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Green Growth and Solar Photovoltaic Technologies in Korea*

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This study discusses the green growth policy, the solar photovoltaic technology policy and the performance of these policies in Korea. In 2009, the green growth strategy was suggested as a new future development paradigm. The legal and institutional basis was established for the implementation of green growth strategy. As a part of the green growth strategy, the improvement of energy technology was a priority, and solar photovoltaic technology has shown many achievements. R&D investment in the solar photovoltaic technology sector increased and the annual supply capacity was largely expanded. Due to the implementation of the green growth strategy, the GHG emissions is gradually declining in Korea, but there are still many challenges ahead to further reduce GHG emission. Therefore, Korea will continue to pursue the green growth policies, which will pave the path towards sustainable development.

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1. INTRODUCTION

The Republic of Korea achieved rapid economic growth from income per capita of 156 USD in 1960 to 27,222 USD in 2015 at current USD. [1)] It is well-known that the unprecedented economic performance in the 1960s to the 1980s depended much on the performance of heavy-chemical industries such as automobiles, steel, shipbuilding, and semiconductors, which are quite fossil-fuel energy intensive. However, fossil fuels are the main sources of greenhouse gas (GHG) emissions. In Korea, it can be said that the country was less exposed to global environmental concerns of economic growth since the international community did not begin collective actions for tackling damaging impacts on environment of economic growth.

Climate change and environmental protection, however, are no longer the problems of one country, but those of the whole world. From the 1980s, the international community started to aggressively take account of the relation between economic growth and the environment. This was reflected by the definition of sustainable development in the *Our Common Future*, also known as the Bruntland Report published by the United Nations World Commission on Environment and Development in 1987 (World Commission on Environment and Development, 1987; Kang, 2012).

With this background, the Korean government became aware that effectively responding to environmental issues and simultaneously achieving economic growth through its traditional growth paradigm was impossible. In 2009, the Lee Myung-bak administration proclaimed “Low Carbon Green Growth” as a national development agenda. It effectively addressed climate change and environmental issues while simultaneously planning new driving forces for national economic growth and job creation.

In order to effectively achieve the targets proposed by the green growth policy, the four areas, legislation, organization, budget, and policy, are well

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[1)] World Bank, World Development Indicators (2016).

and firmly established.

First of all, various laws and acts to support green growth policies were established. The first one was the “Framework Act on Low Carbon, Green Growth” and its enforcement decree that entered into force in April 2010. Others are explained in later sections.

Second, as an organization in 2010, the Presidential Committee on Green Growth (PCGG) was established and operates as the general organization under direct presidential control for mediating the policy throughout the government for considering and resolving major issues. Sixteen regional green growth committees and consultative groups composed of industries, finance, technology, green life, and green IT were created to promote regional and private policies (Kang, 2014).

Even the next government, the Park Geun-hye administration in 2013, has been promoting the green growth as a strategy for achieving sustainable development under the new vision titled “Creative Economy” without using green growth terminology explicitly, and with some changes in policies.

Third, the budget to finance the five years green growth plan was also allocated. The total amount of investment allocated to green growth strategies was 107.4 trillion KRW, which is equivalent to approximately 83.6 billion USD and was about 2% of annual average gross domestic product (GDP) (Presidential Committee on Green Growth, 2009b, p. 373). Finally, very detailed strategies, policy directions, and practical tasks to conduct them with major indicators were included in the green growth plan.

Fourth, green growth policy was not only focused on the organization and the legal framework, but also on the actual policy performance. In particular, investment in the renewable technologies has been stimulated, and the performance in the solar photovoltaic sector have improved markedly.

This study aims to discuss the background of the development and the implementation process of green growth policies, and the first and second five year green growth plans. In addition, the following sections will evaluate the policy of the previous green growth plan and furthermore, discuss the policies and achievements in the solar photovoltaic sector.

2. ECONOMIC DEVELOPMENT AND ENVIRONMENT

During a short 50-year period, the Republic of Korea accomplished remarkable economic growth and rapidly moved from a least developed country to the 13th economic power of the world. It would not be an overstatement to claim that the driving force behind the rapid industrialization of the Republic of Korea in the past was the development of energy intensive heavy-chemical industries and technology, which led to significant amount of greenhouse gas emissions. With a lack of natural energy resources, however, Korea had the limitation of depending greatly on imported energy resources.

Table 1 summarizes the economic performance since 1960 with several representative economic indicators. Korea achieved unprecedented economic growth only within the half-century. Income per capita at current USD increased from 156 USD in 1960 to 1,778 USD in 1980 and 27,222 USD in 2015. Industry structure also reflects rapid industrialization with a decrease

Table 1 Major Economic Indicators

Indicator Name	1960	1970	1980	1990	2000	2010	2015
GDP per capita (constant 2010 USD)	1,103	1,960	3,911	8,795	15,105	22,151	25,023
GDP per capita (current USD)	156	292	1,778	6,642	11,948	22,151	27,222
Industry, value added (% of GDP)		24.48	34.17	38.18	38.09	38.27	37.98
Agriculture, value added (% of GDP)		27.52	15.11	8.22	4.39	2.47	2.31
Exports (current Billion USD)	0.12	1.21	20.47	73.74	196.62	540.90	632.46
Imports (current Billion USD)	0.49	2.12	25.51	76.57	184.99	506.04	536.57
Trade (% of GDP)	15.76	35.41	67.81	52.78	67.95	95.65	84.84

Source: World Bank (2016).

of share of value added in the agriculture sector of GDP from 27.52% in 1970 to 2.31% in 2015. As already well-known, Korea's rapid economic growth depends on outward-oriented external policy through successful combination of export promotion policy and import substitution policy. The outcome is reflected by significant increase of trade share to GDP from 15.76% in 1960 to 84.84% in 2015.

Since economic growth has depended on energy intensive industries by declaring the promotion of heavy chemical industries such as steel, chemicals, nonferrous metal, machinery, shipbuilding, and electronics in 1973, the demand for fossil fuel energy has increased as well. Since Korea has no sufficient fossil fuels energies, most energies were imported. The share of energy imports to total imports increased over periods with high economic growth, increasing from 29.7% in 1981 to 35.6% in 2012. It was reflected by an increasing import dependency of energy from 87.9% in 1990 to 97.2% and 96.0% in 2000 and 2010, respectively (Kang, 2014).

Table 2 summarizes major indicators on CO_2 emissions and energy consumption with the rankings in the Organisation for Economic Co-operation and Development (OECD) countries. First, the total energy imports increased from 10.9 billion USD in 1990 to 174.1 billion USD in 2013, with an increase of energy dependency rate from 87.9% in 1990 to 95.2% in 2013. Second, per capita energy consumption increased more than twice over the period of 1990 to 2013.[2)] It was 2.2 TOE in 1990, but increased to 5.3 TOE

[2)] The Total Primary Energy Supply (TPES) is divided by the population of each nation to calculate the "per capita energy consumption" and the TPES is calculated with the following equation. That is, 'indigenous production' + 'imports' – 'exports' – 'international marine bunkers' – 'international aviation bunkers' +/– 'stock changes.' However, production refers to primary energy which includes hard coal, lignite, peat, crude oil, NGL, natural gas, combustible renewables and waste, nuclear, hydro, geothermal, solar, and the heat from heat pumps and is calculated after removing impurities. Regarding imports and exports, the subjects are coal, oil and gas, and electricity. Refer to the IEA website (https://www.iea.org/statistics/resources/balancedefinitions/, accessed on June 29, 2015) for more detailed information on TPES.

Table 2 Major CO_2 Emissions and Energy Consumption Indicators

	1990		2013	
	Value	Ranking	Value	Ranking
Energy imports (billion USD)	10.9		174.1	
Energy import dependency (%)	87.9		95.2	
Per capita energy consumption (kg of TOE)	2.2	29/34 (OECD) 58/160 (World)	5.3	8/34 (OECD) 17/138 (World)
CO_2 Emissions (million tCO_2eq)	246.9	10/29 (OECD) 13/168 (World)	592.5	4/34 (OECD) 8/203 (World)
Growth rate of CO_2 emissions (from 1990 to 2013)	–	–	140.0%	2/29 (OECD) 76/168 (World)
Per capita GHG emissions (tCO_2eq)	6.8	30/34 (OECD)	13.8	8/34 (OECD)

Note: CO_2 emissions data include carbon dioxide produced during consumption of fossil fuels.
Sources: World Bank (2016), OECD Statistics (2016).

in 2013. Due to this high increase in per capita energy consumption, its world ranking rose as well. Korea's OECD and World ranking was 29 and 58 in 1990, but became 8 and 17 in 2013, respectively.[3] Third, the CO_2 emissions increased from 229.3 million tCO_2eq in 1990 to 592.9 million tCO_2eq in 2012 with 158.6% increase. This rate of increase is the second highest among OECD countries, ranking 76th in the world. However, its share in the world emission was only 1.1% and 1.8% in 1990 and 2013, respectively.[4] Finally,

[3] See Kang (2014, pp. 22-26) for more detailed data and world ranking of GHGs and trend of energy consumption and imports since 1981.

[4] Due to economic growth with fossil-fuel energy intensive industries, the world GHG emissions increased as well. In terms of 6 GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6), China was the top country with 3,808 million tCO_2eq in 1990 and 10,700 million tCO_2eq in 2010 with 181.0% increase between 1990 and 2010. The world share also increased from 18.0% in 1990 to 34.6% in 2010. The second one is USA with emissions of 5,807 million tCO_2eq in 1990 and 6,610 million tCO_2eq in 2010 with 13.8% increase over 1990-2010. Korea was 11th ranking in 2010 with 625 million tCO_2eq with 2.0% world share (Kang, 2014, p. 20,

per capita GHG emissions increased significantly from 6.8 tCO_2eq in 1990 to 13.8 tCO_2eq in 2013. Thus, the OECD ranking became 8th in 2013 from 30th in 1990.

By reviewing the trends of economic growth and environment indicators, it can be seen that Korea is a highly fossil-fuel energy dependent country with high GHG emissions even though the world share of GHG emissions is low with less than 2%. Business sectors tend to argue that Korea is not seriously responsible for current global warming situation. However, the increasing rate of GHGs and the world ranking are more important, which are reflected in the change of the OECD ranking in Table 2. Further, considering the recent per capita energy consumption and GHG emissions, Korea may give signals to the international community that Korea is not attempting to decrease GHG emissions through industry restructuring, innovation, and social adjustments to become a low-carbon society.

As a country that experienced rapid economic growth in the periods with relatively less global environmental urgency, Korea realized that economic growth would be sustainable when traditional fossil-fuel intensive economic development strategy shifts to low-carbon economic development strategy. As a result, the Korean government wanted to play an important role in tackling climate change in the international community. It is Korea's development strategy to sustain economic development and simultaneously decrease GHG emissions. This is the background that the Korean government proclaimed "Low Carbon, Green Growth" as a new economic development paradigm in 2008.

Table 2-4). Due to low world share, business sectors in Korea tend to argue that Korea is not seriously responsible for current global warming situation.

3. GREEN GROWTH POLICIES IN KOREA

3.1. Green Growth Policies, Organization, and Budget

Green growth policies that were initiated in Korea contributed to the establishment and implementation of policies to tackle climate change, with sustaining economic growth not only for Korea, but also for international communities. This is not because of terminology, but because of the first comprehensive economic development plan. In the commemorative speech for the 60th anniversary of the founding of the Republic of Korea in 2008, President Lee defined green growth as "sustainable growth that mitigates greenhouse gas emissions and prevents environmental degradation. It is also a new national development paradigm that creates new growth engines and jobs through green technology and clean technology".[5)]

To implement "Low Carbon, Green Growth", the government established PCGG under direct presidential control in 2009. As a legal basis for green growth policies, the "Framework Act on Low Carbon, Green Growth" and its enforcement decree were legislated and entered into force in April 2010. In addition, a central and local self-governing body was established to promote comprehensive green growth plans. The plan was also subdivided into general plans to include climate change response general plan, national energy general plan, and emission tradable permit system general plan (Kang, 2014).

The most important outcome of the PCGG role is the establishment of the first five-year green growth plan in 2009. The plan targeted for Korea to be the 7th ranked green country in the world by 2020 and the 5th ranked green country by 2050 in the world. It consisted of three strategies with 10 policy

5) The term 'green growth' was used in the title of the book written by Ekins (2000) and later used in the 5th Ministerial Conference on Environment and Development in Asia and Pacific (2005) in Seoul. See Jung and Kang (2012) for more details on various definitions of green growth.

Table 3 First Green Growth Five-Year Plan

Strategies	Policy Directions
1. Mitigation of climate change and energy independence	1) Effective mitigation of greenhouse gas emissions 2) Reduction of the use of fossil fuels and the enhancement of energy independence 3) Strengthening the capacity to adapt to climate change
2. Creating new engines for economic growth	4) Development of green technologies 5) Greening of existing industries and promotion of green industries 6) Advancement of industrial structure 7) Engineering a structural basis for the green economy
3. Improvement of the quality of life and strengthening of the national status	8) Formation of green national lands and transportation 9) Green revolution of living 10) Implementation of a world exemplary green growth policy

Source: Presidential Committee on Green Growth (PCGG) (2009b), p. 31; Kang (2014), p. 38, [Table 2-10].

directions and 50 actions (Table 3). For the investment plan (2009 to 2013), 98 billion USD were arranged, a green growth budget of 2% of the yearly GDP was proposed, and 101 billion USD were invested each year, a greater amount than originally planned (Presidential Committee on Green Growth, 2013).

Three strategies are (i) mitigation of climate change and energy independence, (ii) creating new engines for economic growth, and (iii) improvement of the quality of life and strengthening of the national status. As seen from these three strategies, it can be seen that the green growth plan is a comprehensive economic development plan which covers mitigation and adaptation of climate change, as well as creation of new growth engines. Therefore, the plan seeks simultaneous economic growth and reduction of environmental damages to our living world. This might be a focal point which is in contrast with the climate change oriented policy by developed countries.

One of the main characteristics of the first green growth plan is to seek

greening of current manufacturing industries. Since the main driving forces for rapid economic growth have been energy-intensive heavy-chemical industries, it is impossible for Korean industry sectors to give up current businesses. The fifth policy direction in the first green growth plan includes various policy tools to achieve these targets: (i) construction of resource cycling economy and industrial structures; (ii) greening of industries and diffusion of innovation; (iii) fostering of green small/medium venture businesses; and (iv) fostering of knowledge led green clusters (Kang, 2014).

In order to achieve the objectives of the plan, the government planned to invest about 107.3 trillion KRW for the first green growth plan period, which is equivalent to about 2% of Korea's annual GDP. For the first category, the total investment plan was 57 trillion KRW, which was about 53% out of the total investment plan in five years. The second and third categories were planned investments of 28.6 and 27.9 trillion KRW, respectively (Table 4).[6)]

Table 4 Investment Plan in the First Five-Year Green Growth Plan

(unit: trillion KRW)

Category	2009	2010-2011	2012-2013	Total
Total	17.5	48.3	41.5	107.3
Mitigation of climate change and energy independence	8.6	29.2	19.2	57
Creating new engines for economic growth	4.8	10.7	13.1	28.6
Improvement in quality of life and enhanced international standing	5.2	10.5	12.2	27.9

Source: Presidential Committee on Green Growth (PCGG) (2009b), p. 373.

6) The investment plan simultaneously with green growth plan is one of the characteristics of the Korean green growth plan.

Under the new vision “Creative Economy”, green growth strategy under President Park lost significant parts of green growth dynamics. First of all, the PCGG moved from the president’s office to the prime minister’s office.

Even though the PCGG moved to the prime minister’s office, the new government in 2014, in accordance with “the Framework Act on Low Carbon Green Growth”, announced the second five year plan for the period of 2014 to 2018. The plan proposed three policy goals, which were “achieving low carbon economic and social structures”, “realizing a creative economy through a fusion of green technology and ICT”, and “establishing a pleasant lifestyle safe from climate change”, and selected 20 assignments for “realizing national happiness through harmonious development of the economy and environment” (Joint Work of Relevant Agencies, 2014).

The second green growth plan’s vision of “Realization of National Happiness through Harmonious Development of Economy and Environment” consists of three policy targets with five policy directions and 20 focal issues (Table 5). Three policy targets are (i) settlement of low carbon economic and social structure, (ii) Realization of creative economy through convergence of green technology and ICT, and (iii) Establishment of pleasant lifestyle base comfortable to climate change. The other five policy directions and 20 focal issues are shown in Table 5.

The first green growth plan established the basis for the introduction stage and planned for the creation of new markets initiated by the government. On the other hand, the second green growth plan focuses on practical results and expands the first plan by being privately led. Particularly, green technology and sustainable energy are proposed as specific policy goals. Among the 20 focal issues of the second plan, from 5^{th} to 12^{th} focal issues are related to these areas (see Table 5). The current government set the creative economy as the priority policy goal for the nation, but it is expected that this plan will unify with the green growth plan of the current government.

However, the first green growth plan includes more explicitly the engine of economic growth than the second green growth plan does by considering greening of industries and development of green technologies. The second

Table 5 Second Green Growth Five-Year Plan

Policy directions	Focal issues
Effective greenhouse gas reduction	1) Systematic fulfillment of greenhouse gas reduction roadmap 2) Settlement of Emissions Trading Scheme and vitalization of carbon market 3) Establishment of long-term reduction target 4) Expansion of carbon absorption sources
Establishment of sustainable energy system	5) Strengthening of energy demand management 6) Dissemination expansion of renewable energy 7) Settlement of distributed generation system 8) Securement of energy facility stability
Ecosystem construction of green creative industry	9) Development of advanced fusion green technology 10) Promotion of green creative industry 11) Economic structure policy of recycling of resources 12) Regulation rationalization and green human resource cultivation
Realization of sustainable green society	13) Strengthening of adaptation capacity of climate change 14) Expansion of eco-friendly lifestyle base 15) Construction of green land space 16) Expansion of green welfare and governance base
Intensification of global green cooperation	17) Effective coping with climate negotiation 18) Regional cooperation expansion and international expansion of green growth 19) Expansion of cooperation with developing countries and internal enhancement 20) Cooperation and support strengthening with GGGI and GCF

Source: Joint Work of Relevant Agencies (2014), p. 28.

plan does not include explicitly economic growth strategy except for promotion of green creative industries. Rather it focuses on effective GHG reduction and climate change adaptation.

3.2. Greenhouse Gas Emissions Target and Its Legal Achievement Strategies

Even though Korea is not in the ANNEX B Parties under the Kyoto Protocol, it voluntarily announced its GHG emissions target. This move indicated that Korea was not solely seeking economic growth, but also participating in global tackling of climate change. In November 2009, Korea announced the mid-term national GHG emissions reduction target by 30% in

year 2020 from the 2020 business-as-usual (BAU) level. This is equivalent to 4% below 2005 level. The GHG emissions in 2005 was 594 million tCO_2eq with an increase of 99% from 1990, but decreasing trend of the increase rate since then. Under the various assumptions on prospects of economic growth, industry structure, population, oil price, and investment plan by industry sectors, the government projected 813 million tCO_2eq as BAU in 2020, with an annual average increase of 2.1% (Presidential Committee on Green Growth, 2009a).[7)]

As the first step to reduce GHG emissions, the Greenhouse Gas Inventory and Research Center (GIR) was established in June 2010. It has moved to the Office of Prime Minister in June 2016 and provides the national GHG statistics every year. The process is as follows. The center provides guidelines for measurement, reporting, verification (MRV) to the management institution that calculates GHG statistics by sectors and provides them to the center. Then the center reviews and supplements the data through verification. After technical review by a consultative group and discussion by a working-level group, the center releases the data after the final review and decision by a management committee. Based on the guideline of Intergovernmental Panel on Climate Change (IPCC), the center reports the GHGs data of energy, industrial process, agriculture and LULUCF (Land Use, Land-Use Change, and Forestry), and wastes (Greenhouse Gas Inventory and Research Center of Korea, 2015).

In order to achieve the target, various laws and acts, in addition to the "Framework Act on Low Carbon, Green Growth" and its enforcement decree mentioned above, were entered into force. First, the "Act on the Allocation

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7) In 2015, the Korea government is setting up revised GHG reduction target in 2030, which will be submitted to the United Nations Framework Convention on Climate Change (UNFCCC). Assuming 850.6 million tCO_2eq as business as usual (BAU) in 2030, the government finalized new GHG reduction target which reduces 37% with GHG emissions of 536 million tCO_2eq in 2030. The amount of emissions is about 9.8% lower than 594 tCO_2eq in 2005.

and Trading of Greenhouse Gas Emission Permits" and its enforcement decree were to establish infrastructure for emission trading scheme that includes designation of companies for allocation of emission right, reporting, verification and certification of emissions, and others.

The "Act on the Creation and Facilitation of Use of Smart Grids", which was effective as of 2014, aims to facilitate industry use of smart grids to actively respond to climate change and thus to pursue national development. The "Act on the Support for Construction of Green Buildings" aims to achieve green growth by increasing the number of green buildings through green building formation projects, GHG management plans, and the implementation of green building grade system. Then, the "Development Act for Sustainable Transportation and Logistics" is a green growth strategy in the transportation and logistics through the activation of carbon free means of

Table 6 Legal Arrangement for Green Growth

Institutional Arrangements	Contents
Act on the Allocation and Trading of Greenhouse Gas Emission Permits and its enforcement decree (2012, effective as of 2013. 5. 22)	- to establish a basic plan for emission trading scheme - designation of companies for allocation of emission right - reporting, verification, and certification of emissions submission, carry over, borrowing, offset, and extinction of emission rights - penalties and fines
Act on the Creation and Facilitation of Use of Smart Grids (2011, effective as of 2014. 1. 1)	- to construct smart grids and to facilitate the use of smart grids in order to foster related industries - to actively respond to climate change - to innovate the environment of energy use - to pursue national economic development
Act on the Support for Construction of Green Buildings (2009, effective as of 2013. 3. 23)	- to stipulate matters for the formation of green buildings - to realize low carbon green growth - to contribute to the enhancement of national welfare through reduction of buildings GHG emissions and increase in green buildings
Development Act for Sustainable Transportation and Logistics (2009, effective as of 2013. 5. 22)	- to form a base of sustainable development of transportation and logistics - to contribute to national development in response to changes in transportation and logistics condition such as climate change, energy crisis, and demands for environmental protection

Source: Kang (2014), pp. 42-47.

transportation and logistics. Table 6 summarizes the main contents of the Acts mentioned above.

3.3. Institutional Arrangements for Carbon Reduction

In addition to legal arrangements to promote various green growth strategies, the government established various institutions to expedite GHG reduction. Those are the Greenhouse Gas and Energy Target Management System (GHG and Energy TMS) in 2010, the Renewable Portfolio Standard (RPS) in 2012, and the Emissions Trading Scheme (ETS) in 2012. Furthermore, the government established the energy master plans: the first plan in 2008; and the second plan in 2014.

3.3.1. GHG and Energy TMS

By designating the entities that emit GHG, the GHG and Energy TMS is a system to manage and support their performance of GHG emission and energy consumption targets. The government and the entities mutually agree on the target of GHG emissions and energy consumption. The entities subject to the GHG and Energy TMS are identified by corporate unit and facility unit which are in accordance with the "Guidelines for the Operation of the Greenhouse Gas and Energy Target management System" in 2013. This guideline was amended in May 2015.[8)]

Table 7 summarizes the ranges of companies under the GHG and Energy TMS. Until December 31, 2011, the entities that emitted more than 125 thousand tCO_2eq of GHG and facilities that emitted more than 25 thousand tCO_2eq were subject to the TMS. The entities and facilities that consumed energy more than 500 TJ and 100 TJ, respectively, were included as companies controlled by the GHG and Energy TMS. However, the range of GHG emissions and energy consumption was strengthened in 2012 and

8) Korea Energy Management Corporation (2015).

Table 7 Entities and Facilities that Belong to the TMS

Item	Until 31th Dec. 2011		From 1st Jan. 2012		From 1st Jan. 2014	
	Entity	Facility	Entity	Facility	Entity	Facility
Greenhouse Gas Emission (tCO_2eq)	125,000	25,000	87,500	20,000	50,000	15,000
Fossil Energy Consumption (TJ)	500	100	350	90	200	80

Source: Korea Energy Management Corporation (2015).

further in 2014. For example, the entities and facilities that emitted more than 50 thousand tCO_2eq and 15 thousand tCO_2eq were subject to the GHG and Energy TMS. In terms of energy consumption, the entities and facilities that consume energy more than 200 TJ and 80 TJ, respectively, belong to the companies of the GHG and Energy TMS.

The Ministry of Environment (2014) reported that GHG reduced more than stated in the planned reduction target in 2012, which was the first year under the GHG and Energy TMS.[9] 392 among 434 entities and facilities under the GHG and Energy TMS over-performed their target so that the GHG emission was reduced by about 21 million tCO_2eq, which was about 3.78% of expected GHG emission of 564 million tCO_2eq. This reduction was 2.7 times higher than that of planned reduction rate (8 million tCO_2eq with reduction rate of 1.41%) in 2012. By sectors, petrochemicals and steel reduced 6.90 million tCO_2eq and 5.73 million tCO_2eq, respectively and semiconductors, display and electric, electronics reduced 5.30 million tCO_2eq, and cement reduced 3.87 million tCO_2eq in order (Ministry of Environment, 2014).

3.3.2. RPS

The RPS is a system for power generation suppliers with facilities more than 500 MW to supply certain ratio of total electricity generation by new

9) The share of GHG emissions by the 434 entities and facilities was 61% of national GHG emissions as of 2007 (Ministry of Environment, 2014, p. 1).

Table 8 Requirement Ratio of New and Renewable Ratio by the RPS

Year	2012	2013	2014	2015	2016	2017	2018
Ratio (%)	2.0	2.5	3.0	3.2	4.0	5.0	4.5
Year	2019	2020	2021	After 2022			
Ratio (%)	7.0	8.0	9.0	10.0			

Source: Korea Energy Agency (2017).

and renewable energy.[10] It was implemented in 2012 under the "Act on the Promotion of the Development and Use of New and Renewable Sources of Energy (law no. 10253)" and its enforcement decree (Kang, 2014).

The compulsory supply ratios of new and renewable energy by years are shown in Table 8. In 2012, the required ratio was 2.0% and it increases every year until 2022. After 2022, the ratio is required to be 10%. If these requirements are not satisfied, fines can be imposed by considering the numbers and reasons of non-performance within 150% of the average market price of the renewable energy certificate. Yet, the requirement can be postponed until three more years up to 30% of quantity of non-performance.[11]

3.3.3. ETS

The GHG Emission Trading Scheme (ETS) was prepared under the "Act on the Allocation and Trading of Greenhouse Gas Permits" and its enforcement decree in 2012, and was implemented in January 1, 2015. The "Basic Plan for Emissions Trading Scheme (proposal)" depicts the management directions and principles of the ETS for coming 10 years and 3-phased important objectives, institutional management directions and principles, allotment policy and support policies for domestic industries for 2015-2025.

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10) See Korea Energy Agency (2015) for more details on the RPS in Korea.
11) Korea Energy Agency (2015).

Table 9 Phased Plan to Reduce GHG Emissions

Phase I (2015-2017)	Phase II (2018-2020)	Phase III (2021-2025)
1. Safe reach of the ETS	5. Significant reduction	9. Aggressive reduction
2. Flexible management	6. Expansion of application range	10. Expansion of non-free allocation
3. 100% free allocation of allowance	7. 97% free allocation	11. Expansion of liquidity
4. Infrastructure and experience accumulation	8. Advancement of allocation system	12. Establishment of allocation system

Source: Ministry of Strategy and Finance (2014), p. 25.

In order to effectively reduce national GHG emissions, Table 9 summarizes the phased policies on the ETS by the Basic Plan. In Phase I, the main objectives are safe reach of the ETS, flexible management of the ETS, 100% free allocation of allowance and experience accumulation. Through experience accumulation and experiments, the ETS is planned to be well established in Phase III by allowing aggressive reduction of the GHG emissions.

The ETS will be applied to the entities with more than 125 thousand tCO_2eq and the facilities with more than 25 thousand tCO_2eq emissions of the GHG on annual average basis for recent three years. The entities and facilities under the ETS will not be subject to the GHG and Energy TMS (Ministry of Strategy and Finance, 2014).

3.3.4. Energy master plans

The energy mix policy is well-reflected in the first (2008-2030) and second (2013-2035) energy master plans, but with slightly revised energy mix plan (Table 10). Through expansion of renewable energy, restraint of energy demand, and green technology development, the first energy master plan in 2008 aimed to achieve low carbon green growth. The first plan includes five main strategies with specific targets. For example, there was a plan to increase the renewable energy deployment rate from 2.2% in 2007 to 11% in 2030, and energy intensity decreased from 0.347 tCO_2eq in 2007 to 0.185 tCO_2eq in 2030.

The second energy master plan in 2013 for 2013-2035 did not specify

Table 10 The First Energy Master Plans

Vision	Indicator	2007	2030
Realizing an energy self-sufficient society	Self-development rate	3.2%	40%
	Renewable energy deployment rate	2.2%	11%
	Share of nuclear installed capacity	27%	41%
Moving toward a non-oil-based society	Oil dependence	43.6%	33.0%
Moving toward a low energy consumption society	Energy intensity	0.347	0.185
Creating new growth engines and job opportunities through green energy and green technology	Energy technology level	60% of developed nations	World leader
Realizing a society of shared energy prosperity	Energy poverty rate	7.8%	0%

Source: Ministry of Trade, Industry and Energy (2014a), p. 9.

Table 11 The Second Energy Master Plans (2013-2035)

Tasks	Objective
Transition to energy policies focused on demand management	Reduce energy demand by 13% and electricity demand by 15%
Build a distributed generation system	Supply more than 15% of power from distributed generation
Strike a balance with environmental and safety concerns	Apply the latest GHG reduction technology to new power plants
Enhance energy security and energy supply stability	Build overseas resource development capacity and achieve a renewable energy deployment rate of 11%
Establish a stable supply system for each energy source	Secure a stable supply of conventional energy sources, such as oil and gas
Shape energy policy to reflect public opinion	Introduce an 'Energy Voucher System' in 2015

Source: Ministry of Trade, Industry and Energy (2014a), pp. 30-33.

target indicators as in the first plan (Table 11). The main directions consist of six tasks. For example, the first task is transitions to energy policies focused on demand management by reducing energy demand and electricity demand. However, there were changes in some objectives. For example, the share of renewable energy was targeted at 11% by 2030, but the second plan changed it to 11% by 2035. A striking change was the share of nuclear installed capacity that decreased the target from 41% by 2030 under the first plan to

29% by 2035 under the second plan (Ministry of Trade, Industry and Energy, 2014a).

4. GREEN GROWTH POLICY AND ECONOMIC GROWTH

It is quite true that climate change was caused by mass production of our world. Since industrialized countries are relatively responsible for the current accumulation of GHG, it is well known that developing countries are not well persuaded to join global measures against climate change. Their concern is that current measures against climate change might impede their economic growth; thus, poverty reduction. Therefore, the measures against climate change should be accompanied by economic growth to achieve sustainable development.

Korea has depended on heavy-chemical industries as main growth engines and cannot give up its current industrial structure. Therefore, it is very important to find ways in reducing greenhouse gases by keeping current growth engines, eventually sustaining economic growth. As the second green growth is a continuing extension of the first green growth policy, it is still too early to evaluate the effectiveness of the policy.

First of all, as a direct performance, Table 12 indicates recent trends of greenhouse gas emissions by types. Even after green growth policies were undertaken, the GHG emissions continued to increase from 590.8 million tCO_2eq in 2008 to 680.6 million tCO_2eq, 684.3 million tCO_2eq and 694.5 million tCO_2eq in 2011, 2012 and 2013, respectively. Even the growth rate tended to increase form 1.1% in 2009 to 5.6%, 1.2% and 1.9% in 2011, 2012 and 2013, respectively. With the reduction in 2012, however, the growth rate of GHG emissions was lower than the GDP growth rate. The GDP growth rate for 2011-2012 was 2.00% while the growth rate of GHG emissions was 1.1%. This trend was in contrast with the GDP growth rate (3.70%) and the growth rate of GHG emissions (5.41%) for 2010-2011 (Ministry of Environment, 2014, pp. 3-4).

Table 12 Trends of National GHG Emissions (1990-2012)

(unit: million tCO_2eq)

Year	1990	2000	2008	2009	2010	2011	2012	2013
Total (Including LULUCF)	292.2	498.8	590.8	594.2	653.1	680.6	684.3	694.5
(growth rate, %)	0	7.6	2.6	1.1	10.9	5.6	1.2	1.9
Net Emissions (Excluding LULUCF)	258	406.7	519.4	533.4	540	598.6	632	651.7
Energy	241.3	410.4	505.9	512.4	565.3	594.1	597.3	606.2
Industrial process	20.4	49.8	50.2	46.6	52.5	51.8	51.5	52.6
Agriculture	20.7	20.7	20.3	20.7	21.1	20.2	20.7	20.7
Wastes	9.8	17.8	14.5	14.5	14.1	14.6	14.8	15
LULUCF	−34.2	−58.9	−57.4	−54.6	−54.5	−48.7	−44.8	−42.9

Note: LULUCF indicates Land use, land-use change and Forestry.
Source: Statistics Korea (2017).

Second, numerous research findings provide evidence for the positive spillover effect of green growth. Kang (2011) newly defined green industry in accordance with the green growth policy, comparing green industries with non-green industries and suggesting relatively high effects of green industries in creating job positions.

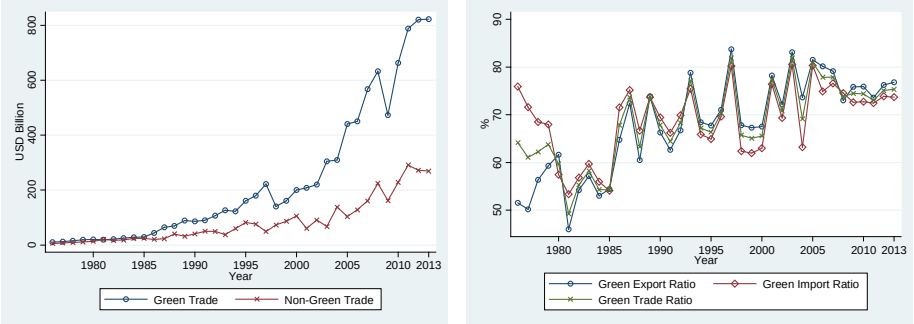
United Nations Industrial Development Organization (UNIDO) and GGGI (2015) analyzed and compared green growth policies of Brazil, Germany, Indonesia, Korea, and South Africa and the positive effects of the policies on job creations. This study proposes the effect on job creation, assuming that each country invests 1.5% of the country's GDP in the clean energy field for 20 years. In Brazil, 806,000 jobs will open in that period, which would be 0.7% of the total workforce.

In Germany, a total of 352,000 jobs will be created, which is 0.9% of the workforce. In Indonesia, 1.8 million jobs will open and the number will assume 1.3% of the labor force. South Africa will create 398,000 jobs during the period and the job openings will amount to 1.9% of the workforce. Finally, in Korea, 276,000 jobs will be created and will assume 1.0% of the total labor force (United Nations Industrial Development Organization and Global Green Growth Institute, 2015).

Figure 1 Trend of Global Green Trade (1976-2013)

Source: Kang (2015).

Figure 2 Trend of Green Trade of Korea (1976-2013)



Source: Kang (2015).

Third, The world is increasing its trade of environmental products (United Nations Environment Programme *et al*., 2012), and Korea is not exempt from this global trend. Kang (2015) observes the transition of trade in green industries and shows that the trade of green industries increasing has been rapidly compare to that of non-green.

Based on the definition of green industry by Kang (2011), Figure 1 shows an increasing trend of global green trade (left) for 1976-2013. The share of green exports, imports, and trade (right) tends to show increasing trends except for the periods of economic crisis in the beginning of the 1980s and during the 2008 financial crisis. Further, Figure 2 shows quite consistent trends with global green trade. Therefore, it is evident that the investment on

Table 13 Trends of Global Green Investment in Renewable Energy

(unit: billion USD)

	2005	2009	2010	2011	2012	2013	2014
Developed	53	113	162	190	149	135	139
Developing	20	66	75	89	107	97	131
Total	73	179	237	279	256	232	270

Source: Frankfurt School-UNEP Collaborating Centre (2015), p. 16.

green industry will help industry sectors sustain their growth.

Finally, global green investment tends to increase as shown in Table 13. This indicates that there will be a new business opportunity for renewable markets. The total investment in 2005 was 73 billion USD, with 53 billion USD by developed countries and 20 billion USD by developing countries. In 2014, the total investment increased to 270 billion USD with 139 billion USD by developed and 131 billion USD by developing countries. Therefore, developing countries increased investment by almost six times for 2005-2014 and developed countries increased investment by about twice.

5. POLICY AND PERFORMANCE OF SOLAR PHOTOVOLTAIC TECHNOLOGY

5.1. Korean Government Polices on Solar Photovoltaic Technology

The development of solar photovoltaic technology is a key part of the national energy strategy. After experiencing the Oil Shock in the 1980s, the Korean government realized the necessity for measures such as diversification of energy sources, reformation of energy consumption patterns, etc., and enacted “Alternative Energy Development Promotion Act” in 1987. This is the first national effort for an institutional change.

However, the initial effort was focused mostly on solar heat and waste energy. The solar photovoltaic technology was brought to light only as of 2008, based on Lee Myung-bak administration’s national agenda of “Green Growth Paradigm”. As Green Growth became the new paradigm for national

development, the emphasis was placed on the need to develop the new and renewable energy technology.

After 2008, the Korean government policies related to solar photovoltaic technology are established based on “Framework Act on Low Carbon, Green Growth” (enacted in 2010), and “Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy” (amended in 2004). Furthermore, the policy details are developed based on “Strategy for Industry Growth of New and Renewable Energy” (published in 2010), “Green Energy Strategy Roadmap” (published in 2011), and “The Fourth Basic Plan for New and Renewable Energy” (published in 2014).

Among the various green technologies that the Korean government intends to develop, the solar photovoltaic technology is of top priority. In 2009, 27 major green technologies — with an emphasis on the key original technologies — were suggested in “Comprehensive Measures on Research and Development of Green Technology” (published in 2009). After 2012, 27 major technologies were focused and narrowed down into 18 technologies. In 2014, Park Geun-hye administration announced “Development Strategy for Climate Change Response Technology”, where 6 major green technologies were suggested. By examining the national plans, it can be identified that the selected technologies are largely focused on the energy source related technologies, and among them, the development of the solar photovoltaic technology is strongly emphasized (refer to Table 14, Table 15).

In “The Fourth Basic Plan for New and Renewable Energy” (published in 2014), the annual shares of the renewable energy — categorized by primary energy sources — were presented. The overall share of the renewable energy is planned to increase from 3.1% in 2012 to 11% in 2035 (refer to Table 16). In the case of solar photovoltaic technology, the share is planned to increase from 2.7% in 2012 to 14.1% in 2035. On the other hand, the share of waste is planned to decrease from 68.4% in 2012 to 29.2% in 2035. This national plan shows the government’s political will to foster the solar photovoltaic technology as a key energy source.

Table 14 18 Major Green Technologies (Selected in 2012)

<Forecasting Technology>	10. Ecological space construction and urban regeneration technology
1. Climate change forecast and response technology	11. Eco-friendly and low energy construction technology
<Energy Source Technology >	12. Intelligent electric power grid and appliances technology
2. Solar Photovoltaic generation technology	13. High efficiency secondary cell technology
3. Wind energy utilization technology	14. Electric power storage technology
4. Bio energy conversion and utilization technology	**<Aftertreatment Technology>**
5. Advanced/Integral light water reactor planning and construction technology	15. CO_2 capture, storage and treatment technology (CCS)
6. High efficiency hydrogen production and storage technology	16. Wastewater treatment and recycling technology
7. High efficiency fuel cell technology	17. Alternate water resource exploration technology
<Highly Efficient Technology >	18. Waste reduction, recycling, and energy recovery technology
8. High efficiency low emission vehicle technology	
9. Intelligent transportation/logistics technology	

Source: Green Technology Center (2014), p. 37.

Table 15 6 Major Green Technologies (Selected in 2014)

Solar Battery	Low Consumption/High Efficiency	Aftertreatment
1. Solar battery 2. Fuel cell 3. Bio-energy	4. Secondary cell 5. New and renewable energy convergence production/ management system	6. CO_2 capture, storage and treatment technology (CCS)

Source: Joint Work of Relevant Agencies (2015), p. 6.

Furthermore, in the “Fourth Basic Plan”, three development objectives for solar photovoltaic technology are listed: first, reach a grid parity for crystalline silicon solar cell; second, commercialize the next generation solar cell, such as building integrated photovoltaics (BIPV), dye-sensitized solar cell, organic solar cell, etc.; third, improve the quality certification procedures, and expand the manufacturing infrastructure of the thin film solar cell equipment (Ministry of Trade, Industry and Energy and Korea New and Renewable Energy Center, 2016, p. 92).

Table 16 The Annual Share of Renewable Energy by Primary Sources

(unit: %)

Category	2012	2014	2020	2025	2030	2035
Share of New and Renewable Energy (Compared to Primary Energy Sources)	3.2	3.6	5.0	7.7	9.7	11
Solar Heat	0.3	0.5	1.4	3.7	5.6	7.9
Solar PV	2.7	4.9	11.7	12.9	13.7	14.1
Wind	2.2	2.6	6.3	15.6	18.7	18.2
Biomass	15.2	13.3	18.8	19.0	18.5	18.0
Hydro	9.3	9.7	6.6	4.1	3.3	2.9
Geothermal	0.7	0.9	2.7	4.4	6.4	8.5
Ocean	1.1	1.1	2.5	1.6	1.4	1.3
Waste	68.4	67.0	49.8	38.8	32.4	29.2

Source: Ministry of Trade, Industry and Energy (2014b), p. 5.

5.2. Policy Outcomes for Solar Photovoltaic Technology

The national research and development (R&D) capacity was focused on the selected major technologies, and the R&D budget for the solar photovoltaic technology was greatly increased. The annual R&D investment performance of the solar photovoltaic technology industry is presented in Table 17. The scale of investment increased dramatically as it was KRW 20.4 billion in 2005, KRW 85.4 billion in 2010, KRW 124 billion in 2010 and lastly, KRW 71.3 billion in 2015.

Due to active R&D investments in the solar photovoltaic technology, the annual supply capacity was largely expanded. In 2005, the supply capacity was only 5.0MW, but by 2015, the capacity was expanded to 1,133.9MW. During the same period, the overall supply capacity of renewable energy increased from 139.2MW in 2005 to 1,869.4MW in 2015. However, unlike the great performance shown through the expansion of the supply capacities, the technological advancement lagged behind. Actual outcome was dismal for technological development with the factory utilization rate of only 50% in 2012, and it was criticized that the R&D investment is heavily distorted towards the solar photovoltaic industry (Joint Work of Relevant Agencies, 2014, p. 9). Also, the restructuring of the renewable energy industry, due to

Table 17 Annual R&D Investment Performance and Supply Capacity of Solar Photovoltaic Technology

(units: KRW billion, MW)

	R&D Investment Performance						Supply Capacity	
	Solar Photovoltaic Technology			All Renewable Technologies			Solar Photovoltaic Technology	All Renewable Technologies
	Gov.	Private	Subtotal	Gov.	Private	Subtotal		
2005	15.0	5.4	20.4	79.4	42.5	121.9	5.0	139.2
2006	19.0	10.9	30.0	115.8	76.9	192.7	22.3	101.5
2007	17.1	11.1	281	120.9	92.8	213.7	45.3	328.6
2008	56.7	28.7	85.4	195.3	173.3	368.6	275.7	413.5
2009	70.6	33.2	103.8	205.6	136.7	342.3	166.8	451.1
2010	84.4	39.6	124.0	240.0	128.9	368.9	126.6	662.6
2011	76.8	42.2	119.0	243.3	213.5	456.8	78.8	532.6
2012	77.3	39.6	116.9	250.3	228.5	478.8	295.2	681.4
2013	63.6	28.3	91.9	248.6	530.8	779.5	530.7	1,796.1
2014	59.7	21.1	80.7	229.1	590.2	819.3	926.3	1,922.4
2015	51.3	20.1	71.3	213.1	273.8	487.0	1,133.9	1,869.4

Source: Ministry of Trade, Industry and Energy and Korea New and Renewable Energy Center (2016), pp. 180-181; Korea New and Renewable Energy Center (2016).

the global economy shrinking from the impact of global financial crisis, and the oversupply of components for solar photovoltaic and wind power systems, has become an obstacle for the development and commercialization of the solar photovoltaic technology (Joint Work of Relevant Agencies, 2014, p. 17).

In 2014, “The Second Five-Year Plan for Green Growth” was published, which included the objectives to actively pursue the development and commercialization of climate change response technologies. In this plan, the objectives related to the solar photovoltaic technology are cost reduction of crystalline silicon photovoltaic generation system, development of original technologies for amorphous solar cell/artificial photosynthesis, and creation of new business models. After the publication of the plan, the technologies related to “crystalline silicon solar cell”, “dye-sensitized/organic solar cell”, and “copper, indium, gallium, selenium (CIGS) thin film solar cell” are being actively developed. Among these technologies, in the case of the crystalline silicon solar cell technology, various technologies along the supply chain —

raw material, thin wafer, module, equipment, accessories, system — are being developed to reduce cost and achieve higher efficiency. Also, in the case of thin film solar cell, in order to obtain the first-mover advantage through cost reduction and efficiency improvement, various technologies are being developed for commercialization (Ministry of Trade, Industry and Energy, Korea New and Renewable Energy Center, 2016, p. 182.).

National Science and Technology Council (2016) has focused on the R&D performance of photovoltaic technology among the various climate change response technologies. It was assessed that the domestic production of components and equipment for silicon solar cell technology has led to industrialization performance of high sales and job creation. Also, the next generation solar cell sector has shown excellent performance as the perovskite solar cell achieved the world's highest efficiency (22.1%), and original technologies were developed in the process.

The uncertainty for the global market of green technology is ever increasing due to various factors, such as global economic situation, the necessity to reduction of greenhouse gases (GHG), energy crisis, etc. Therefore, rather than indiscreetly increasing the R&D investment, there is a need to establish short- and long-term goals through strategic focus and selection, which can serve as a guide for development, industrialization and commercialization of green technologies.

6. CONCLUSION

Korea that has experienced rapid economic growth over past the half-century depended heavily on heavy-chemical industries as growth engines. Even though per capita income increased from 156 USD in 1960 to 27,222 USD in 2015 at current USD, Korea faces huge emissions of GHG with the second fastest growth rate of emissions among OECD countries for 1990-2013 and about 2.0% share of the world emissions. Therefore, in order to sustain current growth engines and expand economic growth further, it is

necessary to shift a development strategy to a more eco-friendly development paradigm. This was why President Lee proclaimed green growth strategy as a new future development paradigm.

To implement green growth strategy, Korea enhanced various implementation steps via legislation, organization, budget, and policy. In legislation and organization, the government established the PCGG under the "Framework Act on Low Carbon, Green Growth" and especially the PCGG was directly under the President's office though it was moved to the Prime Minister's office in 2013. The budget of approximately 2% of GDP was allocated to the policies for implementing green growth even though it was shifted from other sectors to green growth sectors; thus, there was no net increase of government budget. As more concrete steps, the government legislated various Acts and achievement policies to reduce GHG emissions and sustain economic growth such as the GHG and Energy TMS, RPS and ETS, and others.

Since green growth policy has been promoted in Korea, investment in the solar photovoltaic sector has greatly increased. As a result of these efforts, the technology level has been improved and the supply capacity was largely expanded. However, considering the uncertainties in the global market and the need to expand the supply of renewable energy, it is necessary to develop effective policy in terms of e expanding the renewable energy capacity with a long-term perspective.

Even with various measures and organizations, Korea is still facing difficulties in reducing GHGs. Even though growth rate of GHG emissions decreased from 9.9% and 4.4% in 2010 and 2011, respectively to 0.4% in 2012, it is not certain whether this trend is sustainable since lower growth rate might be resulted from recent economic depression with about 3% of economic growth rate. Furthermore, the current government might change the reduction target of GHG emissions when it is compared to the proclamation by the former government.

However, Korea will continue pursuing its green growth strategies to sustain economic growth and protect environments by joining international

community for tackling climate change and sharing Korea's development experiences with more eco-friendly technology transfers and financial supports to developing countries.

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