2012

Governing the transition of socio-technical systems: A case study of the development of smart grids in Korea

Daphne Ngar-yin Mah
Department of Geography, Hong Kong Baptist University

Title Page

Governing the transition of socio-technical systems:

a case study of the development of smart grids in Korea

Daphne Ngar-yin Mah*
Post-doctoral Fellow, The Kadoorie Institute, The University of Hong Kong

Johannes Marinus van der Vleuten
Senior Research Assistant, The Kadoorie Institute, The University of Hong Kong

Jasper Chi-man Ip
Senior Research Assistant, The Kadoorie Institute, The University of Hong Kong

Peter Ronald Hills
Director and Chair Professor, The Kadoorie Institute, The University of Hong Kong

*Corresponding author: Daphne Mah, Tel: (852) 2219 4901; Fax: (852) 2857 2521; daphnema@hku.hk

(Accepted by the journal of *Energy Policy*)

Governing the transition of socio-technical systems:

a case study of the development of smart grids in Korea

Abstract

This paper examines the motivations, processes and outcomes of the development of smart grids in South Korea through the perspectives of governance and innovation systems. Drawing on desktop research and semi-structured interviews, this paper has two major findings. First, the development of smart grids in Korea has been shaped by various factors including macroeconomic policy, the role of the government, and experimentation. The complex interactions between these factors at the landscape, regime and niche levels has impacted on the development of smart grids. Second, while Korea's government-led approach has its strengths in driving change, it has also exposed weaknesses in the country's ability to mobilise the private sector and consumer participation. Major obstacles including partial electricity market reform and public distrust exist. A systemic perspective is needed for policy in order to accommodate the changes required for smart grid development. Regulatory reforms, particularly price-setting mechanisms, and consumer engagement are priority areas for policy change.

Key words: smart grid, Korea, socio-technical systems

INTRODUCTION

Smart grids are electricity networks that utilise information technology to enhance the reliability, security and efficiency of power systems (KSGI, 2011). A distinctive feature of smart grids is the ability to integrate the actions of all users including generators and consumers (IEA, 2011). Smart grids have a major role to play in a low-carbon future: they can be instrumental in energy saving and accommodating a broad range of generation and storage options including renewable energy, and thus are a key to both demand and supply-side management of energy systems.

The potential opportunities and benefits of smart grids could be substantial. The Electric Power Research Institute (EPRI) estimated that an investment of $338 billion to $476 billion for a fully functional smart grid could result in benefits up to $2 trillion in the U.S. (EPRI, 2011). Faruqui and others (2010a) also estimated that 67 billion euros for building and running peak infrastructure could be avoided in the EU if dynamic pricing which is based on smart grids can be adopted.

The US, EU, Japan, and Korea have been among the first-movers in the development of smart grids. These economies have adopted different pathways with varying levels of achievement. In the US, for example, the emphasis is on smart metering and grid modernisation (Executive Office, 2011). In contrast, Europe places emphasis on decentralised systems with active participation from end-users who can sell surplus electricity that they generate from micro-generation technologies such as small wind turbines at household and community levels (Ragwitz et al., 2010).

The transition from large-scale carbon/ nuclear-based electricity grid systems to smart grid systems however is a difficult and complex process that goes beyond technological challenges. Smart grids look very different from today's grid systems, involving a shift from centralised, fossil fuel/ nuclear-based and non-participatory power systems to one which can accommodate a wide range of energy sources including both centralised energy systems and decentralised renewable energy such as wind and solar energy (MKE and KSGI, 2009). Smart grids are also characterised by two-way relationships with well-informed and actively involved end-users. Dynamic pricing, which is the charging of different electricity rates at different times of the day and year to reflect the time-varying cost of supplying electricity (Faruqui and Palmer, 2011, p. 16), and smart meter roll-outs would need to be introduced to enable effective consumer engagement in demand side management (IEA, 2011). The challenges of smart grid development therefore are numerous, including realigning the interests of business, government and electricity consumers to overcome resistance to change (Executive Office, 2011; IEA, 2011). However, little is known about how these challenges can be overcome.

This paper examines governing processes for the transition of socio-technical systems, applied through a case study of smart grids in South Korea (hereafter Korea). The paper examines the motivations, processes and outcomes of the development of smart grids in Korea using the concepts of governance and innovation systems as an analytical framework.

Korea merits study because its government-led and export-oriented approach to developing smart grids appears to differ in many interesting ways when compared with other countries. A number of recent policy developments, most notably the national Smart Grid Roadmap and a major demonstration project known as the Smart Grid Testbed on Jeju Island, can provide useful information for analysis.

The analysis presented here draws on data and information derived from desktop research, semi-structured interviews and field observations. The interview data consists of seven in-depth interviews with stakeholders conducted in Korea in April 2011, two follow-up email correspondence and four telephone interviews.

The richness of the information derived from our face-to-face interviews has the strength to reveal the critical interactions of complex social phenomena (Miles and Huberman, 1994). However, qualitative case studies may suffer from what Miles and Huberman (1994, p. 281) have termed the "limitations of interpretivism" – they may be a "person-specific, artistic, private/ interpretive act that no one else can viably verify or replicate it".

Our study adopted several measures to overcome these limitations. First, the interviewees were carefully selected informants who occupy roles or positions in an organisation, social networks, communities of a political system and are therefore knowledgeable about the issues studied (Johnson, 1990). They came from the government, energy companies, universities and research institutes (see Appendix 1). Second, we used semi-structured questionnaires which were developed on the basis of our literature review as a way to facilitate systematic interviews across interviewees. Third, e-mail correspondence and follow-up telephone interviews were conducted to collect supplementary information and to clarify data. Fourth, the interviews were recorded and transcribed to reduce inaccuracies due to poor recall. Fifth, as far as such information is accessible to us we have used data we collected from publications to corroborate data provided by our interviewees.

The following section provides an overview of smart grid developments in Korea. This is followed by a discussion on the theoretical framework that integrates the key concepts of governance and innovation systems. The framework is then used to inform our analysis of the Korean case.

SMART GRID DEVELOPMENT IN KOREA: AN OVERVIEW

South Korea, officially the Republic of Korea, has a geographical area of 99,720 km^2 and a population of 48.22 million in 2010 (KOSTAT, 2011a). It is a major developed country in Asia which ranks 14^{th} globally by GDP (World Bank, 2011). Korea was the world's 10th largest energy consumer in 2008 (EIA, 2011). As a country that has no oil, no high quality coal, and produces only 1.5% of the natural gas it requires, Korea is dependent on imports to meet almost all of its energy needs (EIA, 2010). The electricity system in Korea is fossil fuel based. Coal, natural gas and nuclear amounted to about 33.6%, 25.3% and 24.1% of its electricity generation capacity respectively while renewable energy amounted to about 1.5% (2009) (Table 1). Electricity consumption increased by 52 % between 2001 and 2009 and reached 433.6 TWh in 2009 (KPX, 2010). Climate change is a key policy issue in Korea (MKE and KSGI, 2009). CO_2 emissions have been rising since the 1990s with carbon intensity reaching 0.67 kg CO_2 per US$2,000 of GDP in 2008 (IEA, 2010).

Table 1: Overview of the electricity sector in Korea (as of Dec 2009)

Fuel mix	
Coal	33.6%
Oil	8%
Natural gas (LNG)	25.3%
Nuclear	24.1%
Renewable (excluding Hydro)	1.5%
Hydro	7.5%
Generation capacity (MW)*	76,078
Peak demand (MW)*	71,310
Reserve margin (%)*	6.23
Total electricity demand (GWh)	433,604
Residential (%)	19.9
Industrial (%)	52.5
Public and Service (%)	22.7
Agricultural (%)	2.5
Educational (%)	1.6
Street-Lighting (%)	0.7
Retail electricity rates (KRW/kWh)	
Residential	114.45
Industrial	73.69
Public and Service	98.50
Agricultural	42.13
Educational	83.56
Street-Lighting	76.65

(Sources: compiled by authors; data from KPX, 2010)[1]
* Data as of end 2010

[1] The data presented in this table excludes electricity that was generated by private generation companies which amounted to approximately 13% of the total installed capacity in Korea (2009).

The government's rationale for smart grids centered around President Lee Myung Bak's "Low Carbon, Green Growth" vision announced in 2008. The vision aspires to use green technology and green industries including smart grids as new engines for growth (Kang and Park, 2011). Detailed studies quantifying the benefits and costs of the deployment of smart grids in Korea are not publicly accessible. However, official data show that smart grids are expected to bring Korea economic benefits that could outweigh investment. It has been estimated that by 2030 smart grids would bring a range of benefits that include new global and domestic markets for smart grid technology that worth approximately 49 trillion won and 74 trillion won respectively, the creation of 50,000 new jobs annually, saving 47 trillion won of energy imports, cost savings of 3.2 trillion won by avoiding building new power plants, and a reduction of 230 million tonnes in GHG emissions (MKE and KSGI, 2010). These benefits would outweigh the investment which is estimated to be 27.5 trillion won, in which 90% would come from the private sector (MKE and KSGI, 2010).

To realise the potential benefits of smart grids, the Korean government has introduced three strategies: the announcement of the national smart grid vision in 2009, the release of a national smart grid roadmap in 2010, and the launch of the Smart Grid Testbed on Jeju Island in 2009. The roadmap sets out a work plan for implementing the smart grid vision in five key areas, namely smart power grids, smart consumers, smart transportation, smart renewables, and smart electricity services. The Testbed is a large-scale demonstration project for testing technologies for the global market and developing business models. The Testbed involves 12 consortia (involving about 170 corporations) and 2,000 participating households (KSGA, 2011; KSGI, 2011; MKE & KSGI, 2010). Stage 2 of the Jeju Testbed was recently launched on 1st June, 2011 following the completion of Stage 1 in end May. According to the roadmap, the Testbed will be scaled up to a citywide level through the pilot of a Smart Grid City by 2012, and to the national scale by 2030.

Smart grid developments in Korea are currently still at an early stage and are mostly in the area of R&D while regulatory and policy frameworks are being strengthened. Following the enactment of the Smart Grid Act in May 2011, the corresponding decree and rule which are critical for the implementation and enforcement of the act were promulgated in November 2011 (MOLEG, 2011a, 2011b, 2011c). Dynamic pricing and smart meter roll-outs – which have been regarded as key enablers of smart grids – have been deployed but on a limited scale. Dynamic pricing has been recently piloted in the Jeju Testbed but the participation rate is low. 2.5 million smart meters have been installed in the industrial, household and other consumer sectors, and the penetration rate is expected to reach 100% with a total of 25 million smart meters to be installed by 2020 (Interview: 12/2011; MKE and KSGI, 2010).

SMART GRID IN THEORETICAL PERSPECTIVE

A scanning of the literature suggests that two substantive bodies of theory are instructive in helping to analyse the development of smart grids: governance and innovation systems studies.

Governance perspective

Central to the concept of governance is the move away from government to governance (Pierre and Peter, 2000). The perspective of governance highlights the importance of new approaches to enhancing governing capacity in which governments reach outwards and downwards to localities, engage with markets, and move out to civil society (Pierre and Peter, 2000). This multi-level and multi-actor approach therefore relies more on collaboration, networking and learning (Goodwin and Painter, 1996; Gouldson et al., 2008; Mah and Hills, 2009).

Governance is a relevant perspective to analyse Korea's smart grid developments for a number of reasons. Smart grids require a transition in electricity systems from a fossil fuel-based and centralised model to a more decentralised form. This transition requires the involvement of a larger number of actors in more open electricity systems in which both established actors (such as the established electricity generation companies) and new comers (such as renewable energy developers and well-informed consumers) interact. The traditional producer-consumer relationship changes to one in which well-informed consumers can play a much more active role in energy saving and even function as a "co-provider" of electricity supply (Nye et al., 2010). These changes also raise a number of key governance issues, such as the changing role of the state, power asymmetries, conflicts of interest, regulatory governance, participatory governance and trust (Beierle and Cayford, 2002; Hood et al., 2000).

Innovation systems perspective

Since the late 1980s the idea of systems of innovation has become a major theme in science and technology studies in the western literature (Edquist, 1997). The notions of "socio-technical" system and the multi-level perspective are particularly useful to highlight the complexity and dynamics of the transition of energy systems to accommodate smart grid technologies.

The notion of socio-technical systems emphasises that transitions of electricity systems are embedded in a broader context that goes beyond technological change. According to Geels et al (2004, p.1), "such system innovations not only involve new technological artefacts, but also new markets, user practices, regulations, infrastructures and cultural meanings". This notion emphasises the importance of co-evolution of technological, social and environmental systems (Kemp and Rotmans, 2005).

The multilevel scheme of Rip and Kemp (1998) distinguishes three inter-related levels of changes: the landscape, regime and niche levels of socio-technical systems. The landscape consists of a range of contextual factors that influence technological developments (Geels, 2001). Regimes refer to rules and institutions that are built up around an established technology (Geels, 2001). Niches are "protected" space in which innovation takes place (Geels, 2001).

This literature is particularly instructive in highlighting the drivers of change and what interactions should be created at the three inter-related levels to drive changes. Coenen et al. (2010) and Watson et al. (2006, 2007) have shed light on how government policies, business incentives and consumers' motivations have to converge to overcome barriers such as the problems of "lock-in" and the lack of a level playing field.

The complementary insights of the perspectives of governance and innovation systems provide us with a general framework for guiding and evaluating changes in smart grid-related innovation systems. This framework suggests that governments, business and consumers are all key players who interact in new kinds of relationships at the three inter-related levels of landscape, regime, and niche, and that such relationships can drive changes in socio-technical systems. Government has an important role to play in formulating coherent policy, fiscal and regulatory frameworks, articulating expectations, creating a level playing field, and enhancing market certainty for innovation processes (Coenen, et al., 2010; Watson, et al., 2006). The business sector needs to collaborate with government to develop new business models such as energy service contracts that can put business incentives and consumers' motivations in place to drive towards changes in energy infrastructure (Watson et al., 2006). Consumers who have access to better information through smart meters can play an active role in microgeneration investment as well as energy saving (IEA, 2011). This framework suggests that the interactions of these key actors would create important forces for change at and between landscape, regime and niche levels. Such forces for change, including visioning, expectation articulation, institutional arrangements, social networking, niche experimentation, second-order learning and feedback are critical for accelerating the mainstreaming of smart grids (Coenen et al., 2010; Watson et al., 2006; Rip and Kemp, 1998).

The literature however is limited in illuminating how system innovations occur in the specific context of smart grids, and is particularly so in the Asian context. Our study therefore addresses the following key questions in the case of Korea: Who were the key actors and what were their motivations? How did key actors interact at the landscape, regime and niche levels in the socio-technical system for smart grids? And how did such interactions facilitate or constrain the development of smart grids?

FACTORS UNDERPINNING KOREA'S SMART GRID DEVELOPMENT

Korea's socio-technical system for smart grids possesses a number of characteristics which appeared to create opportunities as well as barriers for the development of smart grids. These factors can be found at the landscape, regime and niche levels of the socio-technical system.

Landscape Level

At the *landscape* level, macroeconomic policies, a tradition of government-led growth strategies, pre-existing strengths in information technology, and worldviews on GHG reduction are key factors in Korea.

Korea's macroeconomic policies, particularly the "Low Carbon, Green Growth" vision has played a significant role in the emergence of smart grids. The Green Growth Vision introduced by President Lee Myung Bak in the wake of the financial crisis in 2008 was to develop green energy technologies, including smart grids as "new growth engines" (Kang and Park, 2011).

Another landscape factor is a tradition of government-led growth strategies. The government has had a central role in spearheading the rapid development of strategic industries since the 1950s (Ovum Consulting, 2009), including the heavy and chemical industries, petrochemicals, and shipbuilding in the 70s and 80s, and more recently the growth of the electronics and information and communication technology during the 1990s (Kang, 1996). Korea's recent move into the emerging industry of smart grids is an extension of this government-led growth strategy into the energy sector.

The pre-existing strengths of Korea in IT and other smart grid-related industries is another key factor at the landscape level. This high-tech industrialised economy (CIA, 2011) is particularly well placed to enter the global smart grid market because this industry can be built upon Korea's existing IT infrastructure and research networks.

Worldviews on GHG reduction are another important landscape factor. Although Korea is a non-Annex 1 country of the Kyoto Protocol and is not obliged to commit to mandatory emissions reduction targets, it has voluntarily committed to reducing CO_2 emissions by 30% by 2020 based on a "business as usual" baseline, implying a 4% cut from 2005 levels (Jones and Yoo, 2010). Smart grid development has been regarded as a key strategy to meet this commitment (MKE and KSGI, 2010).

Another landscape factor is Korea's long-standing reliance on government-funded institutes as a bridge between government and industry. A key institute for smart grids is the Korea Smart Grid Institute (KSGI). The Ministry of Knowledge and Economy (MKE) is the government agency which is responsible for formulating and implementing the national smart grid vision and policies. KSGI is in effect the executive arm of MKE. Fully funded by the government, KSGI is designated as the secretariat for smart grid initiatives, and it is responsible for implementing the national smart grid roadmap, managing the Jeju Smart Grid Testbed, and coordinating and managing R&D funding.

Regime Level

At the *regime* level, a number of dominant practices, rules and shared assumptions (Kemp and Rotmans, 2005) in Korea's electricity system have shaped the setting in which smart grids have evolved. These include: Korea's partial electricity market reform, a government-led approach to energy policy-making and management, limited market competition, structural problems of Korea Electric Power Corporation (KEPCO), distorted pricing systems and public distrust.

A defining feature of Korea's electricity sector is the presence of partial electricity market reforms. The reforms, which were first launched in 1999, introduced competition into the generation industry in 2001 by dividing KEPCO's generation capacity into six power generation companies (GenCos) as KEPCO's subsidiaries (Lee and Ahn, 2006; Vine et al., 2006). The reforms also created a new institution, the Korea Power Exchange (KPX), as an independent NGO which coordinates the flow of electricity in all regions of Korea (KPX, 2011). Plans for further reforms, including the privatisation of five of the six state-owned GenCos however stalled in 2004 as a result of serious opposition from labour unions for concerns relating to price fluctuations and supply reliability (Vine et al., 2006; Lee and Ahn, 2006).

As a result of the partial market reform, considerable market distortion including state monopolies, energy subsidies and distorted pricing systems remained. To date, the government has retained its commanding position throughout the entire electricity sector through the state-owned KEPCO. KEPCO, which owns 92% of the total electricity generation capacity in Korea (Park, 2011), has remained vertically integrated in nature. It is the sole transmission, distribution and retail company (Park, 2011)(Figure 1). Even in the generation industry where competition has been introduced, the daily operations of five of the six KEPCO-owned Gencos are being managed by two government agencies, namely the MKE and the Ministry of Strategy and Finance (MOSF) (Figure 1). As such, the government manages the daily operation of the five Gencos rather than adopting an arm's-length approach.

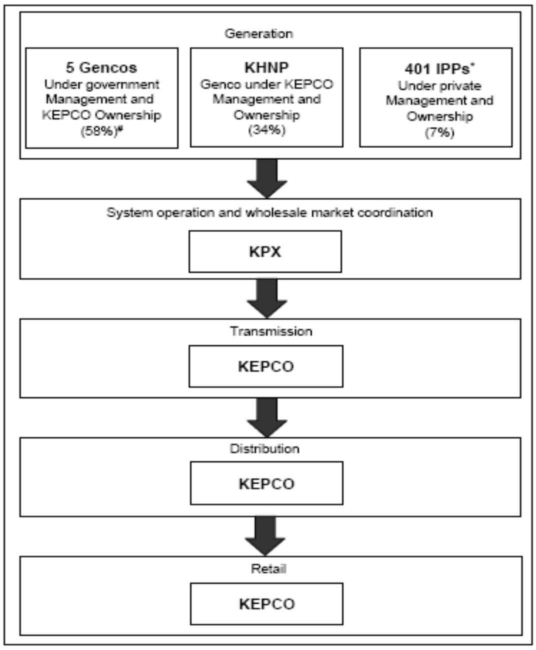


Figure 1: The electricity sector in Korea

numbers in brackets are percentage of generation capacity in Korea in 2009
(Source: Authors; data from KPX, 2010; Park, 2011)

Market distortions have given rise to another key regime factor – a highly distorted tariff system. On the one hand, the tariff system has been distorted by the cross-subsidy policy from residential and commercial to industrial and agricultural sub-sectors (Lee and Ahn, 2006). At present, the household tariff is approximately 114 KRW/kWh, which is 54% higher than the industrial tariff (which is approximately 74 KRW/kWh), and 37% higher than the average retail price to all consumers (Table 1). On the other hand, tariffs have been modulated by the government and have remained at relatively low levels to control inflation (Lee and Ahn, 2006).

These features of Korea's electricity sector have created opportunities as well as barriers for smart grid development. The vertically integrated nature of KEPCO has ensured it has ready access to the planning and management in grid facilities that are critical components of smart grid infrastructure. In addition, Korea's government-led approach to energy planning and management (Vine et al., 2006) has created a political obligation for KEPCO to implement the national smart grid vision. KEPCO has become a first-mover into the emerging smart grid business and has committed to making a US$7.18 billion investment by 2030 (Cho, 2011).

However, the vertically integrated nature of KEPCO has posed limitations for smart grid developments. New entrants including independent power producers (IPPs) such as renewable entities can broaden energy options in smart grids. However, although five of the six GenCos are in competition under the cost-based pool system (Byrne et al., 2004; Interview: 09/2011; Lee and Ahn, 2006), market competition between the five GenCos and the IPPs has remained limited. The 401 IPPs are numerous. They however contributed only 7% of the total generation capacity in 2009 (KPX, 2010; Park, 2011). Similarly, the 353 renewable companies represented only 2% of the total installed capacity as of April 2011

(Park, 2011).

Furthermore, the distorted pricing system and the associated public distrust of the government and KEPCO appear to limit the opportunity for introducing dynamic pricing systems. Dynamic pricing, which generally imposes higher price during peak periods and offering lower prices during off-peak periods, is a key to effective demand response programmes and provides an alternative to the distorted system in Korea (Interviews 05/2011; 06/2011). However, the public has been highly skeptical about the government's motives in changing tariff levels. Although dynamic pricing has the potential to deliver price reductions (Albadi and El-Saadany, 2008), the public would regard introducing new dynamic pricing systems for smart grid as simply the government and KEPCO disguising tariff increases (Interviews: 06/2011; 07/2011). Long-standing public distrust is rooted in a sense of inequity that has emerged from the cross-subsidy policy (Interviews: 4/2011; 6/2011; 7/2011).

Another regime factor is the presence of three structural problems in Korea's electricity sector - reliance on imports, peak load problems and financial losses. The peak load problem has threatened the reliability of the electricity system with potential blackouts (EMSC and KPX, 2009; Interview: 08/2011). The reserve margin against peak load has been decreasing since 2003 (except 2008), and reached a record low of 6.2% in 2010 (KPX, 2011). KEPCO also faced financial problems. It has suffered from financial losses amounting to a total of 3 trillion won for the years between 2008 and 2010 (KEPCO, 2011).

These problems have motivated the government and KEPCO to explore smart grids as a potential solution. Dynamic pricing which could be introduced as a component of the smart grid policy is perceived by KEPCO as an opportunity to introduce changes into the current tariff system (Interview: 03/2011). The opportunities to introduce dynamic pricing also provide an opporuntiy to manage peak load problems more effectively through price-responsive demand. Studies elsewhere show that dynamic pricing has the potential to reduce peak loads by up to 16% (see for example Faruqui et al., 2010b).

Niche Level

At the *niche* level, a major development has been the establishment of the Smart Grid Testbed on Jeju Island in 2009. The Testbed is a government-led large-scale niche experimentation project for domestic companies to test and demonstrate their technologies for global markets.

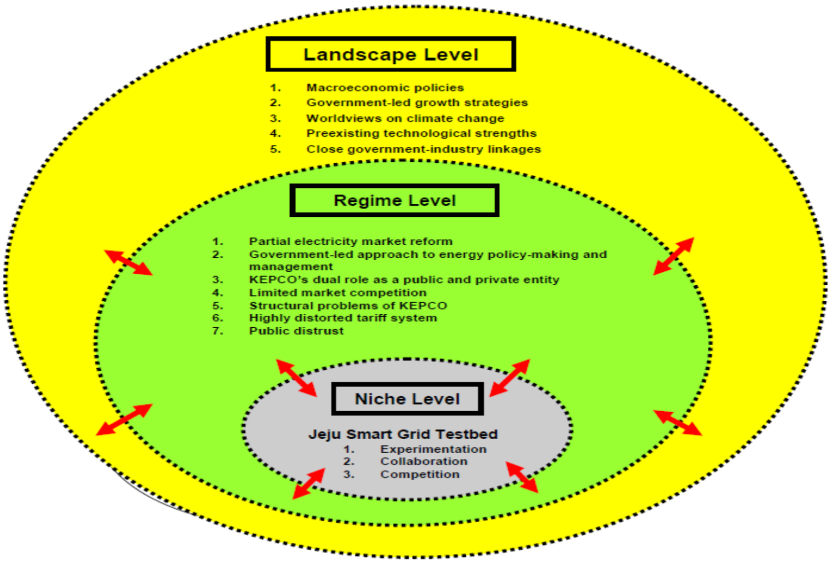
The Testbed, with a geographical area of 185 km^2, is located in a remote community in the rural, north-eastern part of Jeju Island. Jeju won a national competition and became the hosting province for the Testbed in June 2009 (Interview: 10/2011; KGSI, 2011). Jeju was selected for good reasons. Jeju, as Korea's only autonomous province, has the flexibility in institutional, regulatory and legal arrangements and therefore is particularly well placed to pioneer innovative incentives for R&D investment and to experiment with new policy ideas (e.g. dynamic pricing) which are politically sensitive and would be difficult to implement on a nationwide scale.

The Testbed has two distinctive features. The first is its emphasis on collaboration between the central government, industries and the Jeju local government. 12 consortia, involving approximately 170 companies, have been formed in the Testbed. Those companies came from diverse sectors that range from energy to information technology, to steel manufacturing, electric vehicles and home appliance manufacturing. The involvement of well-known companies including KEPCO, KPX, Samsung, LG and Hyundai has enhanced the prominence of the Testbed.

The second key feature is the involvement of local residents. Approximately 2,000 households, about one third of the total households within the Testbed geographical boundary, are participating in the Testbed on a voluntary basis.

To sum up, three features of the socio-technical system are noteworthy. First, as Figure 2 shows, the transition of this socio-technical system involved a wide range of factors that extend beyond technological one. The system is influenced by factors that range from worldviews to macroeconomic policies, a distorted tariff system, the presence of public distrust, and to experimentation in a remote island. Second, a broad range of actors including the government, established actors in the electricity sector (such as KEPCO and KPX), new entrants (such as the IPPs), industries, institutes, consumers and global companies interacted and shaped the path and scale of the smart grid developments. Third, the interactions of the actors are taking place across various governing levels in a multi-level system that comprises of the landscape level at the macro level, the regime level at the meso level, and the niche level at the micro level.

Figure 2: An innovation system approach
to understanding the development of smart grid in Korea



(Source: authors)

DISCUSSION: THE STRENGTHS AND WEAKNESSES OF THE GOVERNMENT-LED APPROACH

The emergence of the Korean model, which is distinguished by a government-led and export-oriented approach, poses a number of important questions: to what extent has this model driven changes in the innovation system? Who are driving (or creating barriers) for change and how? Before discussing our findings, we must begin by acknowledging that our observations should be interpreted with caution. In electricity sectors where large existing investments in fossil fuel-based and nuclear infrastructure has been made, the lock-in effect as a result of sunk investments in infrastructure of established energy technologies tend to make short-term transitions towards smart grids difficult to achieve (UNEP, 2006). In addition, many of the smart grid initiatives, notably the Testbed are at the pilot stage and are on-going. It would be premature to provide an evaluation of the successes and failures of the Korean model. Our observations about causal connections are therefore tentative.

Despite these limitations to our data and observations, our analysis leads us to make some observations relating to the strengths and weaknesses of Korea’s government-led approach. The Korean government has been motivated by a number of factors and has played a pivotal role in driving changes throughout the landscape, regime and niche levels in the socio-technical system. It has initiated, incubated, and set the pace for the development of smart grids through the announcement of the national smart grid vision, the formulation of the national Smart Grid Roadmap, the creation of the Smart Grid Institute as an executive arm of the government to implement the roadmap, and the launch of the Smart Grid Testbed to facilitate experimentation through government-industry-consumer collaboration for technological innovation.

Korea’s government-led and export-oriented model however has also suffered from some weaknesses. In contrast to our framework that suggests government policies, business incentives and consumer motivations have to converge to drive changes in socio-technical systems, our analysis has found that those desirable interactions have been limited in three aspects.

The first weakness is related to the government's regulatory and policy capacity. Our framework suggests that the government has an important role to play in articulating expectations and reducing uncertainty in innovation processes by formulating a coherent regulatory and policy framework (Coenen et al., 2010). In Korea however a strong regulatory and policy framework is still lacking. According to some industrial experts, the policy support for smart grid has been clouded as possible changes in leadership in the upcoming presidential election and National Assembly election in 2012 may lead to a withdrawal of policy support (Interviews: 05/2011; 06/2011). The enactment of the Smart Grid Act in April 2011 could have ensured policy consistency across presidential terms. However, the passage of this law itself was delayed five months from December 2010 to April 2011 as consensus between various stakeholders was difficult to achieve (Interviews: 05/2011; 06/2011). The recent promulgation of the corresponding decree and rule has been regarded as a key to strengthen the implementation and enforcement of the Act. However, there are concerns that the current regulatory framework is still not sufficient to drive major stakeholders, particularly utilities, to break the inertia and move away from the "lock-in" situation (Interview 13/ 2012).

The second weakness is related to the business sector. Smart grid developments require a new producer-consumer relationship in which the business sector and the government would need to collaborate and develop new market rules, user practices and energy infrastructure to enable the more active participation of consumers (Nye et al., 2010). Business models such as energy service contracts therefore are a critical element for accelerating smart meter roll-outs and major changes in energy infrastructure (Watson et al., 2006; Watson et al., 2007). However, although business models have been identified as one of the strategic pilot areas in Stage 1 of the Testbed, experimentation on business models have been negligible, if any (Interviews 5/2011; 6/2011). Driven by the aspiration to access global markets, the Testbed has a rather narrow focus on R&D with a much higher priority given to demonstrate Korea's technological capacity.

The third weakness relates to consumer engagement, in particular the upscaling of experimentation. At present, Korea adopts a flat rate electricity pricing system. Dynamic pricing presents an opportunity for Korea to address the problems of energy subsidies and other structural problems of the electricity sector such as KEPCO's long-standing financial deficit. Elsewhere, countries such as Japan and China have also been contemplating dynamic pricing as an alternative which is more politically feasible to changing the tariff level (JapanFS, 2011; Cheng, 2010; Lin and Jiang, 2012).

Dynamic pricing can take place in various forms, and the three main forms are real-time pricing, critical peak pricing and peak time rebate (DOE, 2008). In Korea, a rebate-based real time pricing (RTP) pilot has been introduced in Stage 2 of the Testbed since June 2011. In order to secure participation, the system is designed in such a way that the participating households would not suffer loss. Consumers who sign up to the RTP would receive a rebate for the electricity saved. The rebate system caps the bill to existing rates so that even if a household would have to pay more under the RTP system it would not be charged more than the existing rate. Furthermore, households participating in the Testbed were offered facilities and equipments such as smart meters and PV panels at no cost (Interview 09/2011).

Evaluations of the Testbed are on-going and are expected to be released by mid 2013

(Interview: 11/2011). Although it is premature to assess the achievements of the Testbed, this pilot – the first of its kind in Korea –has exposed weaknesses in two critical areas. The first weakness is the low participation rate. This rebate-based pilot has been tested in some 2,000 rural households who reside within the geographical boundary of the Tested, and who volunteered to participate. These 2,000 households, however, represent only one third of the total household residing within the Testbed area, about 1% of the total number of households on Jeju (KOSTST, 2011a), and just 0.01% of the total households of the country (KOSTST, 2011b).

Although experiences elsewhere with dynamic pricing have reported positive results (see for example Faruqui & Palmer, 2011), the Jeju pilot was not the case. The low participation rate is particularly a concern as the actual reduction in electricity consumption achieved appears to be minimal. According to a senior executive of KEPCO who is a core member managing the pilot, a preliminary analysis on 105 consumer bills collected in September 2011 shows that only 27 consumers reacted to the real time pricing and the reduction of electricity bills ranged from 3 to 5% on average (Interview 12/2011). Evaluations on the changes in energy consumption and peak load have been on-going, and are not publicly accessible as of October 2011 (Interview 12/2011). Preliminary observations from industrial experts suggest that KEPCO's lack of marketing knowledge and skills appears to be a key factor for the low participation rate and poor consumer responses in a Korean context in which electricity price has been modulated at a relatively low level that make dynamic pricing difficult to be effective (Interview 13/2012). Whether other barriers identified in the western experiences such as a lack of economic incentives and inertia can also apply in this pilot is an important area that needs to be better understood (DOE, 2008; Hargreaves et al., 2010).

The second weakness is related to the programme design. While the rebate element and the provision of free facilities can be regarded as a pragmatic and transitional strategy to attract consumer participation, a major drawback of this approach is its limits in achieving second-order learning. Second-order learning emphasises that learning for innovation should extend from technological advancement to testing actual changes in user practices, new markets, regulator performance and energy infrastructure (Coenen et al., 2010). In contrast to our framework which highlights the critical role of demonstration projects as a protected and "niche" area in which new ideas can be tested and second-order learning can take place, this pilot is not able to explore critical issues such as consumer acceptability of dynamic pricing and how feedback information from smart meters can change consumption behaviour.

Those weaknesses may limit the potential of the upscaling this experimentation. On the one hand, if this rebate-based system is scaled up to a city or national scale without introducing major changes in the incentive system, such a system would be unlikely to build up policy legitimacy. Instead, it may crowd out the adoption of dynamic pricing options. On the other hand, this pilot, which is characterised by its voluntary and virtually zero-risk nature, appears to be designed to reflect many of the unique contexts of the Jeju pilot. The results of this pilot may therefore not be generalisable from this rural community to other parts of Korea and elsewhere in the world where the socio-political and economic contexts can be substantially different.

CONCLUSION

Driven by its "Green Growth Vision", Korea embarked on its smart grid initiatives in 2009. Within just three years the country has made some important progresses in the development of smart grids although problems still exist. This paper adopted the perspectives of governance and innovation systems as a general analytical framework for understanding and critically examining the recent evolution of smart grids in Korea.

We have two major findings. First, we have revealed the complexity of the socio-technical system by highlighting the breadth and depth of those factors which have influenced smart grid development in Korea. Our findings reinforced the view that the convergence of policies, business incentives and consumer motivations is critical to drive changes in socio-technical systems (see for example Watson et al., 2006, 2007). We have demonstrated how the government, business and consumers interacted at and across the landscape, regime and niche levels, and how such interactions facilitated or constrained smart grid development. Various factors that span from macroeconomic policies and global views, to partial electricity market reform and public distrust, and to experimentation in a demonstration project are found to be crucial in the socio-technical system for smart grids in Korea.

Second, our analysis has shed light on the mechanisms for change in socio-technical systems. It is important to understand how socio-technical systems manage to change. However, the barriers to changes must also be understood. We found that the presence of partial electricity market reform and public distrust has created barriers for Korea to develop some of the favourable conditions for change. Favourable conditions such as policy consistency, second-order learning and the development of financially viable business models (see for example Watson et al., 2006, 2007) are still lacking in Korea. These observations can provide a better understanding of the “lock-in” phenomenon (see for example Coenen et al., 2010).

Our findings have some policy implications. A systemic perspective is needed for policy in order to accommodate the changes required for smart grid development. Regulatory reforms, particularly price-setting mechanisms, and consumer engagement are priority areas for policy change. Experiences elsewhere suggest that smart grid literacy programmes may be useful in enhancing the public understanding of such complex issues relating to dynamic pricing and for restoring public trust (Executive Office, 2011; SGA, 2011).

Our findings are country- and sector-specific. We recognise that there are limits to the generalisability of our findings to other countries and other socio-technical systems in non-electricity sectors. The highly regulated electricity sector in which market signals and market competition play a much lesser role than administrative regulation has set Korea apart from other economies such as the US in which electricity sectors are liberalised. However further research may generate useful results if, for example it investigates the transferability of the findings to China – which has also been pursuing smart grid initiatives. China’s electricity sector also remains highly regulated as a result of partial electricity market reforms.

Acknowledgement

We would like to acknowledge appreciation to our anonymous interviewees in Korea for contributing their insights and providing useful information. We thank the two anonymous reviewers for their careful reading and valuable comments on our paper. We remain solely responsible for any errors and omissions in the findings and interpretations expressed in this paper. We gratefully acknowledge the funding of this research by the University of Hong Kong through the Initiative on Clean Energy and Environment.

Appendix 1: List of Interviewees

As some interviewees agreed to be interviewed anonymously, this study indicates interviews by number. The first two digits indicate the interview numbers, and that followed by the year of interviews. The interview formats included face-to-face interview (FI), telephone interview (TI) and email correspondence (EC).

Code	Interviewees Background	Type of Interview	Date of Interview
01/2011	A senior executive, Korea Smart Grid Institute (KSGI)	EC	27 May, 2011
02/2011	A senior executive, Korea Power Exchange (KPX)	TI	31 May, 2011
03/2011	Same interviewee as 01/2011, KSGI	FI	25 April, 2011
04/2011	An associate professor, Graduate School of Environmental Studies, Seoul National University	FI	26 April, 2011
05/2011	Same interviewee as 02/2011, KPX	FI	26 April, 2011
06/2011	A senior executive, Korea Electric Power Corporation (KEPCO)	FI	26 April, 2011
07/2011	A post-graduate student, Graduate School of Environmental Studies, Seoul National University	FI	25 April, 2011
08/2011	A senior executive, Total Operation Centre, KPX	FI	28 April, 2011
09/2011	Same interviewee as in 06/2011, KEPCO	EC	16 June, 2011
10/2011	A government official of Smart Grid Division, Jeju Special Self-Governing Province	FI	28 April, 2011
11/2011	Same interviewee as 02/2011, KPX	TI	27 October, 2011
12/2011	Same interviewee as in 06/2011, KEPCO	TI	27 October, 2011
13/2012	Same interviewee as 02/2011, KPX	TI	30 January, 2012

References

Albadi, M. H., & El-Saadany, E. F. (2008). A summary of demand response in electricity markets. Electric Power Systems Research, 78, 1989–1996.

Beierle, T., Cayford, J., 2002. Democracy in Practice: Public Participation in Environmental Decisions. Resources for the Future, Washington, D.C.

Cho, M. Y., 2011. S. Korea KEPCO to invest $7.2 bln in smart grid by 2030. Via <http://www.reuters.com/article/2011/02/18/kepco-korea-idUSTOE71H00R20110218> (accessed 20/05/2011).

CIA, 2011. The World Factbook, South Korea. Central Intelligence Agency. Via <2011, from https://www.cia.gov/library/publications/the-world-factbook/geos/ks.html> (accessed 20/06/2011).

Coenen, L., Raven, R., & Verbong, G., 2010. Local niche experimentation in energy transitions: a theoretical and empirical exploration of proximity advantages and disadvantages. Technology in Society, 32(4), 295-302.

Devine-Wright, P. (2007). Energy citizenship : psychological aspects of evolution in sustainable energy technologies. In J. Murphy (Ed.), Governing Technology for Sustainability (pp. 63-89). Earthscan, London; Sterling, Va.

DOE. (2008). What the Smart Grid Means to Amercians. Washington, D.C.: The United States Department of Energy. Via <http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/ConsumerAdvocates.pdf> (accessed 10/01/2012)

Edquist, C., 1997. Systems of innovation approaches - their emergence and characteristics. In: Edquist, C., (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. London; Pinter, Washington, pp. 1-35.

EIA, 2010. Country Analysis Briefs, South Korea. Energy Information Administration. Via < www.eia.doe.gov. File://Z:/NewCABs/V6/South_Korea/Full.html> (accessed 20/06/2011).

EIA, 2011. International Energy Statistics. Energy Information Administration. Via < http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2 > (accessed 25/05/2011).

EMSC and KPX, 2009. 2009 Annual Report: Electricity Market Trends & Analysis. Electricity Market Surveillance Committee, Korea Power Exchange, Seoul.

EPRI, 2011. EPRI Analysis Estimates Costs-Benefits of Fully Developing Smart Grid, via < http://my.epri.com/portal/server.pt/gateway/PTARGS_0_234325_317_205_776_43/http%3B/uspalecp604%3B7087/publishedcontent/publish/epri_analysis_estimates_costs_benefits_of_fully_developing_smart_grid_da_777189.html (accessed 20/06/2011).

Executive Office, 2011. A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future. Executive Office of the President of the United State, Washington, D.C.

Faruqui, A., Harris, D., Hledik, R., 2010a. Unlocking the 53 billion Euro savings from smart meters in the EU: How increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy, 38, 6222-6231.

Faruqui, A., Hledik, R., & Sergici, S., 2010b. Rethinking prices: the changing architecture of demand response in America. Public Utilities Fortnightly, January, 30-39.

Faruqui, A., & Palmer, J. (2011). Dynamic pricing and its discontents. Regulation, Fall, 16-22.

G20, 2010. About G20, via <http://www.g20.org/about_what_is_g20.aspx> (accessed 20/06/2011).

GE Energy. (2010). Fast Facts: U.S. Consumer Impressions of the Smart Grid. Via <http://www.itsyoursmartgrid.com/pdf/assets/resources/downloads/GE_U%20S%20%20smart%20grid%20survey%20fast%20facts.pdf> (accessed 10/06/2011)

Geels, F., 2001. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Paper presented at the Nelson and Winter Conference (June 12-15, 2001). Aalborg, Denmark. Organised by DRUID (Danish Research Unit for Industrial Dynamics), Research Policy and Corporate and Industrial Change.

Geels, F., Elzen, B., Green, K., 2004. General introduction: system innovation and transitions to sustainability. In: Elzen, B., Geels, F., Green, K., (Eds.), *S*ystem Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Cheltenham, UK; Northhampton, MA, USA: Edward Elgar, pp. 1-18.

Goodwin, M., Painter, J., 1996. Local governance, the crises of Fordism and the changing geographies of regulation. Transactions of the Institute of British Geographers, 21(4), 635-648.

Hargreaves, T., et al. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy, 38(10), 6111-6119.

Hood, C., James, O., & Scott, C., 2000. Regulation of government: has it increased, is it increasing, should it be diminished? Public Administration, 78(2), 283-304.

IEA, 2010. CO_2 Emissions From Fuel Comubstion Highlights, 2010 Edition. International Energy Agency. Paris. http://www.iea.org/co2highlights/co2highlights.pdf

IEA, 2011. Technology Roadmap: Smart Grids. International Energy Agency. Paris. http://www.iea.org/papers/2011/smartgrids_roadmap.pdf.

JapanFS. (2011, October 17). Kitakyushu to Test Dynamic Pricing for Electricity in FY2012. Via <http://www.japanfs.org/en/pages/031319.html> (accessed 25/10/2011).

Johnson, J. (1990). Selecting Ethnographic Informants. Newbury Park, Calif.: Sage Publications.

Kang, M. J., Park, H., 2011. Impact of experience on government policy toward acceptance of hydrogen fuel cell vehicles in Korea. Energy Policy, 39(6), 3465-3475.

Kemp, R., & Rotmans, J., 2005. The management of the co-evolution of technical, environmental and social systems. In: Weber, M., Hemmelskamp, J. (Eds.), Towards Environmental Innovation Systems. Berlin; New York: Springer, pp. 33-54.

KEPCO, 2011. Dividends Payment Section, via < www.kepco.co.kr> (accessed 25/05/2011).

KOSTAT, 2011a. Preliminary Results of the 2010 Population and Housing Census. Statistic Korea, Ministry of Strategy and Finance, the Republic of Korea. http://kostat.go.kr/portal/english/news/1/1/index.board?bmode=read&aSeq=245048 (accessed 07/11/2011)

KOSTAT, 2011b. Results of the 2010 Population and Housing Census (Households and Housing Units.) Statistic Korea, Ministry of Strategy and Finance, the Republic of Korea. <http://kostat.go.kr/portal/english/news/1/9/index.board?bmode=read&bSeq=&aSeq=249192&pageNo=1&rowNum=10&navCount=10&currPg=&sTarget=title&sTxt=> (accessed 07/11/2011)

KPX, 2010. Handbook of Electricity Statistics in Korea (as of Dec 2009). Korea Power Exchange, Seoul.

KPX, 2011. Korea Power Exchange Website: About KPX, via <www.kpx.or.kr/english> (accessed 18/05/2011).

KSGI, 2011. Korea Smart Grid Institute Website, via <http://www.smartgrid.or.kr/10eng2-4.php> (accessed 18/06/2011).

Lan, X. (2010, October 28). Why the tiers? China mulls a tiered pricing system to curb household electricity use. Beijing Review, 43, via <http://www.bjreview.com/business/txt/2010-10/25/content_306106.htm> (accessed 25/01/2012).

Lee, B. H., & Ahn, H. H., 2006. Electricity industry restructuring revisited: the case of Korea. Energy Policy, 34(10), 1115-1126.

Lee, M. K., 2005. Reviewing tax system and its reform plan for the fuel market in South Korea. Energy Policy, 33(4), 475-482.

Lin, B., & Jiang, Z. (2012). Designation and influence of household increasing block electricity tariffs in China. Energy Policy, *42*(March), 164-173.

Mah, D. and Hills, P. 2009. Collaborative Governance for Sustainable Development: Wind Resource Assessment in Xinjiang and Guangdong Provinces, China, Sustainable Development, In Press, Corrected Proof, Available online 1 June, 2010, doi: 10.1002/sd.466.

MKE and KSGI, 2009. For the World's Green Growth - Jeju Smart Grid Test-bed in Korea. Ministry of Knowledege Economy and Korea Smart Grid Institute. Seoul.

http://www.smartgrid.or.kr/Ebook/JejuTestBed.pdf.

MKE and KSGI, 2010. Korea's Smart Grid Roadmap 2030 - Laying the Foundation for Low Carbon, Green Growth by 2030. Ministry of Knowledge Economy, Korea Smart Grid Institute, Seoul. http://www.smartgrid.or.kr/10eng4-3.php.

MOLEG. (2011a). Act on the Creation and Facilitation of Use of Smart Grids. Seoul: Ministry of Government Legislation, Republic of Korea. Via <http://www.moleg.go.kr/english/searchListR.mo?q=smartgrid&x=31&y=11> (accessed 10/01/2012).

MOLEG. (2011b). Enforcement Decree of Act on the Creation and Facilitation of Use of Smart Grids. Seoul: Ministry of Government Legislation, Republic of Korea. Via <http://www.moleg.go.kr/english/searchListR.mo?q=smartgrid&x=31&y=11> (accessed 10/01/2012)

MOLEG. (2011c). Enforcement Rule of the Act on the Creation and Facilitation of Use of Smart Grids. Seoul: Ministry of Government Legislation, Republic of Korea. Via <http://www.moleg.go.kr/english/searchListR.mo?q=smartgrid&x=31&y=11> (accessed 10/01/2012)

Nye, M., Whitmarsh, L., Foxon, T., 2010. Sociopsychological perspectives on the active roles of domestic actors in transition to a lower carbon electricity economy. Environment and Planning A, 42, 697-714.

Ovum Consulting, 2009. Broadband Policy Development in the Republic of Korea: A Report for the Global Information and Communications Technologies Department of the World Bank. Ovum Consulting, London.

Park, K. S., 2011. The Korean Electric Power Industry & Corporate Governance of KEPCO. Paper presented at the 6th Meeting of the OECD Network on Corporate Governance of State-Owned Enterprises in Asia (May 17-18), Seoul. http://www.oecd.org/dataoecd/35/60/48049493.pdf.

Pierre, J., Peter, G., 2000. Governance, Politics and the State. Macmillan Press, Basingstoke, Hampshire.

Ragwitz, M., Held, A., Stricker, E., Krechting, A., Resch, G., Panzer, C., 2010. Recent Experiences with Feed-in Tariff Systems in the EU - A Research Paper for the International Feed-in Cooperation: A report commissioned by the Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU).

Rip, A., & Kemp, R., 1998. Technological change. In: Rayner S., Malone, E. L. (Eds.), Human Choice and Climate Change. Columbus, Battelle Press, Ohio, Volume 2, pp.327-399.

SGA, 2011. Smart Grid Australia: Maximising Consumer Benefits. Smart Grid Australia, Melbourne. http://www.smartgridaustralia.com.au/uploads/documents/VIC060411_Consumer_Working_Group.pdf.

UNEP, 2006. Global Environment Outlook Year Book 2006. Nairobi, United Nations Environment Program. Kenya.

Vine, E., Rhee, C. H., Lee, K. D., 2006. Measurement and evaluation of energy efficiency programs:

California and South Korea. Energy, 31(6-7), 1100-1113.

Watson, J., Sauter, R., Bahaj, B., James, Patrick,, Myers, L., Gann, D., et al. (2007). Integrating Micro-Generation into Energy Networks and Buildings : Full Research Report. ESRC End of Award Report, RES-338-25-0003. Swindon: ESRC.

Watson, J., Sauter, R., Bahaj, B., James, Patrick,, Myers, L., & Wing, R. (2006). Unlocking the Power House: Policy and System Change for Domestic Micro-generation in the UK. Brighton: Science and Technology Policy Research, The Freeman Centre, University of Sussex.

World Bank, 2011. World Development Indicators database (1 July 2011), via < http://siteresources.worldbank.org/DATASTATISTICS/Resources/POP.pdf> (accessed 01/07/2011).