A Study on Planning and Evaluation System for Carbon-neutral Green City Construction

By

KIM, Byoungki

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

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Executive Summary

Climate change is emerging as the biggest problem threatening human existence around the world. Nearly half of humanity, 3.5 billion people, are currently living in urban areas, and more than 5 billion people are expected to live in cities by 2030. Cities account for 60-80% of energy consumption and 75% of carbon emissions used by humans, and to realize carbon neutrality in the era of climate change, many changes must be made around urban areas.

A carbon-neutral city is a city that minimizes fossil energy dependence and energy consumption to curb carbon emissions caused by fossil energy use and neutralizes or zero carbon emissions inevitably generated by economic and social activities through continuous use of renewable energy sources and maximization of energy efficiency (Kim, Choi, 2011). Realizing carbon neutrality in cities, which account for the largest portion of carbon emissions, is a keyword that clearly shows that carbon neutrality is the first thing to consider to realize carbon neutrality in the era of climate change.

This study aims to examine domestic and foreign cases centered on cities to realize carbon neutrality and to examine the essential components to be considered to create a carbon-neutral city and what performance evaluation should be conducted after introducing them. I hope that this study will help realize carbon-neutral cities in Korea in the future by awakening the necessity of carbon neutrality centered on cities.

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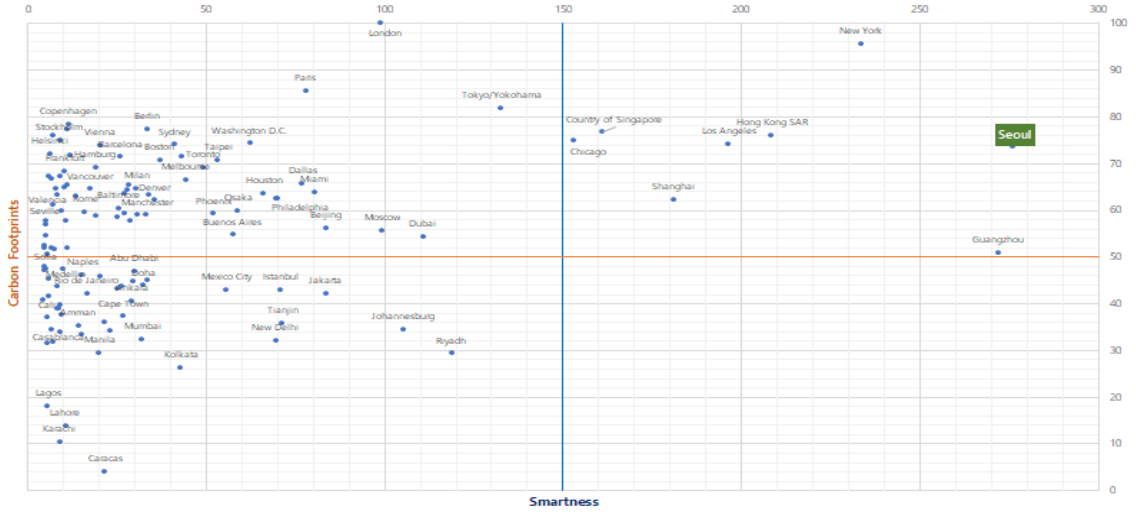
1. Introduction

1.1 Background

Currently, countries around the world are facing two global megatrends. One is about the eco-friendly and energy transition following the implementation of the new climate system, and the other is the Fourth Industrial Revolution. As Korea goes through the development era, the problems of climate change due to indiscriminate energy consumption and greenhouse gas emissions are seriously rising. Korea is an IT powerhouse with the 7th largest economy in the world, but it has the highest growth rate of OECD CO2 and is considered a climate villain in response to the international climate crisis. Seoul, Korea's leading city, ranked first among 500 cities in the 2018 Carbon Emissions Survey, which was released by a team of researchers from the Norwegian University of Science and Technology, Lund University in Sweden, and Yale University in the United States, with 276.1±51.8 Mt (Mt=1 million tons) of carbon emissions.

Figure 1. Smartness and Carbon Footprints for 121 Cities around the World



Source: Global Gridded Model of Carbon Footprints (GGMCF) (2018), IESE Cities in Motion Index (2020)

Half of humanity expects 3.5 billion people to live in urban areas now, and more than 5 billion people will live in cities by 2030. Cities around the world account for only 3% of the earth's area, but they are representative of environmentally polluted areas that account for 60-80% of energy consumption and more than 75% of carbon emissions. Therefore, efforts should be made to reduce energy and emit less carbon around this urban area.

1.2 Research Questions

Until then our city should not remain an emission-type city that accelerates global warming by emitting most carbon using fossil energy without countermeasures, and we should seriously consider whether to transform it into an eco-friendly and recoverable circular city. More specifically, the need for us to increase the proportion of renewable energy use, drastically reduce carbon emissions, and build a carbon-neutral city is as follows.

First, it is necessary to reduce carbon dioxide emissions per person to reduce climate change. Currently, Korea's total carbon dioxide emissions are ranked seventh in the world with 600 million tons, and developed countries have already implemented various policies and are reducing them for a long time, while Korea has been increasing 3.3% annually since 1990 and its per capita carbon dioxide emissions are ranked fourth in the world with 11.7 tons.

Second, climate change is acting as the cause of the outbreak of the new infectious disease pandemic. As can be seen from the COVID-19 phenomenon, which has been suffering greatly so far, rapid climate change and development-induced ecosystem destruction are causing wildlife to move to residential areas, resulting in habitat change, and narrowing the distance between humans and wilds, creating ecosystems vulnerable to exotic species and causing the spread of pathogens with the development of transportation.

Third, resource recycling and pollutant minimization are needed. The risk of health effects is greatly increased due to increasing fine dust and microplastics, and the excess mortality rate due to fine dust is expected to increase and the health effects of microplastic human concentration are expected to increase.

The purpose of this study is to summarize the major components of carbon-neutral cities to respond to serious climate change problems around the world and to suggest a performance evaluation plan to find ways to improve the city to which each component is applied in the future.

2. Methods

2.1 Data Collection

This study examined the concept of carbon neutrality and how important a city is to realize carbon neutrality by examining various literature related to carbon neutrality. In particular, we investigated the carbon neutrality policies implemented in cities, centering on European countries that played a leading role in carbon neutrality policies. In addition, several cases were investigated to include both cases to compare policies implemented in new cities regardless of size with those implemented in existing cities.

In the case of Korea, a data survey was conducted on the current status of early projects related to carbon neutrality. In addition, the recently established carbon neutrality policy and the Green New Deal policy were analyzed to distinguish between policies related to cities. In addition, we further investigated the implementation cases of smart cities that contain the Fourth Industrial Revolution technology in cities and included the carbon neutrality policy introduced in smart cities in this study.

2.2 Data Analysis

The purpose of this study is to suggest the direction in which cities, which account for the majority of carbon emissions, should move forward to respond to serious climate change problems worldwide and achieve a "carbon-neutral carbon-neutral scenario in 2050.

To this end, the effectiveness and effectiveness of each policy and system was confirmed through the case analysis previously investigated. Although there are various policies related to carbon neutrality, the policies were classified based on the elements that are the basis of the city. We also identified the commonalities between the policies being promoted abroad, including at home, and found the essential elements. The policy of a carbon-neutral city that conforms to the 2050 carbon-neutral strategy recently established by Korea was analyzed to ensure consistency in the policy.

To promote effective projects in promoting new government policies and projects, it is necessary to present improved implementation goals for policies and projects and to conduct an objective evaluation of the project. Before this, it was intended to present a plan to establish a KPI for the essential elements of a carbon-neutral city analyzed earlier. By presenting the essential elements for a carbon-neutral city and the direction of development of a city that can help realize the carbon-neutral goal in 2050 by presenting the KPI to evaluate it, efforts were made to contribute to making the city a better place for people to live through urban policies and projects in the future.

3. Literature Review

3.1 Carbon Neutrality

The IPCC (2018) 'Special Report on 1.5℃ Global Warming' is the world's representative comprehensive report on carbon neutrality scenarios. The report states that global net greenhouse gas emissions should be reduced to zero by 2050 to achieve the 1.5℃ goal. The IPCC (2022) 6th evaluation report states that it is difficult to achieve the 1.5℃ goal only with the national reduction target submitted by November 2021 and that global net greenhouse gas emissions must be reduced by 84% compared to 2019 by 2050. The common strategy in the 2050 global energy sector carbon-neutral scenarios published by IEA, IRENA, Shell, BP, and DNV and the EU, US, Japan, and China's carbon-neutral scenario literature is to reduce energy demand and carbon-free power generation (renewable energy accounts for the largest share), electrification, carbon-free fuel utilization, and capture and store residual emissions (Park, 2021).

In Korea, the first carbon neutrality scenario for 2050 was established in October 2021 (2050 CNC, 2021). As the new government is launched in May 2022, implementation strategies such as energy mix will be established while maintaining the upward revision of the 2050 carbon neutrality target and the 2030 national reduction target (Joint Ministry of Relations, 2022a; 2022b; MOTIE, 2022). The carbon neutrality scenario is a combination of reduction measures available to achieve the carbon neutrality goal and will be continuously revised and supplemented in consideration of domestic and foreign energy and resource supply and demand conditions, energy and environmental regulatory trends, domestic energy and climate technology levels, industrial structure, cost and benefits of carbon neutrality, and collection of stakeholder opinions (Park, 2022).

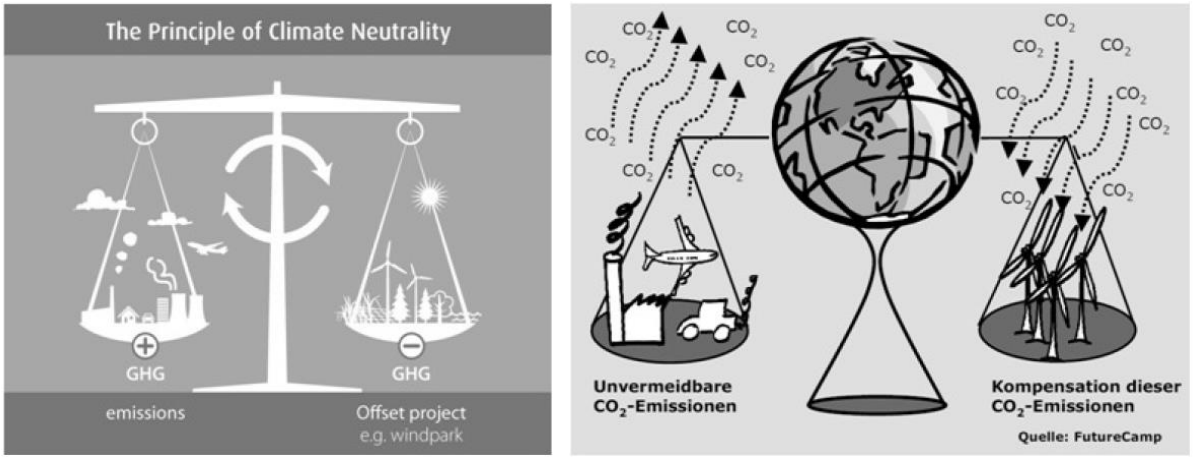
3.2. Carbon-neutral City

The need for carbon reduction, which accounts for the largest share of greenhouse

gases, has increased as the Kyoto Protocol took effect at the 3rd Conference of the Parties held in Japan in 1997 and selected greenhouse gases and obligatory countries. As a result, the concept of a carbon-neutral city has emerged at various levels, from carbon-reducing cities that minimize carbon emissions and reduce the use of energy with high carbon emissions, to zero-carbon cities. (UN, 1997)

A carbon-neutral city is a city that minimizes fossil energy dependence and energy consumption to curb carbon emissions caused by fossil energy use and neutralizes carbon emissions inevitably generated by economic and social activities through the continuous use of renewable energy sources and maximizing energy efficiency. It is also the principle of carbon neutrality or climate neutrality to completely block carbon emissions from fossil fuel use or offset the amount by creating oxygen-supplied forests to maintain the total amount of carbon emitted by economic activities. Therefore, a carbon-neutral city is a city that complies with the principle of carbon neutrality to realize a carbon-neutral or zero-zero city and has a more active meaning than a low-carbon green city that seeks to minimize carbon emissions. (Kim, Choi, 2011)

Figure 2. The Principle of Carbon Neutrality



Source: StMUGV, 2007

Carbon neutrality in urban development refers to meeting three conditions. The first is to reduce energy use wherever possible (especially in buildings and transportation). The second is to use renewable energy that emits no greenhouse gases at any time possible. The third is to offset carbon emissions through purchasing carbon credits, planting, and other renewable options (Peter Newman, Timothy Beatley & Heather Boyer, 2009).

3.3 Smart City

A Smart City is a future high-tech city that can receive information anytime, anywhere through any device centered on information and communication technology. It is currently evolving into an information-oriented city-U-smart city (Lee. Lim., 2008). Smart cities are morphologically defined as cities in which traditional cities, U-city, and low-carbon green cities are integrated. Technically, it refers to a high-tech city that has become intelligent as an IoT and ICT-centered city. Smart cities are not a simple compound word of smart and city, but are the process of making a city smart (Lee, Lim, 2016, Choi, 2011)

Since 2010, U-City has evolved into a smart city that considers environmental technology as well as information technology development. It was predicted that in the future, it will evolve to focus on environmental and information technology in which environmental technology and information technology are fused. Smart cities initially started by functionally and spatially connecting spaces to operate information and services. Currently, services, infrastructure, and management systems are evolving into organic forms as major development keywords for environmental technology and information technology due to issues such as climate change. In the end, it is expected that the morphological appearance of smart cities will evolve into a space form in which environmental technology and information technology are fused. (Han, Lee, 2019)

4. Case Study of International Carbon-neutral City

More and more countries and cities around the world are starting or declaring plans for climate neutrality. Global leaders in carbon-neutral policy Germany and Sweden have declared that they will achieve Net-Zero by 2045, and Switzerland and Denmark by 2050. Efforts at the city level are also very active, and cities that join international initiatives such as the Global Climate and Energy (GCoM), the Carbon Neutral Cities Alliance (CNCA), and the C40 Cities Climate Leadership Group are showing more aggressive actions and attitudes. Copenhagen, the capital city of Denmark, has set a global goal of achieving a 'Carbon Neutral City' first and is expected to achieve that goal by 2027, a little later than the initial goal of 2025. Cities can actively participate in regional climate response plans because they are well-equipped to take specific policy measures in response to social needs. As more and more people are concentrated in cities, cities have played a crucial role in achieving the goals of the Paris Climate Accord.

75% of the population of the European Union (EU) resides in cities and a large proportion of carbon dioxide is emitted from cities. European countries have promised to take the lead in responding to climate change, and the European Union is supporting 100 cities selected through the ‘Net Zero Cities’ project to achieve climate neutrality by 2030 and laying the foundation for all European cities to follow suit by 2050.

The goal of this project is to promote territorial change in pilot cities to remove barriers faced by subsequent cities. About 100 cities have different structures and requirements, so individual concepts must be developed. To this end, 33 entities, including urban networks, research institutes, and urban activists, have formed partnerships to build digital platforms for participating cities together. In addition, Climate City Contracts, a kind of public contract between participating cities and stakeholders, are prepared, including an

action plan accompanied by investment and measures to implement the project, and a list of investment plans and projects to be implemented by 2030. Copenhagen, Denmark, Wildpoldsried, Germany, and Malmöhalle, Sweden, are the most representative examples of the European Union's carbon neutrality, and the main measures for carbon neutrality in each city are as follows.

4.1 Wildpoldsried, Germany

The Wildpoldsried, Germany region is a new and renewable energy business model that generates profits from electricity generation using renewable energy. The Wildpoldsried region, like other rural areas in Germany, is one of the regions that continued to stagnate, and it has fostered new and renewable energy projects as a new industry in the region with the participation of local actors to overcome the downturn. The city of Wildpoldsried has started power generation projects using solar power, wind power, hydropower, and biogas based on village power generation strategies established by villages and local governments since 1998. As of 2020, each power source produced a total of 58,807 MWH of electricity, including solar power 5,446 MWH, wind power 33,472 MWH, biogas 11,8660 MWA, and hydropower, of which 6,135 MWH was used. The city of Wildpoldsried is estimated to have earned 6.7 million euros a year as of 2017 through energy production.

The eco-friendly energy project in the city of Wildpoldsried is being promoted by local governments, and each project promoted by the city is only made up of local government budgets and investments from residents, diversifying the income of residents. In particular, various research institutes participate in the development and application of technology throughout the energy project to develop operation management and power generation systems for power generation facilities, and the developed smart grid technology

is being applied to new projects in the city of Wildpoldsried.

4.2 Copenhagen, Denmark

Copenhagen has pushed forward innovation in three areas: energy, mobility, and urban administration to realize its goal of carbon neutrality by 2025. Among them, energy production is the area where Copenhagen puts the most effort into. Copenhagen has decided to replace 100% of its fossil fuels with solar, wind, biomass, and geothermal energy. Taking advantage of the geographical advantage of strong westerly winds from the Atlantic Ocean, it plans to install 100 (360MW) new large wind turbines by 2025. It uses urban waste and waste as fuel, and it burns about 400,000 tons a year, responsible for 30,000 households' electricity and 130,000 households' district heating. Under the policy that 1% of urban power consumption will be covered by solar power in 2025, efforts such as installing solar cells on 60,000 square meters of land in public buildings are being made.

In the transportation sector, all public transportation will be replaced by renewable energy vehicles by 2025, and the proportion of new and renewable energy vehicles in passenger cars will be increased to 20-40%. In particular, bicycles were viewed as a means of mobility innovation, and 1,000 km of bicycle lanes were built to use bicycles. The ultimate goal is to curb demand for automobiles and increase the share of foot, bicycle, and public transportation in the city to more than 75%.

Denmark is a smart powerhouse that ranked first among 193 member countries in the "2020 E-Government Evaluation" released by the United Nations last year. The "Street Lab" program led by Solution Lab (CSL) under the Ministry of Technology and Environment in Copenhagen is the most representative example. After collecting and analyzing data in real-time with Internet of Things (IoT) sensors installed throughout the streets, the company

is developing solutions such as air quality monitoring, parking space exploration, traffic system and garbage collection optimization, and floating population analysis.

4.3 Malmö, Sweden

Malmö, Sweden was a representative Swedish port city. After the oil crisis in 1973, Malmö began to go downhill together as Sweden's shipbuilding industry collapsed. Malmö established the "City of Tomorrow" at the site of the shipyard and factory relocation to promote eco-friendly urban regeneration. By the principles of the "Sustainable European City Development" and "Urban Planning by Renewable Energy Sources" projects in Europe, which were carried out until 2003, the city's redevelopment began in earnest to supply all the supplied energy in the region to renewable energy sources.

Solar, solar, and geothermal systems were built in all buildings in Malmö, and offshore wind and tidal power facilities were built on the coast to link them with the global energy supply system. District heating operates heat pumps in the district to draw up heat sources in underground aquifers, meeting 83% of the total heating demand in the region, 15% through solar heat, and 2% using biogas from local waste. In addition, to supply 11GWh of energy annually in the region to renewable energy sources, 2MW class offshore wind power generation and solar panels covering a total of 1.2 million square meters were created to meet the electricity demand.

With the revitalization of the renewable energy industry, Malmö has been reborn as a symbol of urban regeneration in Sweden, with the number of unemployed people in Malmö decreasing and the expansion of the urban economy. Urban regeneration based on new and renewable energy has brought about the fostering of an eco-friendly construction industry. As the main industry changed from shipbuilding to knowledge-based industries such as IT

and new and renewable energy, the industrial sector's carbon dioxide emissions also decreased by a quarter compared to 1980. Malmö was selected as the "world's most livable city" by the United Nations Environment Program in 2007 and was selected as an excellent example of the "realization of the introduction of new and renewable energy in Europe" by the Swedish government in 2009.

The main keywords of the policies that foreign carbon-neutral cities focus on to realize carbon neutrality can be summarized as eco-friendly energy, eco-friendly transportation, and smart urban administration. The keywords for other overseas cases are shown in the table below.

Table 1. Policy Keywords of Carbon-Neutral Cities in Overseas

Nation	City	Policy Keyword	Note
German	Wildpoldsried	Renewable energy, Energy independence, Eco-friendly architecture, Citizen participation	
	Freiburg	Plus energy housing (solar), Eco-friendly architecture, Bicycle, Carbon neutral building	
	Neue Weststadt	Energy Management System Combining Renewable Energy, Zero Energy Building, Hydrogen Energy, Electricity-Heating-Cooling-Transportation	New town
	Jenfelderau, Hamburg	Eco-friendly distributed water treatment system, Rainwater utilization, LID, Biogas, Passive House	a small city
Switzerland	Seebrighof	Renewable Energy, Hydrogen Energy, Energy Storage Technology, Apartment Housing	
	Greencity Zurich	Green space, Eco-friendly transportation, Renewable energy, Building energy efficiency increase, Smart IoT	New town

Denmark	Nordhavn, Copenhagen	Smart Energy Solution, Smart Building Control System, Car-free Zone, Waste Energy Plant	a small city

5. As-Is Analysis: Carbon-neutral City Policy of Korea

5.1 Initial Projects for Carbon-Neutral Cities Promoted by Government

In preparation for climate change, the Korean government has promoted various local government-level projects considering environmental sustainability, such as climate change response pilot cities and green cities. Various projects were promoted early in preparation for climate change, but there was a limit to achieving breakthrough project results as projects focused on various ministries and specific purposes for each ministry.

Table 2. Initial Projects for Carbon-neutral Cities Promoted by the Korean Central Government and Local Governments

No	Policy	Department	Policy content	Implemented area
1	"SangSang" city	Presidential Committee on Green Growth	To utilize the climate change crisis as an opportunity for growth, the Korean green growth urban model promotes the development of not only ecology but also energy transportation industries and enables the environment, economy, and society to coexist. Improve the green competitiveness of the region, improve the quality of life, and realize green growth and branding in life by supporting the discovery and diffusion of excellent eco-rich municipalities.	20 County & City

2	Climate Change Response Pilot City (2008~)	Ministry of Environment	As local governments play an important role in implementing the central government's policies to reduce greenhouse gases, they encourage local governments to raise interest in climate change response, develop greenhouse gas reduction programs tailored to regional characteristics, and establish an organic cooperation system between the central and local governments.	7 County & City
3	Green City (Excellent Local Government for Environmental Management) (2004~)	Ministry of Environment	To encourage constructive competition among local governments for the revitalization of eco-friendly local administration by raising interest and participation in the environment of local government heads and residents, Green City has been selected every two years since 2004	26 County & City
4	Eco City (2008~)	Ministry of Environment	Creating an eco-city that can promote regional development while maintaining the framework of environmental conservation policies for underdeveloped areas due to restrictions on land use, et	4 County & City
5	Low Carbon Green Village	Ministry of Environment MOLIT MSIT MOIS Korea Forest Service	Creating early results in the supply of new and renewable energy at low cost by utilizing waste resources and biomass. As a powerful means of fulfilling greenhouse gas reduction obligations, the government has achieved the target rate for the supply of new and renewable energy and promoted it as a green new deal business and a new growth engine business	4 County & City

5.2 2050 Long-term Low Greenhouse Gas Emission Development Strategy (LEDS)

The Ministry of Environment confirmed the "National Long-Term Low Carbon Development Strategy for 2050" (hereinafter referred to as the "Development Strategy") by

operating a forum consisting of six divisions involving 58 experts, civil society, and future generations to be submitted to the climate agreement after public discussion in the first half of 2020.

Based on this, multiple national greenhouse gas emission targets for 2050 have been established in line with the purpose of the 'Long-Term low greenhouse gas emission development strategy (LEDS) in 2050' by reflecting international trends such as the Paris Agreement as well as domestic reality. The Paris Agreement recommended that each State Party establish a Long-Term Low Greenhouse gas emission development strategy (LEDS) by 2020 from the perspective of the long-term vision of climate change response policies. Accordingly, Korea decided to establish an LEDS to participate in the international community's climate change efforts. (Ministry of Environment, 2020) The specific reduction rates and social aspects for each sector are as follows. From the 1st to the 5th draft, detailed goals in five areas were presented based on the reduction of greenhouse gases by up to 75% to at least 40% compared to 2017. Most of the detailed goals in the five fields are related to cities, reminding us that a paradigm shift is urgent in the development of cities.

Table 3. 2050 Low Carbon Development Strategy Reduction Rate and Social Appearance by Sector (Yoon, 2020)

Division	Plan 1	Plan 2	Plan 3	Plan 4	Plan5
Energy supply	▪ Coal-fired power generation ratio: 4% ▪ Renewable energy generation ratio: 60% ▪ The era of the hydrogen economy	▪ Coal-fired power generation ratio: 4% ▪ Renewable energy generation ratio: 60% ▪ The era of the hydrogen economy	▪ Coal-fired power generation ratio: 8% ▪ Renewable energy generation ratio: 50% ▪ Generalization of the hydrogen economy	▪ Coal-fired power generation ratio: 8% ▪ Renewable energy generation ratio: 50% ▪ Generalization of the hydrogen economy	▪ Coal-fired power generation ratio: 12% ▪ Renewable energy generation ratio: 40% ▪ Realization of the hydrogen economy

Industry	▪ Total transformation and expansion of convergence ▪ Maximize resource recycling and revolutionize production processes	▪ Smart Energy Management System Full Propagation ▪ Resource recycling and step-by-step process improvement	▪ Smart Energy Management System Full Propagation ▪ Resource recycling and step-by-step process improvement	▪ Expansion of Smart Energy Management Systems ▪ Introduction of industrial process high-efficiency reduction facilities	▪ Partial Application of Smart Energy Management System ▪ Improvement of Energy Consumption Efficiency of Electric Motor and Boiler Equipment
Building	▪ Green Building Settlement ▪ Maximizing consumption of renewable energy such as unused heat	▪ Green Building Settlement ▪ Strengthen the expansion of renewable energy supply	▪ Generalization of Green Buildings ▪ Strengthen the expansion of renewable energy supply	▪ Generalization of Green Buildings ▪ Promotion of renewable energy supply	▪ Strengthening Green Building Management ▪ Promotion of renewable energy supply
Transportation	▪ Rapid regression of engine cars (7%) ▪ Popularization of eco-friendly cars (93%) ▪ Self-driving, artificial intelligence proliferation	▪ Rapid regression of engine cars (7%) ▪ Popularization of eco-friendly cars (93%) ▪ Changes in the road system in earnest	▪ Progressive regression of engine cars (18%) ▪ Popularization of eco-friendly cars (82%) ▪ Changes in the road system in earnest	▪ Progressive regression of engine cars (18%) ▪ Popularization of eco-friendly cars (82%) ▪ Realization of Road System Changes	▪ Progressive regression of engine cars (25%) ▪ Popularization of eco-friendly cars (75%) ▪ Realization of Road System Changes
Agriculture, livestock, etc	▪ Smart Farm Diversification ▪ Complete natural circulation of waste ▪ Nature-friendly environment	▪ Smart Farm Expansion ▪ complete natural circulation of waste ▪ Nature-friendly environment	▪ Smart Farm Expansion ▪ Reclamation sector aerobic operations and increased proportion of bioplastics ▪ Nature-friendly environment	▪ Smart Farm Commercialization ▪ Increased methane gas recovery and increased waste recycling and reduction ▪ Nature-friendly environment	▪ Smart Farm Commercialization ▪ Increased waste recycling and reduction ▪ Nature-friendly environment

5.3 Korean New Deal Project

In addition, the government announced the 'Korean New Deal Project' as an economic policy direction in the second half of 2020 to respond to COVID-19. The 'Korean New Deal' is promoted as the '2+1 axis' of the Digital New Deal, Green New Deal, and Human New Deal, and its main goal is to invest a total of 76 trillion won. By expanding social safety nets such as BIG3 (Bio, System Semiconductor, Future Vehicle) future engineering such as quarantine and bio, GVC hubs such as attracting high-tech industries, and establishing a national employment safety net. In order to rapidly promote the complex development project linking public facilities (public housing and school) with living SOC, improve old infrastructure facilities, and accelerate the balanced national development project (23 in total, 25.4 trillion won), the basic plan establishment and implementation design were implemented as soon as possible. In addition, more than five additional state-owned property land development project sites were selected by revitalizing state-owned property land development projects and infrastructure investment, and more than 100 places were selected, including base projects with convergence of residential and commercial industrial functions, through urban regeneration innovation districts led by public institutions, and general project manager projects.

The 'Green New Deal' of the Korean version of the New Deal project established the direction of the Green New Deal project to ultimately pursue a carbon-neutral society through the green transformation of infrastructure and energy and innovation in the green industry. The Green New Deal attempted to produce short-term results through eight strategic tasks, and the eight strategic tasks are as follows.

Table 4. Green New Deal Strategic Plans

No.	Strategic Plan	Key action plan
1	Zero Energization of Public Facilities Close to People's Life	▪ Renovation of Public Buildings ▪ Installation of solar, eco-friendly insulation in schools
2	Restoration of green ecosystems in land, ocean, and cities	▪ Creating a Smart Green City ▪ Green Areas in Urban Areas ▪ Restoration of Ecosystems in Damaged Urban Space
3	Establishment of a clean and safe water management system	▪ ICT-based smart water supply, supply of sewage facilities, advancement of water purification plants, and improvement of old water supply
4	Energy Management Efficient Intelligent Smart Grid Construction	▪ Smart power grid configuration (AMI dissemination) ▪ Establishment of a distributed eco-friendly power generation system ▪ Electric wire undergrounding
5	Establishment of a foundation for the diffusion of new and renewable energy and support for fair transition	▪ Spread of new and renewable energy such as wind and solar power
6	Expansion of green mobility such as electric vehicles, hydrogen vehicles, etc	▪ Composition of infrastructure such as charging stations to expand the supply of electric and hydrogen vehicles ▪ The conversion of old diesel cars to eco-friendly cars
7	Fostering promising green enterprises and creating low-carbon, green industrial complexes	▪ Supporting green enterprises and green industries ▪ Creating an industrial complex with a smart energy platform for energy-saving ▪ Support for eco-friendly manufacturing process

8	Establishment of a foundation for green innovation such as R&D finance`	▪ Development of Greenhouse Gas Reduction Technology ▪ Composition of a cooperative organization for reducing fine dust ▪ Promotion of resource circulation ▪ Supporting companies to invest in environmental pollution prevention

6. To-Be analysis: Critical Factors of a Carbon-neutral City

By synthesizing the previous domestic and foreign cases, we analyzed the essential elements of a carbon-neutral city and the policies that need to be applied first. Looking at domestic and foreign cases, a carbon-neutral city is created based on policies for energy and space (buildings), and efforts are being made to realize carbon neutrality through policies such as eco-friendly transportation, resource circulation, and green areas (carbon sinks). By synthesizing each case, we intend to define the policy goals that should be reflected in a carbon-neutral city as follows.

6.1 Spatial Elements of Carbon-neutral Cities

6.1.1 Green Infrastructure

The concept and definition of green infrastructure are a combination of green and infrastructure, and discussions on its concept and definition are continuously being promoted (Kim, 2018). Green infrastructure covers a wide range from large-scale mountain areas to small parks in cities, and at the same time contains the function of basic facilities that form

the basis of socioeconomic activities (Park, 2020). Traditionally, green infrastructure in cities was used as a resting place, but as the negative impact of climate change became serious, it was reevaluated as a major means of solving environmental problems such as the habitat of living things in the city, the effect of reducing heat islands due to climate change, and the function of controlling urban flooding through the expansion of the permeable area.

In addition to its role in adsorbing and absorbing fine dust (Seong, 2020), it has also recently performed various environmental functions that are difficult to perform in other urban spaces, such as supporting social distancing due to the increase in visitors to outdoor green infrastructure due to the COVID-19 incident. To effectively expand green infrastructure, it is necessary to discover and expand green infrastructure that can perform various functions. Examples include the establishment of a disaster-responsive green infrastructure that can reduce disasters and disasters caused by climate change and securing a multifunctional green infrastructure through the creation of a linear park that can connect green spaces and green spaces (National Land Research Institute, 2020).

Disaster and disaster mitigation response green infrastructure should be installed in areas where many people can safely evacuate, among areas where floods and heat waves have occurred due to climate change in the past. In the case of these areas, it is usually a large open space that can absorb carbon, function socially, such as the health of the surrounding residents, and can be used as a space for responding to disasters. A linear park connecting green and green spaces is a form of green infrastructure that connects green infrastructure, which is an area within the city and is located closest to citizens, so that accessibility can be increased. The linear green infrastructure can be a passage for living things, and it can be used as a passage that can introduce garage fresh winds generated by the green infrastructure, which is an area, into the city.

6.1.2 Green Building

Buildings account for a very large proportion of greenhouse gas emissions. In non-industrial fields such as cities, buildings themselves can be said to be the largest source of greenhouse gas emissions. Buildings' greenhouse gas emissions account for nearly half (about 49.0%) of their non-industrial emissions. Therefore, it is necessary to focus on the building sector first to reduce greenhouse gas emissions in cities.

Buildings can be divided into existing structures that have already been built and new ones that will be built in the future. Aged buildings need remodeling projects to improve energy performance. In general, it is necessary to lower carbon emissions and improve the indoor environment by increasing energy efficiency performance through remodeling projects centering on old buildings that are old and have low energy efficiency since they have been built for more than 30 years after completion and approval for use.

According to the roadmap for mandatory zero-energy construction, Korea usually applies regulations to ensure that public and private buildings of a certain size or larger are certified to be rated 5 or higher (energy efficiency grade of 1++ or higher, energy independence rate of 20% or higher) to achieve better energy performance than existing buildings. However, the problem is that these projects are centered on public buildings. As private buildings account for more than 97% of all buildings, it is necessary to drastically reduce carbon dioxide in the building sector and significantly expand existing projects to the private building sector to improve the indoor environment.

6.2 Energy

6.2.1 Energy Independent City, Build Efficient Energy Supply and Consumption Systems

To supply energy for the realization of carbon neutrality, it is necessary to establish a distributed supply chain and an integrated control system first. Renewable energy is characterized by severe seasonal and temporal variations, so it is necessary to monitor the real-time output and electricity quality of the generator to expand and efficiently utilize new renewable energy. In addition, renewable urban energy sources such as solar, wind, biogas, hydrothermal, waste, and fuel cells should be utilized in a variety of ways. It is also a good idea to expand the supply of fuel cells as a complementary means to solve the intermittent problem of renewable energy in the city. (Lee., 2021)

In addition, renewable natural energy sources should be fully utilized. First of all, it is necessary to explore space and review economic feasibility so that solar power can be installed in private buildings as well as public sites such as water and sewage systems and urban railway facilities. At this time, policies to support voluntary participation such as cooperatives are also needed so that citizens can discover and commercialize the site. It is necessary to install small-scale generators and create complexes at the urban level related to wind power. As for wind power in the city, power plants can be installed mainly by using river banks and green areas in parks. Since most cities have rivers or are adjacent to rivers, it is possible to supply cooling and heating energy by utilizing unused hydrothermal energy.

Energy utilization and recovery of waste is also an essential way to realize carbon neutrality in the city. In landfills and sewage treatment plants, biogas generated during the anaerobic digestion process can be collected and used as an energy source. In particular, organic waste resources such as food waste and manure generated in cities can be produced through digestion alone or sewage merger. Biogas has the advantage that it can be used as city gas or fuel for vehicles in the form of gas, and can be used in various forms because it can generate electricity and utilize waste heat. In addition, it is possible to consider the use

of Bio-SRF (Solid Refuse Fuel) made from unused biomass (waste, coffee grounds, etc.). (Lee., 2021.)

6.2.2 Building an Intelligent Power Network

To realize carbon neutrality in the city, it is necessary to implement a city that uses existing energy efficiently by actively utilizing ICT technology. For example, it is necessary to measure energy consumption and provide real-time electricity usage and rate information to users by using a bidirectional communication network, and induce voluntary electricity saving and peak reduction. Specifically, since information comparable to the energy consumption of neighboring houses of a similar scale is provided, it is possible to induce energy-saving behavior in consumers.

Another option is the establishment of microgrids that are being promoted both domestically and abroad. The microgrid is a system that is self-sufficient in electricity in small areas and is a next-generation electricity system that combines renewable energy such as solar and wind power with an energy storage system (ESS). (Korea Economy, 2020) The establishment of such a small-scale independent distribution network will reduce greenhouse gas emissions from existing coal-fired and gas-combined-fired power plants. The microgrid is a system introduced to increase the trust of consumers as well as improve the quality of electricity and is defined as a small-scale distribution network that can operate alone.

Along with the supply of new renewable energy and the establishment of microgrids, the supply of energy storage systems (ESSs) should be expanded. The remaining power energy consumed in the home and industrial sectors should be stored through ESS and utilized appropriately when necessary. This not only solves the intermittent problem of renewable energy but also contributes to the stable operation of the smart grid. As a result,

the energy stored in this way contributes to the activation of the energy market by providing a transaction system between consumers who need it.

6.3 Transportation

Carbon-neutral cities should realize a sustainable smart transportation environment with no greenhouse gas reduction effects and congestion factors by converting eco-friendly means through the development of eco-friendly/carbon-free e-transportation technology. A lot of efforts are being made for eco-friendly transportation worldwide, and the EU plans to ban the sale of internal combustion engine vehicles from 2035.

To effectively introduce eco-friendly means of transportation, eco-friendly public transportation should be the city's main means of transportation, and public support for this should be used to speed up the transition. As an eco-friendly public transportation, the autonomous shuttle based on electric vehicles is expected to reduce greenhouse gases and improve the efficiency of transportation operations through the use of autonomous driving infrastructure. Currently, demonstration projects are being carried out in various regions to transfer commercialization such as infrastructure, technology, systems, and safety of autonomous shuttles. Following the Special Act on Fine Dust Reduction and Management, the existing diesel-based route buses are converted to electric and hydrogen energy-based eco-friendly buses, and Korea has plans to expand eco-friendly buses by 2030 through standard battery-exchange electric bus systems, commercialization of emergency charging systems, and establishment of safety certification systems.

The e-mobility market is growing rapidly and it is necessary to develop and expand e-transport infrastructure based on mobility-energy linkage to cope with the growth of the e-mobility market. It is necessary to establish a center that integrates, shares, and manages

integrated operations based on an integrated platform so that various e-mobility service solutions can be introduced and developed and functional sectors for each service can be integrated. It is necessary to develop an integrated mobility transportation operation system to build an integrated platform-based data integration, linkage, and sharing framework and discover sustainable and diverse mobility services.

6.4 Governance

It can be seen that the secret to the success of a carbon-neutral city with challenging goals abroad is the voluntary efforts of citizens participating in eco-friendly city policies. It is necessary to move toward a hyper-connected society-based city where cutting-edge technologies are combined, especially to achieve sustainable urban development, to solve various urban problems "smartly" or "smartly". (Lee., 2021), the realization of a carbon-neutral city is limited by the simple introduction of ICT and participation and cooperation between citizens and the private sector are very important.

It is striving to develop and build services that reflect the needs of citizens, who are end-users of smart city services worldwide, and to reflect the needs of citizens, it is basic to operate programs so that stakeholders who feel and understand local problems can participate in the project as a major axis of the community. Previously, public-led or technological innovation was the focus, but now the paradigm is changing in the direction of social innovation and citizen-led solving problems.

For the sustainable development of a carbon-neutral city, a "governance" model that applies a free and active bottom-up citizen participation system is required by forming a horizontal cooperative relationship between the public and the private sector. Various channels can be created so that various actors can participate in each field, such as

environment, energy, and transportation, and the sustainability and feasibility of the service can be increased by collecting on-site stakeholder opinions.

6.5 KPIs (Key Performance Indicators)

The realization of a carbon-neutral city should continue with the various policies and projects introduced above over the long term. It is also necessary to frequently check whether policies and projects in effect are being implemented effectively, and if insufficient, continuous supplementation and correction are needed. Performance indicators that can confirm this are needed, and performance indicators should be quantified and anyone can check them. Existing projects implemented to realize carbon neutrality had limitations in measuring the effectiveness of the project. It is difficult to collect data arising from evaluation indicators that have not been characterized by country and local governments, and statistical data collection is absent or limited due to ambiguous evaluation indicators that have not been quantified.

Evaluative indicators are also needed to confirm whether the essential elements for realizing a carbon-neutral city are working correctly, but it is necessary to collect, review, and research more specialized data to set KPIs by quantifying the part that each element contributes to carbon reduction. As a project that has similar characteristics to the creation of a carbon-neutral city, we would like to introduce the KPI setting case of the Busan Eco-Delta City Smart City project and learn about the KPI applicable to carbon-neutral cities.

Busan Eco-Delta City developed a city with residential, commercial, R&D, and logistics functions from 2012 to 2023 for 76,000 people (30,000 households) on 11.8km² in Gangseo-gu, Busan, aiming to be a city that contains the paradigm of the fourth industrial revolution in nature created by the waterfront space. Among Busan Eco-Delta City, Smart

City, designated as a national pilot city, is a city that applies various advanced smart technologies by integrating major city functions such as housing, commerce, R&D, work, culture, leisure, and healthcare for 2.8km² and 8,500 people (3,380 households). Busan Eco Delta Smart City proposed "Fostering 4th Industrial Revolution Technology and Improving Quality of Life" as its core value with the vision of a "Global Innovation Growth City" where people, nature, and technology meet and speed up future life. In particular, the Busan Eco Delta Smart City has set appropriate goals and prepared Key Performance Indicators (KPIs) to achieve them to successfully create a city and secure sustainability. In particular, it aimed to set and continuously manage city concept goals related to 'people', 'nature', and 'technology' presented in the proposed vision. The core and performance management indicators of the KPIs of Busan Eco-Delta City are as follows.

The characteristic of KPI in Busan's Eco Delta City smart city is not to focus on technical factors in setting detailed indicators, but to quantify and present areas where the city's life changes due to the project. This KPI is consistent with the goals pursued for carbon-neutral cities, so it is thought that it will be very helpful in establishing KPIs for carbon-neutral cities in the future.

Table 5. Busan Eco-Delta City KPIs Key Indicators and Performance Management Indicators (K-water, 2017)

	Key Indicators	Goals	Detailed indicators
1	Stay healthy for 5 more years	Smart health care and prevention and quick response to natural disasters Set up 8 performance management indicators	01. Grade 2 or higher water quality of river
			02. Prediction of flood occurrence more than 6 hours earlier
			03. Reduce earthquake early warning to less than 20 seconds
			04. Reduce traffic accidents by 46 percent

			05. 100% completed initial fire response within 5 minutes
			06. Reduce the incidence of five major crimes by more than 25 percent
			07. Average life expectancy increased by 4.5 years
			08. Health life expectancy increased by 3 years
2	Work & Life Balance 50:50	Improve quality of life through smart time management of housework and work Set up 5 performance management indicators	09. Park area per person up to 76.16㎡
			10. Festivals 40 meters wide and 500 meters long create 20,000㎡ wide
			11. Learning using 100% ICT technology
			12. 15% reduction in housework hours
			13. The average working hours per week is 40 hours
3	Renewable energy Plus, 20 percent	Reduce energy consumption in transportation and construction and produce renewable energy Set 3 performance management indicators	14. 50 percent reduction in carbon dioxide emissions
			15. Renewable energy share ratio 120%
			16. Construction of 56 Zero-Energy Houses
4	Recycle 100%	100% water recycling, waste-based energy supply, Recycle resources Set up 5 performance management indicators	17. 100% sewage reuse rate
			18. 20% reduction in water usage and leakage per person
			19. Less than 15% impermeable area ratio
			20. Sewage heat energy sharing ratio 16.5 percent
			21. Combustible Waste Solid Fuel (SRF) Energy Share 35%
5	125 hours a year Time-saving	Return time wasted in existing cities to citizens Set 6 performance management indicators	22. 5 hours of waiting times per year for hospital care
			23. 21 hours a year wasted on administrative processing

			24. 35 hours less time spent on crime prevention and safety per year
			25. More than 20% of bicycle movement share
			26. 4 hours less per year to find parking space
			27. 60 hours less wasted on the road per year
6	28,000 new jobs	Respond to future jobs and ensure economic sustainability Set 1 performance management indicator	28. 28,000 new jobs

Figure 3. The KPIs of Busan Eco-Delta City (K-water, 2017)

7. Conclusion

7.1 Summary

Carbon neutrality is a goal that must be realized for future generations to lead normal life in the era of climate change. In particular, cities are getting bigger and bigger, accounting for most of their carbon emissions, so they must be at the center of change for carbon neutrality. The purpose of this study was to identify the essential elements that a city must have to achieve the goal of a 'carbon neutral city' and the core policies of those elements and to suggest the direction in which the city should move forward. First of all, we investigated advanced overseas cases and analyzed the policies that are being promoted to achieve the goal of carbon neutrality. In particular, we focused on the cases of Europe, which is most actively implementing carbon neutrality policies. And we investigated the major policies introduced by Korea for carbon neutrality and analyzed which areas of the cities we should create in the future should focus on for carbon neutrality.

Carbon-neutral cities should minimize fossil energy dependence and energy consumption. Carbon emissions inevitably generated by economic and social activities should make the most of renewable energy sources and maximize energy efficiency. A simple summary is to make zero carbon emissions from city activities. Many foreign countries, including Korea, are trying to introduce and implement various policies to realize carbon neutrality. Among the various policies, the areas to be more focused were classified into four areas, and it was determined that the following policies should be implemented first.

7.2 Policy Recommendations

The policies introduced by each country to realize a carbon-neutral city can be classified into urban space, energy, transportation, and governance. Although there are policies that do not fall into this category, what can be seen as essential elements in terms of the composition of the city can be abbreviated to the above four elements.

First of all, various green infrastructures should be introduced in carbon-neutral cities. Green infrastructure is a facility that responds to climate change and absorbs carbon sources. In addition, carbon neutralization of buildings that account for the largest proportion of greenhouse gas emissions is required. Existing buildings need to be remodeled to increase energy efficiency, and new buildings should be zero-energy buildings. New buildings should be able to build zero-energy buildings first through the law, and policy support is needed so that existing buildings can be remodeled as zero-energy buildings.

In realizing a carbon-neutral city, the use of energy is the most important. The use of new and renewable energy must be increased, and an efficient energy supply and consumption system must be established. It is also necessary to increase the proportion of solar power generation facilities installed on public sites and private buildings or to install wind power plants using various spaces. Energy conversion of waste generated in cities is also essential. In addition, it is necessary to establish an intelligent power grid using advanced ICT technology to efficiently use energy and to supply energy storage devices to overcome the intermittentness of new and renewable energy.

Carbon-neutral cities should realize a sustainable smart transportation environment without greenhouse gas reduction effects and congestion factors through the conversion of eco-friendly means through the development of eco-friendly/carbon-free e-transportation technology. Carbon emission reduction should be minimized by expanding eco-friendly public transportation, settling the e-mobility market, and integrating data-based transportation systems. The recent active transition to electric vehicles has seen the growth

of growth shrink significantly due to the lack of electric vehicle charging stations and some technical limitations. Additional support for the expansion of government subsidies and technology development is needed so that the transition to eco-friendly vehicles can be accelerated.

For the successful settlement of these structural measures, it is also important to establish an evaluation system that can monitor the participation and performance of citizens. Since realizing carbon neutrality is a goal that cannot be achieved only with short-term investment, continuous feedback should be used to raise the life of the city to the next level. To attract the participation of citizens, it is necessary to be more active in promoting policies and to establish a platform that can collect opinions from various citizens using IT technology

7.3 Limitation and Future Research

Through this study, we tried to prepare detailed KPIs that can periodically evaluate the performance of essential components of carbon-neutral cities, but we could not prepare detailed KPIs ourselves because the technical scope of each element is diverse and the KPIs are set differently depending on the characteristics of the city directly applied. Accordingly, we introduced the case of KPI in Eco-Delta City, Busan, which is successfully promoted in Korea, and it is necessary to supplement these areas through future research. The following research on how to build KPIs for each element will be of great help in realizing and managing carbon-neutral cities.

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