Revaluing K-water's hydro power from the perspective of carbon neutrality and RE100

By

AN, Jaehyuk

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

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Abstract

Responding to the climate crisis, which has come sooner than expected, is a common task that the world should prioritize. In order to cope with climate change, countries around the world are embodying carbon reduction goals and implementation measures to achieve them. Energy transition (from fossil fuels to renewable energy) is the key to reducing greenhouse gases, and in Korea, many efforts are being made to expand the introduction of new and renewable energy to respond to the climate crisis and achieve sustainable development. In addition, RE100 Initiatives are in the spotlight around the world. RE100, abbreviated as 100% renewable energy, is a voluntary campaign to declare that companies will convert their electricity to 100% eco-friendly renewable energy by at least 2050, and it is being expanded and demanded by global companies.

In this trend, domestic power generation facilities are also increasing every year, and the increase in new and renewable energy is prominent. Due to the nature of volatile renewable energy such as solar power, output volatility and predictive uncertainty problems are accompanied by external environmental changes such as weather. For this reason, an appropriate level of flexibility power generation source is required.

The increase in renewable energy is a trend of the times to respond to climate change, and the value of hydro power, a representative flexible resource and renewable energy, was analyzed in this study. Hydro power contributes to the stability of the power system by enabling rapid startup suspension and power generation output adjustment, and the contribution was quantified in this study. In addition, environmental values such as the contribution of the power market and greenhouse gas reduction were quantified based on past performance. I expect that the value of hydro power will be properly assessed for the increase of renewable energy and the stable operation of the power system.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

1.1. Background

Currently, natural disasters such as droughts and floods are occurring more frequently than in the past due to climate change caused by global warming. The global average means surface temperature for the period from 2016–2020 is among the warmest on record, estimated at 1.06 °C to 1.27 °C above pre-industrial (1850–1900) levels (World Meteorological organization, United in Science 2021). These seemingly small changes in figures threaten the ecosystem, raise sea levels rapidly, deepen forest fires and water disasters, and threaten human life. The serious thing is that the climate crisis is getting faster and stronger in progress (World Economic Forum, The Global Risks Report 2022).

In order to respond to increasingly serious climate change, the international community has continued to conclude joint agreements to reduce carbon emissions since the 1990s, and carbon reduction goals and implementation plans to achieve this are becoming concrete.

The Climate Change Convention, the first international agreement to prevent global warming and regulate greenhouse gases, was signed in 1992, the Kyoto Protocol came into force in 2005, and developed countries' reduction goals and specific implementation plans for the climate change agreement were established. In 2007, they adopted the Bali Action Plan and agreed on rules governing the amount of carbon emissions reductions in each country after the expiration of the Kyoto Protocol. In 2010, they agreed to create a green climate fund for sustainable development in developing countries through the Cancun Agreement. The 2015 Paris Protocol was adopted at COP21 as a new climate agreement to replace the Kyoto Protocol after 2020, setting a goal of keeping the average global temperature rise below 2°C compared to pre-industrial levels and working to curb it at 1.5°C by 2100.

Recently, major countries around the world are pursuing carbon reduction policies in earnest, such as declaring carbon neutrality to achieve the goal of suppressing the global average temperature increase of 1.5°C and establishing the 2030 National Greenhouse Gas Reduction Goal (NDC, Nationally determined Contribution). Major countries such as the UK, France, Germany in 2019, Japan, China, Korea, and Canada in 2020 declared carbon neutrality targets, and the United States joined the carbon neutrality declaration in 2021 after President Biden's election.

Table 1. *Global carbon neutrality target*

Continent	Nation	Goal year	2030 Reduction Targets
Europe	EU	2050	55% compared to 1990
	Denmark	2050	70% compared to 1990
	Germany	2045	65% compared to 1990
	Russia	2060	30% compared to 1990
	Luxembourg	2050	55% compared to 2005
	Sweden	2045	63% compared to 1990
	Spain	2050	23% compared to 1990
	Ireland	2050	51% compared to 2018
	UK	2050	68% compared to 1990
	Italy	2050	60% compared to 1990
	France	2050	40% compared to 1990
	Hungary	2050	40% compared to 1990
Asia	Republic of Korea	2050	40% compared to 2018
	Japan	2050	46% compared to 2013
	India	2070	45% compared to 2005
	China	2060	60~65% compared to 2005
America	USA	2050	50~52% compared to 2005
	Canada	2050	40~45% compared to 2005
	Brazil	2050	50% compared to 2005
Oceania	New Zealand	2050	30% compared to 2005
	Australia	2050	43% compared to 2005

※ Source: Media Research

Carbon neutrality allows net emissions to be zero so that the concentration of greenhouse gases in the atmosphere is not further increased by human activity, and is referred to as 'Net-Zero'. Carbon neutrality has been achieved when greenhouse gas emissions from human activities are balanced with global carbon dioxide absorption over a specific period of time.

The Republic of Korea is also accelerating efforts to reduce carbon emissions and convert energy by establishing the 2030 NDC and declaring carbon neutrality in 2020. Korea first established the 2030 NDC in 2015 with the goal of reducing greenhouse gas emissions by 37% compared to BAU (Business as Usual) by 2030 to respond to the Paris Agreement. Since then, the 2030 NDC was revised in 2019, and the notation of the 2030 reduction target was changed from the BAU method, which is subject to random change, to the absolute value method, which is fixed and constant ((existing) 37% reduction compared to the 2030 reduction target BAU → (change) compared to 2017 24.4% reduction), and the goal was raised to a 40% reduction in the 2030 NDC in 2021 compared to 2018. Most recently, in March 2023, the Basic Plan for Carbon Neutral and Green Growth under the Framework Act on Carbon Neutrality was established for the first time, suggesting an annual greenhouse gas reduction goal to achieve a 40% reduction in greenhouse gas by 2030.

Looking at Korea's greenhouse gas emissions, it was found to be a 6.7% decrease from 2018, when it recorded the largest emission at 676.6 million tons of CO_2eq. as of 2021, and an increase of 3.4% from the previous year. The increase in greenhouse gas emissions in 2021 is a global trend, which is analyzed as a result of the recovery of production activities in the global industry and the increase in movement demand after COVID-19.

The proportion of emissions by sector was 86.9% of energy, 7.6% of industrial processes, 3.2% of agriculture, and 2.5% of waste. The energy sector includes the energy industry, manufacturing and construction industry, and transportation, and the industrial process includes the mineral, chemical, and metal industries. In particular, the energy industry's greenhouse gas emissions in 2021 were 241.1 million tons of CO_2eq., accounting for 35.6% of the country's greenhouse gas emissions. The energy industry encompasses the entire industry involving the production and sale of energy, including fuel extraction, manufacturing, refining, and distribution, and can be summarized into coal, electricity, gas, oil, and nuclear industries.

Table 2. *Korea greenhouse gas emissions*

Year	Total emissions	Emissions relative to GDP	Emissions per person
	Million $tCO_2eq.$	$tCO_2eq.$ / Billion	$tCO_2eq.$ / person
2011	638.8	462.3	13.7
2012	687.0	453.5	13.7
2013	695.7	445.2	13.8
2014	690.8	428.3	13.6
2015	691.3	417.0	13.6
2016	692.4	405.7	13.5
2017	709.4	402.9	13.8
2018	725.0	400.1	14.1
2019	699.2	377.4	13.5
2020	654.4	355.8	12.6
2021	676.6	352.7	13.1

※ Source: Ministry of Environment Greenhouse Gas Inventory and Research Center

Table 3. *Korea greenhouse gas emissions by sector in 2021*

Total emissions	Energy	Industrial process	Agriculture	Waste
676.6	587.7	51.4	21.4	16.1
100%	86.9%	7.6%	3.2%	2.4%

1.2. Purpose of the study

Energy transition is a key to reducing greenhouse gases, and interest in electrification is increasing. Electrification is the use of electricity as energy instead of fossil fuels, and electric vehicles and electric oven can be seen as examples. Countries are encouraging the use of electricity in a way that does not emit greenhouse gases as much as possible, and the use of the generated clean electricity in transportation, industry, and home will help curb warming by reducing greenhouse gas emissions. Electricity is the cleanest form of energy source, and there is a growing interest in electrification because end-users can reduce greenhouse gases through the transition to renewable energy and other low-carbon sources. With the development of technology, the construction cost of new and renewable energy is reduced and power generation efficiency is gradually improved, and the use of clean electricity produced through new and renewable energy that replaces fossil fuels is expected to increase in the future.

New and renewable energy is steadily increasing worldwide thanks to policy support to achieve various objectives such as strengthening energy security, improving air pollution, responding to climate change, revitalizing the economy, and resolving energy poverty. According to the Energy Mix Outlook 2021 projection from the International Energy Agency (IEA), the ratio of electricity and hydrogen in terms of global energy source mix is expected to increase to 32% by 2035 and 50% by 2050.

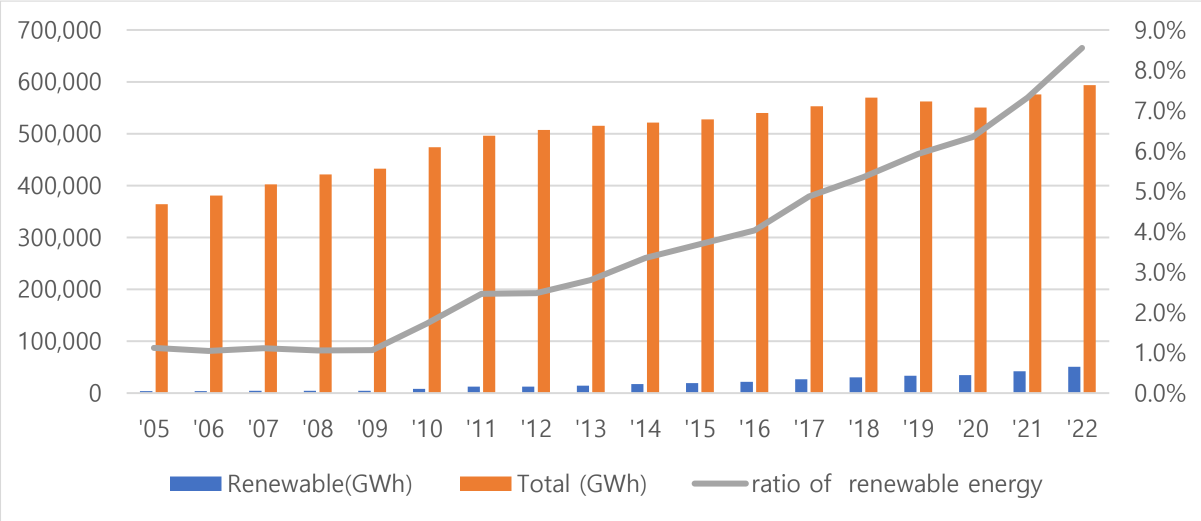
Looking at the amount of power generated by year in Korea, power consumption decreased in 2019 and 2020 due to the influence of Covid-19, but has increased every year. What is noteworthy is that despite the increase in electricity consumption, the proportion of renewable energy generation is steadily increasing every year. The proportion of new and renewable energy power generation (excluding pumped storage power generation) increased from approximately 1.1% in 2005 to 8.9% in 2022.

Table 4. *Trend of electricity generation by year (GWh)*

Year	Sum	Hydro	Steam	Combined Cycle	Nuclear	New & Renewable	Group	Internal Combustion	Waste
2005	364,369	5,189	151,207	57,457	146,779	404	2,758	575	-
2006	380,802	5,219	155,911	67,138	148,749	511	2,597	677	-
2007	402,293	5,042	173415	76,405	142,937	831	3,085	578	-
2008	421,624	5,562	183,655	74,519	150,958	1,373	5,054	503	-
2009	432,747	5,641	206,535	64,486	147,771	1,790	5,827	697	-
2010	473,818	6,472	211,449	94,012	148,596	4,478	8,080	731	-
2011	496,080	7,831	211,205	101,479	154,723	7,592	12,429	821	-
2012	507,480	7,652	216,336	110,882	150,327	8,618	12,913	752	-
2013	515,467	8,394	218,585	124,400	138,784	10,160	14,403	741	-
2014	521,410	7,820	211,172	111,711	156,407	14,696	18,948	656	-
2015	527,513	5,796	216,378	100,598	164,762	17,318	22,018	643	-
2016	540,256	6,634	222,623	96,922	161,995	18,936	32,573	573	-
2017	553,225	6,995	237,332	99,619	148,427	24,145	36,194	513	-
2018	569,847	7,270	237,498	116,836	133,505	27,177	47,033	528	-
2019	561,893	6,247	220,918	110,289	145,910	30,526	46,058	579	1,366
2020	550,486	7,148	189,426	111,759	160,184	31,057	45,567	405	4,940
2021	575,784	6,737	191,575	130,358	158,015	39,102	48,325	491	1,181
2022	593,948	7,256	188,477	123,996	176,054	47,266	49,158	570	1,171

※ Source: Korea Electric Power Statistics No.92 (2023.05.31, KEPCO)

Figure 1. *Trend of electricity generation by year*



As the proportion of renewable energy generation increased, problems in the operation of the power system such as instability of the domestic power system occurred. Since electricity is basically difficult to store, there is no problem with the power system when supply and demand are maintained to match. The largest share of the increase in renewable energy in Korea is solar power generation, which is an intermittent power generation source whose real-time power generation varies greatly depending on the influence of weather, that is, the amount of sunlight. Accordingly, the importance of flexible power generation sources is increasing in the power market. A flexible power source is a power source that can quickly adjust power generation output according to the situation of the power system, and representative examples include gas power generation, pumped storage power generation, and hydro power generation.

K-water is a water management specialized corporation that operates 60% of domestic hydropower, and the main purpose of hydro power generation is to supply electricity through peak power generation to solve the national power shortage. This study aims to examine the value of hydro power from the perspective of responding to climate change such as carbon neutrality and RE100.

2. Method

For this study, the government's policy will first be reviewed in 2017 when the policy to expand renewable energy began in earnest to understand the trends of energy policy. Policies announced frequently by the Ministry of Trade, Industry and Energy, which is responsible for the energy industry, and the basic plan for power supply and demand, which establishes a long-term plan for the next 15 years every two years, are good data to forecast future plans for power generation facilities.

To examine the composition of domestic power generation facilities, power generation capacity, System Marginal Price (SMP), and the current status and changes in the power market from the past to the present, I utilize data from the Korea Electric Power Corporation (KEPCO), responsible for domestic power supply. Additionally, I utilize data from the Electric Power Statistics Information System (EPSIS) operated by the Korea Power Exchange (KPX), which manages and operates the power market. This will allow me to conduct a comprehensive review using the Korean electricity statistics provided by KEPCO and the detailed information available through the Electric Power Statistics Information System of KPX.

To analyze the operational characteristics and performance of hydro power generation, I use data from K-water's water resources operation (WRO). WRO serves as an integrated system for dam, water supply, and power generation operations by K-water. It extracts statistical data such as historical power generation, revenue, and generator operating hours for analysis.

KEPTA (Korea Electric Power Trading Analyzer) is used for power market simulation analysis. KEPTA is a power market analysis system widely utilized by various power generation companies for tasks such as domestic power demand forecasting, generation planning, and SMP prediction. K-water has been using KEPTA since 2015, predicting SMP, and regularly updating the power information DB.

3. Analysis of policy environment

3.1. Energy transition policy

The promotion of the 2050 carbon neutrality goal requires a substantial, sustained, and rapid decline in domestic greenhouse gas emissions. The energy sector, which accounts for more than 85% of national greenhouse gas emissions, is the key to achieving carbon neutrality by 2050. Energy transition is important to reduce greenhouse gases in the energy sector.

The government promoted energy transition policies in earnest by announcing the "Energy Transition Roadmap" in October 2017. The main content of the energy transition roadmap is to increase the proportion of renewable energy and reduce nuclear power generation. The energy transition roadmap proposed a goal of gradually reducing nuclear power generation facilities from 24 in 2017 to 14 in 2038 by canceling the planned construction of new nuclear power plants and prohibiting extension of the lifespan of old nuclear power plants. In addition, a goal was set to increase the proportion of renewable energy generation from 7% in 2016 to 20% in 2030 to replace the decrease in power generation due to the reduction of nuclear power generation.

Following the announcement of the energy transition roadmap, the "Renewable Energy 3020 Implementation Plan" announced in December 2017 suggested a strategy to include government support and institutional improvement directions to increase the proportion of renewable energy generation by expanding the supply of renewable energy generation facilities from 13.3 GW in 2016 to 63.8 GW in 2030. This plan sets the basic direction of expanding the supply of renewable energy centered on solar and wind power, including supplying 63% and 34% of new power generation facilities with solar and wind power, respectively.

The "3rd Energy Basic Plan" announced in June 2019 expanded the scope of energy transition policy to cover supply, demand, market, and overall system. On the demand side, the energy policy paradigm was shifted to focus on consumption structure innovation, and a goal was set to reduce energy demand by 18.6% compared to business-as-usual (BAU) by 2040. On the supply side, a goal was set to expand the proportion of renewable energy generation to 30-35% by 2040. On the system side, the task of building a distributed and participatory energy system was presented, including expanding distributed power sources and strengthening the roles and responsibilities of local governments.

The “Korean New Deal Comprehensive Plan” announced in July 2020 is composed of two axes: Digital New Deal and Green New Deal. The Korean Green New Deal included in the plan has the nature of a fiscal stimulus plan following the spread of Covid-19 to "implement the 2030 greenhouse gas reduction goal and renewable energy 3020 implementation plan without disruption" with a vision of "a green transformation of living infrastructure and energy and promotion of green industry innovation."

The “8th Basic Plan for Electricity Supply and Demand” announced in December 2017 and the “9th Basic Plan for Electricity Supply and Demand” announced in December 2020 specifically presented goals for expanding renewable energy generation and reducing nuclear power generation. In the case of nuclear power plants, there is a plan to cancel construction of 6 new units, stop extending the lifespan of 10 old units, and expand renewable energy from 20.1GW in 2020 to 77.8GW in 2034. In addition, in the case of coal-fired power plants, strengthened policy goals were presented in terms of coal phase-out, such as abolishing all generators within 30 years of operation and converting to LNG fuel.

Energy transition policy has entered a new phase with the presentation of the goal of achieving carbon neutrality in 2050. In a speech to the National Assembly on October 28, 2020, the President announced that carbon neutrality would be achieved by 2050, and this goal was confirmed to the international community through the 2050 long-term low greenhouse gas emission development strategies (LEDS) submitted to the United Nations in December 2020. Then, in October 2021, the 2050 Carbon Neutral Scenario was announced with the vision of “a carbon-neutral society that is safe and sustainable from the climate crisis.”. In this scenario, it consists of two scenarios: Plan A, which reduces emissions as much as possible by completely stopping thermal power generation in order to reduce domestic net emissions to zero in 2050, and Plan B, which actively utilizes removal technologies such as CCUS instead of remaining thermal power generation. The common core of the transition sectors of Plan A and Plan B is a plan to significantly reduce thermal power generation and expand renewable energy and hydrogen-based power generation. This means that in addition to the power generation mix conversion, energy transition in various areas must be carried out simultaneously.

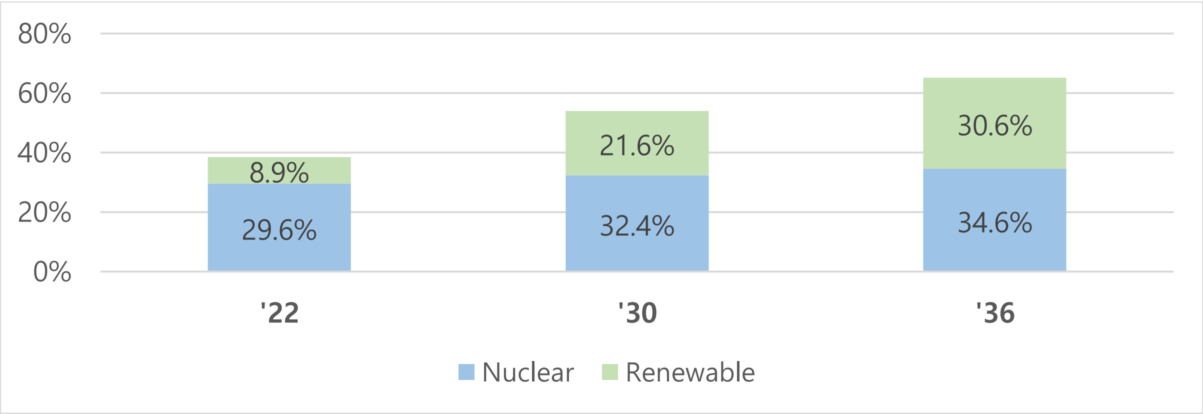
In 2022, there was a major change in domestic energy transition policy. As the new government was launched in May 2022, the “new government energy policy direction” was decided at the Cabinet meeting in July of the same year. As the international carbon neutrality trend continues and international energy supply chain instability increases due to the Russia-Ukraine war, new energy policy goals and directions have been set. The main goal is to increase the proportion of nuclear power plants (27.4% in 2021 → more than 30% in 2030), adjust renewable energy to a reasonable level in consideration of feasibility and resident acceptance, and to induce a reasonable reduction in coal power generation and use carbon-free power sources such as hydrogen and ammonia. The "10th Basic Plan for Electricity Supply and Demand" announced in January 2023 specifies the direction of the new government's energy policy, making stable electricity supply a top priority, and focusing on the use of nuclear power plants and the supply of renewable energy at an appropriate level from the existing energy conversion centered on de-nuclearization, decarbonization, and renewable energy. Although there are significant differences between the existing plan and the use of nuclear power plants, there is no change in the plan that renewable energy will serve as a major power generation source in the future. However, the stability problem of the power system is expected to worsen as nuclear power plants, a rigid power source, are expanded rather than flexible power sources to solve the intermittency of renewable energy. In order to timely accommodate the expanding power generation facilities such as nuclear power plants and renewable energy in the power system, large-scale power grid investment is required, which takes a lot of time. Accordingly, the value and importance of hydro power, which is a flexible resource, is expected to improve.

Table 5. *A comparison of the power composition prospects (GW)*

Year	Plan	Sum	Nuclear	Coal	LNG	Renewable	Pumped	Etc.
2021	9rd	135.3	24.7	37.3	41.3	24.8	4.7	2.5
	10rd	134.0	23.3	37.3	41.3	24.9	4.7	2.5
2025	9rd	165.9	25.3	38.6	50.2	45.5	4.7	1.2
	10rd	163.2	28.9	40.2	47.7	40.5	4.7	1.2
2030	9rd	173.0	20.4	32.6	55.5	58.0	5.2	1.2
	10rd	198.0	28.9	31.7	58.6	72.7	5.2	0.9
2034	9rd	193.0	19.4	29.0	59.1	77.8	6.5	1.2
	10rd	227.7	31.7	28.1	63.6	96.9	6.5	0.9
2036	10rd	239.0	31.7	27.1	64.6	108.3	6.5	0.8

※ Source: the 9th and 10th Basic Plan for Electricity Supply and Demand (Government)

Figure 2. *Ratio of rigid power generation*



※ Source: 10th Basic Plan for Electricity Supply and Demand (Government)

3.2. RE100 Initiative

As carbon neutrality emerges as a major topic around the world, the RE100 initiative is attracting attention. RE100 is an abbreviation for Renewable Energy 100% and is a voluntary campaign to declare that companies will convert 100% of their electricity to eco-friendly renewable energy by at least 2050, and is being expanded and required by global companies.

It was first launched by a joint effort between multinational non-profit organizations The Climate Group and the Carbon Disclosure Project (CDP) during NYC Climate Week in 2014, and began as an advocacy campaign to ensure the success of the 2014 Paris Agreement. RE100 aims to expand demand-based renewable energy by urging a change in the behavior of companies that are consumers rather than energy producers. Conditions for joining RE100 include being a company if it is a company that consumes at least 100 GWh of electricity per year, or if it is a brand or major multinational company that is recognized and trusted at the global or national level, such as Fortune 1,000 companies, or if it has international or regional influence. When joining RE100, there should be a target time and strategy to achieve 100% of power consumption with renewable energy. Annual targets are set autonomously, but 60% by 2030, 90% or more by 2040 are recommended, and 100% by 2050. Renewable energies recognized by RE100 include solar power, wind power, geothermal heat, biomass (including biogas), and hydro power. In the case of hydropower and biomass, only electricity procured in a sustainable manner is recognized, and certification through third-party verification, such as North American Renewable Energy Standard (Green-e) and Low Impact Hydropower Institute (LIHI) certification, is recommended. This recognizes electricity produced in a sustainable manner in terms of environmental, social and economic impacts, as damage to the surrounding environment or biodiversity may be reduced during the construction of hydroelectric power plants and air pollutants may be excessively discharged during the biomass power generation process.

Although it is based on the voluntary participation of companies wishing to expand the use of eco-friendly renewable energy, there are cases where companies join due to indirect pressure from global companies on supply chain companies or requests from overseas financial institutions. Global companies such as Google, Apple, Microsoft, BMW, and GM are gradually increasing their use of renewable energy for electricity, recently, there are increasing cases in which large domestic companies are also required to expand the use of renewable energy from global companies. Global companies are participating in the RE100 initiative and demanding that their partners and parts and service providers use renewable energy, and as a result, the level of demand for domestic companies to participate in the global RE100 is increasing. As of August 2023, 415 companies worldwide have joined RE100, and 36 domestic companies have also joined.

To achieve carbon neutrality, each country is pursuing active policies to expand renewable energy. As a result, renewable energy is rapidly expanding, and renewable energy and RE100 are becoming important standards in the global market. In line with this global trend, corporate awareness and efforts are also important for companies to increase their subscription to RE100 or the expansion of renewable energy use, but above all, they must have the capacity to supply at the national and regional levels to fundamentally meet the demand for renewable energy.

Figure 3. *RE100 member company*

Table 6. *Domestic Global RE100 member company*

Join year	Company	Target year	Join year	Company	Target year
2020	SK Hynix	2050	2022	Kia	2040
	SK Telecom	2050		KT	2050
	SK	2040		LG innotek	2030
	SK Materials	2050		Naver	2040
	SK Siltron	2050		Samsung Electronics	2050
	SKC	2050		Samsung SDI	2050
2021	AmorePacific	2030		Samsung display	2050
	LG Energy Solution	2030		Samsung Electro-Mechanics	2050
	K-water	2050		Samsung Biologics	2050
	KB Financial Group	2040	2023	Samsung Life Insurance	2040
	Korea Zinc	2050		Samsung Fire & Marine Insurance	2040
	Mirae Asset	2025		Lotte Well Food	2040
	SK ieTechnology	2030		Shinhan Financial Group	2040
	Lottechilsung	2040		Kakao	2040
2022	Incheon Airport.co	2040		LG Electronics	2050
	Hyundai Mobis	2040		Lotte Chemical	2050
	Hyundai wia	2050		HD Hyundai xitesolution	2040
	Hyundai Motors	2045		LS electronic	2040

※ Source: Korea RE100 Alliance

3.3. Power system under the energy transition

According to statistics from Korea Electric Power Corporation, the capacity of power generation facilities in Korea as of the end of 2022 is a total of 138,195MW, which is steadily increasing every year, and the increase in renewable energy is remarkable. Most of Korea's renewable energy is solar power, accounting for 74% of all renewable energy generation facilities. This is because solar power can be built on a small scale compared to other power sources, which makes it easy for individuals and the private sector to invest.

Table 7. *Trends in power generation facilities by year (MW)*

Source	2017	2018	2019	2020	2021	2022
Total	116,908	119,092	125,338	129,191	134,020	138,195
Nuclear	22,529	21,850	23,250	23,250	23,250	24,650
Steam	38,265	38,358	38,101	37,951	38,429	38,269
Combined Cycle	32,416	31,224	32,846	33,013	33,013	33,013
Group	7,682	9,208	9,191	9,191	9,229	8,919
Internal Combustion	339	339	341	176	177	137
others	-	-	852	366	367	369
Pumped storage	4,700	4,700	4,700	4,700	4,700	4,700
Renewable	10,976	13,413	16,058	20,545	24,855	28,139

※ Source: Korea Electric Power Statistics No.92 (2023.05.31, KEPCO)

Figure 4. *Trends in power generation facilities by year*

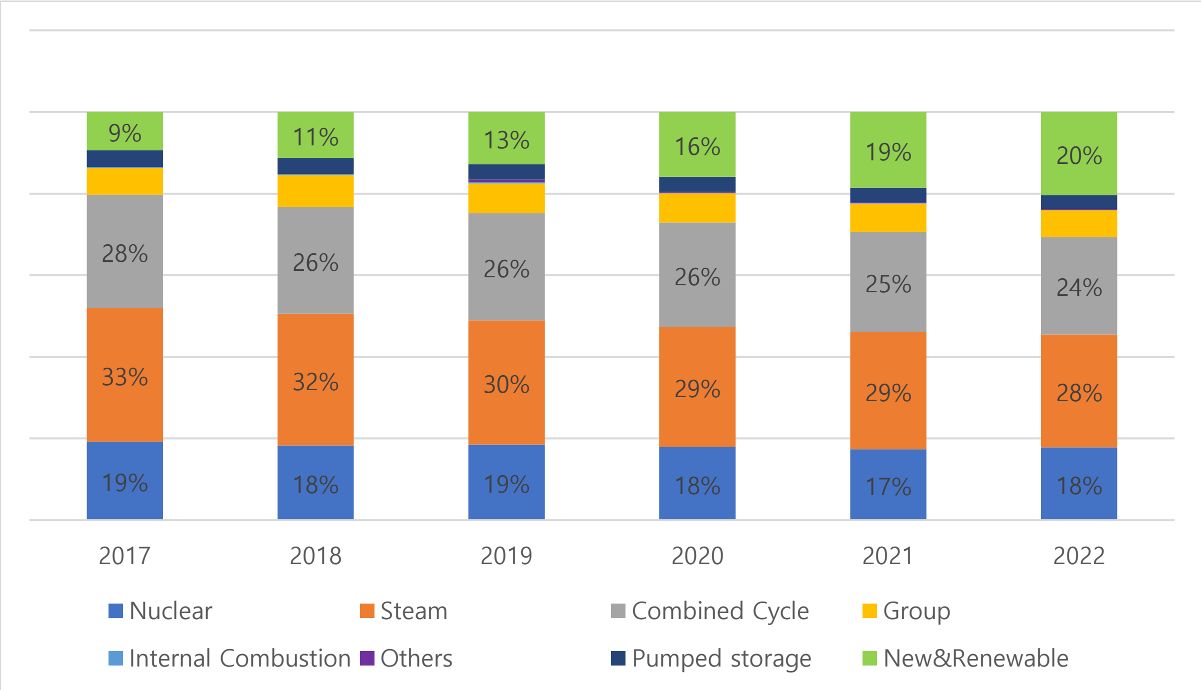


Table 8. *Status of domestic new and renewable energy power generation facilities (MW)*

Total	Hydro	Solar	Wind	Ocean	Bio	Fuel Cell	IGCC
28,577	1,813	21,150	1,893	226	2,269	8805	346
100%	6.3%	74.0%	6.6%	0.8%	8.0%	3.1%	1.2%

The domestic power market is a competitive market system limited to the power generation sector, a cost-based pool (CBP) market based on the fluctuation cost of power generation operators, and operates as a spot market a day before determining the power generation plan and the System Marginal Price (SMP) based on the forecast demand a day earlier. It is a structure in which power generation companies enforce cost determination and market participation of all generators participating in bidding based on variable costs, including incremental costs, no load costs, and startup costs for each generator, Capacity Payment (CP) is provided to recover fixed costs of power generation facilities.

Electricity must balance supply and demand in real time because it is difficult to store. If the power supply and demand are unbalanced, it is difficult to operate the power system, such as frequency fluctuations, and large-scale power outages are likely to occur. The gap between the output determined in the spot market a day ago and the real-time system operation output is widening due to the recent increase in the volatility of generator output due to the increase in the proportion of renewable energy. This is because, due to the nature of variable renewable energy such as solar energy, it is accompanied by problems of output volatility and forecast uncertainty depending on external environmental changes such as weather. The increase in renewable energy is a trend of the times to respond to climate change, and an appropriate level of flexible power source is needed to resolve temporary excess and shortage of power supply.

The generator operating at K-water is 100% renewable energy, operating 1,420 MW of facilities in 112 power plants as of 2022. Of these, 974.6MW are centrally dispatched hydroelectric generators, contributing greatly to power system flexibility.

Table 9. *K-water central dispatch hydro power generator (MW)*

Total	Soyang	Andong	Daecheong	Chungju	Hapcheon	Juam	Imha	Yongdam
974.6	200	90	90	400	100	22.5	50	22.1

Table 10. *K-water power generation facilities (MW)*

Sortation	Total	Central	Non-central			
		Hydro	Hydro	Tidal	Solar	Wind
Capacity	1,419.6	974.6	118	254	65	8
Ratio	100%	68.7%	8.3%	17.9%	4.6%	0.6%
Site	112	8	56	1	44	3

4. As-Is analysis: Advantages of K-water's hydro power

4.1. Quick start/stop and output increase/decrease

The operational time of multipurpose dam hydropower generators operated by K-water is within 6 minutes, allowing for very fast activation. This enables rapid power supply to the grid after the generator is activated, compared to other power sources. In contrast, nuclear and thermal power plants have slower activation times, limiting their ability to respond quickly in situations of power shortage within the power grid.

Furthermore, with its superior output regulation capabilities compared to other power sources, hydropower generators actively contribute to maintaining the power grid frequency. Hydroelectric generators can adjust their output within the range of 25-50% of the rated capacity per minute. In contrast, nuclear power operates with fixed output without the ability for output adjustment, and even in the case of combined cycle power plants with relatively good output adjustment during thermal power generation, adjustments are possible only within the range of approximately 15-20% of the capacity.

In this way, hydropower generation allows for agile responses to changes in power demand through rapid start-stop and output adjustments. It is utilized as peak generation during the times of the day with the highest power demand, responding flexibly. Additionally, it serves as a constant standby reserve to prepare for unexpected failures or dropouts in large-capacity generators such as nuclear and coal-fired power plants, contributing to the overall improvement of power grid reliability.

Table 11. *Start-up time and output rate by power generation source*

K-water Hydro.	Soyang	Andong	Dae cheong	Chungju	Hap cheon	Juam	Imha	Yong dam
Start-up time	5~6 min.	5~6 min.	5~6 min.	5~6 min.	5~6 min.	5~6 min.	5~6 min.	5~6 min.
Output rate	25% MW/min.	50% MW/min.	50% MW/min.	50% MW/min.	50% MW/min.	50% MW/min.	50% MW/min.	50% MW/min.

Other	Nuclear	Coal Power	Combined Cycle
Start-up time	Dozens of hours	6~10 hours	1~2 hours
Output rate	-	2~4 MW/min.	10~20 MW/min.

4.2. Low power generation cost

Hydropower generation, with its low generation cost, has the potential to contribute to a decrease in electricity prices by replacing high fuel-cost (variable cost) generators during peak operation hours when power demand is high.

Electricity, being difficult to store, must be generated in real-time to meet the current power demand. In the domestic power market, the variable cost of generators that ultimately satisfy the time-of-day predicted demand is determined by the System Marginal Price (SMP). Consequently, prices are higher during periods of high demand and relatively lower during periods of low demand. Hydropower generation, utilizing water without consuming a separate fuel, has its variable cost fixed at 0 won in the domestic power market. Considering that K-water hydropower plants operate during peak demand hours, hydropower, especially during high SMP periods, contributes to reducing SMP by replacing the highest marginal generators.

4.3. Clean energy

Hydropower generation is a clean energy source in Korea that utilizes the country's abundant water resources to produce electricity, resulting in minimal environmental costs such as greenhouse gas emissions when compared to other power sources. In the case of central hydropower generators, a small amount of electricity is required for the initial startup of auxiliary equipment. However, once the generator is operational, it powers the auxiliary equipment, and no additional fossil fuels are consumed during the generation process.

With these characteristics, hydropower is classified as the cleanest energy source with the least carbon emissions, not only compared to fossil fuels such as oil and coal but also in comparison to other renewable energy sources like solar and wind power.

5. To-Be analysis: Potentiality of K-water's hydro power

5.1. Contribution in power system

Hydropower contributes to the stability of the power system through its rapid start-stop and output adjustment capabilities. The power exchange market provides additional compensation beyond the power quantity fee, acknowledging the contribution of hydropower to the reliable operation of the power grid. As a peak generation source, hydropower ensures the reliability, stability, and maintenance of electric quality within the power grid by implementing Automatic Generation Control (AGC) and Governor-Free (GF) operation. In return, hydropower receives compensation for providing auxiliary services to the grid operation and settlement funds. GF operation refers to the operation of local generators adjusting their output without instructions from the Korea Power Exchange (KPX), aiming to recover the frequency in the event of a failure. On the other hand, AGC operation involves the KPX central control system issuing output adjustments to each generator to maintain stable frequency during normal operation. To assess the contribution of K-water hydropower generation to the power system, analysis was performed using auxiliary services, settlement funds for emergency power dispatch instructions, and other relevant factors.

During AGC and GF power generation operations for the cooperation of power grid management, it is necessary to operate at a lower output compared to the rated capacity to maintain the frequency of the power grid. This results in generation losses due to decreased efficiency. We assumed that this amount of generation loss could be considered as the grid contribution. For K-water hydropower generators (7 plants) operating under AGC, we utilized the operational performance data in 2022 on a minute-by-minute basis and the comprehensive efficiency tables for each generator to calculate the efficiency reduction for each generator. The quantification method involved calculating the amount of generation loss due to efficiency reduction for each power plant during low-output operation. This loss was then multiplied by the total power sales settlement rate to derive the total value of low-output operation. The total value was divided by the actual power sales quantity over the recent 5-year average to determine the per kWh unit price.

To quantify the value of low-output operation, the following steps were taken:

① Calculation of Efficiency Reduction for Each Hydropower plant

▪ Calculation of Minute-by-Minute Efficiency Reduction during AGC Operation

→ (The maximum efficiency at that specific time point) - (The efficiency at the low-output state during that specific time point)

② Estimation of Generation Loss Due to Efficiency Reduction

▪ Estimated total electricity sales when there is no efficiency reduction

→ (Total electricity Sales) / (1 – Efficiency reduction (%))

▪ Reduction in Generated Power due to Efficiency Reduction

→ (Estimated total electricity sales when there is no efficiency reduction) - (Total electricity sales)

③ Reduction Derivation of total electricity sales unit price

→ (Total electricity sales revenue) / (Total electricity sales)

④ Reduction Derivation of total electricity sales unit price

→ (Reduction in Generated Power due to Efficiency Reduction) × (Total electricity sales unit price) / (Total electricity sales)

Using the operational performance data for each hydropower plant in 2022, the weighted average efficiency reduction can be calculated as follows.

Table 12. *Rate of Reduction in power generation efficiency according to AGC operation*

Hydro.	Unit	average efficiency difference (%)	Operating Time (min.)		Weighted average efficiency difference (%)
Soyang	1	4.10	227,021	→	4.05
	2	3.99	151,104		
Andong	1	2.16	113,923	→	2.01
	2	1.17	20,748		
DaeCheong	1	6.00	874	→	7.17
	2	7.18	127,961		
Chungju	1	3.90	82,921	→	4.51
	2	4.42	110,838		
	3	4.78	118,137		
	4	4.76	114,298		
Hapcheon	1	2.67	51,470	→	2.49
	2	2.37	80,386		
Juam	1	2.65	130,194	→	3.05
	2	3.52	112,957		
Imha	1	4.72	35,383	→	4.31
	2	3.71	24,689		

Using the calculated efficiency reduction rates and past generation operational data as a basis, the reduction in generated power due to efficiency reduction during low-output operation was computed as follows.

Table 13. *Reduction in power generation due to reduced efficiency (MWh)*

Hydro.		2018	2019	2020	2021	2022	Average
Soyang	Power generation performance(a)	498,881	346,778	505,935	313,659	600,096	462,070
	Estimated power generation reduction(b)	21,074	14,649	23,273	13,250	25,350	19,519
	a + b	519,995	361,427	574,207	326,909	625,445	418,589
Andong	Power generation performance(a)	73,198	102,668	122,148	127,797	108,182	106,799
	Estimated power generation reduction(b)	1,499	2,103	2,502	2,617	2,216	2,187
	a + b	74,697	104,771	124,650	130,415	110,398	108,986

Hydro.		2018	2019	2020	2021	2022	Average
Dae Cheong	Power generation performance(a)	161,846	108,524	198,637	121,413	98,845	137,853
	Estimated power generation reduction(b)	12,498	8,380	15,339	9,375	7,633	10,645
	a + b	174,344	116,904	213,976	130,788	106,478	148,498
Chung ju	Power generation performance(a)	664,244	483,672	768,701	573,835	680,443	634,179
	Estimated power generation reduction(b)	31,351	22,829	36,282	27,084	32,116	29,932
	a + b	695,596	506,501	804,982	600,920	712,559	664,111
Hap cheon	Power generation performance(a)	72,512	118,300	176,645	124,090	88,388	115,987
	Estimated power generation reduction(b)	1,849	3,016	4,503	3,163	2,253	2,957
	a + b	74,361	121,316	181,148	127,254	90,641	118,944
Juam	Power generation performance(a)	41,559	57,465	62,243	46,882	36,313	48,892
	Estimated power generation reduction(b)	1,309	1,810	1,961	1,477	1,144	1,540
	a + b	42,868	59,275	64,204	48,358	37,457	50,432
Imha	Power generation performance(a)	41,789	40,319	79,628	31,244	20,104	42,617
	Estimated power generation reduction(b)	1,880	1,814	3,583	1,406	905	1,918
	a + b	43,670	42,133	83,211	32,650	21,008	44,534

Based on the revenue performance and power sales quantity for each hydropower plant over the past 5 years, the per kWh unit price for power sales was calculated as follows.

Table 14. *Power generation sales and electricity sales unit price*

(Units: (a) MWh, (b) KRW million, (c) KRW/kWh)

Hydro.		2018	2019	2020	2021	2022	Average
Soyang	Power generation performance (a)	498,881	346,778	505,935	313,659	600,096	462,070
	Power generation sales (b)	55,057	34,948	41,770	33,222	127,874	58,574
	Electricity sales unit (c)	110.36	100.78	75.82	105.92	213.09	121.19
Andong	Power generation performance (a)	73,198	102,668	122,148	127,797	108,182	106,799
	Power generation sales (b)	8,125	10,925	10,035	13,750	22,307	13,029
	Electricity sales unit (c)	111.00	106.41	82.16	107.59	206.20	122.67
Dae cheong	Power generation performance (a)	161,846	108,524	198,637	121,413	98,845	137,853
	Power generation sales (b)	17,641	11,507	16,776	13,550	20,835	16,062
	Electricity sales unit (c)	109.00	106.04	84.45	111.61	210.78	124.37

<table>
<tr><th colspan="2">Hydro.</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>Average</th></tr>
<tr><td rowspan="3">Chung ju</td><td>Power generation performance (a)</td><td>664,244</td><td>483,672</td><td>768,701</td><td>573,835</td><td>680,443</td><td>634,179</td></tr>
<tr><td>Power generation sales (b)</td><td>71,257</td><td>53,641</td><td>63,095</td><td>64,285</td><td>147,901</td><td>80,036</td></tr>
<tr><td>Electricity sales unit (c)</td><td>107.28</td><td>110.90</td><td>82.08</td><td>112.03</td><td>217.36</td><td>125.93</td></tr>
<tr><td rowspan="3">Hap cheon</td><td>Power generation performance (a)</td><td>72,512</td><td>118,300</td><td>176,645</td><td>124,090</td><td>88,388</td><td>115,987</td></tr>
<tr><td>Power generation sales (b)</td><td>8,686</td><td>12,906</td><td>14,834</td><td>13,863</td><td>18,897</td><td>13,837</td></tr>
<tr><td>Electricity sales unit (c)</td><td>119,79</td><td>109.10</td><td>83.98</td><td>111.72</td><td>213.80</td><td>127.68</td></tr>
<tr><td rowspan="3">Juam</td><td>Power generation performance (a)</td><td>41,559</td><td>57,465</td><td>62,243</td><td>46,882</td><td>36,313</td><td>48,892</td></tr>
<tr><td>Power generation sales (b)</td><td>4,579</td><td>5,843</td><td>5,003</td><td>4,980</td><td>7,284</td><td>5,538</td></tr>
<tr><td>Electricity sales unit (c)</td><td>110.18</td><td>101.68</td><td>80.37</td><td>106.22</td><td>200.58</td><td>119.81</td></tr>
<tr><td rowspan="3">Imha</td><td>Power generation performance (a)</td><td>41,789</td><td>40,319</td><td>79,628</td><td>31,244</td><td>20,104</td><td>42,617</td></tr>
<tr><td>Power generation sales (b)</td><td>4,649</td><td>3,958</td><td>5,960</td><td>3,695</td><td>4,054</td><td>4,463</td></tr>
<tr><td>Electricity sales unit (c)</td><td>111.24</td><td>98.16</td><td>74.85</td><td>118.27</td><td>201.65</td><td>120.83</td></tr>
</table>

Finally, the low-output operation value for each hydropower plant was determined using the previously calculated reduction in generated power due to AGC operation, the unit price for power sales, and the total power sales quantity.

Table 15. *Low power operating value (KRW/kWh)*

Hydro.	2018	2019	2020	2021	2022	Average
Soyang	4.66	4.26	3.20	4.47	9.00	5.12
Andong	2.27	2.18	1.68	2.20	4.22	2.51
Daecheong	8.42	8.19	6.52	8.62	16.28	9.60
Chungju	5.06	5.23	3.87	5.29	10.26	5.94
Hapcheon	3.05	2.78	2.14	2.85	5.45	3.25
Juam	3.47	3.20	2.53	3.35	6.32	3.77
Imha	5.01	4.42	3.37	5.32	9.07	5.44

Hydropower, with its ability to swiftly start and stop operations and adjust output, enables agile responses to changes in power demand, thereby contributing to the enhancement of power grid reliability. While there may be variations in AGC operation performance due to regional demand, supply, and grid differences, quantifying the low-output operation value for each hydropower plant allows for estimations ranging from 2.51 to 9.60 KRW/kWh. Despite potential decreases in power sales revenue due to efficiency reduction during AGC operation, hydropower generators play a significant role in maintaining power grid frequency

5.2. Contribution in power market

According to Article 31 of the Electricity Business Act in the domestic power market, power generation and electricity sales operators must trade electricity through the regulations stipulated in the 'Power Market Operation Rules.' Currently, the domestic power market allows competition and bidding only in the generation sector, with no bidding for the demand sector. The market exhibits the following characteristics.

The domestic power market operates as a Mandatory Pool. The term 'Mandatory Pool' implies that all electricity transactions must take place through the power market. As per Article 31 of the Electricity Business Act, with certain exceptions, all electricity transactions are regulated to go through the power market operated by the power exchange.

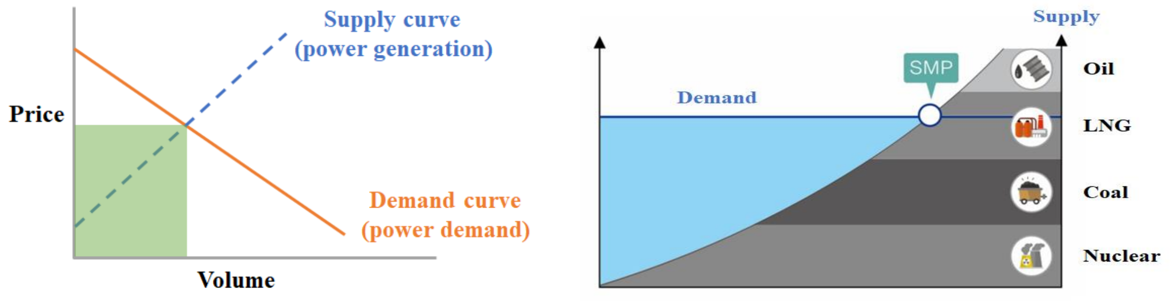
Next, the domestic power market operates as a single market for the entire day. In other words, one day before the trading day, the power exchange predicts electricity demand, and power generation operators bid for their generation capacity, determining the System Marginal Price (SMP) in the power market.

Furthermore, the domestic power market operates as a Cost Based Pool (CBP), which means that actual variable costs (fuel costs) of power generators are taken into accounting when determining SMP. In the CBP market, power generators do not submit bid prices during the bidding process; instead, they only bid their available generation capacity. The bid price is then determined by applying the highest variable cost price of a generator, among those whose variable costs match the demand, as pre-determined by the Cost Evaluation Committee operated by the power exchange on a monthly basis.

The pricing mechanism in the domestic power market is based on the principles of supply and demand, where the market price (transaction price) is determined. In the power market, just as in other markets, prices are influenced by the principles of supply and demand, regulating the production and consumption of electricity. As mentioned earlier, the domestic power market operates as a Cost Based Pool (CBP), meaning that the supply curve of electricity is composed of the actual variable costs (fuel costs) of power generators instead of the bid prices they submit. By combining the bid capacity and variable costs of each generator and sorting them in ascending order of price, the resulting curve represents the supply curve of the power market.

The demand curve for electricity represents the quantity purchased at different market prices. In South Korea, electricity demand is predicted one day in advance by the power exchange, utilizing historical patterns and other factors. This prediction reflects different characteristics of electricity usage during various time periods throughout the day. The market price (variable cost price) is determined at the point where the predicted electricity demand meets the bid capacity of power generators, considering their variable costs. The highest cost among the variable costs of generators participating in the bidding process is known as the SMP, which, in turn, determines the market price for that specific time period.

Figure 5. *Principle of price determination of domestic power Market*



Hydropower generation, not consuming a separate fuel and utilizing water for electricity generation, is assigned a fixed variable cost of 0 won in the domestic power market. In the absence of K-water hydropower participation in the power market, peak-load LNG combined-cycle generation, rather than baseload generation like nuclear and coal, would replace the electricity generated by hydropower. The activation of higher-cost LNG combined-cycle generators would lead to an increase in System Marginal Price (SMP). Typically, as electricity demand increases, SMP rises with the activation of generators with higher generation costs. However, K-water hydropower, bidding during peak hours of electricity demand with a high SMP, counteracts the price increase by providing generation with zero fuel cost. K-water hydropower participates in the power market by concentrating bids during peak hours of power demand without disrupting downstream water supply from dams.

With these characteristics and through a simulated analysis using KEPTA (Korea Electric Power Trading Analyzer), an analysis was conducted on the contribution of K-water's eight central hydropower plants to the stabilization of power market prices through their participation in the power market.

① Estimation of the SMP Drop Effect through Simulated Analysis of the Power Market

→ (Average SMP when participating in the K-water hydro power market) – (Average SMP when not participating in the K-water hydro power market)

② Derivation of Contribution to the Power Market

→ (SMP drop effect) × (Total electricity sales)

Through the KEPTA simulated analysis of the power market, an analysis was conducted on the SMP with a distinction between the participation and non-participation of K-water hydropower. This analysis is based on data from the years 2017 to 2021, considering the introduction of the Real-Time Market based on the Actual System Base in September 2022, which led to a restructuring of the power market system.

Table 16. *Contribution in power market (KEPTA Analysis Results) (KRW/kWh)*

Sortation	2017	2018	2019	2020	2021	Average
Including Hydro. (a)	81.39	95.14	91.03	68.97	93.98	86.10
Excluding Hydro. (b)	81.51	95.29	91.14	69.18	94.16	86.26
Contribution (b-a)	0.12	0.15	0.11	0.21	0.18	0.15

The SMP drop effect resulting from K-water hydropower's participation in the power market was calculated to be an average of 0.15 won/kWh over a 5-year period. Using this calculated value, along with the 5-year average total electricity trading volume in the power market and K-water's electricity sales volume, the contribution of K-water hydropower to the power market was determined. According to power market statistics from KPX, the annual average total electricity trading volume is approximately 528,175 GWh, with a total electricity trading amount of 488.222 trillion won. While K-water hydropower accounts for only 0.3% of the total electricity trading volume, its participation in peak load periods results in an SMP reduction effect of approximately 0.17%, contributing to the stability of power market prices with an annual average of 79.2 billion won.

Table 17. *Results of K-water hydro power contribution analysis in power market*

(Units: (a) KRW/kWh, (b) GWh, (c, d) KRW 100 million)

Sortation	2017	2018	2019	2020	2021	Average
SMP drop effect (a)	0.12	0.15	0.11	0.21	0.18	0.15
Electricity transaction volume (b)	520,917	537,061	529,851	515,983	537,061	528,175
Electricity transaction amount (c)	447,712	507,027	499,718	435,925	550,727	488,222
Contribution in power market (d)	625	806	583	1,084	967	792

5.3. Contribution to the environment

Hydropower is a clean energy source in the domestic resource, utilizing water as a renewable resource to generate electricity, resulting in minimal environmental costs such as greenhouse gas emissions compared to other forms of power generation. In the domestic power market, hydropower is generally considered as an alternative power source, assuming the role of a peaking generator that determines SMP for each time period. When a stable hydropower generator is in operation, it can reduce the operation of more variable generators with higher operating costs to meet the electricity demand during that specific time period. Therefore, to analyze the environmental contribution of hydropower plants, we calculated the weighted average greenhouse gas emission coefficient by considering the number of times each power source determines SMP.

SMP is determined by the power source with the highest variable cost to supply electricity in response to the hourly power demand. According to the Korea Power Exchange's Power Statistics Information System, SMP frequencies are as follows. For LNG, which has the highest variable cost, it determines SMP approximately 87% of the time on average annually. On the other hand, for baseload sources such as nuclear and coal-fired power, they determine SMP around 12% of the time annually. This is influenced by high power demand on weekdays and relatively lower demand during weekends, spring, autumn, and early morning hours.

Table 18. *Number of SMP decisions by fuel source*

Year	Total	LNG	Oil	Anthracite Coal	Bituminous Coal	Nuclear
2018	8,760	8,133	286	58	283	0
2019	8,760	7,818	21	77	844	0
2020	8,784	6,634	0	104	2,046	0
2021	8,760	7,904	0	107	749	0
2022	8,760	7,621	125	9	1,003	2
Total	43,824	38,110	432	355	4,925	2
Ratio	100%	86.96%	0.99%	0.81%	11.24%	0%

When calculating the weighted average by excluding the negligible SMP determination hours for marginal sources like fossil fuels and nuclear power (434 hours), the weighted average SMP determination is as follows: LNG determined SMP approximately 87.83%, while coal (anthracite and bituminous coal) determined SMP around 12.17%.

According to the 10th Basic Plan for Power Supply and Demand (Ministry of Trade, Industry and Energy, January 2023), the greenhouse gas emission coefficients for coal-fired power are 0.8362tCO_2/MWh, for LNG it is 0.3779tCO_2/MWh, and for calculating the substitution effect of K-water hydropower, the greenhouse gas emission coefficient is determined to be 0.4337tCO_2/MWh.

By applying the calculated greenhouse gas emission coefficients to the power sales of eight K-water central hydro power plants participating in the electricity bidding, the reduction in operation of the marginal generator for the grid system boundary allows for estimating a greenhouse gas reduction effect of approximately 715,000tCO_2 annually.

Hydro power plants not only produce clean energy through the generation process itself but also contribute significantly to the environment by replacing power plants that use fossil fuels, thus reducing greenhouse gas emissions.

Table 19. *Results of greenhouse gas reduction calculation*

(Units: (a) MWh, (b) tCO_2)

Hydro.		2018	2019	2020	2021	2022	Average
Total	Power generation performance (a)	1,632,376	1,361,589	2,097,392	1,438,491	1,721,464	1,650,262
	Greenhouse gas reduction (b)	707,961	590,521	909,639	623,874	746,599	715,719
Soyang	Power generation performance (a)	498,881	346,778	505,935	313,659	600,096	462,070
	Greenhouse gas reduction (b)	216,365	150,398	238,941	136,034	260,262	200,400
Andong	Power generation performance (a)	73,198	102,668	122,148	127,797	108,182	106,799
	Greenhouse gas reduction (b)	31,746	44,527	52,976	55,426	46,919	46,319
Dae cheong	Power generation performance (a)	161,846	108,524	198,637	121,413	98,845	137,853
	Greenhouse gas reduction (b)	70,193	47,067	86,149	52,657	42,869	59,787
Chungju	Power generation performance (a)	664,244	483,672	768,701	573,835	680,443	634,179
	Greenhouse gas reduction (b)	288,083	209,769	333,386	248,872	295,108	275,043
Hap cheon	Power generation performance (a)	72,512	118,300	176,645	124,090	88,388	115,987
	Greenhouse gas reduction (b)	31,448	51,307	76,611	53,818	38,334	50,304
Juam	Power generation performance (a)	41,559	57,465	62,243	46,882	36,313	48,892
	Greenhouse gas reduction (b)	18,024	24,923	26,995	20,333	15,749	21,204

Hydro.		2018	2019	2020	2021	2022	Average
Imha	Power generation performance (a)	41,789	40,319	79,628	31,244	20,104	42,617
	Greenhouse gas reduction (b)	18,124	17,486	34,535	13,551	8,719	18,483
Young dam	Power generation performance (a)	78,347	103,863	138,455	99,571	89,093	101,866
	Greenhouse gas reduction (b)	33,979	45,045	60,048	43,184	38,640	44,179

6. Conclusion and Future Research

Climate change respond is an unavoidable and global challenge that requires collective efforts. With the increase in population and economic development, the inevitable reality is the rise in energy consumption. To effectively cope with this, the use of clean and renewable energy is essential. Hydroelectric power, a prominent renewable energy source, faces limitations in new construction due to the need for expansive water reservoirs. As a result, renewable energy, particularly solar power with challenges in output control, is rapidly increasing to meet the growing demand for energy.

In the past, hydropower has been primarily recognized as a power plant alongside nuclear, coal, and gas power plants for electricity generation. However, in this study, the value of hydropower is examined from the perspective of energy transition towards carbon neutrality and climate change response, including initiatives like RE100.

The value of hydropower has been further enhanced in response to the increasing instability in the power grid due to the recent rise in renewable energy. Its ability for rapid maneuvering and output modulation makes hydropower an essential asset. Additionally, the contribution to the power market and the environmental value have been quantified based on historical performance, considering the growing significance of renewable energy.

The K-water hydro power generation that operates AGC is a significant role in maintaining power system frequency (power supply balance), even though there may be a decrease in power generation efficiency, resulting in a reduction in power sales revenue (2.51~9.60 KRW/kWh). Additionally, K-water hydropower offsets the demand for high SMP (System Marginal Price) during peak hours, where the unit price is high, by generating electricity with zero fuel cost, thereby contributing to suppressing SMP increases (0.15 KRW/kWh) and stabilizing the power market with an annual contribution of approximately 79.8 billion KRW. Finally, K-water hydropower contributes to the reduction of greenhouse gas emissions by annually offsetting an average of 715,000 tons of $CO2$ through the substitution of power generation from fossil fuel-based sources.

This study derives and quantifies the value of K-water hydropower based on past performance, providing significance. However, in addition to the presented values, other aspects such as the environmental and social values of hydropower plants, especially multipurpose dams, should be further considered. Moreover, if a comprehensive evaluation is conducted, taking into accouningt not only the costs of electricity production and construction but also the economic, social, and environmental benefits in comparison with other renewable energy sources, it could serve as valuable reference material for shaping the domestic renewable energy portfolio and, further, for achieving carbon neutrality.

References

Korea Energy Corporation Renewable Energy Center. (2023). New and Renewable Energy White Paper

IEA. (2024). Renewables 2023

Korea RE100 Alliance. (2023). Korea RE100 Coalition RE100 Information Platform

KEPCO. (2023). Korea Power Electric Statistics for 2022 (Issue No. 29)

Korea Energy Economics Institute. (2021). Results and Future Directions Study of Energy Transition Policy

Republic of Korea Government. (2020). 2050 Carbon Neutrality Strategy

Republic of Korea Government. (2023). Carbon Neutrality Green Growth National Strategy and 1st National Basic Plan

Energy Transition Roadmap (Ministry of Trade, Industry and Energy, 2017.10.24.)

Ministry of Trade, Industry and Energy. (2017). Renewable Energy 3020 Implementation Plan

Ministry of Trade, Industry and Energy. (2017). 8th Basic Plan for Electricity Supply and Demand

Ministry of Trade, Industry and Energy. (2020). 9th Basic Plan for Electricity Supply and Demand

Ministry of Trade, Industry and Energy. (2023). 10th Basic Plan for Electricity Supply and Demand

Ministry of Trade, Industry and Energy. (2019). 3rd Energy Basic Plan

Korea New Deal Comprehensive Plan (Government, 2020.07.14.)

2050 Carbon Neutrality Committee. (2021). 2050 Carbon Neutrality Scenario

Ministry of Trade, Industry and Energy. (2022). New Government Energy Policy Direction

Incheon Research Institute. (2023). Major Trends and Implications of RE100

World Meteorological organization, United in Science. (2021). A multi-organization high-level compilation of the latest climate science information, https://public.wmo.int

World Economic Forum. (2022) The Global Risks Report 2022

Korea Power Exchange. Electric Power Statistics Information System, https://epsis.kpx.or.kr