The Effects of Policy Portfolio for Greenhouse Gases Reduction and Renewable Energy Expansion: An Analysis Using Computable General Equilibrium

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Abstract

South Korea has pledged to reduce its GHG (Greenhouse Gas) emissions by 30%, relative to the country's projected levels (BAU, Business as Usual) by 2020, and has implemented and promoted various policies to meet the target. Many other countries in the world introduce various policy tools for a low-carbon economy in order to achieve both targets for economic growth and environmental sustainability. The GHG reduction policies can be roughly classified into two major policy types. One is technology-push policy, which includes the research development policy. This type of policies intends to meet the GHG reduction target based on the development of low-carbon or alternative energy technologies. The other one is the market-based policy (pulling the demand for technological innovation), such as emission trading scheme and renewable energy expansion policy (Renewable Portfolio Standard (RPS) and Feed-in Tariff (FIT)). It is important to understand the difference between the two types of policies, technology-push policy and demand-pull policy, which one is more effective to reduce GHG emissions, and to identify the ideal mix of the two. However, there are not enough relevant previous studies that theoretically and empirically analyzed these subjects.

In this regard, the study analysed the effects of these two ways to reduce GHG emissions. One is supported by R&D investments on technologies in energy and environment sector, and it is the main policy instrument within the technology-push policy. The other one is supported by the implementation of emission trading scheme, Renewable Portfolio Standard, or Feed-in Tariff that are the main demand-pull policies. Also, this study drew implications for the analysis on the effects of the existing classification of the GHG reduction policies of the government. In addition, the study analysed the effects of the policy mix to reduce GHG emissions that the government of South Korea currently considers. To this end, the study designs an energy–environment computable general equilibrium model that is applied to the economic system of South Korea and conducts an empirical analysis based on the model.

Keywords: GHG emissions reduction, energy and environmental policy, policy mix, Computable General Equilibrium

1. Introduction

1.1. Background

South Korea has introduced or planned various policies in the energy and environment sector and expanded its R&D investment on energy efficiency improvement as well as on development of new and alternative technologies to meet its GHG (Greenhouse Gas) reduction target.

It is expected that the government's R&D investment on carbon emissions reduction and renewable energy technologies to reduce GHG emissions continues to increase because the national research development investment budget for energy and environment sector increases by an annual average

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rate of 10%. It is a global trend to focus on the policies to expand the R&D investment and to raise subsidies for the development of technologies in line with carbon emissions reduction and renewable energy to tackle the climate change issues. However, according to the previous studies on R&D investment and support, it is strongly recommended to establish policies focusing not only on new technological invention but also on the adoption and diffusion of the results of such innovation. For instance, the R&D of the energy sector in South Korea has showed high success, however, the results hardly lead to the creation of the relevant market (Ministry of Science, ICT and Future Planning, 2013). Therefore, to meet the GHG emissions reduction target and to propel the diffusion of renewable energy, it is critical to plan the proper policy portfolio based on the flexible combination of technology-push policy and market-pull policy.

At this point in time, the government of South Korea shall prepare the methods to attract private R&D investments in order to vitalize the domestic market and establish proper market-based policies while continuously expanding the governmental R&D spendings on the energy and environment sector. For this reason, the government has a plan to implement the emission trading scheme by 2015 to efficiently reduce the GHG emissions of the industry sector based on the market-based policy and to prepare for the international carbon market while achieving the GHG emissions reduction target. In addition, many countries adopting the emission trading scheme has considered renewable energy dissemination and expansion policies, such as Feed in Tariffs (hereinafter, FIT) and Renewable Portfolio Standards (hereinafter, RPS) to reduce their overall GHG emissions as well as to encourage sustainable development (Jung, 2010). Because the energy sector represents a share of about 85% of the total GHG emissions in the world, the sector is widely recognized as a key issue for the climate change mitigation (Korea Electrotechnology Research Institute, KERI). With the growing global attention to the interrelation between energy and climate change, South Korea has converted the FIT into RPS from 2012 as part of the effort to promote the market-based policies for renewable energy expansion.

Other major countries also consider the GHG reduction policies in relation with the energy policies for the purpose of climate change response and sustainable economic growth. The GHG reduction package must be planned and promoted within a more integrated approach, which covers these various policies and reflects the domestic conditions so that the industrial competitiveness of a country can be sustained. Nevertheless, South Korea shows very strong tendency to concentrate on the partial-equilibrium approach, which only focuses on the effectiveness of a single policy. Therefore, the government should notice the importance of the integrated approach considering the impact of one policy on the others (complementarity or conflict) (Kang, 2013). It is not proper that the government only continues the effort to expand the R&D investment on the relevant technological development not considering the effectiveness of simultaneous introduction of energy and environment policies.

For this reason, this study analyzed the effects of the two types of policies to achieve the GHG reduction target in South Korea, technology-push policy based on the R&D investment on the energy and environment sector, and market-pull policy, such as emission trading scheme and RPS. Beyond the effects analysis, it intended to understand the effectiveness of the policy mix that is currently planned by the South Korean government. As a result, it suggests the direction of the policy mix for South Korea to meet the GHG reduction target in the future based on the evaluation on the feasibility of the policy mix that the government currently considers.

2. Research Methods

This study used Computable General Equilibrium (CGE) model for analysis, which generally described the production and consumption, physical capital's flow, and energy consumption trend of the economy of South Korea. In this model, it is assumed that the economy consists of representative producer and consumer agents. The model shows the economy structure in relation with the production and utility function where the products and factors flow across the agents. Under the assumption that producers and consumers make decisions to minimize production costs and maximize utility, the objective function and constraints of each agent are set based on the data from the base year. With this calibrated economic system, various policy shock (or scenario analysis) tests are possible. When there are exogenous policy shocks, such as regulations and policies, the macroeconomic impacts can be described by comparing the existing equilibrium status and the new equilibrium status. For the analysis, this study developed the macroeconomic model based on the CGE approach representing South Korea, which considers and applies the generation-mix data and the electric power development plan in order to understand the effects of adopting energy and environment policies, such as the emission trading scheme and RPS on the overall economy of South Korea.

3. Literature Review

3.1. The Form of Government Intervention on Policy in the Energy and Environment Sector

Jaffe (2005) suggested that the technological advancement and change are crucial to respond to climate change. He also noticed the positive externality of technological innovation that serves as a stumbling block to voluntary activities for technological developments and innovation. Technological innovation commonly has a characteristic as a public good and is diffused through the society by the so-called "spillover effect," thus increasing the economic welfare (Geroski, 1995). However, because the companies who deliver the technological innovation cannot monopolize their performance or profits or cannot be fully rewarded, the lack of economic incentives for technological innovation results in demotivation of the companies for innovation. Accordingly, Jaffe (2005) and Popp (2011) emphasized the need of government-directed efforts to solve two types of market failure, when technological innovation is considered a crucial factor for climate change response. The first type is the negative externality of environmental pollution and GHG emissions, and the second one is the positive externality of technological innovation. In other words, because the low-carbon technology contains two contrary aspects of externality consisting of GHG emissions and technological advancement, there are obstacles to impede the dynamics of technological change.

In this context, Yoon (2009) suggested that given these two externalities, the intervention of public policy is necessary, rather than the voluntary market force, to raise the advancement and diffusion of environmental-friendly technology for climate change response to a socially proper level. He also highlighted that since climate change, in itself, is very uncertain as well as it takes long period of time to evaluate the effects of developed technology on prevention of climate change, the role of government is important regarding the substantial risk related to technological innovation. In addition to the market failure issue, the distinct characteristics of energy industry are considered as a factor for the lack of voluntary private investment on R&D of alternative energy and low-carbon technologies. In the energy sector, because the products are hardly differentiated and niche markets are limited, it is common to spend substantial time and capital to convert previous the energy and electricity generation technologies to the alternatives. In this regard, voluntary innovation in the energy sector is difficult to be realized.

It is clear that since the uncertainty level of climate change and the response to it is high and the energy industry has the distinct characteristics, the low-carbon technologies have a fundamental problem related to the private sector’s investment. Therefore, regardless of the price policies or technological policies, the strong policies driven by the government are necessary (Grubb, 2004; IPCC, 2007; Yoon, 2010). According to Grubb (2004) the government’s policies for the energy and environment sector to respond to climate change and to achieve GHG reduction target are roughly categorized into two policies: technology-push policy and demand-pull policy. The technology-push policy focuses on development of new technologies of low-carbon and alternative energy to solve climate change issues. The common example of the policy is found in the ways of the government or public institutions to manage and distribute the R&D budget. The forms of major policy instrument include R&D funds and subsidies. The researchers who support for technology-push policy emphasize the close interlink between climate change and long-term GHG accumulation function. Furthermore, they insist that technological innovation should be preceded before initiating the policy instruments such as emission controls or carbon tax so that the efforts to reduce GHG are facilitated at low costs following the technological innovation.

Table 1. Classification and comparison of the GHG reduction policies of the government

Classification	Technology-push policy	Demand-pull policy
Definition	The government bears the risks and expenses concomitant with developing new technologies, such as low-carbon technology and alternative energy to encourage technological innovation, thus reducing GHG.	The demands for new technologies, such as low-carbon technology and alternative energy are intentionally expanded to encourage technological innovation, thus reducing GHG.
Long-term perspective	In general, the efforts to meet the GHG reduction target entail high costs without radical innovation for which technological advancement is essential.	Incremental innovation is sufficiently cost-effective to support the efforts to meet the GHG reduction goal.
Major policy tools	▪ Direct funds of the government on R&D and pilot projects ▪ Subsidies and tax incentives on private sector’s technological development	▪ Carbon price: Carbon tax and emission trading scheme ▪ Public procurement: The preferential purchase of low-carbon technology or product by the government ▪ Renewable energy promotion policies: Feed-in Tariffs (FIT) and Renewable Portfolio Standards (RPS)

On the contrary, the demand-pull policy induces the creation and expansion of demand for environmental-friendly technologies based on the market-friendly price or regulatory policies. Emission trading scheme, carbon tax, and RPS are the tools used for this policy. The basic perspective of the policy is that once the regulatory policies on the market are implemented, the profit-driven companies will show the strong motivation to invest in R&D on environmental-friendly technologies, such as low-carbon technology, and to participate in relevant technological innovation in order to gain a competitive advantage over other companies. Therefore, the researchers who support for the demand-pull policy believe that the delay on the implementation of government's regulatory policies, such as GHG emission regulations, slows down the technological innovation of the relevant sector.

In this regard, this study analyzed the effects of the two different ways to reduce GHG emissions. One is supported by R&D investment on the energy and environment sector, which is the main policy instrument of technology-push policy, and the other one is supported by the implementation of emission trading scheme, RPS, and FIT that are the main demand-pull policies. The study also draws implications for the analysis on the effects of the existing classification of the GHG reduction policies of the government.

3.2. Policy Mix of the Energy and Environment Sector

Many countries around the world have implemented various policy instruments in the environment and energy sector to reduce GHG. Kang (2013) argued that because the GHG reduction policies and energy policies are closely interlinked, it is important to approach GHG reduction policies from a comprehensive perspective. He also highlighted that without a comprehensive perspective, the original integrity of each policy could be damaged, causing governmental inefficiency. South Korea has pledged to reduce its GHG emissions by 30%, relative to BAU by 2020, and planned to introduce the emission trading scheme by 2015. In addition, RPS has been implemented since 2012. Based on the current condition of South Korea, Kang (2013) pointed out the government has so far overly focused on the effects of individual GHG reduction policy from a partial-equilibrium perspective. He also expressed the concerns over the current situation in South Korea where the environment and energy policies are indiscriminately and simultaneously introduced without a clear understanding about how much each policy contributes to GHG reduction without comprehensive analyses on the interactions among policy instruments.

Indeed, the analyses on the effects of the energy and environment policies related to climate change have overly focused on a single policy tool analysis or the comparison among policy tools. This is because the analyses are based on the premise in which the policies are interchangeable. However, as multiple policies related to climate change are currently implemented in a mixed form, policy mix issues are being actively discussed. In fact, some policy tools conflict each other, but some are complementary (Gunningham and Sinclair, 1999; OECD, 2007). Bernnear and Stavins (2006) highlighted that when multiple market failure problems occur, it is important to adopt a proper policy mix rather than a single policy tool. Sorrell and Sijim (2003) emphasized that when environment and energy policy instruments related to climate change are implemented in the mixed form, the interrelation among policies should be understood and the evaluation on the policy mix should be followed.

Since overlapped policy tools cause overlapped-benefit or overlapping-regulation problems, the analyses on the effects to implement policy tools in a mixed form are important (Han and Yoon, 2010; Jung, 2010). Policy mixes could correct the market failure, but they could also bring negative effects at the same time. Concerning this matter, Johnstone et al. (2010) warned that some policy mixes that use more than one instrument to achieve a policy target, at the worst, cause only adverse effects. Therefore, when mixing policy instruments as a mixed-from, it is important to fully understand the positive and negative relations among them so that the regulation tools can be complementarily integrated. Other countries are also implementing the policies for GHG reductions in a mixed form, but they lack the capacity to analyze the effects of the policy mixes. In addition, as Kang (2013) pointed out, because the industry structure, the level of GHG reduction technology, and the GHG reduction policy package vary depending on country, South Korea must understand the effects of GHG reduction policy mix based on proper analysis before introducing or implementing it. If the government does not thoroughly examine the effects, the poorly mixed policies could weaken the nation's competitiveness in a long term. Therefore, in the first part, this study analyzed the effects of technology-push policy and demand-pull policy for South Korea's transition to a low-carbon economic system. In the second part, it drew political implications on the policy mix of environment and energy sector considering policy instruments, such as trading emissions and RPS in which South Korea has implemented or planned to introduce.

4. Model Design

4.1. Structure of production sector

1) Production structure of the industry sector (excluding electricity sector)

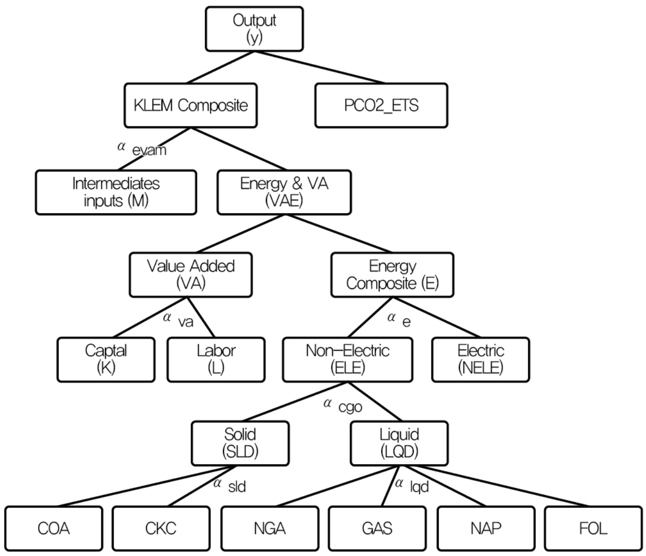

Figure 1. The final goods production structure (excluding the electricity sector)

In this model, 'i' industry produces the goods generally based on its labor, capital, energy inputs, and Amington intermediate inputs. The final goods production structure of 'i' industry is formed in the nested CES function. In this structure, each input element is grouped into a nesting structure, and the groups are again nested at the upper levels, forming the final goods production. In the production nesting process of the final goods, the value added (VA) composed of capital and labor inputs and the energy goods (E) composed of electricity and fossil fuel inputs are combined at the upper level forming the Energy & VA composite (VAE). Here, the energy composite (E) is divided into the electricity (ELE) and the nonelectricity (NELE). The nonelectricity, again, is split into the composite of fossil fuels that emit CO_2. Based on the characteristics of fossil fuels, the nonelectricity is categorized into two substructures that are the solid fuel composite (SLD) into which coal and coke are nested as well as into the liquid fuel composite (LQD) into which crude, oil, fuel oil and naphtha are nested. Within the solid fuel composite and liquid fuel composite, each fossil fuel forms the fossil fuel composite in which composites and CO_2 are mixed. This section skips the explanation on the model details, but Figure 1 shows the nested-production structure.

2) The production structure of electricity sector

In other models, the electricity sector is considered a single sector, but the model, which is designed for the analysis, presents the structure in which the individual electricity generation technology generates the uniformed good, which is the electricity. Based on the model, all the electricity generated by each generation technology is added up, and the total sum is calculated as the production of electricity sector. Thus, the characteristic of each technology can be reflected in the analysis. First, the electricity generation composite (CN) that is formed by the combination of intermediate inputs and the value added (except the capitals that are fixed by each generation technology) has the structure where intermediate inputs, fossil fuels, as well as labor. In such process, the elasticity of substitution among those elements comprising the electricity generation composite (CN) is assumed as 0, forming the Leontief function. The electricity generation composite (CN) is combined with the fixed capital, which is put into the generation technology sector at the upper level, thereby forming the capital-generation composite (KM). Boehringer and Rutherford (2007) and Wing (2006) found that the capital, which is put into each generation technology, represents the capacity limit of each generation technology. Based on this finding, the study also considers the capital, which is put into an electricity generation technology as a specialized fixation element (RKE) that characterizes the generation technology.

In the electricity generation sector, the fossil fuel, which is specialized to each generation technology, is used. For example, in the case of the generation technology based on coal, the coal is used as the intermediate input of fossil fuel that is specialized for the technology. In addition, in this model the backstop technology (PBSP) is also considered along with the fossil fuel that is specialized to each generation technology (PA_ELE). At a lower level, the fossil fuels and the backstop technology are combined, composing the generation technology goods (BCK), and at the upper level, the BCK and the knowledge stock (Knowledge) are combined. This structure organized by each composite stage is created in reference to the structure of ENTICE-BR model that Popp (2002; 2004; 2006) presented. In other words, the composite formed by the combination of the fossil fuel that is specialized to each generation technology (PA_ELE) and the backstop technology (PBSP) is the energy composite that is put into electricity generation. This composite, again, is combined with the knowledge stock (Knowledge) at the upper level of the structure in which the production nesting structure below shows. In addition, the equation of this structure is also shown below.

$$EFF_{ENE} = [\alpha_H H_E^{\rho_{know}} + ({PA_{ELE}}^{\rho_{bck}} + PBSP^{\rho_{bck}})^{\rho_{know}/\rho_{bck}}]^{1/\rho_{know}}$$

$$PBSP_t = {PBSP_0}/{H_{E,t}^{\gamma}}$$

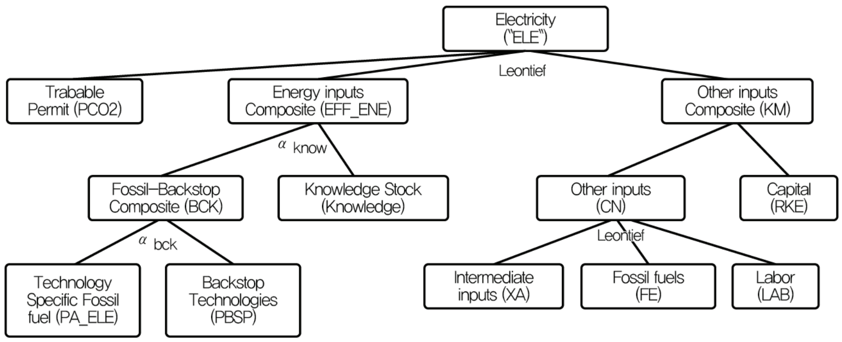

Figure 2. Final electricity production structure of the electricity generation sector

As seen in the equation and the production composite stages, the fossil-backstop composite (BCK) and the knowledge stock (Knowledge) are substitutes for each other. Thus, when the knowledge stock increases in the electricity generation sector, the amount of fossil-backstop composite (BCK) decreases. Considering this relation, the study reflects that energy efficiency improves by increasing the knowledge stock, which is similar to the ENTICE-BR model on which studies of Popp (2002; 2004; 2006) are based. The elasticity of substitution σ_{know} between knowledge stock and fossil-backstop composite in the electricity generation sector is set up as 0.7 (Popp, 2002; 2004). Also, the study assumed that there is an incomplete substitution relation $(\sigma_{bck} = 0.5)$ between the fossil fuel input that is specialized to each generation technology (PA_ELE) and backstop technology. Therefore, when the costs of backstop technology are more competitive than the one of fossil fuel, it can secure the market entry condition. Because there is no sufficient study previously conducted in line with the backstop technology costs for the production compared with the one of the existing fossil fuel, in reference to the study of Oh (2011) on renewable energy costs scenarios, it is assumed that the backstop technology cost is five times more expensive than the fossil fuel cost in 2010, and the cost decreases as the knowledge stock increases.

In this way the model reflects the structure where the energy input composite (EFF_ENE) of the electricity generation sector is combined with the capital-generation composite (KM) at the upper level to produce electricity. When the emission trading scheme is implemented, the structure, where the emissions permit is consumed depending on the input of the fossil fuel that is specialized to each generation technology of the electricity generation sector, is additionally considered. Based on all of these considerations and findings, the electricity production structure of the generation sector is prepared as in Figure 2.

4.2. Knowledge stock and technological advancement modeling

In this section, it is explained how the external effect (spillover effects) of knowledge is reflected in the study based on the industrial R&D investment and the knowledge stock within the model study designed above. First, the level of R&D investment and knowledge stock of each industry shall be estimated according to the industry classification on which the model is based. To this end, the study referred to the study method of Yang, et al. (2012) and capitalized R&D based on the input-output (I-O) table where the research & development spendings are considered as an intermediate consumption. In addition, the level of R&D investment and knowledge stock in 2010 (base year) has been estimated by industry (21 of industry classification on which the model is based).[1] In accordance to this, the knowledge stock of each industry is considered the factor endowment for the main consumers. Based on the estimation of the level of knowledge stock and R&D investment[2], the characteristics of competitive technology and noncompetitive technology are reflected in the model.

As explained above, in the production structure of electricity generation sector, for back-stop technology to enter the market is associated with the R&D investment costs of each generation technology. This means that renewable energy and backstop generation technology are the elements that require the R&D costs as Goulder and Schniedr (1999), Cho and Kim (2012), and Popp (2002; 2004; 2006) suggest.[3] Furthermore, they also consider the characteristics of knowledge, which causes the external effects, and non-competitive elements. Thus, in this model the spillover effect is also reflected. The non-competitive technology is considered as a factor that does not cause production costs while contributing to the productivity of each industry through the spillover effect. (Cho and Kim, 2012)

When it is assumed that technological advancement has externality and spillover effects by knowledge, the production function of the industry sector in the model is shown below. Differing from the equation that is shown above, this function includes $\Phi(H)_i$, which means that it shows the productivity increase level of each industry by the external effects. Also, in the equation, VAE_i represents the composites, such as the capital, labor, and energy. E means the energy composite, including backstop technology, and M_i means the intermediate input. Without $\Phi(H)_i$, the production equation of each sector below, which has the characteristic of constant returns to the scale. However, once the $\Phi(H)_i$ function, which means the external effect is considered, it becomes a function of increasing returns to scale against the principle for general equilibrium (Cho and Kim, 2012). This is because, as explained above, for the complete general equilibrium, three conditions, zero profit, market clearing, and income equilibrium should be satisfied.

$$Y_i = \emptyset(H)_i\left[\alpha_{vae} VAE_i^{\rho_{klem}} + \alpha_m M_i^{\rho_{klem}}\right]^{1/\rho_{klem}}$$

To approach this matter, the study referred to the calculation method of Markusen (1990, 2000) who modified the form of production function above and calculated as below. In the equation below, (Y_i^{β}) means the level of productivity increases according to the external effect of knowledge β. is the important valuable showing the increasing level in the scale. In addition, $F(V_i)$ is the equation of constant returns to scale, $Y_i = \Phi(H)_i\left[\alpha_{vae} VAE^{\rho klem_i} + \alpha_m M^{\rho klem_i}\right]^{1/\rho klem}$.

For β, because the level of external effects can vary depending on the level of R&D investment and knowledge stock of each industry, as the equation of Cho and Kim (2012), the level of spillover is reflected in the model. Here, $H_t = \sum i H_{i,t}$ is the total sum of the knowledge stock and the R&D investment of all industries.

1 Yang, et al., (2012) study on the knowledge-based social accounting matrix, Productivity Journal, 26 (3). 257–285.

2 The knowledge stock of each electricity generation technology in the electricity generation sector is estimated in a way that the knowledge stock in the electricity generation sector is distributed based on the production share of each generation technology.

3 The competitive backstop and renewable energy generation technologies are created through R&D investment, and they are considered an input.

As an external effect, this affects the productivity increase level of each industry. In the equation, the value of γ is set up as 0.03 based on the study of Cho and Kim (2012). Based on this apporach, the study tried to reflect the fact that the level of external effect depends on the level of knowledge stock of each industry in the model.

$$Y_i = \left(Y_i^{\beta}\right)F(V_i) \qquad ; 0 < \beta < 1$$

$$\beta_t = {H_t^{1/\gamma}}\big/{H_t} - 1 \qquad ; \gamma < 1,\ H_t = \sum_i H_{i,t}$$

5. Scenario Set-up and Results

5.1. Scenario Design

The study designed four major scenarios for analysis. The baseline scenario (SC_0) is designed to understand the approach to GHG reduction of South Korea that is based on the technology portfolio compositions that the government currently prepares (technology-push policy for GHG reduction) and its effects. In response to this, the second scenario (SC_1) is designed to analyze the market-based policy for GHG reduction of the government that brings the demand-pull policy and its effect. In the second scenario, the emission trading scheme, which is the main GHG reduction policy (market-based policy) that South Korea plans to implement by 2015, is considered. Under the scenario, the R&D and knowledge stock of each industry sector are not considered. To analyze the effect of GHG reduction led solely by the emission trading scheme market, the knowledge stock and the technological advancement that are mentioned above are not reflected in the scenario. Fischer (2008) pointed out that there are no sufficient studies that theoretically and empirically analyze which type of GHG reduction policies is more effective between the two types of the governmental policy intervention for GHG reduction and climate change response, technology-push policy and market-pull policy, as well as the ideal combination of the two. In this regard, the study analyzes and compares the effects of the two scenarios (SC_0 and SC_1 scenarios) and draws relevant implications.

In addition, the study designed the third scenario (SC_2) where the emission trading scheme is implemented when the entry of the back-stop technology is considered and R&D investment on each industry sector leads technological advancement. SC_2 scenario is a more practical form of policy portfolio in the environment and energy sector of South Korea compared with SC_0 and SC_1 scenarios. This is because in practice, to meet the long-term target of GHG reduction, it is important to keep the direction and pace of technological change. Thus, many countries encourage the development of new technologies while expanding the demand of currently available technology (Yoon, 2009). In addition, several studies that analyze the effects of energy and environment policies show that when technological advancement is considered in a model, the costs for climate change policies decrease (Nordhaus, 1997; Goulder and Schneider, 1999; Goulder and Mathai, 2000; Gerlagh and Zwaani, 2003; Cho and Gang, 2003; Popp, 2006; Bosetti, 2008). In this regard, the study also aims to understand the mechanism in which the introduction of GHG reduction policy (emission trading scheme) brings the costs reduction effects across the economic system of South Korea when technological advancement in the energy and environment sector is considered under the scenario, SC_2.

Under the fourth scenario (SC_3), the situation, where RPS is implemented for the electricity sector, is considered in addition to the condition of third scenario. This is the form of the policy mix that South Korea will take after it introduces emission trading scheme by 2015. As mentioned above, South Korea has pledged to reduce its GHG emissions by 30%, relative to BAU by 2020, and planned to introduce the emission trading scheme by 2015. For this, South Korea has implemented the Renewable Portfolio Standard, which is the policy to expand renewable energy since 2012. Therefore, under the fourth scenario (SC_3), the R&D to develop low-carbon and alternative energy technologies in the energy and environment sector, emission trading, and RPS are all considered. Also, based on the analysis of the results of the scenario, the study tried to analyze the effects of the policy portfolio that South Korea designed for GHG reduction.

Considering that most of the previous studies agree that carbon taxes and emission trading schemes are more cost-effective policy tools compared with renewable expansion policies (Kang, 2013), the study compares the fourth scenario (SC_3) and the third scenario (SC_2) in-depth. The previous studies also indicate that when emission trading schemes and renewable energy expansion policies are simultaneously introduced, social inefficiency increases as the total costs rise. However, South Korea has not conducted enough empirical analysis on it although it has planned to introduce those policies in a mixed form. Thus, the study draws implications on the composition of policy portfolio for GHG reduction in the energy and environment sector that the government currently promotes based on SC_2 and SC_3 analysis. The scenarios designed in the model for analysis and the detailed explanations on them are summarized in the table below. Also, because the computable general equilibrium model is a static model, the target year is set up as 2020 and the effects comparison analysis is conducted by comparing the level of increase and decrease variation among the major variables of each industry and macroeconomics in 2020.

Table 2. Scenarios designed in the analysis model and details about them

Scenarios	Scenario details
SC_0	▪ The R&D investment and knowledge stock of each sector as well as the technological advancement are considered. ▪ Analysis on R&D investment and its effects on GHG reduction led by technological advancement.
SC_1	▪ The R&D investment and technological advancement are not considered. ▪ Emission trading scheme's GHG reduction effects (GHG reduction effect solely by the emission trading scheme market)
SC_2	▪ The implementation of the emission trading scheme under the situation where R&D investment and the knowledge stock of each sector and technological advancement (low-carbon and alternative energy) are considered. ▪ Realistic form of the policy portfolio in the environment and energy sector of South Korea
SC_3	▪ The implementation of the emission trading scheme under the situation where R&D investment and knowledge stock of each sector and technological advancement (low-carbon and alternative energy) are considered + implementation of RPS. ▪ Realistic form of the policy portfolio in the environment and energy sector of South Korea

5.2. Result Analysis

(1) Comparison between technology-push policy and demand-pull policy for GHG reduction

Figure 3 shows the result of the comparison of GHG reduction effect between SC_0 and SC_1. In the first scenario, only R&D and technological advancement are considered without the constraint condition of 30% GHG reduction in 2020 against the BAU of South Korea. When compared with the second scenario (SC_1) where the emission trading scheme is implemented under the 30% reduction target, the first scenario shows relatively low GHG reduction effect. When carbon prices do not exist in the investment policies for R&D on low-carbon and alternative energy, it is difficult to reward the innovative activities, especially the ones in line with new technologies. In other words, without the policies that charge price for carbon emissions, it is hard to drive the motivation for the development of low-carbon technologies. For this reason, the GHG reduction effect of R&D investment, involving technological advancement, is relatively lower than the one of the emission trading scheme market where carbon prices are imposed.

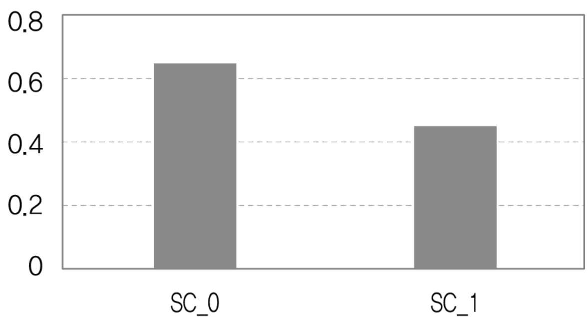

Figure 3. Comparison of GHG emissions level between SC_0 and SC_1

Table 3 shows the change in GDP and the consumption by scenario and the comparison between them. The table indicates that the scenario in which only technological policy is considered has relatively high level of GDP and consumption. This is mostly because knowledge has the characteristic of public goods. Thus, production increases as the knowledge stock of the whole society is accumulated with the support of the industrial R&D and its external effect during the analysis period. Accordingly, the level of consumption of consumers and GDP increases. As a result, the level of consumption and GDP under SC_0 is higher than the one under SC_1. Also, when the emission trading scheme is implemented according to the GHG reduction target under SC_1, the introduction of the GHG reduction policies incurs policy costs. Because the use of the production facility decreases across the society while the costs of energy use to produce the final goods increase as the emission trading scheme is introduced to the economy system, the overall production costs increase. As a result, the indicators show that the decreased production across the economy system causes the declined level of consumption of consumer and GDP loss.

Table 3. Change in GDP and consumption under SC_0 and SC_1

	SC_0	SC_1
Change in GDP (% change for SC_0)	-	-0.73
Change in the level of consumption (% change for SC_0)	-	-0.68

The change in the indicators in the electricity generation sector is also examined by scenario. Based on the share of renewable energy's generation with each electricity generation sector by scenario, it is found that transition to the low-carbon generation system is easier under SC_1 compared to SC_0. Although R&D investment on backstop and low-carbon technologies, as well as the market entry that is facilitated by the investment, are considered under SC_0, the effect on renewable energy generation share is lower than the one under SC_1. This shows that even if R&D investment on renewable energy and low-carbon technologies can lead to the development and invention of new technologies, there are limits for these new technologies to be adopted and diffused into the market. The results of this analysis, which are similar to the ones of Popp (2006), show the limit of technology policy prepared for GHG reduction and for the transition to the low-carbon energy system.

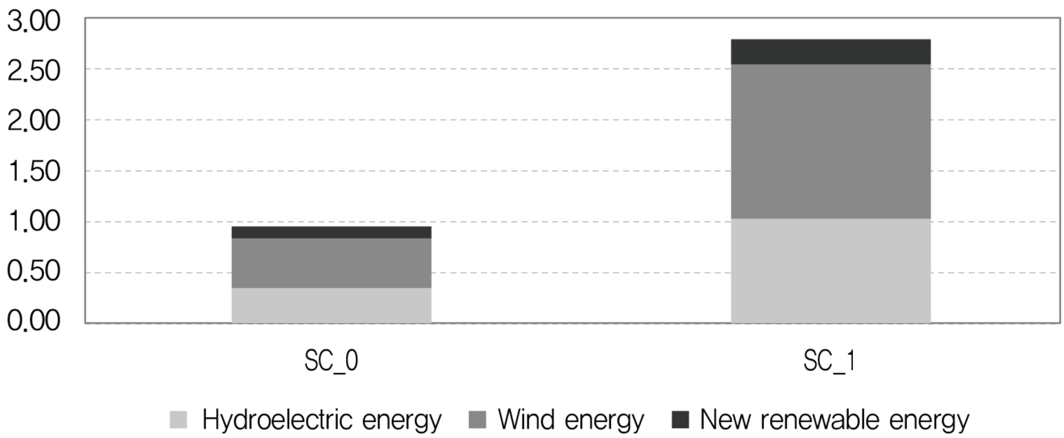

Figure 4. Renewable energy's generation share of electricity generation sectors under SC_0 and SC_1

(2) Analysis on the effects of the policy portfolio in the energy and environment sector

As mentioned above, without the policies that charge price for carbon emissions, it is hard to drive the motivation of companies to develop low-carbon technologies and to ultimately reduce GHG emissions. In practice, the government encourages the double-edged strategies, which stimulate new technology development while expanding the demand for available technologies for climate change response and GHG reduction, rather than the strategies that introduce R&D policy and market-based policy separately. In this regard, this section analyzes the effect of the policy portfolio in the energy and environment sector that South Korea currently prepares beyond the comparison among the types of the governmental policy intervention that was discussed above. In this section, SC_2 and SC_3 are considered. For SC_2, the emission trading scheme is implemented under the situation where R&D investment and the knowledge stock of each sector as well as the technological advancement are considered. It is the case where the R&D investment on low-carbon and alternative energy technologies are made under the situation where the price on emissions is considered. Also, under SC_3 implementation of RPS is added to the conditions of SC_2.

Table 4. Comparison of the change in macroeconomic indicators among SC_0, SC_1, and SC_2 (% change for SC_0)

	SC_0	SC_1	SC_2
Change in GDP	-	-0.73	-0.67
Change in the level of consumption	-	-0.68	-0.21

The table above summarizes the results of comparison of effect on GDP and the consumption level among SC_0, SC_1, and SC_2. The previous studies, which analyzed the effects of energy and environment policies, show that when technological advancement is considered in the model, the costs in climate change policy decrease (Nordhaus, 1997; Goulder and Schneider, 1999; Goulder and Mathai, 2000; Gerlagh and Zwaani, 2003; Cho and Gang 2003; Popp, 2006; Bosetti, 2008). Similarly, this study found that when the emission trading scheme is implemented under the situation where technological advancement is considered (SC_2), the costs needed for environment policy that the overall economic system bears somewhat decrease compared with the one where technological advancement in not considered (SC_1). In this case (SC_2), because of the emission costs that the industry incurs and production activities are depressed, the change in the level of GDP and consumption still has decreased value compared with the baseline scenario. However, when technological advancement is considered, the knowledge stock accumulated across the society brings the ripple effects of knowledge, and R&D investment helps low-carbon and alternative energy technologies to enter the market, thus mitigating the depression on the consumption and GDP loss.

In addition, for two major indicators of the electricity generation sector that are the level of GHG emissions and electricity production, it is found that SC_2 shows higher level of GHG emissions reduction compared with SC_1 where the emission trading scheme is only implemented without the consideration of technological advancement. However, as GHG emissions decline, the decrease level of electricity production is less under SC_2 than the one under SC_1. This is because as the R&D investment on each electricity generation technology helps the backstop technology, which does not emit GHG to secure price competitiveness while accumulating knowledge stock, energy inputs are substituted. For the change in the energy mix of the electricity generation sector compared with SC_1, under SC_2, the share of renewable energy's electricity generation increases while the one based on fossil fuel generation, including coal and gas generation, decreases.

Table 5. Change in the major indicators under SC_1 and SC_2 (% change for SC_0)

	SC_0	SC_1	SC_2
Level of GHG emissions	-	-49.14	-50.50
Electricity production	-	-10.78	-10.65

However, South Korea attempts to realize GHG reduction and low-carbon energy system by introducing RPS, which is the renewable energy expansion policy, along with R&D policies and the emission trading scheme in the energy and environment sector. In this regard, section SC_3 is additionally considered. SC_3 is the most realistic and the main type of policy portfolio that South

Korea will introduce and implement in the energy and environment sector. With this, in the last part of this section, the effect of SC_3 that is designed above is analyzed to draw implications on a more elaborated policy mix of South Korea in the future. The additional government policy interventions for GHG reduction and the renewable energy expansion incur policy costs. Compared with SC_2 under which the emission trading scheme is implemented with consideration of technological advancement, when the emission trading scheme and renewable energy expansion policy are simultaneously introduced, GDP loss and the decrease in consumption level are greater, and finally, larger social losses occur. This means, as indicated by the study results of Paltsev et al. (2009) and Morris (2009), when the emission trading scheme is solely applied to GHG reduction, the most effective technologies can be used, but if it is combined with RPS, the flexibility to choose the most cost effective technologies decreases, incurring economic costs.

In addition, based on the GHG reduction effects of the policy mix that SC_3 considers, it is found that the additional GHG emissions reduction effect will not occur with the introduction of RPS compared with SC_2. In other words, this study found that as long as the emission allowance exists in the economic system under the emission trading scheme, a renewable energy expansion policy will not lead to the additional GHG emissions reduction effect (This result reconfirms what Morris (2009) and Goulder and Stavins (2010) indicated). Because carbon emission permits are traded based on the market mechanism, which depends on the GHG reduction target set up by the emission trading scheme, the industry sectors, including the electricity generation sector, lack the motivation to reduce additional GHG emissions beyond the reduction target (Cap).

Table 6. Change in GDP and the level of consumption under SC_2 and SC_3 (% change for SC_0)

	SC_0	SC_2	SC_3
Change in GDP	-	-0.67	-0.82
Change in the level of consumption	-	-0.21	-0.46

Table 7. Change in the indicators of petrochemistry and steel industry under SC_2 and SC_3 (in comparison with baseline scenario)

% change for the baseline scenario (SC_0)		SC_0	SC_2	SC_3
Petrochemistry industry	Production	-	-1.85	-1.00
	GHG emissions	-	-2.43	-1.53
Steel industry	Production	-	-15.21	-14.10
	GHG emissions	-	-42.83	-40.90

In South Korea, the electricity generation and transformation sector currently shows highest GHG emissions intensity followed by petrochemistry and steel industry sector. To this regard, the study looks at the change in the production and the level of GHG emissions on these sectors. Based on the industry classification of the model, chemical product (no. 13) and pig iron and steel product (no. 15) industry show relatively high GHG emissions intensity than other industries. Table 8 shows the comparison of change in production activities and GHG emissions of those two industries (petrochemistry industry and steel industry) between SC_2 and SC_3. As a result, it is found that when the emission trading scheme and renewable energy expansion policy are implemented in a mixed form, the industries with high GHG emissions intensity shows relatively low decrease level of production and reduction level of GHG emissions compared with the case when the emission trading scheme is solely implemented. The fossil fuel industries, including coal, crude oil, and natural gas also showed similar results like the petrochemistry and steel industry. This is because carbon price (emissions permit price) decreases when the emission trading scheme and RPS are implemented in a mixed form with the specific GHG emission reduction target. When renewable energy expansion policy is additionally introduced, the profitability of producers of carbon-intensive industries and the amount of electricity generated by fossil fuel decline. However, the emission permit quota system leads the decreasing price of emission permit, thus causing the reflective profit for the emission intensive industry groups.

Table 8. Change in GDP and the level of consumption under SC_2 and SC_3 (% change for SC_0)

	SC_2	SC_3
Emission permit price (SC_2 = 1)	1.00	0.93

Table 9. Comparison of GHG emission level between SC_2 and SC_3

	GHG emissions of the electricity generation sector	% change for SC_0
SC_2	0.122	-50.50
SC_3	0.119	-51.67

Table 10. Comparison of energy mix between SC_2 and SC_3

	SC_2	Proportion by energy source (%)	SC_3	Proportion by energy source (%)
Coal	3.02	5.97	3.64	7.11
Fuel oil	0.00	0.00	0.00	0.00
Gas	22.87	45.21	20.46	39.93
Nuclear power	23.04	45.54	23.04	44.96
Water power	0.59	1.17	1.49	2.91
Wind power	0.81	1.60	2.24	4.36
Other renewable energy	0.13	0.26	0.37	0.72
Total electricity generation	50.59	100	51.25	100

In addition, the change in the electricity sector was examined. For the GHG emission level of the electricity sector, it is found that when RPS is implemented with the emission trading scheme, GHG emissions of the sector is more reduced as compared when the emission trading scheme is solely implemented. This is because more restrictions on the fossil fuel-based sector are imposed in line with the electricity generation costs as the quotas of electricity generation and the supply for renewable energy are additionally introduced as a regulation mean, and the introduction of the emission trading scheme charges price for the emission permit. Also, the study found that for the change in the amount of electricity production, when the emission trading scheme and RPS are implemented in a combination form, the electricity production decreases less (compared with SC_2). Comparing the change in energy mix in the electricity generation sector between SC_2 and SC_3, it is found that when RPS is implemented combined with the emission trading scheme, the renewable energy's share of the generation sector is more increased as the quotas are imposed on the renewable energy generation. As a result, it is found that it leads a positive effect only for the electricity sector when implementing the emission trading scheme and RPS together.

6. Results and Implications

The policies for GHG reduction can be roughly classified into two types. One is technology-push policy, such as R&D policy, which intends to meet the GHG reduction target based on development of low carbon or alternative energy technologies. The other one is the market-based policy, such as emission trading scheme and renewable energy expansion policy. It is important to understand the difference between the two types of policies, technology-push policy and demand-pull policy, which one is more effective to reduce GHG emissions, and to identify the ideal mix of the two. However, there is no sufficient relevant study that has been previously conducted, which theoretically and empirically analyzed these subjects. In this regard, this study analyzed the effects of the two ways to reduce GHG emissions. One is supported by the R&D investment on the energy and environment sector that is the main policy tool of the technology-push policy, and the other one is supported by the implementation of the emission trading scheme, Renewable Portfolio Standard, and Feed-in Tariff that are the main demand-pull policies. Also, the study draws implications for the analysis on the effects of existing classification of the GHG reduction policies of the government.

According to the results of the analysis, when the carbon price does not exist in R&D policy, it is difficult to reward the innovative activities, especially the ones in line with new technologies. Also, without the policies that charge price for carbon emissions, it is hard to drive the motivation for the development of low-carbon technologies. Therefore, when the emission trading scheme is solely implemented (with a fixed emission price), the effects on GHG emissions reduction are greater compared with the effects of R&D policy. Also, for the change in energy system in the electricity generation sector, the transition to the low-carbon energy economy system is easier when the emission price is set up. This result indicates that R&D policy and technology-push policy as the policy tools to achieve the GHG reduction target would show high limits in the energy and environment sector.

In the second analysis of the study, the scenario under which the emission trading scheme is implemented with consideration of technological advancement was additionally analyzed. The results showed that when the emission trading scheme is implemented to meet the GHG reduction target, R&D policy can serve as complementary policy. As R&D activities are encouraged, backstop and low-carbon energy technologies are developed or advanced, and the knowledge stock is accumulated across a society, thus causing the spillover effect. Under SC_2 of the study, which reflects this spillover effect, the GHG target was achieved with the relatively low-level of GDP losses and the consumption depression compared with the ones under SC_1. This reconfirms the results presented in the previous studies on other countries. That is, when technological advancement is considered, the policy costs involved with the introduction of environment policy somewhat decreases. Also, the study found that this is also the case for the economic system of South Korea. In addition, based on the analysis of the results, the study confirmed that when the emission trading scheme is implemented under the situation where the technological advancement is considered, transition to the low-carbon system of the electricity generation sector is more facilitated compared which other scenarios under which the emission trading scheme is solely implemented or under which R&D are solely considered. These results showed that GHG is reduced more cost-effectively when R&D and emission pricing policy are considered together as compared when emission pricing policy is solely considered.

For the last part, the effect of the case, where RPS and the emission trading scheme are implemented in a mixed form, was analyzed. The study intended to draw implications on the policy mix of the environment and energy sector of South Korea by comparing the results of this analysis with the case where the emission trading scheme is solely implemented. Accordingly, this study analyzed SC_2 and SC_3, and the results showed that when RPS is implemented, mixed with the emission trading scheme, the positive effect that increases GHG reduction level and renewable energy's generation share occur for the electricity generation sector. However, the study confirmed that although the emission trading scheme and RPS has the common purpose of GHG emissions reduction, the combination of the two policies does not bring additional GHG reduction. In addition, the combination of the two policies decreases the emission permit price while increasing the emissions of emission intensive industries. The study also found that the coexistence of two policies causes depression on consumption and GDP losses, thus increasing the costs of the overall economic system. In this regard, the study lastly analyzed SC_2 and SC_3. Compared with the case where the emission trading scheme is solely implemented, the combination of renewable energy expansion policy and the emission trading scheme brought the positive effect partly on the electricity generation sector, but for the macroeconomic and industrial indicators, more negative effects occur. Based on the findings, the study concluded that the emission trading scheme, which is promoted under the RPS with which the renewable energy target is obligatorily achieved, can be ineffective because it incurs higher GHG reduction costs to meet GHG reduction target. To sum up, the investment on R&D, in itself, is not enough to lead the achievement of GHG reduction target. In other words, the R&D should be supported by the emission trading scheme that charges price for the emissions to meet GHG reduction target cost-effectively. The study also noticed that the emission trading scheme promoted under the RPS in which the renewable energy target is obligatorily achieved is ineffective because higher reduction costs could occur to meet the GHG reduction target.

In order to meet the long-term target of GHG reduction, it is important to keep the direction and pace of technological change and the double-edged strategies that encourage the development of new technologies while expanding the demand of currently available technology (Grubb, 2004; Johnstone et al., 2009; Popp, 2010). In this regard, the study intended to present the direction of GHG reduction policy mix from a comprehensive perspective, comparing the R&D investment on the energy and environment sector, emission trading scheme (planned to be implemented by 2015), and RPS (being implemented from 2012) that the government currently promotes or plans to introduce and by analyzing the effects of the policy mix. The analyses on the effects of energy and environment policies related to climate change have overly focused on a single policy tool analysis or the comparison among policy tools. This is because the analyses are based on the premise in which the policies are interchangeable. However, as multiple policies related to climate change are currently implemented in a mixed form, policy mix issues are being actively discussed. In fact, some policy tools conflict each other, but some are complementary (Gunningham and Sinclair, 1999; OECD, 2007). Since the GHG reduction policies and energy policies are closely interlinked it is important to approach GHG reduction policies from the comprehensive perspective. If not, the original integrity of each policy could be damaged causing the governmental inefficiency. Nevertheless, South Korea has overly focused on the effectiveness of a single policy and could not realize the importance of the integrated approach to see the interaction among policies. Therefore, before introducing several policies indiscriminately, in-depth studies on the analysis of interaction of multiple policy instruments to achieve the GHG reduction should be fully understood first.

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