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REFORMING THE CHINESE ELECTRICITY SUPPLY SECTOR: LESSONS FROM INTERNATIONAL EXPERIENCE

Michael G. Pollitt Chung-Han Yang Hao Chen

20 March 2017

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Keywords power market reform, international experience, China, industrial electricity price

JEL Classification L94

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Reforming the Chinese Electricity Supply Sector: Lessons from International Experience[1]

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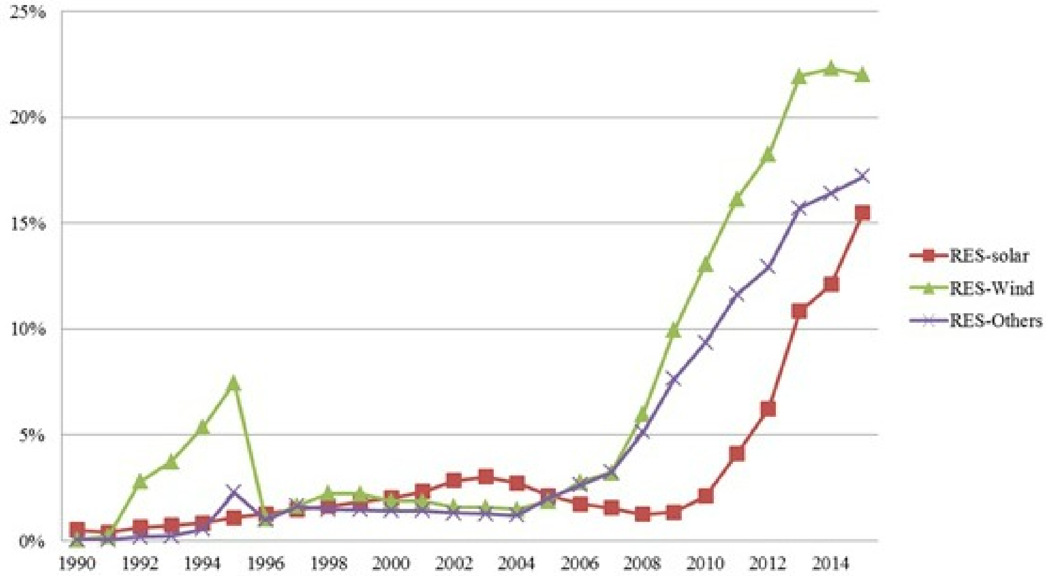
1 Introduction

In 2015 China was the world's largest electricity producer (24% of global production), the second largest producer of non-hydro renewable energy (17% of global production) and the largest producer of coal (3.5 billion tonnes of coal a year or 47% of global production)[2]. Around 45**%** of Chinese coal production is consumed in its power sector and 65% of all its electricity comes from coal[3]. China's coal based electricity sector alone produces at least 7% of global carbon dioxide equivalent emissions[4], and around one third of China's domestic emissions. As Figures 1 and 2 indicate this rise to global prominence is relatively recent and has occurred extremely rapidly in last decades. These figures provide the backdrop to the significant international interest in the Chinese power market and its reform.

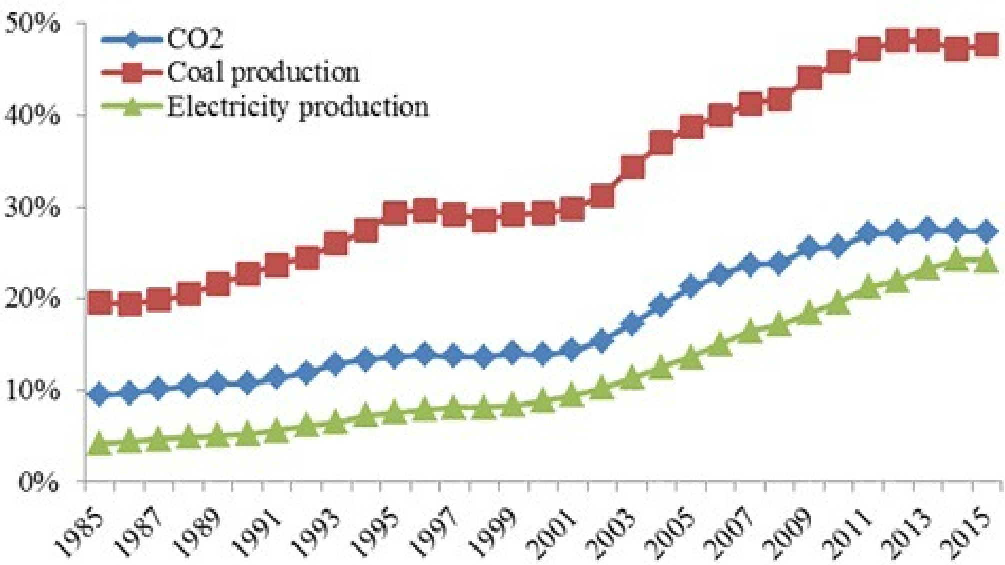
As we describe below, economic reform of the power sector has been on-going since 1985. However, under the current Five Year Plan (FYP13: 2016-2020) China's electricity sector is undergoing a major transition from a state managed system to a market price based one[5], following the publication of the No.9 document of March 2015 which re-launched a new push for 'power market reform' in China. This paper focuses on the international lessons for China in the light of the current round of power market reforms and paying attention to the particular context of the Chinese electricity system.

Figure 1:
China's global share in the fuel consumption for its power generation



Source: BP statistics (2016).[6]

Figure 2:
China's global share in CO2, coal and electricity production



Source: BP statistics (2016).[7]

Looking across the world at electricity reform we can identify fourteen reform elements that form part of a modern power market reform. We take 11 of these from Paul Joskow (2008)[8] who identifies eleven key components of successful processes and supplement these with 3 additional reform elements appropriate to a low carbon transition (based on Pollitt and Anaya, 2016[9]), which involves currently subsidised (but lower carbon) generation technologies. We group the main reform components into four general areas: market restructuring and ownership changes; supportive secondary market arrangements; appropriate economic regulation; and, efficient promotion of low emission technologies. To these four general areas Joskow adds appropriate transition mechanisms, to recognise the fact that power market reform is complex and that a successful transformation cannot be achieved in one step. We use these to organise our discussion of the Chinese case below.

Successful power market reform in a low emissions context, according to Joskow (2008) and Pollitt and Anaya (2016), must therefore take due account of the following:

Market restructuring and ownership changes:
(1) vertical separation of competitive elements (generation and retail) from natural monopoly networks;
(2) sufficient horizontal restructuring of generation to create a competitive wholesale market;
(3) the creation of wide area independent system operators; and
(4) privatisation of monopolies.

Supportive secondary market arrangements:
(5) creation of spot and ancillary services markets to support real time balancing of the system;
(6) participation of demand side in wholesale electricity markets;
(7) regulated third party access to, and efficient allocation of scarce transmission capacity.

Appropriate economic regulation:
(8) unbundling of regulated network charges and competitive segment charges;
(9) mechanisms to ensure competitive procurement of wholesale power for regulated final customer groups;
(10) the creation of independent regulatory agencies to regulate monopoly network charges and monitor competitive segments.

Efficient promotion of low emission technologies:
(11) competitive procurement processes for low carbon generation, with some exposure to wholesale price variability;
(12) cost reflective access terms for renewables; and
(13) appropriate pricing of environmental externalities (both carbon dioxide and other atmospheric pollutants, such as sulphur dioxide).

And finally, all good power market reforms (and indeed, significant economic reforms more generally) involve:
(14) appropriate transition mechanisms.

The aim of this research project has been to understand the nature of the electricity transition process in China and how it can draw on the extensive reform experience of European countries (which began in 1990 in the UK), as well as other reforming countries (in particular, the US). The EU Legislative process has consisted of three electricity directives (1996, 2003 and 2009), that have successively opened up the EU electricity market, in line with Joskow's model for successful reform (see Jamasb and Pollitt, 2005; Pollitt, 2009). These have introduced a competitive wholesale market, regulated third party access to transmission and distribution networks, legal separation of retail businesses, choice of retailer for all customers, unbundling of transmission and distribution businesses from the rest of the sector, regulated cross border trading and independent regulatory authorities. The process has been slow and different European countries have at times moved at very different speeds in implementing reform, but the overall progress has been remarkable.

Since the start of the reform process in the EU there has also been a significant push towards a low carbon electricity system with a large emphasis on increasing the share of renewables in the electricity system and the introduction of a cap on emissions from the electricity sector and the introduction of the EU Emissions Trading System[10] (EU ETS). China is now undergoing its own renewable and low carbon electricity transition, with a remarkable growth of renewable and nuclear energy and significant moves towards a national carbon market[11]. This poses new challenges for the reform process around how to successful integrate renewables into wholesale energy and ancillary services markets; how to facilitate appropriate levels of network access for renewables; appropriate mechanisms for financing renewables; and whether there are implications for the remuneration mechanisms for fossil fuel power plants in the presence of large amounts of renewables. Reform points 11 to 13 above are much less well developed globally (and less supported by empirical evidence). Advanced jurisdictions (such as the UK, Germany, California and New York) are currently experimenting with different mechanisms to support their low carbon transition (Pollitt and Anaya, 2016)[12].

This project aims to collect information relevant to all of the 14 points identified above and to discuss with Chinese stakeholders what China is doing under each of these reform elements. It will seek to assess progress with reform and also what China is learning about how the reform model needs to be adapted for its own particular circumstances. While the outline of a successful reform model may be easily stated, the details vary from jurisdiction to jurisdiction. Thus electricity reform in Germany is very different from the UK and California is different from New York. In what follows, we aim draw out what the particular lessons from the reform model outlined above are for China. Most importantly, we seek to identify what are the key institutional problems to be overcome in bringing about a successful electricity reform transition in the World's most significant electricity system. Our main goal is intended to be a positive contribution to on-going debates about the detailed implementation of electricity sector reform in China and to be a platform for future discussion and informed input on the appropriateness of international reform experience in the Chinese context.

The paper proceeds as follows. We begin with a brief background to the current Chinese power market reforms. We then discuss each of the 14 reform elements that we identify above. Under each of these reform elements we will discuss: its theoretical significance; general reform experiences with it; and its application in the Chinese context. We conclude with some overall lessons and identify some important points for future research into Chinese power market reform.

2 Background to electricity reform in China

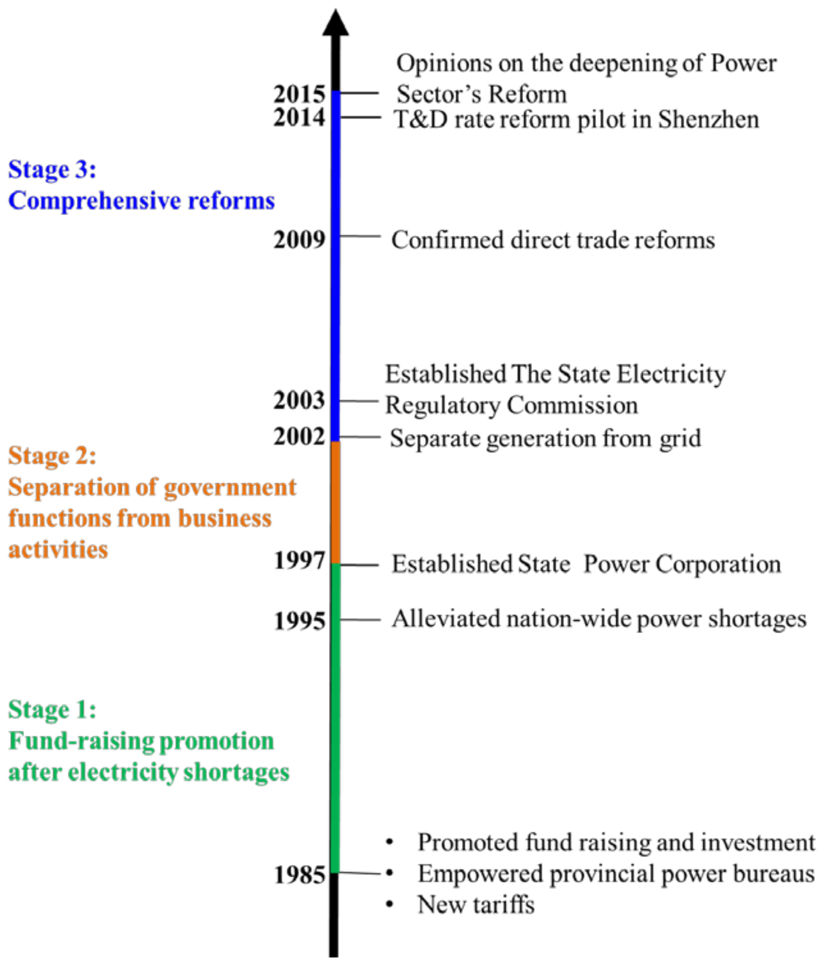
China has embarked on a prolonged process of electricity reform since 1985, as outlined in Figure 3 and Table 1. Up until 1984 there was no private involvement in electricity generation, however after 1985 and in common with other developing countries facing power shortages China did allow multiple public investors and private investors into the power generation sector to help alleviate shortages of electricity. The most significant recent reform was the reorganisation of the power sector in 2002.[13] This saw the separation of generation and transportation/retailing of electricity and represented the most significant structural change to the industry in the modern era. It also saw the creation of two grid companies: State Grid Company of China and China Southern Grid (covering four southern provinces). A regulatory agency for electricity was created and there was an expectation that China would embark on the pathway of the standard international reform model with the creation of competitive wholesale power markets and regulated network tariffs. However, this process stalled around 2007. Generators continued to receive regulated prices for their power and network tariffs were not separately identified and all customers bought power from their local transmission and distribution monopoly. Thus, transmission, distribution and retail continue to be 100%

vertically integrated. There remains significant support for the large grid companies as enabling effective response to large natural disasters (e.g. the Wenchuan earthquake in 2008) and as a counterbalance to the monopoly power of equipment suppliers such as GE and Siemens.[14]

It is worth noting that other energy sectors in China, such as oil and gas state-owned companies, were also liberalised during 1990s. Lin (2008) points out that the Chinese central reformers of oil and gas industries recognized the need to depart from the decentralized approach to industrial governance as early as 1993[15]. However, the reform process had to wait until key domestic interest groups were weakened by macroeconomic disequilibria and global price shocks in the latter half of 1990s. Thus, the Chinese electricity sector reforms, similar to other global reform experiences, take a long period of time, and rely on national cross-sectoral learning.

The previous reforms of the energy prices, resource taxes and subsidies have also paved way for this round of electricity market reform, which has made great progress in assigning a more significant role for the market in allocating resources in China since 1984 (see Mou, 2014; Lin and Ouyang, 2014; Paltsev and Zhang, 2015; Zhang, 2014). Moreover, a new wave of comprehensive reforms were launched by the Chinese leadership in November 2013, and the electricity sector is under the government spotlight due to its important role in helping China's transition to a low-carbon economy and in addressing local air pollution.

Figure 3:
Reform timeline for electricity sector



Source: An Bo et al. (2015, p.6).

Table 1
Reform timeline for electricity sector in China

	1980-1984	1985-2001	2002-Present
Industrial Structure	Vertical integration	Vertical integration	Unbundled generation and transmission & distribution (2002)
Ownership	Predominantly central government owned	Central and provincial government ownership. Increasing private investment in generation	Central and provincial government ownership, declining share of private investment
Dispatch	Economic dispatch based on total embedded cost	Equal shares dispatch	Equal shares dispatch; pilot projects for energy efficient dispatch (2007)
Wholesale Generation Pricing	Internal transfer prices	Investment recovery based on financial lifetime (1985) Investment recovery based on operational lifetime (2001)	Benchmark price (2004) Fuel price-wholesale price co-movement (2004)

Source: Kahrl et al. (2013, p.362)

As Table 1 shows, the regulated prices received by individual power plants have become more sophisticated over time in adjusting to wholesale fuel prices (particularly the price of coal).[16] However, dispatch is not done on a least cost (merit order basis), but on an equal shares basis. This involves plants of a similar vintage being allocated an equal number of annual running hours and being dispatched on a daily basis in line with the need to achieve an equal number of total running hours. We return to this below.

The latest round of power market reforms began in March 2015, promoted by the publication of the CPC Central Committee and State Council No.9 Document of March 2015 (summarized in Table 2). This document foresees a renewed push to establish competitive wholesale and retail electricity markets especially for industrial electricity customers. It is supported by a number of ongoing market pilot projects.

Table 2
Document No.9 of March 2015 and stated reform process

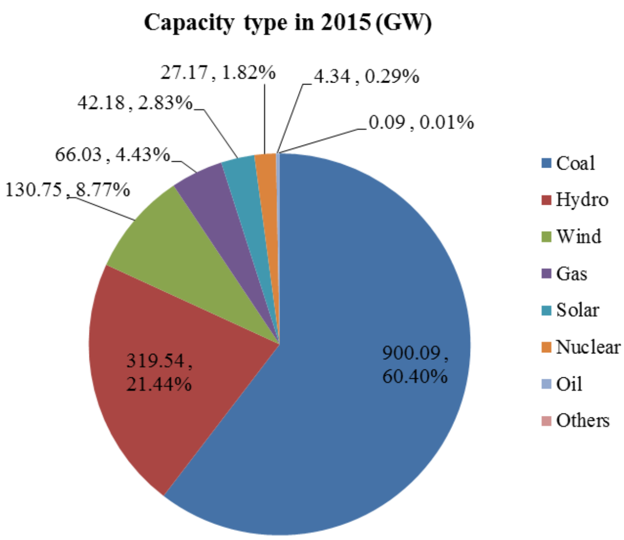
Key Policy Goals	Supporting Documents	Reform Process (mentioned in Document No.9)
Policy Goals No.1 **Promoting electricity power pricing mechanisms**	Implementing Opinions on Document No. 9	State Council China and CPC Central Committee issued the 'Opinions on Further Deepening Power Sector Reform' (Document No. 9) in March 2015. There are two main stages for this round of electricity reform in China. In the first stage (from March to June 2015), NDRC and other related governmental agencies announced five supporting documents. In the second stage (November 2015), NDRC and NEA further issued another six supporting documents. These supporting documents provide the practical guidance for implementing the seven main policy goals set in the Document No.9, which cover the issues of electricity price, power trading system, wholesale side design, power grid and governmental supervision. Electricity ancillary services in China have long been provided by grid-connected power plants. Document No.9 changes this situation by establishing a new "shared responsibility" mechanism. This "shared responsibility, shared gains" mechanism improves the original compensation mechanism, and welcomes user participation in ancillary services by contracting with either generator companies or the grid. In March 2015, the supplement policy document - Guiding Opinions on Improving Electric Operation and Regulation to Promote Greater and Fuller Use of Clean Energy – was published, which aims to advance the ancillary services and promote renewable energy consumption at the same time.
	Implementation Opinions on Promoting Transmission-Distribution Price Reform	
Policy Goal No.2 **Reforming power trading systems and refining market-oriented trading systems**	Notification of Perfecting Formation Mechanism of Trans-Provincial and Trans-Regional Power Trading Prices	
	Implementation Opinions on Promoting Power Market Construction	
Policy Goal No.3 **Reforming power generation, power utilization and the current market mechanisms**	Notification of Perfecting Power Emergency Response Mechanism and Comprehensive City Pilots of Managing Power-Demand Side	
	Implementation Opinions on Orderly Releasing Plans of Power Generation and Power Utilization	
Policy Goal No.4 **Establishing independent electricity trading institutions and a fair and regulated trading platform**	Implementation Opinions on Establishing Power Trading Institutions and Their Normative Operation	
Policy Goal No.5 **Steadily reforming power sales side and distribution**	Implementation Opinions on Promoting Power-Sales Side Reform	
Policy Goals No.6 **Enhancing fair access to power grid and power transmission**	Guidance Opinions on Improving Power Operation Adjustment to Facilitate Multiple and Full Development of Clean Energy	
	Guidance Opinions on Reinforcing and Regulating Supervision and Management of Coal-Fired Self-Generation Power Plants	
Policy Goal No.7 **Reinforcing electricity safety, scientific supervision and an integrated power planning system**	Supervision and Examination Procedures for Pricing Costs of Power Transmission and Distribution (Trial)	

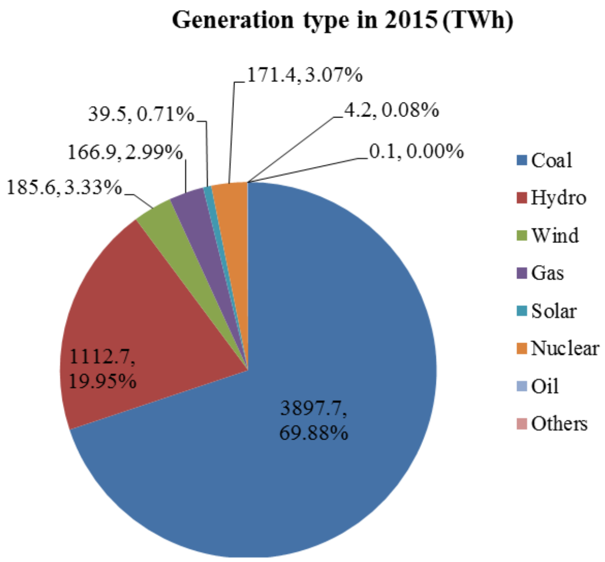
Sources: "Deepening Reform of the Power Sector, Document No. 9, March 21, 2015", China State Council (2015) and China5e Research Institute (2016, p.4-5).

It is interesting to compare the 7 policy goals of the No.9 document with the 14 reform elements [(1) – (14)] we outlined in the Introduction. Policy Goals No.1 to No.6 relate to the economic reform of the sector. Policy Goal No.1 relates to unbundling of regulated network charges from competitive segment charges (reform point: 8). Policy Goals No.2 – No.5 are around the creation of a competitive wholesale market with sufficient vertical separation of generation [reform points: (1) and (2)] and retail from the natural monopoly elements [reform point (1)]. Policy Goal No.6 targets the efficient allocation of scarce transmission capacity (reform point 6). Interestingly, the wording of the No.9 document emphasises the 'trading' of electricity. International reform experience emphasises the use of market mechanisms and the harnessing of competition to allocate scarce resources. It also emphasises 'separation', the idea that the roles of various actors within the sector need to be clearly defined and in particular that boundaries need to be strictly drawn between competitive and monopoly activities, with a key role for regulation in ensuring non-discriminatory access and implementing incentive regulation. Additionally, under the Policy Goals No.2, 4 and 6, the No.9 document emphasises the significance of ancillary services (reform point 5), and stresses the establishment and improvement of purchasing mechanisms for ancillary services.

Before embarking on any discussion of appropriate reform steps to take in the Chinese electric power sector, it is important to acknowledge the achievements of the sector under public ownership[17]. The country has been fully electrified and the technical losses in transmission and distribution were only 5.8% in 2013. The sheer scale of the sector by 2015 is illustrated in Figure 4, which shows the distribution and quantity of capacity type and generated electricity. Figure 5 shows the enormous physical build rate and financial investment involved (around $120bn in 2015). Electrification is universal, has kept pace with sustained high rates of demand growth and the sector is self-financing (unlike in India). This has been an impressive engineering undertaking by global standards.

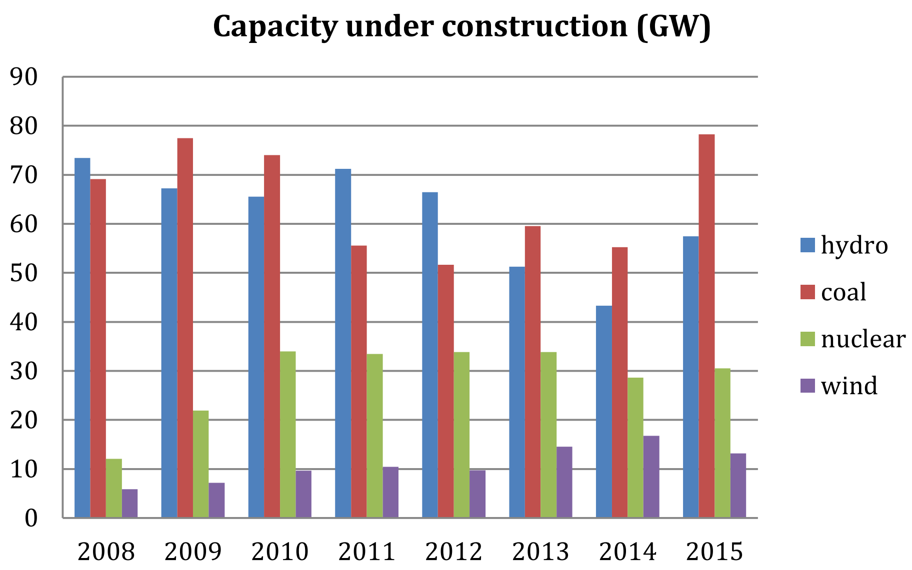
Figure 4
The size of the Chinese electricity sector





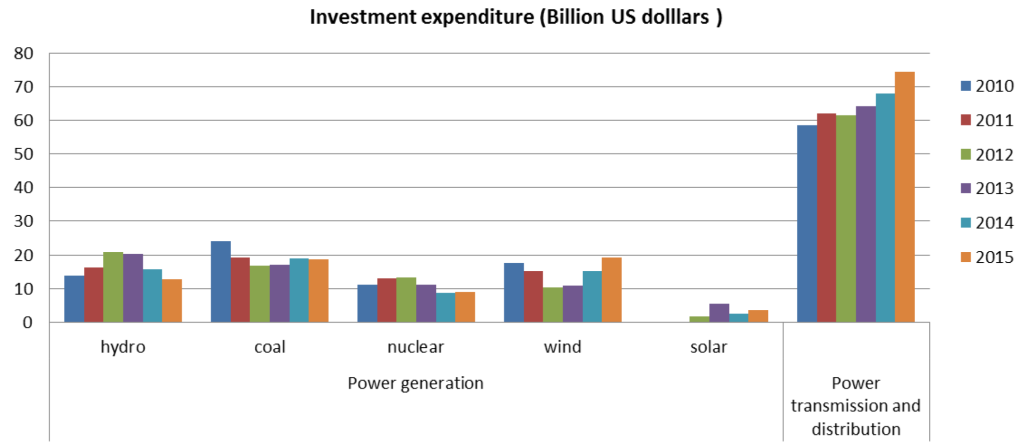
Source: NBS (2016)

Figure 5
The scale of power plant capacity under construction



Source: China Electricity Council (2015)

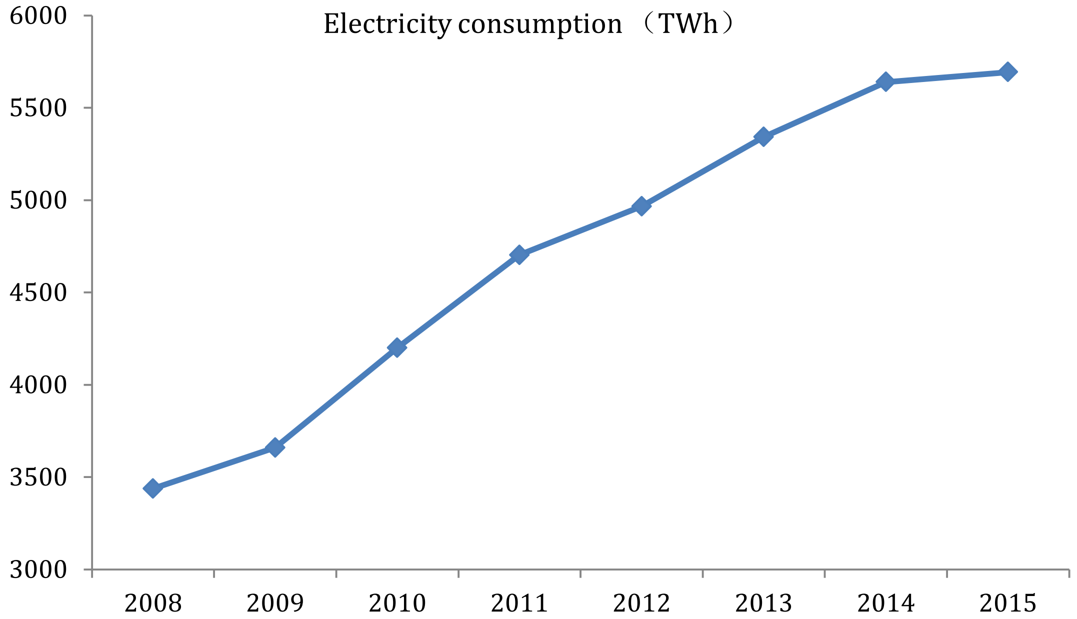
Annual investment in the power system



Source: China Electricity Council (2015)

However, China's rapid growth of electricity demand (at 8.6% p.a. from 2008 to 2014) has appeared to moderate recently (1% in 2015), as can be seen in Figure 6. If this is a genuine 'new normal' for power demand then the rate of investment in new capacity needs to also slow down.

Figure 6
China's Electricity Consumption Slowing Down



Source: CEC website, Available at:
http://www.cec.org.cn/guihuayutongji/tongjxinxi/niandushuju/2013-04-19/100589.html

There is a clear motivation for the current round of reforms. This is the high price of industrial electricity relative to competitor countries, in particular the US.

Table 3 Electricity price and Fuel input price differential with US

	Industrial Electricity Price (US $/kWh) In 2014	*Coal price for generation (US $/kWh) in 2014*	*Gas price for generation (US $/kWh) in 2014*	*Residential Electricity Price (US $/kWh) in 2014*
US	0.0710	0.0241	0.0159	0.1252
China	0.1068	0.0384	0.0778	0.0908
China *minus* US	0.0358 (50% higher)	0.0143	0.0619	-0.0344 (27% lower)

Notes: Chinese prices include VAT tax, see http://cn.manganese.org/images/uploads/board-documents/8._2015_AC_-_Xizhou_Zhou-CN.pdf (p. 20).
Source: Chinese data from Chinese government website (http://zfxxgk.nea.gov.cn/auto92/201509/t20150902_1959.htm) and US data from EIA website

Table 3 shows two major differences with the US – residential prices are lower than in the US and lower than industrial prices and fuel input prices are significantly higher in China. The higher industrial price is not fully explained by higher marginal fuel prices (where gas is the fuel of choice in the US and coal is the fuel of choice in China). Higher marginal fuel prices in 2014 (coal in China minus gas in the US) only explains 63% of the differential, meaning that 37% (or 12% of the 2014 industrial price) is not explained by fuel cost differentials, though some of the price is explained by the higher general value added taxation on the sector. However, given the lower unit labour and unit capital costs in China, we might expect Chinese non-fuel costs to be lower than in the US. The reform of residential tariffs in China is difficult due to the political economy of raising power prices to cost-reflective levels. Moreover, the cross-subsidy from higher industrial electricity prices to lower residential prices can be viewed as a way of improving the efficiency of energy-intensive companies (see Sun and Lin, 2013; He and Renier, 2016; Zhang, 2014).

3 Assessment of Reform Steps

3.1 Market restructuring and ownership changes

3.1.1 Vertical Separation and Horizontal Restructuring

(1) vertical separation of competitive elements (generation and retail) from natural monopoly networks;
(2) sufficient horizontal restructuring of generation to create a competitive wholesale market;

3.1.1.1 Theoretical significance

The electricity sector consists of different vertically related segments with different cost and innovation characteristics. These give rise to different minimum efficient sizes of firms in relation to the relevant market segment. These segments are: electrical equipment;

generation; transmission; distribution; and retailing. Electrical equipment is a competitive input sector, subject to global competition. Generation can be organised into wide area markets where generating firms, which could consist of a single power plant, can compete to provide electricity at lowest cost and to invest to meet future power demand. Transmission has natural monopoly characteristics in the operation of given collections of assets in particular areas. Distribution is a local natural monopoly (often very local) in the operation and investment in lower voltage networks. Retailing is a potentially competitive activity, which involves contracting for power and metering and billing final electricity customers. Individual retail firms can operate over wide areas or concentrate on particular geographies. Each of these activities can have very different minimum efficient scales, risk profiles and very different dominant logics among their management teams. Generation and retailing require significant marketing and trading activity, while transmission and distribution are engineering led activities. Generation and retailing are higher risk investments, while transmission and distribution are much lower risk investments.

Differences in the characteristics of the different vertical segments of the electricity sector argue strongly for vertical separation. Where network monopoly segments remain integrated with competitive generation/retail activities it is necessary for access to these segments to be priced on a non-discriminatory basis, so that any competing generation or retail firms with identical network access requirements are charged the same access charge in order not to distort competition between them.

The generation market is potentially competitive in all but the smallest electricity systems.[18] However such competition depends on the existence of sufficient firms in the price setting part of the market. Thus a large number of base load power plants will not discipline the price in the market at peak times where there are only a small number of firms with peak power capacity. If there are only a small number of firms with price-setting plants, then collusion is likely. It is also the case that if one firm has the capacity to strategically withdraw capacity such as to leave the market without sufficient capacity (as measured by the Residual Supply Index) then that firm can exercise market power to generally raise prices[19].

3.1.1.2 General reform experience

Reform experience across the world has involved significant vertical separation. The EU electricity directives (1996, 2003 and 2009) have specified the creation of competitive generation and retail markets with full legal unbundling from the monopoly transmission and distribution networks.[20] This has over time led to divestment of transmission and distribution businesses and the creation of separate generation-retail companies. There has been a progressive opening up of the retail market to competition, starting with large industrial users of electricity, then all non-domestic customers and finally domestic customers.

In the US there has been a similar process of reform, with a notable absence of privatisation, because most of the industry was already in the private sector[21]. This has involved many individual states forcing significant generation asset sales by incumbent integrated utilities, the expansion of regional generation markets and the gradual extension of retail competition from large industrial users to smaller users.

Where vertical disintegration has not been pursued aggressively there are some well-documented cases of continuing abuse of market power by incumbent monopoly network companies against their competitors in the competitive segments of the industry, such as in Chile[22] and Germany[23].

The introduction of competitive wholesale power markets that moves away from regulation of the generation segment of the electricity sector does pose a significant risk in any power market reform. The early wholesale market in Great Britain following privatisation was characterised by two large firms setting the price 90% of the time.[24] This gave rise to tacit collusion between the two firms, which resulted in the need for first price regulation in the wholesale market and then forced sales of generation assets to create a more competitive market. Significant problems with the Residual Supply Index existed in the Californian electricity market in the run up to its power crisis of 2000-01.[25]

However, experience has suggested that market power risks can be mitigated by allowing generators to sign longer-term contracts with suppliers. Long-term contracts are much more potentially competitive than spot-market contracts, because they can be signed with new entrants prior to entry. It was the failure to allow long term contracting that significantly contributed to the Californian electricity crisis.[26] Short-term market power can also be significantly mitigated by 'market abuse' regulation, which limits the ability of generators to strategically withdraw capacity from the market at short notice to drive up prices.[27]

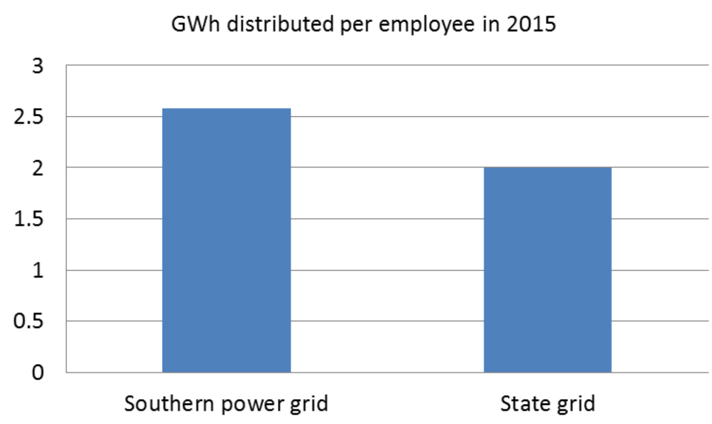
The significance of this sort of collusion between fossil fuel generators has declined in many markets with the rise of subsidised must run renewable generation and the general slowdown in electricity demand growth.

3.1.1.3 Chinese context

China has taken significant and impressive steps to vertically restructure its electricity industry. The most impressive of these was the 2002 reorganisation, which created the 7 large companies from one signal state owned company[28]. This did effectively separate generation from transmission and distribution. It also created two comparative transmission companies. Figure 7 shows some evidence that the smaller China Southern Grid is a more efficient company than State Grid, suggesting the value that China Southern Grid provides as spur to greater efficiency in the sector as a whole. It also created the potential for genuine national competition in generation, drawing on the experience of competition in markets generally, which suggests that 5 roughly equally sized firms is the minimum necessary to ensure effective competition in a market[29]. However the size of all these companies remains a barrier to the emergence of a competitive market in generation, retail and procurement and retail. By assets in 2014, State Grid is four times larger than China Southern Grid and three times larger than the largest generator. State Grid has 1.7 million employees, making it one of the largest corporations in the world by employees and it contains 40% of all the power sector's employees (including equipment manufacturers).[30]

Further steps have been taken recently to separate out the network businesses within the two main grid companies in order to clearly identify the regulatory asset base and associated network cost from the power procurement cost, as part of the market pilot projects and in line with Policy Goal No.1 of the No.9 Document. This is necessary to allow identification of a non-discriminatory third party access tariff for network access.

Figure 7:
Relative performance of State Grid and China Southern Grid



Sources: SGCC (2015) and CSPG (2015)

Unsurprisingly, State Grid and China Southern Grid exercise significant influence on the supply chain and the course of power market reform in the electricity sector in China. This is because they continue to integrate transmission, distribution and retailing within their extremely large service areas. They are also absolutely very large companies with significant political influence within the sector, able to influence the speed of reform in the competitive segments. It was clear that following the 2002 reforms China was following then international reform model and that there was a need for further reforms around 2007 to complete the initial separation process. However, following a severe winter in 2008, which caused some power shortages, the Grid companies were able to argue that progressing with vertical separation put security of supply at risk and further reforms were halted at that time.

Other countries' experience suggests that the organisation of electricity sector does not require transmission and distribution to be integrated[31]. There is also no evidence that security of supply is put at risk by vertical unbundling of transmission, distribution and retailing. Quite the reverse, the evidence is that if anything countries with complete ownership of unbundling of distribution (from both transmission and distribution) have seen improvements in quality of service[32]. Transmission systems are subject to regional/national monopoly, whereas distribution can be a local monopoly at the level of the province or municipality. This has the advantage of comparative competition between distribution companies and competition between management teams, increased competition in input markets and increased responsiveness to customer demands (from generators and from electricity customers) for quality of service.

State Grid and China Southern Grid currently have a monopoly of retailing for almost all customers, apart from large electricity users who can self-generate. This will slow the process of introducing competition into the wholesale market where individual generators compete with grid companies with huge power procurement portfolios for final customers. Such competition needs to be non-discriminatory and this depends on the access charge that the grid companies charge correctly reflecting the average cost of transmission and distribution (not including retailing costs). The ability for incumbent network-retailers to reallocate costs between their network and retail businesses can significantly slow the process of competition. They can do this by allocating much of the fixed costs of their retail business to the network business. In the UK the regulator enforced strict asset allocation rules between distribution and retail, within the incumbent regional electricity distribution companies as the market was opened up to competition. This was because the companies initially tried allocate 90% of their shared assets to distribution, in order to increase network access charges to new entrants and reduce costs within their own retail businesses. The regulator ruled that only around 75% of these costs could be allocated to distribution (see Domah and Pollitt, 2001).

As we have already noted there already is substantial dispersion of ownership of generation assets between companies in China. The 2002 reform did lead to a substantial drop in the price paid to generators for coal-fired generation (apparently due to significant competition in construction between generators)[33]. There is also a substantial emerging surplus of fossil power generation, which suggests that wholesale power prices will not rise above the current level that customers as the market for industrial power is opened up to competition. However within particular provinces residual market power is a potential issue, especially where there are transmission constraints which give rise (for grid stability reasons) to must-run fossil fuel plants on the system[34].

Generators still receive regulated prices for their generation. Table 4 shows the tariffs for coal fired generation in 2014. These are often above the final retail price of industrial power in the US ($0.071/kWh), showing that the regulated prices look generous by international standards.

Table 4
Benchmark Generation tariffs of coal-fired power plants (with FGD) in 2014

Province	Electricity tariff (in RMB/kWh)	Electricity tariff (in US $/kWh)	Province	Electricity tariff (in RMB/kWh)	Electricity tariff (in US $/kWh)
Beijing	0.3987	0.0649	Hubei	0.4702	0.0765
Tianjing	0.4085	0.0665	Hunan	0.5269	0.0858
Hebei North	0.4228	0.0688	Guangdong	0.5122	0.0834
Hebei South	0.4316	0.0703	Guangxi	0.4672	0.0761
Shanxi	0.3887	0.0633	Hainan	0.4888	0.0796
InnerM. West	0.3094	0.0504	Chongqin	0.4401	0.0716
InnerM. East	0.3714	0.0605	Sichuan	0.4607	0.0750
Liaoning	0.412	0.0671	Guizhou	0.3791	0.0617
Jilin	0.4094	0.0666	Yunnan	0.3633	0.0591
Heilongjiang	0.355	0.0578	Shaanxi	0.4002	0.0651
Shanghai	0.4638	0.0755	Gansu	0.3329	0.0542
Jiangsu	0.442	0.0720	Qinghai	0.3570	0.0581
Zhejiang	0.469	0.0763	Ningxia	0.2862	0.0466
Anhui	0.4331	0.0705	Xinjiang	0.2620	0.0427
Fujian	0.4393	0.0715	Henan	0.4382	0.0713
Jiangxi	0.4872	0.0793	Shandong	0.4472	0.0728

Note: the exchange rate between US $ and RMB is 6.1428 in 2014.

Source: NEA website (http://www.nea.gov.cn/)

The scope for competition in generation already exists in China. The issue is the extent to which transmission constraints will allow existing fossil fuel generators to compete with each other for final customers. One issue that is relevant in the wholesale market pilots is that these markets only cover part of both supply and demand. In order for a meaningful market price to emerge in this segment supply and demand curves must be allowed to cross and give rise to single equilibrium price in each trading period. This single market price should be paid by all demanding loads to all supplying generators in the market at that price. This means that sufficient amounts of capacity and of load need to be in the market such that the amount of generation being allocated by a market mechanism can give rise to meaningful price. The introduction of wholesale markets, in which fossil fuel generators were expected to participate without subsidy, would subject new fossil fuel generation investment to market incentives and reduce current over investment in new fossil fuel generation capacity.

If the amount of supply and demand in the market is restricted to be less than a market clearing quantity, then the generators in the market can exercise market power and charge high prices. This seemed to be the case in the Yunnan pilot in 2016, where the price determination mechanism was to restrict demand and supply in the monthly contract market and then inversely match and average the highest bids and lowest offers. This gave rise to different 'market' prices for each block of power in the market, but also scope for gaming by buyers and sellers. Thus, for example, the lowest cost generator could raise its bid and receive a higher payment.

3.1.2 The creation of wide area independent system operators (3)

3.1.2.1 Theoretical significance

A system operator is the 'air traffic controller' of the electricity system[35]. A key job of the system operator is to balance the market in real time on a least cost basis. The larger the control area the more that the system can optimise the use of low cost sources of generation and economise on the holding of reserve capacity (both in the short and the long run). Competitive wholesale markets for electricity are usually co-incident with the area of operation of a single system operator. In many liberalisation processes (e.g. in England and Wales) a wide area system operator already existed and it was a straightforward process to move from cost based merit order dispatch to bid based dispatch. Wide area dispatch on the basis of least cost is the key to reducing total system operating costs.

Extensions of system operator control areas by merging pre-existing control areas has the effect of increasing wholesale market size and single price areas (this has happened in Great Britain, with the extension of National Grid's control area to include Scotland as well as England and Wales, and in the US with the extension of PJM's control area).

The operational independence of the system operator from generators and from retailers (and from local, provincial and national governments) is important because of the strong link between being physically dispatched and the revenue of individual generators. It is essential that dispatch is in the best interests of the system as a whole rather than the narrow interests of one ownership party (or group of parties) in the system.

3.1.2.2 General reform experience

The evidence is that system integration and joint system operation and dispatch has significantly reduced costs and improved efficiency. The extension and evolution of independent system operators in the US, bringing together the previous multiple control areas of individual vertically integrated utilities has reduced costs. PJM's control area extension has produced significant measured benefits in terms of reducing pricing inefficiencies between previously separated areas[36].

System operator dispatch can be successfully conducted on three different bases in liberalised markets. Each of them involves dispatch consistent with least cost power plants being dispatched first. Cost based dispatch has been practiced in Latin America[37] and in Ireland[38]. This involves plants being dispatched in order of audited marginal operating costs calculated on the basis of known plant operating parameters. This is a good way of restraining market power in smaller markets with large pivotal owners of generation plant. Central price based dispatch involves dispatching plants on the basis of price based bids. This is similar to marginal cost based dispatch except the parameters used are bids submitted by the generators in the day-ahead market. This is the standard dispatch system in US ISOs. Self-dispatch is the practice in the EU[39]. This involves generators declaring that they want to be dispatched to the system operator (on the basis of their contractual position), who then has to dispatch them subject to system operating constraints. In theory self-dispatch is more efficient than central dispatch because it can reflect more up to date information on the operating and demand conditions facing individual plants. In practice it gives rise to the possibility that plants will be dispatched out of merit order. Evidence suggests it is slightly more inefficient than central dispatch.[40]

Figure 8:
Regional and provincial grid control areas in China

Source: Wang and Chen (2012, p.144).

3.1.2.3 Chinese context

In China there are 6 regions of operation of generation system (see Figure 8) and the 2002 reform envisaged moving towards 6 regional power markets[41]. This process has not been completed and dispatch is largely organised at the provincial level with some higher-level regional management of bulk power flows – which are often seasonal – between provinces.

Provincial level dispatch is inefficient and does not fully exploit the large opportunities for trading power across regions (e.g. between Yunnan where this often surplus hydro power and Guangdong where there are much higher marginal production costs).[42] Guangdong has three dispatch centres, while Beijing, Tianjin and Hebei operate a joint dispatch centre. The dispatch centres are owned and operated by the relevant grid company, but the annual allocation of hours (for the period 1 January to 31 December) is determined by the provincial government, though the process of its determination is not always transparent or timely (i.e. sometimes after the start of the current year). In addition, there is a national dispatch centre and city and county level dispatch centres.[43]

Dispatch is not currently merit order based and is in need of reform. The provincial dispatch centre is part of the State Grid of China or China Southern Grid (whose provincial areas are also indicated in Figure 8). Plants are dispatched to meet demand on the basis of target annual running hours (+/- 1.5%), subject to priority dispatch for nuclear power plants and renewables[44]. There are also monthly dispatch plans. As discussed in Section 2 above, this implies that on any given day the dispatch schedule will be drawn up on the basis of the cumulative running hours total for the year. Fossil fuel power that are running further behind their target annual running hours are more likely to be dispatched first. According to China's Renewable Energy Law (2010)[45] all available renewable power should be dispatched first. In practice renewables are often constrained off by a combination of transmission constraints, a desire to help fossil fuel power plants meet their annual hours target and the fact the renewables are financially expensive (per kWh of dispatched generation).

Market pilots have focused on monthly contracts for power and the incentive for generators to participate in such pilots is that if they sell more power in the contract market then this can be used to justify the need for them to be dispatched more than would otherwise be the case by their provincial dispatch centre. Given that allocation of annual hours often occurs after the start of year, holding contracts in the market can justify a higher allocation of hours.

The organisation of dispatch is ripe for reform in China. In 2015 around 1.6% of power demand could have been met by renewable generation that was constrained off the system (we discuss curtailment of renewables further below). This is essentially free electricity (once the investment has been sunk). Academic studies suggest that efficient dispatch might reduce coal demand in China by up to 6% via a combination of reducing lost renewable output and dispatching more efficient coal fired power plants first[46]. What is striking is that dispatch savings alone are actually quite small (though they represent essentially free money left on the table within the existing power system). The environmental savings are large at 0.5% of global CO_2e emissions[47]. Coal cost savings of 6% are 1.7% of the value of total industrial electricity expenditure[48], however the price savings would be higher if falls in coal marginal cost meant generally lower prices. Not all of the theoretical savings are realisable once genuine transmission and system stability constraints are taken into account and the fact that many thermally inefficient combined heat and power plants (CHPs) must run because of their heating loads in winter. CHPs accounted for 19% of the total power capacity in 2012 (220 GW) (CEC, 2013). The most important point is that merit order dispatch underpins competition between power plants by massively sharpening incentives to cut running costs at individual plants in order to improve the probability of being dispatched.

In addition, there is substantial inefficiency in regional power flows. This would be significantly helped by elevating the role of regional dispatch centres on the basis of least cost, as opposed to provincial dispatch, which favours provincial generation.

A current constraint in reforming dispatch is the necessary software to optimise the operation of the system. The current estimates are that for most provinces or regions it would take 18 months to develop, test and implement new dispatch software. This does not seem a large medium term barrier. The bigger barrier is the impact on existing generator contracts, which are based on the expectation of sharing the available operating hours. For individual plants the financial impact of reallocating operating hours away from them would be substantial (e.g. consider two plants operating for 4000 hours on the basis of sharing hours, becoming one operating for 7000 hours and the other operating for 1000 hours). The impact on the large generators might not be substantial at the corporate level given that income would be simply being reallocated between plants. The fact that most of the power plants are in some form of state ownership (though divided between national, provincial and local governments and their corporate investment companies) should facilitate internal public sector reorganisations of asset valuations. However, some compensation would doubtless be necessary at the generation company level and / or between different branches of government.

3.1.3 **Privatisation of monopolies** (4);

3.1.3.1 Theoretical significance

Monopoly state ownership gives rise to a number of theoretical problems for performance of an electricity sector (or any other state controlled sector).[49] These include: arbitrary state interference in the operating and investment decisions of the sector; a lack of comparative information on performance of a given state owned firm which allows its own managers and controlling ministry to evaluate and incentivise its performance; a lack of comparative information on performance of different firms which allows external regulators or financial investors to evaluate and incentivise performance; a lack of clearly defined or empirically justifiable corporate objectives, in contrast to a profit driven private firm; lock in to other forms of monopoly control, such as state control of hiring of senior managers, access to capital, control of input purchasing decisions; exemption from or limitation of the rule of law towards the state owned monopoly, leading to anti-competitive behaviour, lax health and safety regulation and environmental regulation and weak enforcement of rules and regulations (in contrast to private sector firms).

Privatisation of a monopoly, even without any change in the structure of the firm, immediately exposes the firm to competitive forces and external regulation in the capital market, labour market and input markets. It also reduces the scope for corruption and arbitrary sate interference. It generally sets up a longer run dynamic which will force a monopolist to improve its performance and be subject to pressure for further break-up under pressure from competitors and anti-trust authorities. The experience following the 1986 privatisation of British Gas as an un-restructured monopoly gas shipper-transmitter-distributor-retailer in Great Britain is an excellent example of this dynamic at work. The end point, in this case, was one of the most competitive wholesale (and domestic) gas markets in Europe.[50]

3.1.3.2 General reform experience

The move away from monopoly state owned enterprises in generation and transmission (e.g. CEGB in Great Britain, EdF in France, UES in Russia, or SEGBA in Argentina) has generally been accompanied by significant privatisation of existing state owned assets. The privatisation has often been consequent to the breakup of state owned assets into separate competing companies for generation and monopoly transmission companies. In addition, there has been significant privatisation of distribution and retail companies (which were often separately constituted as municipal companies). There are well-documented cases of successful distribution privatisations in the UK, Brazil, Chile, Peru and Argentina.[51]

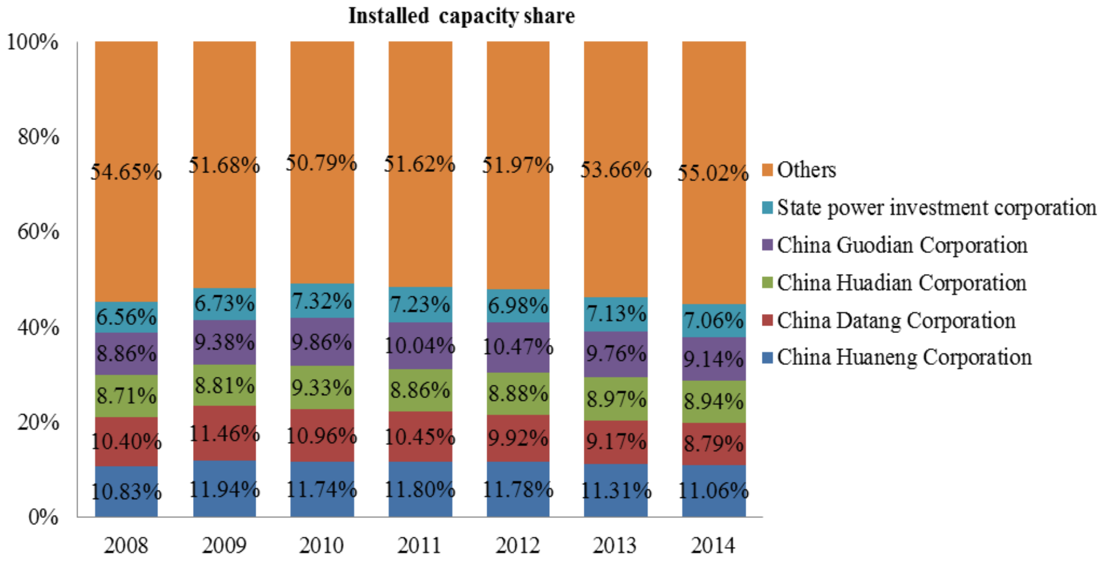
Some jurisdictions have opted for partial privatisation. EdF remains only part privatised and German utilities still have significant government ownership of their stock. In the Netherlands the distribution companies remain largely government owned, while they have all sold their retail businesses.

3.1.3.3 Chinese context

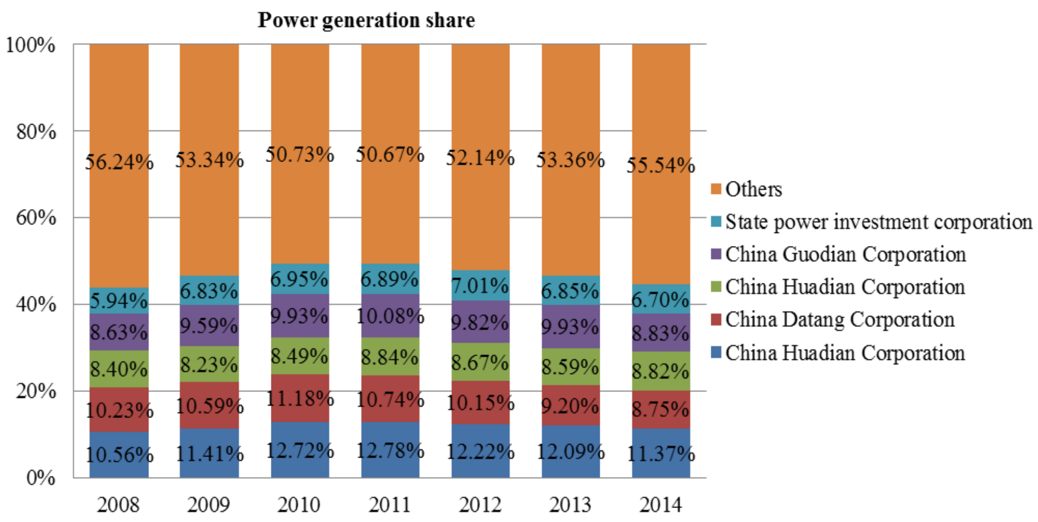
China has had a very significant reform of its electricity sector since 1985, but state ownership remains pervasive throughout the whole supply chain in electricity[52]. There has been substantial entry of private and competing government owned companies into the electricity generation segment. However much of this entry is directed by provincial investment companies who themselves are pursuing non-profit objectives. Most importantly 7 state-owned companies – the big five generators, State Grid and China Southern Grid - constitute around 50% of total generation (see Figure 9) and 100% of transmission, distribution and retailing.[53]

Private ownership is still quite limited in scope and there remain restrictions on private companies entering the generation market in particular.

Figure 9:
Share of Big 5 generators in total capacity and total generation



Source: Annual reports of power generation companies (2015)



Sources: Annual reports of power generation companies (2015)

Privatisation remains a controversial pillar of the global electricity reform experience. Some studies have questioned whether it is a significant contributor to the improvement in performance of sector which liberalisation seeks to unlock[54]. However, in the context of a large middle-income developing country, such as China, monopoly state ownership has a particular constitution and represents a significant, but subtle, barrier to improved performance.

As was evident in the history of the state owned generation and transmission monopoly in Great Britain (CEGB), state ownership of the electricity sector allows non-merit based appointments of senior managers, limits the scope of competition in the input market and shapes investment decisions (often disastrously)[55]. It gives rise to significant scope for corruption and may put a break on competition and responses to price signals even where ownership is dispersed between different state-owned firms. While the European single electricity market is characterised by much continuing partial state ownership of generation assets this does not impede the operation of a competitive market and severely limits the scope for non-market driven investment decisions. European utility reform is also filled with examples of state owned monopolies for which privatisation is the only reasonable solution to improve their performance (e.g. Network Rail and the Royal Mail in the UK[56]), in the face of the need to impose clear regulatory incentives on the access to capital for investment.

Part-privatisation of the largest Chinese generating companies, or the wholesale privatisation of at least one of the big 5, would be a first step to significantly reducing the monopoly control of the central Chinese government and allowing the government to experiment with the benefits of loosening state control on a potentially competitive part of the electricity sector.

3.2 Supportive secondary market arrangements

3.2.1 creation of spot and ancillary services markets to support real time balancing of the system (5)

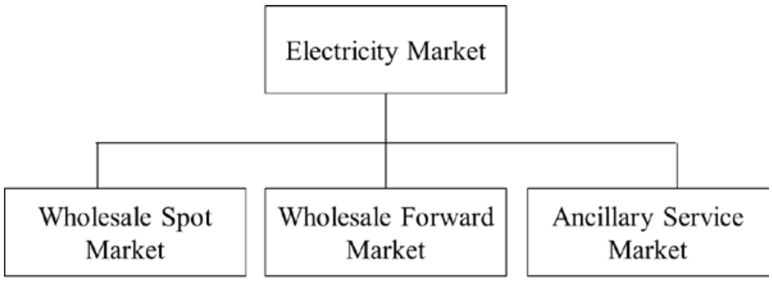
3.2.1.1 Theoretical significance

A market based electricity system involves using the pricing mechanism to price the different electricity products that are necessary to supply kWhs to final customers at the right quality (see Stoft, 2002, for a detailed discussion). A full set of markets would include: spot and forward markets for real energy; and markets for frequency response, reactive power, voltage regulation and reserve capacity (see Figure 10 below).

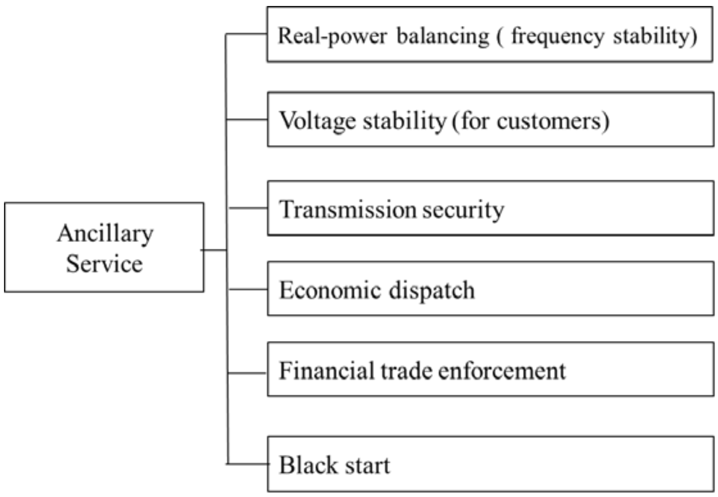
Spot markets reward generators for matching supply and demand in near real time. This typically involves day-ahead markets and intra-day (balancing markets). This gives incentives to generators (and to loads) to adjust their position on the basis of the general condition of the system and their own operating situation. Longer-term markets – such as monthly or yearly contract markets – offer financial hedging to generators and loads.

Ancillary services are to do with maintaining power quality in real time. Traditionally these have been quite a small part of the electricity market in systems characterised by large fossil fuel based power plants. This is because these types of plants can cheaply provide ancillary services as by-products in the production of real energy. As power systems become more complex and involve more renewables the market efficiency of ancillary services provision becomes more important. In Great Britain ancillary services are expected to grow from 2% of wholesale electricity costs in 2015 to 25% by 2030[57].

Figure 10:
List of electricity product markets, including ancillary services products



Source: Stoft (2002, p.82).



Source: Stoft (2002, p.236)

3.2.1.2 General reform experience

The development of spot markets for electricity has been central to the development of wholesale power markets. A spot market provides the basic price signal around which all futures prices can be determined. This is true in all energy based commodity markets. This is because spot prices can provide transparent constantly updated information and are the basis for the determination of longer-term contract prices. Efficient spot markets are visible to entrants and can give good signals on the viability of entry at any given moment. They are also extremely important to signalling to the demand side of the market the value of short run actions to reduce (or increase) power demand.

Sophisticated electricity markets around the world have been developing their markets for ancillary services.[58] This has been because a sharpening of the incentives around the delivery of real energy means that power quality must be appropriately rewarded or there will be pressure for it to deteriorate. This is most obvious in the area of reserve capacity where the move towards a liberalised market means a (necessary) reduction in the holding of reserve capacity. If this leads to the system operating at an unacceptably high risk of a rolling blackout there may be a case for creating a market to specifically reward capacity (separately from energy). However, it is fair to say that incentives for rewarding ancillary services remain a patchwork of no-payment (compulsory provision), fixed payments, bilateral contracts and bid based markets.

3.2.1.3 Chinese context

Individual power plants in general receive a regulated payment for the power that they generate. This is a negotiated price that varies at the provincial level and is agreed with the local National Development and Reform Commission (NDRC) on the basis of local production costs and socio-economic conditions. The aim is to allow a plant to recover a reasonable rate of return considering its costs and the number of allocated hours it is likely to run for (see Ma, 2012). Plants are allocated hours on the basis of 'equal share dispatch' (see Karhl and William, 2014) discussed above. The current terms appear to be very generous (see Table 4 above) and are encouraging over building of new generation capacity (see Rioux et al., 2016).

China has a coal based power generation system that has minimised the need for formal ancillary services markets.[59] There are some payments to generators who must run for system support (voltage support or reactive power) reasons, however there is, in general, no formal payment mechanism for ancillary services. There have been suggestions of how the market might be reformed in a Chinese context.[60]

If power dispatch were to be reformed in China, the lack of formal mechanisms for procuring ancillary services would be more of a problem because some plants which are needed for ancillary services might be in danger of closing on the basis of their lack of competitiveness in the wholesale energy market. Hence one can envisage that reform of dispatch would require reform of ancillary services payments.

3.2.2 participation of demand side in wholesale electricity markets (6)

3.2.2.1 Theoretical significance

One of the cheapest sources of power available in any electricity market is demand reduction. This is where some demand that would otherwise be on the system is paid to not run. This is a key source of flexibility in any electricity system and particularly useful in managing peak demand and the requirements for reserve capacity. Unlocking demand reduction is a low cost way of increasing competition in the market and balancing supply and demand. The introduction of a spot market for electricity greatly facilitates demand side participation, because this is the market in which demand can most easily participate. Demand side participants are frequently large industrial users who can turn down or reschedule their production in response to system conditions. Industrial users can sign contracts with aggregators that pay them significant amounts per kWh of demand they reduce at peak times (or have signed contracts which give them otherwise cheap power, but then expose them to very high prices if they consume at times of annual system peak demand). With the emergence of distributed electrical energy storage the capacity for industrial and commercial loads to further manage their interaction with the wholesale market will increase.

3.2.2.2 General reform experience

Table 5:
Demand participation in liberalised markets

	Texas ERCOT	Great Britain National Grid	US PJM
DSR as % of Peak	3.20%	3.60%	9.10%

Source: Khalid et al (2016, p.3)

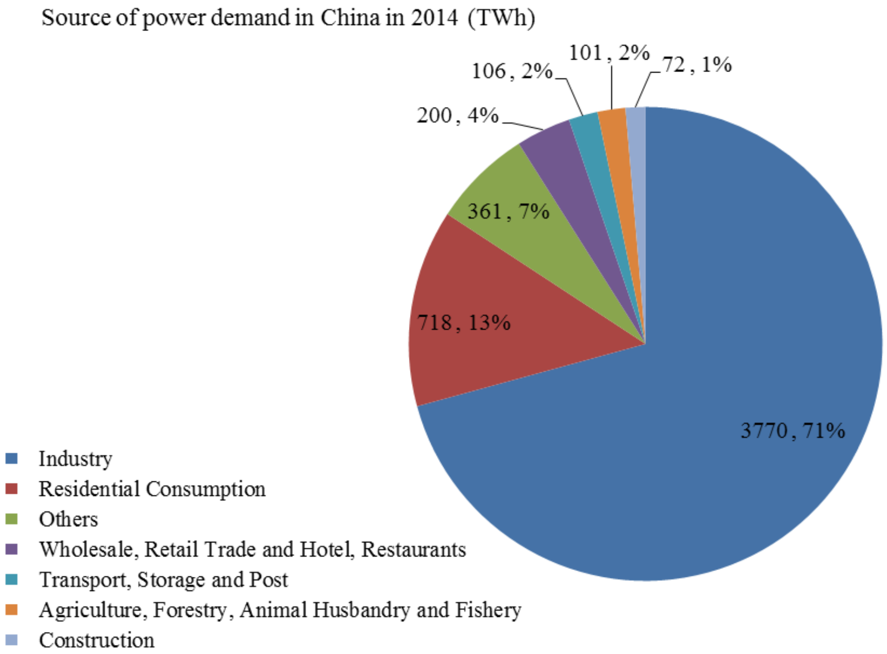
Demand side participation has been very significant in competitive power markets (see Table 5)[61] in that there have been many occasions where there would been blackouts if there had not been active demand side participation in wholesale power markets (in Great Britain there have been several incidents of demand side participation helping the system cope with extreme system conditions).

Demand side participation has been very important in ancillary services markets. Most recently capacity markets in both the US and Great Britain have seen significant price reducing impacts from the inclusion of the demand side in the market.

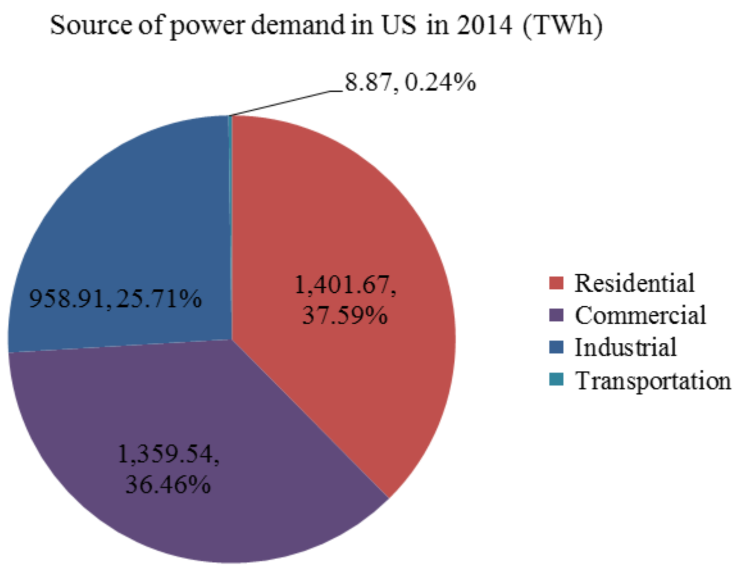
3.2.2.3 Chinese context

One of the limitations on demand participation is that domestic and high value commercial loads are more expensive to incentivise to reduce or shift their demand (per kWh of demand reduction). This implies that deindustrialising economies such as in the US and Great Britain have smaller easier to shift industrial loads over time. This is not the current situation of China, as shown in Figure 11, where 71% of power demand is from industry (as opposed to only 26% in the US). This suggests a high potential for demand side response in China. [62]

Figure 11:
Sources of electricity demand in China and the US



Source: NBS (2015)



Source: EIA (2015)

Projections from Shanghai and the actual experience of Jiangsu suggest a significant and rising percentage of peak demand response as shown in Table 6. In Jiangsu province, the grid companies and related governmental agencies launched a demand-side management pilot project in the summer of 2016. 3154 households participated in this DSR pilot project that saw a peak demand reduction of 3.8 % (the equivalent of 3,520 MW)[63].

Table 6:
The potential for demand response in Shanghai and Jiangsu in selected years

	Jiangsu-2016	Shanghai-2020	Shanghai-2025	Shanghai-2030

DSR as % of Peak	3.8%	1.68%	3.04%	4.09%

Source: The data on Shanghai are from Liu et al. (2015, p.16), and the data of Jiangsu are from http://www.sdpc.gov.cn/fzgggz/jjyx/dzxqcgl/201607/t20160727_812571.html

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It is important to point out that demand response depends on customers being subject to sophisticated metering which can measure their consumption, when they are meant to be offering demand response. In Yunnan, in 2015, only half of all industrial customers had got meters capable of allowing them to participate in a spot market. It also needs to be case that the demands themselves are subject to market based incentives for their output otherwise they may have an incentive to game their participation in demand side response by deliberately running their equipment ahead of an instruction to reduce their demand.

3.2.3 regulated third party access to, and efficient allocation of scarce transmission capacity (7)

3.2.3.1 Theoretical significance

Transmission capacity is a scarce resource.[64] This is because transmission system investments are large and eventually it becomes difficult to expand transmission capacity as a result of objections from the communities through which they pass (and who do not benefit directly from them). Because of loop flows in meshed electricity networks and constraints within the distribution system to which they are connected, transmission building to solve one constraint may create other constraints and vulnerabilities. Building appropriate transmission capacity in the face of rapid growth of generation or loads in some areas (rather than others) often gives rise to transmission constraints in developing countries. Transmission capacity can often only be added in significant sized increments, meaning that until the next incremental expansion of capacity comes along there will necessarily be constraints within the transmission system. Every advanced country in the world has had difficulty in expanding transmission capacity beyond a certain point.

This suggests that a system for allocating the available transmission capacity is necessary. This is important when the cheapest generation sources are a long way from the largest and most valuable loads. Allocating transmission capacity among generators and loads in an efficient way and providing signals for where to expand the transmission system next are important elements of a reformed electricity system. The allocation of capacity among generators and loads should be non-discriminatory. This is important in countries where transmission capacity is still owned by an incumbent generator, to prevent unfair access terms reducing competition in the wholesale market.

One way to indicate where the constraints are in the transmission system is to use short run price signals at every node in the transmission system – locational marginal prices (LMPs) – which indicate a different price for wholesale power between export (lower) and import (higher) constrained nodes.[65] This provides signals to switch off high cost generators and lower value loads in export constrained areas and switch off high cost loads and switch on higher cost generators in import constrained areas. Those using the transmission system have to pay the differences between LMPs at each end of a line to use the system in the direction that the power is flowing.

Another way to do this is to allocate transmission system costs by location such that generators connecting in export constrained areas face higher use of system charges than generators connecting in import constrained areas and vice-versa for loads.[66]

Both of these methods help make good use of the existing transmission system and signal the value of transmission system expansion on the basis of the modelled reduction in constraint related payments.

3.2.3.2 General reform experience

Non-discriminatory access to the transmission system based on regulated third party access has been a central element of power market reform as countries have moved away from integrated generation and transmission utilities. There are well documented cases where continuing integration of generation and transmission did lead to preferential access being given to incumbent generators by their transmission business (e.g. in Chile). This resulted in long running competition disputes.[67] The EU stated that ownership unbundling of transmission from generation with regulated third party access (a single set of access prices) was its preferred model for the organisation of the transmission system.

Allocation of transmission capacity has been largely done on the basis of published tariffs with firm transmission rights (guaranteed access). This results in compensation being paid in the event that generators or loads have to reduce their supply or demand due to transmission constraints. In Great Britain such firm transmission rights do come with the locational signals in the use of system charges for connecting generation in demand constrained parts of the network and vice versa. Independent system operators (ISOs) in the US mainly use LMPs to optimise the use of the transmission system in real time and then allow the trading of financial transmission rights (FTRs)[68] allocated to incumbents every six months that allow transmission system users to hedge their exposure to LMPs.

For significant transmission links, such as long distance HVDC lines in the US[69] or international transmission links in Europe[70], capacity is auctioned and this is a way of efficiently allocating the capacity among users. However, such congestion-based mechanisms for charging do not guarantee that the fixed costs of the line will be recovered and hence additional charges will be almost certainly be needed.

3.2.3.3 Chinese context

Table 7:
Expansion of Chinese transmission and distribution grid

Type	Voltage	2014	2013	2012
AC (km)	l000kV	3111	1936	639
	750kV	13881	12666	10088
	500kV	152107	146166	137104
	330kV	25146	24065	22701
	220kV	358377	339075	318217
	110kV	566571	545815	517983
	35kV	484296	464525	456168
	Total	**1603489**	**1534248**	**1462900**
DC(km)	800KV	10132	6904	5314

660KV	1336	1400	1400
500KV	11875	10653	9145
400KV	1640	1031	1031
Total	**24983**	**19988**	**16890**

Source: China Electricity Council (2015)

Recently China has been rapidly building generation capacity, expanding power demand and building new transmission lines. It has invested significantly in HVDC links[71]. The rapid expansion of the high voltage grid can be seen in Table 7. The allocation of the capacity within the transmission system in China is rather underdeveloped. Thus some significant capacity remains underutilised (e.g. between Yunnan and Guangdong) and other lines are not being allocated efficiently (e.g. to renewables from low cost regions). This suggests that some reform of the pricing and allocation mechanisms around transmission capacity would be beneficial and would be in line with other reforms to dispatch and wholesale power markets.

Under the current system of charging final customers transmission and distribution charges have not be separately identifiable, even for the largest customers. This is because both final customer and generation prices have been regulated by the government. Unit charges have varied for different customers connected at different voltage levels (as would be suggested by optimal allocation of fixed costs between customers). Recently the government has moved away from per unit charging to introducing fixed fees for some large industrial customers.[72] Under the recent market trials transmission/distribution network charges at the provincial level have been identified. However these new transmission and distribution charges in China are cost plus and do not incorporate location or time of use signals of the longer run or real time condition of the network. Generators do not bear any of the costs of transmission system (unlike in some systems such as the UK) and rely on curtailment and regulated energy prices to signal advantageous locations for connection. Reforming the charging for transmission to better allocate the available capacity would seem to be advantageous especially in signalling where to locate renewables, build new transmission capacity and which generation plants should run in constrained areas of the network.

3.3 Appropriate economic regulation

3.3.1 unbundling of regulated network charges and competitive segment charges (8)

3.3.1.1 Theoretical significance

It was Joskow and Schmalensee (1983) who definitively pointed out (following Weiss, 1975) that wholesale generation and retail service were potentially competitive elements within the largely vertically integrated US electricity power industry. Only transmission and distribution networks - which provide the transport capacity to the electricity system - have the characteristics of natural monopolies. Even then distribution networks are local monopolies and multiple distribution systems can co-exist within a single country providing the ability of regulators to benchmark these local natural monopolies against one another using yardstick competition (following Shleifer, 1985). Transmission monopolies can exploit economies of scale over larger areas and over individual lines, but the wide area natural monopoly is actually in system operation rather than the ownership and operation of lines themselves. Thus in many parts of the US transmission ownership is actually dispersed among local companies, while system operation (such as in PJM) is conducted over a wide area.

Such a separation between transmission and distribution networks and the rest of the system allows pricing mechanisms to be clearly distinguished. Prices for wholesale and final retail charges can be competitively determined, while both the level and structure of distribution and transmission charges continue to be regulated monopoly charges. Attention can be paid to ensuring that such charges are non-discriminatory, that is they do not favour any particular user of the network on the basis of their ownership characteristics, in particular whether they are part of the same company that owns the transmission and distribution system.

3.3.1.2 General reform experience

The increasingly strict unbundling of transmission and distribution charges from charges for wholesale and retail elements of electricity supply has been a key element of both the successful creation of competitive wholesale and retail electricity markets around the world. In the UK transmission and distribution network ownership was unbundled from generation ownership at the time of privatisation. At the level of the EU successive electricity directives (1996, 1999 and 2003) required accounting and legal unbundling of the network elements from the rest of the system.[73] This meant that transmission and distribution businesses must be created within companies that remain integrated with generation and retail. Transmission and distribution must be legally unbundled from each other within the EU. The EU has expressed a preference for the ownership unbundling of transmission from the rest of the electricity system, given the key role that non-discriminatory access to the transmission plays in promoting retail competition. As we discussed earlier, strict separation promotes a level playing field in the competitive segments of the electricity supply industry.

A significant share of the total benefit of liberalisation arises in the network businesses themselves. A key success of the separation of network and competitive elements in many countries has proved to be the ability to introduce incentive regulation of the network businesses. This has involved CPI-X regulation of the revenue of network companies, with formulae set in advance for several years (usually 3-5 years). This has resulted in very significant improvements in the efficiency of operation of the network companies. In the UK perhaps one third of the overall gain from the liberalisation process came from improved regulation of the network companies, rather than competition per se (see Littlechild, 2006 and Pollitt, 2012).

3.3.1.3 Chinese context

The power sector reform of 2002 resulted in a very significant set of measures aimed at separating networks from competitive elements. This did result in separation of generation from the rest of the power system. However, as we have already observed transmission, distribution and retail remain bundled within State Grid and China Southern Grid[74]. Generation is under contract to supply the Grid companies with power to supply their final customers. This is a form of single buyer model, which was used in the early days of power market reform in some countries. It was an option under the 1996 electricity directive in the EU. This model has now been discontinued in the EU (for fossil fuel generation) in favour of competitive wholesale power markets to determine the price of bulk power.

Recently several provinces (including Guangdong) have announced network access charges which generators need to pay to use the transmission and distribution system to competitively sell power to final customers[75]. These charges are based on the identification of a regulatory asset base for transmission and distribution assets within the province and the calculation of what charges would allow the relevant grid company to recover a fair return on this asset base while covering its costs. The charges that have been announced are fixed for three years. This would seem to give some incentives for the grid company to cut its network costs and keep the savings.

The move towards stricter separation of network and competitive elements within the power system in China is to be encouraged. For China to bring itself in line with international best practice, there must be strict accounting and legal separation of transmission, distribution and retail businesses. Such strict unbundling would allow the publication of data on network company costs and facilitate independent comparative benchmarking of regulated network businesses, which is currently very difficult to do on the basis of the high level horizontally and vertically integrated business data that is available on China State Grid and China Southern Grid at the moment. This will greatly facilitate non-discriminatory access charging for the use of the distribution and transmission system. It will also allow incentive regulation of transmission and distribution to be introduced. An obvious way forward is to compare distribution and transmission costs at the provincial level and use benchmarking to compare costs and set the efficient level of revenue for the transmission and distribution elements. Setting a CPI-X price cap for 3 years is a good start and does allow some differences in performance to emerge quickly, before moving to setting the price controls for longer periods (in the UK, this was initially 5 years for distribution and 4 years for transmission, later 5 years for both and now 8 years for both). Regulation of investment is also important, given the high rates of investment in networks in recent years. There is currently a lack of incentives to limit these investments, in contrast to jurisdictions with incentive regulation where sophisticated audits and menu regulation have been developed to limit overinvestment by monopoly network companies.[76]

3.3.2 mechanisms to ensure competitive procurement of wholesale power for regulated final customer groups (9)

3.3.2.1 *Theoretical significance*

Unless all of the retail market is liberalised there will continue to be significant numbers of customers who are on regulated final tariffs. If this is the case these customers need to be supplied with wholesale power, which has been procured on a competitive basis. This is because if they are not, this will significantly reduce the degree of competition in the wholesale market. There is no reason why all retailers should not procure their power competitively in the wholesale market, whatever the basis of the final contracts that they need to offer to customers in the regulated retail price market.[77]

3.3.2.2 General reform experience

Most countries across the world that have competitive wholesale power markets also have regulated final tariff customers. This is case in half of all EU countries (see ACER, 2014), most of the US and all of South America. These customers are the default service contract customers in the US and the EU and most of the final household customers in South America who are still on regulated final tariffs. In all of these cases the procurement of the power to supply these protected customers is done on a competitive basis.

This is achieved by the regulator specifying the basis of the contract for bulk power that it allows to be passed through to the regulated final customers. In Italy, the regulator specifies a default mark-up formula for residential customers[78]. This is based on regulated mark-up competitively acquired wholesale electricity[79].

In the US the wholesale power contract to supply default service customers within a particular distribution company area is often auctioned and the auction price then used to price the wholesale cost element of the default service bill that residential customers are charged.[80]

3.3.2.3 Chinese context

Currently, the two large Grid companies procure power at regulated prices for all their customers[81]. The final prices that they can charge and the prices that they pay for wholesale power are regulated. It is highly likely, and in line with international experience, that China will want significant numbers of customers to continue to enjoy regulated tariffs for the foreseeable future. This is particularly true in the residential sector where customers are currently paying below the full economic cost of their service[82]. If Chinese residential prices were raised to US levels this would allow industrial prices to be reduced by up to 5%.[83] Indeed, there are no plans to liberalise the market for residential customers in this round of reforms. This may be because of a debate among senior policy makers about whether electricity is a commodity (which should be priced to reflect costs) or a public service (which should continue to be cross-subsidised).[84]

The continuing presence of default service customers does not mean that there needs to be anything less than full competition in the wholesale market for power. This can be achieved by moving to competitive procurement for wholesale power from fossil fuel power plants. Such a mechanism could also be used to introduce regular cost based updating of retail prices on the basis of changes in underlying power procurement costs. This would be the basis for gradually raising retail prices, as incomes continue to grow, towards fully cost reflective levels. Clearly identifying the procurement costs associated with default service customers, combined with separate network charging, would also clearly identify the level of the subsidy that these customers are currently receiving. This would have the additional advantage of focussing regulatory attention on how this might be reduced over time.

3.3.3 the creation of independent regulatory agencies to regulate monopoly network charges and monitor competitive segments (10)

3.3.3.1 Theoretical significance

Competitive wholesale and retail markets need to be monitored carefully to ensure that they are working properly. This is because they are creations from incumbent monopolies and exhibit natural tendencies to re-integrate. This implies that it is unlikely that a general competition authority will be nimble enough to confront all of the many competition issues that are likely to arise, especially in the early years following liberalisation. In addition, substantial regulated monopolies remain in the sector. These need to be regulated as to the level and distribution of their charges and the quality of service that they are offering to both their retail and generation customers wishing to use their networks. Such regulation is a substantial task and requires detailed knowledge of the cost structures of the industry and attention to the incentive effects of any financial controls that are put in place. These two facts, suggest that in line with other significant utility industries (telecoms, gas, rail and water) a dedicated regulatory body may be best placed to ensure society's continuing interest in these sectors.

The institutional form of such a regulatory body can be debated and depends to some extent on the size and competence of state in which it is situated. It could be merged with other regulated industries (such as in Germany within the Bundesnetzagentur), involve both national and sub-national bodies (such as with Federal Electricity Regulatory Commission (FERC) and the state Public Utility Commissions (PUCs) in the US), be a division of the competition authority (as in the Netherlands with the DTe being merged into the NMa) or involve a separate electricity regulator (e.g. ANEEL in Brazil) or a combined electricity and gas supply regulator (e.g. Ofgem in Great Britain).

In most countries with liberalised power markets, the regulatory body tasked with overseeing competition and monopoly regulation is independent of day-to-day central government control in the sense that it is a non-ministerial government department, where the relevant government ministry (of energy) has limited powers of intervention during the term of office of the board members of the regulatory body. Both the World Bank and the EU have strongly endorsed this approach to regulation[85]. This is because a key problem in liberalised network industries is one of regulatory appropriation (see Gilbert and Newbery, 1994). This occurs when governments have the incentive to encourage private companies to invest and then to force them to reduce prices after investment has occurred in order to 'appropriate' a greater share of the benefits from investors to customers. 'Independent' regulation is primarily aimed at balancing the rights of shareholders to return with the rights of consumers to fair (i.e. reflective of competitive cost levels) prices.

3.3.3.2 General reform experience

The experience of liberalised markets is that independent regulators have supported private investment in liberalised power markets, have had significant roles in monitoring day-to-day competition issues and have made significant progress in developing network regulation. The role of Offer (the GB electricity regulator from 1990-1999) and then Ofgem (the electricity and gas regulator from 1999) have been very significant in the Great Britain context. The presence of a regulatory body with an appointed regulator (and then regulatory board) with statutory duties (in particular, to promote competition) gave investors confidence that the government would not arbitrarily intervene to reduce prices.

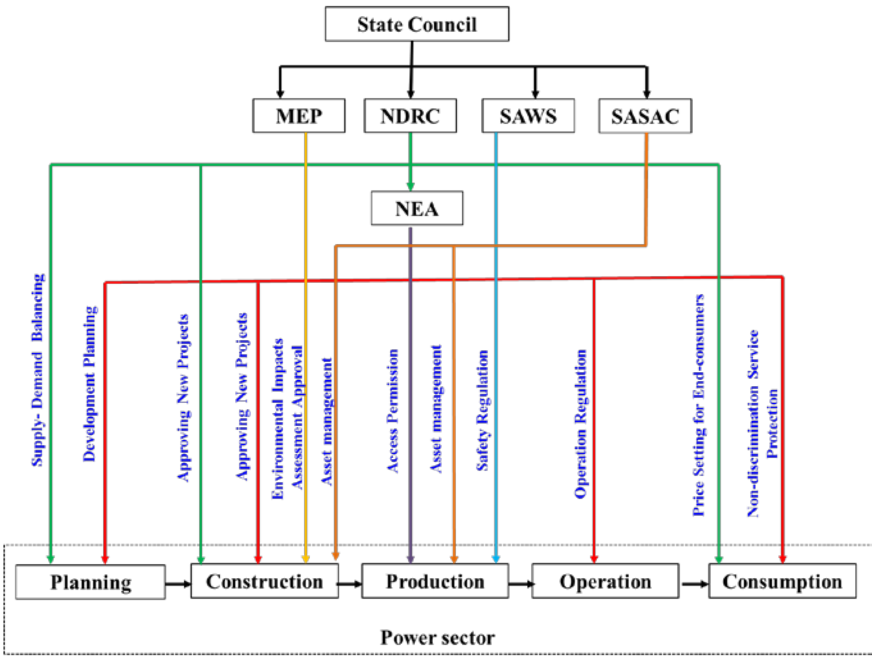
This resulted in significant new investment in the industry in the years following privatisation and eventually significant foreign investment in the sector (which saw the assets being sold at a large premium to oversees investors). It also resulted in close regulatory oversight of the process of competition in the early years (see Newbery, 2005) that did eventually result in competition authority enforcement action (sanctioned by Ofgem) to further break-up the incumbent generators. Offer and Ofgem developed very sophisticated and successful incentive regulation of network companies which saw the level of real charges fall nearly 60% in distribution and 40% in transmission between 1990 and 2005 (see Jamasb and Pollitt, 2007, and Ofgem, 2009). These results have been mirrored elsewhere and Cubbin and Stern (2005) found significant investment benefits in electricity resulting from privatisation and independent regulation across a sample of countries, many of which had previously suffered from chronic under-investment in electricity infrastructure.

A particular success of the regulator in the UK has been to counteract the power of incumbent companies in the sector. This was greatly facilitated by the breakup of the incumbent generator and the separation of the transmission network company from the rest of the system. The regulator has been a consistent advocate for introducing more competition, for instance in the procurement of network assets, and for changes to network and industry rules which increase costs for customers. The regulator has also been a significant source of learning in the sector as problems have been revealed and dealt with and new issues have come to light as the reform has progressed.

Many developing countries have set up nominally independent regulatory agencies for electricity. These often suffer from a lack of genuine political will to leave the sector to be overseen by the regulator and a lack of resources on the part of the regulatory agency to effectively enforce competition and network regulation (see Pollitt and Stern, 2009). Regulatory agencies in many countries need a combination of well-trained economists, lawyers and accountants to adequately undertake economic regulation. Low civil service pay in competition with relatively well-resourced incumbent companies make it difficult to attract high quality staff with relevant industry knowledge and experience to work in regulatory agencies in many countries.

3.3.3.3 Chinese context

Figure 12:
Current structure of regulatory bodies overseeing the Chinese electricity sector

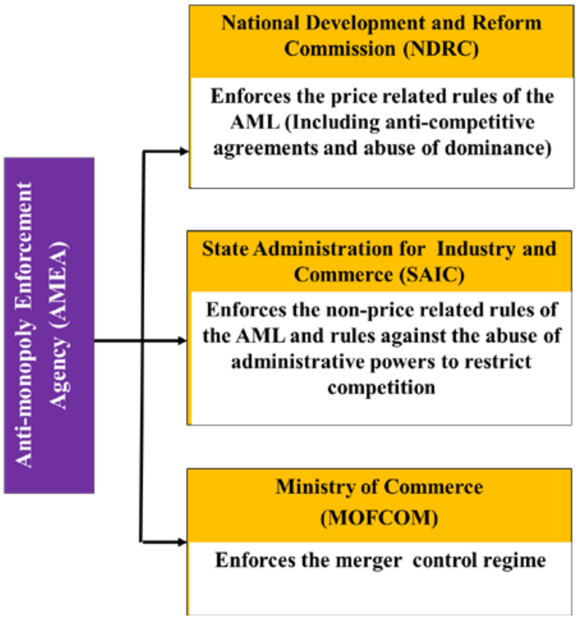


Notes: Ministry of Environmental Protection (MEP), National Development and Reform Council (NDRC), State Administration of Work Safety (SAWS), National Energy Association (NEA), State-owned Assets Supervision and Administration Commission (SASAC).
Source: Tan and Zhao (2016).

As suggested by Figure 12, Chinese regulatory oversight of the electricity is complicated.[86] There was an attempt to create a separate economic regulator in 2003 within the NEA (the Electricity Regulatory Commission) to oversee competition and pricing, but this was merged back in to the NEA. Determination of regulated final prices and the prices paid to generators is currently split between the provincial and national Pricing Departments of the NDRC, which is the government department that oversees economic reform across the whole economy. None of the bodies (in Figure 12) has exclusive power over coordinating the electricity policies and none want to be coordinated by others. Therefore, it is sometimes difficult to balance the actions of different government agencies. One consequence of this is that the energy policy for the 12th Five-Year plan (2011-15) did not come out until 2013.[87]

China does not have a tradition of independent regulation and even in the telecoms sector (where, internationally, deregulation is normally more advanced than energy) there is no regulator separate from the Ministry of Communications[88]. The situation is complicated by the continuing state ownership of most of the electricity supply sector and the role of the State Asset Holding Company[89]. However there has been some success in recent years in improving the functioning of the general competition authority in China, which has become more active in monitoring and enforcing competition across the economy[90]. Section 7, Paragraph 2 of China's Anti-monopoly Law does cover SOEs and prohibits the their abuse of dominant positions. However, the law also protects SOEs that 'implicate national economic vitality and national security' and hence there is a limitation to the extent to which current anti-monopoly legislation covers large SOEs in the electricity sector. Anti-monopoly enforcement activities in China are currently split between three branches of government (see Figure 13), but there is some evidence that the Anti-monopoly Enforcement capability of the Chinese government is increasing. This would be potentially important if the role of the market is extended in electricity, as it has been in advanced countries.[91]

Figure 13:
Anti-monopoly institutions in China



Source: Slaughter and May (2016, p.2)

Regulators can only be as effective as the quality (and quantity) of the staff that they have. Civil service pay remains relatively low in China and this is a problem in recruiting and retaining staff to undertake regulatory functions. There is evidence that salaries in government remain low relative to those in the SOEs that they regulate (see Table 8).

Table 8:
Evidence on civil service pay in China relative to state owned companies

	2003	2004	2005	2006	2007
Electricity, gas and water utilities	121	140	161	185	218
Public sector	100	113	132	147	181

Notes: *Public sector in 2003 = 100*
Source: Chan and Ma (2011, p.305)

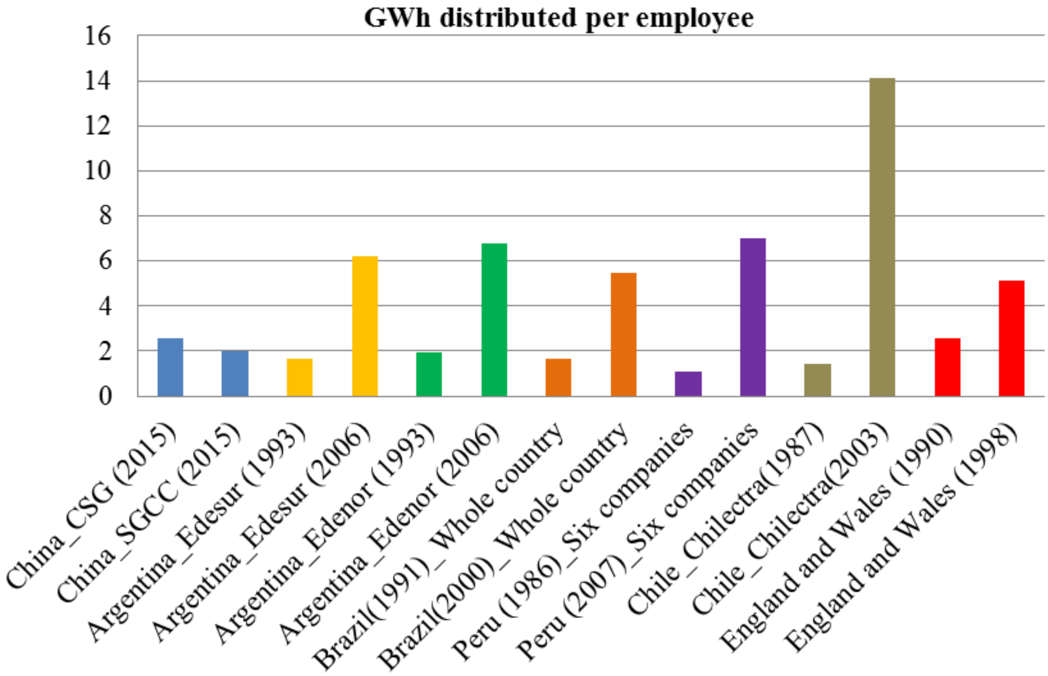
A well-resourced economic regulator is an essential part of a successful on-going reform of the electricity sector in China. FERC in the US has 1500 employees (working on electricity and gas) working at the Federal level, with significant additional numbers in the State PUCs. Ofgem in Great Britain has 907 employees (for a population of 58m).

How to ensure the independence of this regulatory agency in a Chinese context is challenging, given the lack of experience in China with independent regulation. One solution is to incorporate the electricity regulator into the general competition authority to begin with. This would have the advantage of strengthening both functions of the authority and allowing for the initial focus to be on promoting competition (which is the key thrust of the No. 9 Document).

Another way forward would be to create an independent regulator with board members appointed for 5 years and use this as a test case for reforming utility sectors in China. These board members should be from a mixture of backgrounds and consist of both executive and non-executive members of the regulatory agency.

The prize from getting incentive regulation of the electricity distribution network in China is large. Consider the Figure 14 below:

Figure 14:
International comparison of impact of reform on labour productivity in electricity distribution and transmission



Notes: The six companies from Peru in this figure are Electro Sur Medio, Electrolima ,Edelnor, Luz del Sur, Ede Chancay and Ede Cañete.
CSG = China Southern Grid; SGCC = State Grid Corporation of China.

Sources: Anaya (2010), China Electricity Council (2015), Domah and Pollitt (2001), Mota (2003), National Grid Electricity Transmission Report and Accounts, Pollitt (2004 & 2008).

In Great Britain, between liberalisation in 1990 and 1998 employment dropped 43% and labour productivity in electricity transmission and distribution improved over 100%. Given that China State Grid and China Southern Grid have 2m employees, the savings in unit labour costs are significant (conservatively) estimated at $8.7bn p.a. or 2.1% of industrial customer expenditure, thus prices could be reduced by of the order of 2-3%.[92] Not all of the total number of employees are involved in the electricity supply business, a significant number are in other activities, potentially reducing the scope for rationalisation.[93]

According to an NEA regulation report, there is also a problem around grid asset depreciation in China's grid accounting, which can be seen as a strategy to inflate current costs (and charges). For example, the official depreciation period of one transmission line belonging to Guizhou grid is 17 years, however, the actual depreciation period is less than five years.[194] Transmission assets are typically depreciated over 40 years or more in EU countries. Rapid depreciation of new assets in an expanding system raises measured costs and hence prices. Proper regulation of grid asset accounting and their translation into electricity prices, might produce further significant savings for industrial electricity customers.

3.4 Efficient promotion of low emission technologies

3.4.1 competitive procurement processes for low carbon generation, with some exposure to wholesale price variability (11)

3.4.1.1 Theoretical significance

Low carbon generation is, mostly, not currently financially cost competitive with electricity produced from fossil fuels. This implies that if governments want to support low carbon generation they need to find ways to implicitly (e.g. by banning fossil fuel use) or explicitly subsidise it (e.g. by making use of feed-in tariffs). There are two good economic reasons to subsidise low carbon generation in the face of competition with fossil fuel based generation. First, because it is in its relative infancy and hence has not benefited from the cumulative learning that fossil fuel technologies have enjoyed, subsidies can be justified because of their future learning benefits[95]. Second, because fossil fuels produce environmental pollutants, such as particulates, acid rain and carbon dioxide, clean low carbon technologies can justify additional financial support, which reflects the value of reducing these pollutants. A further problem of low carbon generation is that because of the nature of the cash flows associated with such investments – high upfront costs and lower future running costs, relative to fossil fuels. This means that long-term power purchase contracts are more valuable for low carbon generation in order to reduce the cost of capital and improve the relative net present value (NPV) of low carbon investments.

These reasons suggest that long term fixed prices for low carbon generation may be needed to help them earn a return at the current stage of their technological development. This is true for both new technologies such as solar PV and onshore and offshore wind and also for established low carbon technologies such as hydro and nuclear.

Just because low carbon generation must be subsidised relative to fossil fuel generation does not mean it cannot be procured via a competitive process. Clearly it is theoretically desirable to minimise the subsidy costs of a given MWh of clean electricity. This can be done by a suitably designed procurement auction, of the type that we describe below.

Another problem that must be addressed is the fact that electricity is more valuable at certain times of the day, week and season. This argues against simple fixed price contracts for MWh, which do not vary the price paid with the relative value of the power to the system. A way should be found to give more of an incentive for renewable generation to respond to the supply and demand factors that should drive wholesale power prices. This can be done by a contract for difference (CfD) with the government that guarantees a top-up payment based on average wholesale prices, or via a premium FIT where the low carbon generation participates fully in the wholesale market and receives the market price plus a premium set by the government (rather than just a fixed price).

3.4.1.2 General reform experience

While many countries have had fixed feed-in tariffs per MWh, a number have used competitive procurement methods to support low carbon generation, with some exposure to real time price volatility. The most common method is to use Tradable Green Certificates (TGCs)[96]. This involves requiring suppliers to source a percentage of their electricity from 'green' sources by presenting certificates to show that they have done this. Certificates are created when low carbon generators produce a MWh of electricity. This creates a market for TGCs, which trade at a positive price and provide an additional source of revenue for low carbon generators[97]. This exposes the generators to the real time electricity price and if the certificate market is competitive the price of certificates will reflect the lowest cost way of reaching the target percentage. Such schemes exist in many US states (e.g. New York). One issue with the scheme is when the target percentage is too ambitious and there is a shortage of certificates that leads to a penalty price binding. This has consistently happened in the UK with the result that the value of the certificates rises to the penalty price, which may be overly generous[98].

Procurement auctions allowing the acquisition of low carbon electricity have also been used in the UK and the US. These have been very successful in reducing the price paid for low carbon electricity. The UK had an auction to supply low carbon generation from renewables which saw the price paid for on-shore wind and solar PV fall dramatically relative to the previously published administratively determined prices (of the order of 20%). The auction was for a 15 year CfD[99]. The US has made of auctions, particularly for the procurement of small-scale renewables. A good example is the successive rounds of the Renewable Auction Mechanism (RAM) in California that has also seen significant reductions in auction prices for projects of 3-20 MW. These auctions are for fixed prices (not CfDs) but do have up to 50 non-payment hours per year, which means that the incumbent distribution company can curtail the generator off the system when it is not in the interests of the system to run the plant[100].

3.4.1.3 Chinese experience[101]

In China renewables and nuclear power are paid fixed prices per MWh, with the prices being determined at the provincial level in discussions between the NRDC and local government.[102] There is a national renewables target (which includes nuclear) for the percentage of overall generation that is to come from renewables by the end of the 13th 5-year plan period and there are targets for the amount of new nuclear power that the system wishes to add. There are provincial level non-hydro renewable electricity shares for 2020 (see Table 9).

Table 9:
Target share of non-hydro renewable energy in total electricity consumption in 2020

Province	Non-hydro renewable share	Province	Non-hydro renewable share
Beijing	10%	Hubei	7%
Tianjing	10%	Hunan	7%
Hebei	10%	Guangdong	7%

Shanxi	10%	Guangxi	5%
Inner Mongolia	13%	Hainan	10%
Liaoning	13%	Chongqin	5%
Jilin	13%	Sichuan	5%
Heilongjiang	13%	Guizhou	5%
Shanghai	5%	Yunnan	10%
Jiangsu	7%	Tibet	13%
Zhejiang	7%	Shaanxi	10%
Anhui	7%	Gansu	13%
Fujian	7%	Qinghai	10%
Jiangxi	5%	Ningxia	13%
Shandong	10%	Xinjiang	13%
Henan	7%	Total	9%

Source: NEA website.
Available at: http://zfxxgk.nea.gov.cn/auto87/201603/t20160303_2205.htm.

However, individual provinces may wish to add renewables and nuclear for GDP growth target reasons or because of local preferences for clean energy (usually driven by favourable weather conditions for renewables).

Renewables and nuclear power are not subject to either competitive procurement or direct exposure to wholesale prices. Indeed, renewables are often constrained off the system by grid constraints or the desire to meet the contractual running hours targets of large fossil fuel power plants. As noted above, this is because reducing the hours that renewable generation runs reduces system cost, given the subsidy. This suggests that renewable feed-in tariffs do not currently reflect society's willingness to pay for renewables (but lie above this).

Competitive procurement of renewables to set the price paid to renewables would seem to be desirable for two reasons. First, it removes the negotiated price element that seems to result in higher prices than society is actually willing to pay for renewables. Second, competitive procurement is a firmer contractual commitment, in that that improving grid access for renewables will directly reduce the prices in the procurement auction.

There is a need for experimentation with competitive procurement as this would be an unusual process for the government to use to achieve its objectives in an industry dominated by state owned enterprises. There are many companies in the generation sector and there is clearly a lot of opportunity for competitive bidding should the auctions be carefully designed to deliver a competitive outcome. Auctions over wider areas (several provinces) and across different technologies (wind and solar) will highlight the value of location and of different technologies in ways that the current technology and provincially differentiated tariffs do not. Currently none of the market pilot projects involve experimenting with the competitive procurement of renewables. There would seem to be clear opportunity for a pilot project in renewables procurement. The Chinese government has recently announced an intention to introduce a new tradeable green certificate scheme form July 2017[103].

According to Chinese official statistics, under collection of renewable levies has led to an accumulated deficit in the renewable payments fund that has, in turn, delayed payments to renewable generators. This payment deficit grew to 50 billion RMB in January 2017[104].

3.4.2 cost reflective access terms for renewables (12)

3.4.2.1 Theoretical significance

The location of renewables is a particular issue because while fossil fuel plants can be located close to load centres or where transmission capacity is readily available, renewables need to be located where the underlying resources are available. An electricity system with a high penetration of renewables is one where concentrations of loads and generators are often separated by great distances, and where small-scale renewables may be located across the network. Given that the cost of delivering power is a combination of its generation cost and its transportation cost, the pricing of the transportation element faced by generators is very important.

Locational signals on where to connect renewables into the electricity grid are complicated by the fact that renewables are currently subsidised. This means that locational signals may penalise the connection of renewables in places where generation conditions are very favourable (i.e. remote areas which are windy and/or sunny). This produces the counter intuitive result that we would be prepared to pay more for a MWh of wind or solar power generated where conditions are less favourable than where conditions are more favourable.

3.4.2.2 General reform experience

Many international jurisdictions have chosen to pay renewables the same per MWh regardless of location and not to expose them to differential connection charges that reflect the costs to the system of connecting them in particular locations. Indeed, most electricity systems simply socialise the costs of offering firm connection (100% guaranteed export capacity) to renewable generators, so that renewable generators only pay for their direct connection costs (the works to physically connect them to the existing grid or so called 'shallow' connection costs).

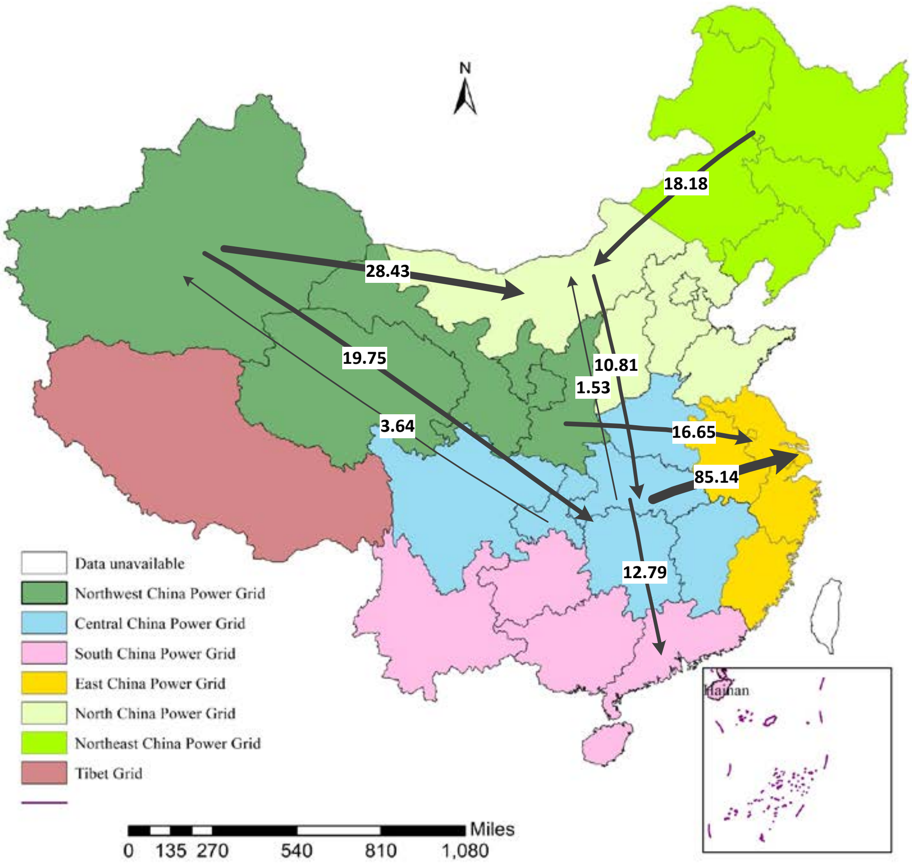
This is now beginning to change as renewables shares increase significantly in some jurisdictions. The RAM auctions in California rank projects after including the costs to the transmission system of absorbing a given project[105] (see Anaya and Pollitt, 2015). In the UK renewable generators do pay a share of the upgrade costs to the system of their connection (they have to pay to be connected at an unconstrained part of the network or bear the costs of upgrading the first substation to which they would be connected, so called shallowish connection costs). The Flexible Plug and Play project in the UK offered non-firm connection to generators in return for paying shallow connection charges and exposing them to the risk of interruption. For small renewables projects embedded in a distribution system built only to supply loads this resulted in significant total project cost savings[106] (Anaya and Pollitt, 2015).

Signalling where to connect and exposing renewables to the system cost of their connection to constrained parts of the network is in its infancy. Given the intermittent nature of renewables and the high fixed costs of renewables projects (which means that maximising MWhs supplied is important) and the high fixed costs of offering firm grid export capacity to renewables this would seem to be important.

3.4.2.3 Chinese experience

The Chinese power grid is already under significant stress even with relatively low penetration of intermittent (i.e. non-hydro) renewables (see Figure 15 shows major long distance power flows in 2013). The potential for long distance power flows is significantly increasing as the volume of renewables grows. Renewable resources are significantly located in the north and west, a long way from the demand centres in the east and south[107]. This suggests significant value in small scale renewables located close to loads.

Figure 15:
Map of major power flows in 2013 (TWh)



Source: Ming et al. (2016, p.576)

At the moment generators are not directly exposed to price signals that indicate the value of their connection to the network at particular locations. They are indirectly exposed to this via their exposure to curtailment. As this curtailment is arbitrary it is not clear that this properly signals the true value of connection at particular parts of the network[108].

Network costs are significant in China and have the potential to rise further. There is, currently, a desire to build out all the constraints in the electricity network and accommodate the projected generation capacity. However, this looks challenging in the face of sustained growth in demand and the increasing use of renewable generation (and indeed fossil generation) located further from loads. Offering efficient connection signals to renewables would seem to be as valuable, if not more valuable, than other countries given the scales involved.

This suggests that renewable generators should be exposed to some locational signals that indicate the value of their connection at particular locations. This could involve a combination of zonal payments for annual connection capacity to the transmission system for transmission connected generation (following zonal transmission charges in the UK)[109] and contributions to distribution system upgrade costs for distribution connected generation that wants higher guaranteed export capacity from the grid[110].

3.4.3 appropriate pricing of environmental externalities (both carbon dioxide and other atmospheric pollutants, such as sulphur dioxide) (13)

3.4.3.1 Theoretical significance

The production of electricity from fossil fuels is associated with significant environmental externalities. These include the production of nitrous oxides (NOX), sulphur dioxide and carbon dioxide, as well the production of particulates. Nitrous oxides and sulphur dioxide contribute to acid rain, carbon dioxide to global warming and particulates to dangerous local pollution inter alia.

Given the presence of different electricity generation technologies with different environmental characteristics it is important to price these external costs in such a way as to signal the relative value of clean production to society.

Environmental pollution taxes, permit schemes and legal liability for damage[111] can all be used to efficiently reflect external costs back on to the producers who create pollution. This raises the costs of fossil fuel based production relative to nuclear and renewables cost.

3.4.3.2 General reform experience

There have been very positive experiences with combining reformed wholesale markets with appropriate pricing of environmental externalities. This has led to big improvements in the quality of the environment and lower imposed system costs.

Three good examples are the US experience with a national sulphur dioxide permit scheme; the South Coast Air Quality Management District (SCAQMD) RECLAIM scheme for the pricing of nitrous oxides; and the EU pricing of carbon dioxide.

The US sulfur permit scheme started in 1994[112] by requiring all large coal fired power plants in the US to produce permits for each tonne of sulphur dioxide that they produced. This scheme successfully reduced SO2 produced from these plants by 60% by 2000 at very low cost by incentivising the introduction of new cheaper FGD equipment and by switching to low sulphur coal.

The RECLAIM scheme was established in 1994[113] and is a permit scheme for pricing nitrous oxides in Southern California (covering Los Angeles). This involves pricing nitrous oxides to reflect the atmospheric conditions over the area covered. This has been successful in managing the amount of local pollution in the area.

The EU introduced a permit scheme for carbon dioxide in 2005. This covers the power sector and a number of other energy intensive industrial sectors (and was recently extended to aviation). The power sector is around 60% of the current scheme. The scheme has resulted in supporting the switching between coal and gas fired electricity generation where this was necessary to stay within the permitted quantities of CO2 in the permit market (see Koenig, 2012).

3.4.3.3 Chinese experience

China has a significant problem with air pollution from power plants. In 2014 approximately 30%, 28% and 5% of SO2, NOX and particulate matter (PM) came from the power sector.[114] Small-scale coal fired power plants have been shut down and replaced with much more thermally efficient larger plant[115]. There has been a move towards installing FGDs on all new coal-fired power plants. It has thus far made very limited use of pricing to reduce this air pollution to socially optimal levels.

However there have been moves to improve the price based incentives towards cleaner production from fossil fuel power plants[116]. The NDRC does allow higher prices to plants with FGDs and 7 carbon market pilots have been introduced which each cover the power sector and work in a similar way to the EU ETS[117]. The pricing of carbon dioxide in the pilot projects is between $1-2 per tonne of CO2. This is well short of the $18.60 that might be required to facilitate switching from coal to gas fired power generation in 2015 (to switch new investment), let alone the price required to switch between a current gas and a current coal plan which would be more like $48.61.

There is some limited pricing of sulphur dioxide in some jurisdictions. Within Shanghai emissions of SOX and NOX are taxed at 4000 RMB/tonne.[118] Regulated generation prices include a premium for production of electricity from coal in the presence of an FGD unit.[119] However, this premium is simply provided for the FGD-equipped power plants without consideration of their pollutant emission reduction performance. Therefore, some power plants installed the low-cost, poor quality FGDs just to earn the benefits from price premium. Moreover, one study found that up to 40% of those generation units equipped with FGDs did not use them (see Chow and Perkins, 2014).

China has announced that it intends to introduce a national carbon dioxide permit market in 2017. This is a key part of its Intended Nationally Determined Contribution (INDC) submitted to COP-21[120]. This will cover the electricity sector and be a significant addition to the global effort on greenhouse gas emissions reduction. This can be gradually tightened to begin to encourage more efficient coal use and switching from coal to gas in the power sector.

A key recommendation would be the need for China to start using market-based mechanisms to price local air pollution, whose costs are both time and location dependent. A national SO2 market covered both the power sector and other industrial sectors would seem to be a good idea, while the idea of local air resources boards (following the experience of RECLAIM) to price local contributions to smog and particulates would also be very valuable.[121]

3.5 All good power market reforms (and indeed, significant economic reforms more generally) involve:

3.5.1 appropriate transition mechanisms (14).

3.5.1.1 Theoretical significance

Economic theory traditionally emphasises end-points and equilibrium outcomes in optimal policy design. It suggests that what is, simply, required is to redesign the whole system in a particular way and that this will deliver a set of desirable outcomes. The problem in power market reform is that the system is large, complex and somewhat unpredictable. Much can go wrong in the course of even the best-intentioned and implemented reforms. More importantly given that many reform elements cannot be costlessly implemented immediately, there will - for many years - be in a situation where not all of the elements for a theoretically robust power market reform will have been implemented. The system will be 'out of equilibrium' and will need to worry about whether such an 'out of equilibrium' situation is better than where it started from. Many economists have suggested that the sequencing of reforms is therefore very important [122] and that transitional arrangements, particularly to protect the key stakeholders that the society is interested in (such as poorer residential customers or small businesses).

3.5.1.2 General reform experience

Many electricity reform processes have not gone as society has expected them to. The Californian electricity reforms of 1996 proved disastrous, resulting in rolling blackouts by 2000-01. As we have already observed, this was partially a result of the combination of transitional arrangements (fixed retail prices and a restriction on the use of hedging contracts by incumbent retailers) and opportunistic behaviour by competing generators in the face of high demand.

Even in successful reform countries, such as the UK, there have been problems with market power in wholesale generation market in the 1990s (see Newbery, 2005) and a lack of competition in the retail market for inert retail customers since 2008 (see CMA, 2016).

Many countries, including the UK have made use of transitional arrangements. These have included offering default regulated tariffs even after the market has opened up to competition. The retail electricity market in Great Britain was fully liberalised from 1999, but incumbent retailers had price controls on their standard tariffs in place until 2002. In Northern lreland, the retail margin charged by the incumbent electricity retailer was still subject to regulation in 2016, in spite of being technically opened up to competition in 1999. This suggests that transitional arrangements can last for some time.

3.5.1.3 Chinese context

China is well experienced at transitional arrangements that restrict full competition and protect incumbent firms and existing customers[123]. Such arrangements are particularly important in economies where so many prices continue to be regulated and where a 'big bang' approach where all prices are simultaneously deregulated would produce significant economic dislocation.

Full wholesale market competition would significantly favour low cost producers of fossil fuels. While this is desirable in the long run it would result in immediate significant losses of output and revenue for certain generation plants and consequent reductions in coal demand from certain mines. Here transitional arrangements might include capacity payments for power plants to keep them open and maintain profitability[124].

Significant retail competition would also result in losses for the incumbent grid companies. This would be premised on them having set the levels of their network charges correctly to continue to allow their operations to be financed.

China is still some way from moving to full wholesale and retail competition. Even where market segments (e.g. large industrial users of electricity) are opened up to competition there is a case for some transitional arrangements (such as maximum prices) or restrictions on the ability of generators/retailers to cross-subsidise competition by increasing prices elsewhere. Transitional arrangements can be introduced selectively and where necessary. Good monitoring of the effects of the introduction of prices on the bills consumers pay and the profitability of state owned companies is necessary in order to assess whether transitional arrangements are adequate or necessary.

A key task of the reform process would seem to be reducing the volume of new investment going into the power sector. As we have already noted this was $120bn in 2015, at a time when demand growth was beginning to moderate. Reducing this level of investment will require the phased redeployment of the huge resources being put into to both new power station building and network asset expansion. Even if this amount could be reduced by only $10bn per year, this would potentially save around 2.5% of the industrial price of electricity[125].

China has instituted a significant number of pilot projects (see Table 10 below), but many of these do not test many of design principles of liberalised markets we have outlined in this paper. For example, experiments to test spot market for power in real time, competitive procurement for renewables and locational pricing signals for renewables are missing from the set of pilot projects. Indeed, it is not altogether clear what is really being tested in the pilot projects beyond the systems and ways of working in price based arrangements, since the principles of liberalisation are well established from global experience.

From Table 10, we are also interested in the role of local governments' energy agencies for advancing these pilot projects. The literature points out that local energy agencies in China do not have a wide range of decision-making power and policy space to launch their own pilot projects. Most of the current pilot projects are designed by the NDRC (though with participation from the provincial and local energy agencies). The central and local NDRCs supervise the provincial energy agencies to implement these local pilots. More freedom to initiate local pilot projects, for instance within the China Southern Grid provinces, with support from local governments and industry stakeholders would seem desirable.

Table 10: Electricity market pilot projects

Selected Local Pilots in China	Progress Summary
Shenzhen City	National Development and Reform Commission (NDRC) launched Shenzhen City's Transmission-Distribution Price reform pilot in November 2014. NDRC had a detail check on the transmission-distribution price, and after implementing this reform pilot, the level of transmission-distribution price even decreased, which also lowered the terminal power-sale price. During this reform period, a number of power-selling companies were set up and the commercial electricity price became lower in Shenzhen City. The industrial and commercial utilities both share the benefits of a lower power price.
Inner Mongolia	In June 2015, the Transmission –Distribution price reform pilot was approved in Inner Mongolia by NDRC. NDRC also reviewed the revenue of power transmission and distribution operations as well as the price in Inner Mongolia in September 2015. This review clarifies the transmission-distribution prices of different voltage levels and for different customers. Basically, this reform indicates that customers should pay different prices based on the voltage levels and the price should also include cross-subsidization. As a result, in this reform scheme the reduced price has mainly brought benefits to the large-scale industrial users.
Ningxia Hui Autonomous Region	NDRC completed its review on Ningxia's Scheme of Transmission-Distribution Price Reform Pilot in September 2015. Ningxia project is also the first pilot reform approved by the State Grid. Compared to other electricity reform schemes in Inner Mongolia and Shenzhen City, the Ningxia Scheme made a clear progress in setting up mechanisms for transmission-distribution price reform.
Yunnan Province	Yunnan Province is a pioneer in China's market-oriented electricity trading. In 2015, the Industry & Information Technology Commission in Yunnan and Yunnan provincial government established a "3134" trading mode, which covers "three main parts, one center, three markets, and four modes." Based on these market-oriented trading and transmission-distribution reform progresses, NDRC reviewed the Scheme of Transmission-Distribution Price Reform Pilot of Power Grid in Yunnan Province in October 2015, and Yunnan thus was approved as a comprehensive power trading pilot in November 2015.
Guizhou Province	In July 2015, the pilot scheme – Deepening Power Sector Reform - in Guizhou province was approved by Guizhou Government. It adopts a similar model with Shenzhen City for reforming the transmission-distribution price. There are four

	drivers for this reform pilot in Guizhou: (i) thermal power companies face difficulties because of the reduced utilization hours of power generation; (ii) Guizhou provinces has abundant coal resources; (iii) High electricity consumption local industries need lower price electricity supply, and (iv) Guizhou province had strong foundation for direct electricity trading.
Shanxi Province	The Shanxi' pilot was approved by Reform Commission NDRC and NEA in February 2016. It is the first reform pilot integrated within the network of State Grid. Three features of this pilot are: (i) The Shanxi Grid independently runs a trading centre and connects with other shareholders together; (ii) This pilot reform sets up a clear increments distribution standard and (iii) It has established a spot trading mechanism.
Chongqing	The pilot in Chongqing was approved by the General Office of NDRC and NEA's General Affairs Department in November 2015. In December 2015, three pilot selling companies were set up, which marked the beginning of Chongqing's pilot. In February 2016, twelve companies entered an agreement with one selling electricity corporation, which shows that the authority has put the pilot in practice and currently keeps refining it.
Guangdong Province	Similar to Chongqing, the selling side reform in Guangdong is however in a slower progress. In 2016, the authority established the basic rules of trading mechanism and enhanced the technical supporting system by simulation operations. The electricity trading will officially start in 2017.

Source: China5e Research Centre (2016, pp.34-61)

Xu (2017, p.170) emphasises the point that previous trials with market competition prior to March 2015 were not successful because of a lack of generation capacity in the trial, below cost retail prices, insufficient interconnection and a lack of experienced regulatory oversight. This highlights the importance of timing and adequate preparation for a sustained and successful reform process.

4 Conclusions

International Lessons and Policy Priorities for China

Successful reform in China is not about the success of its electricity companies as companies (consider the US and Germany), except in the sense that really efficient electricity companies support the rest of the economy by releasing labour to be more productive elsewhere and keeping the cost of power down. The entire utility privatisation programme in the UK between 1979 and 1997 released 2% of the entire workforce back to the rest of the economy and boosting economy wide productivity.

A key driver of the current reform is the high price of electricity for industrial customers relative to the US. We have identified four major savings within the power sector that would bring down prices for industrial customers. These are **reform of dispatch** (which might reduce coal use by up to 6% and allow industrial prices to fall by 1-2%); **increasing the efficiency of the grid companies** (which might reduce industrial prices by 2-3%); and **rebalancing charges away from industrial to residential customers** to better reflect underlying system costs (which might reduce industrial prices by up to 5%) and **reducing the high rate of investment in generation/networks** by $10bn per year could also reduce prices for industrial customers by of the order of 3%. None of the savings are easy to deliver because they have significant re-distributional implications. However, they have been achieved in many other countries, albeit over a period of up to 10 years. They suggest that the non-fuel cost gap - amounting to 12% of the current Chinese industrial electricity price - that we identified between China and the US can be eliminated.

If the gap with the US is to be further reduced, this would take a comprehensive reform of the coal sector (and of value added taxation in the electricity sector). Rationalisation of the coal sector might reduce costs to those in the US, and this would substantially close the remaining price gap. A combination of tax changes or cheaper sources of energy (e.g. shale gas) could further reduce the price differential.

China needs to view electricity market reform in the context of what it can do for the rest of the Chinese economy and resist vested interests within the sector that would seek to limit its rationalisation. A key part of this is the opportunity to simultaneously rationalise the coal production sector (which has 4.3m employees, slightly more than the whole electricity sector), by reducing coal demand and improving coal sector productivity. The decoupling of electricity policy from national procurement strategies for fossil fuel and nuclear technologies was a key driver of cost reduction towards new investment in Europe and the US. An additional impetus to reduce Chinese dependence on coal for power production might be the rapid recent decline in the reserves to production ratio for Chinese coal.

Comprehensive power market reform based on the creation of competitive wholesale and retail markets and separately regulated network businesses is once again being pushed forward in China (following the publication in March 2015 of the No.9 Document), building on the 2002 reform (which separated the grid from generation) but subsequently stalled. The primary objective is to lower prices for industrial customers, with the additional objectives of reducing wind curtailment and reducing overinvestment in new dirty coal fired power plants. The likely extent of power market reform remains linked to reduction in coal use. Unless there is a willingness to rationalise and reduce coal use in China at the individual plant/mine level then power market reform will make limited progress on the ground.

China has devolved a lot of energy investment decisions to the provinces. This has favoured provincial coal mines and encouraged the pursuit of energy independence among the provinces. This is because coal production and coal generation contribute to provincial GDP targets, and local coal mines and coal generation contributes to provincial tax revenue. This undermines a regional/national market emerging to the extent that is fully beneficial to the national economy. Clearly the central government has to strongly regulate interprovincial electricity trade and encourage its development.

While much of the reform process emphasises a move to market trading of electricity, power plants are still not being dispatched in merit order in real time. The government needs to prioritise reform of dispatch (with its implications for coal use and the value of existing generation assets) if a genuine wholesale market is to emerge which drives operational costs down and incentivises significant efficiency gains from making better use of the existing power generation fleet.

The government's current capacity to regulate a competitive power sector is limited. There is a shortage of well-qualified/well-trained staff (accountants, economists and lawyers), who can administer and regulate the institutions of the market, partly due to low public sector salaries (relative to SOE salaries). There continues to be a need to reduce the power of the State Grid Corporation in setting/frustrating policy in favour of well-resourced and independent (of the industry) civil servants. This could be achieved by transferring some of the research functions of State Grid to the central government, and treating State Grid as an interested party with its own internal financial incentives (like generators) in policy discussions.

More encouragingly, the latest round of reforms (embodied in the Number 9 document) have laudable intentions but also are proceeding rather carefully given the complicated and interconnected nature of unwinding the current regulatory arrangements surrounding the power sector. A number of pilot projects introducing wholesale forward markets for industrial power are underway and the government is, rightly, proceeding cautiously towards comprehensive market reform. There has been real progress in separating out generation/retail from the network businesses and provincial prices for network access (based on assessments of the regulatory asset and operating cost base) are now published. 900 companies retail have been registered by the end 2016, but none were actually operational marketing electricity. The preconditions for incentive regulation of the network business of State Grid and Southern China Grid are now in place.

Now is a good moment to push forward with reform. Final prices are high (for industry and this is a major driver of reform because of low US industrial energy prices). The electricity industry is profitable relative to underlying costs (which have fallen in line with commodity price falls). The pilot wholesale markets are showing price reductions for industrial customers. There is also environmental pressure to end wind curtailment (which is very high) and mostly due to the hours based contracts held by coal fired power plants. The moment may of course pass if commodity prices start rising.

Suggestions for future research

We have identified five sources of lower power prices for industrial users. These are all worthy of several multifaceted studies.

1. ***The size of the dispatch savings.*** This requires careful modelling of constraints and of the distributional implications for individual companies and consideration of what compensation is necessary;
2. ***Modelling of the impacts of reallocating charges*** from industrial to residential customers over a 10-year period, during which incomes and household consumption continue to grow strongly;
3. ***Efficiency modelling of the scope for cost reduction in the grid companies*** and exposure to incentive regulation. There is a surprising lack of papers on the efficiency of the different business units of the grid companies;
4. ***Modelling of the financial impact on electricity customers of over-investment*** in generation and consideration of how new investment in fossil fuel generation (to the extent that it is required) can be reduced;
5. ***Further work on the scope for rationalising the fuel input sector in China*** and how China can get access to cheaper coal and gas. This might draw parallels from historical heavy industry rationalisation processes in Europe, Korea and Japan.

In addition, we would note the following:

There needs to be investigation of the design and lessons from the market pilot projects. The current pilot projects need to demonstrate that they are supporting the underlying rationalisation of the sector that is required to bring its costs down and improve its environmental performance. There might be a need for additional pilots to trial different aspects of reform (such as price bid led dispatch).

The calculation of network tariffs needs to be carefully analysed. This benefits from independent study because the regulator is initially in a weak information position relative to the regulated companies. The scope for network tariffs to be calculated wrongly / incentives to be miss-calibrated is quite high.

China has taken a number of significant reform steps since 1985. ***It is, perhaps, surprising that there has not been more careful analysis of the impact of the different reform steps.*** For instance: how have publicly owned generators performed against privately owned ones, or whether different state investment vehicles have a better record of managing their assets efficiently. In particular, it would also be good to look at the impact of the 2002 reorganisation of generation and distribution on efficiency.

China needs to benchmark its performance with those of other countries. This is particularly valuable in the initial stages of reform, when it is difficult to get meaningful internal benchmarks. It would be good to see more comparative analysis of the costs of generation and networks between other countries and China.

China's power market reform still needs to address its air pollution problem. While rationalisation of the power sector will reduce pollution, a low carbon transition is still required and this will necessitate close attention to how renewable and nuclear procurement can be made more competitive.

There should be more attention to comparative research between sectors within China, it would be good to consider whether successful liberalisation and economic regulation of other sectors might inform electricity reform in China. Regulation and liberalisation are transferable skills between sectors and there may be things to learn from, for instance, the IT sector in China.

There needs to be a ***new institutional economic analysis of how to design a successful regulator*** in China (drawing on lessons from other countries and sectors) by considering the incentives within the civil service to effectively regulate large monopoly companies, in a way that ensures a reasonable degree of independence from arbitrary central and provincial government interference.

The question of how best to make use of the ability for different regions to move at different speeds should be carefully considered (e.g. reforming residential pricing in richer provinces first). Research that is specific to the reform circumstances of particular provinces would be valuable.

Finally, given the large degree of misunderstanding (globally) of the macro-benefits of lower power prices and the release of labour from the power and coal system, ***it would be good to see some general equilibrium modelling of the benefits to the Chinese economy of power market reform***.

Appendix A: Calculation process of the switching carbon prices from coal to gas fired power plant investment in 2015

NO.	Steps	Coal	Gas	Source
1	LCOE (discount rate 7%)(USD/MWh)	77.72	92.79	IEA (2015, P.98)
1	LCOE (discount rate 7%)(USD/KWh)	0.07772	0.09279	
1	LCOE difference (USD/KWh) (Coal -gas)	-0.01507(0.07772-0.09279)		
2	fuel consumption	442.216(g/KWh)	0.19125 (Nm3/KWh)	Zhang et al.(2012, P.232)
2	Emission coefficient(Coal)	2.78124 kg CO2/ kg Coal		Zhang et al.(2012, P.233)
2	Emission coefficient(Gas)	2.19362 kg CO2/ Nm3		Zhang et al.(2012, P.233)
2	CO2 emission(kg CO2/KWh)	1.230 (442.216*2.78124/1000)	0.420 (0.19125*2.19362)	
2	CO2 emission(ton CO2/KWh)	0.00123	0.000420	
2	CO2 emission difference (kgCO2/KWh)(Coal -gas)	0.000810(0.001230-0.000420)		
3	Switch Price from coal to gas (USD/ ton)	18.60 (0.01507/0.000810)		

Appendix B: Calculation process of the switching carbon prices from coal to gas fired power generation in 2015

	Industrial Electricity Price (US $/KWh) In 2014	*Coal price (US $/KWh) in 2014*	*Gas price (US $/KWh) in 2014*	*Switching price $ / tonne CO2*
US	0.0710	0.0241	0.0159	6.98
China	0.1068	0.0384	0.0778	48.61

China

	Coal	Gas
Heat rate	(g/KWh)	(Nm3/KWh)
	442.216	0.19125
Price	yuan/ton	yuan/m3
	534	2.5
carbon emissions	kg CO2/ kg Coal	kg CO2/ Nm3
	2.78124	2.19362
Power generation cost difference （yuan/KWh）	-0.241981656	
carbon emissions difference (ton/KWh)	0.000810379	
Switching CO2 price ($/ton)	48.61	

US

	Coal	Gas
Heat rate	(g/KWh)	(Nm3/KWh)
	442.216	0.19125
Price	$/ton	$/m3
	54.5	0.1555995
carbon emissions	kg CO2/ kg Coal	kg CO2/ Nm3
	2.78124	2.19362
Power generation cost difference （$/KWh）	-0.005657632	
carbon emissions difference (ton/KWh)	0.000810379	
Switching CO2 price ($/ton)	6.98	

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[1] Michael Pollitt and Chung-Han Yang travelled to Beijing for a week of meetings with electricity industry stakeholders in Beijing and Yunnan. The objective of the trip was to ask research questions around the research proposal (attached) on evaluating Chinese power market reform in the light of 14 reform elements identified in the previous literature from a theoretical and empirical perspective. We are very grateful to Christian Romig, Head of Renewable Energy at the British Embassy in Beijing, who facilitated our meetings, and to all of the many individuals and organisations who took the trouble to meet us. These meetings and follow-up discussions have greatly informed this paper. However, all the views expressed in this paper are those of the authors alone and do not represent the views of either the British Embassy in Beijing or any other organisation with whom we are associated. We acknowledge the financial support of the ESRC Global Challenges Research Fund and the In Search of 'Good' Energy Policy Grand Challenge Project. The comments of David Newbery and Lewis Dale are gratefully acknowledged, as are those of an anonymous referee. All the views expressed in this paper are the views of the authors and should not be taken to represent the views of any individual or organisation with which they are associated.

[2] International Energy Agency (2014). China PRC: Electricity and Heat for 2014, Retrieved from https://www.iea.org/statistics/statisticssearch/report/?country=China&product=electricityandheat

[3] The data are from China Energy Statistics from NBS (2015). Moreover, China's coal is depleting fast although its reserves may seem to be high. The reserves-to-production ratio has reduced to 35 years due to the rapid increase coal production in the past 30 years, while the comparable number is 250 years in North America, nearly 500 years in Russia, and 100 years in India. In addition, the heavy burden of coal transportation (from mines to power plants) also poses challenges for the railway transportation system in China. The share of coal transportation in total rail transportation increased from 41.4 percent in 2000 to 50.6 percent in 2011, while the distance it travelled from mines to power plants increased from 548 km in 1990 to 642 km in 2010. See Xu (2017, p.30, p.32).

[4] If we assume electricity sector emissions of 3500m tonnes from the power sector, and global emissions of 49000m tonnes. Actual figures are not published and may be higher. Global CO2e figures are published periodically and electricity and heat figures for emissions are often combined for China. Thus we can find the world's total CO2 (only) emissions in 2014 is 33472.0 Mt (BP, 2016), and while China's Electricity and heat generation emitted 4384 Mt in 2014 (IEA, 2016).
[5] See National Development and Reform Commission (NDRC) PRC China (2016) An Overview of 13 the Five Year Plan, Retrieved from http://en.ndrc.gov.cn/policyrelease/201612/t20161207_829924.html and NDRC (2016) 'How China's 13th Five Year Plan Climate and Energy Targets Accelerate its Transition to Clean Energy'. Retrieved from https://www.nrdc.org/experts/alvin-lin/how-chinas-13th-five-year-plan-climate-and-energy-targets-accelerate-its. For commentaries on the current five year plan, please see Ma (2016). China's 5 Year Plan for Energy, *The Diplomat.* Retrieved from http://thediplomat.com/2016/08/chinas-5-year-plan-for-energy/
[6] See BP's the Statistical Review of World Energy 2016, Available at: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html
[7] See BP's the Statistical Review of World Energy 2016, Available at: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html
[8] Points 1-10 and 14 below are from Joskow (2008).
[9] Points 11-13 below are from Pollitt and Anaya (2016).
[10] Newbery (2016a) and Ellerman et al. (2016).
[11] See China State Council (2015.
[12] See Pollitt and Anaya (2016).
[13] This followed the publication of State Council 'power system reform program' (the No.5 Document) in December 2002. Source: China5e Research Centre (2016).(Source:中国能源网研究中心, 中国电改试点进展政策研究与建议).

[14] See Xu (2017, pp.157, 258 and 303).
[15] See Lin, K. C. (2008) and Lin, K. C. (2014).
[16] For more details on the substance of the 2002 transition see Wang & Chen (2012).
[17] See Yu (2014).
[18] See Bessant-Jones (2006) discussion of the success of wholesale electricity market in Guatemala with a total capacity of 1.875 GW in 2002.
[19] See Rahimi, A. F., & Sheffrin, A. Y. (2003) and Sheffrin, A. (2002).
[20] See Jamasb and Pollitt (2007) and Pollitt (2008b).
[21] See Joskow (2003).
[22] See Pollitt (2005).
[23] See Bergman et al. (1998, pp.158-162).
[24] See Newbery (2005).
[25] See Sweeney (2002).
[26] See Sweeney (2002).
[27] For instance in Great Britain, generators license conditions include such a clause.
[28] See Cunningham (2015).
[29] See also: Kahrl et al. (2016) and Kahrl et al. (2013).
[30] Source: China Electricity Council.
[31] Global trends in transmission system operation arrangements are discussed in Chawla and Pollitt (2013).
[32] See the discussion of the experience of New Zealand with ownership unbundling of distribution in Nillesen and Pollitt (2011).
[33] Construction costs for coal fired generators reportedly fell from 8000 Yuan/kW to 4000 Yuan/kW indicating that even if the price of power was regulated the separate generators had the incentive to cut their supply chain costs.
[34] For a discussion of the Yunnan pilot, see Feng (2016).
[35] See O'Donnell (2003).
[36] See Mansur and White (2012).
[37] See Newbery (2016a).
[38] See Pollitt (2008b).
[39] See Pollitt (2012).
[40] See Sioshansi et al. (2006).
[41] See Zhang et al. (2015).
[42] Electricity trading among different provinces will affect the electricity generation from local power companies, thus affecting the provincial GDP. Therefore, this political economy between central

government and local government is a barrier for the wider area for electricity trading. See Xu (2017, p.141, p.176-179).
[43] See Kahrl, F., and Wang, X. (2014).
[44] See Pingkuo and Zhongfu (2016).
[45] China' Renewable Energy Law (2010) sets general principles on renewable energy development. Regarding the regulatory incentives for renewables dispatch, please see Chapter 4, especially Article 14 to 18. Also the NDRC issued notices on Feed-in Tariff for polar energy (2011), geothermal power (2013) and wind power (2014).
[46] Ibid 34.
[47] A 6% saving of total coal use as a result of fuller utilization of more efficient coal fired power plants would reduce CO2 emissions by roughly 248m tonnes (or 0.5% of global CO2e). This is because coal consumption in the power and heat sector in 2014 was 1485m tonnes in 2014 (IEA (2016) Coal Information, Paris: OECD)) and 2.78 tonnes of CO2 are produced when 1 tonne of coal is burnt (i.e. 0.06*1485*2.78=248).
[48] 6% of 1485m tonnes of coal at 534 RMB/tonne divided by $402bn of industrial electricity expenditure (2014 figures).
[49] For a good general discussion of privatization see Newbery (2002).
[50] Contrast the initial negative assessment of Bishop et al. (1994) with an assessment of the impact of the privatization in Florio (2004).
[51] For the UK: Domah and Pollitt (2001); from Brazil: Mota (2003); from Chile: Pollitt (2005); from Peru: Anaya (2010); and from Argentina: Pollitt (2008a).
[52] See Zhang and Heller (2007) and CNESA (2015).
[53] The subsidiaries of the 'Big five' are not included in the others in this graph, and the others include the private companies, international companies and other state-owned companies except the 'Big five'.
[54] See Pollitt (2005).
[55] For a fascinating account of how this played out in the CEGB from 1962 to 1989 see Kim (2016).
[56] See http://news.bbc.co.uk/1/hi/business/7401722.stm
[57] See Newbery et al. (2016) for a discussion of the possible increase in importance of 'flexibility' markets within the electricity system to 2030 in Great Britain.
[58] See Pollitt and Anaya (2016) for a discussion of recent market developments in Germany, Great Britain and New York.
[59] See Ming et al. (2014).
[60] See Zheng and Zhou (2003), Ming et al. (2014), Yao et al. (2015) and Mingtao et al. (2015).
[61] See Taylor et al. (2014).
[62] See NDRC (2010), Crossley, (2014) See also Zhang et al. (2017) and Wang et al. (2010).
[63] The data of Jiangsu province are from http://www.sdpc.gov.cn/fzgggz/jjyx/dzxqcgl/201607/t20160727_812571.html
[64] See Hogan (1992).
[65] See Bohn et al. (1984).
[66] This is the case in Great Britain, for instance, where there is a substantial difference in transmission charges for loads in Scotland (lower) and in London (higher) due to transmission constraints between generation centres in the north and load centres in the south.
[67] See Pollitt (2005).
[68] Chao and Peck (1996).
[69] See Archer et al. (2017). See also Zhou et al. (2016).
[70] See Bergman et al. (1998).
[71] See Zheng et al. (2016).
[72] See National Development and Reform Commission, Available at http://www.sdpc.gov.cn/zcfb/zcfbtz/201607/t20160706_810665.html and http://www.chinasmartgrid.com.cn/news/20160909/618793.shtml

[73] See Jamasb and Pollitt (2007).
[74] See Li et al. (2016).
[75] See Zheng et al. (2016).
[76] See Jamasb and Pollitt (2007) on the UK.
[77] For a discussion of this in the context of Ohio, see Littlechild (2008).
[78] See ACER (2014).
[79] See IEA (2016) Energy Policies of IEA Countries – Italy, Available at https://www.iea.org/publications/freepublications/publication/EnergiePoliciesofIEACountriesItaly2016Review.pdf
[80] See Littlechild (2008).
[81] See Ma (2011).
[82] See Feng (2016).

[83] US residential prices in 2014 were $0.125 / kWh, in China they were $0.0907 / kWh. Raising Chinese prices by 38% would raise an additional $14.65 bn of revenue (assuming a demand elasticity of 0.3 (He et al., 2011) and initial sales of 718 TWh). This would (roughly) allow for around a 5% drop in the industrial price of $0.10675 / kWh, assuming an elasticity of 0.18 (He et al., 2011) for industrial demand (This can be roughly calculated by adding three effects: the initial additional residential revenue equals 3.6% of initial industrial revenue + industrial demand response from the price drop (a further 0.7% or 0.18 * 3.6%) + system savings due to reduced residential demand (0.5% of total system costs due to aggregate demand falls if industrial prices fall 5% and residential prices rise 38% and the marginal system saving is the coal cost of $0.038/kWh).

[84] See Xu (2017, p.117).

[85] See Bessant-Jones (2006) for a World Bank view on independent regulation and power market reform; and Jamasb and Pollitt (2007) and Pollitt (2008b) on independent regulation within the EU electricity directives.

[86] See An et al. (2015).

[87] See Xu (2017, P.83, P.122,P.126).

[88] See Yeo (2008).

[89] See China National Energy Agency (2016) and China National Energy Agency (2015)

[90] See Slaughter and May (2016).

[91] In the UK, arguably the competition authority has been more significant in advancing competition in the wholesale electricity market than the regulator (see Newbery, 2002).

[92] 43% of the 2015 employees (870,000) could be released from the sector at $10,000 per employee. Industrial demand is 3770 TWh, paying $0.1068 per kWh. The average wage in China was 62029 RMB or $8965 (6.92 RMB to the $). Industrial price elasticity is assumed to be 0.018.

[93] For example, State Grid reportedly had 1.5 million employees in total in 2005, of which 72 percent were in the electricity business (generation, transmission, and retailing), 21.6 percent were in construction and 2 percent were in research and design (see Xu, 2017, p.142).

[94] See http://zfxxgk.nea.gov.cn/auto92/201606/t20160614_2264.htm.

[95] See Grubb et al. (2008) and Twomey and Neuhoff (2008).

[96] See Currier (2013).

[97] See Ciarreta, A., Espinosa, M. P., & Pizarro-Irizar, C. (2014).

[98] See Pollitt, M. G. (2012). Lessons from the history of independent system operators in the energy sector. Energy Policy, 47, 32-48.

[99] See DECC (2015)

[100] Anaya, K.L. and Pollitt, M.G. (2015)

[101] See Liu et al. (2013); Kahrl et al. (2011a) (2011b) and Chen et al. (2010).

[102] The national benchmark prices for onshore wind and solar PV are reasonably generous at 0.60 RMB/kWh and 0.98 RMB/kWh in 2016.

[103] 'China to launch green certificates for renewable power in July' Retrieved from http://www.reuters.com/article/us-china-economy-renewables-idUSKBN15I0AK

[104] Please refer to http://www.jyjch.com/xzlw/2017/0119/4746.html

[105] See Anaya and Pollitt (2015).

[106] See n. 96

[107] See Hove and Mo(2016). See also Guo Q (2014). "国家能源局召开风电产业监测沟通会," China National Renewable Energy Centre, February 25, 2014, Retrieved from http://www.cnrec.org.cn/hd/2014-02-25-412.html.

[108] See Zhang et al. (2015) and Zhang and Li (2012).

[109] See Pollitt and Bialek (2007).

[110] See Pollitt and Anaya (2016).

[111] See Viscussi et al. (2005) for a good introduction.

[112] See Ellerman (2003).

[113] See Fowlie et al. (2011) available at: http://nature.berkeley.edu/~fowlie/fowlie_holland_mansur_reclaim.pdf

[114] Source: China Electricity Council and National Bureau of Statistics.

[115] See Wei et al. (2011) and Dupuy et al. (2015).

[116] See China National Energy Agency (2012)

[117] See Zheng, X. (2016). See also Yu et al. (2014).

[118] See Yuan et al. (2016).

[119] The national premium level for production of electricity from coal with FGD is 0.0015 RMB/KWh during the period from July 1st, 2007 to May 1st, 2014. In the latest policy, the government gives a premium of 0.001RMB/KWh (connected to network before June 1st, 2016) and 0.0005 RMB/KWh (connected to network before June 1st, 2016) to coal-fired power plants. Sources: http://www.nea.gov.cn/2014-04/04/c_133235649.htm;

http://www.hebwj.gov.cn/News.aspx?sole=20160104163510593;
http://www.cec.org.cn/xinwenpingxi/2011-08-25/65025.htmlhttp://www.cec.org.cn/xinwenpingxi/2011-08-25/65025.html; http://www.sdpc.gov.cn/fzgggz/jggl/zcfg/201404/t20140403_615508.htm

[120] Available at: http://newsroom.unfccc.int/unfccc-newsroom/china-submits-its-climate-action-plan-ahead-of-2015-paris-agreement/ See also Jackson et al. (2015) and Sha et al. (2015).
[121] See Chen et al. (2016).
[122] See Aghion et al. (1994).
[123] See Mathews and Tan (2013) and Kahrl et al. (2011a) (2011b).
[124] See Menezes and Zheng (2016). See also China National Development and Reform Commission and National Energy Agency (2015)
[125] $10bn out of industrial electricity revenue of $402bn in 2014.