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# Explaining the role of incumbent utilities in sustainable energy transitions: A case study of the smart grid development in China

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**Abstract**

Smart grids (SGs), though widely recognized as an enabling technology for delivering more sustainable energy futures, have yet to achieve significant deployment across the world. The nature of the key agents of change in sustainable energy transitions has remained under-studied. This paper critically examines and explains the role of incumbent utilities in facilitating or impeding sustainable energy transitions, with particular reference to a case study of SG developments in China. We have three major findings. First, China has developed an incumbent-led model for developing SGs in which the two major state-owned grid companies have played a central role. Second, these two grid companies act as strategic first-movers and were the infrastructure builders of SGs by mobilizing massive investment in grid enhancement and smart meter installations. They also demonstrate incumbent advantages in terms of financial strength, innovation capacity, and strategic networks. Third, they also appear to act as a fundamental block to the structural changes in the socio-technical regimes that are required to realize higher-order SG benefits. Incumbents' disincentives, inertia, excessive reliance on incumbents to provide public goods, and a lack of expertise in developing new energy products and services have resulted in major weaknesses in China's incumbent-led model.

**Keywords**

Smart grid, incumbent utilities, governance, socio-technical regimes, distributed energy sources, China

**Abbreviations**

| | |
|---|---|
| **CEC** | China Electricity Council (中国电力企业联合会) |
| **CSG** | China Southern Power Grid Co. Ltd. (中国南方电网) |
| **DE** | Distributed energy |
| **DPV** | Distributed photovoltaic |
| **NDRC** | National Development and Reform Commission(国家发展和改革委员会) |
| **NEA** | National Energy Administration(国家能源局) |
| **SERC** | State Electricity Regulatory Commission(国家电力监管委员会) |
| **SGs** | Smart grids |
| **SGCC** | State Grid Corporation of China (国家电网) |

## 1. Introduction

SGs, which are advanced technologies based on the intensive use of IT and communication technologies over the entire generation, transmission and distribution systems of the electricity sector, are in general recognized as an enabling technology for achieving sustainable energy transitions (Liu, 2013; Mamo *et al.*, 2009). SGs have the potential to support a broad range of advanced energy technologies in both the supply-side (e.g. large scale integration of renewable energy and distributed energy sources) and demand-side of energy management (e.g. demand responses) (IEA, 2011). Although SGs may be defined and deployed in various ways in different contexts, they have been increasingly developed worldwide since the mid-2000s, more notably in the US, the UK, Italy, Japan, and South Korea (Energy and Climate Change Committee, 2015; Executive Office, 2011; Mah *et al.*, 2012; Mah *et al.*, 2013).

China is a late-comer in the context of SG developments. A three-stage SG plan announced by the state-owned State Grid Corporation of China (SGCC) in 2009 is widely regarded as a key milestone that marked the beginning of SG developments in China. When compared with SG developments elsewhere, China's approach is significant and atypical in several ways. As a late-comer, China has the potential to leapfrog the deployment process for SGs. In 2010, China already surpassed the US in total SG expenditures, with costs of the nationwide grid upgrade projects estimated to be US$100 billion through 2020 (EIA/SAIC, 2011). Second, China's SG initiatives have largely focused on high-voltage transmission networks (Liu, 2013), and this focus has set it apart from its counterparts. The US approach has focused on energy system resilience and reliability (Connor *et al.*, 2014) while South Korea's is export-oriented with the establishment of the iconic large-scale demonstration project on Jeju Island, and the Japanese model is business-driven and community-based (Mah *et al.*, 2013).

Another notable feature of China's SG developments is the prominence of the two large state-owned monopolized grid operators: the State Grid Corporation of China (SGCC) and China Southern Power Grid Co. Ltd. (CSG). These two grid operators, which account for 88 percent and 17 percent of national power consumption respectively (Brunekreeft *et al.*, 2015), are the driving forces and first movers in this industry primarily by mobilizing massive investment in grid enhancement and smart meter installations (Zpryme, 2011).

Given the key role of the two state-owned grid companies in SG deployment in China, this paper aims to examine the role of incumbent utilities from the perspective of governance for sustainable energy transitions. We investigate the extent to which, how and why, these two incumbent utilities have facilitated or impeded SG deployment in China.

This paper is a qualitative case study of China's SG developments. Our findings are derived from desktop research, semi-structured face-to-face interviews, and field visits. 18 interviewees were interviewed in 11 interview meetings which took place in Beijing, Tianjin, and Guangdong between 2014 and 2016. The interviewees were carefully selected informants and stakeholders who occupied roles, positions, or status in organisations, social networks, or communities of the political system and were therefore knowledgeable about the issues studied (Johnson, 1990). They included (1) a senior government official and senior researchers from the National Development and Reform Commission (NDRC), (2) senior researchers from various research institutes of NDRC and the two grid companies, (3) academics, (4) consultants, and (5) a manager of a solar system developer.

All the interviews were audio-recorded and transcribed. Some follow-up email correspondence and telephone calls were made to request supplementary information and updated data. Not all interviews were not cited, but those not cited are still useful for this study as they provide important contextual information. As some interviewees agreed to be interviewed only anonymously, this study indicates interviewees by number. The first two letters indicate the location (BJ for Beijing, TJ for Tianjin, and GD for Guangdong), the two digits indicate the interview numbers, and this is followed by the year of the interviews. The list of interviews is provided in the appendix.

This paper is organized into six sections. The section develops an integrated framework that focuses on the linkages between the concepts of socio-technical regimes, agents of changes, and the incumbent-challenger relationships. This framework is then used to guide our analysis of the case study of China. The discussion then moves on to examine the characteristics of SG developments in China. This is followed by a review of the features of China's incumbent-led approach to developing SGs, and identifies the major roles of the two grid operators. We also critically examine and assess the achievements as well as the limits of the role of these grid operators. We then critically analyse their roles as facilitators of and/or barriers to SG deployment. The final section of the paper offers some concluding thoughts and policy recommendations.

## 2. The role of incumbents in SG deployment: A theoretical discussion and a conceptual framework

SGs have been commonly regarded as an enabling technology for realizing sustainable energy transitions but major challenges exist in such transitional processes. A scanning of the literature in the fields of sustainable energy transitions and governance suggest that there are three strands of research that are instructive in providing a better understanding of the nature of these challenges: socio-technical regimes, agents of change and incumbent-challenger relationships.

The notion of socio-technical regimes proposed by Geels (2005) uses the concepts of regimes and path-dependency to explain how and why it is difficult to achieve a transition toward more sustainable energy futures. Geels argues that path-dependency or the "lock-in" effect of established energy technology has been re-inforced in energy systems by their own ideas, culture, user practices and technical competence that have developed over time (Sovacool, 2009; Szatow *et al.*, 2012). Fundamental regime changes that threaten the vested interests of incumbents are therefore difficult to achieve over the short terms (Geels, 2005; Szatow *et al.*, 2012).

The literature suggests however that energy systems which are more accommodating to SG developments would require major structural systemic changes (or regime changes) in order to realize the potential benefits offered by these new energy options (Agrell *et al.*, 2013; Erlinghagen and Markard, 2012; Markard and Truffer, 2006). Important SG applications, including high penetration of distributed energy (DE) generation and extensive use of demand response programmes are examples. Such applications require more fragmented and decentralized energy markets in which incumbent utilities in centralized, vertically integrated systems would have to manage different types of DE resources (Mah *et al.*, 2012). Incumbents are also required to manage new utility-consumer relationships as consumers can both produce and consume electricity and proactively take part in demand response programmes (ten Heuvelhof and Weijnen, 2013).

Another theme in the literature on energy transitions sheds important light on a key question: who would be the key change agents of such regime changes? While there is a growing body of the literature exploring the variety of approaches for such transitions, two types of actors are distinguished in the literature on socio-technical transitions. These are incumbents and new entrants (Erlinghagen and Markard, 2012). This distinction centers on a debate around a basic question: Could major breakthroughs to socio-technical regime shifts come from incumbents or do these have to come from new market participants?

The literature presents a mixed picture of such incumbent-challengers relationships. Incumbents are established firms, or regime actors, of the focal sector. Electric utilities, which generate, transmit, or distribute electricity and recover the costs through a regulatory framework have the tendency to become incumbents because utilities, particularly grid/network operators, are a natural monopoly (DOE, 2008; Governor of NYS, 2014). These incumbents themselves have a strong culture, including their beliefs and dominant logic (Chesbrough and Rosenbloom, 2002), and are highly intertwined with the core technologies, business models and user-practices of the regime (Erlinghagen and Markard, 2012).

New entrants are actors that have entered the sector concerned (Erlinghagen and Markard, 2012) and are generally smaller, and more innovative (Mitchell and Woodman, 2010). Often they are recently founded, being associated with a niche which may challenge established socio-technical regimes of energy systems. Energy services companies (Liu *et al.*, 2013), the ICT sector (such as mobile and fixed carrier businesses) (Erlinghagen and Markard, 2012), property developers (Szatow *et al.*, 2012), and even social housing corporations (e.g. in the Netherlands) (IEA-RETD, 2013), are some of the examples of new entrants which have emerged in the transitions towards more sustainable energy futures.

There is a relatively extensive literature which sheds light on the centrality of incumbent utilities in not only effective implementation of low carbon mechanisms, but also in becoming prime movers to push innovation (Markard and Truffer, 2006; Martinot and McDoom, 2000). In the UK, studies have found that major companies are a key to the effectiveness of the UK renewable obligation (Martinot and McDoom, 2000). In France, the state-owned Électricité de France (EDF) has been the driving force for SG initiatives (Mamo, 2010). Incumbent utilities can play a strategic role in SG developments, notably by acting as distribution network operators, or smart integrators/ orchestrators who manage distributed energy sources (Governor of NYS, 2014; Lehr, 2013).

Unlike private entities which are generally profit-maximizers, state-owned/controlled utilities may be motivated by strategic considerations rather than short-term economic benefits to support energy innovation experimentation (Radcliffe *et al.*, 2014). Incumbent utilities also exhibit unique advantages, or structural advantages, over challengers, which explains why they capture first-mover advantages in developing new energy options, including SGs. These advantages include access to resources (Markard and Truffer, 2006), the establishment of strategic alliances, resilience to regulatory and market risks (Radcliffe *et al.*, 2014), pre-existing competencies in infrastructural planning, asset management and operation (Curtis and Khare, 2004), and customer loyalty (Curtis and Khare, 2004).

The literature, however, also cautions against a possibly over-optimistic view on the role of incumbent utilities. Lehr (2013), for example, argues that incumbent utilities is the last place where innovation can be expected to occur (Lehr, 2013). Utilities, particularly those that are monopolies and state-protected, have reduced monopoly power as SGs develop (ten Heuvelhof and Weijnen, 2013). They lack incentives to innovate, minimize costs, or to take risks while having strong incentives to prevent market entry by competitors (Lehr, 2013; Martinot and McDoom, 2000). The dominance of incumbent business interests in the transition may achieve short-term gains in GHG emission reduction and technological learning only, but has major limitations in achieving the institutional or cultural changes that are also required for delivering sustainable energy transitions (Laes *et al.*, 2014).

Another theme in the literature focuses on the role of new market players, or challengers in initiating forces of change which may converge, accumulate, and subsequently challenge socio-technical energy regimes (Markard and Truffer, 2006). While the success of these challengers are still to be tested with empirical evidence (IEA-RETD, 2013; Raven, 2006; Szatow *et al.*, 2012), work by Szatow *et al.* (2012) explains why these newcomers have such potentials. In their study on Australian electric power systems and DE, the authors documented the ways in which a property company utilized its pre-existing resources and networks, expanded its business functions to become an energy service provider, and subsequently competed with the incumbents. The property company, for example, captured the potential to integrate master planning and building design considerations with providers of energy, water, waste and other services in a way that can provide clean energy services (e.g. renewable electricity) more cost-effectively. The property sector can access finance and resources on a scale and at price that enables it to compete with incumbents (Szatow *et al.*, 2012). However, the literature also suggests that while new entrants may deviate radically from existing business practices, they often lack financial resources, technical skills, and political influence to initiate large-scale system change

(Shomali and Pinkse, 2015; Zhang *et al.*, 2014).

Our focus on incumbent utilities and China is of academic significance. Most literature on SG developments is located in the West. The literature on SGs in China has been limited and the discussion on socio-technical regimes in the Chinese context is also limited (see, for example, (Mah, *et al.*, 2012; Yuan *et al.*, 2012). The emerging body of the literature has presented a mixed picture of the role of Chinese incumbent utilities in sustainable energy transitions. The two grid operators and the five major state-owned power generation companies (the Big Five) are the key to the implementation of major energy policies, most notably pollution abatement and renewable energy (Mah and Hills, 2008; Zhang *et al.*, 2016). However, on the other hand, they may also be a major barrier to new energy technologies such as distributed energy generation (Liu *et al.*, 2013). The size and monopoly power of the grid operators also makes regulation difficult (Brunekreeft *et al.*, 2015). The role of Chinese incumbents and how they interact with new market players, and how such interactions impact on SG developments in emerging market contexts need to be better understood.

Based on our theoretical discussion, we develop a conceptual framework as a guide to our analysis. We are looking beyond a polarized debate, in which incumbent utilities are understood as either a major contributor or a major barrier to sustainable energy transitions. Our framework is intended to advance a deeper understanding of the extent to which, where, under what conditions, and why incumbent utilities may facilitate or impede sustainable energy transitions. We will therefore address the following questions:

i. How did the incumbent utilities respond to new SG developments in China?
ii. In what ways did they exercise incumbent advantages for SG deployment?
iii. In what ways did they act as barriers to SG deployment?
iv. What are the outcomes of the incumbent-led model on SG deployment in China? To what extent has this model worked to scale up SG deployment in the absence of new market actors?

## 3. SGs in China: Motivations, major policy initiatives, and China's partial electricity market reforms as a contextual background

China, as the world's largest energy consumer and greenhouse gas emitter (C2ES, 2015; EIA, 2016), has been motivated to develop SGs mainly to improve reliability of energy supply, facilitate integration of renewable energy, and enable extensive deployment of demand response programmes (Brunekreeft *et al.*, 2015; Zpryme, 2011) (Interview BJ/04/2014). In addition, SGs present a cost-effective energy option for China through the development of energy markets, as well as energy products and services (Interview BJ/04/2014).

While some countries have introduced national SG plans or roadmaps (e.g. South Korea) (Mah *et al.*, 2012), it is important to note that the Chinese government has relied on a loose policy framework and an incumbent-led approach to guide SG developments. The Chinese Government has however not yet developed a national plan for SGs.

The first major initiative on SG in China was not made by the Chinese government, but by the SGCC. In 2009, the Corporation announced its 3-Stage SG plan, which is widely regarded as a milestone in SG developments in China. This was followed by CSG's announcement of its 2-Stage SG plan in 2010. Since then, these industry-level initiatives have been gradually elevated to a strategic national priority (Hart, 2011). In 2010, the then Chinese Premier Wen Jiabao announced that construction of a SG was a national priority, with completion planned for 2020 (EIA/SAIC, 2011). SG was then included in the 12$^{th}$ Five-year Plan of National Economic and Social Development (2011-2015), and further highlighted as one of the key national strategies for delivering energy transitions in the 13$^{th}$ FYP which was recently endorsed in March 2016 (Yuan *et al.*, 2014). Two important policies announced by the NDRC in 2012 and 2015 respectively are regarded as being instrumental in strengthening the policy framework for SGs. The 2012 NDRC special plan on SG provides policy guidelines on industrialization, standard systems, and demonstration projects of SG technologies. The 2015 NDRC document reaffirms the 2020 target to establish a SG system, and outlines a relatively comprehensive strategy which extends policy support in the areas of IT systems, economic viability, international standardization and new business model development (NDRC and NEA, 2015) (Table 1). These five-year plans and NDRC documents are further supported by a large number of SG-related policies at both national and local levels, which cover a broad of energy technologies, from renewable energy, energy efficiency, micro-grids, to electric vehicles and green industries.

Table 1: Chronology of SG policy developments in China

| | |
|---|---|
| 2009 | SGCC announced a Three-Stage SG plan (2009-2020). Stage 1 (2009-10): Initial planning and piloting, where the master plan and selected pilot projects are created and put into action; Stage 2 (2011-15): Comprehensive construction involving breakthroughs in key technology and equipment for achieving extensive application; and Stage 3 (2016-20): Upgrading, enhancing, and optimizing grid performance with respect to resource allocation, security, and efficiency, interplay among power grid, power generation and customers (Xu *et al.*, 2014; Yuan *et al.*, 2014) |
| 2010 | CSG announced a Two-Stage SG plan. Stage 1 (2012-2013) involves planning, research and demonstration. Stage 2 (2012 and after) involves demonstration and implementation (Yuan *et al.*, 2014). |
| 2010 | The then Chinese Premier Wen Jiabao announced that construction of a SG as a national priority, with completion planned for 2020 (EIA/SAIC, 2011). |
| 2011 | The 12$^{th}$ Five-year Plan of National Economic and Social Development included "advancing SGs" as a key task for delivering power system transition, indicating that SG has been included in China's national energy policy (Yuan *et al.*, 2014). |
| 2012 | NDRC announced a special plan titled "Special Planning of 12$^{th}$ Five-Year Plan (2011-15) on Smart Grid Major Science and Technology Industrialization Projects", which aims to acquire key SG technologies, formulate an independent technology and standard system for SG, as well as integrated supply chain; and complete the construction of modern SGs. It also includes over 75 SG-related demonstration and industrial projects at different levels (MIT, 2012; Yuan *et al.*, 2014) |
| 2015 | NDRC and NEA jointly announced the Guiding Suggestion on Boosting Smart Grid Development (NDRC & NEA, 2015) which aims for the initial completion of a national SG system by 2020, with supporting measures in technical assistance, mutual complementarity of renewable energy sources, IT and cloud systems, disaster response and economic viability, international standardization, encouraging new business model development. |
| 2016 | In February 2016, NDRC, NEA, and Ministry of Industry and Information Technology jointly announced "The Guiding Opinion Regarding the Carrying Out of "Internet" and Smart Energy Development". This Opinion highlighted the development of the internet of energy through advanced metering infrastructure and other assisting infrastructure by measuring real-time energy consumption. It also highlighted the importance of regulating an advanced metering infrastructure network in order to realize a safe, reliable, and rapid bi-directional utility-end user communication (NDRC *et al.*, 2016). |

The development of SGs in China has been strongly shaped by the on-going electricity market reforms. As one of the major outcomes of the 2002 electricity market reform, two state-owned grid companies and five power generation companies were established as the current incarnation of the State Power Corporation of China – which was a state-owned, vertically integrated monopoly that owned 90 percent of China's grid assets and 46 percent of power generation assets (Mah and Hills, 2008). So far, market competition has been introduced only to the power generation segment. In this somewhat stalled state of reform, the two grid operators have remained geographically monopolies which control electricity transmission, distribution, and retails in their respective regions (Figure 1 and Table 2). They have ministry-like status, and have remained large and influential (Brunekreeft *et al.*, 2015; RAP, 2008; Interview BJ/03/2014). The dominant role of the two grid operators in China's power market to a large extent explains their prominence in China's SG initiatives.


Figure 1: The geographical coverage of SGCC and CSG (Source: St. John (2014))

Table 2. Basics of SGCC and CSG

| | SGCC | CSG |
|---|---|---|
| **Geographical scope** | ▪ It serves 26 provinces (including autonomous regions and direct-controlled municipalities), with the exception of South China.<br>▪ It covers 88 % of China's territory, over 1.1 billion people<br>▪ It provides electricity that meets 83 % of national power consumption<br>▪ It includes five regional grids: Northwestern Grid, North Grid, Northeastern Grid, Central Grid, and East Grid | ▪ It serves 5 Southern Provinces: Guangdong, Guangxi, Yunnan, Guizhou and Hainan<br>▪ Electrical transmission and distribution covers 12 % of China's territory, serving roughly 230 million people, and 72.92 million clients.<br>▪ It provides electricity that accounts for 17 % of the national power consumption |
| **On-grid total Installed capacity (2014)** | 1049 GW | 246 GW |
| **On-grid Energy mix (2014)** | Thermal – 740 GW (70.5%)<br>Hydro – 199 GW (19.0%)<br>Wind – 75 GW (7.2%)<br>Solar Photovoltaic – 22 GW (2.1%)<br>Nuclear – 13 (1.2%) | Thermal Power – 127 GW (51.6%)<br>Hydro Power – 103 GW (41.9%)<br>Wind Power – 8 GW (3.3%)<br>Nuclear Power – 7 GW (2.8%)<br>Solar Photovoltaic and Others (Biomass, waste, geothermal) – 1 GW (0.4%) |

(Sources: Geographical scope – (Brunekreeft *et al.*, 2015; Ma and He, 2008; SGCC, 2015a; Zpryme, 2011); installed capacity and energy mix - (CSG, 2015a; SGCC, 2015a; Interview GD/03/2015).

# 4. Discussion

## 4.1 An incumbent-led model of SG development in China

SGs in China have developed differently from those in other countries. This study found that a defining feature of the Chinese approach is the central role played by the two grid operators, SGCC and CSG. In China's incumbent-led model, the two grid operators were the prime movers and driving force of many SG developments. SGCC has been regarded as the main proponent of SGs (EIA/SAIC, 2011; Zpryme, 2011). CSG has played a secondary role in the development of SG technologies, letting SGCC to take the lead (Zpryme, 2011). However, both SGCC and CSG have played a decisive role in the construction of SG in China (World Energy Council, 2012). The 3-Stage SG Plan (2009-2020) announced by SGCC in 2009 and the 2-stage SG Plan announced by CSG in 2010 have set the direction as well as timeline for SG developments for the nation.

What, then, are the motivations of the two grid companies to develop SGs? Political obligations and social responsibility appear to be the primary motivation. SGCC, which serves over 1.1 billion people and accounts for 83 percent of the national electricity consumption, believes that it needs to take the lead in developing SGs or China will lag behind international standards for power system development (Interview BJ/07/2014). In addition, the two monopolies have also been motivated by material benefits: through strengthening their own grids as well as empowering a supporting domestic equipment industry, particularly for the smart meter market (Schleicher-Tappeser, 2012). It is also noteworthy that the two grid companies focus on different aspects of SG development: SGCC focuses on ultra-high voltage transmission systems while CSG places more attention to high penetration of distributed energy sources and demand-side management (Interviews BJ/03/2014; GD/03/2015).

## 4.2. Major roles of the two grid companies in SG development

Our case study has found that the two grid companies did actively respond to the potential opportunities offered by SG developments in recent years. They appear to have played five important roles: as infrastructure planners and builders of SGs, as transmission network operators, as regulators through standard-setting, as technology developers, and as energy services providers.

(1) As SG infrastructure planners and builders

The two grid companies have created SG infrastructure through mobilizing massive investment in grid enhancement and smart meter installations. During the 12th Five-Year Period (2011-2015), SGCC was expected to invest RMB 1.6 trillion in grid expansion and upgrades, with RMB 286 billion – approximately 18 percent-designated to SG projects. A substantial part of this early investment has been allocated for smart meter deployment, in order to realize its target to deploy 300 million meters by 2015 and up to 380 million meters by 2020 (Alejandro *et al.*, 2014; Stern, 2015). CSG was also expected to invest about RMB 66 billion in grid expansion and updates (CSG, 2015a), with a target of reaching a 100% smart meter rollout by 2020 (Interview GD/03/2015).

In terms of actual smart meter rollouts, China is already the world's largest market. Smart meter installations are expected to grow from 139 million units in 2012 to 377 million units by 2020, reaching 74 percent market penetration (Alejandro *et al.*, 2014). CSG has lagged behind in smart meter installation. At present about some 1.3 million of the 3.5 million electric meters installed by CSG's end-users are "smart meters", which can possess the function of two-way communication between utilities and end-users. This represents a penetration rate of only 37 percent (Interview GD/03/2015).

(2) As distribution network operators

The two grid monopolies have increasingly expanded their functions as distribution network operators. Under a growing body of Chinese regulations regulating grid access and pricing policies for DEs (ERI, 2013), SGCC and CSG are required to manage distributed energy sources. They are mandated to provide grid connection and electricity metering free-of-charge (Liang, 2015). They also provide subsidies on behalf of the national government. For example, a 0.42 yuan/kWh subsidy has been provided for electricity produced from distributed PV facilities (Liang, 2015), in the context that the on-grid prices for coal-fired electricity across provinces and direct-controlled municipalities range from RMB 0.26 to 0.45 (NDRC, 2015).

In China, DE sources which include distributed photovoltaic, small hydropower, distributed wind generation, and natural gas distributed energy (Zeng *et al.*, 2015) totaled 34.36 GW, representing only approximately 3 percent of the national total installed capacity (in 2012). While this study does not have access to the most comprehensive and up-to-date data on grid-connected DE projects, available data suggests that the two grid companies have been increasingly active in providing grid connection services to DE projects in recent years. SGCC provided grid access services to 1,052 DE projects, involving a total installed capacity of 2,650 MW and 6,936 consumers by the end of 2014 (SGCC, 2015b). CSG provided grid access services to renewable projects with a total installed capacity of 16,214 MW by end 2015; these include distributed PV (DPV) projects and utility-scale PV of an installed capacity of 819 MW and 1,500 MW respectively (Interview GD/03/2015, supplemented with updated data provided through email correspondence).

(3) As regulators – through setting standardization

The two grid companies have also introduced SG-related regulations, which are mostly related to technical requirements on technologies such as distributed energy generation. SGCC has published 166 enterprise-class standards, as 42 national and industry standards for DE generation were developed and amended under contract (Liu, 2013). One of the most significant regulations introduced by SGCC was the regulation it introduced in 2012 which states that SGCC provides free-of-charge connection services for DPV electricity producers who are located close to customers so as to encourage local electricity consumption first (SGCC, 2012). That regulation was symbolic because it demonstrated explicit support from SGCC for grid access and connection of DE (SGCC, 2012; Interview BJ/01/2014).

(4) As technology developers and knowledge creators

SGCC and CSG have played an important role as technology developers and knowledge creators primarily through conducting a large number of SG pilot projects (Interviews BJ/07/2014; GD/03/2015). SGCC alone has implemented about 230 SG pilot projects to solve technical issues, test designs, and develop management systems in the first stage of it SG plan (between 2009-2010) (Zpryme, 2011). In addition to technology studies, they also conducted market (e.g. the potential new markets) and policy studies (e.g. tariff reforms) (Interviews BJ/04/2014; GD/01/2015).

(5) As new energy service providers

Although the core business of the two grid companies has remained in the traditional technologies, they have moved into new service areas in response to the opportunities offered by SG technologies. SGCC, for example, has conducted studies exploring options for new business models. In one of its case studies of business model innovation, SGCC explored the possibility of providing value-added services associated with the use of power optical fibre cable to its clients in Shanghai (Interview BJ/07/2014). CSG has also set up a subsidiary providing energy audit services to clients (CSG, 2015b).

### 4.3. Achievements and limitations of China's incumbent-led model

To what extent, then, is China's model for SG developments effective? This study adopts a refined smart grid maturity model developed by Mah *et al.* (2013) to evaluate SG transitional processes. Based on this model, which differentiates three orders of transitional process, our study found that SG development in China has yet to progress beyond the first-order of SG maturity, and hence has not been able to realize higher orders of SG benefits (Table 3).

Under this incumbent-led model, China has realized some major achievements in smart meter installations and, most notably, in the expansion of ultra-high voltage transmission systems. The two grid companies have also carried out a large number of experimental projects involving SG technologies in pilot projects. Such achievements, however, must be interpreted with caution. The Chinese model has revealed some major limitations. There has been a lack of structural change in China's electricity sector. The electricity sector has remained fossil fuel-based, and is still dominated by incumbent power utilities. Higher-order potential benefits offered by SGs, such as extensive use of demand response programmes and high penetration of renewable energy have not yet materialized in China in at least four important ways (Table 3):

- Smart meter deployment: smart meter installation reached an 80 percent penetration rate but the functional benefits of web-based data visualization which can enable two-way utility-end user communication have not been realized (Interview BJ/01/2014).

- Demand response (DR) programmes: DR programmes could be enabled by automatic control technology and decision-support technology but at present DR programmes have been largely limited to the pilot scale. Dynamic pricing, which is essential for effective DR programmes, has been emerging, but remains at a very early stage of development in China (Interview GD/07/2016).

- Distributed energy (DE) generation: the operational benefits of SG technologies to enable high penetration of DE have not materialized in China. DE sources contribute only approximately 3 percent of the national total installed capacity (in 2012) (CNREC, 2013; SGCC, 2012).
- Business model (BM) innovation: BM developments for supporting new products, services, and markets which may be created by applications of SG technologies are also remained limited in China (Interview BJ/04/2014).

Table 3. An assessment of China's SG developments

| Orders of SG Development | Indicators | Our assessment | Illustrative examples |
|---|---|---|---|
| **First-order transformation** | ▪ Visions and policy strategies are in place.<br>▪ But business cases not in place and benefits (including operational, customer and societal benefits) of smart grids are not realized. | ● | • SG plans and policy initiatives are in place.<br>• Approximately 190 million smart meters have been installed, representing about 80 percent penetration rate in China (Interview BJ/03/2014). But the functional benefits of web-based data visualization and two-way utility-end user communication have not been realized (Interview BJ/01/2014).<br>• The two grid companies have conducted a large number of DR pilots in order to test customers' responses. However, these pilots were superficial in nature, to a large extent because there is a lack of a functioning dynamic pricing system which could have realized the functional benefits of DR programmes (Interview BJ/03.2014). A DR pilot in Foshan, Guangdong Province, conducted by CSG offered economic compensation for industrial end users but was not able to offer such compensation beyond that pilot project (Interview GD/03/2015).<br>• In China, DE sources which include distributed photovoltaic, small hydropower, distributed wind generation, and natural gas distributed energy (Zeng *et al.*, 2015) amounted to 34.36 GW (approximately 3 percent of the national total installed capacity) (in 2012) (Figure 2) (CNREC, 2013; SGCC, 2012 ). Most of these DE comes from hydropower while solar PV, wind, and other DE sources remain limited in scale (Figure 3).<br>• BM developments are slow, and mostly at the pilot scale. Most SG pilots aim to overcome technical challenges, with a negligible number of pilots experimenting in BMs (Interview GD/03/2015). One of the exceptions include a recent pilot project conducted in Foshan, Guangdong, which tries to involve insurance companies in order to mitigate market risks associate with solar PV projects (Guangdong DRC, 2014). |
| **Second-order transformation** | ▪ Business cases are emerging and investments are being made.<br>▪ Operational benefits are realized but not customer and societal benefits. But some applications for particularly markets are validated.<br>▪ Operational linkages are established between two or more technological aspects of smart grid; | ○ | • Changes in business models and regulatory arrangements are not noticeable in China |

| | | | |
|---|---|---|---|
| | cross-functional benefits are achieved; partnerships are cultivated.<br>▪ Some minor regulatory changes such as new incentive systems for smart meter installations are introduced, mostly in pilot scale. But major regulatory changes involving tariff structure and market structure are not introduced. | | |
| **Third-order transformation** | ▪ Smart grid functionality and benefits (including operational, customer and societal benefits) are realized.<br>▪ New business models are economically sustainable. New products, services and markets are created.<br>▪ Major regulatory changes involving tariff structure and market structure are also introduced. | ○ | |

●: Strong evidence

◐: Moderate evidence

○: Indiscernible evidence

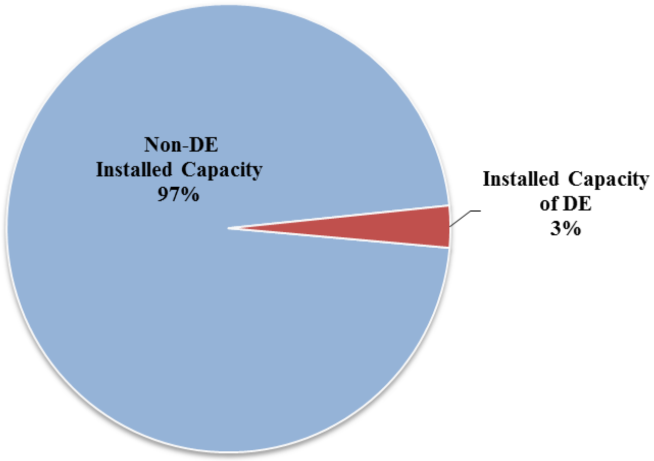


Figure 2. Installed capacity of DE in China (2012) (Source: by Authors; primary data from (CNREC, 2013; SGCC, 2012))

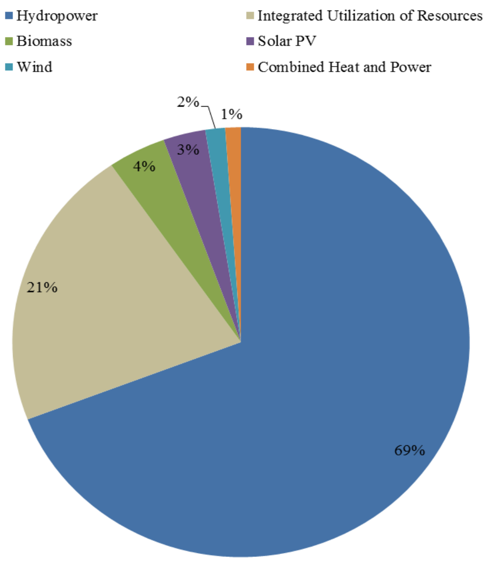


Figure 3. Installed capacity of DE by types in China (2012) (Source: by Authors; primary data from (CNREC, 2013; SGCC, 2012))

### 4.3. Incumbents as enablers and as barriers: What are the explanations of this mixed picture?

Our review of China's incumbent-led model of SG development found that the two grid operators have access to several incumbent advantages that are available to them only by virtue of their state-owned, monopoly position. These advantages include financial strength, access to technical expertise and innovation capacity, and extensive networks with strategic stakeholders. These advantages have enabled them to act as the driving force for SGs. The two grid companies, on the other hand, have however acted as a fundamental block to the structural changes in the socio-technical regimes that are needed for major SG developments. Four major problems, incumbents' disincentives, inertia (and a lack of competition), excessive reliance on incumbents to provide public goods, and a lack of resources and expertise in developing new energy products and services, have resulted in major weaknesses in China's incumbent-led model of SG development.

#### 4.3.1. The advantages of the incumbent utilities

The first incumbent advantage of the two grid companies relates to their financial strength. With their origins in China's highly centralized planned economy in which massive resources can be mobilized effectively (but not necessarily efficiently) for specific national goals (Ma and He, 2008), the two state-owned grid companies were able to mobilize the massive investments required for grid expansion and smart meter installation. During the 12$^{th}$ Five-year Period (2011-2015), SGCC was reported to invest RMB 1.6 trillion in grid expansion and upgrades. A substantial proportion of this early investment was planned for smart meter deployment in order to meet SGCC's target of installing over 300 million meters by 2015 (Stern, 2015). CSG was reported to invest RMB 66 billion in grid projects (CSG, 2015a).

The second advantage which the two grid companies possess is their relatively high technical expertise and innovation capacity. As the monopoly grid operators for the country, the two companies possess the pre-existing technological competence in planning, financing, constructing, as well as managing major grid infrastructural works and other major energy facilitates such as power plants (Interview BJ/03/2014). Their technological expertise has also allowed them to take the lead in developing technical standards relating to SGs in China (Interviews BJ/04/2014; GD/01/2015).

It is important to note that the in-house research institutes of SGCC and CSG are important institutions that have strengthened the technological expertise and innovation capacity of the two companies (Interview BJ/03/2014). Both SGCC and CSG have set up SG-specific research divisions to respond to SG developments. SGCC's State Grid Smart Grid Research Institute has been reorganized and became the Internet Global Energy Research Institute in February 2016 (SGCC, 2016). CSG's Smart Grid Research Institute is one of the seven institutes of the 292-staff Electric Power Research institute (Interview GD/01/2015). These SG research institutes have been actively developing a broad range of SG-related research and demonstration projects which cover not only technological challenges but also business model innovation, pricing reforms as well as policy recommendations (Interviews BJ/07/2014; GD/03/2015).

The third incumbent advantage is associated with their extensive networks with several strategic SG stakeholders. Based on Geels's (2004) framework, this study found that the two grid companies have well established political networks, financial networks, industrial networks, research networks, and utility-end user networks (Figure 3).

In terms of policy networks, because of their ministry-like status, SGCC and CSG possess *policy linkages* at both the central and local government levels. They have played an important role in providing policy recommendations to government, in implementing national and local policies, and conducting SG and DE pilot projects. In addition, *complementarities*, either in terms of resources or expertise, are a key to sustaining such political linkages. For example, because of SGCC's advantage of its access to a great amount of detailed consumption data, local governments tend to be keen to collaborate with SGCC to conduct SG-related studies (Interview BJ/04/2014).

The two incumbents' financial networks have been reinforced by their linkages with state-owned banks. Chinese state-owned enterprises (SOEs) can access low-interest loans provided by state-owned banks so they have greater opportunities to mobilize sufficient capital for massive projects. They may also be able to sustain operating losses over time (Santalco, 2012). Such financial linkages with state-owned banks have become critical to help the incumbents overcome some of the economic barriers to SG deployment, including high upfront costs, long pay-back period and market risks. The high entry barriers have deterred private enterprises from entering the Chinese SG market (Interviews BJ/02/2014; BJ/05/2014; BJ/07/2014).

In addition, SGCC and CSG have also developed industry networks with generation companies, and various technology providers, components manufacturers, and suppliers. Both grid companies have been expanding their business portfolios across the value chain. SGCC has notably taken over domestic engineering firms and leading electric power equipment manufacturers (Brunekreeft *et al.*, 2015). Many of these suppliers are either the subsidiaries of the two grid companies, or long-term business partners (Interview BJ/02/2014). These strategic alliances are likely to enable the grid operators to better manage costs, as well as effecting a stabilization process in terms of perception of policy support which thus reduces market and policy risks (Radcliffe *et al.*, 2014).

In addition to their in-house research capacity, externally the two grid companies have developed extensive research networks through collaboration with universities and other research institutes in many of their SG pilot projects. Such enterprise-university research networks have been developed in the context of the decentralization of R&D responsibilities and administrative authority that commenced in the early 1980s. Since then, horizontal ties between power utilities, universities, and research institutes have been strengthened and incentivized (Mah and Hills, 2014).

The grid companies possess customer loyalty. Because the two grid companies are geographically monopolies, electricity end-users have no choice of energy suppliers, and end-users in China tend to be the followers and seldom challenge utilities for any technological or policy changes to be introduced (Interviews BJ/07/2014; GD/01/2015; GD/03/2015). While smart meter installations have been one of the major causes of smart meter backlash in a number of western economies (Mah *et al.*, 2011a), Chinese end-users in general are less skeptical to SGCC and CSG's technicians when they install smart meters for households. The trust relationships between grid companies and household end-users in China can at least partly explain the relatively rapid deployment of smart meters in China.

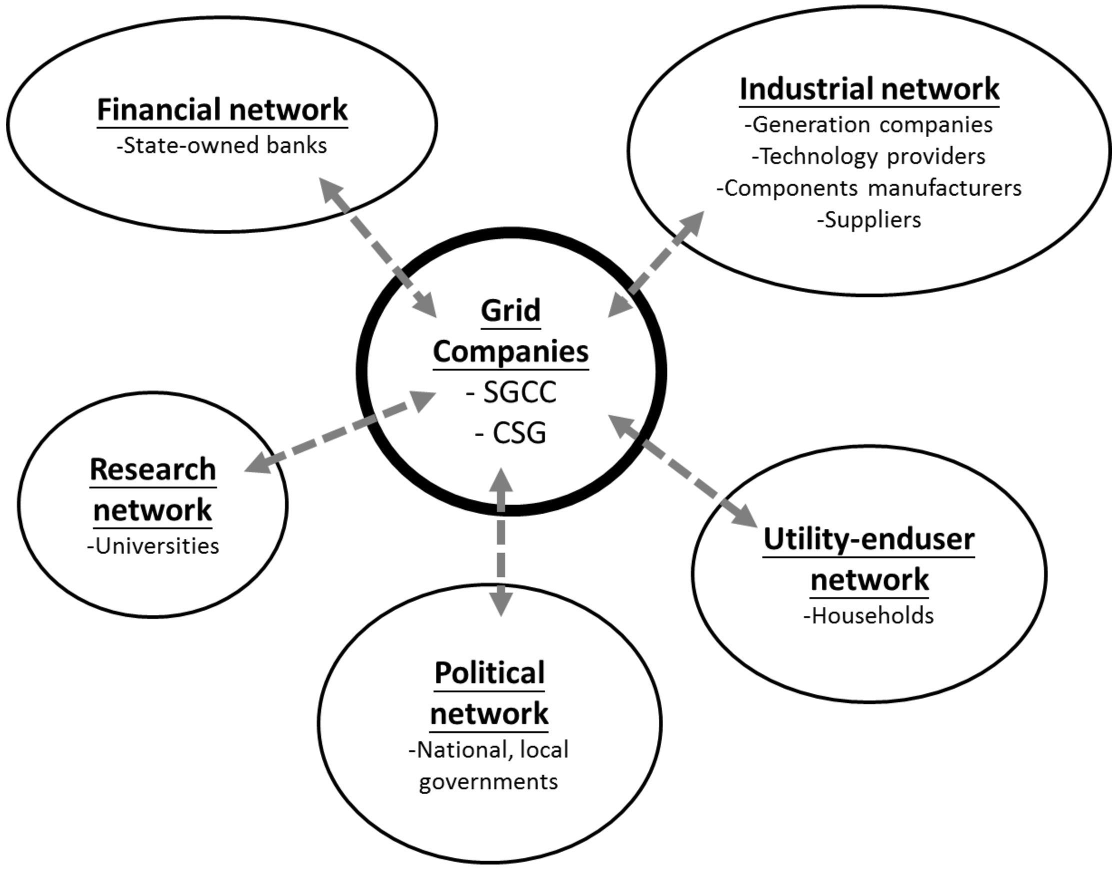


Figure 4. Networks between SGCC, CSG and other SG stakeholders in China (Source: Authors)

#### 4.3.2. Major problems associated with the incumbents

The two grid companies, on the other hand, have acted as a barrier to SG developments. Four problems associated with these incumbents seem to have resulted in major weaknesses of China's incumbent-led model of SG development.

The first problem relates to incumbents' disincentives. In response to SG developments, the two grid companies, which have a strong tradition of vertical integration, have increasingly acted as distribution system operators. In addition to planning, building, and managing traditional power girds, they now also plan and operate the distribution grids in ways that facilitate the integration of distributed energy sources as we discussed in an earlier section.

Incentives for more radical changes in the functions of network operators are however limited even though a growing number of regulations have been introduced in recent years. The mandatory requirements imposed on the two grid operators to integrate DE sources are a good case in point. At present, there is no pricing system that allows them to recover the costs of ancillary services, such as voltage support service (Zeng *et al.*, 2015a). Extra costs may also be incurred by a grid company if solar electricity from distributed sources is of sub-optimal quality because a grid company may need to invest more to address these technical challenges (Interview GD/07/2016). In addition, pricing reforms which could allow distributed energy sources to compete in markets are yet to be put in place (Interview TJ/01/2014). As a result of the lack of effective pricing and compensation mechanisms associated with the additional costs incurred from SG-related ancillary services, SGCC and CSG have very limited incentives to facilitate a high penetration of distributed energy sources into their grids.

The second problem relates to inertia. SGCC and CSG are very resistant to structural changes in the power sector. Their utility’s logic centres on energy security and reliability. They regard technological innovation, cost reduction and profit maximizing as lesser concerns (Interviews BJ/03/2014; BJ/04/2014). Their financial strength, as mentioned in earlier sections, tends to reinforce these inertia effects and they may therefore pay less attention to technological innovation (which can drive down costs and promote efficiency and competitiveness) because they may sustain operational losses due to the financial back-up provided by state-owned banks (Interview BJ/01/2014). In addition, forces for change from new market players have remained limited. In addition, electricity end-users in China generally do not have a choice of energy suppliers, and grid operators do not need to take end-users’ needs for new energy products and services into account (Interviews BJ/01/2014; BJ/02/2014).

The third problem is the existence of a vicious cycle due to an excessive concentration of multiple roles in the two grid companies. Apart from managing transmission, distribution, and retailing in the power sector, these incumbents have also taken the lead in developing technical standards for SG technologies. The critical importance of standard-setting, and other functions which are public goods in nature, in sustainable energy transitions has been extensively discussed (see, for example, Mah and Hills, 2014). Standard-setting is critical to energy technology innovation because codes, standards, and certification can reduce commercial and purchase risks as well as negative perceptions of technology performance (Martinot and McDoom, 2000). Certification and testing agencies can allow manufacturers to easily verify compliance with standards and provide purchasers with performance assurance (Martinot and McDoom, 2000). The lack of familiarity and experience with large-scale DE penetration can lead to perceptions of greater technical risk than for conventional energy sources (Martinot and McDoom, 2000).

In China's incumbent-led model, standard-setting for SG developments has been an industry-led process. However, senior government officials and experts in the field indicate that the development of technical standards has been too slow, and is unlikely to be able to support significant uptake of, for example, DE generation in China (Interviews BJ/04/2014; GD/07/2016). One good example to illustrate this problem is that following the SGCC's introduction of policies regulating grid access to distributed energy sources (ERI, 2013), it took CSG another two years to formulate similar rules in 2014 (Interview BJ/07/2014). The incumbents' disincentives and inertia operating against structural changes in the power sector together with the government's reliance on the grid companies to set standards have created a vicious cycle that tends to reinforce the status quo rather than to promote socio-technical shifts. Such problems associated with excessive reliance on incumbents, particularly their incentives to prevent market entry by competitors have been documented in the literature (see, for example, Brunekreeft *et al.*, 2015; Martinot and McDoom, 2000).

The fourth problem is a lack of resources and expertise to develop new energy products and services. While the two grid companies are competent in developing and managing large-scale energy projects, these two monopolies which traditionally do not need to response to consumers' needs are found to be lacking the competence and resources to develop new energy products and services (Interviews BJ/02/2014; BJ/07/2014; GD/03.2015).

## 5. Conclusions and policy recommendations

This paper has examined the role of incumbents in facilitating or impeding sustainable energy transitions from the perspective of governance. Based on a detailed case study of SG developments in China, this paper has provided an analysis of the extent to which and under what conditions existing grid operators in China had impacted the deployment of SGs.

We have made three major theoretical contributions to the literature on governance for sustainable energy transitions. Firstly, we have characterized the Chinese model of SG development as an incumbent-led approach. Secondly, we have provided more precise mapping of the roles of incumbent utilities in sustainable energy transitions. Based on our case study, we argued that the two monopoly grid operators in China play five major roles in the SG deployment. While our findings confirm the literature on SG that incumbent actors may assume important roles as network operators (Cossent *et* *al.*, 2009; Nepal *et al.*, 2014; Pollitt, 2010) and standard setters (Pullinger *et al.*, 2014), our findings also highlight other important, but less well-studied roles of such actors. These include the roles of infrastructural enablers, technology developers, and new energy service providers. This finding can also contribute to the scholarly debate as to who are likely to be the key agents of change. This finding makes a valuable contribution to the growing body of literature on the roles of incumbents, governments, the market, and civil society in sustainability transitions (Laes *et al.*, 2014; Mah *et al.*, 2013; Markard and Truffer, 2006)

Thirdly, we have specified *the extent to which, under what conditions, and how* incumbent actors may facilitate or impede sustainable energy transitions. We found that incumbent utilities have acted as strategic first-movers in the early stage of SG developments in China. A number of non-state actors working outside the government have emerged. However, these actions do not amount to what Geels sees as "regime shifts" (Geels, 2004; Geels, 2005). With regard to the refined SG maturity model developed by (Mah *et al.*, 2013), which differentiates SG transformation processes into three orders, our case study suggests that the China's incumbent-led model can make secure important achievements only in the early stage of SG deployment. Higher-order SG benefits including large scale deployment of distributed energy generation and demand responses programmes are yet to be put in place. We found that the SGCC and CSG demonstrate incumbent advantages in terms of financial strength, in-house R&D capacity, and networks, but that they have also become barriers to SG deployment as a result of utilities' disincentives, inertia (and a lack of competition), and a lack of resources and expertise in developing new energy products and services.

Our analysis confirms the findings of other literature on the potential roles of incumbent actors as enablers as well as barriers to sustainable energy transitions. More importantly, our analysis has provided a better understanding of the complexity of the roles of incumbent actors – we need to avoid oversimplication and cannot assume that incumbents are *either* an enabler or a barrier; they can be *both* an enabler and a barrier in a continuing transitional process. Our understanding of the conditions (i.e. the existence of the incumbent advantages as well as the major problems) and the manner in which the two grid operators have reacted in the observed ways in our case study has instructively enrich the literature. The impacts of the partial, incomplete, electricity market reforms on the motivations and behavior of the two grid operators are of particular significance. This finding can therefore enrich the literature which discusses the extent to which, and how, market liberalization acts as a driver for radical changes in energy socio-technical regimes (see for example (Anuta *et al.*, 2014; Arocena, 2000; Markard and Truffer, 2006)**.**

Our review of the role of SGCC and CSG has raised two major questions for policy-makers in China: first, since incumbent utilities can be both an enabler and a barrier to SG deployment, how can the Chinese government minimize the utilities' impacts as a barrier? Second, can the potential offered by SGs be fully realized by this incumbent-led approach in China, without involving many new market actors?

We have two specific major policy recommendations in response to these two questions. Firstly, the government can assume a much more important role in regulating SG developments. China's incumbent-led model tends to focus on the technical aspects of SGs. Institutional changes and market transformation which are critical to enable SG deployment are areas which have yet to receive sufficient policy attention. The government needs to strengthen its regulatory systems in such a way that incumbent grid companies are provided with incentives to serve as distribution system operators, to plan and operate distributed grids, and to facilitate the entry of new DE electricity suppliers into the market. Incentive systems are required to compensate for the costs of ancillary services, and to address the utilities' disincentives to allow large scale distributed energy generation.

Such regulatory systems are also required to protect the interests of new market players, such as electricity suppliers of DEs and prosumers. Non-state actors require strong regulatory and policy support in order to grow in power and present challenges to the status quo. The NDRC and State Electricity Regulatory Commission (SERC), the regulators of China's electricity sector, needs to be more determined in regulating, firstly, which parts of the transmission and distribution network systems can be opened up to competition, and secondly which players must be subject to regulation.

Our second policy recommendation is that sufficient attention should be given to the negative consequences of relying on incumbent utilities in sustainable energy transitions. The slow progress in standard-setting which is limits and constrains the uptake of DE in China is a good example. Although the 2012 SGCC's utility-level regulation which permits direct sales of electricity from generators to other users within the same power zone was regarded as a major milestone of DE regulation, it took the NDRC's NEA two more years to introduce a corresponding national regulation for DPV in 2014 (Interview BJ/01/2014). Such an incumbent-led approach for standard-setting also provides opportunities for the incumbents to prevent new market players from entering the market (Interview BJ/04/2014).

It is noteworthy that other countries have adopted different approaches to standard settings for SG technologies - instead of relying on utilities, governments as well as industrial associations seem to play more important roles in providing this critical function which is public goods in nature. The Japanese government, for example, assumed the central role in the standardization of Japanese SG technologies. Major government initiatives include the introduction of the "International Standardization Roadmap for Smart Grid" by the Ministry of Economy, Trade and Industry (METI) introduced, and the establishment of the Working Group on International Standardization of Smart Grid (Mah *et al.*, 2013). In the US, the National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce has been collaborating actively with SG stakeholders in order to develop SG standards and protocols in a timely and efficient manner (NIST, 2013). The Chinese government therefore may explore the roles played by industrial associations such as the China Electricity Council (中国电力企业联合会), a major industrial association of China's power enterprises and institutions, in coordinating and facilitating standardization of Chinese SG technologies.

Our findings are based on a single case study which is country and technology-specific. However, they can be generalized to other countries, such as France and South Korea, where incumbent utilities still assume a central role in electricity markets (Mah *et al.*, 2012; Mamo, 2010). Further research on a comparative study of China and these countries may improve the generalizability of these findings. This study is not able to pay sufficient attention to the changing relations between incumbent actors and challengers, such as real estate developers and prosumers in China. A growing body of literature has examine interactional incumbent-challenger relationships and the associated impacts on sustainable energy transitions (see, for example, (Betsill and Stevis, 2016). Such investigation in the Chinese context or from a comparative perspective should be the focus of future studies.

**Appendix: List of interviewees**

18 interviewees were interviewed in 11 interview meetings; in some meetings, there were two or more than two interviewees.

| Code | Background of interviewee | Date of interview | Format of interview |
|---|---|---|---|
| BJ/01/2014 | A senior executive of an energy-related consulting company, Beijing | 23 July, 2014 | FI |
| BJ/02/2014 | A middle-rank consultant of an energy-related consulting company, Beijing | 23 July, 2014 | FI |
| BJ/03/2014 | A Senior executive of the State Grid Energy Research Institute of SGCC | 23 July, 2014 | FI |
| BJ/04/2014 | A senior government official in the Department of Renewable and New Energy, NDRC | 23 July, 2014 | FI |
| BJ/05/2014 | A senior advisor in Energy Research Institute of NDRC | 24 July, 2014 | FI |
| BJ/06/2014 | A researcher in Guangzhou Institute of Energ Conversion, Chinese Academy of Sciences | 24 July, 2014 | FI |
| BJ/07/2014 | A senior executive in State Grid Energy Research Institute of SGCC | 24 July, 2014 | FI |
| BJ/08/2014 | A middle rank executive in State Grid Energy Research Institute of SGCC | 24 July, 2014 | FI |
| TJ/01/2014 | A professor in the School of Elecrical Engineering & Automation of Tianjin University | 25 July, 2014 | FI |
| TJ/02/2014 | A researcher in the School of Elecrical Engineering & Automation of Tianjin University | 25 July, 2014 | FI |
| TJ/03/2014 | A senior executive in a green building research institute in Tianjin | 25 July, 2014 | FI |
| GD/01/2015 | A senior executive in Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences | 7 January, 2015 | FI |

| | | | |
|---|---|---|---|
| GD/02/2015 | A researcher in Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences | 7 January, 2015 | FI |
| GD/03/2015 | A senior executive in Smart Grid Institute of CSG<br>*updated data was provided by the interviewee through email correspondence, dated 12 May, 2016 | 7 January, 2015 | FI/EC |
| GD/04/2015 | A researcher in Smart Grid Institute of CSG | 7 January, 2015 | FI |
| GD/05/2015 | A researcher in Smart Grid Institute of CSG | 7 January, 2015 | FI |
| GD/06/2015 | A middle-rank executive of a solar technology company in Zhuhai | 14 March,2015 | FI |
| GD/07/2016 | A professor at The Lab of Solar PV and Mico-grid Applied Technology, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences | 3 March, 2016 | FI |

*In order to keep our interviewees anonymous, this study indicates interviews by number. The first two letters indicate the location (BJ for Beijing, TJ for Tianjin, and GD for Guangdong), the two digits indicate the interview numbers, followed by the year of interviews. The interview formats included face-to-face interview (FI) and email correspondence (EC).

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%E5%B1%95%E6%A8%A1%E5%BC%8F%E5%92%8C%E7%BB%8F%E8%90%A5%E7%AE%A1%E7%90%86%E6%96%B9%E5%BC%8F%E7%A0%94%E7%A9%B6-%E6%80%BB%E6%8A%A5%E5%91%8A-2013-9-22 (In Chinese).

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