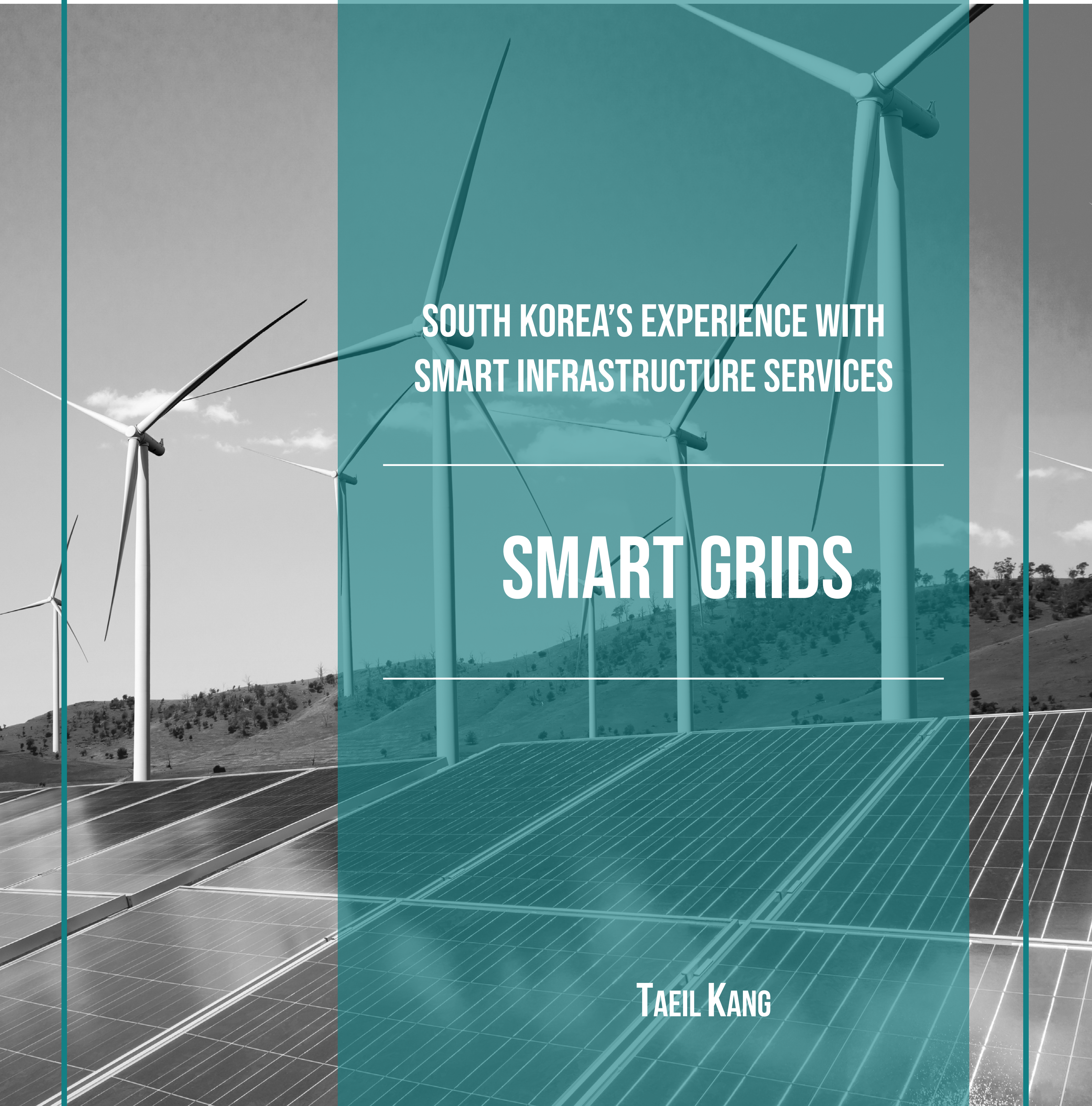

South Korea's Experience with Smart Infrastructure Services

Smart Grids

Taeil Kang

KDI

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CONTENTS

1. EXECUTIVE SUMMARY

In 2005, the South Korean government assembled the "Electric Power IT Task Force," which included policymakers, industry experts, and researchers both from the energy and IT sectors. The mission of the task force was to draft a plan for the advancement of the national power grid through the application of ICT (Information and Communication Technology), initiating the first phase of the Korean Government's initiatives for the development of national smart grid. The "Electric Power IT Task Force" was followed by the "Smart Grid National Roadmap" in 2009 and the 1st and 2nd Intelligent Power Grid Master Plans in 2012 and 2018, respectively. The Smart Grid National Roadmap set critical milestones for the nation's power grid transition from 2010 to 2030, while the subsequent Intelligent Power Grid Master Plans drafted detailed action items to achieve the milestones. The 1st Intelligent Power Grid Master Plan put its focus on R&D and commercialization of key smart grid technologies through implementing testbed projects. The 2nd Intelligent Power Grid Master Plan focused on the creation of new business models in the energy industry.

Those policy programs aimed at the development of a nationwide smart grid. The underlying intention and background to the initiative were to utilize advanced ICT to transform the power grid to one that decouples from fossil fuels and reduces carbon emissions while achieving the optimized energy efficiency of both supply and demand. The transition process involved the development new energy technologies in convergence with ICTs (Information and Communication Technology), but the eventual goal of the initiative was to create a market for innovative business models and ventures with spun-off technologies from the transition process and thereby find and nurture a new growth engine for the country in the preparation for the Fourth Industrial Revolution era.

The smart grid development in South Korea is at halfway on its original milestone plan. For the past 10 years since the announcement of the Smart Grid National Roadmap, the Korean government has provided financial and policy resources to establish foundations. Previous efforts have included outcomes of various technologies and applications, each of which will be a building block to complete a fully developed smart grid in the future. South Korea still has another halfway to go in order to create and nurture a new energy market in which new business models and players flourish with new products and services. Those remaining missions are left to be completed for the next 10 years.

The purpose of this paper is to review the development and progress of smart grids in Korea, analyze the effectiveness of smart grid policy in terms of development of key technologies in this field and lessons learned in the process, and discuss opportunities to apply the smart grid technologies to LAC (Latin American Countries) and the Caribbean region.

In Chapter 1, the paper will introduce the concept of smart grid and background of the smart grid development in the South Korea. As a country with a high energy-intensive industry and most of the energy resources relying on imported fossil fuels, South Korea recognized it compelling and inevitable to advance its energy infrastructure to more efficient and smarter one if the country desires to sustain its competitiveness in the global economy in the coming Fourth Industrial Revolution era. The smart grid was conceived as a strategy for the country not only to advance its energy infrastructure but to create a new growth engine in the future.

Chapter 2 will review the key smart grid policies and programs including the Smart Grid National Roadmap, the 1st and 2nd Intelligent Power Grid Master Plans, and achievements of those programs in the development of smart grid infrastructure in Korea.

In Chapter 3, this paper will present a case study of an island microgrid in order to exemplify the key smart grid application. The microgrid case covered in the chapter is the Gasa Island Microgrid. The Gasa Island Microgrid is small in size with 286 inhabitants in 168 households. Nevertheless, this microgrid presents typical characteristics and technical issues of an island grid which tested on the replacement of a fossil fuel base power generation system with renewable energies and a latest EMS (Energy Management System). This microgrid targeted decoupling from diesel fuels in electricity generation with solar PV and wind power. Unlike the conventional power systems, this microgrid system adopted the BESS (Battery Energy Storage System) to function as the base energy source and to control the voltage and frequency in the grid. This was a challenging task since the new system had to prove not only its technical reliability but also its financial feasibility compared to the conventional diesel power system. After the initial operation, the Gasa Microgrid has proved that an island microgrid with renewable energy sources is technically reliable.

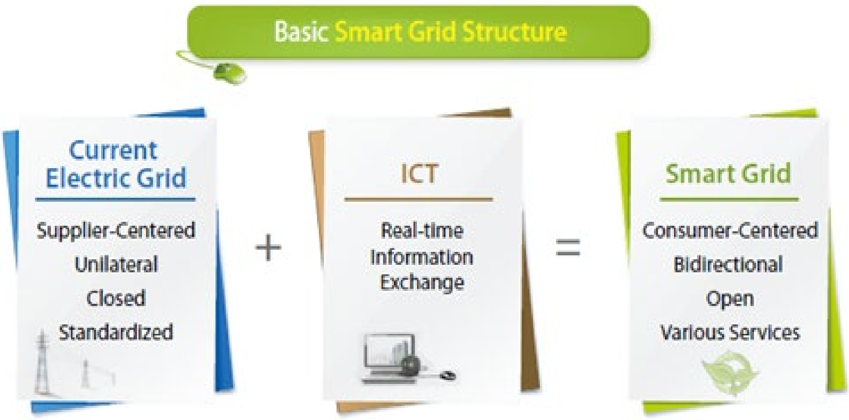
The last chapter discusses opportunities to apply the smart grid technologies to LAC (Latin American Countries) and the Caribbean region, as these regions may have the same socio-economic needs for energy infrastructure transition. In particular, the current COVID-19 pandemic and its devastating impact on the economies in the LAC and the Caribbean make this transition timely and necessary since LAC and the Caribbean island countries face an urgent need of self-reliant and sustainable energy infrastructure after COVID-19. Based on the study and assessment of the Korea’s smart grid experiences, some practical, field-oriented implications, and technical and policy-side recommendations will be provided at the final stage.

2. INTRODUCTION

2.1 SMART GRID: CONCEPT AND ANTICIPATED BENEFITS

According to the Korean government, the smart grid is defined as a "next-generation power system network that integrates information technology (Smart) into the existing power grid (Grid) to optimize energy efficiency through a two-way exchange of electricity information between suppliers and consumers in real time" (Ministry of Knowledge and Economy, Republic of Korea, 2010). Through open, bi-directional, and real-time communications between suppliers and consumers, the smart grid enables a more efficient energy system and diversifies various energy-related services.

FIGURE 1. CONCEPT OF SMART GRID



Source: Korea Smart Grid Association (www.ksga.org)

The smart grid can also be described as the "digitalization of information of energy flows." Digitalized information can be monitored, analyzed, and controlled in real-time. It also allows the bi-lateral flow of information. In the conventional grid, information of energy flow is analog and one way. Such one-way flow of information is effective as long as the energy generation systems are entirely controllable and the demand-side players remain passive. However, the conventional grid is no longer effective in managing the electricity grid when uncontrollable renewable energy sources come into play.

According to the Korean government's vision, the smart grid brings significant changes to suppliers, consumers, and the market. Unlike the conventional grid in South Korea, where the national utility is solely responsible for the one-way supply of electricity, the smart grid is an open system, and it allows bilateral exchanges of information and energy transactions. The smart grid offers utility operators the flexibility to incorporate with the power grid through various distributed energy sources, energy prosumers, electric vehicles, and energy efficiency applications. As a result, the smart grid maximizes the operational efficiency of the overall power system, secures the reliability of the power grid even with a high penetration of intermittent renewable energy sources, and provides energy consumers with optimized energy consumption and a wide array of value-added services. Eventually, the smart grid creates new energy market and business opportunities for green technologies, products, and entrepreneurs.

Meanwhile, the smart grid is not a fixed concept with defined contents and detailed descriptions of its features. Rather, it is an evolving theme which has become possible with the two key technological

developments—the wide availability of ICT and the fast development of renewable energies. Convergence of the ICT and renewable energies are expected to allow unprecedented interactions of distributed energy sources and participants in the power grid; and such new interactions are anticipated to create an entirely new feature and dynamics of the energy market in which infinite numbers of energy prosumers trade energy in real time and optimize the overall energy market efficiency.

Such vision and anticipated benefits invited participation from countries around the world in efforts to contribute to the climate change action, improve energy efficiency, and create new growth engines. In general, the anticipated roles and benefits of the smart grid is summarized as below.

The smart grid accommodates a high penetration of intermittent renewable energy sources in the power grid without causing technical problems.

a) The smart grid allows the participation of various distributed energy systems that utilize locally available energy sources to meet energy demand in local communities.
b) The smart grid enables the integration of electric vehicles with the electricity grid.
c) The smart grid achieves the overall energy efficiency of a country's energy system by enabling maximized efficiency of power generation facilities, real-time balancing of energy supply and demand, and the convergence of energy and transportation systems.

As mentioned, all of the changes are expected to be available with two key drivers. The first is the continuing innovation and evolution of ICT, which started in the late 20th century. The second is the very recent innovations and cost decline of renewable energy technologies. Although our society is yet to fully foresee how the smart grid may change the energy market in the future, we are undoubtedly standing at the entrance into the process of new, evolutionary changes of the global energy infrastructure. Moreover, the changes will not be limited to the energy industry. The impact of smart grids could be profound and wide-ranging throughout the entire socio-economic structure of our society.

2.2 BACKGROUND AND PURPOSE OF SMART GRID DEVELOPMENT IN SOUTH KOREA

2.2.1 ENERGY ENVIRONMENT IN SOUTH KOREA

South Korea is a resource-poor country with 94% of its energy consumption reliant on overseas imports. Nonetheless, it is the eighth largest energy user in the world (Table 1-1). This inherent problem of imbalance of energy supply and demand makes the country vulnerable to external changes such as rising oil prices.

TABLE 1. ENERGY-RELATED RANKING IN SOUTH KOREA

	GLOBAL RANK	NOTE
TPES	8	282 mil. ton
Oil Import	5	109 mil. ton
Power Consumption	7	544 TWh
CO2 Emission	7	589 MTCO2

Source: World Energy Balance 2018 (IEA)

In addition, South Korea is one of the countries with the highest energy-intensive industry in the world. The per capita annual energy consumption of South Korea was 4,660 kg of oil in 2011, almost double the world average of 2,418 kg of oil. Compared to the cases in other advanced economies around the world, the energy consumption of industry in South Korea is remarkably high. The industry segment is responsible for 56.6% of the country's total energy consumption, while the OECD average is 37.3% (World Energy Balance 2018, IEA).

2.2.2 DRIVING FACTORS FOR SMART GRID

There are three driving factors to carry forward with the smart grid in South Korea. The first is to respond to climate change, the second to enhance energy efficiency, and the third to create a new growth engine.

TO RESPOND TO CLIMATE CHANGE

Through Intended Nationally Determined Contributions (NDCs), the Korean government set the goal to reduce greenhouse gas (GHG) emissions by 37% compared to the business as usual (BAU) baseline by 2030. To achieve the GHG reduction target, South Korea must establish a low carbon energy infrastructure. Promoting the use of renewable energy and electric vehicles to reduces carbon emissions is not feasible with the conventional power grid. Therefore, it is imperative for South Korea to transit to smart energy infrastructure in order to achieve the NDCs target.

TO ENHANCE ENERGY EFFICIENCY

Energy efficiency plays a crucial role in reducing carbon emissions. Energy efficiency has been the highest priority in energy policy in South Korea. With its strong ICT foundation, South Korea has very favorable condition to promote efficient use of energy through real-time monitoring and control of power demand and various consumer-centered power services.

TO CREATE A NEW GROWTH ENGINE

South Korea needs to foster the smart grid industry as a new growth engine that surpasses the semiconductors and IT industry, which are current growth engine of the country. The smart grid is expected to have a great ripple effect in the economy not only in the power and heavy electric industries but also in related industries of communication, home appliances, construction, and transportation. The smart grid is anticipated to contribute to creating new business models and high-quality jobs for the country.

2.2.3 COVID-19 AND GREEN NEW DEAL IN SOUTH KOREA

As mentioned, the smart grid was accepted as an evolving and open-ended theme. Initially, the Korean government set a broad vision of the smart grid as "the next-generation power system network that enables open, bi-directional, and real-time communications between suppliers and consumers" and set direction to integrate information technology into the existing power grid. Under this vision and direction, the government took an active role as an initiator at the early stage of the smart grid development and funded the R&D activities and testbed projects for new technologies

and applications. In addition, the government has established policies for the facilitation of new energy markets and the birth of new business models. These seeds and the initial test sites need to evolve to construction and completion of the nationwide smart grid with active participation of private players in the energy market. This objective needs to be accomplished through the market by 2030.

Meanwhile, on July 14, 2020, the Korean government has announced a "Green New Deal," as a recovery measure for post COVID-19. The government differentiated the Green New Deal from other ordinary new deals which involved massive scale of civil work projects. According to the Korean government, the Green New Deal will be coupled with Digital New Deal and become the two key pillars of the country's post-COVID-19 strategy. Digital New Deal will build a digital infrastructure to support public services and commercial activities and Green New Deal will strive to install green infrastructure to support the energy supply and demand. The strategy aims not only at the mere economic recovery from the COVID-19 crisis but also at the taking more active and preemptive action to the global climate change crisis and advancing South Korea to the global leader in the comping Fourth Industrial Revolution.

For the Green New Deal part, the government plans to invest 73 trillion Korean won (US$ 61 billions) by 2025 in i) transition of the urban infrastructure to green infrastructure, ii) expansion of low carbon, distributed energy systems, and iii) building innovative green industry ecosystem to help grow new business models and ventures in the energy sector. The Korean government plans to further accelerate its renewable energy capacity, mostly solar PV and wind, and promote the green mobility fleet with electric vehicles and hydrogen-powered vehicles. The plan also promises the refurbishment of public rental housing and schools to make them energy independent and transformation of urban areas into smart green cities.

The COVID-19 is calling for changes of how we live and work in the society. It requires transformation in industrial activities and infrastructure. The Green New Deal is not a simple measure for recovery but an active response to that call. The Green New Deal targets to fundamentally transform the country's industrial structure into a green and sustainable one. Therefore, what the smart grid programs have achieved in the past 10 years is anticipated to provide adequate technological resources for the implementation of the Green New Deal. At the same time, the Green New Deal is expected to accelerate the smart grid development in the future since the energy infrastructure transition will become a core part of the nationwide industry infrastructure transition after the COVID-19 crisis in South Korea.

3. KOREA'S EXPERIENCES

3.1 HISTORY OF SMART GRIDS IN SOUTH KOREA

3.1.1 ELECTRIC POWER IT TASK FORCE (2005)

In 2005, the Korean government launched the Electric Power IT (Information Technology) Task Force. The task force was comprised of invited industry experts as well as policymakers in the energy and IT industry. The main purpose of the TF was to draft a detailed plan for the advancement of the national power grid through the applications of information technologies to the country's energy infrastructure. Even before the concept and necessity of the "Smart Grid" was widely recognized in the global energy industry, the Korean government predicted the convergence of ICT with energy technologies, and this trend would become the "Next Big Theme" in the coming industrial revolution.

KEY ACTIVITIES OF THE ELECTRIC POWER IT TASK FORCE

With the inception of the task force, the Korean government finalized six key agendas as follows:

1. Core R&D of electricity IT technologies;
2. Investment in new technology ventures in the power industry;
3. Human capacity building in electric power IT;
4. Task force for the advancement of the power grid;
5. Promotion of R&D activities of public utilities; and
6. Establishment of new energy industry standardization.

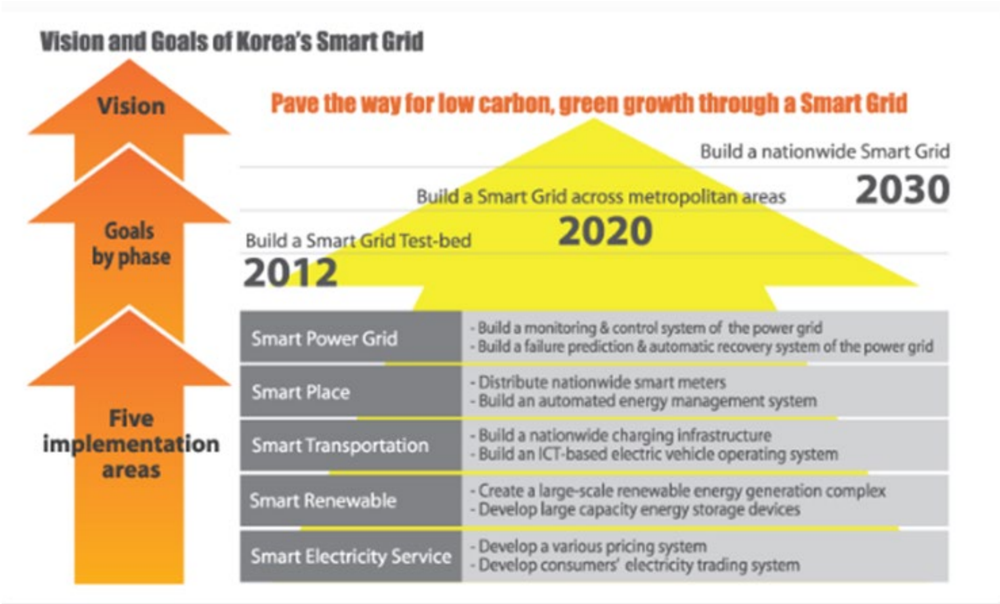
The Korean government allocated US$250 million in core electric power IT R&D activities for the following 5 years. The Electric Power IT TF laid down the first key foundation for the transition to the smart grid.

3.1.2 SMART GRID NATIONAL ROADMAP (2009)

In 2009, the Korean government announced the Smart Grid National Roadmap. This roadmap sets the vision and broad objectives for the country to pursue smart grid infrastructure development in the long run. The roadmap defines its vision as "low-carbon green growth through the smart grid" development and its objective as the completion of the nationwide smart grid by 2030.

In order to achieve the vision and objectives, the Korean government has developed implementation roadmaps for the following five strategic areas with planned investments of US$25 billion and expected reduction of carbon emissions by 230 million tons until 2030: Smart Power Grid, Smart Place (Smart Consumer), Smart Transportation, Smart Renewables, and Smart Electricity Service. For each of the five strategic areas, South Korea sets specific goals and quantifiable targets (Figure 2-1).

FIGURE 2. VISION AND OBJECTIVES OF SMART GRID



Source: http://www.smartgrid.or.kr/

The roadmap provided the general guidelines to follow and, therefore, needed detailed implementation plans to carry out the proposed key agendas.

3.1.3 THE 1ST INTELLIGENT POWER GRID MASTER PLAN (2012)

BACKGROUND AND PURPOSE

Following the Smart Grid National Roadmap in 2009, the Korean government drafted a detailed action plan to implement the broad agenda into specific policies. The implementation plan was first drafted and announced in 2012 in the name of "the 1st Intelligent Power Grid Master Plan." The main objective of the plan focused on testing new technologies in the power grid, including smart demand control, integration of renewable energy, and electric vehicle charging networks. The master plan differentiated the "intelligent power grid" from the existing grid in the following way.

TABLE 2. COMPARISON OF EXISTING POWER GRID TO INTELLIGENT POWER GRID

EXISTING POWER GRID	INTELLIGENT POWER GRID
Analog & mechanical communication	Digital & intelligent communication
Central, hierarchical system	Distributed, network system
Manual recovery	Automated recovery
Fixed tariff	Real-time pricing and billing
One-way information exchange	Bilateral information exchange
No consumer's choice of service	Various service choices

Source: Korea Smart Grid Association

KEY PROGRAMS OF THE 1st INTELLIGENT POWER GRID MASTER PLAN

The core part of the 1st Intelligent Power Grid Master Plan was R&D and the commercialization of key smart grid technologies. Smart grid technologies were categorized into supply and demand side applications. The supply-side application included renewable energy and energy storage, and the demand-side application included energy efficiency technologies, including demand response and smart building. Electric vehicles were also included as an essential element in smart grid technologies. Each of the supply and demand-side technologies could serve a specific market needed in the energy industry, be integrated together, or be designed as convergence application models. Still, the smart grid is in the evolving stage, with the supply-side technologies in active service in the market and the demand-side technologies in the early stage of commercialization.

In addition to the developments in technology, the government selected the following two pilot projects as the major programs in the 1st Intelligent Power Grid Master Plan:

- Smart Grid Test Bed Project in Jeju Island: As a testbed to build and operate smart power infrastructure at a municipal level with the coverage of 6,000 houses, the Jeju Smart City had a bold objective. It aimed to test all the five key implementation elements—smart power grid, smart place, smart transportation, smart renewable, smart power grid, and smart service—stipulated in the Smart Grid National Roadmap in one place. Hence, the project incorporated the key smart grid technologies: solar PV and wind power systems, energy storage system (ESS), smart meters, electric vehicles, demand responses, and advanced transmissions and communications tools.

- K-MEG Project: A group of test beds at commercial buildings and industrial facilities with the application of the smart grid concept to test energy optimization at the building or factory level.

Although the objectives and scope of these testbed projects were very bold and challenging, the testbeds provided a fertile ground for researchers and industry experts to experience experiments and trials and errors in the application of new and emerging energy technologies in the field.

3.1.4 THE 2ND INTELLIGENT POWER GRID MASTER PLAN (2018)

BACKGROUND AND PURPOSE

In 2018, the Korean government announced "the 2nd Intelligent Power Grid Master Plan." Unlike the 1st plan, which focused on technology testbeds, the 2nd master plan focused on the development of new business models that aimed to capitalize on smart grid technologies for commercialization. This was partially due to the worldwide trend of creation of new business models and ventures in the energy industry along with fast deployment of distributed energy sources, including renewable energy, ESS and electric vehicles,

In this context, the plan puts its major objectives on the creation of new energy business. The plan defined the concept of Intelligent Power Grids as "an innovative growth engine" for creation of new business and jobs.

KEY PROGRAMS OF THE 2ND INTELLIGENT POWER GRID MASTER PLAN

The government selected the following projects as the core implementation programs of the 2nd Intelligent Power Grid Master Plan with the following selected projects:

- Development of new electricity services
- Demand response program for individual users
- Retail electricity sales market for small, distributed energy sources
- Deployment of AMI (Automated Metering Instrument) at 22.5 million homes and buildings nationwide
- Promotion of block-chain application in energy trading.

The 2nd Intelligent Power Grid Master Plan is still underway to be completed. Meanwhile, as explained in the previous chapter, the Korean government has announced Green New Deal and Digital New Deal in July this year as the country's strategic program of the post COVID-19 crisis. The new deal program includes broader and more aggressive agenda for the energy sector transformation. Therefore, the existing smart grid program is likely to be integrated into the new deal program.

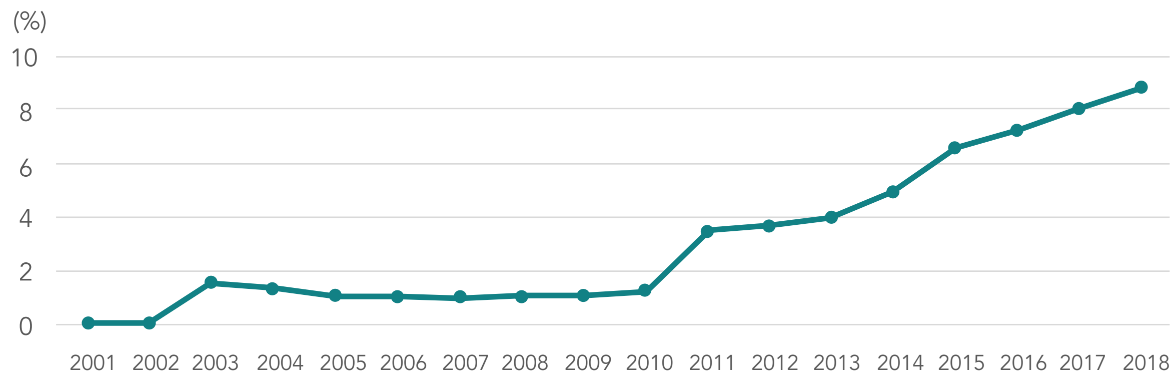
3.2 KEY ACHIEVEMENTS OF SMART GRIDS IN SOUTH KOREA

The Korean government's continued commitment and its initiatives for the development and commercialization of smart grid technologies yielded the following outcomes and changes for the energy industry.

3.2.1 DEPLOYMENT OF RENEWABLE ENERGY

To overcome the high dependency on imported fossil fuel, the Korean government has put its top priority on promoting the deployment of renewable energy. As a result, the share of renewable energy, mostly non-hydro power, in the country's electricity supply grew from 1% in 2009 to 8.8% in 2018 (Figure 2-2).

FIGURE 3. RENEWABLE ENERGY SHARE IN TOTAL POWER GENERATION



Source: Korea Energy Agency

The government implemented various programs to promote renewable energy. The Korean government introduced mandatory programs for utility companies and public organizations while providing supportive programs with financial incentives for individual users. The following table shows the major promotional programs for the renewable energy of South Korea.

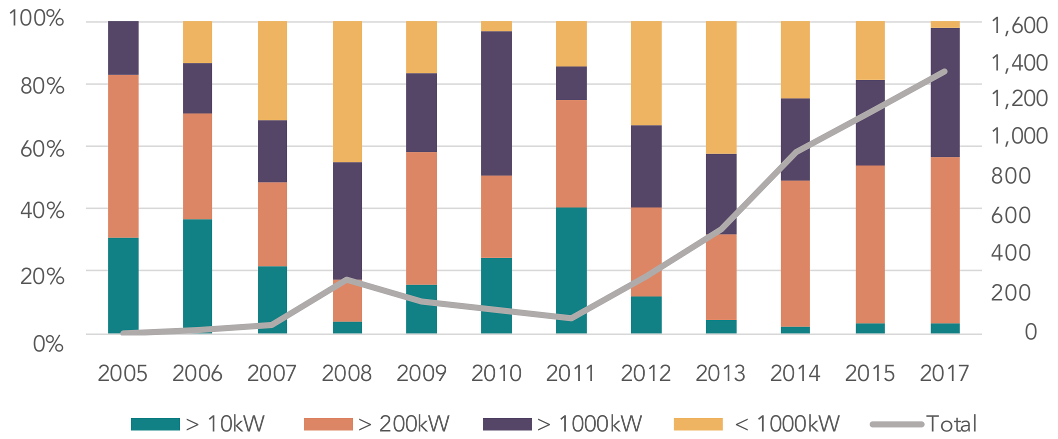
TABLE 3. KEY RENEWABLE ENERGY DEVELOPMENT PROGRAMS IN SOUTH KOREA

[MANDATORY PROGRAM]	
Renewable Portfolio Standard (RPS)	Eighteen utility companies were mandated to supply 10% of their electricity supply from renewable energy sources by 2023.
Renewable Fuel Standard (RFS)	The transportation sector was required to use 3% of biodiesel in their fuel by 2020.
Mandatory installation for Public Buildings	Public buildings were required consume 30% of their total expected energy usage with renewable energy sources by 2020.
[SUPPORTIVE PROGRAM]	
Subsidy for households buildings and communities	About 50% of installation cost of renewable energy was subsidized for households, buildings, and local communities.
Solar PV Rental Program	Solar PV rental companies were allowed to install and rent PV systems to households and get paid back from rental fee s and selling renewable energy points. In the program, h ouseholders paid energy bills in average less than 80% of the previous bill.
Soft Loan	Long term and low-interest loans were provided to renewable energy installers.

Source: Korea Energy Agency Homepage, www.energy.or.kr

At the end of 2018, the total installed capacity of renewable energy sources was 11.6 GW. Among the total installed capacity of renewable energy sources, solar PV was 7.1 GW followed by wind power of 1.4 GW. One of the distinctive features is the sharp increase of the share of small solar PV systems (Figure 2-3). From 2014 to 2017, more than 70% of installed solar PV systems were less than 1 MW in size, while almost 50% of the solar PV systems were less than 200 kW in size. This proves that the government's supportive programs for the public and individuals to participate in the energy market as suppliers of green energy have been highly effective. As the smart grid infrastructure further evolves in South Korea, the small energy producers are expected to play an important role as energy prosumers in the market.

FIGURE 4. ANNUAL INSTALLED CAPACITY OF SOLAR PV BY SIZE



Source: Korea Energy Agency, Energy Yearbook 2019

Government policies also contributed to lowering the cost of renewable energy. The price of the REC (Renewable Energy Credits) declined from 220,554 Korean won (US$ 183.8) per MWh in October 2013 to 40,725 Korean won (US$ 33.9) per MWh in February 2020 (Figure 2-4). The REC is a subsidy for electricity generated from renewable energy sources. The supplier of renewable energy sells electricity to the spot market at the System Marginal Price (SMP). One REC is credited to a unit of renewable energy electricity sold on the market. The renewable energy supplier, therefore, earns a revenue stream from both SMP and REC per each unit of electricity sold. For the same period in the following Figure 2-4, the SMP price has been moving in the range of 80,000 Korean won (US$ 66.7) to 120,000 Korean won (US$ 100) per MWh. In South Korea, the cost of renewable energy is higher than the conventional energies sources, but the gap represented by the REC price has been narrowing down within 50% of the cost of conventional thermal energies.

FIGURE 5. REC MARKET PRICES (US$/MWH, JUN 2013 TO FEB 2020)

Source: Korea Energy Agency

3.2.2 DEVELOPMENT OF SMART GRID INFRASTRUCTURE

In addition to the increased contribution of renewable energy sources in the country's energy supply, South Korea has developed significant infrastructure for the transition to the smart grid during the 1st and 2nd Intelligent Power Grid Master Plans. Some of the key smart grid infrastructure developments included:

- **Market-Based Demand Response Program:** In 2014, the government introduced a new market-based demand response program. Unlike the previous demand response program, which was managed by Korea Electric Power Corporation (KEPCO), the new demand response program provided incentives for energy users to participate in a market-based demand response process voluntarily. The outcome was remarkably successful, and, today, South Korea possesses 4.3 GW demand response resources, mostly from industrial users. This 4.3 GW of demand side energy source is equivalent to 5% of the country's total power generation capacity.

Market Based Demand Response Program

Concept of Demand Response (DR)

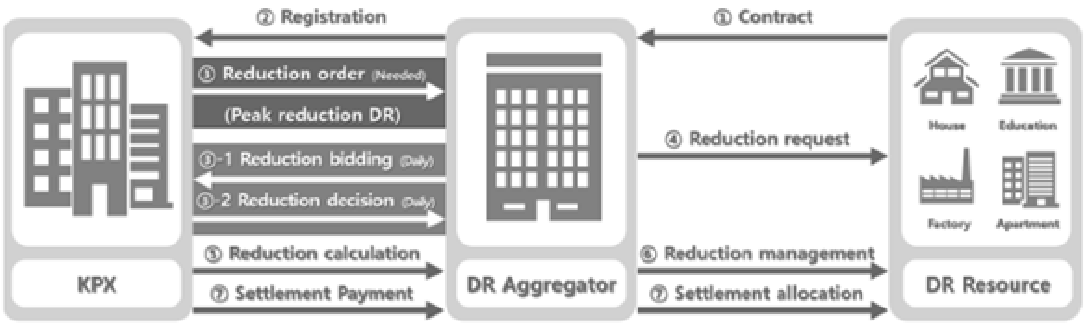
In power grids with a central operating systems, supply and demand must always be balanced to ensure the stability and safety of the power system. At the same time, it has been technically challenging and commercially expensive to store electricity for supply and demand balancing. To achieve supply and demand balance on the power network, the power system operator predicts the demand and then secures the supply capacity to meet the demand. Since the electricity demand is uncontrollable, the power system operator needs a reserved capacity in the supply side to respond to an event that requires supply and demand balancing. Traditionally, the DSM (Demand Side Management) was the main tool to control the volatility at the demand side. However, after the 1st Oil Shock in the 1970s' which made it more costly to run a reserve capacity of thermal power plants for balancing, the power system operators recognized the importance of voluntary participation of users on demand-control-based incentives. However, this idea was not developed to a workable platform until the wide availability of IT technologies in the energy industry was achieved. Recently, however, there have been a few emerging events that forced the power grid operators to approach the task from the demand-side. Due to the increasing penetration of intermittent renewable energy sources, the control of the power at the supply side is becoming harder. At the same time, the spread of smart meters and advanced metering infrastructure at the supply side has allowed an interesting opportunity for the grid operators to design an automated, market-based mechanism for balancing the demand and supply gaps. In this new mechanism, large electricity consumers are invited to cut off their peak demand from the central grid and turn to their power sources in order to meet their peak demands. In return, the consumers are paid by the grid operator for the amount of energy that they used from their own energy sources. For the mechanism to be effective, the responses from the users' own energy supply (demand-side resources) should be reliable, fast, flexible, and large enough to compete with the central grid (supply-side resources).

Market-Based Demand Response

The demand response market was introduced in 2014. In the past, the demand management was implemented through the program operated by the Korea Electric Power Corporation (KEPCO). However, in the new demand response market, a third party called "aggregators" was allowed to participate as a deal broker. The aggregators recruited the demand response resources from customers who wanted to participate in the demand response business. Figure 2-5 shows the process of the trading mechanism of the demand response market. The demand response market trades demand resources arranged by the aggregators. Trading demand resource is required to come from more than ten users, and the power

resource for trading should be at minimum 10 MW. The aggregators collect consumers to organize demand resources. After registration to the KPX (Korea Power Exchange), these resources are certified for trading. Demand resources are put on a bid to the power grid operator (KPX) on a daily base, When the bid is sold, demand curtailment begins. Once a curtailment order is issued by KPX, consumers are required to switch off on demand from the utility grid within an hour of dispatch order. During the curtailment, the consumers turn on their own power sources to meet their power demand.

FIGURE 6. TRADING MECHANISM OF DEMAND RESPONSE MARKET



Source: Case Study of Demand Response Operation using Management Program in South Korea

Performance of Demand Response Market

Since the introduction of a new demand response market, a significant progress from both quantity and quality perspectives has been achieved. The number of consumers who participated in the market grew from 90 to 3,592 and curtailed energy amounts to 175,771 MWh, up by 342.6 times from 513 MWh (Table 2-3 and 2-4). The transition to an advanced demand response market has also produced benefits in the policy side. As the program matures along with an increasing number of demand resources integrated into the electricity market, market participants felt comfortable to understand the system, and this enabled for the demand response market to be activated.

TABLE 4. NUMBER OF CONSUMERS AND CURTAILED POWER BEFORE NEW DR MARKET

YEAR	2010	2011	2012	2013	2014
NO. OF CUSTOMERS	90	119	158	159	159
CAPACITY AVAILABLE FOR CURTAILMENT (MW)	2,219	3,049	3,612	3,615	3,615
CURTAILED POWER (MWH)	513	690	785	556	682

TABLE 5. NUMBER OF CONSUMERS AND CURTAILED POWER AFTER NEW DR MARKET

YEAR	2014.12~2015.11	2015.12~2016.11	2016.12~2017.11	2017.12~2018.05
NO. OF AGGREGATOR	15	15	17	20
NO. OF CUSTOMERS	1,323	1,970	3,195	3,580
CAPACITY AVAILABLE FOR CURTAILMENT (MW)	2,444	3,272	4,352	4,271
CURTAILED POWER (MWH)	208,109	392,853	175,771	121,206

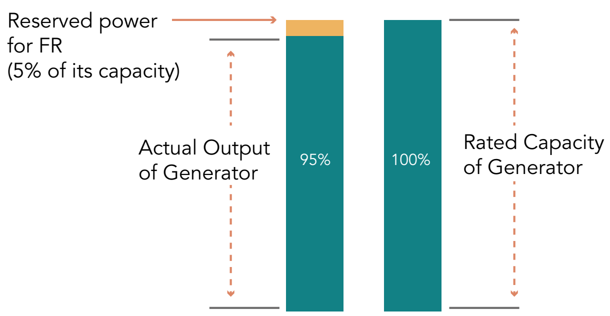
Source: Case Study of Demand Response Operation using Management Program in South Korea

- **Energy Storage System (ESS) for Frequency Regulation:** South Korea successfully replaced the conventional thermal generators with the ESS for frequency regulation. One of the key applications of the ESS is for grid stability. The ESS plays as an essential role, contributing to counteract the imbalance of electrical supply and demand. When there is an increasing penetration of intermittent renewable energy supply to the electrical grid, the ESS can be applied to sustain electrical supply stability. From 2014 to 2017, KEPCO initiated an ESS for Frequency Regulation (FR) program with the total installed capacity of 500 MW in KEPCO's major substations nationwide. The new frequency regulation mechanism with ESS enabled fast and precise response to abnormal events of frequency deviation in the power grid, and hence provided KEPCO with great flexibility in power grid operation in particular with high penetration of intermittent renewable energy sources to the grid. In the ESS industry for frequency regulation, South Korea is among the front-runners worldwide, following the US in the number of projects and installed ESS capacity.

ESS for Frequency Regulation

The concept of FR (Frequency Regulation) is to maintain the power frequency constantly at the standard, 60 Hz in Korea, in the events of the discrepancy of supply and demand. In the conventional system, frequency regulation was performed by a reserved capacity of thermal generators (Figure 2-6). KEPCO kept 5% of its thermal power capacity for frequency regulation.

FIGURE 7. CONVENTIONAL FREQUENCY REGULATION



Source: CAREC Knowledge Sharing Program on ICT for Energy, KEPCO

Compared to the conventional frequency regulation, the advantages of frequency regulation using the ESS include the fast and precise response to abnormal frequency deviations and saving the idle capacity of conventional thermal generators reserved for frequency regulation

From 2014 to 2017, KEPCO installed 500 MWh ESS for frequency regulation nationwide at KEPCO's major substations. The total investment of the 500 MWh was estimated to be US$300 million to 400 million. KEPCO selected multiple contractors both foreign and domestic through a series of competitive tenders for the installation of the ESS. Among those who passed technical evaluations, the contractors were selected with the price competitiveness. This process allowed KEPCO to test different ESS technologies both from home and overseas while reducing the cost of ESS. The ESS FR program successfully contributed to the stability of the national electrical grid in the country. Compared to the conventional method of FR, the ESS FR proved to be faster and more effective. According to KEPCO's independent evaluation, the ESS application for FR proved to be beneficial and effective in the following ways.

Cost reduction: reducing the necessity of reserve thermal power capacity for frequency regulation, and utilizing the reserve capacity of generators for additional electricity sales.

Improved power quality and reliability of power grid: being able to respond in milliseconds to frequency regulation requirement and ramping up much faster than conventional thermo power plant in a transient situation

Supporting renewable energy penetration: accommodating more renewable generation to the system

KEPCO has not released a detailed analysis of benefits from the ESS FR in numbers. However, according to an analysis of economic benefits of ESS in power grid applications in South Korea, the economic benefit of 100 MWh ESS for frequency regulation, measured by the saved fuel costs of the reserved thermal power plant, was estimated to be 47.3 billion Korean won (US$ 3.9 millions) per year (Table 2-5). Based on this estimate, the economic benefit of the 500 MWh ESS for frequency regulation could be reasonably estimated at US$19.5 million per year. The payback period of the KEPCO's ESS FR, therefore, is estimated to be in the range of 15 to 20 years. The simplified estimate of the payback period is too long to be justified for investment. However, considering that the ESS FR contributed to power quality improvements and the reliability of the grid, KEPCO's ESS FR program is considered to be more beneficial than the simplified numbers. At the same time, with the fast decline of ESS prices in the international market (Table 2-5), it is reasonably expected that the ESS FR will soon become a universal solution of frequency regulation in the world.

TABLE 7. ECONOMIC BENEFIT OF ESS IN POWER GRID APPLICATIONS IN THE KOREAN ENERGY MARKET

SEGMENT	FUNCTIONALITY	BENEFIT (BILLION WON/100MWH)
Supply side resource	Reserved capacity	1.1
	Frequency regulation	47.3
Demand side resource	Reduced transmission traffic Congestion	24.7
	Demand response	10.7
	Emergency power supply	8.1
Supplementary renewable energy source	Control of short-term intermittency	27.2
	Load shift	10.4
Power quality	Improved power quality	11.7

Source: Analysis of economics of large scale ESS in power grid applications, Moon, Seung Ill

- **Jeju Smart Grid Testbed and Island Microgrids:** One of the key programs in the `1st and 2nd Intelligent Power Grid Master Plans was various testbed projects for the R&D and commercialization of smart grid technologies, in which the Jeju Smart Grid Testbed played an important role. From 2009 to 2011, the Korean Government started the smart grid demonstration project in Jeju Island, which served as a testbed assessing the viability of various smart grid technologies and foster their development in the future. Total investment in the project was 246.5 billion Korean won (US$205 million), with 30% of the funding from the Korean government, 10% from KEPCO, and the remaining 60% from private companies in the project (https://home.kepco.co.kr/) . The Jeju Smart Grid Test Bed focused on verifying the five key themes of smart grids in one place: Smart Power Grid, Smart Place, Smart Transportation, Smart Renewable Energies, and Smart Electricity Services. The key testbed infrastructure included 2,000 homes and buildings connected to the testbed with smart meters; an EV infrastructure with 140 fast-charging stations and 82 EVs; 4,540-kW wind turbine, 220 kW solar PV, 60 kW small hydropower, 250 kW diesel generators, and 2,605 MWh ESS battery; and Total Operational Center (TOC) which monitors and controls energy flows in the testbed (https://www.smartgrid.or.kr/). Since the inception of the testbed, performance data of smart grid technologies have accumulated and are available for public and commercial purposes.

- In addition to the testbed project, South Korea has constructed renewable energy-based microgrid projects over 20 islands with funding from the government or through joint ventures with private companies. Although the majority of those projects are yet to be commercially proven, the testbed project and island microgrids offered fertile ground for researchers, industry experts, and policymakers to verify emerging energy technologies in the field. One of the island microgrids, Gasa Island Microgrid, will be presented in detail in the following chapter.

3.2.3 ISSUES AND CHALLENGES

There have been several attributes that helped South Korea achieve the outcomes. The strong ICT industry infrastructure and technologies of South Korea played a vital role in the development of smart grid technologies. The funding support from the Korean government in R&D activities and commercialization of new technologies was the main driver to the smart grid. Also, the participation of private companies seeking new business opportunities played key roles in implementing new smart grid technologies in the field.

Even with those outcomes, South Korea still faces issues to be solved if the country is to achieve the vision and objectives to become the world's leader in smart grids. Although South Korea made significant advancements in new technology development, the creation of new business models and growth of new energy ventures are yet to have succeeded. Despite the support from the government and the active participation of private sector players, some core technologies of smart grids are still in the pilot stage and yet to be proven commercially feasible. The electricity tariff in the country is among the lowest in the world. Therefore, it is particularly challenging for any new technology to beat the current energy services without government's subsidies. Also, the electricity retail market is controlled by KEPCO, the national utility. KEPCO retains the monopolistic position in the market. It also keeps the ownership of electricity big data. In order to support the energy industry which nurtures new ideas, business models, and ventures, it is imperative for the government to take an active role to change the energy market structure.

4. CASE STUDY: THE GASA ISLAND MICROGRID

4.1 BACKGROUND

4.1.1 CHARACTERISTICS OF A MICROGRID IN AN ISLAND

The microgrid is a comparable concept to the conventional macro grid. The conventional grid is based on large scale generation plants, mostly thermal or nuclear power in the case of South Korea, and nationwide and centralized transmission and distribution lines. On the other hand, a microgrid is located close to where electricity demands exist. The main purpose of a microgrid is to reduce the dependency of energy supply on the conventional grid and achieve self-reliance of energy supply at the community level. The microgrid with small diesel generators has been popular in remote villages or islands where no access to the central grid is available. As the cost of renewable energies declines, the microgrid has come into focus as a feasible solution not only to replace diesel generators on remote villages or islands but also to reduce the dependency on a conventional grid in urban areas and achieve carbon emission reduction.

The microgrid has the following characteristics. First, the microgrid usually incorporates multiple energy sources, including renewable energies, which supply electricity to users directly. A renewable energy IPP (Independent Power Producer) connected to an existing central grid but without a direct link to electricity users, therefore, cannot be categorized as a microgrid.

Also, the microgrid needs a solution for integrated monitoring and control of distributed energy sources. The main purpose of the microgrid is to supply reliable energy to users of a community in a cost-effective way. To achieve this purpose, the microgrid must achieve optimized utilization of multiple energy sources with variable loads. In a stand-alone microgrid in a remote village or an island without access to the central grid, the optimization must be achieved within the isolated boundary without support from the central grid. There are two critical issues in a stand-alone microgrid: achieving the balance of energy supply and demand; and maintaining quality of electricity in terms of control of voltage and frequency in a regulated range. When a microgrid is linked to the central grid, any mismatch between supply and demand can be compensated by electricity trades with the central grid. In a stand-alone microgrid, on the other hand, any mismatch between the supply and demand must be balanced within the isolated system. In particular, the higher the penetration of renewable energy sources, the more challenging the balancing becomes in a stand-alone microgrid. The intermittency of renewable energy sources makes it hard to control the flow of electricity in the grid. Therefore, a stand-alone microgrid usually demands a higher level of integrated operation among different energy sources, and a faster and more precise level of monitoring and control of energy flows.

4.1.2 ISLAND MICROGRID PROJECTS IN SOUTH KOREA

There are about 471 populated islands in Korea, among which 302 islands of the total number of inhabited islands are connected to the national grid, and the remaining 127 islands are powered by stand-alone microgrids, mostly with diesel generators. The cost of power generation for the 127 islands is approximately 490 Korean won (US$40.8 cents)/kWh in average. The cost of electricity generation is over four times that of the mainland. However, the same electricity tariffs as in the mainland are applied to the users in these islands. The tariff to residents on the islands was about 130 Korean won (US$11 cents)/kWh. The government subsidizes the balance between the high generation costs and the electricity fee charged to the users. The source of the subsidy is the Electricity Industry and Infrastructure

Fund, where the fund is sourced by 3.7% surcharges on the electricity bills and by penalties imposed on utilities that fail to fulfill Renewable Energy Standard (RPS) mandates. In 2018, the government subsidized 119,000 million Korean won (US$100 million) to the 127 islands.

Among the power systems in the 127 independent islands, 65 islands are managed by KEPCO, 22 islands are managed by municipalities, and the remaining 40 islands are managed by cooperative entities of residents. These stand-alone microgrids adopted costly and polluting diesel power systems for electricity generation. In 2015, the Korean government announced a plan to replace the power system in those isolated islands with renewable energies and targeted the 65 islands managed by KEPCO as the first phase of renewable energy microgrids in South Korea. Initially, the government plan was to invite IPPs from the private sector to those islands, but the decline of oil prices in the international market delayed the implementation of the IPP plan. However, even before the IPP plan, the Korean government started funding for renewable energy microgrids in the isolated islands from the early 2010s. The purpose of the funding was to have testbeds for the development of renewable energy microgrid and testing smart grid technologies, and to provide private companies with field experiences of the design, construction and operation of a renewable energy microgrid project.

4.2 ENERGY ENVIRONMENT OF GASA ISLAND

Gasa Island is located approximately 6 km southwest of the Korean Peninsula. It currently has a population of 286 inhabitants and 168 households. Before the construction of the microgrid, the island was supplied by two 100 kW diesel generators operated in parallel during normal hours and one additional standby generator. As of 2013, the average annual fuel consumption of the island was 285,000 liters/year. The main industry of the island was fishery, and electricity demands were from households and refrigerators of fishery farms.

TABLE 8. ENERGY ENVIRONMENT OF GASA ISLAND

CLASSIFICATION	DETAILS
Location	Gasado-ri, Jodo-myeon, Jindo-gun, Jeonnam (6 km from Kahak Port)
Area	6.4 km^2
Population	286 people / 168 households
Power generation facilities	Diesel: 100kW × 3 units (built in 1994) Power distribution lines: 2 units (a total of 8km)
Status of load	Average load: 96kW, Maximum load: 173kW, Minimum load: 61kW
Major load	Abalone farms, salt farm, Radar bases, lighthouses, abalone farms, salt farm
Major industries	Agriculture, abalone farming

Source: Green Technology Center, 2016

FIGURE 8. GASA ISLAND'S VIEW AND LOCATION

Source: Korea Electricity Industry Association

4.3 DESIGN OF THE GASA ISLAND MICROGRID

4.3.1 BUSINESS MODEL OF THE GASA ISLAND MICROGRID

The renewable energy microgrid system on the Island was constructed by KEPCO in 2014 with public and private joint funding. Of the total investment of 9.2 billion Korean won (US$7.6 million), 60% was funded by the central government, and the rest was funded by KEPCO (35%) and the provincial government (5%). The purpose of the contribution of the provincial government was to support the growth of the regional industries by facilitating the commercialization of new technologies in its territory. Since KEPCO was already in charge of the supply of electricity in the island, there was no change in the existing energy business structure on the island. The residents in the island did not play a meaningful role in the process since the energy bills they were paying would remain unchanged. Therefore, the pilot project was purely focused on testing renewable energy microgrid engineering technology and verifying the techno-economic feasibility of a renewable energy microgrid system in an island.

4.3.2 SYSTEM CONFIGURATION OF GASA ISLAND MICROGRID

Table 3-2 lists the specification of components of the Gasa Island Microgrid. Three diesel generators had been already in operation in the island before the design of the microgrid project. The Energy Management System(EMS), developed by KEPCO, played the core part of the operational system. The EMS includes multiple functions for the island's microgrid such as forecasting renewable energy production, monitoring, and automatic controlling of energy flows among different energy sources and loads.

TABLE 9. SYSTEM CONFIGURATION OF THE GASA ISLAND MICROGRID

CATEGORY	QUANTITY	DESCRIPTION
EMS (Energy Management System) & PMS (Power Management System)	1 unit	Monitoring and control of energy flows among various energy sources and demands
BESS Inverter	500kVA x 2 250kVA x1	Frequency and Voltage Control
BESS	3 MWh	Lithium ion ESS, life span: 4,000 cycle
Wind Turbine	100kW x 4	On shore wind power system
Solar PV	314kW	Ground-mounted and roof-top (266 kW) Floating system on a lagoon (48kW)
Diesel Generator	100kW x 3	Existing diesel generators

Source: Design and Dynamic Performance Analysis of a Stand-alone Microgrid – A Case Study of Gasa Island, South Korea, Journal of Electrical Engineering & Technology Vol.6, 2011

FIGURE 6.MAIN POWER GENERATION FACILITIES AND OPERATING SYSTEM IN GASA ISLAND

4.3.3 DESIGN APPROACH FOR GASA ISLAND MICROGRID

The uniqueness of the Gasa island microgrid is the use of renewable energy as the base energy source, which is responsible for setting the voltage and frequency of the power grid. Unlike the conventional micrograds which adopted diesel generators to set the nominal system frequency and voltage, the Gasa Microgrid applied Battery Energy Storage System (BESS) for frequency and voltage control. This was possible in part due to the continuous decline in the price of BESS. However, there were two challenges that must be addressed when using BESS for frequency control in the stand-alone microgrid. First, its capacity should be large enough to work as the main source as well as energy storage. Second, the capacity of BESS should be limited due to its expensive installation and maintenance costs. To find an optimal capacity of BESS to fulfill these conflicting goals, the design of the microgrid adopted economic considerations in the optimal sizing of BESS.

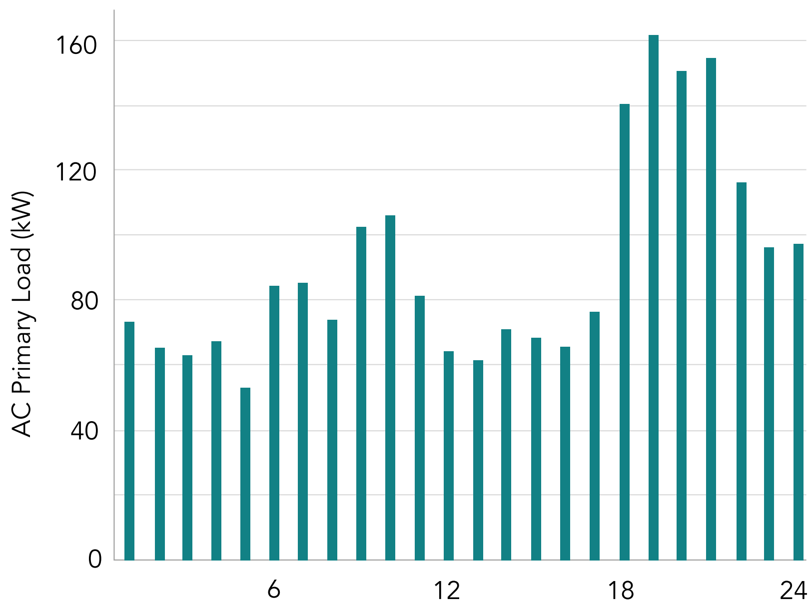
ANALYSIS OF RENEWABLE ENERGY RESOURCES

According to solar radiation data from NASA Surface Meteorology, the annual average solar radiation in the island was 4.01 $kW/m^2/day$. The annual average wind speed of Gasa Island was measured at 6.07 m/s at 50 m above the sea level according to the NASA database.

ANALYSIS OF DEMAND

When designing a stand-alone microgrid, it is fundamentally vital to analyze the loads that will be connected to the microgrid and to estimate its temporal evolution. In Gasa Island, there is a school, a town hall, a lighthouse, and a cluster of seaweed and fish farms; the average load and daily electricity consumption of the island were measured at 95 kW and 2,164 kWh. The load factor, the average power divided by the peak power, was calculated to be 0.48. Figure 3-3 illustrates the average daily load of Gasa Island used for the microgrid design. The average daily load of the island shows the typical load profile of resident islands with two peaks a day: the 1st smaller peak is detected during the daytime and the 2nd one in the evening.

FIGURE 9. AVERAGE DAILY LOAD PROFILE OF GASA ISLAND



OPTIMAL DESIGN OF MICROGRID

Based on the load data, and renewable energy resources, the sizing and economic analysis of the Gasa Island Microgrid was simulated using HOMER (Hybrid Optimization Model for Multiple Energy Resources) tool. The simulation outcome suggested the following energy mix, with expected benefits, as the optimal design of a microgrid for the island (Tables 3-3 and 3-4).

TABLE 10. OPTIMAL MICROGRID DESIGN FOR GASA ISLAND

COMPONENT	BATTERY ESS (KWH)	SOLAR PV (KW)	WIND TURBINE (KW)	DIESEL GENERATOR (KW)
Capacity	3,000	300	400	200

Source: Design and Dynamic Performance Analysis of a Stand-alone Microgrid – A Case Study of Gasa Island, South Korea, Journal of Electrical Engineering & Technology Vol.6, 2011

TABLE 11. EXPECTED BENEFITS OF THE GASA ISLAND MICROGRID

ITEM	RENEWABLE ENERGY CONTRIBUTION (%)	SAVING OF DIESEL FUEL PER YEAR (LITER)	CARBON EMISSION REDUCTION PER YEAR (TON)
Value	94.0	214,895	566

Source: Design and Dynamic Performance Analysis of a Stand-alone Microgrid – A Case Study of Gasa Island, South Korea, Journal of Electrical Engineering & Technology Vol.6, 2011

4.4 PERFORMANCE OF GASA ISLAND MICROGRID

In the Gasa Island Microgrid, BESS is used to control the system frequency and voltage instead of the conventional approach of using synchronous generators. This makes the microgrid immune to mechanical inertia and help the ESS respond to power imbalance events fast and dynamic way. This feature allows high penetration of renewable energy.

According to data from two full years of operation from 2015 and 2016, it was evaluated that the annual consumption of diesel fuel could be reduced by as much as 200,000 liters every year (Table 3-4), along with a significant reduction in greenhouse gas emissions. At the same time, it was found that the frequency level was maintained within the regulated level.

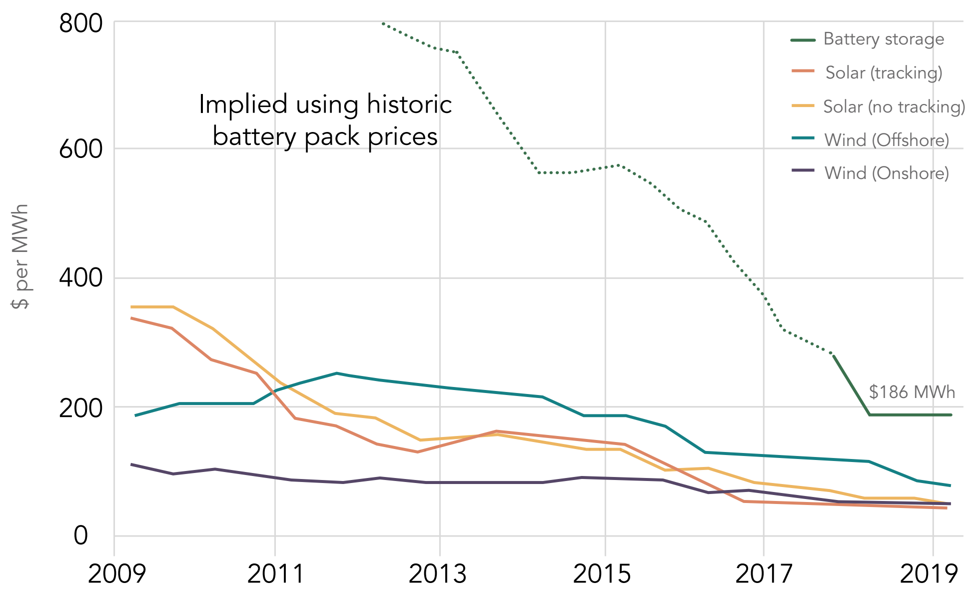
TABLE 12. ANNUAL DIESEL FUEL CONSUMPTION IN GASA ISLAND

YEAR	ANNUAL DIESEL FUEL CONSUMPTION (LITER)	SAVED DIESEL FUEL FROM 2013, (LITER)	RATE OF DIESEL FUEL SAVING FROM 2013, (%)
2013	260,847		
2014	214,921	50,797	19.5
2015	60,194	205,524	77.3
2016	72,416	193,302	72.7
Total		449,623	

Source: KEPCO Research Institute

 The project investment, 9.2 billion Korean won (US$7.67 million), was jointly funded by the Korean government, the provincial government and KEPCO. The observed annual diesel fuel savings was 320 million Korean won (US$270,000). Based on the diesel fuel savings for 2015 and 2016, the project's payback period was estimated to be longer than 25 years. From the financial perspective, the project could not justify investment. The Gasa microgrid was a testbed project with the main purpose of testing key microgrid engineering technology and verifying the functionality of key power system devices in a microgrid environment. At the same time, since the completion of Gasa microgrid, the cost of ESS, which was estimated to be more than 30% of the total investment cost, has been falling rapidly in the international market (Figure 3-4). This trend is expected to help island microgrids, like the one in the Gasa Island, achieve economic feasibility in the near future.

FIGURE 10. LEVELIZED COST OF ENERGY 2009-2019



Source: Bloomberg NEF

Even with the drawback of the costly technical applications, the Gasa microgrid provided useful knowledge and experience that can be used to design a renewable energy microgrid in a similar energy environment in both South Korea and other parts of the world. The followings are those knowledge and experiences.

4.4.1 TECHNOLOGY SIDE

- It has been found that with EMS and BESS, renewable energy sources can be used as a base energy source replacing diesel generators in stand-alone microgrid, and that the intermittent flow of renewable energies can be successfully controlled, and the quality of electricity supply and grid reliability can be assured.

- However, it has been found that achieving 100% renewable energy penetration is not financially feasible. The cost of BESS to replace diesel generators would be financially impractical, if not infeasible technically. The role of diesel generators as a back-up power system is considered to be imperative in a stand-alone microgrid even with the fast decline of BESS costs.

Based on the operational experience of the Gasa Island Microgrid, it is recommended that the development of a renewable energy microgrid could be implemented with the following process.

- For the time being, this approach would be more suitable for a small, remote, and stand-alone microgrid like Gasa Island which has low system inertia and where the demand is high for renewable energy sources that could replace costly and pollution-inducing diesel generators.
- As the cost of BESS declines in the future and knowledge and experience of renewable energy microgrids accumulate, the renewable energy microgrid can rapidly replace fossil-fuel-based energy systems in both islands and mainland areas.
- Eventually, the current microgrid solution is expected to evolve to encompass not only the supply side of a power grid but the demand side of the power grid and electric vehicles. If this happens, the microgrid will develop to the full scale of smart grid.

4.4.2 POLICY SIDE

In the case of the Gasa Island microgrid, there was no conflict of interests among key stakeholders or players. KEPCO was solely responsible for the generation and supply of electricity in the island before and after the power system transition. The residents of the island were not impacted in terms of economic benefit by energy system transition since the gap between the cost of electricity generation and the price of electricity charged to the users was subsidized by the government. Most of all, the majority investment cost was borne by the government to accelerate the development and commercialization of a renewable energy microgrid.

In order to promote renewable energy microgrids with the participation of private companies, the following issues should be addressed.

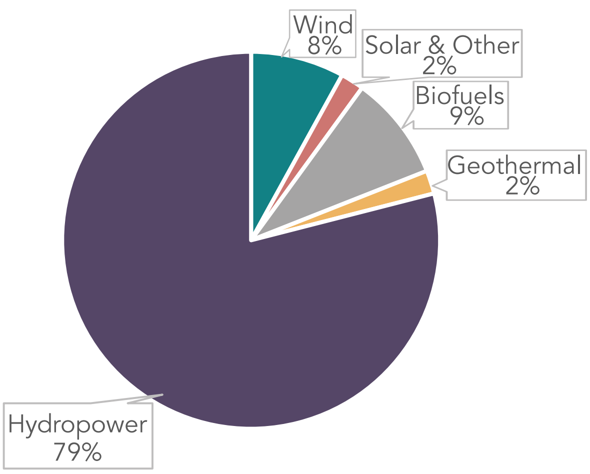
- If a private renewable energy producer is invited to a region where an existing national utility is responsible for energy generation and supply, a competition may occur between the two; the renewable energy company and the existing utility may compete for the prioritization of dispatch when a mismatch occurs between the supply and demand of electricity. To solve this potentially conflicting issue, thoughtful design of a power purchase agreement(PPA) is recommended to minimize such a conflict by setting a clear boundary between the responsibilities of electricity generation and supply, as well as the priority of dispatch order.
- The benefit of cost-saving and efficient operation from the automatic control of renewable energy microgrids may not be fully achieved if the employment contract with diesel operators prevents the streamlining of the operational unit working for the existing power plant.
- The active role of government with proper policy design is important in preventing those problems in advance by incentivizing the participation and collaboration among key stakeholders.

5. IMPLICATIONS AND RECOMMENDATIONS FOR LAC COUNTRIES

5.1 ENERGY MARKET ENVIRONMENT OF LAC

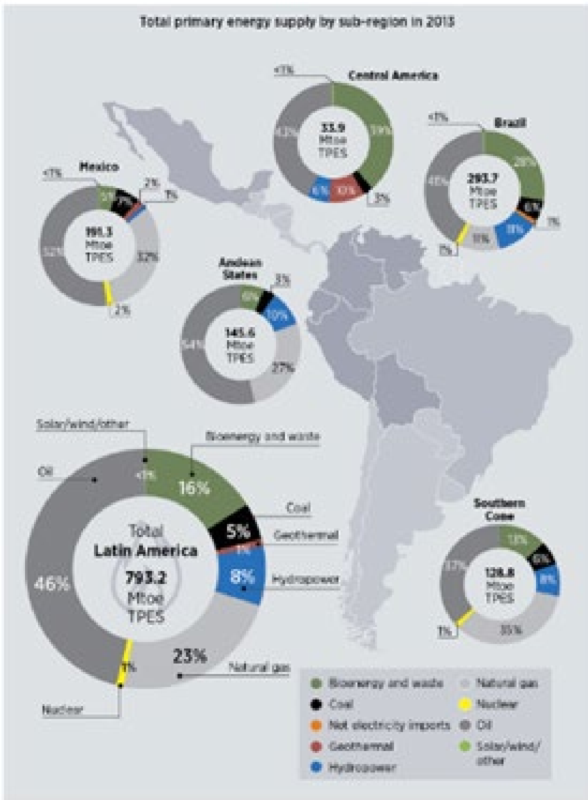
Latin America hosts some of the world's most dynamic renewable energy markets, with hydropower, biofuels, and wind power being the dominant renewable energies (Figures 4-1 and 4-2). "Latin America has seen significant investment in renewables. With close to two million people employed regionally in the sector and increasing degrees of local manufacturing, the socio-economic benefits are apparent. Rapid cost reductions, maturing renewable energy technologies and the consolidation of renewable energy policies with some of the world's best renewable resources have offered an unprecedented opportunity to accelerate the uptake of renewables across all sectors" (*Henning Wuester,* Director of IRENA's Knowledge, Policy, and Finance Centre).

FIGURE 11. SOURCE OF RENEWABLE ENERGIES IN LAC



Source: International Renewable Energy Agency, 2017

FIGURE 12. SHARE OF RENEWABLE ENERGIES IN LAC



Source: International Renewable Energy Agency, 2017

As stated by Henning Wuester, the fast growth of renewable energies in LAC should be attributed to multiple factors: rich renewable energy resources, proper government policies, and active participations of private sector investment. The following table shows that investments in renewable energies excluding hydropower increased from US$4.6 billion in 2005 to US$16.4 billion in 2015. Solar and wind energy sources attracted a majority of the investments (Figure 4-3).

FIGURE 13. INVESTMENT IN RENEWABLE ENERGY, 2010-2015: BY TECHNOLOGY (US$ BILLION)

Source: Bloomberg New Energy Finance, 2016

5.2 NEEDS FOR ENERGY INFRASTRUCTURE TRANSITION IN LAC AND THE CARIBBEAN

According to the understanding of the energy environment of LAC, the conditions for building smart grid infrastructure in LAC seem to be maturing. Most of all, despite recent unfavorable macro-economic conditions that face this region, the path to transition of the existing energy infrastructure to a greener and smarter one is inevitable and irreversible. The advantages, both quantitative as well as qualitative socio-economic, are tremendous. For the sustainable development of LAC in the future, the transition to smart energy infrastructure with the utilization of endowed rich renewable energy sources will be reasonable and feasible. In particular, due to the devastating impact of COVID-19 on the economies of the small island countries in the Caribbean region, the necessity of decoupling the economies from imported fossil fuels through the accelerated deployment of renewable energies is urgent. This new, unexpected socio-economic condition will require LAC and the Caribbean island countries to modernize existing power grids through the application of smart grid technologies. To facilitate such transition, LAC and the Caribbean region can be incentivized to learn and borrow knowledge from countries, like South Korea, which has been accumulating valuable knowledge and experience in energy infrastructure transition. The following is the specific areas for which LAC and the Caribbean region may hope to learn from abroad.

5.2.1 MODERNIZATION OF POWER GRID FOR HIGHER RENEWABLE ENERGY PENETRATION

First, there will be an increasing need for the improvement or modernization of the power grid. The existing power grids in LAC were designed and built for controllable energy sources, and therefore, increased contribution of intermittent renewable energy will cause problems with the reliability of the existing power grid and instability of the power supply. Grid operators will find it challenging to control the quality of the electricity supply as the penetration of renewable energy increases. In particular, the abundant wind energy resources allowed LAC to experience a rapid increase in wind power. The intermittency of wind power is known to be three times of that of solar power. The increase of renewable energy in the power supply will make it the highest priority for the grid operators in LAC to control the volatile energy flows of renewable energies in the power grid.

Furthermore, as the share of various non-conventional energy sources increase, the need for increased operational efficiency of the power grid through optimized operations among different energy sources and demands will become important and challenging. Unlike the case in the conventional grid where the flows of energy were controlled in one direction, the increased numbers of distributed energy sources, EVs, and new demand side technologies will create bi-directional, volatile, and unpredictable energy flows.

To solve those problem, as shown in the cases presented in Chapters II and III, South Korea has tested new technologies and applications including ESS for frequency regulation and market-based demand response. Those technologies and applications have been proven effective in controlling renewable energies in the existing power grid and improving the operational efficiency of power generation assets. Those experiences and knowledge will help LAC both minimize trial and error, and thus save time and resources spent on further deployment of renewable energies and achieve the optimized efficiency of the overall power system.

5.2.2 POST COVID-19 ENERGY INFRASTRUCTURE TRANSITION TO ACHIEVE SELF-RELIANCE OF ENERGY SUPPLY IN THE CARIBBEAN REGION

COVID-19 has highlighted the importance of climate change issues and self-reliance of a country's economy. This is in particular critical to the small island countries in the Caribbean region. Small islands, like those in the Caribbean, are among the areas that have been hit hardest by COVID-19. In the Caribbean region, the fuels, technologies, and experts, to run the energy and transportation systems are often recruited to the region from abroad. During the COVID-19 crisis, in the relatively small island countries, the supply of fossil fuel and generated electricity have been struggling to adjust to the reduced power demand and the strict border controls to imported fuels. At the same time, tourism, the main economy of most of the islands, is at a standstill. Most of Caribbean countries pay for the imported fossil fuels from tourism income, which is devastating due to COVID-19. The recovery effort after COVID-19, especially of increased self-reliance of the economies in this region would be crucial. Increasing the self-reliance of energy supply should be a key part of the recovery process in the Caribbean region.

The efforts for the increased self-reliance of energy should start from changing the existing fossil fuel-based power generation systems to renewable energy-based power systems. Despite the rich renewable energy resources, including solar, the contribution of renewable energies to energy supply in the Caribbean island countries is very low. In 2018, the share of renewable energies including solar, wind, waste to energy, and hydropower in the power supply in the Caribbean region was 13.3% (THE STATUS OF RENEWABLE ENERGY IN THE CARIBBEAN, Renewable Energy Caribbean, November 2018). As the costs of renewable energies and ESS decline, the economic feasibility of the replacement of diesel-based generation systems with renewable energy sources has become more compelling in the Caribbean region. However, the high penetration of renewable energies for island causes significant technical challenges on sustaining the reliability of the existing power grid. The following case of the power system at the Santa Cruz-Baltra Islands, Galapagos, Ecuador, presents such technical challenge.

Case: Zero Fossil Fuel Initiative, Santa Cruz-Baltra Island, Galápagos, Ecuador

Located in Pacific Ocean, the Galápagos Islands consist of 127 bodies of land including islands, islets, and rocks. The islands are registered at UNESCO National Patrimony of Humanity to be protected and are comprised of a total land area of 8,010 km². Locals are restricted to live in the 3.3 % (236.5 km²) land area on the five inhabitant islands including Santa Cruz, Baltra, San Cristobal, Isabela, and Floreana.

The Galapagos Islands were declared a World Heritage site in 2001, boasting its unique and pristine marine ecosystem, and historical importance. In addition, the tourism industry hosts more than 200,000 visitors each year and is the primary source of income for many of the island's residents, representing most of the economic activities on the Galapagos. A sustainable and reliable source of electricity is necessary to support the islands environmentally and economically. In the past, a heavy reliance on diesel fuels has damaged the ecosystem and made the local economy vulnerable to external market forces. In January 2001, an oil leakage accident near the coast of the Galapagos brought about the recognition of an urgent need to transition to renewable energy and protect the natural environment (Figure 4-1). The spill accident by an Ecuadorean-registered tanker, the Jessica, which was carrying about 243,000 gallons of diesel fuel near the archipelago's easternmost island of San Cristobal, caused massive environmental damage. The estimated leakage of diesel fuel was about 150,000 gallons (570,000 liters).

FIGURE 14 . IMAGE OF THE ACCIDENT

In 2007, the government of Ecuador launched the "Galapagos Islands Zero Fossil Fuel Initiative" in order to protect the ecosystem and conserve the environment on the islands. Considering the cultural and scientific significance of the islands, the Ministry of Electricity and Renewable Energy made the plan to replace diesel power generation with renewable energies in order to reduce greenhouse gas emissions and environmental risks in the Galapagos islands. The initiative aims to reach the 100% energy transition to renewable energies in the Galapagos Islands by 2025.

Currently, Santa Cruz and Baltra islands operate 1.5 MW solar PV and 2.25 MW wind power systems in conjunction with existing diesel generators. The peak demand of the islands is about 4 MW. In 2016, ElecGalapagos, the national utility in charge of the electricity supply in the islands, produced 33,097 MWh in total and 6,678 MWh from solar and wind powers. Although the share of electricity supply of wind and solar was about 20% in average, the instantaneous impact of renewable energies, especially from more volatile wind turbines, on the power grid was found to be very problematic. The government of Ecuador successfully attracted renewable energy projects from international organizations and aiding agencies to the Galapagos Islands, but each project came from separate funding sources without considering the optimized operation of the overall power system. As a result, the current power grid on the islands is found to be unprepared for such levels of renewable energy activity.

In order to analyze problems and find a solution, a technical feasibility study funded by the Korea Energy Agency, and Ministry of Trade, Industry, and Energy, Republic of Korea, was conducted in 2017. The study found following troubles in the power system of the Santa Cruz Island, and those trouble were

suspected to be caused by the volatile behaviors of wind and solar PV on the island.
Grid Instability: The voltage and frequency of the grid were found to be unstable, fluctuating out of the regulated range. The cases were observed when wind and solar power systems were operating at the full capacity. Such instability caused poor power services to users, as well as having negative impact on the longevity of key equipment in the power system.

Inadequate application of ESS which resulted in improper functioning of ESS: To control the intermittency of wind power, ElecGalapagos installed a 4 MWh lead acid storage battery near the wind power substation. However, the lead acid battery was designed for long-term energy storage, but not for fast response to instantaneous changes of energy flows from the wind turbines.

Sub-optimal Performance of PV and Wind Power System: In order to avoid grid problems, a curtailed operation has been enforced on the existing wind turbines, resulting in the performance of wind turbine capped at two thirds of the designed capacity of the wind turbines.

Source: Feasibility Study on the Integration of a Microgrid Using Energy Storage System at Santa Cruz and Baltra Islands, Galapagos, Ecuador, One Energy Island Co., Ltd.

As a solution to the identified problems in the above case, the feasibility study proposed the application of EMS and ESS to monitor and control the flows of energy in the power grid, and optimize the operations of different energy sources—diesel generators, solar PV, and wind turbines—in a way to sustain grid stability as well as to achieve efficient operation of the power generation assets. The underlying ideas and logics that the feasibility study adopted for the diagnosis and proposed solution were based on knowledge from the renewable energy island microgrids in Korea, including the Gasa Island microgrid presented in the Chapter 3 in this report.

Most of the islands in the Caribbean region have a similar energy environment and power grid structure with Santa Cruz island. Therefore, the replacement of diesel generators with renewable energy sources will produce the same technical problems as in the case above. Compared to a macro-grid on the mainland, a power grid on an isolated island is much more sensitive to the volatility of energy flows. Therefore, the design of a power grid on an island should focus on sustaining reliability of power grid, and grid operators should consider the following issues.

- Any mismatch between the supply and demand must be balanced within the island boundaries since there is no central power grid to support balancing. In particular, the number of such a mismatch event increases sharply when the penetration of renewable energy sources increases.

- A power grid on an island becomes more susceptible to electricity quality issues. In the macro-grid in mainland, the voltage and frequency are controlled by a large capacity of reliable and controllable energy source—thermal, large hydro or nuclear power, for example. In an island, on the contrary, a diesel generator plays the role. However, when the share of renewable energy increases, there is a point beyond which a renewable energy source should take over the task of voltage and frequency control. The technical aspect and challenge of using renewable energies as base energy source was presented in the case study of Gasa Island microgrid in the Chapter III.

Replacement of a fossil fuel-based power system with renewable energies in an island is still an evolving trend in the world. However, such transitions are expected to take place in the Caribbean over the next decade. To those who are responsible for the power system in the Caribbean region, the Gasa Island microgrid project will provide useful knowledge and experience for optimal design of a renewable energy microgrid and reducing avoidable trials and errors in implementation process.

5.3 RECOMMENDATIONS FOR LAC

The energy market structure and dynamics vary by country. Therefore, it may not be applicable if the knowledge and experience of the South Korean smart grid is directly copied to LAC in energy infrastructure transition. Even in LAC, each country may have a different energy market environment. Nevertheless, in the technical side, it is considered that the Korean smart grid technologies could be adopted universally to most LAC. Whereas in the policy side, the learning and experience of the Korean smart grid development should be carefully and wisely interpreted and accepted. With this in mind, this paper offers the following recommendations for LAC.

5.3.1 TECHNOLOGICAL RECOMMENDATIONS

- The market - based demand response program and the ESS application for frequency regulation in South Korea can be emulated within LAC in the design and construction of an advanced power grid within LAC. The experience of South Korea in demand response and ESS for frequency regulation is expected to help utilities or power grid operators in LAC design power grids with increased flexibility and an increased share of renewable energies.

- Technologies of the Gasa Island microgrid could be applied in effect to energy system transition of the Caribbean islands when countries in this area have to replace the power system with renewable energies. South Korea already experienced technical problems through the various microgrid projects that are typical to an island microgrid with renewable energy playing the majority role of electricity supply. Consequently, these experiences such as trials and errors, and knowledge from the island microgrid project, can be valuable resources to the Caribbean islands in designing optimal renewable energy microgrids.

5.3.2 POLICY RECOMMENDATIONS

When energy infrastructure transition takes place, it is natural to see increasing conflicts of interest among stake holders, especially between the existing utility and the new players coming into the market seeking new business opportunities. This potential conflict of interests involves dispute and discussion between the existing utility and new entrants concerning the impact on the reliability of the power grid and the cost competitiveness of emerging technologies. Electricity is a basic commodity in a society, and it must be supplied without interruption and remain affordable. Therefore, an existing utility tends to resist new technologies. Without the government's timely intervention, it is particularly challenging for any new technology or new business model to find opportunities to be proven in the market.

From this perspective, it may be useful to review the Korean government's previous interventions in the energy market. In 1999, the government span-off the KEPCO's generation unit into six independent subsidiaries. In 38 years after its inception, the power generation business was separated from KEPCO, leaving the corporation as the monopoly of the country electricity trade, and transmission and distribution business. Subsequently, the government allowed a private IPP (Independent Power Producer). Initially a few IPPs entered the energy market with CHP (Combined Heat and Power), but the number of IPPs increased dramatically after the government started the promotion of renewable energies. As the next step, in an effort to open the energy market to new technologies and business ventures, the Korean government is considering the following actions:

- Opening the electricity "Big Data" to the public so that anyone who wants to design a new energy business model can have access to the data. Currently, KPX (Korea Power Exchange), a subsidiary of KEPCO, keeps the data base.

- Opening electricity retail sales markets at the community or regional level to private companies.

As mentioned, the energy market structure in South Korea has been centralized and dominated by the national utility. This central market system has served as a double-edged sword in promoting new technologies and growing new business ventures. The system worked very effectively in top-down decision making, and investment and development of new technology. However, it was not so effective in building a blossoming industry for new energy ventures to emerge and grow. Therefore, one of the key tasks for policy makers is how to design a new energy market system that encourages entrances of new participations and nurture the growth of new ideas and ventures while coordinating interests of various players in a way of maximizing the benefit as the whole society. As explained in the previous sections in this paper, South Korea has been experiencing the same issues as it develops smart grid infrastructure as the country's new economic growth engine. Therefore, the historical change of energy market and experiences of smart grids in South Korea could provide the energy policy makers in LAC with some of the useful ideas and guidelines in designing their own energy policies when they plan a new socio-economic environment that is green, thriving, and sustainable.

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