A Study on Policy Interactions between Cap-and-trade and Renewable Portfolio Standards in the South Korean Power Sector[1]

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1. Policies to Address Climate Change and their Potential Interactions

Global communities are paying growing attention to climate change. Greenhouse gases that cause climate change are a representative environmental bad in economics. As with goods, the efficient allocation of a bad is achieved through optimization behavior of market agents. Microeconomic theory predicts that consumers maximizing their utility as producers maximize profits can lead to the optimization of social welfare. However, this is conditional on the premise that no market failures exist due to, for instance, externalities. In case of market failure, the government can intervene in

1 This article draws heavily on the research project entitled "A Study on Policy Interactions between Cap-and-trade and RPS in the South Korean Power Sector".

the market through policy instruments such as regulation to improve social well-being.

The South Korean government has been making efforts to address climate change through various policies. While tackling environmental externalities, regulations could impose heavy burdens on the industrial sector, which is the major source of greenhouse gas emissions. Hurting business can have a negative impact on the economy, discouraging more aggressive greenhouse gas abatement from industry. This implies that the cost-effectiveness of any climate policy should be thoroughly investigated.

South Korean climate policies can be roughly categorized into greenhouse gas abatement policies and energy policies. Both aim to ensure that the production level of greenhouse gases is determined at the point where social marginal costs equate to social marginal benefits. In reality, however, environmental externalities occur in various markets, and policies to address individual externalities affect each other. This suggests that it is difficult to maximize social welfare if an individual policy takes only into account the social marginal costs of one environmental good or bad. Therefore, it is necessary to estimate the exact social marginal costs and benefits through qualitative and/or quantitative analyses of policy interactions.

As one of these efforts, this study performs a policy interaction analysis that has not yet been performed in the process of establishing environmental and energy policies. Specifically, the interaction between the cap-and-trade and RPS (Renewable Portfolio Standards) policies, both representative measures for coping with climate change that are applied to the power wholesale sector in South Korea. The wholesale power sector is suitable for studying the interaction of environmental and energy policies in that it is not only a field in which a large amount of greenhouse gases and other local pollutants are emitted, but also one greatly influenced by government policies. Although this study does not directly estimate social marginal costs or benefits, the results of the paper provide critical evidence that can be used in internalizing environmental externalities.

The rest of this paper is organized as follows. First, it introduces environmental co-benefits that could serve as a theoretical foundation for policy interactions. Then I introduce an analytical model that I developed and perform a quantitative analysis. The results of the empirical analysis are describes, and I conclude the paper by explaining its implications for policy.

2. Environmental Co-benefits

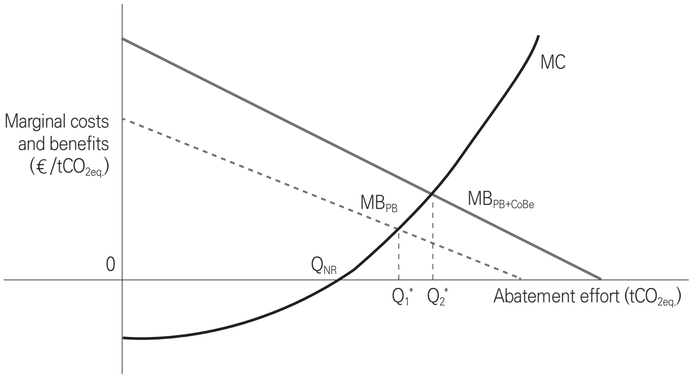
Environmental co-benefits carry useful implications for the interaction analysis carried out in this study. In order to maximize social well-being in the presence of pollutant-driven externalities, individual pollutants should be regulated by measures (such as taxes) that reflect marginal environmental damage. In reality, however, there are multiple pollutants, and some pollutants are not subject to regulation. In addition, even if regulated, situations often arise that do not accurately reflect marginal environmental damage. There are three potential explanations for this. First, it is possible that social costs and benefits of pollutants are not precisely estimated due to technical limitations and/or lack of information. Second, even if one has successfully estimated social costs and benefits of pollutants, it may be difficult to reflect them for political reasons. Third, changes in or development of processes and technologies have incurred costs and generated benefits that differ from those originally estimated.[2]

For the aforementioned reasons, the realization of maximum social welfare through the regulation of pollutants poses considerable difficulties. What further complicates the problem is that regulations on one pollutant can affect the emissions of another. In the literature, various techniques were used in numerous areas to analyze whether these benefits exist and, if so, whether they are positive or negative (that is, whether regulations on one pollutant lead to an increase or decrease in emissions of another).

Recently, the public interest has been highlighted among environmental co-benefits as an important subject, especially in the climate change literature. Reducing greenhouse gas emissions, for instance, can bring about various public benefits including improved health outcomes, ecosystem preservation, a stronger national economy and social equity. If the public benefit

2 Fullerton, Don, and Daniel H. Karney (2018), "Multiple pollutants, co-benefits, and suboptimal environmental policies", *Journal of Environmental Economics and Management*, 87, pp.52-71.

Figure 1. The Impact of Environmental Co-benefits on Optimal Greenhouse Gas Emission Abatement Levels



Source: Ürge-Vorsatz, Diana, Sergio Tirado Herrero, Navroz K. Dubash, and Franck Lecocq (2014), "Measuring the co-benefits of climate change mitigation", *Annual Review of Environment and Resources*, 39, pp.549-582.

is not taken into account as shown in Figure 1, the optimum reduction in greenhouse gas emissions may be underestimated. In Figure 1, the social marginal benefit (MB_{PB}) that is not considered in the public benefit (Q_1^*) can be found to be less than the optimal reduction (Q_2^*) when considering the public benefit.

3. How Do Environmental Policies Interact in the Real World?

In the U.S., then-Representatives Henry Waxman and Ed Markey co-sponsored the American Clean Energy and Security Act in 2009. Also known as Waxman-Markey Bill, it was a noted landmark policy attempt that included comprehensive coverage of climate change and energy issues. The Waxman-Markey Bill sought to implement a number of related policies simultaneously, including a revision of the Clean Air Act, the introduction of a greenhouse gas emission trading system, regulations related to renewable energy and energy efficiency and regulations requiring the installation of CCS (carbon capture and storage) technologies in coal-fired power plants. Although the enactment of the bill failed to materialize due to Republican opposition, the Waxman-Markey Bill opened the door for discussions on the impact of multiple environmental and energy policies being implemented simultaneously.

While the Waxman-Markey Bill was a federal-level policy initiative in the U.S., there are also state-level policies. In particular, the practice of the state of California, which has played a pioneering role in the areas of environment and climate change, carries useful implications for Korea. California has implemented a number of policies to reduce greenhouse gas emissions, including cap-and-trade, RPS, land-use regulations for reducing mileage, and LCFS (Low Carbon Fuel Standards). Among them is cap-and-trade, which shares significant similarities with LCFS and RPS in terms of its goals and targets.

RPS in California is a set of regulations that requires power plant operators to produce more than a certain percentage of electricity using renewable sources, similar to Korea's RPS. The minimum requirement, however, is much higher than Korea's RPS: 60 percent of the total power generation must come from renewable energy by 2030. The simultaneous implementation of RPS and cap-and-trade can provide incentives for power generation businesses to comply with cap-and-trade, via increased generation from renewable technologies. This is an additional restriction which affects social wellbeing by preventing power plants from freely choosing emission reduction measures.

4. Results of Empirical Analysis

(1) The Analytical Model: Introduction, Limitations, and Potential Applications

This study first develops an analytical model that describes the Korean wholesale power sector. The model consists of an objective function and its constraints. The objective function minimizes the net present value of the levelized cost of electricity generation over a period of 30 years under consideration for this study. Constraints consist of: (1) an equation of motion, (2) a capacity factor restriction, (3) a restriction on exogenous loads, (4) market clearing conditions, (5) a restriction on planning reserve margin, (6) a cap-and-trade, (7) RPS, (8) a restriction on renewable energy generation, (9) thermal constraints and (10) a restriction on the exogenous generation capacity. The data used in the analysis were obtained through various sources, including the Eighth Basic Plan for Power Supply and Demand.

It is a dynamic optimization model which reflects the characteristics of the Korean power wholesale market, with a focus on power plants deciding optimal generation capacity through investment in each period. The model addresses the optimization problem of power wholesale market participants and it obtains the values of key endogenous variables such as generation capacity, generation levels, and investment. By modifying existing constraints or adding new ones, the model gives answers to questions such as how power wholesale market participants react when policies are changed or newly-implemented.

Although the model captures most of the important characteristics of the Korean power wholesale market, it still has the following limitations, which require attention when interpreting results.

First, in this study, the generation levels of baseloaders such as nuclear and coal plants may be higher than what they are in the real world, as the restrictions on ramping rates are not considered.

Second, cap-and-trade is applied to industry as a whole, which includes the power sector, but this study assumes that the power generation sector is the sole object of the policy. In addition, a power plant may earn offset credits through greenhouse gas reduction performance outside of the country, but this is not allowed in the model, either.

Third, the domestic power wholesale market still has some characteristics of a regulated market. It necessitates a way to model some unique components of the market, such as the adjustment factor and capacity prices, but this study does not take these into account. It discusses, however, the potential application of the model by introducing the strategies necessary to embed these characteristics in the model.

The model is based on linear programming. Once one introduces the MCP (Mixed Complementarity Problem), one can easily incorporate the adjustment factor, capacity prices, endogenous electricity demand and others.

(2) Environmental and Energy Policies Considered in the Model

There are two environmental/energy policies in the model: cap-and-trade and RPS. This section briefly summarizes how each regulation works in South Korea.

Cap-and-trade was implemented on January 1, 2015 to achieve the country's goal of reducing greenhouse gas emissions through a market mechanism. Six greenhouse gases are subject to the regulation: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). Cap-and-trade was designed to encourage firms to abate greenhouse gas emissions cost effectively by allocating emission allowances to firms that emit a large amount of greenhouse gases. Individual companies can sell or procure allowances through transactions.

Firms that have lower marginal abatement costs will achieve more cuts than their allocated emissions allowance; they can then sell the unused allowance to the market, where those with higher marginal abatement costs will purchase it. The introduction of the market mechanism allows firms to flexibly cope with the regulation by comparing the market price of emission allowances with their marginal abatement costs. It is expected to promote the efficient allocation of resources.

Emission allowances give firms the right to emit greenhouse gases. There are two types of allowances: (1) KAU (Korean Allocation Unit); and (2) KCU (Korean Credit Unit). KAU is allocated by the government under the allocation plan, while a KCU is earned when a company certifies that the performance of its greenhouse gas reduction projects meets international standards. A scheme to utilize KOC (Korean Offset Credit) by converting it to KCU was introduced in 2015. The offsets can be used up to ten percent of the annual emission allowances. The firms can also meet cap-and-trade by banking and borrowing allowances.

RPS was implemented as of January 1, 2012 to expand electricity generation to renewable technologies. Power generation operators with a generation capacity of 500 MW or higher are subject to RPS, and they are obligated to produce at least a certain level of their electricity using renewable sources.

REC (Renewable Energy Certificates) is a measure to comply with RPS. REC is a certificate that proves electricity suppliers produced renewable-based electricity. It is calculated by multiplying weights by the amount of electricity produced by renewable technologies. The weighting is announced by the government every year in consideration of the type of installation. Energy sources with the highest ESS (Energy Storage System) weighting are those connected to solar panels, at a value of 5.0 as of 2019. On the other hand, landfill gas, wood pellets, and wood chips are assigned a weight of 0.5, the lowest.

Generators may respond to RPS by either procuring RECs on its own or purchasing RECs from the market. Power plants can also meet RPS requirements by transferring certificates from the previous year. The government allows a delay in performance of up to three years within 20 percent of the annual RPS requirements. In the event that generators fail to meet the requirements a fine will be imposed within 150 percent of the average market price of REC.

Annual RPS requirements are designed to gradually increase from two percent at the beginning of the policy to ten percent in 2023. In 2019, approximately 27 terawatt-hours (TWh), or six percent of the previous year's total generation was confirmed as the mandatory level. As of 2019, there are 21 generators subject to RPS, including six utilities, two public firms and 13 private ones. Most of the obligation is imposed on six utilities which bear 80.2 percent of RPS requirements.

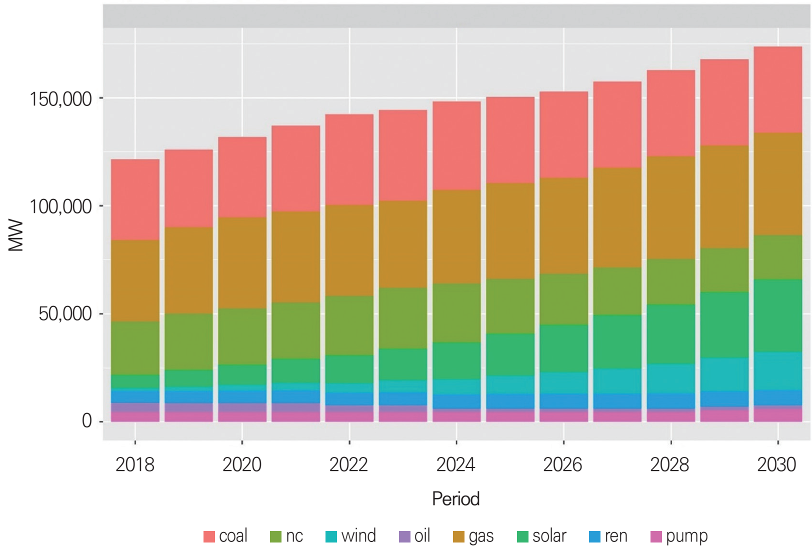
(3) Benchmark Equilibrium

I establish benchmark equilibrium performing a counterfactual analysis. At the benchmark, the model successfully replicates the Eighth Basic Plan for Power Supply and Demand. Both generation levels and generation capacity are characterized by a reduction in nuclear and an increase in solar, wind and other renewables. The share of LNG increases by a small amount, whereas the share of coal increases at the beginning of the period and then starts declining.

(4) Simulation Results

As shown in Table 1, this paper considers four scenarios: BMK (benchmark),

Figure 2. Generation Capacity by Technology: Benchmark



NOCAT (no cap-and-trade), NORPS (no RPS) and NOPOL (no policy).

Figure 3 illustrates electricity generation levels by technology in each scenario. When the cap-and-trade constraint disappears (NOCAT), coal plants generate more electricity while LNG and solar generators produce less. It means that cap-and-trade curbs coal, which is the most carbon intensive fuel, while incentivizing LNG and solar. Since there is room to increase the share of coal, lifting cap-and-trade (that is, NOCAT) results in more coal-fired electricity, as it is cheaper than LNG and solar. There is no significant

Table 1. Four Scenarios

Scenario	Description
BMK	- Benchmark equilibrium - All constraints in the model are included
NOCAT	- Assumes a hypothetical world without cap-and-trade - Cap-and-trade restrictions removed from the model - RPS is the only environmental/energy policy in the model
NORPS	- Assumes a hypothetical world without RPS policy - RPS restrictions removed from the model - Cap-and-trade is only environmental/energy policy in the model
NOPOL	- Assumes a hypothetical world without cap-and-trade and RPS - Both cap-and-trade and RPS restrictions are removed from the model - There are no environmental/energy policy in the model

change in the amount of wind power and other renewable generation as power plants are still subject to RPS in NOCAT.

In the NORPS scenario, where the RPS constraint is eliminated, the proportion of coal generally decreases over time. A decline in the share of other renewable generation is more dramatic particularly in the early stages of the period. On the other hand, the share of LNG increases by a large margin, which could be interpreted as a result of not being able to reduce renewables generation anymore due to cap-and-trade. Note that there is no significant difference in fuel mix between the BMK and NOCAT scenarios. But in NORPS, the existence of RPS functions as a binding constraint by driving the power sector to adopt renewable technologies early on.

In NOPOL, both cap-and-trade and RPS constraints are removed, leading to a significant reduction in the share of solar, wind, and other renewable technologies. Instead, coal thrives due largely to its lowest levelized cost of electricity (LCOE).

Greenhouse gas emissions are heavily dependent on policies (Figure 4). In particular, the impact of cap-and-trade is greater than that of RPS. Comparing the total sum of greenhouse gas emissions during the period, emission levels are about 0.07 percent (1.77 percent) higher in the NORPS

Figure 3. Generation by Technology Over Time: Counterfactual Analysis

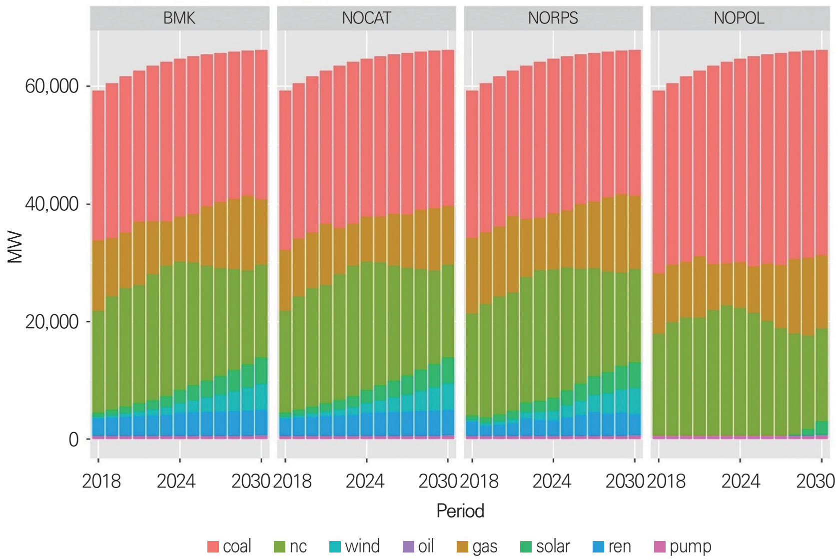
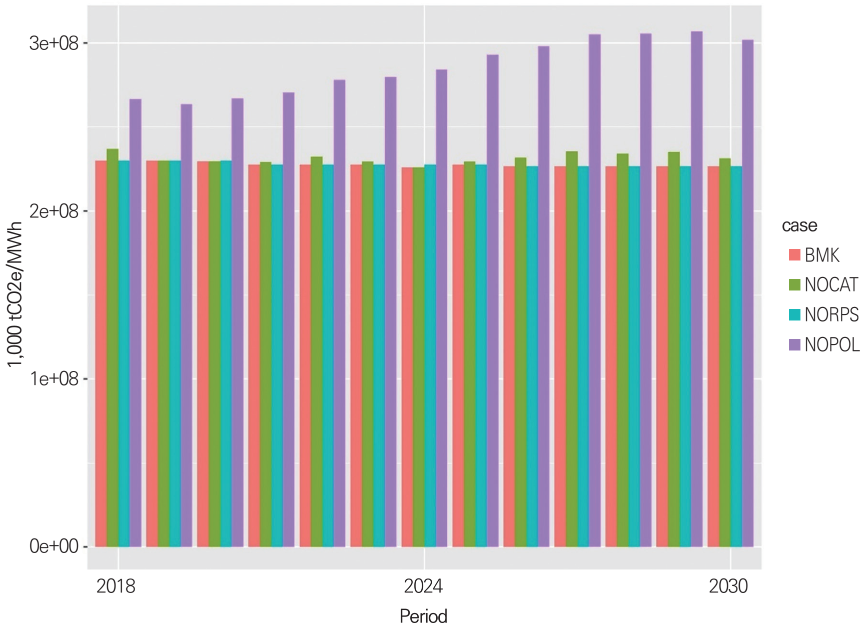


Figure 4. Aggregate Carbon Emissions Over Time



(NOCAT) scenario than in BMK. This impact is substantially larger in a NOPOL scenario, where emission levels are 25.75 percent higher than in the BMK.

Based on the results of the counterfactual analysis, I calculate the extent to which policy interactions affect greenhouse gas emissions as well as renewables generation. Cap-and-trade has a greater impact on the reduction of greenhouse gas emissions in the power generation sector, and the interaction between the RPS and the cap-and-trade results in 755 $MMTCO_2E$[3] less reduction. RPS is a more effective policy when it comes to promoting renewable generation. The policy interaction leads to a reduction in renewable energy generation by about 70 gigawatt-hours.

The price of emissions permits increases about 30 percent when the RPS was not implemented. This can be interpreted as the result of increasing the amount of renewable energy generation through the RPS policy, which helped power generation businesses comply with cap-and-trade. REC (Renewable Energy Certificate) prices are more affected by cap-and-trade. In

3 Million metric tons of carbon dioxide equivalent.

scenarios without cap-and-trade, REC prices are about four times higher than in a BMK scenario.

5. Implications

(1) Implications for the Korean Power Sector

The results of the empirical analyses carry important policy implications. First of all, the results of the analysis can help policymakers craft strategies for responding to the policy challenges faced by Korea's power generation industry. The power generation industry is subject to strengthening regulations as it is a major source of greenhouse gas emissions in the country. Revisions to the Roadmap to Reduce Greenhouse Gases, issued in July 2018, confirmed a reduction of about 24 million tons in the transition sector (power generation and collective energy) but did not provide specific reduction plans covering 34 additional million tons of emissions. In other words, the power generation industry will have to achieve a significant amount of additional greenhouse gas emissions by 2030.

There are several reasons why such a stringent emission reduction obligation is imposed on the power generating sector. First, the sector is the largest greenhouse gas emitter in Korea. According to the Greenhouse Gas Inventory and Research Center (2019)[4], the share of greenhouse gas emissions produced by the power generation sector has continually increased since 1990, accounting for about 36 percent of the country's emissions in 2017. Second, the majority of the power generation sector is composed of state-run companies, although many private businesses participate in the market. As of 2017, KEPCO and its subsidiaries represented approximately 77 percent of the market in terms of generation capacity. Compared with private companies, public corporations are likely to be more cooperative in complying with regulations. Third, if greenhouse gas emissions are significantly reduced from the power generation sector, the effect spreads

4 Greenhouse Gas Inventory and Research Center (2019), "2019 National Greenhouse Gas Inventory (1990 to 2017)".

to those that use electricity, resulting in indirect abatement. For instance, the result of this study shows that carbon intensity decreases from 0.443 (1,000 tons of carbon dioxide equivalent per megawatt-hour) in 2018 to 0.391 in 2030. Assuming that industry consumes about 300 TWh of electricity a year, it would have emitted about 132.9 billion tons of greenhouse gases in 2018, and about 117.3 billion tons in 2030 will come from power consumption in the industrial sector. In other words, the lower the carbon intensity of electricity, the less emissions, even if the same amount of electricity is consumed.

There are four strategies that the power generation sector can utilize to achieve such a significant abatement. First, power generators can choose to reduce the share of coal, the most carbon-intense fuel, from the generation mix. Reducing generation from a particular technology inevitably leads to an increase in other technologies, since the electricity demand should be met. RPS regulates the amount of renewable energy generation. In other words, the policy does not pay attention to the technology that is being substituted. On the other hand, cap-and-trade reflects the carbon intensity of each fuel; it is thus essential to establish a low-carbon power mix. Coal and nuclear are the main sources of baseload. The government's departure from nuclear power plants, however, will lead to a gradual decrease in the share of nuclear after 2023, so replacing a significant amount of coal with nuclear power is infeasible. Replacing coal power plants with LNG plants can be seen as the most realistic strategy, but such a fuel switch poses two major problems. For one, the diversity of the country's power portfolio directly affects national energy security, especially when the Korean power grid is isolated from rest of the world. With an increased reliance on LNG, soaring international gas prices could deal a heavy blow to the nation's economy. Moreover, although LNG is a less carbon-intensive fuel compared to coal, it is still relatively more carbon-intensive than renewable energy. With these considerations in mind, LNG is not a fundamental solution.

The second strategy the power industry can adopt is to purchase an emission allowance rather than directly reducing emissions. It can be economically advantageous especially for power plants with a high share of coal-fired generation, due to their high marginal abatement cost. Cap-and-trade regulations are continually strengthening, however, and the government has sent consistent signals to the market that such a trend will continue. This trend leads firms to bank their extra allowance rather than selling it in the market, which makes the purchase of emission rights a partial solution for power generators.

Third, the power generation sector can consider developing technologies that can help reduce greenhouse gas emissions. In particular, expanding the use of CCUS (Carbon Capture, Utilization, and Storage), which is emphasized in the Five-year Plan for Green Growth, is considered one of the most viable option at present. However, even CCUS technology are still in the development and commercialization stages, which makes widespread adoption is difficult in the short- to mid-term.

Finally, securing KOC by expanding domestic and overseas projects can also be a valid strategy. The opportunity to secure KOC by promoting greenhouse gas reduction projects in developing countries is likely to increase, as more efforts are being made to cope with climate change worldwide. As developing countries are also obliged to reduce their emissions after the Paris Agreement, however, there is a risk that ownership problems could emerge for some of the reductions created by reduction projects.

In sum, there is no perfect strategy to achieve rapid and significant emissions reductions in the near future. As the power industry plays the essential role of forming the foundation of the national economy, I suggest the following policies. The suggested policies could help the power industry successfully reduce greenhouse gas emissions while still maintaining industrial competitiveness.

First, reduced policy risk and R&D support for abatement technologies such as CCUS is needed. CCUS is considered one of the most realistic alternatives among current abatement technologies. In particular, the emphasis on CCUS in government policies such as the Five-year Plan for Green Growth is an important advantages. In-depth interviews with power plant operators revealed that power plants have great anxiety due to the lack of clear standards on how and how long the CCUS-driven emission reductions will prove a legitimate option in meeting cap-and-trade standards. Therefore, efforts will be needed to overhaul related systems and promote them within industry.

Second, the government should reconsider the subject of the regulations. The power generation industry is a supplier. While regulating suppliers through policy instruments such as RPS and cap-and-trade, it should be also considered that demand-side regulation is also essential. The government announced a plan to reduce electricity demand by 0.5 to 1.3 percent from business-as-usual (BAU) through demand management. As a means of demand management, the government is considering high-efficiency devices, energy management systems, enhanced efficiency management, and small-scale solar panels. Since there has already been a consensus on the importance of demand management, it is predicted that carbon abatement will lessen the burden on the generation industry if more innovative demand management measures are developed.

Third, the government needs to improve systems related to overseas abatement projects. Under cap-and-trade, firms can acquire KOC that can be obtained from projects reducing six types of greenhouse gases. Utilities, representing the vast majority of Korean power industry, are burdened by public opinion that their overseas business constitutes an outflow of national wealth. They are also concerned that developing countries could claim ownership of some of the cut. Since overseas projects take more than three years for the administration of paperwork, it is difficult to actively pursue these projects given such anxieties. Therefore, the government needs to help the power generation industry pursue emission reductions through abatement projects by readjusting relevant policies.

(2) Environmental and Energy Policy Implications

Environmental and energy policy implications from a more general perspective derived from the results are described in this section. First, cap-and-trade and the RPS are functioning well in the power generation sector. An interaction analysis has shown that it is inefficient to implement multiple policies with similar objectives, it would be more appropriate to pursue a few of the most efficient polities to achieve desired outcomes. Second, cap-and-trade and the RPS are affecting each other in such a way that RPS lowers emission prices while cap-and-trade reduces REC prices. The drop in emission permit prices could provide less incentive for firms to cut greenhouse gas emissions through innovation. To this regard, future research is necessary to more accurately estimate the impact of interaction on social wellbeing through a welfare analysis using a general equilibrium model.

The model developed in this study can help identify the differences in social welfare between a regulated and deregulated Korean power wholesale sector. It can also provide a framework for quantitative analysis of the effects of various policies pursued for the dissemination of renewable energy. Further, modeling endogenous electricity demand makes it possible to analyze the impact of various environmental and energy policies on the manufacturing industry through the channel of changes in electricity prices.

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