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Review of Status of Wind Power Generation in South Korea: Policy, Market, and Industrial Trends

Ji-Won Hwang[1], Jung Keun Kook[2], Han-Bin Jeong[3], Ju-Hyun Mun[4], and Sanghee Kim[5],*

[1]*Department of Architectural Engineering, Kyonggi University, Suwon 16227, South Korea*
[2]*Department of Architectural Engineering, Jeonbuk National University, Jeonju 54896, South Korea*
[3]*Department of Architectural Engineering, Kyonggi University, Suwon 16227, South Korea*
[4]*Department of Architectural Engineering, Kyonggi University, Suwon 16227, South Korea*
[5]*Department of Architectural Engineering, Kyonggi University, Suwon 16227, South Korea*

Abstract

Various policies in South Korea have been implemented to reduce greenhouse gas emissions and to spread new and renewable (N&R) energy, and the cumulative wind-power generation capacity was increased by approximately 2.6 times from 2012 to 2018. The Korean version of the New Deal policy has been officially announced, and aggressive investment in wind power generation has been secured. In this regard, this study aimed to review related trends in the energy policy, market, and the overall industry. The government has established a total of four plans in relation to green energy. The Fourth Plan is currently being implemented; its goal is to increase the average annual growth rate to 16.5%. Companies have also invested to develop large-capacity wind turbines and components such as blades with a length of 60–80 meters and a speed increaser of 2.5 MW. Incidentally, despite being green energy, the power generation complex has raised many issues in energy production or installation, especially low-frequency noise (12.5-80 Hz). To overcome some issues, residents and the government agreed on a peaceful solution, which involves the profit-sharing and recovery model and the government providing guidelines for low-frequency noise, including management procedures and solutions.

Keywords: Renewable energy, Wind-power generation, Greenhouse gas, Korean New Deal.

I. INTRODUCTION

The seriousness of greenhouse gas (GHG) emissions has been acknowledged and understood throughout the world, as manifested by the adoption of the Tokyo Protocol in 1997. Accordingly, many countries have initiated efforts to reduce GHG emissions since 2005. South Korea has also been implementing various policies to reduce GHG emissions. Currently, the three main GHG reduction policies in Korea are 1) GHG and energy target management system, 2) emission trading (ET) offset system, and 3) ET reduction facility support project in the industrial and power generation sectors [1]. First, the GHG and energy target management system in the industrial and power generation sectors is a key means to realize reduction in GHG emission, and the aim of implementing this system is to manage companies that emit significant quantities of GHGs. To achieve the national GHG reduction goal (reduction of the total emissions in 2017 by 244/1,000 by 2030), this system designates companies with large GHG emissions and high-energy consumption as companies to be managed, assigns reduction targets for GHG emissions and energy consumption, and verifies and manages their performances (Table 1). The targets of this system are companies and businesses whose average GHG emissions and energy consumption over the last three years (as of January 1st of the corresponding year) exceeded the criteria mentioned in the "Enforcement Ordinance of the Framework Act on Low Carbon and Green Growth." Second, the ET offset system in the industrial and power generation sectors is operated to achieve the national GHG reduction goal (37% by 2030 compared with Business As Usual (BAU)) in an efficient and cost-effective manner. The purpose of this system is to improve the flexibility of companies with GHG emissions in terms of GHG production. The contents of this system are categorized into three. First, the government allocates emission permits to workplaces with GHG emissions for a year based on ET, so that the workplaces can perform emission behavior within the allocated range. The practical GHG emissions of the workplaces are evaluated to allow transactions between them for remaining or insufficient emission permits. Second, external businesspersons can sell the Korea Offset Credit (KOC) issued through external businesses to companies subjected to the allocation of emission permits based on the offset system; then, the companies can convert the purchased KOC into Korean Credit Unit (KCU) and perform offset or transactions under the ET scheme. Third, GHG emissions are reduced, absorbed, or removed in a way that meets international standards in emission facilities or activities outside the boundaries of companies subjected to the process of allocation of emission permits through external businesses. Third, the ET reduction facility support project is proposed for the industrial and power generation sectors; the purpose of this project is to induce the practical GHG emission reduction effect of the companies subjected to the process of allocation of emission permits and to reinforce their ET implementation capacity by supporting the introduction of GHG and energy reduction facilities. This project supports the installation cost of facilities with excellent GHG and energy reduction effects for small and medium-sized companies among the companies subjected to the process of allocation of emission permits in the industrial and power generation sectors.

Table 1. Criteria for designating companies to be managed for GHG emissions [1]

Category		GHG (total CO_2)	Energy (Tera Joule)
Until December 31, 2011	Company	125,000	500
	Workplace	25,000	100
From January 01, 2012	Company	87,500	350
	Workplace	20,000	90
From January 01, 2014	Company	50,000	200
	Workplace	15,000	80

One of various methods used to reduce GHG emissions is the use of new and renewable energy. Efforts to develop and utilize renewable energy have also been actively made in South Korea. Consequently, the "New Energy and Renewable Energy Development, Use, and Spread Promotion Law" [2] was established, and the "Fourth Basic Plan for the Development, Use, and Spread of New and Renewable Energy Technologies (2014–2035)" is currently being executed [3]. The term "new and renewable energy (hereinafter referred to as N&R energy)" is used in Korea, and is defined as alternative energy sources that can replace fossil fuels [4]. For N&R energy, new energy comprises three areas, namely, fuel cells, coal liquefaction/gasification, and hydrogen energy. Renewable energy comprises eight areas, namely, solar heat, photovoltaics, biomass, wind power, hydropower, geothermal heat, marine energy, and waste energy. Among various N&R energy sources, there is recently growing interest in wind-power generation. Wind energy can produce electricity by converting the natural wind into rotational kinetic energy in the wind turbine. Wind energy is a clean energy source that does not emit pollutants, and the scope of wind power generation is limitless [5–7]. Commercialization of wind energy is easy owing to the relatively low power-generation costs compared with those of other N&R energy sources; additionally, wind power facilities such as windmills can be used as tourist attractions. In South Korea, wind energy is harvested by installing large-scale wind power generation complexes in coastal or mountainous areas abundant in wind resources, such as Daegwallyeong, Jeju Island, and Taebaek City. In recent years, offshore wind power plants have been constructed owing to the beneficial geographical location of South Korea, which is surrounded by sea on three sides, and more wind power plants will be built in the future. In July 2020, the President of South Korea set the goal of joining the global top five countries in terms of offshore wind power by 2030 [8]. To this end, three directions were established for increasing the offshore wind power of 124 MW generated from three complexes by 100 times to 12 GW in 2030. The president also mentioned that the government would provide active support for systematically developing large-scale wind power generation complexes led by local governments. He announced that sites with excellent business potential and small damage to the fishing industry would be identified, and that the licensing procedure would also be simplified for smooth project implementation. It was also announced that the initial demand could be created with large projects for domestic companies to increase their price competitiveness and technology competitiveness, and that the investment in technology development would be continued. The president also said that a growth engine would be created in response to the climate crisis using green energy and "offshore wind power."

As mentioned above, wind-power generation has attracted considerable attention as a renewable energy source in Korea. Therefore, this study aimed to summarize the policies, international cooperation projects, and market and industrial trends of wind-power generation in South Korea. In addition, an attempt was made to predict the future of the wind-power generation industry in South Korea.

II. GOVERNMENT POLICIES

The Korean government has established policies mainly on the "goal of developing, using, and spreading technologies," "proportion of the power generated," and "implementation method" since 2001 to promote the development, use, and spread of N&R energy technologies [1]. Starting with the announcement of the "Basic Plan for the Development and Spread of Alternative Energy Technologies" in February 2001 [9], the "Second Basic Plan for the Development, Use, and Spread of N&R Energy Technologies (December 2003 to 2012)" was announced in December 2003 [10]. The "Third Basic Plan for the Development, Use, and Spread of N&R Energy Technologies (December 2008 to 2030)" was announced in December 2008 [11], and the "Fourth Basic Plan for the Development, Use, and Spread of N&R Energy Technologies (2014 to 2035)" was announced in September 2014 [3]. The main contents for each step are shown in Table 2. The first plan targeted the construction of energy supply systems based on the activation system of the alternative energy industry. The second plan attempted to improve systems and policies by reviewing the introduction of the renewable portfolio standard (RPS). The third plan included plans to achieve the goal of the spread of N&R energy and to perform research and development (R&D). The fourth plan involved the development and expansion of N&R energy technologies. Among the various existing renewable sources, solar heat, solar power, biomass, wind power, hydropower, geothermal heat, marine energy, waste energy, fuel cells, coal liquefaction/gasification, and hydrogen energy were designed as primary targets. Among them, contents related to the wind-power generation industry are summarized in section 2.1.

Ⅱ. Ⅰ Promotion of Wind Powered Generator System

In the first plan (2001), in a project for wind-power energy, plans were formulated to develop a medium-sized (60–750 Kw) wind-power generator by 2004, and to create a new system based on the previously developed rotor manufacturing technology [9]. The expected power generation cost was $0.083/kWh (92 KRW/kWh) and was determined to be economically efficient, as the power generation cost was set to $0.0539/kWh (60 KRW/kWh; sales cost: $0.0541 [60.23 KRW]) for the construction of a large 10 MW complex. In addition, the Green Fields Program was operated to activate the N&R energy market. The introduction of a subsidy system was reviewed through the program, and wind-power energy was intensively spread with subsidies. An attempt was made to link wind energy with energy projects in each area, and a plan was established to create a wind farm in Jeju Island with respect to wind-power generation. The set goal involved the production of 10% (150,000 Kw) of the demanded electricity in Jeju Island through wind-power generation in the island by 2006. In addition, Green Village, a village creation program that enables energy self-sufficiency using natural energy, was also planned.

Table 2. Established plans and main contents [3,9-11]

Date	Established plans and main contents
February 2001	Basic Plan for the Development, Use, and Spread of New and Renewable Energy Technologies - Expansion to the development, use, and spread of technologies - Construction of energy supply systems based on the activation system of the alternative energy industry
December 2003	Second Basic Plan for the Development, Use, and Spread of New and Renewable Energy Technologies - Among the supply proportions of new and renewable (N&R) energy, the target proportion of wind-power generation was set to 3% in 2006 and to 5% in 2010 - The target proportion of the power generated from research and development (R&D) energy was set to 7.0% for 2010 from 2.4% set in 2006 - System and policy improvement by reviewing the introduction of the renewable portfolio standard (RPS)
December 2008	Third Basic Plan for the Development, Use, and Spread of New and Renewable Energy Technologies (December 2008 to 2030) - Achieving the goal of the spread of N&R energy was sought by separating it from R&D - Basic directions to efficiently respond to changes in policy environment surrounding N&R energy were set - Spread goals were presented based on various criteria that meet international comparison and domestic policy goals
September 2014	Fourth Basic Plan for the Development, Use, and Spread of New and Renewable Energy Technologies (2014–2035) - 1.0% of primary energy to be supplied with N&R energy by 2035 - Focused on the creation of a N&R energy market ecosystem to convert the government leadership into public–private partnerships - Expansion to overseas markets for sustainable growth

In the second plan (2003), an attempt was made to implement policies for the spread of N&R energy aggressively. Correspondingly, it was planned to increase the proportion of wind energy and to provide it with strategic and intensive support continually. Further, areas with excellent wind conditions were selected. Accordingly, it was planned to distribute 40 MW in Yeongdeok, Gyeongbuk in 2004, 98 MW in Daegwallyeong, Gwangwon in 2005–2006, 30 MW in Sinan, Jeonnam in 2007–2009, and 45 MW in Saemangeum, Jeonbuk in 2010. In terms of technology development, it was planned to develop 750 Kw and 1 MW wind-power generators with domestic technologies for the supply of alternative energy power, and to add the Green Villages in 2003 for the application of combined wind-power technology.

The key task was the technological development to secure economic efficiency, such as increasing the size of wind-power generators and reducing the system cost. Given the prior determination that government-led spread activation measures were required to create the initial market, it was planned to implement detailed tasks on wind power. It was targeted to gradually increase the production of electric energy to 1 MW in 2005, 1.5 MW in 2008, and 3 MW in 2012, by establishing the foundation for the industrialization of wind-power generation technology, promoting large wind farms, and increasing the size of wind-power generators. It was also targeted to decrease the wind power generation system cost from $1,200/kWh in 2003 to $600/kWh in 2012 and to reduce the power generation cost from $0.1/kWh in 2003 to $0.03/kWh in 2012. The distribution of 2,250 MW power generation facilities by 2012 through the local manufacturing and enlargement of wind-power generation systems was targeted. In this instance, it was targeted to increase the onshore wind-power generation from 207 MW in 2006 to 1,587 MW in 2012, and to increase the offshore wind-power generation from 5 MW in 2006 to 680 MW in 2012. Technology development policies for wind-power energy were formulated and were applicable in three stages based on the division of the period from 2003 to 2012 in four-year intervals. Stage 1 involved the development of technology to be distributed and promoted from 2003 to 2006. A medium-sized 750 Kw-class system and a small-sized 30 Kw-class system were developed and commercialized. In addition, a database on wind-power resources was constructed and the prediction technology was developed. Stage 2 involved the development of technology for distribution in large quantities (from 2006 to 2009). A large-size (1–1.5 MW) wind-power generator technology was developed and a demonstration project was implemented on a 1 MW wind-power generator. In addition, an offshore wind-power generator technology was developed. Stage 3 is for the development of technology to be commercialized at a low cost (from 2009 to 2012). An ultra-large 3 MW wind-power generator technology was developed and commercialized. In addition, the commercialization of power connection and applied technology was achieved, and a database on offshore wind-power resources was constructed.

In third plan, it was determined that wind power development was remarkably insufficient owing to problems, such as the lack of economic efficiency, concentration of supply on specific N&R energy sources, and poor technology levels and domestic industrial bases. Therefore, the predicted demand for wind-power energy and targets were re-established, and intensive support for core-technology development and workforce training was planned. The table below lists the predicted demand for wind-power energy and targets. According to the plan, the predicted demand for wind-power energy will be 4,155 thousand tonnes of oil equivalent (toe) in 2030.

Table 3. Predicted demand for wind-power energy and targets [3]

Year	Predicted demand for wind energy (thousand toe)	Proportion of wind-power generation among N&R energy
2008	106	1.7%
2010	220	2.9%
2015	1,084	9.2%
2020	2,035	11.6%
2030	4,155	12.6%
Average annual growth rate	18.1	18.1%

There were three targets for the development of wind-power energy technology. The first was to become one of the world's top five technologically advanced nations in 2020. The second was to develop onshore/offshore wind-power generation systems with high reliability and high efficiency. This task aimed to reduce the system cost from $2.71/W (3000 KRW/W) in 2010 to $2.16/W (2400 KRW/W) in 2020 and $1.53/W (1700 KRW/W) in 2030. In addition, it was planned to increase the facility capacity from 2 MW in 2010 to 3 MW in 2012 and to 5 MW in 2016. The third aim was to secure technologies for power system stabilization control and assessment of wind-energy resources. To achieve these targets, technological development was performed in three stages.

Stage 1 related to the technological independence and industrialization until 2010. The development and verification of 2–3 MW onshore/offshore wind-power generation systems, development of a 5 MW wind-power-generation system, development of domestic technology based on airfoil and high-efficiency blades, speed increaser weight-reduction technology, and a large permanent magnet generator, construction of onshore/offshore wind-power resource maps, and the development of medium-sized and large combined power generation technology and low-noise technology were specified.

Stage 2 related to the development of technology to reduce costs from 2011 to 2020. It was specified to develop a 10 MW offshore wind-power generation system, integrated blade forming technology, radar interference avoidance technology, floating offshore basic technology, wind-power–hydrogen-hybrid-connection technology, and wind-farm operation technology.

Stage 3 related to the expansion of the base of industrialization from 2021 to 2030. It was specified to develop a floating offshore wind-power system rated at 10 MW or higher, a high-altitude wind-power-utilization system, large-capacity, wind-power generator, hybrid-power generation technology, and multicountry system operation technology based on wind-power forecasts, and for the operation of a small wind-power generation system to be applied to buildings.

The key areas of the development of wind-power energy technology are low-cost onshore wind-power systems and 3 MW or higher offshore wind-power systems. The main technology development targets were also determined based on the period. In the short-term case, there were four targets, i.e., a) the development of a 2 MW, low-wind-speed, direct-drive-type wind-power generation system for industrialization, b) development and commercialization of a 5 MW offshore wind-power generation system for industrialization, c) development of devices related to low-voltage ride through (LVRT) and control technology as original technology, and d) optimum design and operation of wind farms in complex terrain and weather as original technology. In the long-term case, there were two targets, i.e., the development of large-blade technology with high efficiency that can be adapted to wind conditions and floating/new large blade technology as original technology.

In the Fourth plan, the fourth plan also aimed to develop wind power as a key energy source. The task was targeted to increase the proportion of wind-power energy from 2.2% in 2012 to 18.2% in 2035; that increased the average annual growth rate to 16.5%. And it was also targeted to decrease the wind-power generation cost from $0.195/kWh (217 KRW/kWh) in 2013 to $0.073/kWh (81 KRW/kWh) in 2035 (Fig. 1). In particular, in the fourth plan, measures were formulated to use the existing technologies more efficiently and practically (Table 4). Moreover, it was announced that the peak contribution of N&R energy would be improved by installing energy storage systems (ESSs) in wind-power facilities, and by increasing the weight of renewable energy certificate (REC), this would be expanded to other energy source facilities in the future. It was also announced that variable weights that can be selected would be introduced to wind-power energy sources that require high-initial investment costs, and that the capability of R&D on N&R energy would be reinforced by establishing a technological development road map along with target costs for each N&R energy source for smooth market entry based on the minimization of the investment cost. The table below shows the contents to be implemented with respect to wind-power energy. In addition, it was targeted to reduce the power generation cost with the use of these technologies as unit turbine capacity increase technology, complex optimum design technology, and offshore wind-power system linkage technology.

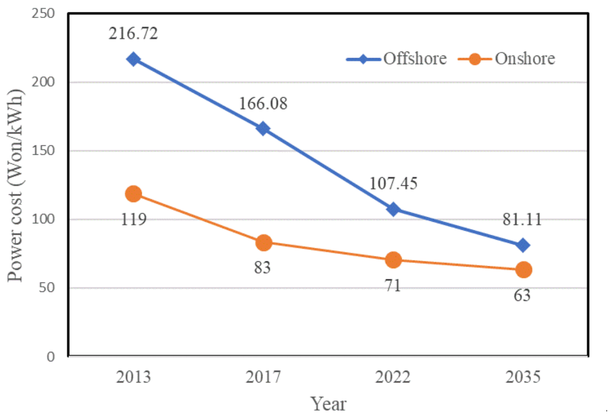

Fig. 1. Wind-power generation cost reduction scenario (Won/kWh) [3]

In the "Economic Policy Directions for the Second Half of 2020" announced by the Korean government in June 2020, the implementation plan of the "Korean version of the New Deal policy" for "constructing a leading economic base" was specified [12]. The Korean version of the New Deal policy will be implemented on the two axes of a digital new deal and a green new deal, and aims to create 1.9 million jobs by investing $ 143.7 billion (160 trillion KRW) by 2025 [13]. The green new deal is a policy in which a net-zero society is oriented by combining infrastructure/energy green transformation and green industry innovation. In the policy, a target of low-carbon/decentralized energy management has been established and it will be realized by constructing the foundation for spreading the three N&R energy sources of solar power, wind power, and hydrogen [14]. The foundation for the spread of the three N&R energy sources, i.e., solar power, wind power, and hydrogen, will be established, and large-scale R&D/verification projects and citizen shareholder projects will be implemented for solar power, wind power, and hydrogen [15]. The Government announced that wind-condition measurement and feasibility studies on wind power will be supported for up to 13 regions to identify sites for large-scale offshore wind farms through specific, major investment projects, and system improvement tasks, and hinterlands/verification complexes will be constructed in stages. Moreover, a test bed and a verification complex for offshore wind turbines will be constructed [14].

Table 4. Technology development plan for wind-power energy [3]

Task name	Technology overview and expected effect
Development of optimal corrosion management technology to secure the designed lifetime of offshore wind-power structures	▪Development of optimal corrosion management technology to secure the stability of offshore wind-power structures and reduce maintenance cost, and contribution to the reduction of the maintenance cost of offshore wind-power structures
Development of a simultaneous submarine cable burying machine for shallow-sea waters	▪Development of a simultaneous submarine cable burying machine for shallow-sea waters and soft ground, reductions in construction cost and period expected by reducing the existing three-step method (excavation → laying → protection) to a single step
Development of industrial convergence facilities using offshore wind-farm seawater space and verification research	▪Development of industrial convergence facilities using offshore wind-farm seawater space to create additional benefits and increased social acceptance from the coexistence of offshore wind-power and marine resources
Verification research on supporting structures for full-scale offshore wind turbines	▪Verification of supporting structures for full-scale offshore wind turbines and securing of design/construction technology, the world's first verification scheme. The installation cost can be reduced by 30% by reducing the offshore installation period

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Ⅱ. Cooperation Project

South Korea is willing to respond to climatic changes through international cooperation. To accomplish this, it is performing various international cooperation projects. According to Korea Energy Agency [16], the main projects are divided into “multilateral cooperation” and “bilateral cooperation” Projects. The purpose of the multilateral cooperation is to expand international cooperation networks and discover cooperation agendas by participating in international conferences on energy efficiency and N&R energy (Table 5).

The purpose of the bilateral cooperation is to exchange energy-related policies and other information to construct cooperation-based systems, and to discover cooperation projects. South Korea is pursuing cooperation projects on energy efficiency and N&R energy with various related overseas institutions, such as the Sri Lanka Sustainable Energy Department, Uzbekistan Ministry of Economy, Tanzania Ministry of Energy and Minerals, Peru Ministry of Energy and Minerals, and Cambodia Ministry of Mines and Energy (MEM), and multilateral development banks [16].

Ⅲ. WIND POWER MARKET TREND

The table 6 lists the wind-power generation distribution at different years. The proportion of wind-power generation in Korea is expected to continually increase owing to the government policies and the increased demand for N&R energy **[18]**. The cumulative power generation capacity was 492 MW in 2012, but it increased by approximately 2.6 times to 1,303 MW in 2018. Among the cumulative power generation capacity in 2018, 1,230.5 MW was from onshore facilities and 72.5 MW from offshore facilities.

Table 5. Main multilateral cooperation projects of South Korea [16]

Project name	Contents
United Nations Framework Convention on Climate Change (UNFCCC) (KEA 2020; MOFA 2015)	Attending conferences and responding to agendas with respect to the UN Convention on Climate Change signed in 1992 for the regulation of the greenhouse gas (GHG) emissions to prevent global warming
Asia-Pacific Economic Cooperation Energy Working Group (APEC EWG)	Information exchange and cooperation on energy saving and N&R energy
International Energy Agency (IEA) Energy Efficiency Working Party (EEWP)	International cooperation on the development of policies on energy efficiency among Organization for Economic Cooperation and Development (OECD) countries
International Partnership for Energy Efficiency Co-operation (IPEEC Policy Committee and Executive Committee)	Officially launched at the G8 Energy Ministerial in May 2009 to reinforce international cooperation on energy efficiency
ASEAN+3 Energy Cooperation (New and Renewable Energy/ Energy Efficiency Forum)	Joint energy cooperation among the ten ASEAN member countries and three countries in Northeast Asia (Korea, China, and Japan)

Table 6. Wind power generation distribution status in South Korea at different years [19]

Category	2012	2013	2014	2015	2016	2017	2018
New installation (MW)	73	92	61	208	187	114	161
Cumulative capacity (MW)	492	583	645	853	1,035	1,143	1,303
Onshore	-	-	-	-	-	1,105	1,230.5
Offshore	-	-	-	-	-	38	72.5

Table 7 shows the power generation as a function of the region in 2017 and 2018. The results are similar with the exception of Gangwon, Gyeongbuk, and Jeonnam. Power generation increased by 5, 21, and 4 MWh in Gangwon, Gyeongbuk, and Jeonnam, respectively. The increase in wind-power generation in Gyeongbuk and Gangwon is related to mountainous areas because these areas are optimal for the installation of wind power plants as they are located in the Taebaek Mountains. Additional wind-power plants are expected to be constructed in these areas in the future.

Table 7. Power generation in different regions in 2017 and 2018 (unit: MWh) [19]

Regions	2017	2018	Difference
Gyeonggi	6	5	-1
Chungnam	3	3	-
Jeonbuk	20	20	-
Jeonnam	310	350	+40
Gangwon	640	690	+50
Gyeongbuk	520	730	+210
Gyeongnam	80	80	-
Jeju	540	540	-

Ⅳ. WIND-POWER ENERGY INDUSTRIAL TREND

Policies, such as the "Renewable Energy 3020 Implementation Plan" [20] and "Plans to Reinforce the Competitiveness of the Renewable Energy Industry" [21], were prepared to promote the spread of the wind-power generation to support related industries and the implementation of the government policies, and to respond to the various demands arising in the industry. In the process of establishing policies and preparing systems, a wind-power generation council is organized and operated to reflect various requirements from industries. In addition, efforts have been made to prepare measures to discover large-scale wind-power projects and support policies, including the investigation of the wind-power project investment plans of private companies, such as public electric power companies, and the collection of opinions on policy support requirements that can be accepted by the government. For industrial growth, attempts have been made to link wind-power generation with related competitive industries, such as shipbuilding, offshore plants, and information and communication technology (ICT) to create a stable domestic market, and to secure key technologies earlier. The related policies are as follows: 1) Creating high-added values for wind-power systems and achieving differentiation in the market (optimization of large wind farms) by applying ICT to the design, construction, and operation and maintenance (O&M) of large complexes, 2) implementing offshore wind power (2.4 GW) in the planned site in the Southwest Sea led by the local government and providing management and support for the 23 (1.3 GW) projects scheduled to begin by 2020, 3) developing four key components (e.g., blades, generators, and speed increasers) and wind-power service key technologies (e.g., complex construction and operation and maintenance (O&M)) by 2022, 4) developing ultra-large 10 MW or higher turbines and related components as a package, 5) developing and verifying floating wind turbines and floating bodies, and 5) securing insufficient key technologies, such as next-generation technology improvement and turbines early on based on the introduction of external technologies, and 6) presenting projects pertaining to wind-power generation for each region (Table 8). In particular, regional power generation directions show that the focus is given to the Gyeongnam region and the East Sea region. The Gyeongnam region is optimal for wind power-related studies and projects because various industries have been developed and many companies have factories in the region. In addition, the East Sea region has abundant wind resources and good site conditions to facilitate installation of wind turbine towers. As these two regions are close to each other, it is expected that there will be no difficulty in applying the R&D results to the field.

Currently, European and American companies are leading the global wind-turbine market, the global market share of major

Table 8. Projects of Wind power generation for each region [22]

Region	*Gyeongnam*	*East Sea*
Site conditions	▪ Eighty-four companies specializing in wind turbines and components are located.	▪ Seven hundred and fifty companies specialized in shipbuilding, offshore plants, and heavy industries are densely located. ▪ This area has abundant wind resources (8–8.5 m/s)
Project	▪ 1.9 GW wind power projects are planned, including the Yokjido offshore wind power	▪ The creation of a 1 GW floating offshore wind farm near the East Sea gas reservoir is planned
Goal	▪ Specialization of the region as a site for the development, verification, and production of ultra-large wind-power systems and components	▪ Development and early industrialization, including R&D, verification, and commercialization of floating offshore wind power

Table 9. Overview of wind turbines and main components [18]

Component	Wind turbine	Main components of wind turbines			
		Blade	Tower and forged products	Generator	Offshore foundation structure
Overview	Wind power generation system composed of approximately 8,000 components	Device to convert wind energy into rotational power	Supporting structures to position the main components of turbines at a certain height	Device to convert rotation power into electric energy	A structure installed on the sea bed or water surface for the installation of wind turbines above the sea
Characteristics	Vertical integration strategy led by Europe and USA Large scale and offshore installation	Self-production reinforcement Monopoly supply market High-entry barrier	Outsourcing Local procurement Low-entry barrier	Self-production reinforcement Oligopoly supply market Somewhat high-entry barrier	Outsourcing, local procurement Oligopoly supply market Somewhat low entry barrier
Domestic companies	Doosan Unison Hanjin Hyosung	Human composites DACC Aerospace Kwang Dong FRP Industrial Co.	CS Wind Dongkuk S&C WIN&P SPECO	Doosan Hyosung Hyundai–Electric Bokuk Electric	Doosan Samsung Heavy Industries Hyundai Heavy Industries DSME

companies is approximately 50%. The major companies of South Korea include Doosan Heavy Industries & Construction, Unison, Hanjin Industries, and Hyosung Heavy Industries [18]. The main companies of South Korea are also capable of producing the main components required for wind-power generation, such as wind turbines, blades, generators, and offshore foundation structures. Domestic companies are also changing to vertical integration as with overseas companies. Table 9 summarizes the contents related to domestic companies from the overview of wind turbines and the main components in the “Problems with Domestic Solar Power/Wind Power Generation Industries and Improvement Measures” report.

According to the KOSME report [22], published in 2019, as technological development and large-capacity power generation are required, related companies are developing large-capacity wind turbines and components. The length of the blades installed in wind-power generators has increased from approximately 40 m to 60–80 m [22]. Due to the increase in the trend of using large-sized wind turbines, the distribution rate of the speed increaser of 2.5 MW and over is also increasing. In South Korea, many companies participated in businesses related to a speed increaser, but the formation of the domestic market for key components related to wind power has been delayed because domestic wind turbine companies have reduced wind-power businesses [22].

Wind-turbine generators that convert mechanical rotation power into electric power are key components that determine system efficiency. For them, technology development will reduce the power generation cost by increasing the size of turbines and by applying ESSs (Table 10). Onshore wind-power generators can produce high-power generation at a low cost for the 2–3 MW class. Therefore, focus is given to the development of systems with low-power generation cost [22].

Table 10. Domestic status on the development of wind-power generators [22]

Company	Technology development status
Doosan	Developed the first 3 MW and 14 MW offshore wind-power generators in Korea
Bokuk	Developed a 750 kW large-scale wind-power generator
Unison	Developed 750 kW, 2 MW, and 2.3 MW large-scale wind-power generators and exported them to the USA, Jamaica, Seychelles, Ukraine, Japan, and Ecuador

V. EXAMPLES OF PROBLEMS AND SOLUTIONS

One of the major problems with wind-power generation is noise. Eighty eight wind turbines were installed in four wind farms in the area of Yangguri, Gyeongbuk. These represent 14.8% of the nationwide wind power-generation capacity [23]. Some residents are refraining from outdoor activities at night due to the noise. In particular, on rainy days, residents are complaining about falling water droplets. They insist that the noise from wind turbines adversely affects their daily lives and health. According to the "Guideline on Low-Frequency Noise Management" of the Ministry of Environment (ME), there is the influence of low-frequency noise if the sound pressure level criteria are exceeded within the 12.5–80 Hz (85–45 dB) frequency range [23, 24]. The guideline also presents management procedures and solutions if the occurrence of low-frequency noise is determined. According to a research report by the Korea National University of Transportation, seven out of 15 private houses within a radius of 1 km from a power generation complex were affected by low-frequency noise [23, 25].

There is an area in which this noise problem and the environmental destruction problem were solved and the method of collaborating with local residents was presented. For the wind farm in Gasiri, Jeju Island, there has been no complaint about noise even though it is approximately 5 km away from the village where residents live [26]. This is because the construction of the wind farm was determined by the village residents themselves based on their consent and their opinion that "the recovery must be possible in the future." In addition, a "profit sharing" model was presented from an economic perspective. The village development funds received from the Jeju Energy Corporation were utilized as scholarships for students and welfare funds for elderly people.

Ⅵ. CONCLUSIONS AND FUTURE PROSPECTS

In this study, the South Korean government policies and projects were identified for the development of the wind-power industry, and the market and industrial trends were presented. As wind power generation is an industry that is significantly affected by the wind direction and site characteristics, it is necessary to evaluate various site environments, such as the wind volume, topography, climate, and population, for the construction of wind farms. In recent years, the government has strongly recommended N&R energy and significantly relieved policy restrictions for the revival of related industries. Therefore, market entry and investments and from additional companies are expected in the future. In particular, the construction of offshore wind farms is expected among the wind-power generation. It was revealed that sites for offshore wind farms can be secured more easily than those for onshore wind farms with the possibility of increasing the size of wind farms and that the wave sounds can cancel the noise of wind turbines [27]. There are still problems to be solved for the expansion of offshore wind-power generation. Representative problems include the high-initial investment cost for the construction of offshore wind power and high-power generation cost. The cost of nuclear power generation is \$0.053/kWh (58.3 KRW/kWh), whereas the cost of wind power generation in Jeju Island is \$0.14/kWh (149.9 KRW/kWh) [28]. The South Korean government, however, will attempt to technically solve these problems, and the proportion of N&R energy is expected to continually increase. In particular, the government will keep supporting industries related to wind-power generation through policies, and the industries are also expected to develop related technologies and invest in relevant businesses.

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