Master's Thesis of Engineering

A Panel Data Analysis on Policy Instruments for Renewable Energy Deployment

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Graduate School of Engineering
Seoul National University
Environmental, Energy and Engineering Economics

Jayoung Yoon

Abstract

Studies that analyze the correlation between renewable energy policies and renewable energy deployment are increasing in number as more countries are putting efforts into implementing the policies for renewable energy deployment. Efficiently analyzing the policy effects of renewable energy deployment, while integrating the policy stringency into the analysis, is important as it would provide sufficient information about the effectiveness and substance of the policy itself.

Thus, in this study, six categories, as provided by International Energy Agency (IEA) and International Renewable Energy Agency (IRENA), were considered for the analysis: economic instruments, RD&D, policy support, regulatory instruments, information and education, and voluntary approaches. For economic instruments and RD&D, the budget for supply support and R&D by each country were used as variables to overcome the limitation of not reflecting the implementation stringency. For the other categories, dummy variables were used for analysis due to the difference in implementation by country as well as endogenous problems among policy instruments.

Firstly, factors such as net capacity of renewable energy and renewable energy generation were used as dependent variables for expanding the supply of renewable energy. The analysis showed that both renewable energy generation and renewable capacity have a correlation with the increase in (+) the government's budget for public support and RD&D. In addition, the regulatory instruments were found to have a positive effect on the capacity to install renewable energy and on renewable energy generation. Policies encouraging support and voluntary participation have resulted in an increase in renewable energy generation.

Subsequently, the number of patent applications related to renewable energy was analyzed as a dependent variable to determine the extent of renewable energy technology’ s development. The analysis found that the government's budget for both supply support and RD&D had a positive effect. Moreover, policy support and voluntary approach policies were also found to contribute in increasing the number of patent applications.

The findings of this study will make it possible to predict in advance the dissemination effects resulting from the implementation of the policy during the formulation of the government’ s policies and budget allocation. Unlike previous studies, this study classified and analyzed policies according to their implementation strength. This confirmed that the results for each policy and implementation intensity differ and, this is valuable in that, each country can increase the desired effect by establishing appropriate policies and allocating the budget according to the current status of renewable energy supply and technology development.

Keyword : Renewable Energy, Renewable Energy policy, Renewable Energy Deployment, Policy Evaluation, Feed in Tariff, Renewable Portfolio Standard, Panel data analysis

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Chapter 1. Introduction

1.1. Research Background

In 2000, the share of renewables in capacity electricity generation in OECD countries was only 7.5%. In 2017, renewables accounted for more than 17%, and this share is expected to grow further (IEA, 2018). Climate change and environmental degradation across the globe has led to increased concern for energy transition and renewable energy dissemination. As members of one of the most important organizations in the world, OECD countries have made considerable efforts to foster and support renewable energy deployment in their countries.

Renewable energy policies have been instrumental in the expansion of renewable energy use. Many countries have set targets for using renewable energy, and a wide range of policy instruments have been deployed to overcome economic, technical, and institutional barriers (IEA, 2018). The public budget spent on renewable energy is still increasing and precedes the spending on fossil fuels.

The governments of OECD countries have implemented various renewable policies and invested considerable funds in accomplishing their goals. Their efficient policy-making structures and government' s support for renewable energy deployment have made them progress in renewable energy generation.

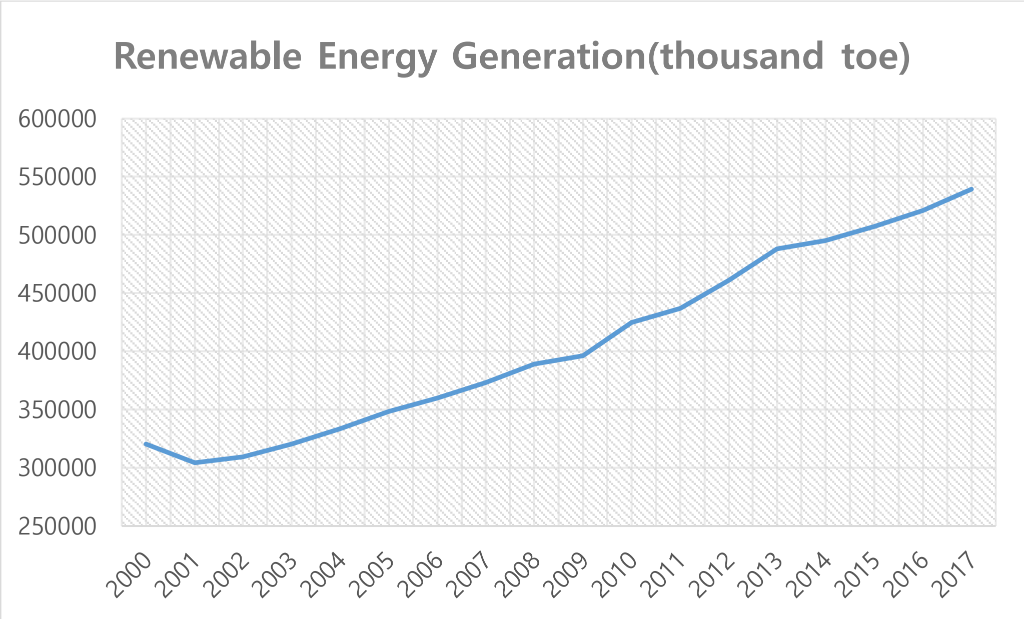

Figure 1 Renewable Energy Generation in OECD countries.

Source: IEA World Energy Statistics and Balances: Extended world energy balances

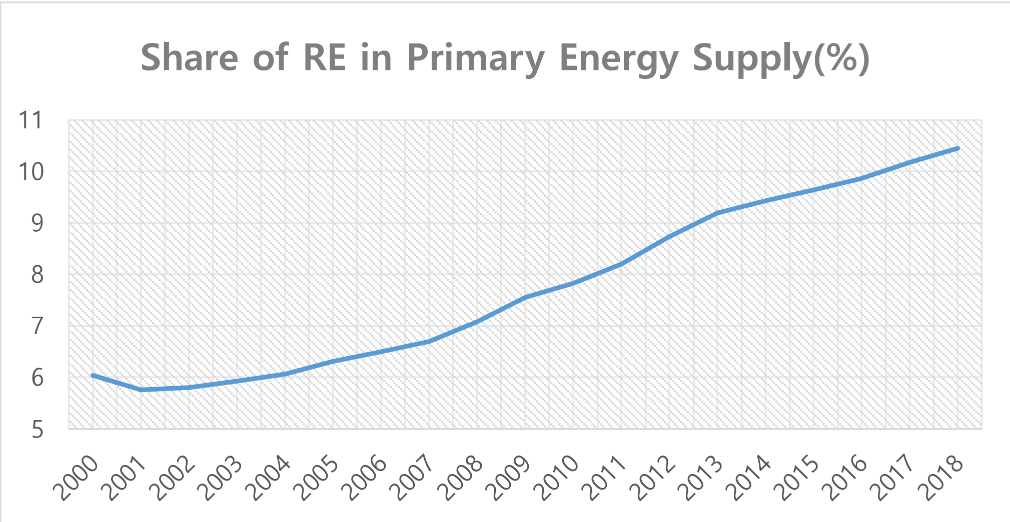

Figure 2 Share of Renewable Energy in Primary Energy Supply in OECD countries.

Source: IEA World Energy Statistics and Balances: Extended world energy balances

The recent rapid increase in the funding of various projects has highlighted the importance of so-called evidence-based policies. Policies that can guarantee value for money should be expanded while efforts should be made to reduce and abolish policies that are based on arbitrary and political demands. (Woo, 2018)

Major energy-related international organizations, such as the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), and Renewable Energy Policy Network for the 21st century (REN21), have also published reports on the importance of policies in the dissemination of renewable energy. They agree that policies have played a significant role in the growth of renewable energy and have helped advance technologies.

In this regard, sufficient research has been conducted to analyze the impact of policies on renewable energy deployment. However, previous studies have only examined the implementation of feed-in-tariffs (FITs) and renewable portfolio standard (RPS). The effectiveness of the policies was not analyzed explicitly as the classification of policies was not used for the analysis. Moreover, a review of the empirical literature on innovation in the renewable energy industry revealed that patent analysis is scholars' preferred approach to measure innovation in this area (Berger et al., 2016).

Also, according to Yun Wang et al. (2019) and Kim Eun-sung (2015), the strength of policy implementation should be included when analyzing the policy's effect.

Accordingly, this study tried to analyze whether the effectiveness of each policy differs based on classification by applying various classifications of renewable energy policies. Besides, the governments intend to analyze the effectiveness of each policy implementation by using the amount invested and the number of implementation policies as variables.

This study aims to find the relationship between renewable energy policies and renewable energy deployment.

1) Research Hypothesis I: Does each policy instrument have a different impact on renewable energy deployment?

2) Research Hypothesis II: Does the stringency of the policy implementation have a different impact on renewable energy deployment?

In this study, panel data was used to investigate the impact of renewable energy policy on renewable energy deployment in OECD countries. There are mainly two reasons I chose the OECD countries as a research sample: First, except for some Asia–Pacific countries, OECD countries make up a large section, and play an essential role in the world economy. Second, in the past few decades, OECD countries have taken a lead role in promoting renewable energy growth. Investigating the renewable policy instruments as well as stringency and the path adopted by OECD countries for renewable energy growth will provide a significant lesson for other countries.

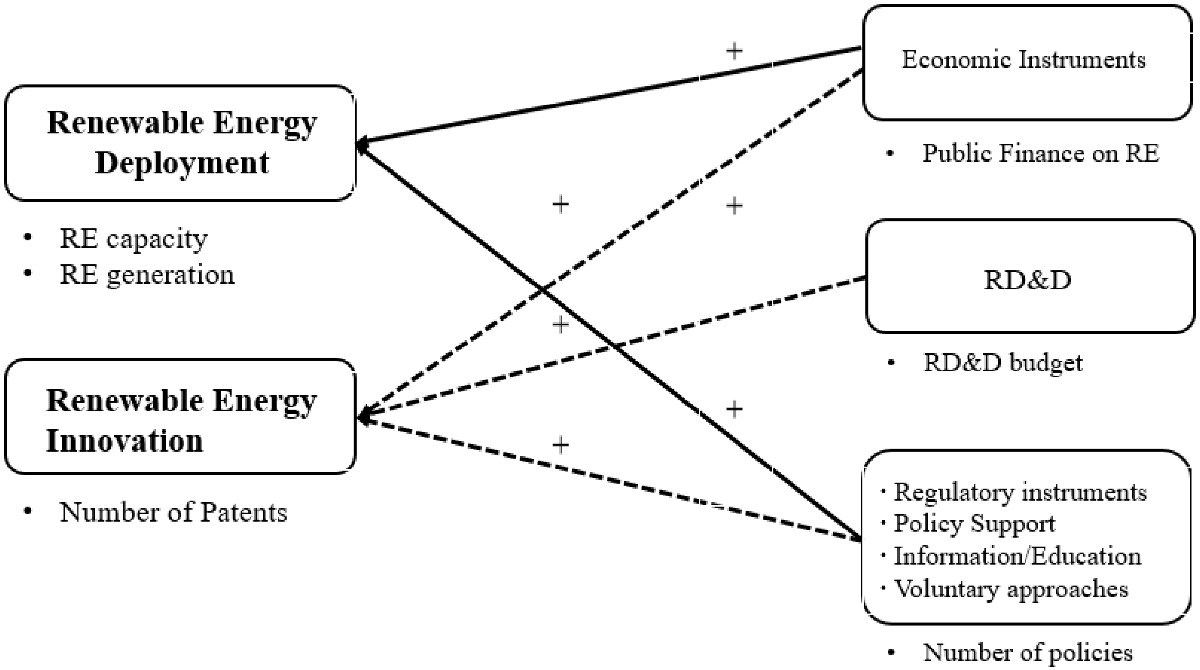

Figure 3 Conceptual Framework of Research Hypotheses

1.2. Research Objective

Environmental concerns and the previously cited limitations of fossil fuels have resulted in the governments' attempting to promote renewable energy technologies. Energy policy plays a crucial role in deploying innovation and cost reduction in renewable energy production. Different countries have implemented different policy instruments in varying stringencies to promote renewable energy deployment and technology innovation. These include economic instruments, research development and demonstration, regulatory instruments, policy support, information and education, and voluntary approaches. Some countries may have the same target, but theoretically, they have different operation schemes. Also, some policies can be more effective than others. In this regard, creating a balance between these policies plays a crucial role in renewable energy deployment. Lessons from advanced countries with indigenous factors will help developing countries to develop renewable energy. The findings of this research are expected to provide an empirical reference for future renewable budget allocation and policymaking.

This study seeks to empirically analyze the effect of policy instruments on renewable energy deployment and technology development in OECD countries using panel data regression between 2000 and 2018.

1.3. Research Design

The first chapter of this paper is the introduction. The research background and objectives of the study have been discussed in this chapter. It also explains the order of the thesis and the conceptual framework of the research.

In the second chapter, the six types of policy instruments have been described. This chapter also provides a brief overview of the renewable energy policies in key countries and Korea.

The third chapter includes a literature review of the previous theoretical and empirical studies.

The fourth chapter contains a description of the data and empirical methods used in the analysis. The empirical results are discussed in Chapter Five.

Lastly, conclusions derived from the research, along with the policy implications and suggestions for further research, are discussed in Chapter Six.

References and appendices for supplementary data have been included in the end.

Chapter 2. Overview of Renewable Energy Policies in OECD countries

2.1. Introduction

Renewable energy support policies have been instrumental in the expansion of renewable energy. Many countries have set themselves targets for renewable energy, and a wide range of policy instruments are being deployed to help overcome economic, technical, and institutional barriers.

As discussed in the previous chapter, a main contribution of this study is the differentiation between policy instruments and implementing intensity as the two main dimensions of renewable energy deployment.

This chapter develops the respective tools and methods. The development process is structured as follows. Section 2.2 introduces policy instruments in renewable energy deployment, discusses their main features and representative examples covered in this study. Section 2.3 dedicated to the measurement of policy stringency. After a discussion and evaluation of the stringency of each policy instruments, the chapter also includes the major renewable energy policies in selected OECD countries.

2.2. Policy Instruments

Policy instruments are measures implemented by state actors in order to achieve a specified target or solve a specific problem. They differ in type and how they operate. (Howlett, 2007, 2017). Therefore, it is important to make an analysis based on each instrument.

In this study, classification based on policy types provided by the IEA/IRENA Joint Policies and Measures Database was applied.[①] Based on the classification of policies provided by the agency as the most public-spirited institution in the renewable energy sector, the analysis of this study may be more feasible. Those classifications include Economic Instruments, Research Development and Deployment, Regulatory Instruments, Policy Support, Information and Education, and Voluntary approaches.

Policy Instruments can be divided as follows.

① The IEA/IRENA Joint Policies and Measures Database provides information on governmental policies, strategies, and programs supporting the deployment of renewable energy technologies, striving to increase energy efficiency and combat climate change. This database was created in 1999, and the data set is being reviewed and updated by IEA countries and by IRENA countries.
(https://www.iea.org/policiesandmeasures/renewableenergy/)

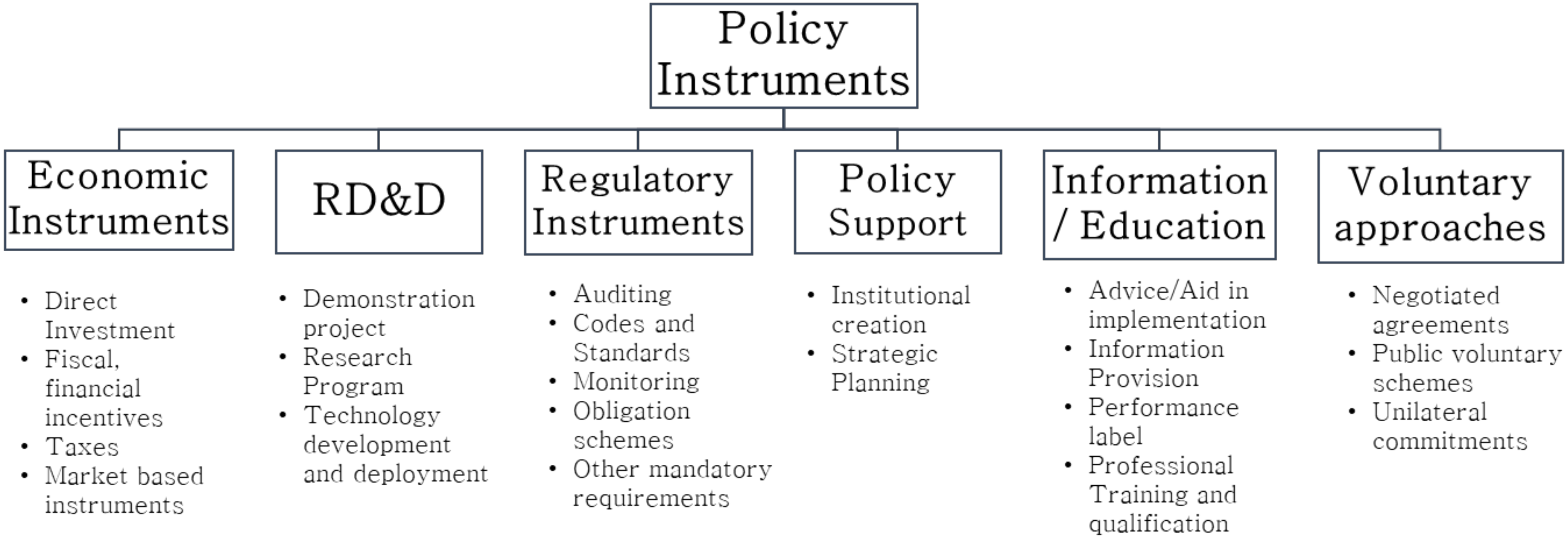

Figure 4 A classification of policy Instruments

2.2.1. Economic Instruments

■ Direct Investment

Renewable energy power plants are often capital intensive with relatively low running costs. Therefore, governments may offer financial subsidies for renewable electricity technology in terms of specific dollars per kilowatt grants, or grants set as a percentage of total investment. Investment subsidies are the most common type of support. However, a major disadvantage of this instrument is the lax of incentive to operate the plant as efficiently as might be the case if production-based financial support was offered. This led to a growing number of countries have begun to apply financial incentives based on production (Uyterlinde, 2004).

■ Financial and Fiscal incentives

Financial and fiscal incentives are used to improve access to capital, lower financing costs, reduce the burden of high upfront costs or the production costs of large-scale renewable energy projects, and address split incentives associated with energy-efficient technologies. They can be introduced in the form of tax incentives, rebates, grants, performance-based incentives, concessional loans and guarantees, and measures to mitigate risk (NREL, 2016b).

■ Tax incentives

Tax incentives are typically offered in the form of reductions in sales, energy, value-added or other taxes, or in the form of investment tax credits, production tax credits, or accelerated depreciation.

2.2.2. Research Development and Demonstration

The overall aim of research, development, and demonstration is to achieve cost reductions, increase efficiency, enhance process reliability, and reduce environmental impacts. Advanced technologies have a direct impact on the development of the industry where they related and at the root of the dramatic reduction in the cost of all renewable technologies in recent years. However, renewable energy still has a long way to go before it reaches more proportions of supply in energy. While some technologies can already cost competitive even without the full internalization of external costs of fossil fuels, significant further cost reductions are necessary through market development and research and development.

Research and development (R&D) have a vital role to play if the potential of renewable energy is to be fully exploited. Policy measures, such as taxes, cap, and trade schemes, obligations, and feed−in tariffs, which take into account environmental impacts and, in particular, the social cost of carbon dioxide emissions, will contribute to faster deployment. However, investment in R&D will not be delivered by market signals alone; extensive support at the national and international levels is needed to accelerate the development of renewable technologies.

2.2.3. Regulatory Instruments

Government targets and policies have led efforts to advance the deployment of all types of renewables in the power sector. Targets provide a high-level signal to various actors to encourage investment in renewable energy and provide the foundation for many of the support policies and measures covered in this chapter. Key policies that enable the translation of targets into concrete actions include mandates, market-based approaches, finance mechanisms, and voluntary consumer and corporate programs.

Initially, investments in solar PV and onshore wind were driven mainly by regulatory and pricing policies such as feed-in-tariffs, offered along with guaranteed access to grids and priority dispatch. As renewable technologies have matured and their costs have fallen, large-scale power projects have been increasingly supported by auctions, which can be designed to fulfill multiple policy objectives.

- Quota and mandates

Renewable energy targets can be cascaded down to electricity suppliers, generators or consumers through electricity quota obligations also referred to as renewable portfolio standards(RPS) or renewable purchase obligations(RPO)

2.2.4. Policy Support

Policy support refers to policies that serve as a keynote to support other policies. It is to establish strategic planning for each country. Typical examples are the National Energy Plan, National Strategy for green growth, and 5-year plan for green growth.

For example, the Korean government has established the National Energy Master Plan every five years, covering the next 20years since 2008. For the plan released in 2014, the plan outlines future energy policy direction, such as the realization of a low-carbon society, and calls for energy security increase, rational use of energy, and environment protection. The government will actively support the development and deployment of non-fossil energy, such as new and renewable energy and nuclear, along with energy demand-side management. Climate change is also viewed as an urgent issue, and the government will facilitate the carbon market and promote public energy-saving activities.

The plan sets various energy targets: to reduce final energy consumption by 13% below BAU level by 2035, and to achieve the share of 11% of renewable energy in total energy consumption by 2035. Moreover, South Korea also seeks to emerge as a major renewable product manufacturer and target to cover 20% of the global solar manufacturing market by 2030 from about 5% in 2008.

2.2.5. Information and Education

It includes the policy as the government provides the notice or a guideline.

For example, in order to promote advanced renewable technology application and industrial upgrading and enhance renewable products and engineering quality management, improve the renewable technology progress and industrial upgrade, the government may implement the "leader "projects by arranging a special market scale every year.

The governments may also provide notice guidelines and obligations on the province in regards to further deployment of renewable energy installations. The notice puts the following requirements (IEA, 2019):

- To recognize the high importance of promotion and construction of new renewable energy installations in an orderly manner.
- To strengthen and speed up the planning process.
- To promote the construction of large scale installations and innovative construction models.
- Guide and coordinate annual development plants along with the development and expansion of the power grid.
- To standardize project management of power grid access and operation management.
- To strengthen the quality of the project management.

2.2.6. Voluntary Approaches

Consumers and companies are being increasingly empowered to make choices about power consumption that align with specific preferences and goals. Key policies and approaches enabling this transformation include information awareness programs on the benefits of renewable energy generation, community-based programs corporate procurement and supply chain greening, and voluntary REC markets.

Information awareness programs often lay the groundwork for community programs and are aimed at educating electricity end-users on the benefits of renewable energy, such as local economic development, GHG emission reduction, air-quality improvements, climate resilience. These programs can be designed by utilities or local and national governments.

Building on awareness outreach, community-based programs enable electricity consumers to either choose renewable energy sources for their electricity generation or invest directly in a community renewable energy project. Under the former approach, often called community choice aggregation, transmission, and distribution services remain unchanged, and consumers are given options about electricity generation supply (e.g., opting in for a certain percentage of electricity to be drawn from renewable sources). Under the investment-based approach, often called community or shared wind or solar programs, consumers can purchase a portion of a local wind or solar project (NREL, 2012). Under profit-sharing, approaches for community wind or solar in the United States, the utilities or another third party owns the renewable energy project, while a share of the profits goes to local communities.

Table 1 Renewable energy policy instruments in selected OECD countries(2018)

	Economic Instruments	RD&D	Regulatory Instruments	Policy support	Information &Education	Voluntary Approaches
Australia	✓	✓	✓	✓	✓	✓
Austria	✓	✓		✓	✓	
Belgium	✓	✓	✓	✓		
Canada	✓	✓	✓	✓		✓
Czechia	✓		✓	✓	✓	
Denmark	✓	✓	✓	✓		
Finland	✓	✓	✓	✓	✓	✓
France	✓	✓	✓	✓		✓
Germany	✓	✓	✓	✓		✓
Greece	✓	✓	✓	✓		
Hungary	✓	✓	✓	✓	✓	
Italy	✓	✓	✓	✓		
Japan	✓	✓	✓	✓		✓
Korea	✓	✓	✓	✓		
Mexico	✓	✓	✓	✓	✓	
Netherlands	✓	✓	✓	✓	✓	✓
New Zealand	✓	✓	✓	✓	✓	✓
Norway	✓	✓	✓	✓	✓	✓
Portugal	✓	✓	✓	✓		
Spain	✓	✓	✓	✓	✓	
Sweden	✓	✓	✓	✓	✓	✓
Switzerland	✓	✓	✓	✓	✓	✓
United Kingdom	✓	✓	✓	✓	✓	✓
United States	✓	✓	✓	✓	✓	✓

2.3. Renewable energy policies in OECD countries

Energy policy systems differ among the countries according to their characteristics, which include natural resources endowments, political and economic systems, and cultural traditions (Couture & Gagnon, 2010). The differences among countries affect policy choices and may make some policies not applicable in certain countries. All of these factors can lead to differences in energy policies.

2.3.1. Republic of Korea

The Korean government put its top energy policy priority on renewable energy. The government pushed to gradually decrease the number of nuclear and coal and instead move toward clean and safe energy sources to meet the country's demand for electricity

Korea is a resource-poor country that relies on 97% of its energy consumption on overseas import; nonetheless, it is the 9th largest energy-consuming country in the world. This inherent problem of energy supply and demand structure in Korea makes it vulnerable to external environmental changes such as rising oil prices.

Korea's various renewable energy policy strategies can be streamlined into two categories: (i) regulatory programs and (ii) supportive programs.

Firstly, regulatory programs include the Renewable Portfolio Standard (RPS), Renewable Fuel Standard (RFS), and mandatory renewable energy installation in public buildings. These schemes enforce the use of a certain level of renewable energy sources in the power generation, transportation, and public sector.

Secondly, in order to stimulate the market expansion of renewable energy systems, various support schemes for renewable energy deployment are provided - soft loans and subsidies to renewable energy installations at households and buildings, eco-friendly energy town, and energy independent island projects.

Table 2 Key Renewable Energy Policies in Korea(2017)

Policy	Description
Renewable Portfolio Standard(RPS)	18 utilities with over 500MW installed capacity are mandated to supply a certain level of electricity from renewable energy sources. (10% by 2023)
Renewable Fuel Standard(RFS)	The transportation sector is required to use a certain mix of renewable energy in their fuel. (Biodiesel 3% by 2020)
Mandatory Installation for public buildings	Public buildings need to consume more than 21% of their total expected energy usage with renewable energy sources. (30% by 2020)
Subsidy for Homes, Buildings, and Local communities	Renewable energy system installation cost is partially subsidized for households, buildings and local communities.
Solar PV rental program	Solar PV rental companies install and rent PV systems to households and get paid back from rental fee and selling renewable energy points. Household owners pay cheaper power bill less than 80% of average bill.
Soft Loan	Long term and low interest loans are provided to renewable energy installers.
Rural Community PV	Local acceptance of renewables is improved while increasing PV development in rural agricultural areas, as farmers can earn benefits by participating as investors in PV systems.
Eco-friendly energy town	Induce communities to install renewable energy systems on unwanted facilities such as sewage treatment plants, and earn new sources of income and enjoy better welfare.
Energy independent Island	Micro-grid systems are installed to replace expensive diesel generators on islands

Korea's continued efforts for renewable energy development and deployment have achieved a huge increase in renewable energy power generation ratio, from 1.24% in 2010 to 7.27% in 2016.

For the past few decades, Korea has strived to expand renewable energy systems across the country. This effort has been greatly accelerated in the recent global energy paradigm shift from fossil to renewable energy, based on two key drivers: the global effort to cut back on carbon emission, and remarkable advance in green energy technologies.

Under the new climate regime, all countries are actively seeking the solution to a carbon free economy. This is becoming gradually possible thanks to technology innovation and cost effectiveness in the renewable energy sector. Hence, renewable energy is considered as the core technology to enable a massive shift in the energy paradigm.

In response to this global shift, and to secure safe energy for the Korean people, the government of Korea launched in May announced denuclearization and de-carbonization in the power sector. Nuclear power plants will be gradually phased out and the shutdown of nuclear power plants under construction will be posted to public discussion. For coal power plants, planned constructions at an early phase will be reexamined of their necessity while new construction of coal plants will be prohibited. The operation of old coal power plants will be suspended for at least four months a year, and 10 coal power plants that are over 30 years old will be retired before the end of the administration's term of office in 2022.

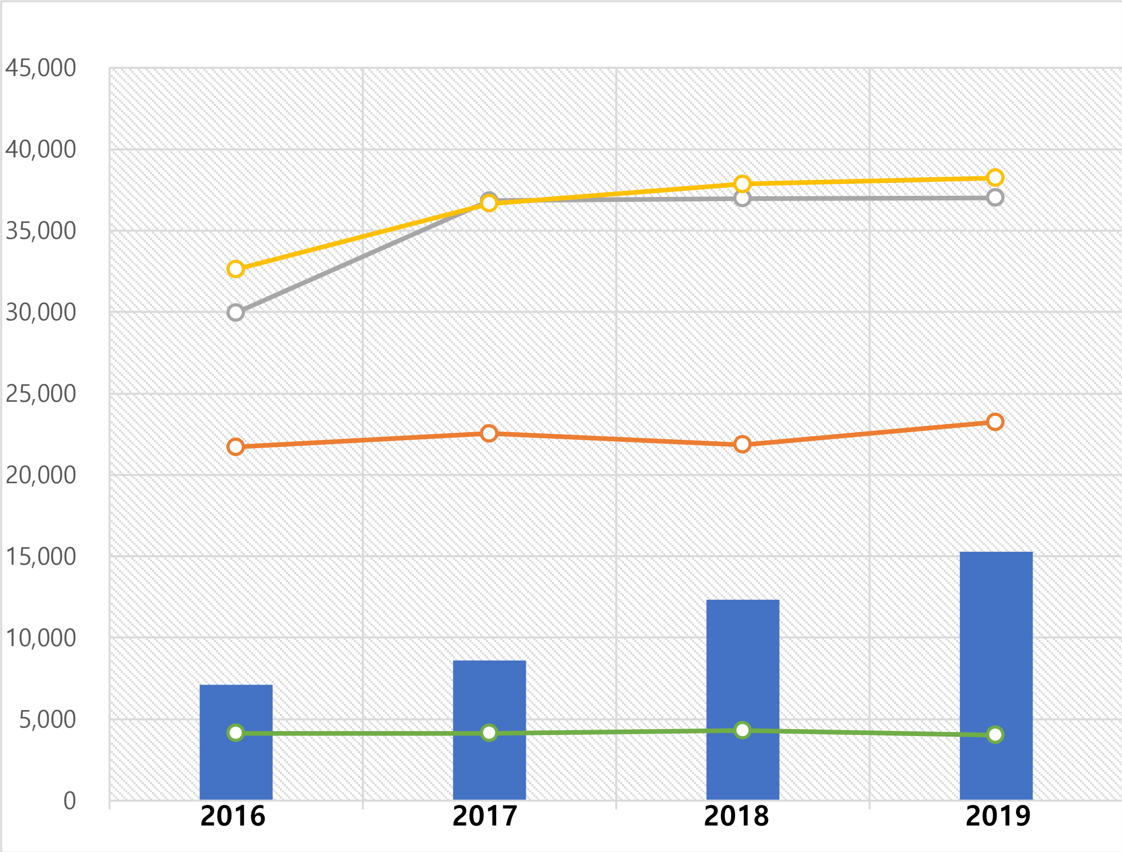

Figure 5 Installed Capacity in Korea, 2016–2019

Source: Redesigned the data of Korea Electric Power Corporation, 2019

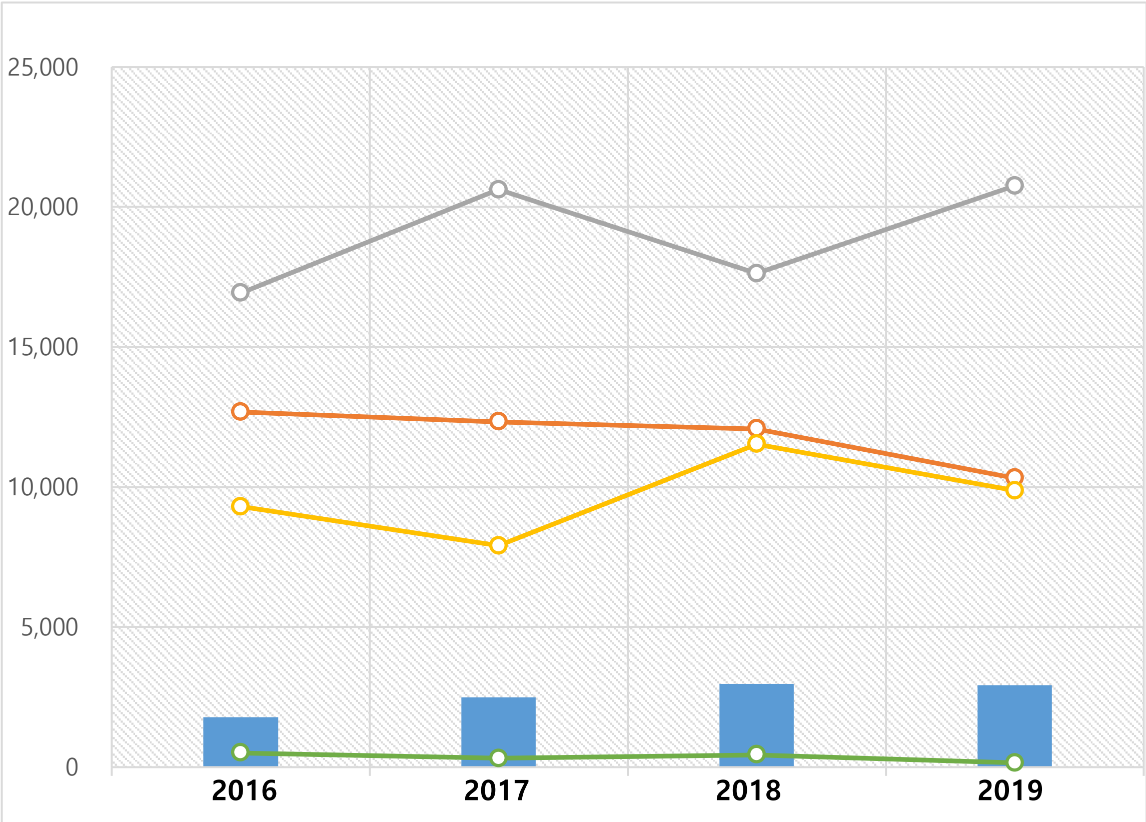

Figure 6 Electricity Generation by sources, 2016-2019

Source: Redesigned the data of Korea Electric Power Corporation, 2019

The government released its power plan through 2030 and growing calls to improve the country's air quality and fears over atomic power. The plan calls to increase the amount of renewable power in the country's energy mix to 20 percent by 2030 from 6 percent, reducing its dependence on coal and nuclear.

In order to meet this goal, Korea must install an additional 53GW of renewable energy, mainly solar PV and offshore wind power by 2030, which in accumulation will amount to 68GW.

To achieve cost-effectiveness of wider renewable energy deployment, Korea shifted its policy focus in 2012 from subsidy-based Feed-in-Tariff (FIT) to market-based Renewable Portfolio Standard (RPS). RPS has significantly lowered the fiscal burden on the government in its effort to deploy renewables, and has led to the creation of a large renewable energy market where cost-efficient options are available, particularly in solar PV and wind power generation.

For example, Energy Independent Island model enables remote islands with limited energy access to enjoy clean, cheap, stable energy supply and increases energy welfare of these communities. Under this model, solar PV, wind power and ESS replace conventional diesel in power generation. As of 2017, the program is underway in 14 islands, as collaborative programs between central and local governments. Another example of welfare renewable energy is Sun Sharing Power Plant. It is recognized as an excellent and practical example of promoting renewable energy and enhancing energy welfare at the same time. Under this program, social enterprises have supported the energy-poor group by sharing profits gained from public solar PV facilities with low income groups in both Korea and abroad.

2.3.2. The United States

Renewable energy in the United States accounted for 12.9 percent of the domestically produced electricity in 2013. Renewable energy reached a major milestone in the first quarter of 2011, when it contributed 11.7 percent of total U.S. energy production (2.245 quadrillion BTUs of energy), surpassing energy production from nuclear power (2.125 quadrillion BTUs). 2011 was the first year since 1997 that renewables exceeded nuclear in US total energy production.

Hydroelectric power is currently the largest producer of renewable power in the U.S. It produced around 6.2% of the nation's total electricity in 2010 which was 60.2% of the total renewable power in the U.S. The United States is the fourth largest producer of hydroelectricity in the world after China, Canada and Brazil. The Grand Coulee Dam is the 5th largest hydroelectric power station in the world.

U.S. wind power installed capacity now exceeds 65,000MW. For calendar year 2014, the electricity produced from wind power in the United States amounted to 181.79 terawatt-hours, or 4.44% of all generated electrical energy. Texas is firmly established as the leader in wind power development, followed by Iowa and California.

Several large solar thermal power stations have also been built. The largest of these solar thermal power stations is the SEGS group of plants in the Mojave Desert with a total generating capacity of 354 MW, making the system the largest solar plant of any kind in the world. As of 2015, the largest photovoltaic (PV) power plant in North America is Solar Star, a 579 megawatt photovoltaic power station near Rosamond, California. The Geysers in Northern California is the largest complex of geothermal energy production in the world.

With 2,957 MW of installed geothermal capacity, the United States remains the world leader with 30% of the online capacity total. As of early 2009, 120 new projects are underway. When developed, these projects could potentially supply up to 3,979 MW of power, meeting the needs of about 4 million homes. At this rate of development, geothermal production in the United States could exceed 15,000 MW by 2025.

The development of renewable energy and energy efficiency marks "a new era of energy exploration" in the United States, according to President Barack Obama. In a joint address to the Congress on February 24, 2009, President Obama called for doubling renewable energy within the next three years. In his 2012 State of the Union address, President Barack Obama restated his commitment to renewable energy and mentioned the long-standing Interior Department commitment to permit 10,000 MW of renewable energy projects on public land in 2012.

2.3.3. Germany

Germany has been called ‘the world’s first major renewable energy economy’ (Burger, 2014). Renewable energy in Germany is mainly based on wind, solar, and biomass. Germany had the world’s largest photovoltaic installed capacity until 2014, and as of 2016, it is third with 40GW. It is also the world’s third country by installed wind power capacity, at 50GW, and second for offshore wind, with over 4GW.

The renewable energy sector benefited when the Alliance '90/The Greens party joined the federal government between 1998 and 2005. Support for renewable energy continued under all following governments, regardless of composition, including the current CDU/CSU and SPD coalition government starting in 2018. The renewable energy sector was aided especially by the Renewable Energy Sources Act that promotes renewable energy mainly by stipulating feed-in tariffs and recently also market premiums that grid operators must pay for renewable energy fed into the power grid. People who produce renewable energy can sell their 'product' at fixed prices for a period of 20 or 15 years. This has created a surge in the production of renewable energy. In 2012, Siemens estimated the total cost of renewable energy would come to at least 1.4 trillion euros by 2030.

For the 2011–2014 period, the federal government set aside 3.5 billion euros for scientific research in the country. Additionally, in 2001 a law was passed requiring the closing of all nuclear power plants within a period of 32 years. The shutdown time was extended to 2040 by a new government in 2010. After the Fukushima incident, the law was abrogated and the end of nuclear energy was set to 2022.

After the 2013 federal elections, the new CDU/CSU and SPD coalition in important areas continued the Energiewende of the previous government, but also agreed on a major revision of the EEG.

The German energy policy is framed within the European Union, and the March 2007 European Council in Brussels approved a mandatory energy plan that requires a 20% reduction of carbon dioxide emissions before the year 2020 and the consumption of renewable energies to be 20% of total EU consumption (compared to 7% in 2006). The accord indirectly acknowledged the role of nuclear energy — which is not commonly regarded as renewable, but emissions-free — in the reduction of the emission of greenhouse gases, allowing each member state to decide whether or not to use nuclear-generated electricity.

Also, a compromise was reached to achieve a minimum quota of 10% biofuels in the total consumption of gasoline and diesel in transport in 2020.

In Germany, electricity from renewable sources is mainly supported through a market premium scheme. For most installations, the award and the level of the market premium is determined through a tendering scheme. However, small power plants up to 100 kW are still supported by a feed-in tariff. The criteria for eligibility and the tariff levels are set out in the Renewable Energy Sources Act (EEG 2017). In 2017 the tenant electricity surcharge has been added to the EEG, which supports electricity produced and consumed in the same residential building. Moreover, low interest loans for investments in new plants are provided for by different KfW-Program and there is an additional subsidy to promote the installation of flexible biogas capacities.

In Germany, the Guidelines for the support of RES-H set out the Market Incentive Program (MAP), stipulating support schemes for the promotion of heat produced from renewable energy. BAFA is providing investment support for individual heat installations as well as district heating systems, while KfW offers low-interest loans.

There is no support scheme addressing particularly the use of renewable energy sources for the transport sector. A greenhouse gas reduction quota is in place, which can be fulfilled by the usage of biofuels. A KfW loan provides – among other -support for the commercial purchase of hydrogen, hybrid and electric vehicles and private individuals can benefit from buyer's premium when buying such vehicles.

Plants for the generation of electricity from renewable sources shall be given priority connection to the grid. Furthermore, grid operators are obliged to give priority to electricity from renewable sources when purchasing and transmitting electricity. Moreover, those interested in feeding in electricity may demand that the grid operator expands his grid.

Germany provides policies for the promotion of renewable energy sources covering training, certification and research programs, a self-commitment of public authorities, the support of district heating networks and the introduction of building obligations regarding the use of heat produced from renewable energy.

2.3.4. Denmark

Denmark has a long tradition of setting ambitious national energy targets. In 2030, renewables should cover at least half of the country's total energy consumption. By 2050, Denmark aims to be a low-carbon society independent of fossil fuels. The country is moving convincingly to meet these world-leading targets. Electricity generation in Denmark has changed fundamentally over the past two decades. Coal generation has been vastly eroded, and the bulk of power generation now comes from wind and bioenergy. Supported by a flexible domestic power system and a high level of interconnection,

Denmark is now widely recognized as a global leader in integrating variable renewable energy while at the same time maintaining a highly reliable and secure electrical-power grid. The heating sector is also critical for Denmark's low-carbon ambitions. Denmark's large-scale use of combined heat and power plants with heat storage capacity, and the increasing deployment of wind power offer great potential for efficient integration of heat and electricity systems. However, policies and regulations need to be aligned to realize that potential. Finding the right levels of energy taxation is particularly important.

Denmark has successfully decoupled its economic growth from greenhouse gas emissions, thanks to a combination of energy efficiency improvements, and fuel switching to renewables. As in all countries, more needs to be done to limit emissions from transport.

In Denmark, electricity from renewable sources is mainly promoted through a premium tariff and net-metering. The premium tariff for wind and solar PV installations is awarded through tenders, furthermore, Denmark supports the construction of pilot windmills trough a separate state fund. This support is also granted trough tenders. Renewable energy sources for heating purposes are exempt from the tax obligations on the production, supply and use of energy sources. The use of biogas for heating purposes is supported through a direct tariff. The main incentive for renewable energy use in transport is a quota system. Selling of biogas for transport purposes is supported through a direct tariff.

Access of electricity from renewable energy sources to the grid shall be granted according to the principle of non-discrimination. With regard to the use of the grid, renewable energy shall be given priority. The connection of a heat generation plant to a district heating network in Denmark always involves grid development, since the construction of a plant must occur simultaneously with the development of the district heating grid.

Chapter 3. Literature Review

3.1. Theoretical Studies

Literatures on energy policy have analyzed the relationship between policy and RE deployment in a number of different ways, generating evidence for policy makers to support their decisions. Fundamental questions such as influence of price or quantity based mechanisms have been addressed. A number of researchers have observed the importance of policy instruments like FIT, RPS and tax credits

1) Sapan Thapar et al (2018)

Sapan Thapar et al (2018) investigated key determinants of renewable energy growth in India. Since the wind energy has been considered as an important resource to meet the energy needs of India, this research focused on wind energy growth. They analyzed wind growth in six resource rich states of India using panel data regression, considering 16 explanatory variables categorized under policy, geographic, economic, social, technical, and commercial heads. Contrary to expectation, both policy variables FIT and RPO came out as insignificant factors.

2) Friedmann Polzin et al (2015)

Friedmann Polzin et al (2015) examined the impact of public policy measures on renewable energy investments in electricity generating capacity made by institutional investors. They investigated the influence of different policy measures in a sample of OECD countries to suggest an effective policy mix which could tackle failures in the market for clean energy. The results call for technology specific policies which take into account actual market conditions and technology maturity. To improve the conditions for institutional investments, advisable policy instruments include economic and fiscal incentives such as feed-in-tariffs (FIT), especially for less mature technologies. Additionally, market-based instruments such as greenhouse gas (GHG) emission trading systems for mature technologies should be included. These policy measures directly impact the risk and return structure of RE projects. Supplementing these with regulatory measures such as codes and standards (e.g. RPS) and long-term strategic planning could further strengthen the context for RE investments.

3) Reinhard Haas et al (2011)

A wide range of strategies is implemented in different countries to increase the share of electricity from renewable energy sources. A still controversial discussion is whether quantity driven or price driven instruments lead to preferable solutions for society. The main objective of this research is to compare the perspectives of quota-based certificate trading systems for an efficient and effective increase of renewable energy sources with FIT. Reinhard Hass et al (2011) found that the success of renewable energy growth in EU member countries in recent years had been triggered by FIT implemented in a technology specific manner at modest costs for European citizens. Also, Tradable Green Certificates systems in most countries applied have shown a low effectiveness with respect to renewable energy sources deployment of less mature technologies such as solar PV. Therefore, they found that a well-designed FIT system provides a certain deployment of renewable energy sources in the shortest time and at lowest costs for society.

4) Shin-Je Li et al (2017)

Shin-Je Li et all (2017) measured the policy effectiveness of power purchasing agreements, capital grants, tax incentives, preferential loans, and research, development, and demonstrations for photovoltaic and wind power development in the member countries of the European union. They found that the feed-in-tariff is more efficient than renewable portfolio standards (RPS) for PW and wind power development while RPS still have an effect on wind power development. However, the other economic instruments are all inefficient for PV development but are efficient for wind power development, except for tax incentives.

5) Nurcan Kilinc–Ata (2016)

Renewable energy policies are implemented to promote the diffusion of renewable energy sources within the market. However, their effectiveness on renewable electricity capacity remains subject to uncertainty. Nurcan Killinc–Ata (2016) addressed what renewable policy instruments are effective ways to increase capacity of renewable energy sources. They conducted an econometric analysis of policy instruments, feed–in–tariffs, quotas, tenders and tax incentives, in promoting renewable energy deployment in European Union countries and United States. The result suggested that renewable energy policy instruments play a significant role in encouraging renewable energy sources, but their effectiveness differs by the type of renewable energy policy instruments. Findings reveal that fee–in–tariffs, tenders and tax incentives are effective mechanisms for stimulating deployment capacity of renewable energy sources for electricity, while quota which is the other commonly used policy instrument is not.

6) Eunsung Kim and Eunnyeong Heo (2015)

This study analyzed the amount of renewable energy generation according to the introduction of RPS and FIT. The amount of renewable energy generation was analyzed using a dynamic panel analysis, judging that it would be correlated with the generation of the previous year. The analysis shows that FIT has more impact on the increase in renewable energy generation than RPS.

In this study, Eunsung Kim and Eunnyeong Heo (2015) mentioned as a limitation of this research as only the implementation of FIT and RPS was used in the analysis, and the differences in the stringency of implementation were not considered.

There is much research on the impact of renewable energy policies on renewable energy generation or generation capacity. However, most studies found that only the implementation status of FIT(Feed-in-Tariffs) and RPS(Renewable Portfolio Standards) were used in the analysis.

Therefore, in this study, various policy classification was introduced to address the lack of the analysis in diverse policy instruments and the lack of differences in implementation stringency, which can be seen as limitations of previous studies, and the use of policy variables to reflect the differences in implementation stringency.

Table 3 Summary of selected existing studies

#	Authors	Period	Region	Dependent variables	Independent variables	Methodology
1	S. Thapar et al(2018)	2003–2016	India	Renewable generation	FIT, RPO	Panel data regression
2	E. Kim (2015)	1990–2011	OECD	Renewable generation	FIT, RPS	Panel data analysis
5	Carley (2009)	1998–2016	United States	Renewable generation	RPS	Panel data
6	Cicea et al (2014)	1990–2008	European Union	Renewable power production	Policies and Subsidies	Panel data
7	Mariana and Ibikunle (2014)	1990–2010	BRICS	Renewable power production	RPS	Panel data
8	Dombrovski (2015)	1990–2011	European Union	Renewable capacity and generation	FIT, RPS, and fiscal incentives	OLS

9	Killinc Ata (2016)	1990–2008	European Union and United States	Percentage of renewable electricity grid	FIT, RPS, TGC and tax incentives	Panel data
10	Antonio et al (2017)	2004–2011	developed and developing countries	Renewable power generation	Regulatory policies, Fiscal incentives, Public investments	Panel data
11	Nicolini and Tavoni (2017)	2000–2010	Europe	Renewable power generation	Incentives and Tariff	OLS
17	Shin Je Li et al (2017)	1996–2013	European Union	Renewable generation	PPA, Capital grants, tax incentives, preferential loans, RD&D	Panel data
18	F. Polzin et al(2015)	2003–2011	OECD		Economic instruments, Policy support, Regulatory instruments	Panel data analysis

3.2. Studies using panel data estimation methods

1) Panel Data estimation

Panel data is a combination of time series data and cross-section data. The time-series data has multiple points of observation for a particular object, whereas the cross-sectional data has multiple objects that are observed at a particular point in time. That is, the panel data records the phenomena or characteristics of different objects by a series of observational points.

Panel data estimation has the advantage over time-series or cross-section data, while cross-section data can only be estimated in static relationships between variables because it is an investigation of multiple objects at a given point in time. By comparison, the panel data can estimate because individual variables appeared repeatedly.

Second, it is possible to consider the unobserved heterogeneity of the analyzers explicitly. Panel data can address many of the issues of endogenesis, especially without the need for tool variables. It is very advantageous to estimate policy effects because it does not have to be challenging to find tool variables with panel data. For example, if there are variables that are important in the determination of y, but are not observed by the researcher, and the missing variables are correlated with the policy variables, the OLS estimates do not have consistency.

Third, the panel data provides more information and variability of variables than other data. As a result, there is the advantage of having an efficient estimator. Also, the linear regression model can alleviate the problem of multiple resonances. Even if the variation in the description variables in various forms, the correlation between the explanatory variables can be reduced, even though there is a strong correlation between the two explanatory variables.

However, there are also shortcomings. First of all, there are difficulties in collecting data. Also, there may be a group-wise correlation between panel groups for data that are investigated by setting up a country or region as a panel group. Therefore, the correct reasoning results can be obtained when these intergroup correlations are considered in the model estimate.

Munlak et al. (1978) determined the nature of the regression model based on how to define unobserved heterogeneity. If unobserved heterogeneity is correlated with an independent variable, it is called a fixed-effect model, and if not, a random effect model. When evaluating policies using panel data, the model selection should also be considered. First, the fixed-effect model allows the correlation between unobserved heterogeneity and explanatory variables. It is a more conventional model compared to arbitrary effects that do not allow for correlation. However, for fixed effects, it is highly likely that the policy effects could be misestimated because they should be estimated using the in-group variances that have changed during the individual's observation. That is, a policy effect that is not statistically significant may be estimated. A random-effects model is a model that adds to the strong assumption that there is no correlation between fixed effects and explanatory variables. Therefore, the estimated policy effects are likely to differ depending on the missing variables.

2) Benefits of using Panel Data estimation

The reasons for using panel data analysis methods in this study are as follows.

First, with panel models, regional differences and time-variant effects can be controlled to estimate the effects of independent variables on the dependent variables.

Second, although the cross sectional samples are not enough in number, the data can be integrated with the corresponding time series data, thus increasing the significance levels and efficiency of the estimated parameters.

Third, panel models can address the multi-collinearity problems that may occur when determining the influence of policy measures on investments in RE capacity because spatial and temporal effects could overlap. (Marques et al, 2010)

The panel data combines time-series and cross sectional observations, resulting in a large panel data set in statistics and econometrics. The estimates of coefficients derived from models of pooled regression, fixed effects or random effects, can be subject to omit small sample bias from outlier. Hence, this study uses panel data which contain multiple countries and years to investigate the policy effectiveness of economic instruments for renewables accurately.

3.3. Measures of policy implementation stringency

Following on the discussion and classification of different policy instruments, this section covers implementation of policy stringency. Putting implementation stringency as second dimension to the overall evaluation framework is essential to understand how serious countries' efforts to promote the renewable energy deployment are. Therefore, generally applicable and reliable indicators are required to make implementation intensity measurable, to compare intensities between countries, and to track its changes over time.

However, the question of how to reliably measure the stringency of policy has traditionally been one of the challenging questions (Berger et al, 2016). Although multiple alternative approaches have been applied in empirical research, there is no one single standard tool for stringency measurement. The tools applied in empirical studies vary considerably depending on factors like research question and data availability. The latter being a critical issue as it appears to be strongly dependent on industry context, national context, and time period covered in the data sample. (Jaffe et al, 2002; Berger et al, 2016).

Developing meaningful measures of environmental regulation is a key challenge in research on trade and the environment. Brunel and Levinson (2013) identify four inherent obstacles of commonly used measures of regulatory stringency. The first obstacle is that environmental regulations cannot easily be captured by one measure of stringency. The second one is that countries with strong economies or bad pollution problems may impose more stringent regulations, which means that it's hard to develop stringency measures which isolate regulations' effect on economic performance from the opposite effect of economic performance on governments' willingness to adopt stringent regulation.

Due to the complexity of policy portfolios and the instruments themselves, multidimensionality is the main drawback of this approach. This is especially the case for measures of policy strictness which attempt to compare the stringency of alternative policy instruments based on their actual wording and provisions.
Aggregated policy indices are another solution for the multidimensionality issue. The idea is to summarize the estimated stringency levels of all relevant provisions in one aggregated measure. This approach has a great appeal with researchers and has been applied by Johnstone et al (2012) and Polzin et al (2015).
The last group of policy-based stringency indicators is public expenditures on policy enforcement on pollution abatement. The advantage of measuring regulation based on expenditures is the relatively high data availability and quality and the good comparability among countries.

OECD also reported environmental policy index (EPS) for OECD countries in 2014, Wang Yun et al (2019) used this index as a policy stringency indicator. Diederich Henning (2016) used the share of renewables in countries' electricity mix as an ideal intensity measure but this is much more of a policy's effect than a policy's intensity.

Therefore, in this study, the research was used as a dependent variable to find out the results of the policy on renewable energy, power generation capacity, and patent collection during the prior period, and the input cost and number of policies were to be analyzed using the strength of the policy.

Chapter 4. Data and Research Methodology

4.1. Data

As discussed in previous section, the main contribution of this study is the differentiation between policy instruments and stringency of the policy as the two main dimensions of renewable energy deployment.

The variables used in this study can be divided into three main variables: dependencies that are subject to analysis, explanatory variables to identify the effects of the policy, and control variables to control the effects that could affect other dependencies.

4.1.1 Dependent Variables

In the previous studies that analyzed the effects of policies for the deployment of renewable energy, three variables – the capacity of the installation of renewable energy, the amount of renewable energy generation among the total energy – have been used as variables that represent the effect of implementing the policies.

Effectiveness is the extent to which intended objectives are met, for instance the actual increase in the output of renewable electricity generated or shares of renewable energy in the total energy supplies within a specified time period. (Mitchell et al, 2011). If the main policy objective is to deploy RETs(Renewable

Energy Technology), then suitable indicators are the installed capacity and the amount of electricity generated(IRENA, 2014).

The expected results vary slightly depending on each variable.

The capacity to install renewable energy has the advantage of inducing investment in policies. It is because the same capacity can avoid errors in power generation depending on the climate or operational efficiency of the year. On the other hand, most policies are implemented for advanced power capacities, so power generation is more closely related to actual policies than to installed capacity. The advantage of using the power generation ratio is that it can control the increase in renewable energy generation due to the increase in total energy use.

The purpose of this study was to observe the effects of the distribution of renewable energy by using the installed capacity and power generation as a dependent variable.

The number of patents released in the renewable energy sector is also used as a dependent variable as a representative of renewable energy innovation.

1) Installed capacity of Renewable Energy(Mwe)

The first dependent variable used in this analysis is Installed Capacity of Renewable Energy. The data for install capacity of renewable energy in each county are collected from IRENA(International Renewable Energy Agency) Data and Statistics② between 2000 to 2018.

2) Renewable Energy Generation(GWh)

The dependent variable used in this analysis is Renewable Energy electricity generation in each country. Renewable Energy generation data for 16 countries in OECD countries during 2000 and 2018 are collected from IRENA(International Renewable Energy Agency) Data and Statistics③.

② https://www.irena.org/Statistics

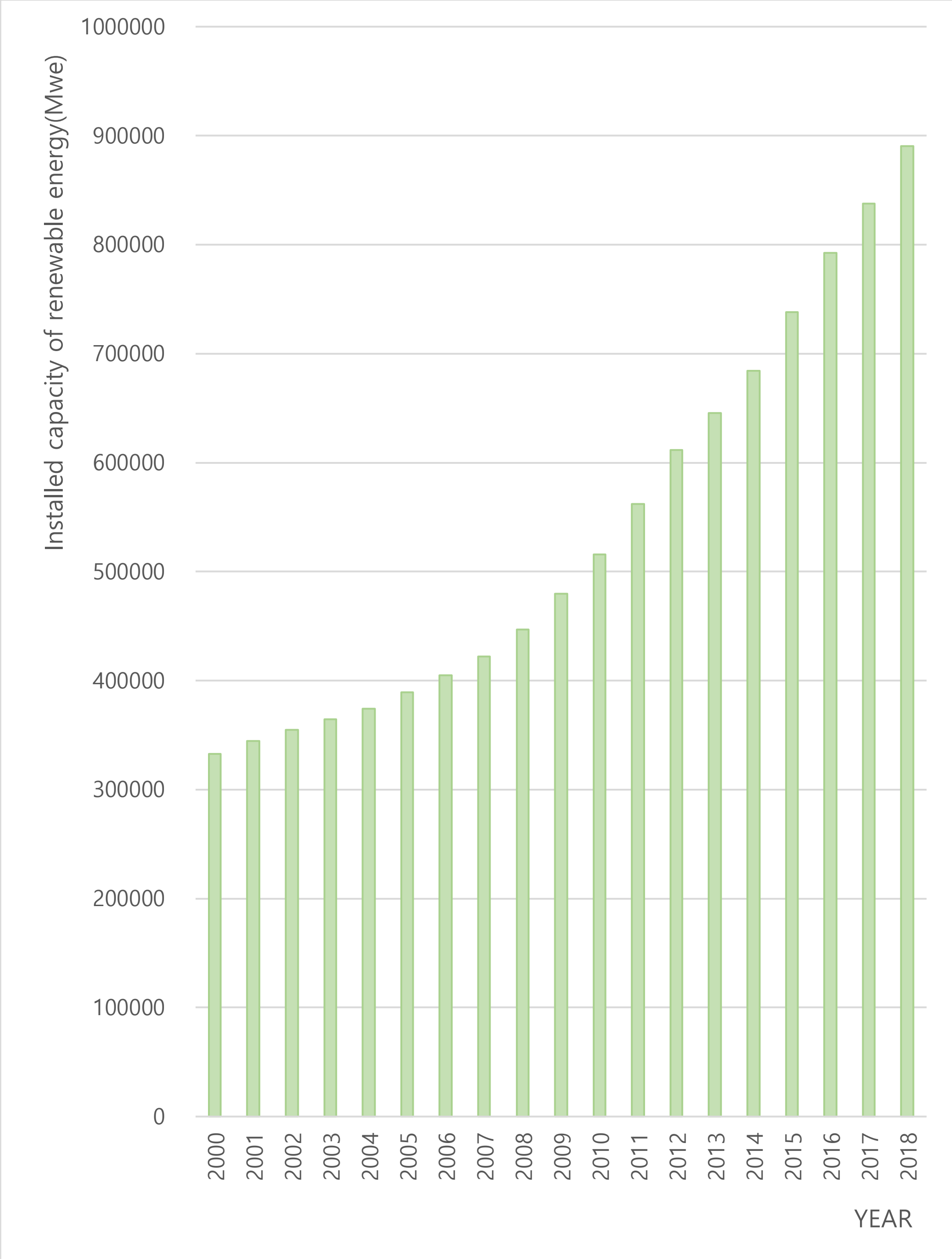

Figure 9 Cumulative installed capacity of Renewable energy, 2000−2018

Source: Redesigned the data of IRENA, 2019

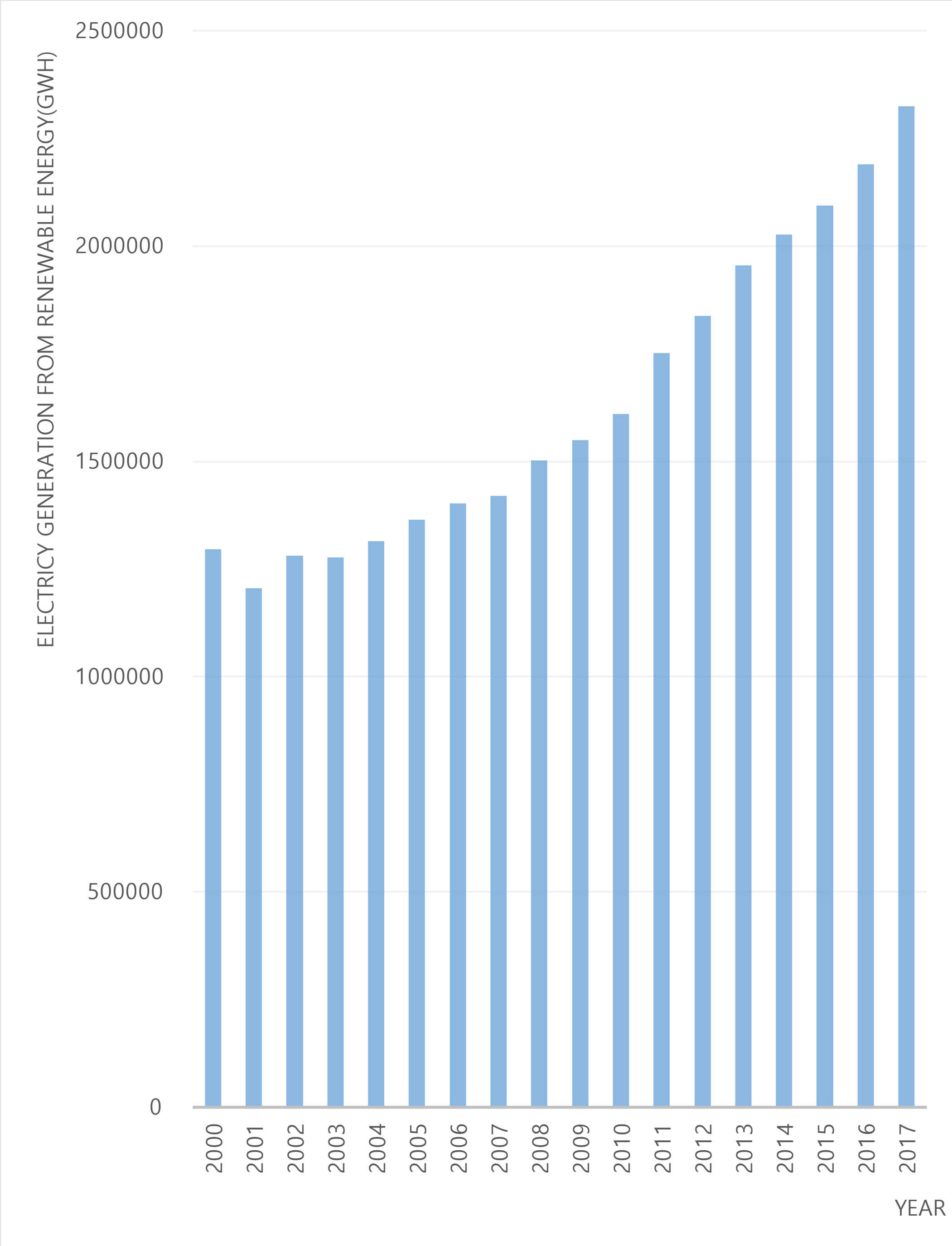

Figure 10 Annual Renewable Energy generation, 2000-2017

Source: Redesigned the data of IRENA, 2019

3) Number of Patents in Renewable Energy sector

The number of patents was adopted as a dependent variable to evaluate the development of the technology. Patents data for each country are collected from EPO PATSTAT and also uses the Climate Change Mitigation Technologies (Y02) classification by EPO.[④]

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④ The patent classification is based on IRENA INSPIRE(www.irena.org/inspire).

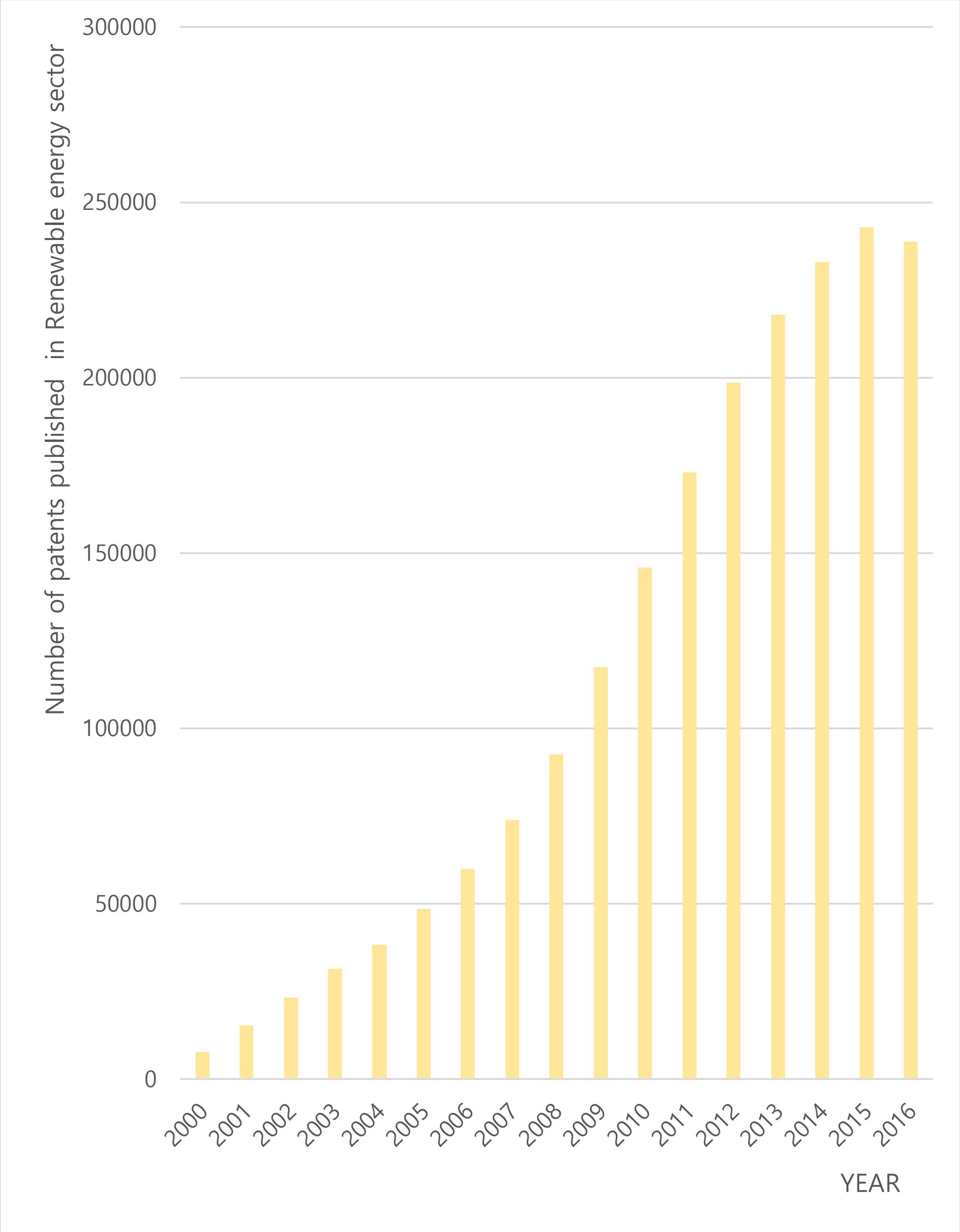

Figure 11 Renewable Energy Patents Evolution in OECD countries, 2000-2016

Source: Redesigned the data of IRENA and EPO STAT,2019

4.1.2 Independent Variables

As discussed in previous section, Policy Instruments were used for the independent variables to analyze the impact of each instruments.

For the Economic Instrument and Research Development and Demonstration of policy variables, it is not significant to perform analysis simply whether it is implemented or not because most countries are in place. In particular, it was expected that the deviation would be mainly depending on the input budget.

E. Kim (2015) stated that an analysis of the relationship between renewable energy generation and renewable energy generation based on the stringency of the implementation of the policy is necessary. In this study, the Public Finance on Renewable Energy of each country was used as the representative variable of the Economic Instruments, and the Public RD&D bridge on Renewable Energy was used as the representative variable of the Research Development & Demonstration.

In the case of the Regulatory Instruments, Policy Support, Information and Education, and Voluntary Approaches, it can be thought that the timing and availability of implementation were significant for each country, and it was difficult to find quantitative indicators, so dummy variables were used according to the implementation of the policy.

The source of policy information used for this research are IEA and IRENA Joint Policies and Measures Database(IEA/IRENA,

2019) [5], and the OECD's IEA Energy technology RD&D statistics(OECD,2019). Public Finance data are collected from the annual reports provided by the National energy authorities and Bureau of Statistics. The data for Australian Renewable Energy budget are available in annual reports released by the Department of the Environment and Energy. [6] The European county data can be found on the IRENA's annual reports[7] and European Environment Agency. The Korea data and Japan data are collected from the budget of Ministry of Trade, Industry and Energy(MOTIE) in Korea and New Energy and Industrial Technology Development Organization (NEDO) [8], respectively. And the budget plan of Government of Canada[9] and USA are also used.

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⑤ https://www.iea.org/policiesandmeasures/renewableenergy/
⑥ http://www.environment.gov.au/about-us/accountability-reporting/budget-statements
⑦ Renewable Energy Cost 2019, IRENA
⑧ https://www.nedo.go.jp/library/pamphlets/ZZ_pamphlets_00029.html
⑨ https://www.budget.gc.ca/2018/home-accueil-en.html

4.1.3 Explanatory Variables

Even if the same policy is implemented in the supply of renewable energy, there could be differences among countries. For example, one can estimate that the higher the GDP, the higher the amount that can be invested in renewable energy generation. Also, the total land area for solar power generation is solar power generation will be more favorable for the more extensive country can be estimated.

Thus, additional control variables were used by different countries to control these differences.

1) Socioeconomic factors

Energy is essential to run the country's economy, with the demand depending upon its economic growth and energy usage patterns. Ruhul and Shuddhasattwa(2012) found a correlation between GDP growth and energy demand.

Also, the renewable power feeds into country's energy supply. Therefore, it can be inferred that the higher the demand for energy, the higher the need for supply, which leads to the expansion of renewable energy. Energy use will also increase with larger populations. As such, GDP, energy consumption and population are used as explanatory variables.

Interest in environmental issues is also deeply related to the supply of renewable energy. The Paris Agreement on Decreasing GHG Emissions and the Kyoto Protocol also recommend energy conversion to reduce the use of fossil fuels and increase the use of renewable energy as an alternative to reducing greenhouse gas emissions. As such, CO_2 emissions is taken as an explanatory variable.

2) Country factors

The net energy imports of each country is also important variables. Energy availability and prices are vulnerable to geopolitics, which impact the energy security of importing nations (Thapar et al, 2019). Especially the land area of each country directly impacts to specific renewable energy sources, such as solar power.

As such, the net energy imports and land area are used as explanatory variables.

Table 4 Data description and sources

		Indicator	Source
Dependent Variables	Renewable Energy Deployment	Renewable energy capacity(Mwe)	IEA statistics
		Renewable energy generation(Gwh)	IEA statistics
	Technology Development	Number of Patent application	EPO PATSTAT
Independent Variables	Economic Instruments	Number of economic instruments per country and year	Bureau of Statistics and Energy agency of each countries
	RD&D	RD&D budgets on Renewable energy per count	IEA statistics
	Information/Education	Number of Information and Education policies per country and year	IEA and IRENA joint policies and measures database
	Policy Support	Number of policy support policies per country and year	
	Regulatory Instruments	Number of regulatory instruments per country and year	
	Voluntary approaches	Number of voluntary approaches per country and year	
	Socioeconomic factors	Energy consumption	World Bank
		GDP	
		Population	
		CO2 emissions	
	Country factors	Net energy import	
		Land Area	

4.2. Methodology

Panel estimation methods are used for empirical analysis in this research since using panel data has some benefits over estimation methods.

First, using panel data for analysis can effectively solve the multi collinearity problems that can may occur when determining the influence of policy measures. The multi collinearity problem can lead to inaccurate parameter estimations and cause severe loss of statistical power. Hence, addressing this issue is important to avoid misleading interpretations and conclusions in the analysis.

Second, using panel data can account regional differences and time variant effects with relatively small number of cross sectional data.

With these advantages, this study applies panel data estimations for the empirical analysis.

4.2.1 Decision for fixed effects and random effects model

4.2.1.1 Hausman Test

Panel data estimation method can be chosen depending on whether the error term is presented as fixed effects or random effects.

Consider the following linear panel regression model

$$y_{i,t} = (\alpha + u_i) + \beta x_{i,t} + e_{i,t} \tag{1}$$

From Equation (1), fixed effects model considers $(\alpha + u_i)$ as a fixed parameter for each panel data object, and random effects model considers $(\alpha + u_i)$ as a random variable following random distribution with $(\alpha + u_i) \sim N(\alpha, \sigma_u^2)$.

It is possible to select the fitting model for panel estimations between fixed and random effects models by conducting Hausman Test. The null and alternative hypotheses for the test are as follows:

$$H_0: cov(x_{i,t}, u_i) = 0 \tag{2}$$

$$H_1: cov(x_{i,t}, u_i) \neq 0 \tag{3}$$

Failure to reject the null hypothesis means that random effects model is suitable for estimating the panel data; rejection of the null hypothesis means that fixed effects model is more efficient model to obtain consistent estimates in panel series.

4.2.2 Panel fixed effects model

The following equation considers the panel regression model with statistically significant variables to be estimated and further interpreted in the results.

$$\mathrm{Renewable}_{\mathrm{i,t}} = \alpha + \sum_{k=1}^{K} \beta_p Policy_{k(i,t)} + \beta_1 X_{socioeconomics} + \beta_2 X_{country} + \varepsilon_{i,t}$$

Where $\mathrm{Renewable}_{\mathrm{i,t}}$ means Installed capacity of Renewable electricity(MWe), Renewable electricity generation(Gwh) and number of policy patent application. $\mathrm{Policy}_{\mathrm{k(i,t)}}$ means policy instruments, $\mathrm{X}_{\mathrm{socioeconomics}}$ means socio−economic factors such as energy consumption and GDP, and $\mathrm{X}_{\mathrm{country}}$ means country factors such as net energy import and land area,

Chapter 5. Empirical Results

5.1. Results for test of model decision

The aim of this study is to find out the influence of different policy instruments in renewable energy deployment. Policy makers are interested in improving their country’ s transition toward renewable energy should implement measures for attracting private institutional investment.

The following selection briefly describes the results for the test of hypothesis with panel data which are considered to prior to conducting panel estimations with fixed effects and random effects. These tests are essential to confirm the suitability of the models used for estimations.

Table 5. Results of Hausman test of capacity for fixed effects model and random effects model

Chi squared statistics	p-values
$\chi^2(6)$=31.35	Prob $> \chi^2 = 0.0000$
$\mathrm{H}_0: cov(x_{i,t}, u_i) = 0$	

Table 5 shows the result of the Hausman test of the Renewable capacity model for the fixed−effects model and the random−effects model. It fails to reject the null hypothesis, which means that the random−effects model is suitable for estimating the panel data.

Table 6 Results of the Hausman test of renewable generation for fixed effects and random effects model

Chi-squared statistics	**p-values**
$\chi^2(6)$=5.84	Prob > χ^2 = 0.4417>0.005
Reject $H_0: cov(x_{i,t}, u_i) = 0$	

Table 5.1 shows the result of the Hausman test of the Renewable generation model for the fixed-effects model and the random-effects model. Rejection of the null hypothesis means that the fixed-effects model is more efficient in obtaining consistent estimation in panel series.

Table 7 Results of the Hausman test of the renewable patent application for fixed effects and random effects model

Chi-squared statistics	**p-values**
$\chi^2(6)=0.92$	$\text{Prob} > \chi^2 = 0.9884>0.005$
Reject $H_0: cov(x_{i,t}, u_i) = 0$	

Table 5.12 shows the result of the Hausman test of the Renewable Patent model for the fixed−effects model and the random−effects model. Rejection of the null hypothesis means that the fixed−effects model is more efficient in obtaining consistent estimation in panel series.

5.2. Empirical Results

5.2.1. Empirical results of installed capacity of Renewables Energy

The annual growth of renewable energy installation capacity had a significant correlation between R&D and regulatory policies, information, and education provision. Also, increasing the installed capacity of renewable energy research and development budget increase could tell.

A significant correlation between the installed capacity by year and support budget does not appear. This result is because the support budget is also used to carry out repairs and closures on a country-by-country basis and year-by-year basis.

Comparing the accumulated amount to the accumulated installed capacity, the larger the budget support, the larger the accumulated installed capacity. Regulatory policies have also had a negative impact on the increase in installed capacity but have had a positive impact on the increase in cumulative installed capacity. Regulatory policies and budget investments have confirmed that there is a positive long-term impact on the increased capacity of renewable energy installations.

Table 8 Empirical results of installed capacity of Renewable Energy

	Economic Instruments	RD&D	Regulatory Instruments	Policy Support	Information and Education	Voluntary Approaches
Growth in Capacity of Renewable Energy (MWe)	-0.6690 (0.85115)	6.9788** (2.7005)	-855.4379*** (294.8898)	359.7243 (226.7697)	1411.159*** (489.7326)	857.1223* (371.8487)
The ratio of capacity growth on budget growth	0.0002 (0.0001)	-0.0017 (0.0009)				

Additional analysis for Cumulative value

The total installed capacity of Renewable Energy	0.4998** (0.2534)	8.3505*** (0.3399)	1225.119* (656.2679)	341.9204 (542.8237)	-2442.983** (1153.867)	-392.3251 (833.9828)
	-0.0001049 (0.00021)	-0.000011 (7.16e-10)				

Table 9 Empirical results of capacity by country

	Model 1 Fixed Effects model		Model 2 Random Effects model	
	Coefficient	Std.err	Coefficient	Std.err
Economic Instruments			0.01449***	0.0015
RD&D			0.0082***	0.0015
Regulatory Instruments			0.0498***	0.0147
Policy Support			-0.0542**	0.0183
Information and Education			-0.0138	0.0243
Voluntary Approaches			-0.0664	0.0297
	By Hausman Test, p-value=0.000<0.005; Accept H0(cov(xi, ui) = 0)			
Australia			1.4497***	0.1154
Austria			1.7763***	0.0946
Canada			3.1086***	0.0099
Denmark			0.4006***	0.0107
France			2.1841***	0.1030
Germany			2.3326***	0.1338
Italy			2.1787***	0.1058
Japan			1.6878***	0.1231
Korea, Rep of	Standard group			
Netherlands			-0.4888***	0.1141
Norway			2.6235***	0.1009
Spain			2.2553***	0.1027
Sweden			1.9616***	0.0994
United Kingdom			0.5650***	0.0872
United States			3.6538***	0.2356

5.2.2. Empirical results of electricity generation from Renewable Energy

Annual renewable energy generation had a significant correlation with not only the support budget, but also all policies such as regulatory policies, policy support, education and information provision, and voluntary participation inducement. Among them, only the education and information provision policies represented a negative correlation between renewable energy generation and other policies that were all found to have a positive effect on the increase in renewable energy generation.

On the other hand, the annual increase in renewable energy generation compared to the previous year was the only positive impact on the R&D budget, the report showed. Although it is not possible to directly expand power generation through R&D budget investment, it can be said to contribute to the growth of power generation in the long term as it increases the amount of power generation.

Table 10 Empirical Results of Renewable electricity generation

	Economic Instruments	RD&D	Regulatory Instruments	Policy Support	Information and Education	Voluntary Approaches
Annual Renewable Energy Generation (Gwh)	0.00013*** (0.0000346)	-0.000138 (0.0000881)	0.1257** (0.2191)	0.1257*** (0.02191)	-0.1102*** (0.0456)	0.1102** (0.0342)
Ratio of generation growth on budget growth	2.44e-08 (1.72e-08)	-7.39e-08 (9.78e-08)				
Growth in Renewable Energy Generation (GWh)	198.0421* (134.368)	653.867** (308.2954)	-384.9882 (193.0381)	-70.8699 (153.2806)	653.7325** (308.0808)	143.9704 (261.8323)

+

Table 11 Empirical Results of electricity generation by country

	Model 1 Fixed Effects model		Model 2 Random Effects model	
	Coefficient	Std.err	Coefficient	Std.err
Economic Instruments	0.0053	0.0191		
RD&D	0.1010*	0.0442		
Regulatory Instruments	0.0720**	0.0282		
Policy Support	0.1380***	0.0223		
Information and Education	-0.2024***	0.0452		
Voluntary Approaches	0.0853	0.0388		
			By Hausman Test p-value=0.4417>0.05; Reject H0(cov(xi, ui) = 0)	
Australia	1.4929***	0.1778		
Austria	2.2290***	0.1568		
Canada	4.3813***	0.1041		
Denmark	0.8576***	0.0970		
France	2.3926***	0.1145		
Germany	2.8813***	0.1026		
Italy	2.0185***	0.1339		
Japan	3.2127***	0.1186		
Korea, Rep of	Standard group			
Netherlands	0.9445***	0.1259		
Norway	2.8952***	0.1415		
Spain	2.3961***	0.1259		
Sweden	2.5801***	0.1033		
United Kingdom	1.4389***	0.1295		
United States	5.0739***	0.4432		

5.2.3. Empirical results of Patents application in the renewable energy sector

The number of patents was used as a measure of the development of renewable energy technology.

The higher the R&D budget, the more voluntary participation policies, the more regulatory policies, the more negatively affected the number of patent applications per year.

The number of patent applications was also intended to perform a long-term analysis through cumulative results. The cumulative number of patents also showed an increase in the budget for supply support or research and development as well. However, the increase in the number of patents increased due to the expansion of the budget for supply support. Also, policies that encourage policy support or voluntary participation affected the increase in the number of patents.

Table 12 Empirical results of patent application in Renewable energy

	Economic Instruments	RD&D	Regulatory Instruments	Policy Support	Information and Education	Voluntary Approaches
Number of New Patents in the Renewable Energy Sector	0.9189 (0.5986)	3.1381* (1.9321)	-425.207** (196.9433)	-79.1164 (158.3781)	639.0904 (324.5086)	6.4129* (255.5197)
The ratio of increasing patent on budget growth	-0.0011 (0.0001)	-0.00102 (0.0007)				
Additional analysis for Cumulative value						
Number of Patents in Renewable Energy Sector	0.0011*** (0.0023)	0.0001201*** (0.000306)	-0.0109 (0.0592)	0.1787*** (0.0489)	-0.1127 (0.1040)	0.1779** (0.0752)
	-3.97e-8** (2.00e-8)	5.01e-14 (6.46e-14)				

Table 13 Empirical Results of patents application by country

	Model 1 Fixed Effects model		Model 2 Random Effects model	
	Coefficient	Std.err	Coefficient	Std.err
Economic Instruments	-0.0247	0.0389		
RD&D	0.5002***	0.0933		
Regulatory Instruments	0.0337	0.0591		
Policy Support	0.2498***	0.0453		
Information and Education	-0.1412	0.0925		
Voluntary Approaches	0.2608**	0.0804		
			By Hausman Test, p-value=0.9884>0.05; Reject H0(cov(xi, ui) = 0)	
Australia	-1.6317***	0.3573		
Austria	-1.8736***	0.3180		
Canada	-5.0286***	0.2130		
Denmark	-1.1340***	0.1910		
France	-2.5356***	0.2393		
Germany	-2.6127***	0.2025		
Italy	-1.2015***	0.2713		
Japan	-4.9782***	0.2365		
Korea, Rep of	Standard group			
Netherlands	-0.1063	0.2497		
Norway	-3.5929***	0.2948		
Spain	-3.5697***	0.2481		
Sweden	-1.6155***	0.2093		
United Kingdom	-5.0894***	0.2641		
United States	-4.2897***	0.4526		

Chapter 6. Conclusion

6.1. Summary of the findings

This study conducted empirical analyses on how policy instruments affect renewable energy deployment and innovation in 16 OECD countries from 2000 to 2018. For the empirical analysis, the study adopted panel data estimation to facilitate comparisons between countries.

First, this study highlighted the effectiveness of economic instruments as a policy instrument that guarantees a certain impact on the input of resources. Economic instruments such as feed-in-tariffs and direct investments have been used in most of the countries on a diverse scale. Therefore, the analysis used the amount injected into the policy by each country to analyze the performance according to the input amount. The aggregated results revealed a significant positive correlation between renewable capacity, renewable generation, and renewable patent counts. As the budget for supporting renewable energy supply increased, the amount of renewable energy generation and number of patents increased. It was found that the annual generation of renewable energy increased significantly as the amount increased. For the capacity installed, although it differed from year to year, the cumulative capacity increased in proportion to the cumulative support amount. The number of patents has also increased in the renewable energy installation capacities and increased research and development budget. Although there was no significant relationship between annual renewable energy generation, the power generation increased as compared to the previous year, and hence, a positive relationship was observed in the long term. However, the effect differs across countries. The US and Canada showed the highest growth-five times more than Korea-while the Netherlands showed a negative increase in installed capacity growth. It can be inferred from the fact that the US and Canada expand their facilities very faster based on their large amount of investment and territory. As Korea is in the early stage of introducing renewable energy, there was a sharp increase in facilities, whereas the Netherlands is at a relatively stable stage.

Further, RD&D is one of the most critical instruments for increasing the supply of renewable energy. Generally, it is known that RD&D has a more significant effect depending on the investment. This study confirmed that, as the RD&D budget increases, the annual number of renewable energy facilities increases, and the cumulative amount of facilities increases. It was also found that annual investments also increase the number of patents and cumulative patents in the renewable energy sector annually. However, the number of patents has not increased proportionately to the increase in the amount invested. Therefore, it is necessary to design and allocate an appropriate RD&D budget based on the current situation of each country rather than increase the budget without planning. South Korea saw the number of patent applications grow 173 times over the recent 17years, the highest growth rate among OECD countries despite not having the highest R&D budget. It was found to be more efficient and effective in implementing R&D policies than in other countries.

Next, regulatory instruments should be decided carefully as legal actions can be imposed by setting up auditing, monitoring, and setting standards. Renewable-Portfolio-Standards (RPS) and Greenhouse Gas Emission rights systems are also included in this sector. The implementation of the regulatory policy showed an increase in the amount of renewable energy facilities and the renewable energy power generation. In particular, the capacity of renewable energy facilities increased significantly. However, it was found that the number of patents applied annually had a contrary effect on the implementation of regulatory policies. Regulatory instruments may have increase renewable energy generation momentarily, but they have not been found to be effective in terms of technological innovation.

Policy support primarily includes a national strategic plan for renewable energy. However, a problem with policy support, which may be endogenous with other policy variables, is that it directly impacts the growth of renewable energy generation in each country. If a significant growth is not observed or if the growth is less, it will be necessary to raise the specific policy implementation plan.

Information and education sector can also contribute to the distribution of renewable energy by providing information and education at the national level. This sector can provide specific information to help the government with the adoption or training of experts through state-funded education. This study found that the amount of renewable energy facilities in countries that implement these policies was more than in countries that did not and that the amount of renewable energy power generation was negatively impacted. However, while information provision and education are intended for common citizens and organizations, the amount of facilities required is decided by the government or businesses, which can be interpreted as a case in a country where the government's interest is large enough to implement education policies rather than directly relate to policy variables. However, the increase in the number of patents in countries that implemented the information provision and education policy was not significant. Further analysis by country showed that the Netherlands and Denmark had lower growth rates compared to other countries. In a country that has already acquired the economic feasibility of renewable energy generation, this could be seen as a rather negative aspect.

There are also policy variables that encourage voluntary participation. In case of renewable energy, these policy variables are becoming more important than traditional energy sources as small businesses are encouraged to participate. The analysis showed greater increase in renewable energy power generation and patent applications than in countries that implemented voluntary approach policies. This is a targeted policy, as mentioned earlier, and may have a relatively small correlation with the amount of facilities that require support from the state or business.

The analysis indicated the policies had different effects based on the various policy variables in place. These results could be used as a basis for further policymaking in line with the country−specific circumstances, as mixed results were observed depending on the amount of implementation or whether they were implemented by the country.

Some implications are as follows: First, policy instruments of renewable policy have different effect on renewable deployment and technology innovation. Also, analyzing policies using multiple instruments is statistically more significant than analyzing a single policy instrument. Therefore, governments should adopt a system that can evaluate various policy instruments. Second, the analysis included only the stringency of the implementation. Thus, the results differed depending on the stringency of the policy instruments, which included economic instruments, research development and demonstration, and regulatory instruments.

6.2. Discussion

In the 2000s, many countries started paying attention to the development and dissemination of renewable energy and to implement renewable support policies. The IEA report states that expansion of the renewable energy market is more comprehensive than individual policy measures while ensuring the sustainability and predictability of policy measures. Therefore, accurate analysis and comprehensive implementation of policy instruments are required.

As of 2019, the national energy target exceeded by 20% of the electricity generation and is expected to continue to expand, which translates into a huge opportunity for manufacturers of renewable energy equipment. Many governments have realized this and have started to formulate renewable energy policies. They have realized that, if applied properly, these policies will benefit the environment and renewable energy generation alike. The main question is how to design policy portfolios that foster the creation of an internationally competitive renewable energy equipment industry. By classifying policy instruments, this study has proposed two research hypotheses for an in-depth analysis:

1) Each policy instrument has a different effect on the installation of renewable capacity, the generation of renewable energy, and the number of patents published in the renewable energy sector.
2) As the stringency of policy implementation increases, the installation of renewable capacity, the amount of renewable generation, and the number of patents published in the renewable energy sector also increase.

The objective of this research was to study the relationship between different types of renewable energy policies and he intensity of renewable energy deployment. With this regard, renewable energy deployment was defined as renewable dissemination and technology development.

This study adds to the prior research by extending the policy, country, and time dimension, and by applying the exact policy data.

First, it statistically defined the premise that the higher the intensity of policy implementation, the higher the effect. Second, while the importance of the policy instruments partly varies across countries, the direction of their impact on innovation is quite similar to the technology innovation and deployment of renewable energy. The strongest policy effects can be found in economic incentives, and RD&D. It has generally followed a similar trend, although there have been differences depending on the extent of renewable energy generation by the country. The role of budget allocation becomes more significant if the country is in the initial stage of renewable energy. Third, a longer policy duration is found to significantly increase the deployment in the case of patent publications and cumulative installed capacity.

According to IRENA (2018), by 2020, all technologies that are now in commercial use will be competitive with fossil fuels. However, to meet the advanced goals of the Paris Climate Agreement and the aspirations of the Sustainable Development Goals, this will not be enough. Power generation only accounts for 20% of the total global energy demand, whereas heating and cooling, and the transport sector account for 80%. There is a lack of alternative technologies in these sectors. Therefore, the challenge will be to adapt the policy instruments to be used in these sectors.

Another limitation in developing renewable energy is that, while technology is not economically viable the renewable energy policy will ultimately have to be designed to make renewable energy more competitive with traditional energy sources, as there is a limit to the budget, too. In other words, it is necessary to promote innovation in technology.

Thus, a closer analysis of this study is required. IEA divides renewable energy technology in three generations. The first generation refers to a technically mature energy source with hydropower and biomass. The second generation refers to energy sources that are currently advancing rapidly, such as solar and wind power. The third generation is an energy source currently in the early stages of development, such as solar power and marine energy. Renewable energy technologies may have different relationships according to their respective policies, depending on their maturity. In this study, the effects of each renewable energy source were not analyzed due to the limitation in the data, but these sources deserve further analysis.

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Abstract

기후변화 대응 및 에너지 전환을 위해 세계 각국에서는 재생에너지 보급을 위한 정책을 수립, 시행하고 있다. 재생에너지 정책과 재생에너지 보급 확대(Deployment)의 상관관계에 대해 분석한 많은 연구가 존재한다. 하지만 구체적으로 어떠한 정책 요인이 영향을 미치는가에 대해 분석한 연구는 부족하다. 본 논문은 2000년부터 2018년까지 OECD 국가에서 시행되었던 재생에너지 정책에 대해 국가별로 정책 시행에 따른 효과를 알아보기 위해 패널 자료 모형(Panel Data Model)을 이용하여 분석하였다.

기존의 재생에너지 정책에 대한 연구들은 다양한 정책 범주 중 RPS(Renewable-Portfolio-Standard)나 FIT(Feed-in-Tariff)의 정책만을 독립변수로 사용하여 분석하였다. 하지만 최근에는 대부분의 국가들이 RPS와 FIT를 도입하고 있으며, 그 외에도 다양한 정책들을 시행하고 있기 때문에 위의 두 변수로는 정책의 효과를 파악하는 것에 한계가 있다. 또한, 단순히 정책의 시행여부에 따라 분석하였기 때문에 정책 시행의 강도(Stringency)를 분석에 반영하지 못한다는 한계점을 지닌다. 따라서 본 연구에서는 IRENA와 IEA에서 제공하는 정책 분류를 사용하여 Economic Instruments, RD&D, Policy Support, Regulatory Instruments, Information and Education 과 Voluntary Approaches 의 6가지 분류를 분석에 사용하였다. 특히, Economic Instruments와 RD&D의 경우, 각 국가별 보급지원예산과 연구개발예산을 직접 변수로 사용하여 위의 두 한계점을 극복하고자 하였다. 나머지 분류의 경우, 국가별로 시행 여부의 차이가 있을 뿐 아니라 정책 변수 간의 내생성(Endogenous) 문제를 해결하기 위하여 정책의 시행 여부를 분석에 사용하였다.

첫번째로, 재생에너지 보급 확대를 위한 종속 변수로 재생에너지 발전량과 재생에너지 설비 용량을 사용하였다. 분석 결과, 재생에너지 발전량과 설비 용량 모두 정부의 보급지원예산 과 연구개발예산의 증가에 따라 증가하는 양(+)의 상관관계를 가지는 것으로 나타났다. 또한, 규제 정책(Regulatory Instruments)은 재생에너지 설치 용량과 재생에

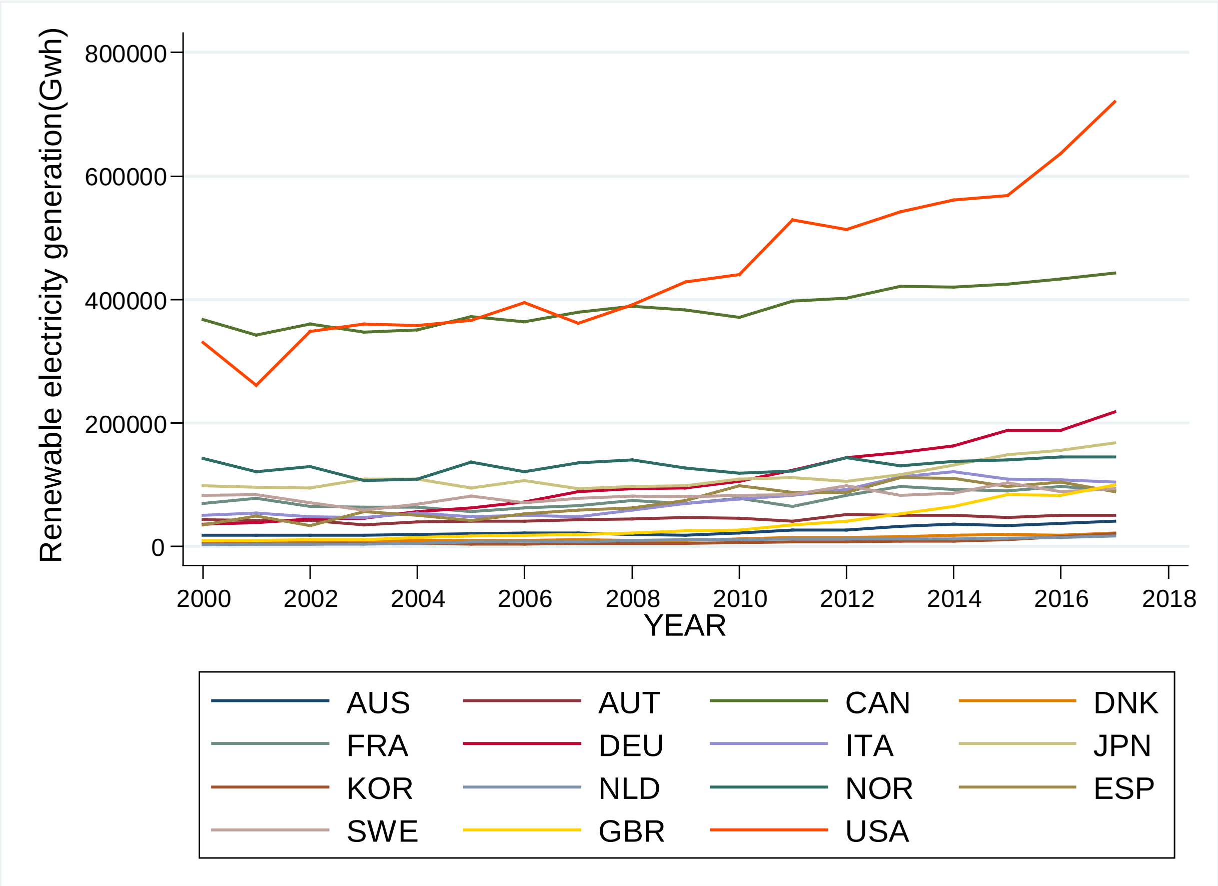
너지 발전량 증가에 긍정적인 영향을 미치는 것으로 나타났다. 규제 정책과 정책 지원을 시행하는 국가들에서 역시 재생에너지 발전량이 더욱 증가하는 것으로 나타났다.

다음으로, 재생에너지 기술의 발전 정도를 알아보기 위한 종속변수로 재생에너지 관련 특허 출원 수를 사용하여 분석하였다. 분석 결과, 정부의 보급지원예산과 연구개발예산이 증가할수록 특허 출원 개수도 증가하는 것을 확인하였다. 뿐만 아니라 정책 지원(Policy Support)과 자발적 참여 독려(Voluntary Approaches) 정책을 시행하는 국가에서 특허 출원 수가 더욱 증가하는 것을 알 수 있었다.

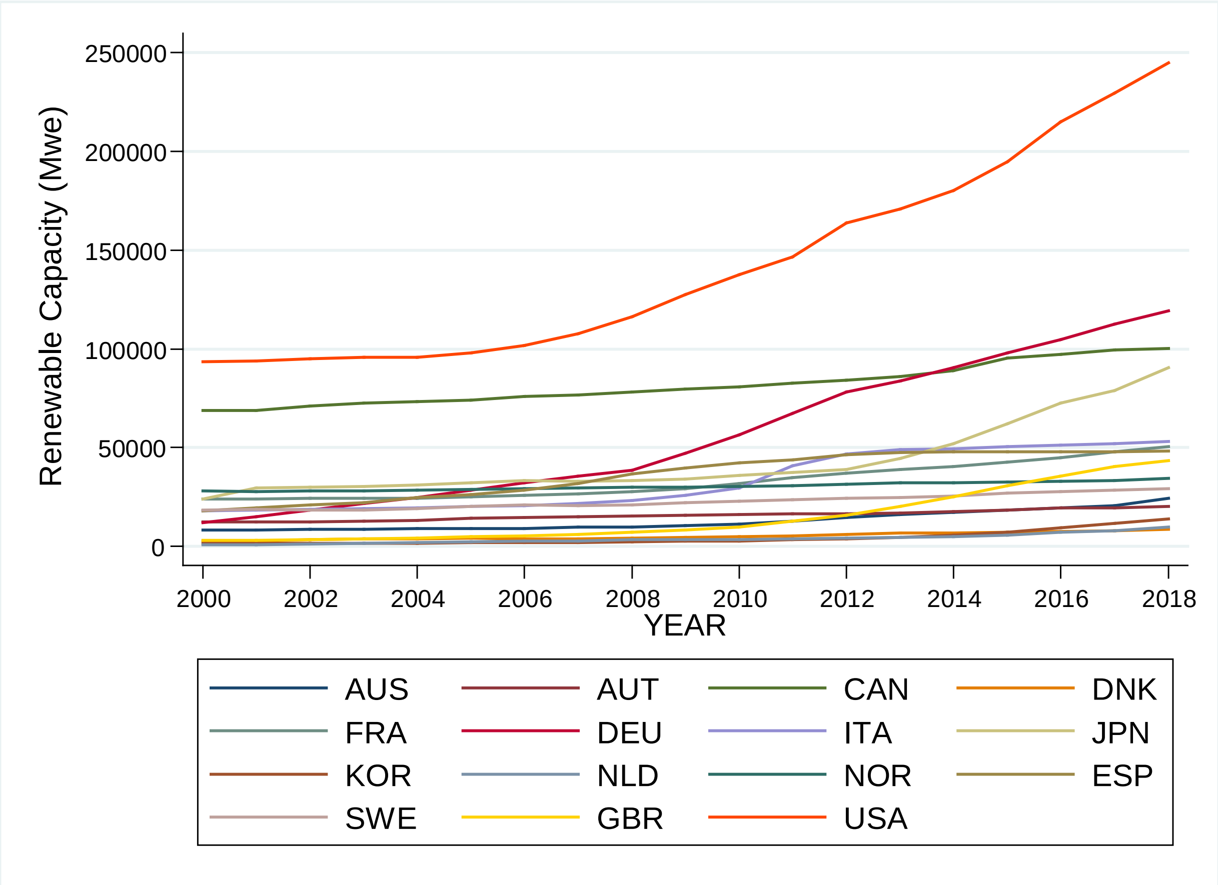
본 연구가 시사하는 바는 다음과 같다. 정부 주도의 에너지 정책과 같은 사업은 자원의 투입이 대규모로 이루어질 뿐 아니라 사회경제적 파급력이 광범위하다는 점에서 효율적인 운영과 정확한 평가가 요구된다. 본 연구는 정책의 분류를 사용하여 각각의 정책 요인에 대한 재생에너지 보급 효과를 분석하였다. 이러한 결과는 정부의 정책 및 예산 수립 시 정책의 실행으로 인한 보급 효과를 미리 예상 가능하게 한다. 본 연구에서는 기존의 연구와는 달리 정책을 분류하여 시행 강도에 따른 분석을 실시하였다. 이를 통해 각각의 정책과 시행 강도에 따른 결과가 다르다는 것을 확인하였고 이를 고려하여 국가별로 재생에너지 보급 및 기술발전 현황에 따라 알맞은 정책 수립과 예산 분배를 통해 원하는 효과를 증대시킬 수 있다는 점에서 의의가 있다.

Appendix

A. Renewable electricity generation of selected countries.



B. Renewable capacity in selected countries.



C. Number of patents in renewable energy sector in selected countries.