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System Integration of Renewables and Smart Grids in Korea

Supporting Germany's Energy Dialogue with Japan and Korea

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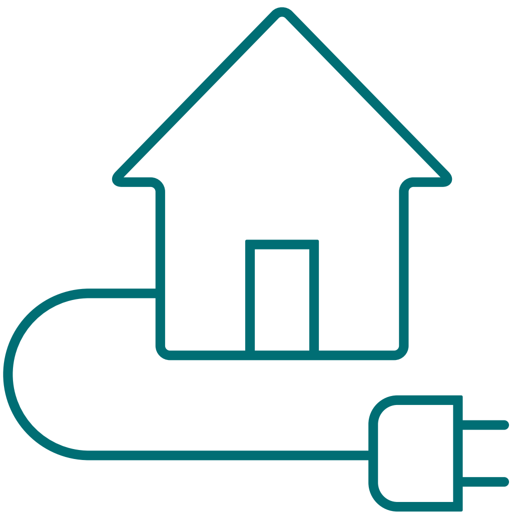

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Abbreviations

AMI	Advanced Metering Infrastructure
BAU	Business as usual
DR	Demand Response
DSM	Demand Side Management
EERS	Energy Efficiency Resource Standards
EMS	Energy Management System
ER&D	Energy Research & Development
ESS	Energy Storage System
EV	Electric Vehicles
FIT	Feed-In Tariff
GORE	grid optimisation before reinforcement before expansion
HVDC	High Voltage Direct Current
IEA	International Energy Agency
KEPCO	Korea Electric Power Corporation
KPX	Korea Power Exchange
LCOE	Levelised Cost Of Electricity
MOTIE	Ministry of Trade, Industry and Energy
NIMBY	Not In My Backyard
PtX	Power-to-X
RD&D	Research, Development & Demonstration
RPS	Renewable Portfolio Standard
SMP	System Marginal Price
V2G	Vehicle to Grid
VRE	Variable Renewable Energy

Executive Summary

In the context of the German-Korean Energy Policy Dialogue, integration of renewable power sources and smart grids have been identified as topics with high relevance. This study aims to support mutual learning and exploration of new fields for collaboration by identifying similarities and differences in the respective status quos, strategies and policies in both countries.

After a short introduction to the South Korean energy situation, Chapter 2 provides an overview of the South Korean power market, its situation regarding renewable power sources and the Korean definition of smart grids. Chapter 3 of this study highlights the major South Korean energy strategies and regulatory frameworks relevant to integration of renewable energies and smart grids. In Chapter 4, the status and perspectives of renewable energy sources integration and smart grids in South Korea are discussed, presenting various demonstrative examples, new business models and the current situation of technology deployment. Chapter 5 puts South Korea in the global context and compares it to Germany. Finally, Chapter 6 draws conclusions and presents recommendations on suitable areas for mutual learning.

As described in Chapter 2, South Korea is a de facto an island in terms of electricity supply. Energy security has always been a major concern of South Korea's governments. A transition to a more sustainable energy system based on domestic renewable energy sources is considered essential for a secure, resilient and sustainable power supply. The Moon government, sworn in in 2017, has provided great impetus for energy transition. South Korea also has great renewable energies potential, estimated to be ten times larger than the current power consumption. However, the country also faces significant challenges.

The liberalisation of the electricity market, started in 1999, was halted in 2003 after only the power generation segment had been liberalised, with still no date set for completing the liberalisation process. Even in the generation segment, competition remains limited, while transmission, distribution and retail remain firmly in the hands of the Korea Electric Power Corporation (KEPCO).

Further, the current share of renewable energies in final energy consumption is low, accounting for only 3% in 2016. According to the 3rd Energy Master Plan (2019), South Korea plans to achieve a share of renewable energies in power generation of up to 35% by 2040. While this represents a great increase compared to status quo, it is rather unambitious in the international context. In addition, the powerful nuclear lobby, along with parts of academia and media, opposes the energy transition which would reduce the role of nuclear power and increase the share of renewables in power generation. Public acceptance for renewable energy has often been lacking and opposition to individual projects (Not-In-My-Back-Yard, NIMBY) has been common in Korea for years.

Nevertheless, South Korea is pushing ahead in various areas of its energy transition. One of these is expansion of smart grids, under which South Korea understands five specific areas: smart power grids, smart places, smart transportation, smart renewables and smart electricity services. Apart from being able to integrate renewables into the power grid, smart grids are envisioned to increase the number of prosumers, create new markets for energy services and improve system resilience against disruptions.

Many technologies and business models have seen rapid progress in Korea. Demand response (DM) market has taken off since regulation was adapted in 2014. Korea is also one of the leading countries in deployment of grid-connected battery energy storage systems (ESS), and both front- and behind-the-meter applications have established themselves. New business models have emerged in the solar photovoltaic (PV) market such as leasing and renting out property for third-party systems. In addition, 15 microgrid projects have been implemented across the country since 2011 and 34 million smart meter have been installed to date.

South Korea has also implemented the legislative framework necessary to support its energy transition. The Energy Act (2006) and Framework Act on Low Carbon and Green Growth (2010) represent the basis for energy planning, including the Energy Master Plan which is updated every 5 years. This plan provides the basic orientation for all aspects of energy policy.

Other aspects of Korea's energy transition have not been as successful. As much as 5GW or about half the total installed PV capacity might not yet have been connected to the grid. Transmission grid expansion is also experiencing setbacks. Lagging expansion of the electric vehicle EV charging infrastructure has often been blamed for slow uptake of EVs. Virtual VPP market has also not taken off yet (change in legislation is expected that will ease market access to small generators).

Compared to other countries, Korea has a good starting point for deployment of smart grids. Apart from a very stable power system, its internet coverage is exceptionally good, with high-speed internet typically available far from urban centres. In comparison to Germany, South Korea pursues a different strategy with regard to integration of renewables: rather than expanding the transmission grid, it bets on smart (micro)grids where renewable power is generated, traded, saved, used and managed, acting as an intermediary between power generation, transmission and use. Smart grids are also expected to increase public acceptance by facilitating citizen participation, as well as increase power system resilience.

This study identifies specific areas where Germany and Korea can learn from each other's experience and where closer cooperation can be mutually beneficial. If Korea pursues its energy transition, Germany's experience with supply and demand forecasting, congestion management, integrated power grid planning and sector coupling will become relevant. Korea can also look to Germany's VPP market for inspiration and learn from Germany's experience with power retail market liberalisation. On the other hand, Korea has been vastly more successful in terms of smart meter deployment, is a global leader in battery energy storage systems (ESS), has an established demand response (DR) market and is betting on becoming a leader in hydrogen and fuel cell applications in transport. Smart (micro)grids where Korea has gathered valuable experience might also become more relevant in Germany in the future as the share of renewables continues to increase.

1 Introduction

South Korea has one of the largest economies worldwide, with an income of more than 30.000 USD per capita in 2018 (Statista 2019). The focus since the mid-1950s was on developing a cheap and reliable electricity supply, leading to a rapid industrialisation in the 1960s and rapid economic growth. Now Korea is characterised by a highly export-reliant industrial structure with a relatively small domestic market. Korea's leading industries such as semiconductors, petrochemicals, steel, and automobiles are energy intensive, making any changes to energy policy a sensitive matter.

Korea is also the 7th largest CO2 emitter in the world and international pressure for it to reduce its emissions has been increasing over the last decade as the severity of climate change has become more evident. At the same time, Korea is facing air quality problems and the government has been put under pressure to act by the domestic public.

While energy transition has not been high on Korea's political agenda in the past, the Moon Jae-in government, sworn in in May 2017, has provided a much needed impetus for it. Mid- to long-term renewable energy targets have been increased under the 3rd Energy Master Plan to 30-35% share of renewables in the power generation mix in 2040. While this is less ambitious than in many other developed nations, it represents a drastic increase compared to the status quo. Many observers have characterised this as a paradigm shift. At the same time, Korea's energy transition faces considerable internal challenges, e.g. high population density, strong nuclear lobby and traditionally low power prices.

This study investigates Korea's status quo and summarizes its efforts with regard to renewable energy integration and smart grids. It puts the findings in international context and compares Korea's situation to that of Germany. Lastly, it identifies specific topics where Korea might profit from Germany's experience, or vice versa, in order to derive recommendations for possible areas of closer cooperation between the two countries.

2 The Korean power market, state of renewable power sources and smart grids

2.1 Structure, roles, regulatory framework of the power market

Historical & political background

Since the end of the Korean War (1950-1953), the main goal of the power industry has been to supply cheap and stable electricity to promote industrial activities. Stable supply has also been given high priority in order to prevent disruptions. To achieve this, the power industry was based on large-scale centralised systems designed to reduce the cost of power through economies of scale. In addition, a single publicly owned corporation was considered the best way to construct and operate power supply facilities.

Structure

The Korea Electric Power Corporation (KEPCO) has traditionally had a monopolistic position in the production, transmission, distribution and sales segments of the domestic power market. The change came in 2000 with the Act on the Promotion of Restructuring of the Electricity Industry, according to which KEPCO's power generation sector was divided into six companies. In addition, the Korea Power Exchange (KPX) was established and operationalised in the same year.

However, due to a changing political environment, as well as fears of price volatility and unstable supply, reforms were halted in 2003 (Kim, Kim 2011). Until today, only the power generation segment has been liberalised while the transmission, distribution and retail segments remain in ownership and control of KEPCO and its subsidiary companies. In addition, contrary to the original plan to introduce a competitive electricity generation, the six power generation companies (GENCOs) are still responsible for more than 80% of the total electricity production (KEPCO 2018).

Apart from these, 18 private power companies[1] and 11 community energy providers[2] are active in the power generation segment (Korea Powerplant Maintenance Association without year). They are obligated to sell electricity to KEPCO through the KPX, which in turn sells it to the end users.

The KPX forecasts the demand for each trading day and receives proposals from the generation companies for the supply of available capacity one day in advance. KPX then determines the system marginal price (SMP) for each trading hour to meet the demand throughout the trading day. This effectively forms the market price. Capacity payments are made to each generation company based on the amount of available capacity indicated in their bids submitted. Large consumers (>10 MWh) can buy power directly from the wholesale market, while smaller and domestic consumers are

[1] As of 2017, the installed capacity of six GENCOs stands at 81,998MW and that of the 18 private power companies at 19,137 MW. The major private companies are Posco Energy, CGN, Dongducheon Dream Power, GS EPS, Pocheon Power, SK E&S, GS Power, Pyungtaek Energy Service and S-Power.

[2] As of 2017, the installed capacity of 11 community energy providers stands at 514MW. They are Daehan City Gas, Hanjin City Gas, Jungbu City Gas, Seoul City Gas, Chungnam City Gas (SK E&S), Taegu City Gas, Samsung Everland, Keangnam Enterprises, KENERTEC, HUCES and Samchully.

subject to regulated tariffs. Electric power volumes above 20 MWh must be traded in the wholesale market.

The tariffs charged by KEPCO for retail electricity supply are determined by a framework established under the Electricity Business Act and the Price Stabilisation Act. The pricing methodology for electricity tariffs is intended to provide for KEPCO to recover costs of purchase, transmission and distribution of electricity at wholesale level as well as an appropriate return on the capital invested in these transactions. The Ministry of Trade, Industry and Energy (MOTIE) approves tariff proposals after prior consultation with the Ministry of Strategy and Finance, and review by the ERC (Electricity Regulatory Commission, established under the Electricity Business Act) (Practical Law 2019).

2.2 The Korean power grid

Korea's electricity system is isolated due to its geographical and political situation.

In 2017, the total power generation capacity in Korea stood at 113,667 MW. Thereof, the highest share was coal (32%), and followed by natural gas (31.3%), nuclear (19.8%), renewables (8.5%), hydropower (4%) and oil (3.4%) (KPX 2018).

In 2018, the total amount of electricity generated was 570,647 GWh. Thereof the highest share was coal (41.9%), followed by natural gas (26.8%), nuclear (23.4%), renewables (6.2%), oil (1%), and hydropower (0.7%). The share of renewables increased by 40% compared to 2016 (KOSIS 2019).

The electricity produced by the six major power companies and private generators transmitted at high voltage to the central distribution station of each region, and from there to the substations. Korea's power system voltage levels are relatively high at 765kV, 345kV, 154kV and 22.9kV. This contributes to reliability of the power system and reduces the transmission losses. In 2016, Korea's transmission-to-loss ratio was only 3.59%. In addition, the use of ultra-high voltage 765kV direct current (HVDC) transmission is increasing, providing further efficiency gains and stability improvements.

Final consumption is divided into industrial, commercial, household, agricultural, educational, streetlight, and late night, with different rates applying for each purpose. Industrial consumption accounts for 55.7% of total electricity sales, commercial 22.2%, residential 13.9%, agricultural 3.5, late night 2.4%, educational 1.6%, and street lighting 0.7% (KOSIS 2018). Total power consumption is increasing from year to year, with an increase in 2018 of 3.6% compared to 2017 and more than 40% compared to 2009. In the households, one of the main drivers for increase in power consumption is the rising number of hot days and with it, the need for air conditioning. In agriculture, the increase has been due to low power rates (42 KRW, about 0.03 EUR per KWh) which are driving the switch from oil to electricity.

In 2005, the price of industrial electricity was 60 KRW (about 0.05 EUR) per KWh, which was just over a half of the 111 KRW (about 0.08 EUR) per kWh which households were paying. Since then, industrial electricity rates have increased by 78% to 107 KRW (about 0.08 EUR) per kWh in 2015. However, after farming and late night rates, electricity rates for industrial users remain the lowest in Korea.

Korea's household electricity prices in 2016, as listed in the OECD's Electricity Information 2017, are 0.12 USD per KWh (about 0.11 EUR), which is low compared to Japan's 0.22 USD (about 0.20 EUR), Germany's 0.33 USD (about 0.30 EUR), Denmark's 0.34 USD (about 0.31 EUR) and the US 0.13 USD (about 0.11 EUR).

Industrial electricity rates in 2016 have been 0.12 USD per KWh (about 0.09 EUR) in Korea, 0.16 USD (about 0.14 EUR) in Japan, 0.14 USD (about 0.13 EUR) in Germany, 0.09 USD (about 0.08 EUR) in Denmark, and 0.07 USD (about 0.06 EUR) in the US.

2.3 Status, targets and potentials for renewables in Korea

As already mentioned, due to its geographical and political situation, South Korea is a de facto an island in terms of electricity supply. With regard to the expansion of renewable energies, this presents South Korea with unique challenges.

A characteristic feature of the South Korean energy industry is its vulnerability to price shocks and supply disruptions due to its high dependence on fossil fuels imports. Currently, over 95% of South Korea's primary energy consumption is imported (IEA, 2018). Against this background, energy security has always been a major concern of Korea’s national governments. A transition to a more sustainable energy system that uses domestic renewable energy sources is considered essential for a resilient and secure energy supply (Hong et al. 2019).

According to Hong et al. (2019), the share of renewable energies in final energy consumption accounted for 3% in 2016 (IEA 2019). However, if the categories for renewable energies as defined by the Organisation for Economic Cooperation and Development (OECD) are applied, the share decreases to a very low 1.1 percent (FES 2017)[3]. On the other hand, the existing renewable energy potential (primarily wind and solar energy) offers South Korea the opportunity to significantly reduce its dependence on energy imports. According to a recent report by the Korea Institute of Energy Research, the potential of renewable energies is estimated at around 6.478 TWh per year (Hong et al. 2019). The potential thus corresponds to more than ten times the total current electricity generation. While increased use of renewable energies certainly represents a technical challenge, it is above all an opportunity to significantly improve the security of energy supply and reduce the vulnerability of the domestic economy.

According to the 3rd Energy Master Plan, MOTIE plans to achieve a renewable energy share in power generation of up to 35% by 2040. This corresponds to a significant increase compared to the current situation. However, with some OECD countries already having renewable energy shares of 35 percent or more (Germany 35%, Spain 38%, Italy 39%, Portugal 50%, Denmark 69%), it is evident that more ambitious target could have been set.

[3] Instead of ‘renewable energy’, the term ‘new and renewable energy’ is used in South Korea. According to the definition, ‚new energy’ includes hydrogen, fuel cells, coal to liquid, and coal to gas, whereas ‚renewable energy’ includes solar, wind, hydro (including hydropower >10 MW), ocean(tide), geothermal, bioenergy, and waste. Currently, energy from waste accounts for more than 60%. This includes waste heat from industries, originating from fossil fuels.

2.4 Smart grids

The definition of a smart grid in Korea, as stated by the Korean Smart Grid Association, is as follows (KSGA without year):

"*A Smart Grid is a next generation electricity network in which two-way exchange of information on power generation and consumption is conducted in real time, through the convergence of the existing electrical grid with ICT. In this way, smart grids optimize energy efficiency.*"

The Korean Government's Smart Grid Roadmap of 2010 describes smart grids as interactions of power transmission and information technologies in five areas (Zpryme Research & Consulting 2011): smart power grid, smart places, smart transportation, smart renewables, and smart electricity services.

Smart Power Grids

Smart power grids are providing the basis for the other four areas. Envisioned for Korea is deployment of open electricity networks in which various forms of suppliers and consumers can be connected, initiating new business models. Another objective is to provide a reliable power supply by establishing systems to forecast grid failure and recover it automatically. Such a smart grid testbed has been running in Jeju Island since December 2009.

Smart Places

By integrating smart appliances into homes and buildings, consumers should be enabled to make smart choices. The target is to reach a 100% diffusion of advanced metering infrastructure (AMI) and achieving efficiency targets by 2030. Interactive management systems based on AMI are expected to support the rationalising of energy consumption patterns.

Smart Transportation

Smart transportation is to be achieved predominantly by the introduction of vehicle to grid (V2G) systems. In these systems, electric vehicles will be charged when the electricity rate is low and sell power back to the grid when the rate is high. The preconditions for this are setting up the necessary charging infrastructure and to creating vehicles equipped with smart decision-making systems. Such new business models will be part of the smart city testbed in Sejong, running from 2019 to 2021. In the first stage, AMI, in the second stage PV and ESS, and in the third stage PV, ESS and V2G systems will be introduced.

Smart Renewables

Smart renewables designate the use of microgrids in combination with wind and solar electricity generation. The aim is to build an infrastructure that is able to connect reliably renewable energy sources with the existing grid. Microgrids will consist of self-sufficient green homes, net zero energy buildings and green villages. Microgrids, energy storage systems, power quality compensation and electricity trading infrastructure are aimed to guarantee stable connection between renewable energy and the existing grids.

Smart Electricity Services

Smart electricity services will rely upon real-time electricity trading and markets. Diverse energy-saving pricing schemes, tailored to individual needs, and demand response schemes are to be established. Further objectives are to provide various value-added electricity services using the combination of electricity and ICT, and to set up a real-time trading system.

3 Energy strategy, regulatory and legislative framework

3.1 Strategic energy plans and technology roadmaps

Several plans, roadmaps and acts promoting the use of renewable energy and the adoption of smart grids are available in Korea. The first smart grid related legislation goes back to 2010. Broader strategic energy plans are revised in regular terms. In the following section, the most relevant legislation regarding renewable energy and smart grid is presented.

In 2006 the Korean government passed the **Energy Act** and in 2010 the **Framework Act on Low Carbon and Green Growth**. These two acts form the basis for Korean energy policy. Based on these acts, the government is required to establish a **national Energy Master Plan** every five years, with a planning period of 20 years.

According to the **Electric Utility Act**, MOTIE has to formulate a **Plan for Long-Term Electricity Supply and Demand**, targeting the stabilisation of electricity supply and demand. Further, the **Act on the Promotion of the Development, Use, and Diffusion of New and Renewable Energy** requires drafting a **Basic Plan for New and Renewable Energies**, including the national strategy for development and use.

In order to present the mid- to long-term direction of the government policy in the electricity grid sector, a comprehensive **Smart Grid Roadmap** has been released in 2010. After that, the **Smart Grid Construction and Utilization Promotion Act** was enacted in May 2011, and the 1st Intelligent Grid Basic Plan was set up in 2012 for the next 5 years. The 2nd plan was published in 2018.

In 2017 the Moon Jae-in government separately disclosed its policy regarding new and renewable energy matters through its **New and Renewable Energy Plan 3020.**

3rd Energy Master Plan

MOTIE published the third Energy Master Plan in June 2019. The implementation period of this plan runs from 2019-2040. The Master Plan provides the basic orientation for all energy-related areas and defines the direction of medium and long-term energy policy (FES 2017).

One of its stated goals is to improve the energy consumption efficiency to 38% compared to 2017, and to reduce energy demands by 18.6% compared to BAU level by 2040. This is to be realised by strengthening sectoral demand response and by activating a demand response market (i.e. including DR businesses and services, using EVs as energy storage, expanding AMI, making investment in energy efficiency mandatory, restructuring the energy pricing system, etc.).

In terms of providing a clean and safe energy mix, the Master Plan sets the target for electricity generated by renewable sources at 30-35% for 2040. At the same time, the share of nuclear power generation is to be reduced gradually, and the share of coal power generation rapidly.

The number of electricity prosumers is envisioned to increase, while local governments' roles and responsibilities are to be strengthened.

This 3rd plan was intensively discussed and heavily criticized by nuclear academia and parts of the media (e.g. The Korea Herald 2019). The main point of criticism relates to the goal of increasing the share of renewable energies to 35% in 2040. This was claimed to be unrealistic considering the current share of 7-8%. Though the new target is still lower than the global average of 40% estimated by the IEA, it was claimed that reaching its target would be very challenging for South Korea. This concern is also shared by neutral media as well as science (e.g. MK 2019, Hong et al. 2019), suggesting that variable renewable energies represent a risk for the reliability of power supply and would lead to increase in power prices. The goal of reducing energy consumption was also claimed to be unrealistic (The Korea Herald 2019).

8th Basic Plan for long-term Electricity Supply and Demand

The Basic Plan for long-term Electricity Supply and Demand represents the government's strategy regarding the Korean electricity market for the coming 15 years. It has to be revised every two years. The current 8th Basic Plan runs from 2017-2031 and the next update is expected to being released by end of 2019.

A basic shift from coal and nuclear energy to new and renewable energy is envisaged. As part of this transition, deployment of distributed energy resources (DERs) is to be promoted. These "*small-sized generation facilities and generation facilities applicable to points of demand with minimal construction of transmission lines"* are expected to account for 18.4% of total generation output by 2030. As a prerequisite, KEPCO guarantees grid connection to small-sized renewable energy power plants (below 1MW). After an amendment of the Electricity Utility Act, there is no limit on the electricity trading volume for PV self-generators, making them more profitable.

Also foreseen is the establishment of a renewable energy control system in order to enhance renewable sources generation forecasting and strengthen response to output variability. A test-run is planned from 2018 on and its full operation by 2020. Annual as well as long-term plans of transmission and transformation facilities are to be established.

Another objective of 8th Basic Plan for long-term Electricity Supply and Demand is to move from supply-oriented energy policies to demand-oriented ones. Demand Side Management (DSM) measures are to play a significant role, especially measures focussing on peak demand reduction, including energy efficiency resource standards (EERS) and an Energy Champion certification system. The EERS was enacted in 2018 as a mandatory system, obliging energy suppliers to disseminate highly efficient devices to secure a certain reduction in electricity consumption. Planned are e.g. DSM services based on big data for electricity, as well as step-by-step introduction of energy storage systems in public organisations. Additionally, an adjustment of industrial electricity rates, taking into account "off-peak load" rates, is to take place.

4th National Basic Plan for New and Renewable Energies

The latest Renewable Energy Basic Plan was released by MOTIE in September 2014. It covers the implementation period from 2014-2035 and has to be renewed in 2019 (every 5 years).

The target for renewable energy stated in this plan stands at 11% of the total primary energy in 2035. This includes the reduction of the share in energy from waste (68.4%

to 29.2%) and an increase in solar (2.7% to 14.1%) and wind power (2.2% to 18.2%). In order to reach this, the renewable energy market should move from a "government-led growth" to a "private partnership" market.

New and Renewable Energy Plan 3020

In 2017 the Moon government released its own energy policy strategy as laid down in the "New and Renewable Energy Plan 3020". The target is to increase electricity generated by new and renewable energy sources to 20% by 2030. More specifically, more than 95% of this increase is planned to be supplied by solar power (63%) and wind power (34%). By 2030, 63.8 GW of new and renewable energy capacity should be reached, consisting of 57% PV, 28% wind, and 15% biomass, waste and others (Lee 2019a).

As the above number show, the focus lies on the expansion of solar power systems. This has come at least partly as a consequence of decreased Chinese demand for Korean solar PV components caused by introduction of trade protection measures and reduced subsidies by the Chinese government. The focus of the Korean industrial policy for solar system components has thus shifted from overseas to domestic markets (Global Legal Insights 2018).

National Smart Grid Roadmap 2030

The Korean Government drafted the "Smart Grid Roadmap 2030" in 2010. This roadmap includes a vision, short- and medium-term goals for 2012, 2020 and 2030, and the five implementation areas of smart grids (smart power grid, smart buildings, smart transportation, smart renewables, smart electricity service, as described in section 2.4). In order to achieve its goals, an investment plan for technology development and the construction of infrastructure was issued (Unescap without year).

Expected effects of the smart grid development are a reduction of about 230 million tonnes of greenhouse gas emissions, a creation of 50,000 jobs annually, a generation of 74 trillion KRW (56 billion EUR) worth of domestic demand, a reduction by 47 trillion KRW (36 billion EUR) in energy imports, a reduction by 3.2 trillion KRW (2.4 billion EUR) in investment volume for construction of new power plants, and an increase in exports by 49 trillion KRW (37 billion EUR).

Milestones of the roadmap include building a smart grid testbed by 2012, deployment of smart grids across metropolitan areas by 2020, and deployment of a nation-wide smart grid by 2030. Additionally, export of smart grid technologies is part of the roadmap.

Smart Grid Construction and Utilisation Promotion Act

The Smart Grid Construction and Utilisation Promotion Act, released in 2011 and last amended in 2017, aims to build the world's first nation-wide smart grid (MOTIE 2017a). It was enacted to overcome the limits of conventional law and to promote smart grid activities, as the existing Electricity Business Act does not adequately promote an intelligent electricity grid. The main purpose of the act is to "*create smart grids and facilitate the use thereof to develop related industries, cope proactively with global climate changes, lay foundations for future industries oriented to low carbon and green growth, and ultimately contribute to the innovation of the* *environment for the use of energy and the growth of the national economy,*" (The Government of south Korea 2016).

One of the foci of the Smart Grid Construction and Utilisation Promotion Act is setting up a framework for collection, use and protection of relevant data. It also established a specific legal framework for the relevant industries such as the registration of intelligent grid operators, and envisions investment support.

The Smart Grid Construction and Utilisation Promotion Act also calls for development and implementation of Masterplan for Smart Grids (see below).

1st and 2nd Master Plan for Smart Grids

The Master Plan for Smart Grids (sometimes also called Smart Grid Implementation Plan) is established every five years in accordance with Article 5 on the Smart Grid Construction and Utilization Promotion Act. The first Smart Grid Basic Plan (July 2012) states the three focus aspects of smart grids which are to be created: infrastructure, services and markets.

Infrastructure creation aims at deployment of AMI, renewable energies and ESS. The AMI deployment is under way (section 4.2) but has been hampered by patent disputes over the underlying telecommunication technology. In the energy services, market segments such as demand response management and services in connection to EVs have seen success (section 4.3). With regard to market creation, the most important policy goal, "Building Smart Grid Hub Cities by Seven Metropolitan Areas", was not pursued due to the lack of technology and institutional framework. Instead, only AMI and energy management system (EMS) which are easier for commercialisation have been demonstrated in 16 local governments.

Intending to make up for these limitations, the 2nd plan aims at "Creating an Ecosystem for the Consumer Focused-Electric Power Market under the Energy Transition" which mainly uses AMI information to create services and provide them to consumers. Four major policy tasks were set up in the 2nd plan: new services for smart grids, infrastructure and facilities expansion, experiential complex development, building a foundation for vitalizing smart grids.

3.2 Concrete measures

This section provides a short overview of the most measures implemented by the Korean government in order to promote renewables integration and smart grid deployment.

Legislative and market design measures

Since 2012, a Renewable Portfolio Standard (RPS) for the promotion of alternative energy sources is in place. In contrast to the Feed-In Tariff (FIT) scheme it replaced, it does not provide a feed-in premium for generators but rather facilitates market uptake for renewables by creating demand. This is achieved by defining the minimum share of new and renewable power that power producers must feed into the grid. The power producers that fall under the RPS obligation must buy renewable energy certificates (CER) from renewable power generators. In 2018, the RPS was 5%; it will increase to 7% by 2020, and 20.5% by 2029. (Re-introduction of the FIT system for small producers is envisioned in the New and Renewable Energy Plan 3020. Lee, Cho, Shin 2019; GTAI 2018.)

The RPS scheme is not only used to create market uptake for renewable energy but also to steer the market via differentiated CER weights. For example, wind power demanding longer connection to grid is rewarded with a higher CER weight which translates into higher revenues from selling the power under the RPS. In addition, the CER weights are differentiated to promote specific technologies relevant for integration of renewables and expansion of technologies relevant for smart grids. For example, the combination of renewable power and ESS is awarded the highest CER weight. ESS is further supported by introduction in 2017 of obligation for public institutions to install ESS capacity corresponding to 5% of their contract power.

Under the New and Renewable Energy Plan 3020, renewables deployment and integration is promoted by relaxing the regulations regarding admissibility of sites for renewable energy generation, and ensuring unlimited grid connection for small-scale renewable energy complexes (section 3.1).

Since the government (through MOTIE, section 2.1) determines the electricity tariffs, it has used these to facilitate the necessary conditions for market uptake of technologies relevant to renewables integration and smart grids. For example, variable power tariff for industry provides a business case for behind-the-meter battery ESS by enabling cost savings resulting from shifting the power load into the off-peak tariff. In Korea, the power price in peak period can be almost 3 times as high as in off-peak (DGFNEZ 2019). For electric vehicles, the charging tariff was designed so as to enable recovery of charger installation costs. Apart from that, KEPCO provided a very generous EV charging tariff on the Jeju Island smart grid testbed. The government has also supported expansion of EV charging station infrastructure, providing subsidies for installation of slow-charging stations.

As mentioned in section 4.4, regulations governing market access to small renewable energy generators are expected to be updated in order to facilitate VPP-based business models.

Measures for increasing public acceptance

To ensure public acceptance for renewables, different measures have been implemented (section 4.4), such as public deliberation and ensuring public participation in renewable energy projects through community and co-op business models. Apart from that, long-term, low interest soft loans to farmers for PV installations are available, and agricultural PV projects are promoted where land is used simultaneously for farming and installations. In addition, the Act on Compensation and Assistance for Areas Adjacent to Transmission and Transformation Facilities has been introduced to counter local opposition to specific projects. The Smart Grid Construction and Utilisation Promotion Act has also introduced a framework for collection, use and protection of relevant data.

R&D

According to IEA, Korea's total public energy Research, Development & Demonstration (RD&D) budget in 2018 amounted to 757 million USD (690 million EUR) (IEA 2019). This would suffice for 8th place globally. Out of this budget, 189 million USD

(172 million EUR) has been spent on energy efficiency, 60 million USD (55 million EUR) on fossil fuels, 188 million USD (171 million EUR) on renewable energy sources, 81 million USD (74 million EUR) on nuclear, 50 million USD (36 million EUR) on hydrogen and fuel cells, 146 million USD (133 million EUR) on other power and storage technologies, and 43 million USD (39 million EUR) on cross-cutting issues. In particular, the high budgets for renewable energies and other energy and storage technologies show the importance the Korean government attaches to the integration of renewable energies and smart grids.

In the Korean Smart Grid Roadmap 2030 (section 3.1), the Korean government also set aside 2.2 trillion won (1.7 billion EUR) by 2030 for development of technologies relevant to smart grids, while the private sector is expected to contribute 4.8 trillion won (3.7 billion EUR). Additional 500 billion won (380 million EUR) by the government and 20 trillion won (15 billion EUR) by the private sector is to be invested in infrastructure expansion.

However, to Lee, Cho, Shin (2019) come to the conclusion that the energy research & development (ER&D) investment by the private sector is sub-optimal and needs to be increased, as the current statistics show that private companies in the energy industry invest much less in R&D than the government.

4 Status and perspectives of renewable energy sources integration and smart grids in Korea

The IEA uses four stages to define a country's status of variable renewable energy (VRE) integration (IEA 2018a). South Korea is currently still in phase 1 – the VRE capacity has no noticeable impact on the system. By reaching the 20% target in 2030, South Korea would reach phase 2. According to IEA, in phase 2, the impact of VREs becomes noticeable and system operational issues need to be improved. In this chapter, the status and perspective for the integration of renewables will be analysed.

4.1 Demonstration and research projects, initiatives, platforms and partnerships

Microgrid demonstration projects

The Korean government announced promotion of microgrids in the 2030 New Energy Industry Expansion Strategy (2015) to cope with greenhouse gas reductions and increase the number of energy prosumers. Microgrids will be deployed nationwide at 10 universities, 100 industrial complexes, and a number of Korea's islands. A total of 15 microgrid demonstration projects with about 1.7 trillion won (1.3 billion EUR) invested have been implemented in Korea since 2011.

IoT-based Microgrid Demonstration Project at Seoul National University

Investing KRW 18 billion (14 million EUR) between 2015 and 2019, 21 institutions including LSIS, KEPCO Research Institute (KEPRI) and Seoul National University participated in the project. By combining IoT-based cell platforms with campus building models, customized solutions have been developed. Through this demonstration project, various data streams such as power consumption, temperature, humidity, and ventilation of the building are collected and analysed. In addition to the power supplied from the existing power grid, distributed power sources such as PV, V2G and ESS are used during times of high energy prices. Starting in 2019, some buildings will be able to operate independently for four hours if their external power supply is cut off. The project is also expected to reduce the electricity bill by 20%.

Microgrid smart operating platform for industrial complexes

From 2016 to 2018, 10 institutions including universities, research institutes, and local governments participated in this project, investing KRW 8.6 billion (6.5 million EUR) for a total of 32 months. The project's goal is to develop an industrial complex-type microgrid commercialization model by designing a thermal energy analysis system and sensor node device, installing a 600kWh photovoltaic power generation system, and developing one M2M based e-IOT gateway.

Energy Independent Island Project

From 2012 to 2015, KEPRI introduced Korea's first microgrid technology based on EMS on the Gasado Island. With the goal of supplying 100% power from renewable energies and reductions in fuel cost and CO_2 emissions of up to 50%, KEPRI installed a 400kW wind power generation, 314kW photovoltaic power generation, and 3MWh battery on the island to build a stable power supply system. In addition, an EMS has been developed which enables an estimation of electricity generation and load, battery charge and discharge management, and automatic control of distributed power generation. Based on the Gasado microgrid model, 'Green Energy Independent Island' project will be carried out in more than 120 islands in Korea. By minimizing the use of existing diesel generators, about 16 billion KRW (12 million EUR) annually in electricity supply costs will be saved.

Smart Grid Experience Complex

The smart grid testbed was operated on Jeju Island from 2009 to 2013. Since this is a rural area with many elderly people, the limitations of the project quickly became apparent, e.g. the realised demand response was low due to low power consumption. To overcome this, the government plans to create a smart grid service experience complex in two cities. The smart grid experience complex will operate as an eco-friendly energy community that uses distributed power facilities, housing demand management based on hourly electricity tariff and V2G. The services verified through 3 steps from 2019 will be applied to the “Sejong Smart City Pilot Project”, which will be completed by the end of 2021.

Strengthening public-private policy cooperation network

The Smart Grid Policy Council is comprised of KEPCO, EPX, Korea Smart Grid Institute, Korea Institute of Energy Technology Evaluation and Planning (KETEP), Korean Agency for Technology and Standards (KATS) and Korean Smart Grid Association (KSGA). Its goal is to activate private collaborative networks in order to identify particular needs in the field, build infrastructure and improve the relevant institutions.

4.2 Status of deployment of technical measures

Advanced Metering Infrastructure (AMI)

The current total number of electricity meters in Korea is estimated at about 34 million, including 22.7 million owned by KEPCO and 11.5 million in owned by the households. About 120,000 smart meters have also been installed by the Government since 2012 in order to promote the smart grid infrastructure and create the initial market.

By 2018, 6.8 million households in Korea have been equipped with smart meters. The target for 2020 is to reach 22.5 million households. This would equal a market penetration of about 66%. KEPCO plans to distribute 100% AMIs in private new buildings and more than 50% in existing buildings by 2022, and achieve a 100% AMI coverage in all sectors by 2025.

Integrated Power Control System

The next generation integrated control systems that can better predict, monitor and control the real-time output of renewable energy power supply are to be built according to the Second Grid Plan (MOTIE 2018). The system development will be finalised by 2020 and the Electricity Market Operation Rules will also be revised in parallel. Some sources state that this system is to be supported by artificial (Lee, Cho, Shin 2019).

Grid-connected battery energy storage

In 2017, 800 MW of grid-connected battery energy storage was installed in Korea, the most of any country in the world (IEA 2019b), while the total installed capacity has reportedly increased to about 5GWh in 2019 (Li-ion Tamer 2019). There are currently more than 1,250 battery ESS installed in Korea, according to PV Magazine (2019a). Some of the leading global batteries manufacturers are Korean, and business cases to drive such a rapid deployment are present in Korea (section 4.3).

Renewable energy virtual power plants (VPP)

VPP is a single generator which aggregates small renewable energy sources in order to better predict the amount of electricity generated, bid on the market, and control the equipment according to the power supply. This helps overcome the variability of distributed renewable energy plants which are small in capacity, hard to monitor individually in real time, and cannot follow the demand by adjusting power production artificially. Such aggregation enables small renewable energy generators with capacity under 1MW to participate in the power market. The first power aggregator has been registered in Korea, and the market regulation is expected to shift to a more open one, allowing for new entrants and diverse VPP-based business models.

Expansion of EV charging infrastructure

According to the 1st Smart Grid Implementation Plan, a new tariff system was established for each operator and the charging rate was reduced. However, due to the low sales volume of electric vehicles and the high cost of installing chargers, the economic feasibility of the business is still low. Despite this, the number of publicly available chargers has grown in Korea from 62 in 2011 to 9,300 in 2018 (IEA 2018c). The government plans to supply 3,428 high-speed battery chargers by 2021 to improve air quality which has been deteriorating.

Top platform and system for intelligent transmission and distribution

'The multi-terminal DC transmission and distribution system' project for the development of HVDC in the intelligent transmission sector has been in progress since 2016. KEPCO will also invest 30 billion won (22.8 million EUR) to develop Advanced Distribution Management System (ADMS) from 2017 to 2020.

Since 2013, KEPCO has been developing top-level platforms (xGrids[4]) that can connect various systems in the transmission and distribution and integrate them in real time. It analyses the information collected from various power systems (SCADA, DAS, ESS etc.), and provides grid management services to operate the national grid with improved stability and efficiently. The government plans to invest about 2.5 trillion (1.9 billion EUR) won in upgrading the national power system for next five years.

4.3 Relevant new business models in the power market

Promoting new business models is an essential part of the Korean government's energy transition strategy. The Smart Grid Roadmap mentioned open electricity networks in which various forms of suppliers and consumers can be connected, initiating new business models. As noted in section 3.1, the 1st Master Plan for Smart Grids envisioned "Building Smart Grid Hub Cities by Seven Metropolitan Areas", which however was not implemented. The 2nd edition of the plan focuses on a market-

[4] xGrids: Extensible power grid management platforms with intelligence

driven ecosystem based on AMI data to offer the consumer smart new services. This is in line with the 3rd Energy Master Plan which envisions an increase in the number of prosumers (section 2.1).

In addition, the Park government announced in 2015 six new energy businesses which are to be developed with support of MOTIE and were expected to create 10.000 new jobs and a market value of 4.6 trillion KRW (3.5 billion EUR) (MOTIE 2014, KPMG 2015):

- Electricity demand response
- Integrated energy management service
- Independent microgrids
- PV rentals
- Electric vehicle servicing and charging
- Recycling wasted heat from thermal power plants

Demand response

Demand response (DR) market, also known as the 'Negawatt' market, has grown substantially since 2014 when consumers became able to offer their demand response capacities on the market. Electricity users such as industrial factories and commercial buildings would save electricity during a specified timeframe and be compensated for saving electricity. At the end of 2018, there were more than 25 qualified demand response service providers in South Korea (International Trade Administration 2019). The total current demand response capacity stands at about 4.3GW (Choi et al. 2018). However, limitations remain in Korea for the expansion of energy services due to the lack of institutional framework, e.g. use of power-related big data.

Energy storage systems (ESS)

Korea counts as the global powerhouse for grid-connected battery systems. Korean manufacturers LG Chem, Samsung SDI are world leaders with strong exports; the domestic market is expected to grow at an average annual rate of 10%, from 300 billion KRW (228 million EUR) in 2016 to 440 billion KRW (336 million EUR) in 2020.

Adequate policies are also in place which provide market viability for energy storage systems. For example, increased weighing of the renewable energy certificates is applied under the RPS scheme if renewable energy generation is combined with ESS. When using ESS for peak demand reduction, monetary savings occur as a result of differences in time-of-use electricity rates (ADB 2018). Apart from behind-the-meter installations, battery-based ESS have also established themselves in the generation/transmission segment. For example, KEPCO has installed a 376MW battery system to improve grid stability. It states that the system will pay itself back in six months (EY 2018).

Solar PV

For solar PV, business models based on third-party ownership have expanded in Korea. Here, the land or property on which a solar PV power plant to be installed is leased to investors. This model has been deployed both on residential as well as on commercial and industrial properties. This solution has proven very well suited for the Korean context of limited land area available for renewable energy installations (EY 2018).

Microgrids

An emphasis has been laid on the development of island-based microgrids, as part of the Smart Grid Roadmap. The first independent microgrid using a Korean-built energy management system on small Gasa Island came into full operation in 2013 (Lexology 2019). KEPCO and MOTIE shared the implementation costs. As KEPCO continues to have a strong influence on the distribution and sale of electricity to customers, it has taken initiatives to develop microgrids, so that more competition at the retail level of the electricity market can lead to increased investment by private companies in smart grids, including microgrids (Lexology 2019).

EV charging

The market for services related to EV charging has evolved in Korea, with several start-ups like EVAR (Electric Vehicle Automatic Recharging) or Greencharge. Services range from managing charging platforms, EV charging software, EV charging consultancy to technical solutions for EV charging such as autonomous robotic chargers.

4.4 Public debate and acceptance

According to a paper by the Friedrich-Ebert-Stiftung, energy-related topics dominated the 2017 presidential election campaign, and four out of five candidates promised to shut down the aged nuclear and coal power plants and replace them with gas and renewables (FES 2017).

According to the head of MOTIE renewable energy policy division, there is a broad public consensus in Korea that the country should pursue a higher share of renewable energies (Shin 2019). The broad public is also largely willing to pay a premium typically associated with increased share of renewables. A study published in 2016 by Lee and Heo finds that Korean consumers are willing to pay additional 3.21 USD per month for electricity generated by renewable energies. While this represents roughly a doubling in comparison to earlier similar studies for Korea, the authors also note that this value is low compared to other developed economies and propose that information campaigns and other awareness-raising measures be taken by the government in order to increase it (Lee and Heo, 2016, Yoo and Kwak 2009).

Nevertheless, there has been opposition to expansion of renewable energies and associated infrastructure such as transmission lines. Opposition has mostly come towards particular projects (NIMBY), citing potential environmental degradation, problems due to noise and vibration in case of wind parks, and threats to the local businesses such as farming and fishing (Shin 2019; Asianpower 2016). Misinformation and even fake news with regard to renewables spread by the nuclear lobby are still common in Korea and considered one of the main reasons for lacking public acceptance. On the other hand, awareness on risks associated with fossil and nuclear power sources and opposition especially to nuclear have also increased after the 2011 Fukushima disaster as well (Friedrich-Ebert-Stiftung 2017).

The government has recognised the lacking public acceptance as a potential risk to its energy strategy. A concrete approach has been outlined by the Korea Energy Agency with regard to implementation of the Renewable Energy 3020 Plan. It is based on ensuring the inclusion of local public in the renewables project through assessing the initial acceptance for it, public deliberation, including regarding the choice of the project site, and financial participation of local stakeholders through community and co-op business models. Apart from that, the government enacted in 2014 the Act on Compensation and Assistance for Areas Adjacent to Transmission and Transformation Facilities (Yi and Park 2019).

4.5 Main stakeholders in system integration and their interests

The Moon **government** took office in 2017 and has pursued a paradigm shift with regard to the country's energy system (section 3.1). Reflecting the plans to move from a centralised to a more decentralised power system, the Moon government is planning to shift some competencies from central to **local authorities**. This is also intended to ensure that local stakeholders are involved in decision-making and not excluded from the benefits.

Interest groups, however, have been critical of the proposed energy transition away from nuclear and coal towards renewables and gas. As Friedrich-Ebert-Stiftung reports, 34 **labour unions** from the energy industry established the Energy Policy Network with the stated goal of addressing topics such as energy democracy, energy fundamental rights, energy welfare and just energy transition. Among other things, the Network has called for re-education and training programmes. It has to noted that not all its members were against nuclear phase-out (FES 2017).

As already mentioned in the section 4.4, different parties which together form the **nuclear lobby** have fought the government's plans to reduce nuclear power generation. Especially visible have been parts of **academia** and **media**. Part of their strategy has been spreading misinformation and even fake news in order to sow doubt among the general population that transition towards renewables can still provide affordable and reliable power supply.

KEPCO, Korea's monopolist transmission and distribution network operator, together with its near-monopoly power generation subsidiaries, has been presented with many challenges due to the Moon government's remaking of energy policy. It has nevertheless largely played along with the intended changes and even suggested it would invest heavily in renewables and smart grids, and has been involved in all the areas of smart grid roadmap (section 2.4) (Nikkei Asian Review 2017; Ko 2017).

4.6 Main challenges associated with integration of renewables and smart grids in Korea

According to the IEA (2018b), Korea currently finds itself in phase 1 of VRE integration. Because of the low total generation capacity, effects of the variable renewables are not yet relevant on the power system level. The challenges Korea is currently experiencing are therefore different from those of countries with higher shares of renewables.

As mentioned in sections 4.4 and 4.5, public acceptance, often referred to in Korea as "rational consent" for the expansion of renewable power generation, is not taken for granted and often cited as one of the main challenges by the government representatives (Shin 2019). The problems have been exacerbated by the nuclear lobby's campaign against renewables. The lacking acceptance is particularly worrying because the share of renewables is still low in Korea, power supply is very reliable and electricity prices (especially for households, section 2.2) are lower than in most other developed countries.

Shortage of land available not just for wind and solar power plants but also for the necessary transmission lines represents an issue in Korea as well. With 513 persons per square kilometre (UN Statistics Division 2019) and mountainous terrain, Korea is already experiencing land constrains. "Deteriorating conditions" for expansion of transmission lines were reported as far back as 2010 (KSGI 2010). In March 2019, the president of Korea's New and Renewable Energy Center stated that more than 5GW of solar PV is still not connected to the grid – this would represent roughly half of the total PV generation capacity in Korea (Korea Energy Agency 2019, PV Magazine 2019).

A further set of challenges are structural. For one, before the onset of the Moon government, low prices have always been prioritised over environmental sustainability. In addition, KEPCO did not have to fear competition in any segment of the power market and was even assisted by the government with tailor-made regulatory interventions when power generation costs increased due to hikes in fossil fuel import price (Pittman 2014). Some observers believe this has increased the power sector's resistance to paradigm shift that the Moon government is trying to implement. Secondly, and perhaps more importantly, the retail segment of the power market has not been liberalised. In other countries, this has proved crucial for establishing of new business models.

Lastly, a challenge not exclusive to Korea but also one the country is not immune to is related to governance. It has been pointed out by some observers that the willingness of the Korean institutions to enforce the rules laid out by the government cannot be taken for granted (The Law Reviews 2019, IEEFA 2018). For example, when power generators failed to meet the obligatory RPS targets in the past, the government chose to lower the targets rather than letting the generators be fined by the regulators. However, if the institutions show the necessary determination and push through with unpleasant measures, this will foster fair competition in the power market and facilitate trust among the general public in the government's ability to successfully steer Korea through its energy transition.

5 Korea's activities concerning renewables integration in the global context and in comparison to Germany

Korea's strategy regarding renewables integration is pragmatic and business-oriented like in Taiwan, China or Japan. Korea aims to pursue IT-enabling of its power grid with a modular approach to smart grid construction. The strategy involves a broad range of Korean companies such as LSIS and Samsung SDI, as well as the state-owned KEPCO (Kim, Mathews 2016).

5.1 Legislative

Liberalisation of the electricity market

The liberalisation of the electricity market in Germany started around the same time as in Korea, in 1998, on the basis of a decision by the EU Commission to create a single European energy market. Some of the important milestones not yet reached in Korea were free choice of the electricity supplier and the legally ensured, priority grid access for renewable electricity suppliers. Studies show that liberalisation of the electricity market in Germany and other EU countries has had a positive impact on supplier diversity in favour of more sustainable electricity production (Agentur für Erneuerbare Energien 2018). Liberalisation also led to an above-average increase in electricity production from renewable energies compared with countries lagging behind in liberalisation. However, the Bundesnetzagentur as an independent regulatory body for the power market (2005) and the strict vertical unbundling of production, transmission and distribution segments (2010-2012) were implemented much later. The liberalisation of the electricity market has also led to increased decentralisation in Germany, not only with regard to technology, but also with regard to decision-making structures.

5.2 Technical

The technical conditions in South Korea are perfect for the vast deployment of smart grids: the electricity grid is stable (average duration of interruption is less than 10 minutes; for comparison: 10.29 minutes in Germany, 17,9 minutes in France and 470 minutes in the USA) and the internet connection is more robust, faster and more developed than in almost any other country, with broadband connection available even in rural areas (MOTIE 2017; CEER 2018; U.S. EIA 2018).

Grid expansion and smart grids

In Korea, the current discussions and plans are primarily focused on a nation-wide implementation of smart grids, and only then on grid expansion. This is different in other countries, especially in Germany. The rapid increase of renewable energies and the opening of the electricity grids to a cross-border European electricity market are pushing the current capacities of the German transmission and distribution grid to their limits. In addition, German nuclear power plants, along with a number of conventional power plants, are to be shut down in near future. These factors make it necessary for more than 7,500 kilometres of transmission grid to be optimised, reinforced or expanded over the next few years (BMWi 2019). Long planning procedures and, last but not least, massive citizen protests are leading to delays in the expansion.

In 2016, the law on the digitisation of the energy transition laid down the legal framework for smart grids in Germany. The focus is on the introduction of intelligent metering systems. However, since the legal requirements for data protection and data security in Germany are much stricter than in Korea, rapid implementation has not been achieved (see the following section for more information on smart meter deployment).

Smart meter deployment

As described in section 4.2, Korea currently has about 34 million smart meters, with the goal of 100% deployment by 2025. The European Third Energy Package includes a smart meter roll-out target of 80% market penetration by 2020. Currently, however, only about 37% of European consumers are equipped with smart meters (ACER 2018). The implementation rate within the countries varies heavily: There are the frontrunners like Sweden with 100% penetration, Finland (99%), Estonia (98.2%) and Spain (91.27%). Other countries, like Germany, Greece or Ireland do not have a concrete roll-out plan at present. In Germany, certification of the smart meter gateways which are the prerequisite for a comprehensive rollout has proven problematic due to very strict data security requirements. To date, only two models have been accredited by German Federal Office for Information Security (BSI) (2019). The rollout has not yet started. According to current plans where metering points with annual power consumption of 6,000 kWh will have to switch to smart metering, about 7.5 million smart meters are to be deployed in Germany.

EV charging infrastructure

The number of EVs is growing rapidly globally, with a stock of more than 5 million in 2018. China accounts for 24% of the global fleet and the U.S. for 22%, while Norway is the global leader in terms of the EV market share. In Korea, there were nearly 60,000 EVs in 2018 with about 34,000 of them sold in the same year. In Germany there were about 83.200 EVs in 2019, with about 29.000 added in the same year (Statista 2019a, IEA 2019c).

In 2019, there were 170,149 public charging stations for EV in Europe, with Germany accounting for more than 25,000 (Statista 2019b). By comparison, the number of public charging stations available in Korea is rather low at 9,300. This lack in infrastructure is criticised as being the reason for a low uptake of EVs (Baik, Jin, Yoon 2018).

Virtual power plants (VPP)

Currently, North America is the biggest market for virtual power plants (VPP). In Germany, VPP systems have entered into a commercial stage, with the legislative framework providing good business opportunities. The first major business for VPP in Germany was pooling medium-sized renewable energy generators and selling the power in the wholesale market. In addition to RE generators, VPP presently include gas-fired CHP, battery storage, emergency power supply systems and demand response (Ninomiya, Schröder, Thomas 2019). Unlike Europe, there is no open control reserve market in Korea.

The German company Next Kraftwerke is the operator of one of the largest VPP in Europe and has developed a network technology which connects and controls distributed energy resources. It also provides a VPP software service. Using this software, the Korean solar energy company Haezoom, the first registered power aggregator in South Korea, will obtain live data from its assets and thus be able to operate them according to grid situations and fluctuating decentral power supply (Next Kraftwerke 2019).

Grid-connected battery energy storage

Until 2018, South Korea was the world's largest grid-connected battery energy storage market. 2018 was also the record year in terms of global capacity added, with massive growth mainly driven by Korea, followed by China, the United States and Germany (IEA 2019). In 2019, the U.S. overtook Korea for the first place in new installations (Renewable Energy World 2019).

The US sector is dominated by front-of-meter activities, while Japan and Germany are concentrating more on behind-the-meter systems in the residential space (Energy Storage News 2019). For Korea, the REC scheme which rewards solar and wind generation in combination with ESS has been an important driver for front-of-meter deployment, while behind-the-meter applications are also present. Korea's experience seems to confirm the widely spread impression that policy support mechanisms are essential for battery ESS deployment (IEA 2019).

Sector coupling

Power-to-X technologies that use power for water electrolysis to produce green hydrogen represent an option for using surplus electricity from variable renewable energies such as solar and wind. A further advantage is the possibility of decarbonizing the transport sector and parts of industry such as steel production. Germany currently has more experience with the use of PtX technologies, with more than 50 PtX projects planned or in operation; private sector companies have announced their plans for further increasing the electrolysis capacity in the next few years (Jensterle et al. 2019). Additionally, since September 2019 the German Federal Ministry for Economic Affairs and Energy (BMWi) has been funding 20 projects within the framework of "Real-world Laboratories of the Energy Revolution", focusing on testing green hydrogen technologies under real conditions and on an industrial scale. The aim of these projects is to make Germany the world leader in supply-side hydrogen technologies.

In terms of demand-side applications, while in Germany the focus lies on transport and industry, the Korean Hydrogen economy plan focuses mainly on transport, with the goal of making hydrogen cars the next economic growth engine (Ha 2019). The goal of the Korean government is to increase the number of hydrogen-powered cars from 2,000 in 2018 and 4,000 in 2019 to 6.2 million by 2040 and to make the country the world's leading manufacturer of hydrogen-powered cars and fuel cells by 2030 (Ha 2019). The next steps are building a hydrogen industry cluster to promote RD&D collaboration and implementing a testbed to demonstrate innovative technologies. In addition, three cities will be selected in 2022 to become national hydrogen testbed cities (Ha 2019).

5.3 Effects on the market

Market actors

Different statuses in terms of power market liberalization lead to different market structures. Germany today has 900 power generation companies, including 83 generators with at least 100 MW in their portfolio, four TSOs, around 900 DSOs and around 1.300 retailers, to go with 110 energy storage operators and 56 power traders (BDEW 2019). In contrast, Korea has six big power generation companies (“GENCOs”) with over 100 MW in generation portfolio each, 18 private power companies, 11 community energy providers and 25 qualified demand response service providers. Transmission, distribution and retail remain under control of KEPCO.

Korea’s monopolistic market structure generally represents high entry barriers for private operators, hampers competition and lacks the necessary incentives for the consumers to turn into active market participants. While certain technologies and business have established themselves and attracted participants (VPP, DSM), there are others where Korea lags behind other countries. For example, no Korean company has joined the RE100, the corporate initiative committed to 100% renewable energy (currently, the total number of companies committed to RE100 is 203, including many European and German companies).

Demand response market

The demand response market has been growing since 2014 in Korea. In Europe, including Germany, potential is given but is often left unused. A few countries, e.g. Italy, Spain and UK, already utilise up to 6% of their peak load as DR capacity. In Germany, there is significant potential for demand response in the energy-intensive industries and some of it is already marketed, for example in the balancing market. However, regarding to current market conditions, loads are often solely shifted to reduce grid charges (Stede 2016).

PV market

In Germany, customers can already choose between buying, leasing or renting solar PV systems. There are currently more than 1.7 million solar PV systems in Germany, most of them small rooftop systems, according to Agentur für Erneuerbare Energien (2019). Many private companies as well as electricity providers offer various solutions to the German customer. While in Korea, the number of installed systems is lower, new ownership models have emerged and costumers are also able to buy or lease PV systems, or rent their property to third party which builds a solar PV system.

Research and development

As mentioned in Section 3.2, investment by Korean private companies in energy research and development (ER&D) is low, mainly because it does not bring rapid profitability compared to other sectors due to the long development period. Results from other countries implementing policies to promote ER&D investment in the private sector show increased investment in renewable energy (Lee, Cho, Shin 2019). Among German companies, energy is ranked third among the most frequently mentioned fields of technology where R&D is taking place (Schasse, Gehrke, Stenke 2018).

6 Recommendations

In terms of energy transition, the context and the current status of Germany and Korea diverge significantly from one another. While Korea is essentially an island in terms of its power system, Germany's grid is intertwined with those of 10 of its neighbouring countries. Germany's policy, as well as legislative and regulatory framework, underlie those of the EU while Korea is not part of any such supranational entity. Further, according the IEA (2018b), Korea is currently in phase 1 of VRE integration where the low overall shares of VRE have no significant system effect. Germany currently finds itself in phase 3 which already requires substantial system-relevant measures. While Germany's principle solution for congestion management resulting from high renewables penetration has been to optimise, reinforce and expand its transmission grid, Korea's approach is to start deploying smart (micro)grids at an early stage of its energy transition.

On the other hand, if Korea pursues its renewables targets, Germany's experience with renewables integration will become increasingly relevant. Germany has managed to integrate a high share of VRE into its power systems without putting at risk its reliability (Agora Energiewende 2019). Most of the basic principles followed in Germany can be applied to Korea to some extent or another: grid optimisation before reinforcement before expansion (GORE) which reduces the necessary investments and decreases public opposition; bottleneck management in a way that minimises curtailment of renewables; anticipating the impact of increased renewables shares in long-term grid planning; enhanced VRE forecasting; lowering the must-run capacity of conventional power plants; increasing energy storage and enhancing demand response. Some of these measures are already envisioned in Korea under the 8th Basic Plan for long-term Electricity Supply and Demand and other strategy documents.

Another source of valuable practical experience for Korea has to do with Germany's power sector liberalisation. Germany today has 83 generators with at least 100 MW in their portfolio, four TSOs, around 900 DSOs and around 1.300 retailers, to go with 110 energy storage operators and 56 power traders (DBEW 2019). Market competition does not only exist in the generation and retail segments but to some extent also in the distribution segment, as distribution grids are often owned by municipalities which commission private companies to operate them.

Such a complex structure however comes with its own challenges worth considering (as well as with extensive need for regulation): recent spike in balancing power costs triggered suspicions of market speculations on the side of the power traders. Germany also still has not found the definitive answer to strong opposition to renewable energy projects and transmission lines expansion, demands for higher compensation, and lawsuits by nature conservationists. Project delays and cost overruns are common, to the extent that the lagging grid expansion is now considered a major obstacle of Germany's energy transition.

Nevertheless, in a liberalised power retail market, retailers can react to the market demands. In Germany, this has led to time-of-use power tariffs (determined in advance but differentiated by day of the week and/or hour), dynamic pricing (where user pays a fixed monthly rate plus whatever the current price on the power exchange is), and tariffs offering exclusively green power. Of these, only time-of-use tariffs have been introduced in Korea; the other two options are not possible due to the market design. Especially renewable power tariff could prove impactful and further increase demand for renewable power in Korea. Tailored energy services based on real-time electricity trading are also envisioned under the "Smart electricity services" segment of the 2010 Smart Grid Roadmap. It is hard to imagine this can be implemented without a liberalised power retail market.

Korea can also look to Germany for inspiration with regard to VPP when it opens its control reserve market to allow easier entry. This could also represent an opportunity for Germany's technology providers, as the first registered power aggregator in Korea already uses VPP software developed by Next Kraftwerke.

On the other hand, Korea is ahead of Germany with regard to smart meter deployment, has much more experience with microgrids and is a global leader in grid-connected battery ESS, both in front- and behind-the-meter applications. When the smart meter roll-out finally takes off in Germany, Korea's experience with regard to new markets, business models and user data policies could be very relevant to German policymakers, regulators and private companies. The same can be said for microgrids if their role in the German energy transition increases. As for battery ESS, if the EU's plans to become one of the leading battery producers become reality, this would almost certainly spur deployment of grid-connected systems in Germany. Here too, Korea's experience can provide as much guidance as that of any other country.

Both countries envision a role for hydrogen in their future energy systems. Germany is a world leader in green hydrogen supply-side applications with numerous PtX projects and sees a role for hydrogen particularly in industry and transport end-use sectors, while Korea's industrial policy envisions its car manufacturers becoming global leaders in hydrogen and fuel cell technologies. The countries thus occupy different positions on the hydrogen value chain and are mostly not direct competitors. Further, if their hydrogen demand rises significantly in the mid- to long-term, both countries will likely have to import hydrogen produced abroad. Collaborating on technical and sustainability standards, pilot projects and RD&D (for example on hydrogen shipping technologies) could help establish international hydrogen market as well as strengthen both countries' position on it.

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