The Impact of Environmental Regulations on the Manufacturing Sector: The Role of Electricity Prices[1]

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1. Introduction

The role of policy (among various other factors) in determining the stability of the power supply and electricity rates is becoming more important. Policy-based pressure on rising electricity prices is expected to intensify as countries prepare stronger environmental regulations in an international effort to cope with climate change. Under the Paris Agreement, countries submit Nationally Determined Contributions (NDC) that comprise plans to reduce greenhouse gas emissions by 2030. South Korea has declared a goal of reducing greenhouse gas emissions in 2030 by 24.4 percent compared to 2017 levels. In addition, at the end of 2020, countries submitted plans of a long-term low-carbon vision by 2050. Recently, major countries including the United States, European nations and South Korea have been pushing for a Green New Deal, and more and more countries are targeting net-zero emissions. This trend has only intensified in the post-COVID-19 era, as countries build consensus around the establishment of an eco-friendly and low-carbon society.

GHG reductions and environmentally-friendly trends are likely to lead to higher electricity prices. It is self-evident that if the shares of renewable energy and natural gas of the power mix increase and the amount of power generated from fuels that were previously responsible for baseloads (such as nuclear and coal power) decreases, upward pressure on electricity prices will continue to build.

South Korea's economic structure is more energy-intensive compared to other major countries, which makes South Kore more vulnerable to environmental regulation-driven fluctuations in energy prices. According to the OECD, South Korea's energy intensity was measured at 0.17 TOE/thousand USD as of 2014, about 31 percent higher than the OECD average. Energy intensity as defined by the OECD refers to energy consumed by a country (tons of oil equivalents,

1 This article draws heavily on the research project "The Impact of Environmental Regulations on Manufacturing Sector: The Role of Electricity Prices".

or TOE) in generating 1,000 USD of GDP. This means that countries with greater energy intensity consume more energy to produce equivalent value-added. South Korea's energy intensity is higher than that of Germany (0.10) and Japan (0.11) as well as the U.S. (0.15), a country known for consuming a large amount of energy.

The South Korean economy has an energy-intensive structure and the manufacturing sector in particular is a major consumer of electricity. As of 2019, the manufacturing sector accounted for 50 percent of electricity sales and 55 percent of electricity sales revenue in South Korea. According to the a 2018 study by the Korea Institute for Industrial Economics and Trade, 94 percent of manufacturing firms cited electricity as an energy source related to the production of their main products. The study found that 45 percent of companies were able to accommodate an increase of less than one percent in the event of an increase in electricity prices due to an energy transition policy, but that they would take certain measures — such as raising product prices, lowering margin rates or adjusting production levels — if price increases grew to unacceptable levels.

The purpose of this study is to reveal the future impact of power sector-related regulations on the manufacturing sector and to provide insight for firms in establishing strategies to deal with such policies. To this end, the cost function of the major manufacturing industries is estimated using the structural-form model. Estimated parameters are used to combine the manufacturing sector model with the power wholesale market model to develop an integrated power-manufacturing model.

How changes in electricity rates impact manufacturing is a key factor affecting government policy. In addition, the results of this study carry significant implications for policy in that they help preemptively predict corporate responses to changes in electricity rates caused by policies. It is appropriate at this time to analyze the costs involved in the implementation of a low-carbon policies through decarbonization of the manufacturing and power generation sectors and to derive relevant policy demands amid the setting of challenging goals to curb climate change.

2. Environmental Policies and Their Potential Impact on the Electricity Market: A Qualitative Assessment

The energy transition refers to sector-wide innovation that goes beyond changes in the power generation mix and includes optimization of the energy mix. It aims to achieve a high-efficiency consumption structure and to promote the energy industry. Several countries have set targets to use safe and clean energy to tackle climate change, reduce greenhouse gas emissions and address other environmental issues. South Korea is also actively pursuing energy transition policies in line with this trend.

The basic framework of the energy transition policy is to increase the share of renewable energy and to reduce the share of conventional fuels, such as coal and nuclear energy. South Korea has set gradually increasing goals for renewable energy: 7.6 percent in 2017, 20 percent by 2030 and 30-35 percent by 2040. More renewables in the power sector will be accompanied by improved energy consumption efficiency by strengthening demand-side management.

The National Energy Basic Plan (NEBP henceforth), which is the basis for South Korea's energy transition policy, establishes a 20-year long-term plan every five years. Changes in the composition of power generation due to changes in the keynote of the energy and power generation sectors follow the Basic Plan for Power Supply and Demand (BPPSD hereafter), which is established based on predictions of power demand. The BPPSD, a mid-term 15-year plan, is a detailed part of the NEBP, and it is announced every two years based on the Electricity Business Act.

This study considers four policies that are implemented under the energy transition framework: (1) environmental dispatch, (2) PM (particulate matters) measures, (3) cap-and-trade (CAP) and (4) the renewable portfolio system (RPS). The potential impact of each of these policies on electricity bills is analyzed as follows.

First, if the government implements tax reform on generation fuels and environmental dispatch, the cost difference between coal and liquefied natural gas (LNG) power generation will decrease, encouraging LNG power generation, but also causing an increase in electricity bills. According to Eugene Investment & Securities (2019), taxes imposed on coal for power generation were raised from KRW 36/kg to KRW 46/kg in April 2019, while taxes levied on LNG were reduced from KRW 91.4/kg to KRW 23/kg. This could have potentially raised the electricity price by KRW 4.9/kWh. There are other reasons for increasing electricity prices, as the bills are expected to reflect external costs of air pollutants, greenhouse gas emissions, and emission trading costs.

To reduce PM levels, the South Korean government decided to suspend and restrict the operation of coal power plants from December to March, the annual period of high concentrations of fine dust. The government can also suspend nine to 14 coal power plants in consideration of electricity supply and demand according to temperature forecasts. In March, when average PM concentrations are high, the government plans to halt operations at up to 27 coal-fired plants. The coal power plants that are not subject to the shutdown will operate at a reduced output of 80 percent. In South Korea, where coal power accounts for 28.7 percent of the primary energy supply, LNG-based electricity generation needs to replace coal in order for the government to achieve climate and other environmental goals, which will result in inevitable increases in electricity bills. However, all fossil fuel combustion is responsible for higher PM concentrations in the atmosphere and not just those generated by coal power plants. Thus ultimately a phased transition to renewable energy is essential. Decreasing the share of fossil fuels as much as possible and transitioning to pollution-free renewable energy is a fundamental measure to reduce PM from the power generation sector, but this is highly likely to lead to an increase in electricity bills.

Regarding the CAT, the Ministry of Environment announced in 2020 that it would expand and introduce the benchmark (BM) method through its National Emission Allocation Plan 2021-2025. As a result, the emission coefficient of coal power generation will gradually be reduced, which is expected to contribute to a reduction of the proportion of coal power generation. At the same time, however, it is highly likely that it will serve as a factor in raising electricity bills as the cost burden shifts to customers due to reduced free emission permits for power generation.

Since the RPS is limited to a small number of public utilities, KEPCO (Korea Electric Power Corporation) pays a certain portion of the cost of fulfilling the renewable supply obligation. However, there is a possibility that the cost burden passed on to the final power consumers will continue to increase due to the expansion of renewable energy. The total annual compensation paid for RPS obligations on the Korea Power Exchange has increased more than 10 times from KRW 147.6 billion in 2012 to KRW 1.565 trillion as of 2017. In other words, if the mandatory supply of renewable energy is raised from 10 percent to 28 percent, the increase in the price of Renewable Energy Certificates (REC) is estimated to be 31.72 trillion KRW. In addition, the government believes that lifting the RPS cap is necessary to expand renewable energy, and is discussing a legislative plan to do so, raising the possibility of an increase in electricity bills.

3. Empirical Model

(1) Estimating Cost Function of the Manufacturing Industry

This study simulates the process in which major environmental policies including the energy transition affect electricity prices, which again influences businesses in the manufacturing industries as they use electric power as a major input in production. In order to do so, the following are required: (1) a power wholesale market model, (2) a model that represents the optimization of the manufacturing industry and (3) electricity prices linking the two models.

In this study, we estimate the manufacturing cost function where inputs consist of electricity, fuel, capital, labor and intermediate goods. Then the estimated function is applied to analyze the impact of changes in electricity rates on manufacturing production activities. For this reason, we build on the KLEM model, where the production function has four arguments — capital (K), labor (L), energy (E), intermediate goods (M) — and differentiate energy into electricity and fuel. This modified model allows us to consider firms' input substitution behavior.

The functional form of the manufacturing cost function is assumed to be a translog function. The cost of production of industry k is a function of the costs (wik) of input i and output (yk). As mentioned earlier, we consider five inputs — three from the traditional KLEM model (K, L, M), and two by differentiating energy into electricity and fuel. Fuel consists of coal, oil and petroleum products and gas. The industry is divided into ten sectors: food and tobacco, textiles and clothing, wood and wood products, pulp and printing, petrochemicals, non-metallic minerals, steel, machinery and electronics, transport equipment and others.

Using Shephard's lemma, the translog cost function is converted into a cost-sharing equation for each input. The coefficients in the equations are estimated using a system-of-equations model. The estimated values are used as parameters in the integrated model for power-manufacturing industries.

We collect input costs and other price data from World KLEMS and Asia KLEMS. Energy-related data are provided by the International Energy Agency. We also use various domestic datasets, such as the Energy Statistics Yearbook.

(2) Developing an Integrated Model for Power-Manufacturing Industries

The integrated power-manufacturing model builds heavily on the electricity wholesale market model in Lee and Kim (2019).[2] The electricity wholesale market model developed in Lee and Kim (2019) is a linear programming model in which power producer minimize the net present value of generating costs by optimally choosing choice variables such as generation levels. To be specific, there is a single power producer in the wholesale electricity market. The power operator owns power plants for each of eight fuel types: coal, oil, LNG, nuclear, solar PV (photovoltaic), wind, other renewables and pumped storage. In the power market, the operator should produce electricity at a level where production meets exogenously determined demand. There is no additional cost associated with the expansion of the transmission and distribution system. The model consists of an objective function and ten constraints.

Two major modifications introduced to Lee and Kim's model by this study are the use of a static model and the endogenization of electricity demand. First, Lee and Kim (2019) developed a dynamic model. Due to the nature of the dynamic model, the solution of the model includes optimal values of the choice variable for each year. For a dynamic model to be established, however, the model requires projected values of key parameters. In Lee and Kim (2019), key parameters such as generation capacity, electricity demand, and generation from renewable energy are obtained from BPPSD. Since the government provides the data, the reliability

2 Lee, Sul-Ki and M. Kim (2019), "A Study on Policy Interactions between Cap-and-trade and RPS in the South Korean Power Sector".

is guaranteed to a certain extent. On the other hand, the manufacturing sector is integrated into the power sector model. Thus, constructing a dynamic model over the same period as the preceding study requires an annual forecast for the price and demand of inputs such as capital costs, employment, labor costs, and energy prices by 2030. Deriving reliable forecasts for such variables is beyond the scope of this study, so we construct the model by converting it into a static model.

The original model in Lee and Kim (2019) assumes exogenous electricity demand. Such an assumption is reasonable since the main goal of the study is to analyze the impact of external shocks on the power industry On the other hand, this study focuses on the channel through which shocks introduced in the power wholesale market are transferred to major manufacturing industries. Therefore, it is essential to estimate the cost function of manufacturing and to derive the factor demand function for power based on it. Under the current pricing system, the direct and immediate transmission of shocks to the power wholesale market is limited; since the government sets the price rather than the price being determined by the market. Of course, if the shock is big enough, it will increase the pressure on the government to set a higher price, but in general, a shock does not necessarily lead to an immediate price increase. This study mitigates such constraints. That is, the model immediately transfers the changes in wholesale prices, affecting the retail price of electricity to which the manufacturing industry is subject.

The manufacturing model is the estimated factor demand function. Since electricity is one of the four factors in the model, introducing factor demand for electricity into the wholesale power market model yields an integrated power-manufacturing model.

4. Results of Empirical Analysis

This study considers five scenarios, four of which correspond to the policies analyzed in Chapter 2. The other is a benchmark equilibrium (Table 1).

Table 1. Five Scenarios

Scenario	Description
BMK	- Benchmark equilibrium
ENVDSP	- Environmental costs embodied in fuel costs as proposed environmental dispatch is designed - Coal is a more costly fuel than in the benchmark
LOCOAL	- Restricted capacity factor of coal in order to reflect PM measures - (sensitivity check) Capacity factor of coal is set to 0.9, 0.8, and 0.7 times compared to that of the benchmark
MORPS	- Minimum RPS requirements are increased - (sensitivity check) 1.1, 1.2, and 1.3 times the RPS requirements in the benchmark
MOCAT	- More stringent greenhouse gas emission caps - (sensitivity check) 0.9, 0.8, and 0.7 times the emission caps in the benchmark

Table 2. Changes in Electricity Demand of Major Electricity-intensive Manufacturing Industries (ENVDSP Scenario)

Industry	Decrease in electricity demand (%)
Petrochemical	5.467
Non-metal minerals	5.424
Steel	5.436
Machinery and Electronics	5.445
Transport equipment	5.406

(1) ENVDSP Scenario: Environmental Dispatch

As the fuel mix becomes greener, greenhouse gas emissions from the power generation sector decrease 2.5 percent compared to the benchmark. Emissions abatement, however, comes at a cost: electricity prices rise 5.7 percent. In response, manufacturing industries substitute electricity with other factors. There is industrial heterogeneity in the reduction of electricity demand, as low as 4.12 percent in the paper and pulp industries and as high as 5.55 percent in the food and tobacco industries. Electricity-intensive industries cut electricity use by about 5.4 percent with a small degree of inter-industry heterogeneity (table 2). Production costs increase by 0.001 percent in manufacturing industry as a result of the increase in electricity prices.

(2) LOCOAL Scenario: PM Measures

The capacity factor of coal-fired plants are restricted in the LOCOAL scenario, which results in a decline in the share of coal. To check sensitivity, this study assumes three difference cases: capacity factors of 90, 80 and 70 percent of the benchmark. Since coal is responsible for baseloads, less coal-based electricity means higher electricity prices. Electricity rates are 8.5

Table 3. Changes in Electricity Demand of Major Electricity-intensive Manufacturing Industries (LOCOAL Scenario)

Industry	Decrease in electricity demand (%)		
	90% capacity factor	80% capacity factor	70% capacity factor
Petrochemical	7.880	16.538	21.155
Non-metal minerals	7.817	16.413	24.975
Steel	7.835	16.450	25.027
Machinery and Electronics	7.848	16.475	25.063
Transport equipment	7.791	16.362	24.900

percent higher when the capacity factor is restricted by 10 percent, and 33.3 percent higher in the case of 30 percent restriction. Electricity demand decreases as in Table 3. The higher electricity prices affects the manufacturing sector by increasing production costs. Average production costs increase by 0.0012 to 0.0035 percent, while the petrochemical industry (the most affected sector) faces 0.022 to 0.077 percent higher production costs. As the use of most carbon-intensive fuel is curbed, greenhouse gas emissions drop by 8.4 percent (a 90 percent capacity factor case) to 25.7 percent (a 70 percent capacity factor case).

(3) MORPS Scenario: More Stringent RPS

In the MORPS scenario, minimum RPS requirements are increased from five percent in the benchmark by 10, 20, and 30 percent, respectively. In sum, higher RPS requirements lead to an increase in electricity prices (from 0.3 to 37.1 percent), lower electricity demand (from 0.27 to 27.26 percent), a decrease in electricity generation from fossil fuels, higher production costs for manufacturing industries (as high as 0.004 percent), and carbon abatement (from 0.3 to 24.3 percent).

The RPS constraint is non-binding in the benchmark; thus, the REC prices — the shadow value of the RPS constraint — is not derived from the model. In the MORPS scenario, however, REC prices are 820,000 KRW in the 130 percent RPS requirements case.

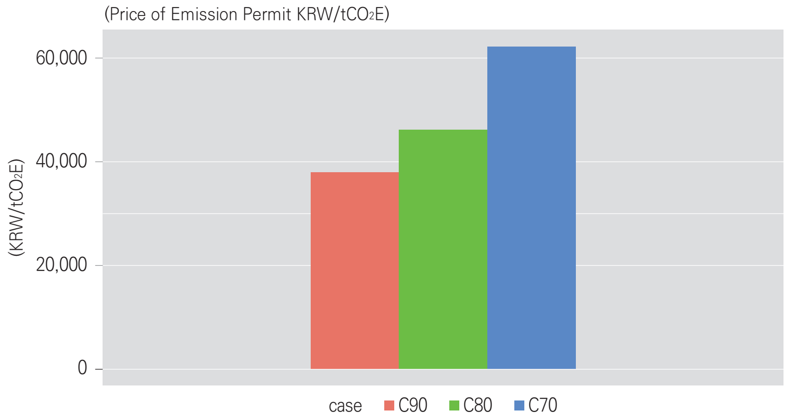
(4) MOCAT Scenario: More Strict CAT

The results of the MOCAT scenario are similar to that of the MORPS scenario. The fuel mix becomes greener, and electricity-intensive industries consume less electricity. For instance, the steel industry reduced electricity demand by 11.567 to 28.233 percent. The price of electricity increases by 13.0 to 39.2 percent, and greenhouse gas emissions in the power generation sector decrease in proportion to the emission cap. Overall, production costs increase by 0.002 to 0.004 percent. Since the CAT constraint is

Table 4. Changes in Electricity Demand of Major Electricity-intensive Manufacturing Industries (MORPS Scenario)

Industry	Decrease in electricity demand (%)		
	110% RPS Requirements	120% RPS Requirements	130% RPS Requirements
Petrochemical	0.272	15.116	27.264
Non-metal minerals	0.270	15.001	27.072
Steel	0.270	15.034	27.127
Machinery and Electronics	0.271	15.057	27.166
Transport equipment	0.269	14.953	26.992

Figure 1. Price of Emission Permits



binding in the MOCAT scenario, emission permit prices are calculated from the model. The permit prices are shown in Figure 1.

5. Implications

As the government implements more stringent climate change policies, the importance of policies as a major determinant of electricity consumption in major manufacturing industries is growing.

Industrial production processes are accompanied by the combustion of fossil fuels, which inevitably lead to greenhouse gas emissions. For example, it is impossible for steel manufacturers to produce steel products without coke used in furnaces. Even if carbon capture, utilization, and storage technologies (CCUS) are commercialized in the future, it is not possible to achieve net-zero without extreme greenhouse gas reductions. That is why changing the production process over the long run is essential. Electricity is the most likely alternative to fossil fuels, and this type of fuel transition is called electrification.

Yet electrification is a burden on firms in many ways. First, we found that that an increasing dependence on electricity in the energy mix will lead to environmental regulation having a greater impact on electricity price increases for firms. Second, the cost of replacing facilities for electrification can be expensive. This cost may be lowered, however, if electrification facilities are introduced at the end of their product life, as in the case of Europe. Third, there are additional costs associated with electrification. For example, once electrification is introduced in the petrochemical industry, methane will no longer be able to be used as a fuel in the naphtha cracking processes; the industry will need to find a way to deal with that. This is because releasing methane into the atmosphere causes climate change and increased levels of PMs. Firms may incur additional costs in storing or collecting methane.

The manufacturing sector faces a dilemma regarding power consumption. To be specific, it is necessary to reduce fossil energy consumption in the long run amid greater electrification, but the expansion of eco-friendly power generation leads to higher electricity rates, which puts a greater burden on industry. The decarbonization of industries requires significant changes, including the introduction of next-generation production processes and innovation in the energy consumption structure. Therefore, aside from industry's own efforts, government policy support is required to maintain industrial competitiveness in the process of decarbonization.

Policy measures to enable steel production from electric furnaces are also required. The commercialization of hydrogen reduction ironmaking techniques, which are expected to drastically reduce carbon emissions in the steel industry, would encourage the use of more electric furnaces; thus promoting electric furnaces in the long-term is essential. In order to do so, stabilizing prices and ensuring a supply of scrap iron is crucial. This is because scrap iron represents the majority of production costs. One can first consider developing and operating a platform that combines information for suppliers and consumers, such as scrap iron generation, collection, transaction volumes, conditions and so forth. It is also necessary to develop technologies to use direct reduced iron (DRI) rather than steel scrap. U.S. firm Nucor has successfully developed such technology.

In the case of the petrochemical industry, technology development projects should be carried out to come up with a way to utilize methane. As mentioned earlier, electrification will force the industry to figure out a new way to utilize methane and other byproduct gases.

The development of CCUS technology is an essential challenge to be met while pursuing decarbonization and electrification. Also, it is time to open a discussion on the effectiveness of a policy to ease electricity bills for energy-intensive manufacturing industries.

Financing is necessary to implement the policy measures introduced above. Financing through imposing new taxes is politically expensive. Yet this issue may be alleviated if the auction revenue raised from the second period of the South Korean CAP could be considered. The South Korean government's Second Basic Plan for Emissions Trading System is preparing industrial support measures to mitigate CAT's impact on domestic industry. It specifies that financial and tax support is possible under the principles of efficiency, equity, and rationality of financial support. For financial resources, auction revenue from the emission rights accounts for the largest portion, and the policy highlights that it is desirable to "link auction revenue with the government's financial expenditure." The Third Basic Plan for Emissions Trading System also describes how EU members use auction revenue. Moreover, the Ministry of Environment announced that it will use auction revenue of permission rights to support industrial greenhouse gas reductions.

As the government has consistently expressed its intention to use auction income to support industry's greenhouse gas reductions since CAT was first implemented, detailed measures should be prepared. In particular, as the government has announced aggressive greenhouse gas abatement plans, as evident in its Long-term Low-Emissions Development Strategies (LEDS) and declaration of net-zero by late 2020, it is urgent to come up with appropriate support measures.

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