742.8	736.9	358.4	359.1

[22] In the research from Newbery and Pollitt (1997), the authors considered social weight for different incomes: public money is 1, making consumption 0.975, made up of 50:50 domestic consumption value at 0.95. In this paper, however, since we only focus on the welfare change of consumers, we don't take the social weight into consideration.

	Total Net Benefits					
9	Excluding Externalities	5+8	740.0	734.3	355.5	356.5
10	Including Externalities	5+8+4	889.3	856.8	377.8	374.9

Table. 6 shows the results for the two counterfactual scenarios and two discount rates (one closer to a social discount rate – 6%, the other closer to a private sector discount rate – 10%). We use the same discount rates as in Newbery and Pollitt (1997). As can be seen from Table 4, most savings are coming from the cost saving.

The CO2 and SO2 savings are calculated from the total coal consumption (Fig. 18). The price of the SO2 and CO2 is set as the prices in 2020. To simplify the calculation, it is assumed the price is not changing from 2021 to 2030[23]. To fill in the blanks in Line No.2 and No.3 of Table. 4, the CO2 and SO2 savings are calculated based on the coal consumption reduction[24].

"Total cost savings" can be categorised into two savings, the generation cost saving and the network cost saving (Line No. 6 and No.7 in Table. 4). The "actual value" from 2012 to 2020 and counterfactual assumptions of network price (ex VAT) and generation price (ex VAT) are shown respectively in Fig. 16 and Fig. 17. These savings contribute the most to the total net benefits for the reform.

"Fuel Savings Excl. Externalities" includes the savings from the coal consumption reduction because of the generation mix change, savings from generators switching from coal to cleaner energy and the savings from efficiency increase of the coal generation. From the collected data and resources, there is no evidence that the power market reform gives the generation companies the motivation to switch coal generators to gas or renewable energy generators, mainly due to the fact that coal generation is much cheaper than gas generation and the gas supply (most of the gas is pipeline gas) is not stable in Jiangsu. Furthermore, the single generation company provided in Section 4.6 shows that the efficiency of coal generation is not increasing during the past decade (approximately 0.25 kg of coal consumption per kWh of electricity generation). Therefore, the "Fuel Savings Excl. Externalities" only considers the savings from the generation mix change. The assumptions for the "Pro-reform" case is less conservative about the

[23] The CO2 and SO2 price variations do not affect the final result of the measured NPV of reform. They only result in small differences in line 2, 3, 4 and 10 of Table. 6.

[24] The SO2 emission can reduce during the period, but we don't take this into consideration in our research. The actual SO2 emission might be lower.

coal consumption reduction without the reform than one for the "Pro-no reform" case, which leads to more savings from the forecasted coal consumption.

Since the savings from the generation price change has already taken savings from the generation mix change into consideration, so we don't double count the "Fuel Savings Excl. Externalities" in the "Total Net Benefits" calculation.

We calculate a measure of reform costs. We assume that this equal – at a minimum - to the estimated cost of the power exchange. The controlling share of Jiangsu Power Exchange Center (JSPX) is held by several generation companies in Jiangsu and JSEPC. Therefore, the reform cost can be the sum of the capital cost to set up the JSPX and the annual revenue. JSPX is now a non-profit institution and the annual report do not include the audit information, such as sales revenue and expense. The registered capital of JSPX is 0.1 billion Yuan at the beginning in 2016. There were several registered capital changes, which can be summarized as 0.00533 billion Yuan in 2019, 0.04303 billion Yuan in 2020 and 0.14835 billion Yuan in 2021. The annual revenue is estimated using one of the European power exchange companies, EEX Group, which is shown in the last line of Table. 5 is calculated as follows:

$$R_{JS,i} = \frac{\sum_i R_{EEX,i}}{\sum_i Q_{EEX,i}} \times \frac{1\ billion\ €}{1000000\ k€} \times Q_{JS,i} \times \frac{6.5\ Yuan}{1\ €} \times \frac{CPI_{2020}}{CPI_N} \qquad (16)$$

Where $R_{EEX,i}$ and $Q_{EEX,i}$ represent the market volume and sales revenue of European power spot market. $Q_{JS,i}$ And $R_{JS,i}$ are the market volume and annual operation revenue of JSPX.

The datasheet for calculation of annual operation income of JSPX is shown in Table. 7. The annual cost of the years after 2020 is assumed to be unchanged. We might have considered the wage difference between China and Europe, but we ignore it due to the lack of data. Anyway, the reform cost is relatively small comparing to the total cost savings, so it will not significantly affect the result of net benefit calculation.

Table. 7. Datasheet for the calculation of Annual revenue of JSPX

	Unit	2016	2017	2018	2019	2020
European power spot market volume (EEX Group) ($R_{EEX,i}$)	TWh	535	543	577	598	622

Sales revenue of Power Spot Europe (EEX Group) ($Q_{EEX,i}$)	k €	67555	67652	72585	72654	72687
Jiangsu power market volume ($Q_{JS,i}$)	TWh	15.8	126.5	266.0	310.6	295.8
Annual operation revenue of JSPX ($R_{JS,i}$)	Billion Yuan	0.01	0.10	0.21	0.25	0.24

(Sources: EEX Group, 2017, 2018, 2019, 2020, 2021)

To further investigate the result shown in Table. 4, the equivalent annualized price reduction (EAPR) can be calculated as follows:

$$EAPR = \frac{B_{total} \times r}{Q_{total,2020} \times p_{pre-reform}} \quad (17)$$

Where B_{total} is the total net benefit excluding externalities. Q_{total} is the annual industrial and commercial consumption volume of the SCBA base year (2020). $p_{pre-reform}$ is the retail price before PSR 2015 adjusted by CPI and r is the discount rate.

Since the 6% cases are selected for the calculation because it is closer to a social discount rate. $p_{pre-reform}$ would be 0.890 Yuan/kWh, which can be calculated from the 2012 regulated retail price and then adjusted by CPI. Therefore, EAPR is 9.1 %. We compared the SCBA result of PSR 2015 in Jiangsu with other PSRs and they are shown in Table. 8. As can be seen from Table. 8, the gains in other PSR cases are positive but modest (around 5% lower revenue/costs) and in general not fully received by consumers. The Jiangsu case in our analysis, however, has a much more positive consumer gain than other cases.

Table. 8. Result Comparisons for SCBA of different PSRs

Authors	**Reform and company / date / country studied**	**Measured NPV of reform (central estimate)**	**Key distributional impacts identified**
(This paper)	Establishment of electricity market/ 2015/ Jiangsu, China	Permanent reduction of 9.1% of 2020 electricity costs for industrial and commercial costumers	Most of net gain is reduction in generation price and network price

Galal et al., 1994	Privatization of CHILGENER – generation and transmission /1981–1986/Chile	Permanent gain in welfare of 2.1% of 1986 sales	2/3 of aggregate gains go to foreign shareholders.
Galal et al., 1994	Privatization of ENERSIS – distribution /1986/ Chile	Permanent gain in welfare of 5% of 1986 sales	Paying consumers gain an amount almost equal to the aggregate impact
Newbery and Pollitt, 1997	Privatization and breakup of CEGB - Generation and Transmission monopoly/1990/UK	Permanent gain of 6% of 1995 turnover	Consumers lose initially and overall, CO2 and SO2 benefits significant
Domah and Pollitt, 2001	Privatization of 12 Regional Electricity Distribution Companies/1990/UK	Permanent gain of 9% of 1995 turnover	Consumers lose initially
Toba, 2002	Privatization of distribution company –Meralco/1986/ Philippines	Permanent gain of 6.5% of 1999 sales	Most of net gain is reduction in CO2 and NOX, consumers do gain by more than 50% of aggregate gain
Mota, 2003	Privatization of distribution companies/ 1995–2000/Brazil	One off gain equal to 2.5% of GDP	Producers gain around 2/3 of aggregate benefit
Toba, 2007	Introduction of Power Purchase Agreements with Independent Power Producers by incumbent generator, NPC/1990–93/ Philippines	One off gain of around 13% of GDP	Economy wide benefit due to earlier ending of power crisis
Anaya, 2010	Privatization of 2 Distribution and Retailing Companies/ 1994/Peru	Permanent gain of 27% of costs when earlier connection included	Existing consumers lose, new consumers gain earlier connection

Sources: Pollitt (2012, p.133).

6. Conclusions

According to the analysis above, the following conclusions can be drawn.

(1) This paper has sought to discuss the electricity price change in Jiangsu province before and after the new round of power market reform from a societal perspective. All the figures and tables in the paper

are all generated based on online public data resources. From the analysis, the reform brought the electricity price down substantially to 2020. Among the components of the reduction, the reduction of generation prices and network charges are the most significant ones. However, many estimations need to be made due to the lack of published data, such as the monthly breakdown of the annual trading contract volumes. More detailed and accurate analysis could be done if the missing data was available.

(2) The overall electricity price can reflect the changing generation cost (essentially the medium- and long-term coal price) and the relationship between supply and demand to a certain extent, especially in the monthly centralized market. However, since there is only medium- and long-term market existing, actual time and space value of electricity cannot be fully reflected in the price at the moment. At present, Jiangsu is in the early stages of the power market reform and only has a medium and long-term market. Whether the overall electricity price may change after the implementation of spot market is yet to be known.

(3) The power system reform has a positive welfare impact for society in terms of reducing the industrial consumer price. Based on the assumptions in the study, the result shows that despite the existence of the reform costs, there is still a considerable total societal net benefit. This comes mainly in the form of lower prices (and potentially costs). There are potentially additional benefits from lower fuel use and environmental cost savings. There are some limitations to our study. For example, it is difficult to distinguish whether the SO2 and CO2 savings are the impact of the power market reform or the impact of government policies to reduce emissions in electricity sector (i.e. the “Dual Carbon Goals”). Furthermore, there are many assumptions made to estimate the net benefit, so are results can only be taken to be indicative of magnitude and direction of reform impact.

Jiangsu province can strengthen the positive effects of the reform in the following ways.

(1) Accelerating the construction of electricity market, especially the spot market. A mature spot market can effectively reflect the time and space value of electricity into price. The true price of electricity can guide the generation companies and market operators to make production plans. The current medium- and long-term market have limitations. Witness for example, the failure in 2021 of the monthly market due to the rapid rising of coal price. The construction spot market is crucial to power market reform process.

(2) Putting the Renewable Portfolio Standard (RPS) and Green Certificate Market into effect and coordinating them with the power market. China is trying to achieve the "Dual Carbon Goals" which will have higher expectations for renewable energy development. The RPS and the pricing of green certificates can promote investment in renewable energy generation with market-oriented means. More renewable energy generation in electricity sector could leads to less emissions and more environmental cost savings.

(3) The construction of ancillary service markets and a capacity market may promote reform and decarbonisation. With the deepening of RPS 2015, the coal generators' profit margins could continue to be squeezed, both on the unit electricity profit and on the trading volume. Operating a power system with high proportion of renewable energy generators is much more difficult than operating the present coal generation dominated power system. Ancillary services can be provided by traditional thermal power generators to mitigate the intermittency of renewable generation. Ancillary services also provide profit alternatives for coal fired generators as their contribution to total electrical energy generation declines. The capacity market is an economic incentive mechanism that enables a conventional generator to obtain stable revenues outside the highly uncertain electricity energy market. It can encourage the maintenance of thermal power generators so that the system can have enough redundancy and inertia in extreme circumstances caused by fluctuations in renewable energy generation or peak load demand.

For the future work, the authors will aim to provide more detailed and updated analysis of the effects of PSR in Jiangsu. In particular we would like to investigate the impact of the reform on underlying costs in order to work out the producer and overall welfare effects of reform. More accurate data on the underlying price, revenue, cost and environmental impacts would allow our analysis to be updated and made more precise.

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