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Project Report

Strategy of Developing Innovative Technology for Sustainable Cities: The Case of the National Strategic Project on Carbon Mineralization in the Republic of Korea

Jongyeol Lee [1], Changsun Jang [1], Kyung Nam Shin [1] and Ji Whan Ahn [2,*]

[1] Division of Climate Technology Cooperation, Green Technology Center (GTC), Seoul 04554, Korea
[2] Center for Carbon Mineralization, Mineral Resources Division, Korea Institute of Geoscience and Mineral Resource (KIGAM), Daejeon 34132, Korea
* Correspondence: ahnjw@kigam.re.kr

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Abstract: Technology cooperation, including technology transfer, development of projects, and establishment of international networks, is an important instrument for attaining greenhouse gas mitigation and the sustainable development of a global society. In this context, carbon mineralization technology has received attention because of its high potential for carbon sequestration, environmental conservation, and economic market value. This project report introduces a national top-down approach for developing and implementing international technology cooperation in the Republic of Korea, focusing on carbon mineralization. The Ministry of Science and Information and Communication Technology (MSIT) leads international technology cooperation, identifies prominent climate technologies, and addresses scientific agendas to presidential meetings. The inter-ministerial bodies established the climate technology roadmap and masterplan for a climate change response. With the support of these inter-ministerial efforts, a National Strategic Project on carbon mineralization was developed by a presidential-level decision as a top-down approach. Furthermore, the demonstration of this technology was emphasized to enhance the possibility of success in commercialization. This project also includes demonstration of a pilot, sequestering 6000 tons of CO_2 and manufacturing 30,000 tons of carbonate. This successive and holistic approach, comprising of a range of hierarchical levels of government, is recommended for deriving a high impact on global society of prominent climate technology.

Keywords: National Strategic Project; carbon mineralization; carbon utilization; National Designated Entity (NDE); climate cooperation

1. Introduction

As the greenhouse gas (GHG) mitigation targets of each country were set after the Paris Agreement, technology transfer was considered a crucial measure for the implementation of international GHG mitigation in the context of a New Climate Regime [1]. The technology mechanism established by the United Nations Framework Convention on Climate Change (UNFCCC) in 2010 became a fundamental instrument of international climate technology cooperation. In addition to this systemic basis of technology cooperation, the identification and development of prominent climate technologies are crucial tasks for the mitigation of global climate change and environmental problems.

The solution of environmental problems is also a timely issue in the context of Sustainable Development Goals (SDGs). Particularly, waste management and recycling are common concerns of all countries because the generation of urban waste has been rapidly increasing [2]. Furthermore, an increasing demand for electricity is pushing developing countries to utilize more coal-fired power plants, generating a substantial amount of coal ash waste and related environmental problems [3–5]. Recently, the implementation of circular economy—the concept of facilitating the circulation of material and energy by improving the level of recycling—has been attempted ambitiously to establish this conceptual model in the real world [6].

The Republic of Korea has also devoted itself to sustainability and climate change mitigation. The roadmap of GHG mitigation was developed in 2016 to attain a 37% reduction in GHG emissions compared to business-as-usual (BAU) levels in the context of the Paris Agreement. In this roadmap, GHG mitigation was imposed in each sector, including electricity, industry, waste, and transport. However, the energy efficiency of the industry sector in the Republic of Korea is already at the highest level. Carbon capture and storage (CCS) technology, which captures the outlet of CO_2 and stores it in stable geological and marine structures, has the potential for GHG mitigation. However, the applicability of this technology is not sufficient in the Republic of Korea because of the geological limitations and high cost [7,8].

Meanwhile, several environmental problems threatening sustainability are still serious despite strict environmental regulations. Abandoned mines, which were operating during the Republic of Korea's period of rapid economic growth, cause several problems in local communities, such as the heavy metal contamination of soil and water ecosystems, and the risk of geological subsidence [9–11]. Accordingly, innovative technology that can shift the process and structure of society is essential to the Republic of Korea.

Carbon mineralization has received attention in the backdrop of climate change mitigation and sustainability. Carbon mineralization technology converts CO_2 gas into valuable inorganic compounds [12–14]. Carbon utilization, including carbon conversion and carbon mineralization, is expected to generate a market size of 800 billion dollars yr^{-1}, and sequester 7 billion metric tons of CO_2 yr^{-1}, at maximum, by 2030, in the case of strategic actions at the global scale [15]. In particular, utilizing CO_2 for manufacturing building materials (aggregates of carbonate and concrete) showed the largest potentials of market size and CO_2 sequestration: 550 billion dollar yr^{-1} and 5 billion tons of CO_2 yr^{-1}, respectively [15]. In addition to these direct benefits, the externality of environmental problems from coal ash and industrial waste can be solved by carbon mineralization technology. Therefore, carbon mineralization might be a realistic solution for CO_2 sequestration and environmental problems, while also encouraging the participation of the private sector.

Recently, the government of the Republic of Korea has devoted itself to the development of climate technology and international cooperation, including carbon mineralization technology. Developing countries have encountered complexities in economic growth and environmental regulation. Sharing the similar experience of rapid economic growth and environmental conservation in the Republic of Korea—which were possible on the basis of science and technology with education—could contribute to solutions for developing countries. Thus, establishing an international network, implementing systems of technology cooperation, and determining a strategy for technology development were led by the government of the Republic of Korea with contributions from ministerial to presidential levels. Finally, nine National Strategic Projects, organizing a consortium of the national research institutes and private corporations, were developed to enhance the already high potential of prominent technologies. Carbon mineralization was also selected as prominent technology, and the project of carbon mineralization includes technology development, progressive demonstration, environmental monitoring and standardization, and methodology development of the Clean Development Mechanism (CDM).

A detailed analysis of carbon mineralization in the Republic of Korea can provide a national roadmap of climate and environmental technology policy for other countries. Accordingly, this article describes the strategy and process of climate technology development and international cooperation, led at the national level. The component and consortium of the National Strategic Project on carbon mineralization of the Republic of Korea is also introduced. Then, a new model of climate technology development and cooperation is suggested to contribute to global GHG mitigation and environmental solutions.

2. The National Strategic Project on Carbon Mineralization

The National Strategic Project on carbon mineralization was developed to obtain a packaged technology including 1) the recycling of industrial wastes and CO_2 gas from factories and power plants; 2) the manufacturing of green cement and carbonate for abandoned mine reclamation; and 3) the development of a CO_2 sequestration project methodology. In particular, carbon mineralization technology was applied to the production of carbonate. The duration of the project (2017–2022) consists of a 1st phase (demonstration of mini-pilot), 2nd phase (demonstration of pilot), and 3rd phase (operation of demonstration plant and achievement of outcome), with a total governmental grant of 13 million dollars. This research project group consists of six teams: demonstrating low-concentration CO_2 treatment; demonstrating carbonate production; demonstrating production of green cement and construction of waterproof layer; demonstrating aggregate production and construction for abandoned mine reclamation; standardizing CO_2 and environmental monitoring system; and researching the methodology of the carbon mineralization CO_2 sequestration project (e.g., CDM) (Table 1).

Table 1. The consortium of the National Strategic Project on carbon mineralization.

Research Team	Task
Pre-treatments of low-concentration CO_2 gas and raw material	- Establishment of a database for utilizing low-concentration CO_2 from the exhaust gas of power plants and factories - Developing a packaged technology of collecting resources
Production of carbonate	- Enhancement of CO_2 fixation to inorganic waste (e.g., coal and industrial residue) - Development of continuous and rapid process technology
Demonstration of green cement production and waterproof layer construction	- Enhancement of waterproof cement - Development of optimal technology of mixing carbonate and cement for waterproof layer
Production and demonstration on abandoned mine reclamation	- Development of scale-up package technology with considerations of mine tunnels and geological stability - Design of optimal material for mine reclamation
CO_2/environmental monitoring and standardization	- Development of integrative CO_2/environmental monitoring technology on materials of mine reclamation - Development of a standardization technology for the domestic and international standardization of products for mine reclamation
Development of Clean Development Mechanism (CDM) methodology for the carbon mineralization project	- Development of new CDM methodology in accordance with mechanisms under the United Nations Framework Convention on Climate Change (UNFCCC)

Low-concentration CO_2 is captured from outlet of power plants and factories. After the pre-treatment of filtering impurities, this captured CO_2 is utilized in the manufacturing process of carbonate by a chemical reaction between CO_2 and metal oxide (e.g., calcium oxide and magnesium oxide). This carbon capture and utilization (CCU) fixes CO_2 emission to the atmosphere. Then, aggregate for abandoned mine reclamation is produced with the carbonate. Accompanying this is construction of a waterproof layer that prevents the outlet of leachate from the surface of abandoned mines after reclamation. From this, a construction standard for abandoned mine reclamation with these products and environmental monitoring systems would be established. Finally, the effect of CO_2 sequestration by the successive packaged technologies is quantified by the CDM project.

The demonstration of the carbon mineralization technology in the reclamation of abandoned mines is planned in Gangwon and Chungcheong provincial regions, where most power plants and cement and mining corporations exist (Figure 1). There are more than 2500 abandoned mines in the Republic of Korea, and approximately 480 of these abandoned mines are located in Gangwon Province. In the process of the demonstration, power plants and cement factories are major components, providing raw materials and manufacturing building materials for mine reclamation. Furthermore, the support of public and private sectors will be provided in the demonstration process. The central government supports the organization and operation of the project. The municipal authorities support the administrative processes by permitting the demonstration. The participating companies cooperate by providing low-concentration CO_2 and the testbed of abandoned mines for the demonstration. This project is expected to be a pilot demonstration, annually manufacturing 30,000 tons of carbonate with sequestering 6000 tons of CO_2 (fixation rate of 20%) by the demonstration of abandoned mine reclamation.

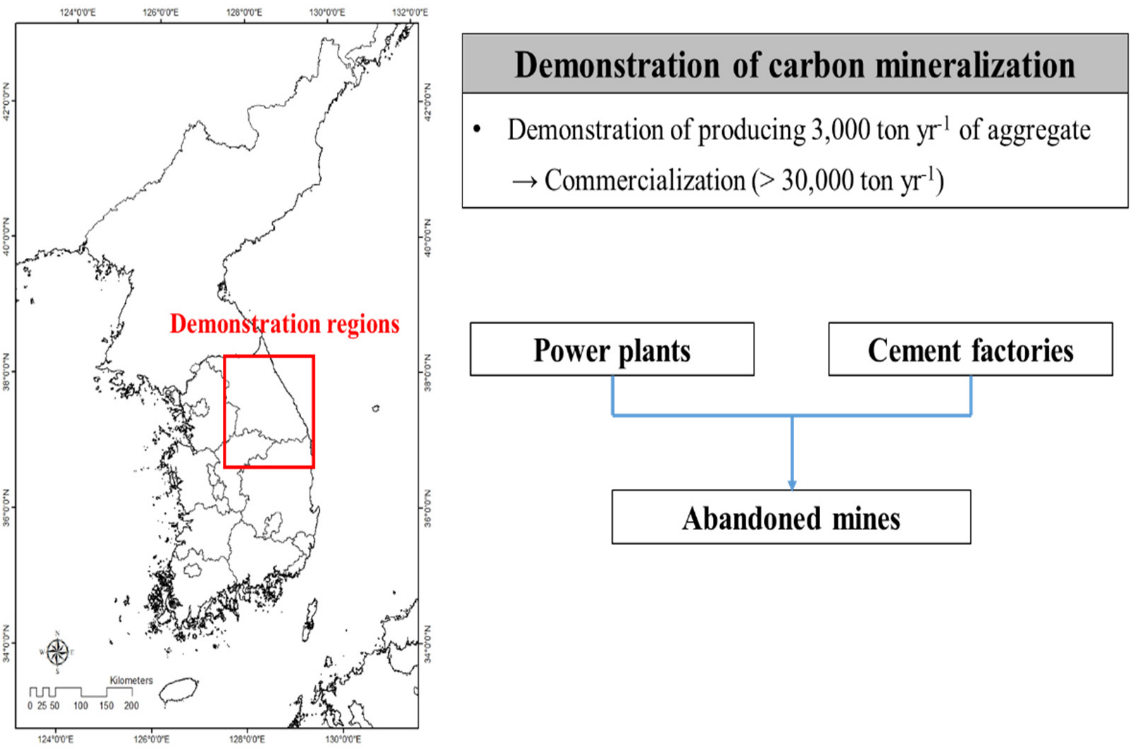

Figure 1. Demonstration plan of the National Strategic Project on carbon mineralization in Gangwon and Chungcheong provincial regions in the Republic of Korea.

3. Process of Developing the National Strategic Project on Carbon Mineralization

The National Strategic Project on carbon mineralization technology was developed by successive processes at the national scale, comprising of a range of hierarchical levels (Figure 2). The inter-ministerial approach, led by the Ministry of Science and Information and Communication Technology (MSIT), established a framework for developing climate technology and international technology cooperation. The national top-down approach was led by the presidential councils with inter-ministerial support. Each process, identified by three phases (initial, intermediate, and final) is described in detail in the following subsections.

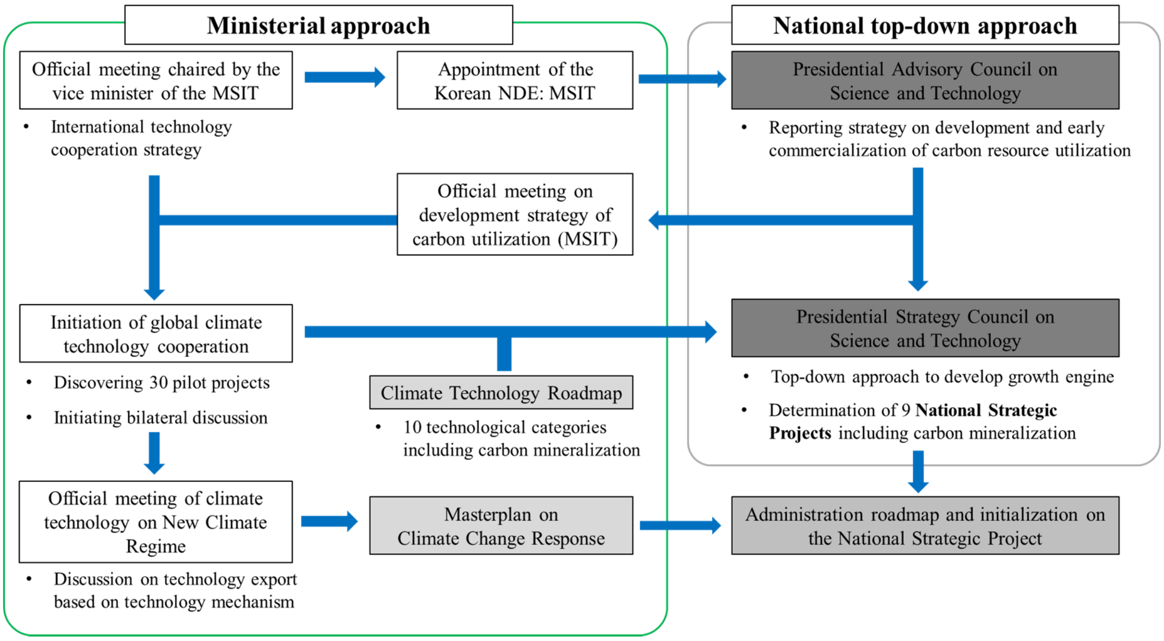

Figure 2. Schematic diagram of the governmental processes to develop the National Strategic Projects. The white, light-gray, and dark gray boxes represent the activities of the Ministry of Science and Information and Communication Technology (MSIT), inter-ministerial bodies, and presidential bodies, respectively.

3.1. The Initial Phase

The official meeting on the mitigation of national GHG emission and developing new industries, held by the vice minister of the MSIT in September 2015, initiated the international technology cooperation strategy of the Republic of Korea. This meeting included discussions about attaining the national GHG mitigation goal and developing new environmental industries with the consideration of three strategies: 1) acting as a main player in the international technology cooperation mechanism; 2) expanding international technology cooperation projects; and 3) establishing inter-ministerial cooperation to promote the technology cooperation. Particularly, measures for facilitating the export of Korean climate technologies to developing countries by global technology cooperation were also conferred.

The technology and financial mechanisms were established under the UNFCCC in order to mitigate GHG emission and enhance the capacity of adaptation to climate change (Figure 3). The technology mechanism is responsible for primary cooperation in the transfer of technology among countries. The financial mechanism amplifies the effect of the transferred technology through financing. The MSIT was appointed as the National Designated Entity (NDE) of the Republic of Korea in December 2015, which is responsible for a national channel for the technology cooperation. The Ministry of Economy and Finance was appointed as the National Designated Authority (NDA) as a part of the global financial mechanism.

Unlike most other countries, the Republic of Korea appointed the MSIT as NDE, rather than the Ministry of Environment. This implies a strong will towards leading international cooperation by facilitating innovative technologies under the technology mechanism. This Korean NDE contributes to the export of Korean technologies and creating new industries in the context of the New Climate Regime. Consequently, a Climate Technology Cooperation Team was established under the MSIT in March 2016 in response to the appointment of the NDE. This team arranges domestic, UNFCCC, and global cooperation (Figure 4).

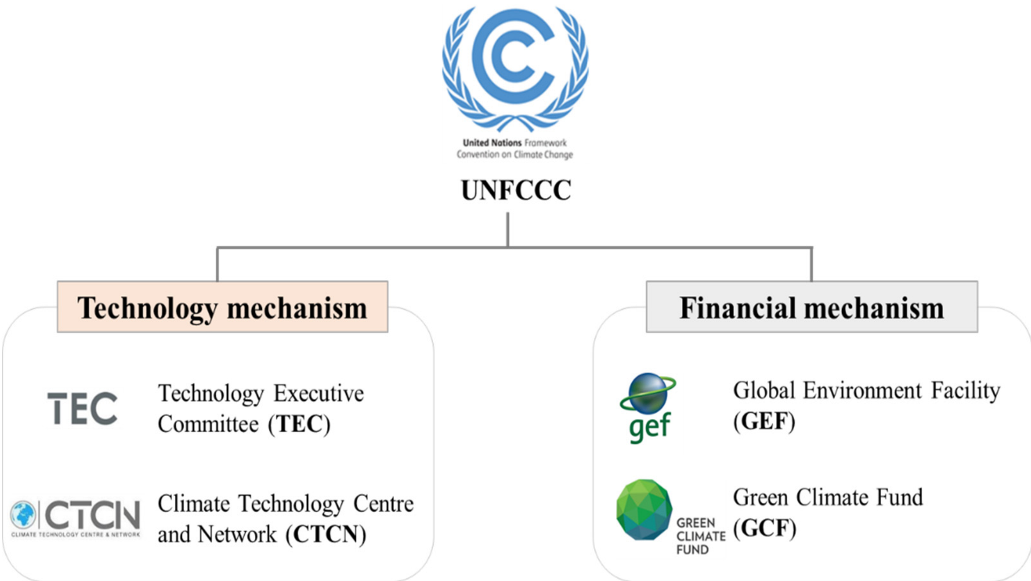

Figure 3. The technology and financial mechanisms under the UNFCCC.

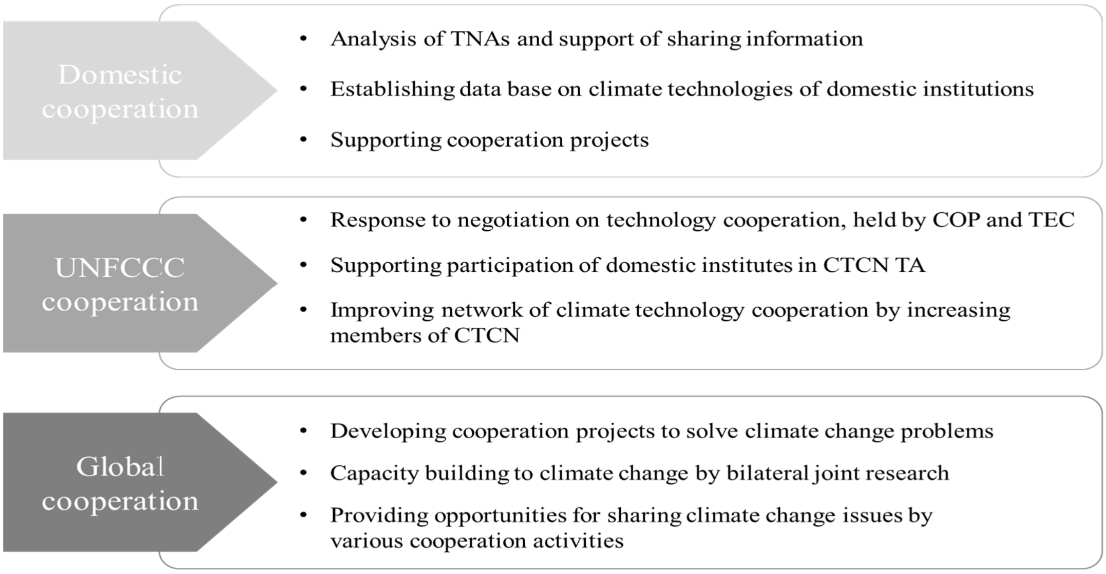

Figure 4. Functions of the cooperation team of the National Designated Entity (NDE). Abbreviations: Technology Needs Assessment (TNA), Conference of Parties (COP), Technology Executive Committee (TEC), Climate Technology Center and Network (CTCN), and Technical Assistance (TA).

The National Strategic Project team plans to implement international technology cooperation on carbon mineralization on the basis of the technology mechanism. After a feasibility study on application of carbon mineralization technology, demonstration will be operated for scale-up of the transferred technology. A bilateral network of cooperation among governments, led by the NDEs, facilitates successive measures (e.g., large-scale project and commercialization).

The MSIT also addressed the scientific agenda on climate technology after identifying prominent climate technology in the Republic of Korea. With this support from the MSIT, the importance of carbon mineralization technology and science diplomacy started to be emphasized from the 33rd meeting of the Presidential Advisory Council on Science and Technology (PACST), held in April 2016. The strategy for the development and early commercialization of carbon resource utilization technology was reported to mitigate GHGs and produce valuable chemical products.

Meanwhile, the MSIT has prepared inter-ministerial measures to strengthen science diplomacy with support from other ministries in that meeting of the PACST. These measures aim to lead international cooperative research, enhance the basis of customized and packaged partnerships, and expand the global science network. Integrating Korean official development assistance (ODA) and the Climate Technology Centre and Network (CTCN) of the UNFCCC into this science diplomacy was also proposed. After the meeting, a follow-up meeting was held in May 2016 to discuss governmental support for the development, demonstration, and commercialization of carbon utilization. The role of national research institutes in early commercialization was also emphasized.

3.2. The Intermediate Phase

Global technology cooperation was launched by the MSIT by identifying 30 pilot projects and initiating a bilateral discussion among countries. The MSIT analyzed the Technology Needs Assessments (TNAs) of potential counterpart countries and then provided the analysis results to 25 national research institutes and 5 science-specializing universities. Then, potentially cooperative items were investigated and selected on the basis of the current technologies of these organizations. Twenty organizations submitted 110 possible and available items, and then 15 prominent cooperative business models were determined. Particularly, two carbon mineralization technologies (i.e., inorganic waste recycling and abandoned mine reclamation with green cement) were proposed for Vietnam. This proposal was considered in the official meeting of the MSIT on the development strategy for carbon utilization technology (May 2016) after the 33rd meeting of the PACST. Then, the MSIT would support the establishment of domestic and international partnerships, with financing from international organizations (e.g., the Green Climate Fund (GCF) and multilateral development banks (MDBs)) in order to develop a successful model for GHG mitigation.

The Climate Technology Roadmap (CTR), initiated by the inter-ministerial body in March 2016, was completed in June 2016 to support the development of climate technology and implement the Paris Agreement from the perspective of national research and development. Ten major climate technologies in three categories were selected as follows: carbon mitigation (solar cells, fuel cells, biofuel, secondary cells, electricity information technology, and CCS), carbon utilization (byproduct gas conversion, CO_2 conversion, and CO_2 mineralization), and climate change adaptation (common platform). The analysis of the environments (market, technology, policy, and demand) of CO_2 utilization technology was provided in the CTR. In this context, the development of a technological package for the utilization of low-concentration CO_2 emissions and residual waste from power plants and factories, and a complementing demonstration project for CO_2 sequestration were also indicated.

Based on the results of the previous CTR, PACST, and discussions on global climate technology cooperation, nine National Strategic Projects were finally determined in the second meeting of the Presidential Strategy Council on Science and Technology (PSCST) in August 2016 (Figure 5). This determination characterized the top-down approach to developing a new growth engine and to improve life quality based on science and technology. The carbon mineralization technology was included in the carbon utilization category.

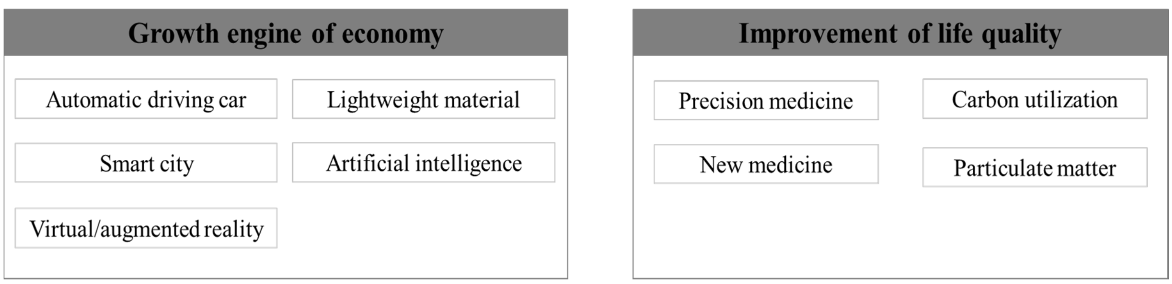

Figure 5. The list of the National Strategic Projects in the Republic of Korea.

3.3. The Final Phase

In the final phase, the official meeting of climate technology in the New Climate Regime was held in November 2016 to discuss the growth of climate industries and facilitation of the technology mechanism of the UNFCCC for the export of technology. In particular, facilitating the technology mechanism by technical assistance of the CTCN received attention. These contexts were reflected in the Masterplan on Climate Change Response in December 2016 and concerned GHG mitigation from international cooperation. This masterplan established a basis for climate technology cooperation, particularly supporting the utilization of a climate change decision-making process by the comprehensive analysis of climate technologies and related activities. Finally, with the consideration of these discussions and this masterplan, the demonstration roadmap of the National Strategic Project was completed in December 2016. The demonstration was planned to be conducted by the following steps (Figure 5): simulation of processes (until 2016); mini-pilot demonstration (2017–2018); pilot demonstration (2018–2022); and large-scale demonstration with commercialization (from 2023) (Figure 6). Carbon mineralization is expected to sequester 10 Mt CO_2 yr^{-1} and generate an economic benefit of 15 billion dollars yr^{-1} by 2030 according to this roadmap. As already introduced in Section 2, the project consortium was organized and initiated during May–August 2017.

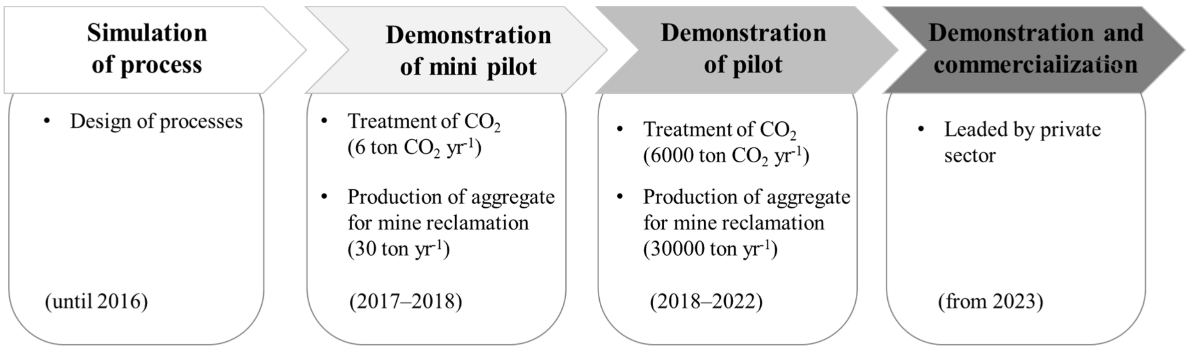

Figure 6. Process of demonstration for the National Strategic Project on carbon mineralization.

4. Discussion

The National Strategic Project on carbon mineralization was developed to facilitate the effects of carbon mineralization technology on the environment and society. Several future social and environmental benefits are expected from this research project. CO_2 sequestration is possible due to the utilization of captured CO_2 gas from plants and the substitution of original GHG-emission-intensive materials for abandoned mine reclamation [12,16]. The manufactured aggregate and cement could contribute to the establishment of a new climate industry in the context of the New Climate Regime after the Paris Agreement. Meanwhile, as the aggregate is manufactured by recycling coal ash and industrial residue from power plants and factories, environmental problems from these wastes can be solved [12]. These wastes contain metal oxide, which can chemically react with CO_2 by carbon mineralization technology [17,18]. With the consideration of environmental problems from coal ash and industrial wastes, the framework of this technology is highly beneficial. Recycling wastes and energy savings can support the establishment of circular economy [6]. Furthermore, the adverse effects of abandoned mines would be prevented after reclamation by the package technology of carbon mineralization in this research project.

However, the benefits of the carbon mineralization technology would not be improved without the successive implementation of top-down national processes. This implies that the magnitude of the effect of prominent climate technology could depend on the level of governmental support. The governmental support comprises the bottom-up approach from the identification of prominent technology by the MSIT and the top-down approach of the presidential organizations (Figure 7). First, the MSIT identified prominent climate technology (e.g., carbon mineralization). In addition, the

MSIT identified the technology needs of counterpart countries and established networks with them. The top-down approach of the presidential bodies was possible because of the support of the MSIT and inter-ministerial bodies, including addressing the scientific agenda and implementing a national system of climate technology. Finally, the cooperation and export of technology could be facilitated by the supports mentioned above.

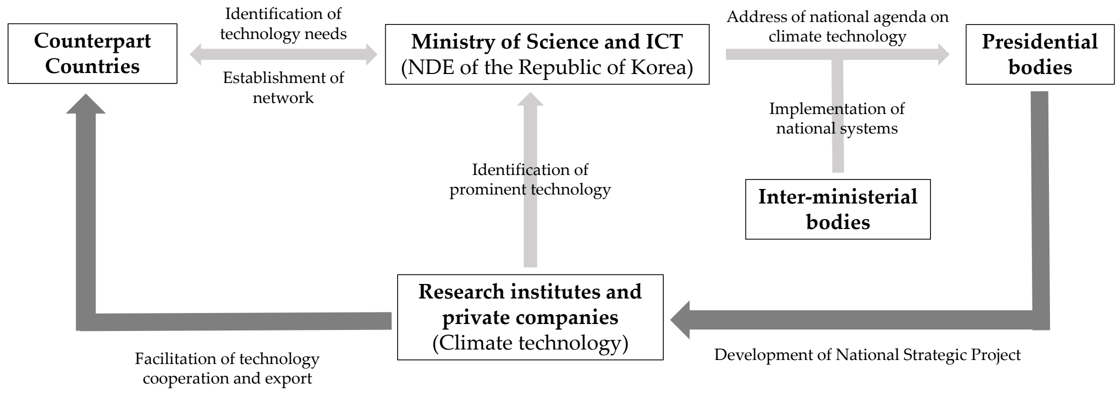

Figure 7. A framework of the Republic of Korea's governmental strategy for international climate technology cooperation. The light-gray and dark-gray arrows represent processes of inter-governmental support, and the facilitation of technology by the national top-down approach, respectively.

The MSIT of the Republic of Korea demonstrated a new model of NDE in climate technology development and cooperation. The designation of the MSIT as NDE, compared to most other countries which designated ministries related to the environment, implies a strong will of the Republic of Korea to lead international climate technology cooperation on the basis of the technological mechanism of the UNFCCC. In addition to the role of a path toward international technology transfer as NDE, the MSIT identified prominent climate technologies. Carbon mineralization technology was selected as one of the prominent climate technologies because of its CO_2 utilization efficacy, consistency with environmental problems, and the need of counterpart countries (e.g., coal ash from thermal power plants). Several technologies were then addressed in the agenda by the MSIT at the presidential meetings, in order to amplify the effectiveness and scale of these technologies in the context of international climate technology cooperation.

The inter-ministerial activities also contributed to the implementation framework of international climate technology cooperation. An inter-ministerial approach is essential because technology cooperation entails the development of technology, standardization and environmental assessment, procurement of materials, participation of corporations, and other subsidiary implementation systems. For this reason, the CTR and the Masterplan for Climate Change Response were prepared by the inter-ministerial bodies. The MSIT, Ministry of Environment, and Ministry of Trade, Industry, and Energy were also involved in the development of the National Strategic Project on carbon mineralization. Therefore, the inter-ministerial approach is essential to the facilitation of climate technology cooperation, rather than being solely enacted by the NDE.

Finally, the national top-down approach was determined by the high-level hierarchy of the government. The meetings of the PACST and PSCST thoroughly discussed the facilitation of climate technology development and cooperation, with considerations of the technology agenda from the MSIT and the inter-ministerial implementation framework. After the determination of the development of the National Strategic Projects, the demonstration roadmap for these projects was also developed. Accordingly, systemic processes and cooperation with the inclusion of various hierarchical levels of governmental bodies are recommended to facilitate prominent climate technology.

5. Conclusions

This project report suggests a new strategic framework of climate technology development. The top-down approach to developing carbon mineralization and international cooperation, involving ministerial to presidential levels, comprises the identification of technology, the establishment of an international network and implementation framework, and the development of a national project. The establishment of an international network with other governments could facilitate the impact of this technology on a global scale. This project was expected to be a pilot demonstration, sequestering 6000 tons of CO_2 and manufacturing 30,000 tons of carbonate. It was also expected to sequester 10 Mt CO_2 yr^{-1}, and provide an economic benefit of 15 billion dollars yr^{-1} by 2030 on the basis of carbon mineralization technology. Accordingly, a strategic and holistic approach of climate technology development and international cooperation from a higher organizational level would contribute to global GHG mitigation and the achievement of SDGs.

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