A SUSTAINABLE ENERGY POLICY

TO MEET THE CHALLENGE OF CLIMATE CHANGE

IN THE REPUBLIC OF KOREA

by

Heung-Won Seo

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy and Environmental Policy

Spring 2016

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ACKNOWLEDGMENTS

Above all, I would like to thank Dr. Wang, Young-Doo, my teacher and advisor. He has been supportive of me all through my years in the Ph.D. program. Since I could not complete my dissertation for coming back to Korea, I had almost given up on the dissertation for six years due to my works; however, I could manage to finish it with the advice and encouragement of Dr. Wang.

I also would like to express my gratitude to Dr. Byrne, John, Dr. Kim, Jong-dall, and Dr. Wagle, Subodh. As committee members, they gave me invaluable comments, which had deepened and elaborated the contents of the dissertation. They pointed out which part in the dissertation has a logical weakness and what should be added to the dissertation. I had benefited from their comments and feedback, resulting in enhancing the quality of dissertation. In particular, Dr. Byrne's helpful advice enabled me to upgrade the dissertation in more sophisticated one as a whole.

I am grateful for a number of friends and colleagues who gave me support and help to finish the dissertation. A special word of gratitude is due to Dr. Park, Hun who gave me great help in fixing the frame of this dissertation. He also did a variety of essential and tough tasks for me, including printing and sending materials to Dr. Wang, the university administration and me. He deserves special mention for his great help in various points.

I would like to thank my father-in-law and mother-in-law as well as my siblings for encouraging and supporting me. Under any difficult circumstances, they always have been my supporters. I also deeply thank colleagues who understand and encourage me when I was busy to prepare the dissertation.

Most of all, I am immensely indebted to my family - my wife, Kim, Do-Young; my two sons, Seong-Il and Woo-Gwon. When I almost gave up the dissertation and had a hard time, they were always standing by me, and giving me endless support and new hope. The moral support and precious love of my family kept me going more than anything else. To my sons, I always want to be a father who put efforts to fulfill responsibility and I am so happy to do so as completing the dissertation.

Finally, I dedicate this dissertation to my deceased parents. After my mother passed away, I was always sorry for letting my father alone when going abroad for studying. In particular, I still feel a pang of sorrow whenever thinking on my father who passed away before I came back to Korea. They are real my 'Giving Trees' who gave birth to me, raised me and now are looking down on me from heaven.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEEI	Autonomous Energy Efficient Improvement
BaU	Business as Usual
BEMS	Building Energy Management System
BLMP	Base Load Marginal Price
BoK	Bank of Korea
BP	British Petroleum
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CEA	Center for Energy Alternative
COP	Conference of the Parties
DOE	US Department of Energy
EC	European Community
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Agency
ESCO	Energy Service Company
ESI	Energy Security Index
ESMC	Energy Supply Market Concentration
FEMS	Factory Energy Management System
FiT	Feed-in-Tariff
GCF	Green Climate Fund
GDP	Gross Domestic Income
GHG	Greenhouse Gases
GNP	Gross National Income
HEMS	Home Energy Management System
HDI	Human Development Index
ICRG	International Country Risk Guide
IDA	International Development Association
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IMF	International Monetary Fund
INC	Intergovernmental Negotiating Committee
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel in Climate Change
ISA	Integrated Sustainability Analysis

JI	Joint Implementation
JISEEF	Joint Institute for a Sustainable Energy and Environmental Future
KAIST	Korea Advanced Institute of Science and Technology
KEEI	Korea Energy and Economics Institute
KEMCO	Korea Energy Management Corporation
KEPCO	Korea Electric Corporation
KEI	Korea Environment Institute
KIER	Korea Institute of Energy Research
KIET	Korea Institute for Industrial Economics and Trade
KMA	Korea Meteorological Administration
KNOC	Korea National Oil Corporation
KNSO	Korea National Statistical Office
KRX	Korea Power Exchange
KRW	Korean Republic Won
LBNL	Lowrnce Berkeley National Laboratory
LULUCF	Land Use, Land-use Change and Forestry
ME	Ministry of Environment
MKE	Ministry of Knowledge Economy
MOCIE	Ministry of Commerce, Industry & Energy
MAFRA	Ministry of Agriculture, Food and Rural Affairs
MOTIE	Ministry of Trade, Industry & Energy
NGOs	Non-Governmental Organizations
NIER	National Institute of Environmental Research
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Cooperation and Development
OVI	Oil Vulnerability Index
O&M	Operation and Maintenance
PMO	Prime Minister's Office
PM-10	Particulate Matter which has a diameter less than 10 ㎛
RCP	Representative Concentration Pathways
R&D	Research and Development
REC	Renewable Energy Certificate
RPS	Renewable Portfolio Standard
SETP	Solar Energy Technologies Program
SIDS	Small Island Developing States
SMP	System Marginal Price
TFC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
T&D	Transmission and Delivery
UN	United Nations

UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework on Climate Change
UNSD	United Nations Statistics Division
USD	United States Dollar
VOC	Volatile Organic Compounds
WCED	World Commission on Environment and Development
WEC	World Energy Council
WNA	World Nuclear Association

[Unit]

bcm	Billion Cubic Meters for Natural Gas
toe	Ton of Oil Equivalent
Mtoe	Million Ton of Oil Equivalent
t_CO_2	Ton of CO_2 Equivalent
M t_CO_2	Million Ton of CO_2 Equivalent
t_C	Ton of CO_2 (As Expressed in the Weight of Carbon)
Mt_C	Million Ton of CO_2 (As Expressed in the Weight of Carbon)
GWh	Giga-watt Hour
TWh	Tera-watt Hour

ABSTRACT

Energy is indispensable to sustain a society. However, rapid increase in energy consumption has caused many problems such as environmental pollution, ecological degradation, and worldwide climate change. Especially, climate change caused by anthropogenic GHG has been seriously threatening the world. According to the IPCC, the global temperature is expected to rise by 4.8 °C and sea level by 0.95 m compared with pre-industrial period, provided that the world would keep consuming fossil fuel without making resolute efforts for reduction (2014: 10-11).

Nonetheless, the world has not taken sufficient actions to address these crises. Korea is no exception. Korea's GHG emissions have increased by 2.57 times during 22 years, from 2.17 toe in 1990 to 5.57 toe in 2012 based on per capita (MOTIE & KEEI, 2014: 5). According to IEA, Korea is the world's 7th largest GHG emitting country and its per capita emission is 2.8 times higher than that of the world (2015a). Confronting these challenges, it is necessary to reform Korea's current energy system toward a sustainable one within the frame of global equity and responsibility. A sustainable energy system should satisfy the key elements of sustainable development: namely, minimizing environmental pollution or degradation, preventing dangerous anthropogenic interference with the climate system, sustaining continual economic development, improving social equity, stability and balanced development, and, if possible, contributing to other countries.

To keep GHG emissions within a level believed to be sustainable, the Korean government has established many policies such as the *National Basic Energy Plans*,

the *Basic Plans on Developing and Disseminating New and Renewable Energy*, the *Basic Plans for Electricity Supply and Demand*, and the *Plan for Setting Post-2020 GHG Reduction Goal (hereinafter referred to as 'INDC plan')* which was developed for submitting to the UNFCCC secretariat that included Korea's INDC. Among these policies, *the INDC plan* includes the most challenging goal – 37 % of GHG reduction by 2030 compared with BaU scenario, which means the emission reduction to 535.5 Mt_CO_2 from 850.6 Mt_CO_2. Provided that Korea achieves this reduction goal, per capita emissions in 2030 will amount to 10.3 t_CO_2. However, the target is not sufficient to satisfy the international requirement to bind the global temperature rise within 2 °C – around 3.3 ton of per capita CO_2 emissions (Byrne & Wang et al., 1998). This means that Korea's current and future energy system is far from fulfilling what is required for sustainable energy system.

Recognizing these limitations, this study analyzes the situations of Korea's energy system and suggests policy alternatives to contribute to constructing sustainable energy system. For this, it designs a new BaU scenario, which predicts that Korea's TFC would amount to 272.4 Mtoe and TPES 372.2 Mtoe by 2030. This study also estimates the potential of renewable energy would be 272 (3,022 TWh) ~ 363 Mtoe in 2030, and foresees that renewable energy would increase to the extent that exceeds the energy demand of Korea – 449 Mtoe (5,652 TWh) in 2050 – due to technological advancement and growing public acceptance. Based on these, this study establishes an alternative scenario taking four policy recommendations into consideration. The first is the reform of industrial structure. Since Korea's economic system is significantly dependent on energy intensive manufacturing industries, this study suggests lowering their portion from 6.3 % (*the INDC Plan*) to 4.2 % (KEEI's

2006 scenario) based on the value-added. The second is to end the use of domestic coal. Domestic coal industry has been sustained by various environmentally harmful subsidies, tax exemption and political supports. The substitution of natural gas for domestic anthracite is, therefore, suggested. The third is to make and implement aggressive efficiency improvement policies, following the JISEEF report which analyzes the overall saving effects to be 27.1 % as TFC and 27.7 % as GHG. The fourth is to reduce energy service requirement. Public engagements by using public transportation, saving energy through adjusting temperature for heating and cooling, consuming local and seasonal food are the examples of these policies. If these all factors are adopted, Korea's TFC would decrease to 162.2 Mtoe from 272.4 Mtoe in 2030.

In addition, renewable energy is found to have price competitiveness from the mid-2020s with the internalization of external social costs. The gradual reflection of external costs, even if controversial, will not make the economy vulnerable given that other taxes like labor tax are adjusted together. With these policies, Korea is expected to reduce GHG emissions to 325.4 Mt_CO_2 or 6.2 t_CO_2 of per capita emissions by 2030 (or 4.4 t_CO_2, if overseas purchase of emission certificate is considered) and to achieve one of the most important goals for sustainable energy system by 2050 – the accomplishment of 3.3 t_CO_2 emissions based on per capita. Extended use of renewable energy could also contribute to accelerating regional development, since renewable energy is relatively well-distributed across regions. The burden of importing energy, which is usually identified as the ratio of energy import costs to GDP, is expected to go down significantly, from 12.9 % to 5.9 % by 2030 and much less by 2050. In addition, when the burden of energy import is relieved, it is possible to secure a stable energy supply. In sum, the policy alternatives suggested in this study are expected to make Korea's energy system more sustainable from the perspectives of environment, economy, and socio-politics.

Starting from the scenario that reflects the government's premises, this study elicits the possibility of constructing a sustainable energy system. Even though the Korean government and many economy-oriented experts express their concerns, the transition from a fossil fuel-based centralized energy system to a renewable energy-based decentralized one is indispensable and achievable with additional benefits such as clean environment, economic soundness and various socio-political advantages. For this, additional policies to reduce social resistance – the reform of tax and subsidy system, more aggressive renewable energy policies, active diffusion of efficient technologies, and the change of lifestyle based on self-sufficiency – are required. In addition, efforts have to be made to reduce the resistance of interested groups and people who do not want change.

Even though this study has limitations in analyzing Korea's energy situations and suggesting policy alternatives, the reform of Korea's energy system into a sustainable one is important and imperative. Recently, the world at the COP21 in Paris agreed to reduce GHG emissions to hold the increase of global temperature within 2 °C or less. The policy recommendations of the study could be suggestive to Korea and, hopefully, to other countries.

Key words: Sustainable Energy System, Industrial Structure, Energy Efficiency, Energy Service, Renewable Energy

Chapter 1

INTRODUCTION

1.1 Background and Goals

Energy has played a pivotal role in human history. As energy consumption has markedly increased in every stage of civilization (MacKenzie, 1992: 15-24), people come to believe in the mythology of ‘civilization = k × energy’ (Basalla, 1980: 39-41). Many countries have devoted much attention to energy exploitation, production and consumption to realize economic growth and secure material prosperity. This, however, has brought not just benefits but also adverse effects such as environmental pollution, ecological degradation and climate change, as seen in the direct dangers to SIDS (IPCC, 2013: 22-23, 96-99; Byrne & Glover, 2005: 7; Barnett & Adger, 2003: 321-326).

Korea is no exception. It has achieved a remarkable economic growth despite the scanty reserves of energy resources. Korea’s economic system became heavily dependent on energy, especially imported conventional energy such as oil, coal, natural gas, and nuclear power[1]. Currently, 95 ~ 96 % of energy consumption in Korea relies on imported energy every year, even though the percentage has been decreasing with the expansion of renewable energy. In addition, Korea’s energy consumption has increased rapidly: per capita energy consumption in 1990 was 2.17

[1] Even though the Korean government classifies nuclear power as ‘domestic production’, this study classifies it as an ‘imported energy’ because the fuel, Uranium, is all imported.

toe, which grew to 5.57 toe in 2012 – 2.57 times larger in 22 years (MOTIE[2]/KEEI, 2014:5).

With the rapid expansion of economy and growing energy consumption, Korea's energy import has increased 3.3 times over the last twenty-two years, and the cost of import 17 times at the same time. In 2012, Korea spent USD 185 billion to import energy, which accounted for 17.1 % of GDP, up from 4.1 % in 1990, and this placed a great burden on the economy. It indicates Korea's deep dependency on overseas energy as well as its vulnerable energy system. Figure 1-1 shows the relative change in the energy import and economy-related indicators.

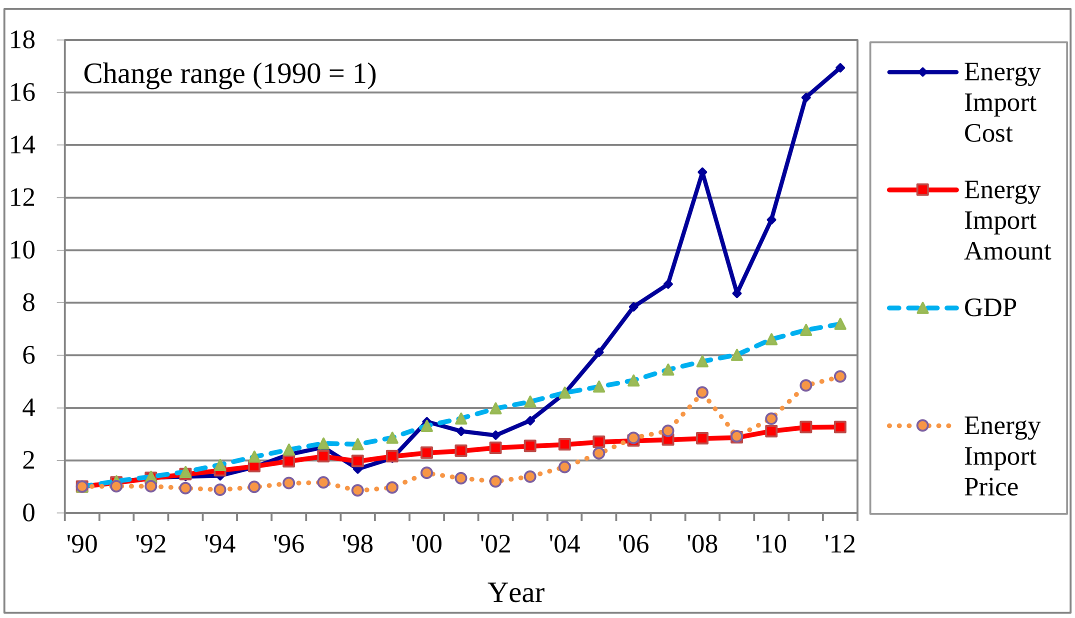

Figure 1-1: Relative Changes in Energy-Related Economic Indicators.
Source: MOTIE/KEEI (2010, 2014)

[2] MOTIE has changed its name several times. It had been MOCIE during 2000~2008 and MKE during 2008~2013. In this study, MOTIE, MOCIE and MKE are used according to their existing periods.

Comparing with other countries, it can be easily noticed the weakness and vulnerability of Korea on energy. According to Table 1-1, Korea's per capita GDP is USD 21,600, much less than that of other developed countries like Japan, the US, and Germany. However, Korea's per capita TPES and GHG emissions are higher than those of Japan and Germany, but even less than those of the US. They are also much larger compared with other developing countries including China and Mexico. The data in Table 1-1 show the vulnerability of Korea's economic system distinctively.

Table 1-1: Comparison of Major Energy-related Indicators among Selected Countries in 2012

Category	Korea	Japan	The US	Germany	Mexico	China
Population (million)	50.00	127.55	314.28	81.92	117.05	1350.70
GDP (USD billion 2005)	1078.2	4694.4	14231.6	3073.9	1027.5	4522.1
Per capita GDP (USD thousand 2005)	21.56	36.80	45.28	37.52	8.78	3.35
Per capita TPES (toe)	5.27	3.55	6.81	3.82	1.61	2.14
Energy Intensity (toe/ USD thousand 2005)	0.24	0.10	0.15	0.10	0.18	0.91
CO_2 per Unit TPES (tCO_2/toe)	2.25	2.70	2.37	2.42	2.31	2.84
Per capita CO_2 (t_CO_2)	11.86	9.59	16.15	9.22	3.72	6.08
CO_2 per Unit GDP (t_CO_2/USD thousand 2000)	0.55	0.26	0.36	0.25	0.42	1.81

Source: IEA (2014: 48-57)

High energy consumption could consequentially lead to environmental, economic, social, and other problems. Korea has experienced serious energy-related environmental problems during the period of rapid economic growth. Even though Korea has overcome or mitigated some of them, it still confronts many other pollution issues: while air pollutants such as SOx and CO have been continuously decreasing, NOx, micro particulates (PM-10) and VOC have been increasing or have not started to decrease yet (NIER, 2015). Economic strategies focusing on energy-intensive industries have been effective in achieving rapid economic growth, but they have exacerbated its economic vulnerability with conflictions of socio-political interests. This can be observed in the two oil shocks in 1973 and 1978, and recently occurring frequent fluctuation of oil price (Leder & Shapiro, 2008; Asif & Muneer, 2007). The current energy prices are relatively low, but they can always rebound (EKN, 2015). The fact that Korea is heavily dependent on oil from the Middle East where political situations are unstable also poses threats to the national security. The growing instability of international politics as seen in the Middle East, Strait of Malacca, Spratly Islands, Pinnacle Islands, Korean Peninsula and related countries just deepens Korea's vulnerability, if it continues to depend on overseas energy sources (Lee, 2008; Lee, 2013:17-21, 26-40; EIA, 2013; NBC News, 2014; Business Insider, 2015). Moreover, many consider with concerns the increase of nuclear power plants as a threat. Besides, the centralization of the power system could deepen imbalanced regional development and social injustice, as it puts higher priority on urban areas rather than rural communities and strengthens the influence of the central government and electricity suppliers upon people, local governments and consumers.

Recognizing these problems, the Korean government has implemented energy policies with a view to secure stable energy supply, regulate energy demand, promote energy efficiency, and reduce environmental pollution. Often, MOTIE has taken a leading role in establishing long-term GHG reduction plans up until now. In 2008, the government planned to reduce GHG by 12.4 % compared with BaU scenario by 2030 (PMO et al., 2008: 52). In 2009, the government set the GHG reduction target as 30 % below the BaU scenario by 2020 (Committee on Green Growth, 2009). In 2014, MOTIE established the *Second National Basic Energy Plan*, in which 13 % of primary energy reduction and 15 % of electricity reduction goals by 2035 are included (2014a: 23). Recently, the government developed *the INDC Plan* to submit to the UNFCCC Secretariat, in which the government plans to reduce GHG emissions by 37 % compared with BaU scenario – 25.7 % in domestic and 11.3 % in purchase from the international carbon market (PMO et al., 2015).

However, these plans do not satisfy the growing demand for addressing climate change. For example, *the INDC Plan* shows that the per capita GHG emission is expected to be 10.3 t_CO_2 even if being accepted the whole scheme including 11.3 % purchase of overseas emission certificate. The IPCC suggested to reduce 50-70 % of GHG emissions from the 1990 GHG emissions levels (1996:9-11), which corresponded to around 3.3 t_CO_2 per capita, based on the population in 1990 (Byrne & Wang et al, 1998: 335-339). Even though not being able to meet the internationally required level, Korea needs to have a more ambitious target to contribute to global reduction goals. In addition, the increase in energy consumption could weaken the economy and national security in the future, unlike the expectation of the government.

Confronting these crises, Korea needs to have a more ambitious GHG reduction target for the sake of the environment, economy and security. Therefore, it is meaningful to examine whether or not Korea has a potential to transform itself into a low-carbon economy from the current conventional energy-centered system. This study examines the transition from the path currently set by the government into a renewable energy-centered energy system, and analyzes the environmental, economic and security issues and their effects. In this process, the concept of 'sustainable development' will play a key role in securing continuous economic stability and development. The potential of renewable energy is also explored since the transition has to be feasible in physical, economic and technical aspects.

1.2 Study Questions

The failures or limitations of the national energy policies have raised questions on the current energy system as follows:

(1) What does energy sustainability or a sustainable energy system mean? What are the conditions that a sustainable energy system should meet?

(2) What are the outcomes of current energy policies and what are their limitations in accomplishing a sustainable energy system?

(3) To build a sustainable energy system, what kinds of energy policies should be newly developed or additionally revised?

In light of these questions, this study aims to find quantitative solutions to restructure Korea's energy system. The Korean government appears to be concerned about the possible deterioration of national economic competitiveness when more aggressive policies are adopted and implemented. However, some argue that a sustainable energy system would not be bound to put heavy burdens on the economy and it could also deliver additional socio-political benefits. According to U.K.'s eminent Stern Review, the current energy system, if it goes unchanged, would cause more serious loss in the future, while early measures against climate change would bring more benefits than costs (HM-Treasury, n.d.; Park, 2006).

Taking these into account, this study seeks to set and suggest policy directions for Korea to participate in and contribute to the international efforts in addressing global climate change. However, the purposes of this study are not confined to climate change: it also aims to reduce environmental damages and find economically-efficient ways as well as socio-politically equitable and stable methods. To elaborate the goals of this study, the followings are given:

(1) As an environmental goal, this study aims to reduce the level of GHG emissions in Korea to the level required to prevent *'serious global climate change'*[3]. As mentioned above, it also aims to reduce the emissions of air pollutants by internalizing their external costs.

(2) As an economic goal, this study aims to minimize potential damages to the national economy, which results from how new policy suggestions would affect the economic development projected by the government's referential models.

(3) As a socio-political goal, this study seeks to improve social equity and stability by securing balanced energy development across regions and by reducing the energy instability factors.

(4) In addition, this study recommends some policy directions and instruments to resolve or alleviate existing social problems and barriers which block the transition from the current energy system to a sustainable one.

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[3] The UNFCCC, in the Article 2, describes that "[the] ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".

This study can offer additional advantages. Provided that the policy initiatives in this study are proved to be successfully designed toward the goals of energy sustainability, they should be able to serve not only for Korea but also for many other developing countries facing similar troubles. Even though this study is mainly about the improvement of Korea's energy system, its benefits are likely to extend well beyond Korea.

1.3 Framework of the Study

The process of establishing a sustainable energy system requires the intervention of values. Some experts criticize that value intervention is inappropriate in scientific approach and analysis, but researches that examine environmental, economic and socio-political phenomena cannot be free from normative propositions. Especially, when a scientific research is related to the impacts on the planet, value intervention is indispensible (Jacobson & Kammen, 2005).

Sustainable development is generally examined, at least, from three perspectives: environment, economy, and socio-politics (EC, 2015; Harris, 2000; Newman & Kenworthy, 1999; Parris & Kates, 2003; Spangenberg, 2004; UN, 2015; Wang, 2001; WCED, 1987). Therefore, the concept of sustainable development includes normative values (Lele & Norgaard, 1996).

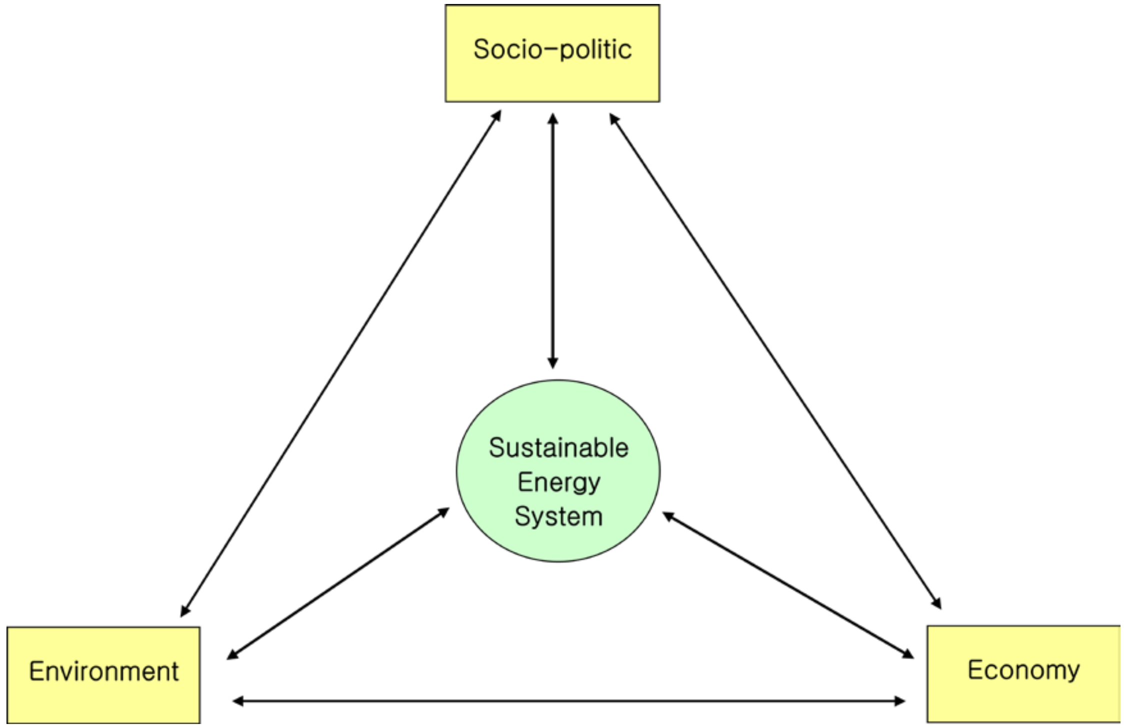

Figure 1-2: Basic Framework of Sustainable Energy System.

As a sub-system of sustainable development, sustainable energy system must be analyzed from these dimensions. This study examines the concept of sustainable energy system from environmental, economic, and socio-political point of views. From an environmental perspective, it explores whether Korea can reach the long-term GHG reduction target which is recommended and suggested by the IPCC and substantiated by Byrne & Wang et al. (1998) – around 3.3 t_CO_2 as the value of global average GHG emissions based on the population in 1990.

From an economic aspect, the main focus is given to the price change of energy sources in the future, based on the internalization process of external costs and the further technological development. In addition, the change of imported energy-to-GDP will be examined so as to analyze the impact of energy on the economy.

From a socio-political point of view, the harmony between energy policies and balanced regional development will be examined. In this sense, electricity balance index, the ratio of electricity demand to electricity supply, will be used to evaluate the improvement of social equity among regions. Since Korea merely imports other energy sources except electricity, their local distributions are not included for review. In addition, this study includes energy security issue based on OECD's ESI. What are keys to the ESI are the share of domestic energy production, energy import and the weight of each energy source in TPES.

One of the most important concerns in this study is whether renewable energy is able to have price competitiveness. Since renewable energy emits less or no pollutants and GHG[4], and is evenly distributed all over the region relatively, their substitution of conventional energy with economically efficient way is a key concern.

1.4 Methodology of the Study

1.4.1 Major Data Sources

The data required for this study are regarding energy supply and consumption, future energy scenarios, renewable energy potential, and international security issues, the prospect of technological progress, and social and economic issues.

Major data sources are as follows:

[4] In lifecycle analysis, renewable energy technologies and instruments like PV panels and wind turbines emit air pollutants and GHG. However, they are attributed to related manufacturing activities. Even though this characteristic is also applicable to nuclear power, this study differentiates renewable energy from nuclear issues because nuclear has many other environmental, social, and security-related problems.

1) Energy supply and consumption data: KEEI, MOTIE (previously MKE and MOCIE), KEPCO and related articles.

2) Renewable Energy Potential Data: MOTIE, ME, MAFRA, KMA and related articles.

3) International Energy and CO_2 Data: the IPCC, IEA, BP, UN, OECD and related articles.

4) Political Stability Index: ICRG

5) Energy Indicators and Economy-related Data: KEEI and related articles.

6) Data for Energy Scenarios: KEEI, MOTIE, the IPCC, KNSO, BoK, and related articles.

The data collected are used directly or changed into appropriate forms. In the modeling for estimating promotion of renewable energy and reduction of conventional energy, the price comparison between renewable energy and conventional energy is a key determinant, and the necessary data will be acquired from a number of studies and an analysis on energy price trends.

1.4.2 Scopes of the Study

This study mainly focuses on the analysis of overall and sectoral energy supply and consumption. It also analyzes price changes of renewable energy to examine their future potentials of expansion given its competitiveness compared with conventional energy, and their contribution to balanced regional development with a view to promote decentralization and social equity. As an economic side, it will internalize external costs to have more precise price for each energy source.

With regard to timetable, this study examines the energy constitution for 2030 and 2050. Firstly, it analyzes energy savings and GHG reduction by 2030 and compares them with the government's targets. Then, it evaluates the 2050 prospect in order to examine the possibility of attaining the goal suggested by the IPCC.

1.4.3 Methods Applied

This study adopts a 'mixed approach' between bottom-up and top-down approaches in estimating the future GHG reduction potential, and thereby to build a sustainable energy system. Firstly, as a top-down approach, it assumes that anthracite will not be used from 2026 and be substituted by city gas, based on the comparative price analysis. The internalization of external social costs generated from air pollutants and CO_2 is also looked at based on a top-down approach. On the contrary, the energy saved from having less energy service requirements and policies to improve efficiency should be examined through a bottom-up approach. Bottom-up approach was also used to estimate renewable energy potential. By combining these two methods, the study estimates potential saving and GHG reduction brought by the future energy.

This study examines future energy saving and GHG reduction potential by means of applying the following political instruments. Firstly, it estimates future energy consumption mainly based on the premises of the government's 2015 report (PMO et al., 2015) – GDP, population and industrial structure based on value-added – and the methods that KEEI has introduced (2006). This will serve as a basis for estimating the BaU scenario, as shown in Figure 1-3.

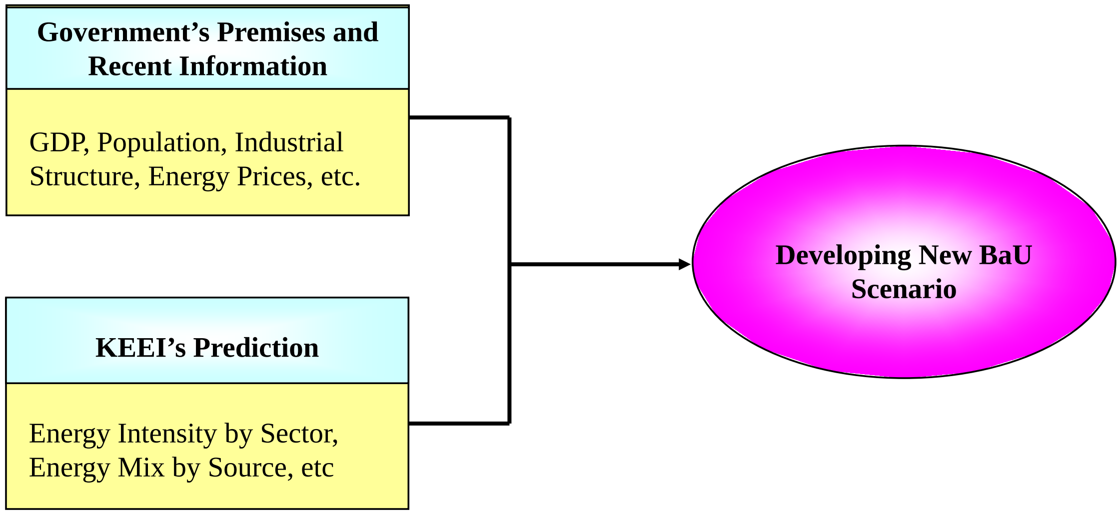

Figure 1-3: Diagram for Developing a New BaU Scenario.

Based on this BaU scenario, this study first looks at the change of industrial structure from what the Korean government adopted in 2015 to a less energy-intensive one adopted by KEEI's 2006 research. Next, the study observes the fuel substitution of natural gas for domestic coal. Domestic coal is acknowledged as inefficient, but nonetheless has continued to be produced and used as a fuel for low income class and power generation. The study also assumes that the anthracite will be no longer used, as it will be substituted with natural gas. This substitution has the potential of reducing GHG emissions, even though not considerably enough to contribute to reducing energy consumption.

Third, this study envisions the energy saving and GHG reduction through the adoption of energy efficient technologies. Basically, the study adopts the result of JISEEF's *Energy Revolution: 21 Century Energy and Environmental Strategy*. It analyzes that Korea has 95.4 Mtoe of primary energy saving potential and 58.9 Mt_C of GHG reduction potential by 2020, with the full implementation of suggested energy efficiency instruments and insulation technologies (Byrne & Wang et al., 2004).

Fourth, this study plans to reduce energy demand through the political instruments such as education and public campaign for sound energy consumption. In addition, the study predicts expanded use of renewable energy so as to reduce GHG emissions by means of comparing future energy costs by source. Here, gradual internalization of external costs will be applied, which is generated from fuel combustion. This study also analyzes available reserves of renewable energy sources, considering their potential is expected to be limited, at least, in the near future.

1.5 Outline of Chapters

Chapter Two provides theoretical background of this study. This chapter examines climate change narratives, reviews literature on sustainable development and develops a framework for this study. In this chapter, the main focus of analysis is the characteristics of sustainable development. Its characteristics will be examined by comparing the arguments between weak sustainability and strong sustainability.

Chapter Three provides major energy policies and policy suggestions in Korea. The major policies include *the National Energy Basic Plans, the Basic Plans on Developing and Disseminating New and Renewable Energy, the Basic Plans for Long-Term Electricity Supply and Demand, and the INDC plan*. This study reviews literature classifying them into five categories as follows: researches on overall energy policies, researches on the relationship between energy consumption and economic growth, researches on balanced inter-regional development, researches on energy efficiency, and researches on energy security issues.

Chapter Four describes construction of a sustainable energy system for Korea. Firstly, a BaU scenario is designed and analyzed. This study develops a new BaU Scenario based on the BaU Scenarios already established by MOTIE and KEEI. It uses these scenarios with a few revisions to examine whether or not Korea would achieve sustainable development under the government's premises. Renewable energy potential is also examined in Chapter Four.

Chapter Five analyzes the results of Chapter Four. Firstly, this study examines implications of the four political suggestions made in the study. The results are evaluated by comparing them with the BaU and government's scenarios, using the energy sustainability indicators which are mentioned in Chapter Two. The main target of examination is TFC, including energy consumed during the transformation process, TPES and GHG emissions. In addition, the environmental, economic and socio-political impacts are analyzed.

Chapter Six, the last chapter, summarizes and concludes the arguments, analyzes political implications, and offers policy recommendations to establish a more sustainable energy system in Korea. The limitations of the study as well as future research directions are also suggested. In sum, this study shows that Korea is able to realize a sustainable society, achieving GHG reduction and securing economic development and social justice.

Chapter 2

THEORETICAL BACKGROUND

The theoretical background for this study is introduced in this chapter. For this, previous researches on climate change issues such as climate change mechanism, historical and expected impacts of global warming, and related international movements are examined first. To build sustainable energy system, the concept of sustainable development is also examined from environmental, economic and socio-political perspectives. Through these reviews, sustainable energy system is conceptualized and established.

2.1 Climate Change Narratives

2.1.1 Brief Examination on Climate Change

Climate change is linked to the presence of GHG in the atmosphere. GHG[5] trap the earth-emitting long-waved infrared rays, while transmitting short-waved solar rays. GHG raise the temperature of the earth in the same way a greenhouse does. Without it, the average surface temperature would fall to -19 °C (Le Treut & Somerville et al., 2007). However, the excessive concentration of GHG raises the atmospheric temperature higher than necessary, causing undesirable global climate conditions and thereby threatening the ecosystem and human society.

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[5] GHG cover six gaseous elements such as dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and hexafluoride (SF_6). However, GHG are not confined to these six categories of substances.

Anthropogenic GHG has begun to affect the climate system slowly but steadily since the Industrial Revolution. Hitherto, CO_2 has reached 391 ppm in 2011 from around 280 ppm in 1750, methane 1,803 ppb from around 700 ppb, nitrous oxide 324 ppb from around 270 ppb, and tropospheric ozone and other anthropogenic GHG also have increased (IPCC, 2001a: 6-7 & 2013: 5).

According to the IPCC, the average global temperature has risen by 0.85 ºC over the period between 1880 and 2012, making the 1983-2012 period as the warmest period of 30 years; snow cover and ice extent have decreased continuously; global sea level has risen by 0.19 m over the period between 1901 and 2010; and at regional and global levels, intense rains have become severe with a longer duration, and extreme weather events have occurred more frequently (2013: 5-10).

Korea, also, has been experiencing serious impacts of climate change. As a case in point, the increase rate of average temperature in Korea is twice higher than that of the global average; the rate of sea level rise is three times higher; the frequency of extreme weather events such as heat wave and heavy rain has been increasing (KMA, 2014: 2, 37-46). According to Lee, the sea level of Jeju Island has risen around 22 cm during the last 40 years (2008).

However, these phenomena are just the tip of the iceberg. Since global climate and ocean circulation systems have a long-term inertia (IPCC, 2001a: 17), the impacts of global warming and sea-level rise are expected to continue throughout the 21st century, causing more serious damages to the earth.

2.1.2 Future Impacts of Climate Change

The world has continued to emit more GHG, despite clear warning indications on climate change. Therefore, the atmospheric concentration of GHG is expected to increase persistently. According to RCP Scenarios[6], the global temperature by the end of the 21st century will be likely to rise by 0.3~1.7 °C (RCP 2.6), 1.1~2.6 °C (RCP 4.5), 1.4~3.1 °C (RCP 6.0), and 2.6~4.8 °C (RCP 8.5) compared with the period of 1986-2005, and the sea level is also expected to rise by 0.25 ~ 0.95 m under RCP 2.6 ~ RCP 8.5 during the same period (IPCC, 2014: 10-11).

The impacts of increasing GHG are not confined to global warming and sea level rise. Climate change will affect the whole aspects of human life: it can affect human health directly and indirectly through heat stress, flood and storm, and other various diseases; it can be a threat to ecological productivity and biodiversity like the extinction of some vulnerable species; it can cause frequent abnormal weather phenomena such as heat waves, intensive precipitation, floods and droughts, causing tremendous threats and losses to life; it can affect the agricultural products; and it can also cause serious loss on the world economy (IPCC, 2014: 10-16). Such effects tend to be more serious to small islands, geographically low-lying coastal areas, and developing countries (Byrne & Glover, 2005: 7).

Its impacts on Korea are also expected to be serious: temperature is expected to rise by 2 °C (RCP 4.5) ~ 4 °C(RCP 8.5) by 2100 (KMA, 2014: 25); extreme weather events such as floods and droughts are likely to occur more frequently; agricultural productivity is likely to decrease; human health would be threatened by possibly increased exposure to vector-borne infectious diseases and heat stress; and the threat

[6] RCP scenarios were made based on four different GHG emission scenarios: RCP 2.6 is the most stringent mitigation scenario, which aims to control the global temperature to increase only less than 2 °C compared with that of the pre-industrial era; RCP 4.5 and RCP 6.0 are two intermediate scenarios; RCP 8.5 is the highest GHG emission scenario. (IPCC, 2014: 8). In RCP scenarios, the numbers mean possible increase ranges of radiative forcing (W/㎡) compared with pre-industrial values.

on biodiversity would be exacerbated (IPCC, 2001b: 14). Kainuma estimates that the forest loss in Korea might reach 2 % due to climate change in his “AIM-mitigation potential in Asia” (re-cited from the article of Lee, 2008).

2.1.3 International Response to Climate Change

Climate change first emerged as an international political agenda in 1988. The UN General Assembly adopted a resolution on the protection of global climate for present and future generations in order to take action on the proposal from Malta[7]. The debate in the UN General Assembly created the IPCC (Intergovernmental Panel on Climate Change), an agency to assess scientific, technical and socio-economic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. The IPCC has published five successive assessment reports: the First Assessment Report (FAR) in 1990, the Second (SAR) in 1995, the Third (TAR) in 2001, the Fourth (AR4) in 2007, and the Fifth (AR5) in 2014.

Of these, the FAR formed the background for the Ministerial Declaration of the Second World Climate Conference in November 1990, which recommended that negotiations concerning the framework convention on climate must begin without delay. In December 1990, the UN formally launched negotiations on a framework convention on climate change by establishing the INC (International Negotiating Committee) (Yamin and Depledge, 2005: 23). In just 15 months, the INC adopted the UNFCCC by consensus, which was opened for signature at the UNCED in Rio de

[7] In September 1988, Dr. Tabone, the Minister of Foreign Affairs of Malta, made a proposal in the United Nations that climate should be considered as a common heritage of mankind.

Janeiro, Brazil, on June 4, 1992 and came into force on March 21, 1994. As the Convention took effect, the COP, as the supreme body of the UNFCCC, has been convened annually for 20 years, as shown in Table 2-1.

Among the COPs, the third COP (COP-3), which was held in Kyoto in 1997, adopted the *Kyoto Protocol* unanimously. The key elements of the Protocol are as follows: all Parties have general commitments, and the Parties listed in Annex B must reduce 5 % of GHG emissions by 2012 based on the 1990 emission level. However, the target range of each country differs from -8 % (reduction) to 10 % (increase). Emission targets also cover certain carbon sequestrations in the LULUCF sector. Also JI, CDM and emission trading can be used to help meeting targets (Yamin and Depledge, 2005: 25). The COP-4 adopted the *Buenos Aires Plan of Action*, which sought both to advance the implementation of the Convention such as technology transfer, adaptation, and impacts of responsible measures, and to complete the unfinished works from Kyoto. Even though the then US President, George W. Bush, rejected to join in the Kyoto Protocol in March 2001, the successive COPs managed to keep the Protocol that entered into force with the participation of Russia.[8]

The negotiation for post-Kyoto initiated at the COP-11, after establishing a consultative body and holding four workshops under the guidance of COP. It means two-track approaches, which both stimulates discussion on climate change actions for all Parties and builds the strengthening of the Kyoto regime for Annex I countries.

[8] Russia ratified it on November 18, 2004, which satisfied the ratification requisite: the countries which account for about 55 % of the global GHG emissions should ratify Kyoto Protocol. Kyoto Protocol came into force on February 16, 2005.

Table 2-1: History of COP and Relevant International Events

Criteria	Dates	Venue	Major Accomplishments
			IPCC(1988.11; UNEP+WMO) IPCC's FAR(1990) Earth Summit(Rio, 1992) UNFCCC(1994.3)
COP-1	1995.03.28~04.07	Berlin, Germany	Berlin Mandate IPCC's SAR(1995.12)
COP-2	1996.07.08~07.19	Geneva, Switzerland	Geneva Ministerial Declaration
COP-3	1997.12.01~12.12	Kyoto, Japan	Kyoto Protocol (KP)
COP-4	1998.11.02~11.13	Buenos Aires, Argentina	Buenos Aires Plan of Action
COP-5	1999.10.15~11.05	Bonn, Germany	
COP-6	2000.11.13~11.25	Hague, Netherlands	
COP-6	2001.7.16~7.27	Bonn, Germany	US's Rejection of KP IPCC's TAR(2001) Bohn Agreement
COP-7	2001.10.29~11.10	Marrakesh, Morocco	The Marrakesh Accords
COP-8	2002.10.23~11.01	New Delhi, India	Delhi Ministerial Declaration
COP-9	2003.12.01~12.12	Milan, Italy	
COP-10	2004.12.06~12.17	Buenos Aires, Argentina	Russia's ratification of KP Discussion on Post-2012 started.
COP-11	2005.11.28~12.09	Montreal, Canada	Enactment of KP(2005.2)
COP-12	2006.11.06~11.17	Nairobi, Kenya	
COP-13	2007.12.03~12.14	Bali, Indonesia	IPCC's FAR(2007) Bali Roadmap for Post-2012
COP-14	2008.12.01~12.12	Poznan, Poland	
COP-15	2009.12.07~12.18	Copenhagen, Denmark	Copenhagen Accord
COP-16	2010.11.29~12.10	Cancun, Mexico	
COP-17	2011.11.28~12.09	Durban, South Africa	Durban Platform
COP-18	2012.11.26~12.08	Doha, Qatar	
COP-19	2013.11.11~11.23	Warsaw, Poland	Warsaw Mechanism
COP-20	2014.12.01~12.12	Lima, Peru	

At the COP-13 in Bali, the Parties agreed to prepare for the post-Kyoto by COP-15 in 2009. At the successive COPs, the Parties agreed to establish a legally-binding deal by 2015, which would take effect in 2020 and substitute for the Kyoto Protocol, and to create the GCF to help developing countries adapt to climate change. The Parties also adopted the concept of "loss and damage." COP-19 invited all Parties to submit INDCs to achieve the 2015 agreement at COP-21 in Paris. Following the invitation, many countries submitted their INDCs. The US released its plan to reduce 26-28 % of GHG by 2030 in comparison with 2005 (UNFCCC, 2015a). China plans to lower GHG emissions per unit GDP by 40-45 % based on 2005 level by 2030 (UNFCCC, 2015b). Japan announces to reduce 25.4 % of GHG emissions compared with 2005 by 2030 (UNFCCC, 2015c). These international actions, although limited to some parts, are encouraging contribution to creating a positive atmosphere for post-2020 agreement.

Given the international politics of climate change, the pressure of Annex B countries, which requires the participation of developing countries, would get stronger as COPs proceed. Until now, some developed countries have borne the responsibility in the name of *differentiated responsibility*. However, the situation might change toward expanding the participation of more countries – in particular, the leading developing countries like Korea – in the name of extended *common responsibility*. The US vetoed the Kyoto Protocol, requiring the participation of developing countries, and the positions of such countries would reinforce this argument. Therefore, the global situations would not favor Korea which has been passive in participation. Climate change can be an immediate challenge to Korea whose economic system is very vulnerable especially to energy and environmental threats.

2.2 Literature Review on Energy Sustainability

Development has been recognized as a synonym, or almost so, to (economic) growth, especially the increase of GNP or GDP (Redclift, 1987: 15-16; Winner, 1982: 266-7). The modern age, marked by technological advancement and material abundance, has consumed a significant amount of energy in order to even maintain the status quo. However, the increase of energy consumption, despite the benefits it brings, has caused many regional, national, and global problems such as environmental degradation, social inequality, geographically unbalanced economic situations, frequent political disputes and climate change. Through the reflection of these problems, the concept of '*sustainable development*' was established, and began to affect energy policies in the name of 'sustainable energy', 'energy sustainability' or 'sustainable energy system' (Commission of the European Communities, 2006; Geller, 2003; Wang, 2001).

'Sustainable development' is one of the most frequently mentioned terminologies in many fields. Most of the recent development projects, policies and plans, whether they are included in the public or private sectors, are connected to sustainable development. At first, many policies did not live up to the concept of sustainable development. However, policies have been enhanced as being more sustainable by gradually reflecting the demands changed over time and accepting new scientific evidences on environmental problems, social injustice and climate change. Davoudi & Layard (2001: 9-10) pointed out this trend as follows.

> …… some tokenistic approaches such as putting the environmental chapter at the beginning of the plan, or providing a list of environmental objectives without having strategies to implement them. But gradually planners have made genuine attempts to incorporate some of the principles of the 'new' environmental agenda, albeit with limited success.

Even though the concept of sustainable development was introduced by WCED, it was not accepted unanimously, and consequently, various interpretations and disputes have been made. Experts from various fields and organizations accepted, interpreted and re-defined it, reflecting their political positions and scientific backgrounds; for example, economists give greater weight to economic objectives, ecologists to environmental dimensions, and social theorists to social issues. Even though many people seem to formally and/or publically advocate sustainable development, their concepts are not same or similar (Norgaard, 1994: 11; Harris, 2000:7; Kates et al., 2005). This specifically shows that the use of sustainable development without clearly defining its meaning might cause misunderstanding and unnecessary conflicts.

Therefore, it is necessary to examine more closely the process of how sustainable development has evolved. For this, historical background of sustainable development is briefly introduced and the controversial characteristics of sustainable development and energy sustainability are examined in this section.

2.2.1 Brief Examination on the History of Sustainable Development

For a long time, the dominant concept of development has been an economic growth based on technological advance (Rosenberg, 1972: 3-50) to follow the pattern of industrialized societies' economies and the chase for material affluence represented by GNP or GDP. This has become the prototype of development. The following quotation of Spangenberg (2004) from *Economists* appropriately shows this trend:

> ...... the only quality that counts is quantity: the more growth, the better, for all members of society and in all respects.

The assertion of Rostow reflects this belief: categorizing the maturing process of each society into five stages, he insisted that developing countries should follow the way which the industrialized countries already passed to reach the apex of development, a high mass-consumption stage[9] (1960: 4). They believe that developing countries can acquire genuine autonomy and greater independence only through the adoption of the developed countries' technology and system.

The concept of growth-oriented development, however, has been criticized[10] and begun to change, expanding its domain from economic issues to social and humanitarian concerns such as education, nutrition, health, and sanitation since the 1970s. The appearance of HDI in UNDP is an example of this progress. The concept of development has also begun to involve other issues such as environmental problems, social equity and natural resources management. With the rise of these new issues and problems, the traditional concept of development has become more refined, complex and value-implicative.

Depending on the economic model of industrialized nations, many developing countries have propelled economic growth, supported by greater multinational cooperation, industrialized countries, and international organizations like the World Bank, IDA, and UNDP. Many of them, however, have failed; they have suffered from

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[9] Rostow (1960) classified development stages into five steps: the traditional society, the preconditions for take-off, the take-off, the drive to maturity, and the age of mass-consumption.

[10] For example, Redclift (1987: 16) criticizes this trend as follows: "...... GNP is a particularly inadequate guide to development since it treats sustainable and unsustainable production alike and compounds the error by including the costs of unsustainable economic activity on the credit side, while largely ignoring process of recycling and energy conversion which do not lead to the production of goods or marketable services."

the shortage of food, water and medicine; investments and technology transfers have increased their debts and deepened their dependency on industrialized countries; resources in those countries have been excessively exploited and used not to develop their own economies but to pay debts; social inequalities between the haves and have-nots have widened; indigenous people have been expelled from their habitats and farmers have lost their croplands, seeds and fertilizers; and, their environments have been seriously degraded with the destruction of forest, local pollution, and waste problems (WCED, 1987: 1-13; Onimode, 1988: 1-22, 128-140; O'Connor, 1989: 1-11; Shiva, 1991: 21-58, 171-192; Esteva, 1992: 6-23; Ayupan & Oliveros, 1994: 113-120; Korten, 1994; Yamaguchi, 2003; Tansey, 2011). The lives of the people are still in an unsatisfied condition: almost half the world population live on less than USD 2.5 a day (Global Issues, 2013), and two billion live without access to basic public energy services such as electricity (UNDP, 2000: 3).

Development-related problems are not confined to the Global South. The Global North is also suffering from many serious problems: the excessive use of chemicals and fossil fuels has brought global-scale environmental threats such as stratospheric ozone depletion, acid precipitation, and global warming; agriculture based on chemicals is polluting food, soil and water bodies; great subsidies for agricultural sector have distorted the international market, collapsing the lives of the peasants of some developed countries (WCED, 1987: 1-13; Higgins, 2013).

These problems make people reconsider economic growth and the pattern of energy consumption. Through this reflection, the concept of sustainable development has been established and has begun to affect the domain of energy policies.

2.2.2 WCED's Definition of Sustainable Development

The WCED defines 'sustainable development' as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (1987: 43). This is an innovative concept which requires great change of political, economic, social, technological, international, and administrative systems (Elliott, 1999: 9).

In relation to sustainable development, WCED suggests major policy directions focused on population, food security, species and genetic resources, energy, industry, and human settlements. The main contents are as follows:

(1) Population stabilization and human resource development;

(2) Development of effective incentive systems in favor of the small farmers in developing countries, cutting surpluses, reducing unfair competitions (subsidies and protections), promoting ecologically sound farming practices in developed countries, and establishing redistribution systems for those who lack purchasing power;

(3) Conservation of disappearing species and threatened ecosystem;

(4) Recognition of the limits of the Earth's capacity (limits to no more than twice the energy presently used), promotion of energy efficiency measures, R&D on environmentally sound and ecologically viable alternatives, increasing safety of nuclear energy, and assistance for developing countries to change their energy consumption patterns;

(5) *A five-to-ten folds of increase* in manufacturing output to match the consumption level of developing countries with that of developed countries, and developing technologies to produce more with less;

(6) Decentralization of funds, political power, and personnel to local authorities.

The fact that WCED puts forward this concept is very meaningful, considering that the report, *Our Common Future*, is the consensus of the international society in which many contradictory political values and beliefs are reciprocally addressed (Davoudi & Layard, 2001: 13). WCED’s sustainable development sets the improved, more persuasive and environment-centered concept: it recognizes the limits of economic growth; combines social issues with economic growth; deals with the environmental problems more seriously compared with conventional optimists[11]; considers not only the current generation but also future generations; and stresses decentralization or local-based decision-making and renewable energy expansion.

WCED’s sustainable development has been accepted by many international organizations, national and local governments, private organizations, and social movements. In particular, *Rio Declaration* and *Agenda 21*, the successors to *Our Common future*, definitely support the implementation of sustainable development (Lafferty, 1998: 271-2).

However, the concept of WCED has critical defects. As Daly criticized, it supports the persistent material growth of the world economy. This shows that WCED’s concept is also limited to the category of material growth, despite its qualitative progress compared with previous concepts.

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[11] Even though some conventional optimists take environmental problems seriously, they basically believe that ‘technology can solve all’. They regard nature as an instrumental capital which can be substituted with. To them, most environmental problems are “the outcome of a decision to adopt the cheapest technique available to a given productive process” (Rosenberg, 1972: 190, 193, 198).

2.2.3 Disputes on Sustainable Development

Even though the terminology of ‘sustainable development’ prevails, its concept is not accepted unanimously. Rather, it is regarded as an ambiguous and confusing concept. However, it is an important concept which considers, evaluates and integrates various social issues and harmonizes conservation and development. Therefore, it is necessary to examine major disputes surrounding sustainable development. This study mainly observes these views from the point of the nature (or environment), economy and society. To simplify the disputes, the study divides them into two groups: one is an economy-oriented group, and the other is an environment-centered one.

Disputes on Human-Nature Relationship: There are diverging views on the evaluation of the nature between these two opposite groups. Economy-oriented experts and technological optimists see the nature as an instrument for human convenience and as a material supplier and waste storage with sufficient self-purification capacity. Some even insist that natural resources are free of charge (Peet, 1992). To them, the degradation of nature is not important, provided that losses are not bigger than profits. On the contrary, environment- and ecology-centered experts recognize that the crucial and intrinsic value of the nature itself is independency from human interests (Lele & Norgaard, 1996). On the stream of these thoughts, they argue that a human desire is greater than the nature’s capacity and is likely to undermine its stability by squandering limited resources. According to them, people have to pursue self-sufficiency so as not to compensate nature’s resilience instead of chasing for unlimited desire (Tansey, 2011).

Another controversial concept is whether natural capital can be recognized as a substitute for human-made capital, and vice versa. It is related with ‘substitutability’.

The economy-oriented groups accept the concept of substitutability, which is generally called as ‘weak sustainability’. This is well-known as ‘Solow-Hartwick rule’, which justifies the decrease of natural capitals, provided that these resources are reinvested for the same as or more than their returns (Harris, 2000). On the other hand, environmentalists and ecological economists indicate the limitations of ‘substitutability’ (Emas, 2015). Even though they do not negate the concept of substitutability, they are concerned about the irreversible destruction of nature’s vulnerable chains. Therefore, they insist the stable utilization of natural resources only within their capacity (Daly, 1990). Their assertions can be classified as ‘strong sustainability’. The following describes the disputes of weak and strong sustainability based on substitutability;

> In 1900 one of the world’s richest phosphate deposits was discovered on Nauru and today, as a result of just over ninety years of phosphate mining, about 80 per cent of the island is totally devastated. At the same time, the people of Nauru have had, over the past several decades, a high per capita income. Income from phosphate mining enabled the Nauruan to establish a trust fund estimated to be as large as $1 billion. Interest from this trust should have insured a substantial and steady income and thus the economic sustainability of the island. Unfortunately, the Asian financial crisis, among other factors, has wiped out most of the trust fund. The people of Nauru now face a bleak future. Their island is biologically impoverished and the money Nauruan traded for their island home has vanished. The “development” of Nauru followed the logic of weak sustainability, and shows clearly that weak sustainability may be consistent with a situation of near complete environmental devastation. This case illustrates a telling argument against weak sustainability. A substitution of natural for manufactured capital may be one-way: once something is transformed into manufactured capital there is no way to return to the original situation (Ayres et al, n.d.).

The difference in the stability and capacity of the nature is also worth mentioning. Economy-oriented group usually assumes that the capacity of the nature is sufficient enough for people to use natural resources in a stable manner. They believe that people are able to overcome the deficiency in resources through the development of alternative materials and fuels, or the utilization of advanced technologies. On the contrary, environment-centered group argues that the current human activities are threatening the ecosystem and global climate system. They basically consider that the current economic conditions have already exceeded the limit of the earth's capacity or have been approaching to this limit (Vitousek et al., 1986; Daly, 1990:45-47; Constanza et al., 1997).

Disputes on Economy: Neo-classical economists and technological optimists are aware of asserting the need for quantitative growth. They firmly assert that the earth can provide humans with infinite or plentiful resources for growth or that technological progress enables human to solve the issue of resource scarcity (Beckerman, 1996; Huber & Mills, 2005). On the contrary, most environment-centered group denies the possibility of further growth without degrading the nature and compensating the needs of next generations; these environmentalists view the quantitative growth as a threat to sustainable development. Daly criticizes the concept of WCED's sustainable development as "an impossibility theorem" (1990:45-7). According to Daly, *growth* means "to increase naturally in size by the addition of material through assimilation or accretion," while *development* means "to expand or realize the potentialities of; to bring gradually to a fuller, greater, or better state" (1990: 45-7). Wang also maintains the same position with Daly. According to Wang, "[d]evelopment differs from growth: when something grows, it gets quantitatively bigger; when something develops, it gets qualitatively better" (2001: 1).

In relation to the indicators of economic progress, economy-oriented group looks at the role of GDP or GNP as positive, while the critic group stresses their limitations. To environmental economists, the problems of GDP/GNP are that they do not reflect external costs; however, it does not mean that they do not accept the use of GDP/GNP. Many government and economic institutions, however, set their own economic goals based on GDP/GNP taking into account this perception. However, environment-centered group generally criticizes the limitations of GDP/GNP-based economic analysis or targeting. Redclift points out the limitations of GDP, mentioning that GDP "treats sustainable and unsustainable production alike and compounds the error by including the costs of unsustainable economic activity on the credit side, while largely ignoring processes of recycling and energy conversion which do not lead to the production of goods or marketable services" (1987: 16). Based on these criticisms, they insist that the current account system must be changed into a 'green' one, by internalizing social costs such as climate change and environmental loss and damage, and embracing the value of natural service into the account.

Disputes on Society: In relation to social perspectives of sustainability, three major issues can be identified as follows: equity between classes, equity in regional distributions, and the relationship between current and future generations.

Generally, economy-oriented group give greater values to the total welfare of society, while environment-centered group places greater values on individual welfare, especially those of the alienated. Accordingly, the economy-oriented group is found to be more interested in economic efficiency, while the environment-centered group in social equity issue between classes.

Since the economy-oriented group is more interested in the overall social welfare of a society, it is more concentration-oriented, while environment-centered group is more distribution-oriented. Applying these positions to an energy issue, the former is likely to be more interested in a centralized energy system, while the latter in a localized or distributed energy system. Moreover the former prefers the energy source that brings more economic benefits, while the latter is more interested in the energy source which brings socio-economic benefits but less environmental damages. In other words, the former is more interested in the conventional energy, while the latter renewable energy. The impacts of the former can be easily found in the current energy policies. The construction of massive centralized power plants fueled by coal and nuclear and the R&D for IGCC and CCS technologies are some of the examples of the former, while energy policies focusing on renewable energy and efforts to internalize the external costs can be the examples of the latter.

The relationship between the current generation and the future generations is also important. Economy-oriented group tends to give priority to the welfare of the current generation than the needs of the future generations, although this group does not overlook the future interests. A major instrument of them is to apply an excessive discounting rate to the future economic values[12], which can seriously downgrade the value of the benefits for the future generations. On the other hand, the environment-centered group insists the application of zero or smaller discounting rate, not to impair the wellbeing of the posterities.

[12] For simple example, the value of $1 million one hundred years from now is depreciated into merely $72, if 10 % of discount rate is applied (Harris, 2000).

In conclusion, the world cannot sustain continued economic growth and an exponential increase of material consumption such as fuel, natural materials and food, since the resources cannot quantitatively meet the demand. Therefore, it would be advisable to consider an efficient use and conservation of limited natural resources, not only for the benefits of the present generation but also the needs of the following generations. In this regard, the use of renewable energy which does not risk depleting natural resources should be considered as a way to sustain development.

2.3 Developing a Framework on Sustainable Energy System

The goals of energy policies are generally to secure a stable energy supply, sustain an efficient and competitive infrastructure, and accomplish sustainability (Commission of the European Communities, 2006). These goals have changed, following the evolving energy market situations. Securing a stable energy supply was the main target for the period of oil crises; enhancing competitiveness of the energy industry was given attention when liberalization was promoted in the energy industry; and recently, building sustainable energy system is gaining greater values worldwide (Ahn, 2007).

Since WCED suggested the concept of sustainable development, it has served as a touchstone for various public policies including energy policies. Therefore, it is necessary to examine the concept or characteristics of sustainable energy system based on previously examined narratives and perspectives related to environment, economy, and socio-politics.

2.3.1 Energy Sustainability from Environmental Point

Major environmental issues related to energy include the destruction of ecosystem, water (ocean) pollution, nuclear-related problems, and the emissions of air pollutants and GHG. Among them, this study focuses on GHG emissions with the following reasons.

Destruction of Ecosystem and Water Pollution: The issues on ecosystem destruction and water pollution are more related with energy exploitation and accidents. Since Korea imports most of its energy resources, environmental problems regarding energy exploitation are not significant within the Korean territory, and they can be internalized into the import costs. The energy-related accidents can cause critical damages as shown in the accidents of Sea Prince Spillover in Korea and Exxon Valdez Spillover occurred at the Alaskan coast. However, these accidents are the results of some abnormal situations and are difficult to be analyzed in connection with the establishment of sustainable energy system in Korea. Therefore, this study does not include these issues.

Nuclear Issues: Nuclear advocates regard nuclear power as one of the most desirable solutions for sustainable energy supply, whereas nuclear opponents criticize it as an unsustainable energy source. Regarding this, the position of this study is that nuclear power is not a desirable alternative for constructing a sustainable energy system from the points of environmental, economic and social perspectives, the reasons of which are as follows.

As Korea imports all uranium fuel, the issue of environmental destruction from mining and milling might not be a direct concern. However, environmental destruction from mining and milling is not negligible. Currently, the global average concentration of uranium ore is around 0.15 % U_3O_8, meaning that more than 667 kg of ore has to be processed to obtain 1 kg of uranium fuel. During the enrichment process, a significant amount of fresh water and many chemicals such as sulfur, sodium chlorate, ammonia and lime are also consumed (Storm van Leeuwen, 2007), which are also expected to cause significant environmental pollution.

The GHG emissions from nuclear power are one of the strongest arguments. Nuclear advocates say that the life-time GHG emissions of nuclear power plant are only 6g of CO_2 in generating 1kWh of electricity, less than other efficient renewable energy facilities (Nuclear Energy Institute, 2007; Spadaro et al., 2000, WNA, 2014). However, critics argue that the lifetime GHG emissions are significant (ISA, 2006; Storm van Leeuwen, 2006 & 2007). According to Sovacol who screened 103 lifecycle studies on GHG emissions from nuclear power plants, the mean value of GHG emissions are 66.08 g_CO_2/kWh, ranging from 1.36 g_CO_2/kWh to 288.25 (2008). Although much less than fossil fuel-fired power plants, it is much larger than renewable energy sources. Figure 2-1 shows the comparison of lifetime GHG emissions from various power generation technologies, summarized by NREL.

Storm van Leeuwen, who analyzed the lifetime GHG emissions from nuclear power plants in relation to uranium ore grades and resource limits, estimates that the GHG emissions from nuclear power plants amount to 20~40 % of gas-fired power plants, and insists that it would increase rapidly with the depletion of rich uranium ores (0.15 % ~0.2 % of U_3O_8) within 20 years (2006 & 2007). In addition, he indicates that other GHG such as Freon, fluorine and chlorine are also generated significantly during the enrichment process, even though it is difficult to quantify their emissions exactly.

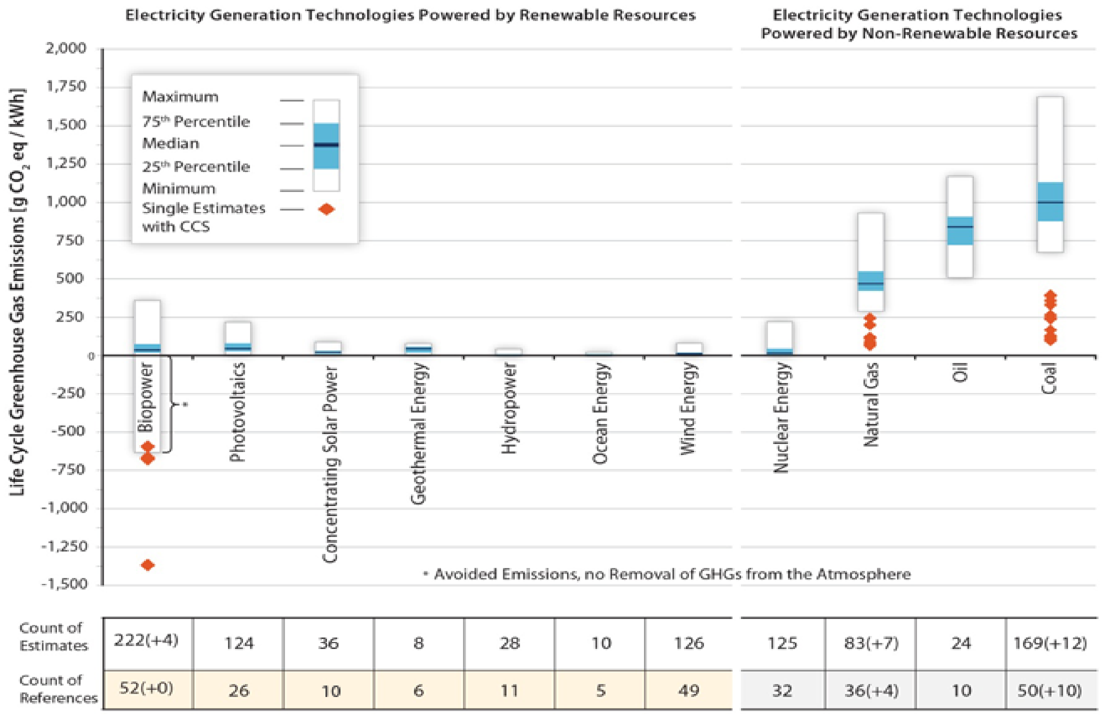


Figure 2-1: Lifecycle Estimates of GHG Emission for Electricity Generators. Source: NREL (2014)

In addition, radioactive pollution is also significant. Two atomic bombs dropped in Japan and the accidents of 'Three Mile Island' and 'Chernobyl'[13] as well as recently occurred Fukushima Daiichi Nuclear Power Plant have shown vividly the danger of nuclear power plants (OECD/NEA, 2013). In addition, these accidents are not finished yet, as they are considered as ongoing accidents (Greenpeace, 2015). The reasons of such accidents are various: trivial operational and mechanical errors, and external forces like a massive earthquake and successive tsunami. The disposal and

13 The damages of Chernobyl Nuclear Accident are formidable, despite 2.5 % of the radioactivity in the reactor has been released. Approximately 1,000 square miles around the plants are permanently contaminated, and more than 40,000 cases of cancer are estimated to be caused by this accident (Schobert, 2002: 423-424).

management of nuclear wastes also require much attention to prevent radioactive accidents. Considering these various risks, the external costs and environmental problems would be greater than what is currently being estimated.

According to Voss, the quantifiable external costs[14] of nuclear power are 0.2 Euro-cents/kWh, while that of coal 2.6, gas (combined cycle) 1.1, PV 0.8, wind 0.09, and hydro 0.07 (re-cited from Bertel & Fraser, 2002). The European Commission also presents a similar outcome by suggesting the external costs of nuclear to be around 0.3 Euro-cents/kWh (2003; Owen, 2004 & 2006). However, as examined previously, the lifetime GHG emissions from nuclear power plants are significant, even though much less than current fossil fuel-fired power plants. Jang also indicates that the current evaluation does not include the hidden costs, which make the nuclear power un-economic (re-cited from Lee, 2012). In addition, as the grade of uranium ores deteriorates, the costs of nuclear power are expected to increase continuously, weakening its price competitiveness, as shown in Figure 2-2.

From a social perspective, the major issues when discussing nuclear power are the proliferation of atomic weapons, social acceptance of nuclear power plants construction, and the security related with terrorism, war and natural disaster. First of all, the use of nuclear energy raises concerns about the possibility of the proliferation of nuclear weapons. The development of nuclear bombs from North Korea, Iran and Pakistan, and the import of nuclear wastes by Japan have added to the global concerns (Asif & Muneer T., 2007). As shown in the violent demonstrations related to nuclear issues in Korea, many people are strongly concerned about the construction of nuclear

[14] The estimation includes the costs of health effects, material damages, noise nuisance, acidification/eutrophication, and global warming (Bertel & Fraser, 2002).

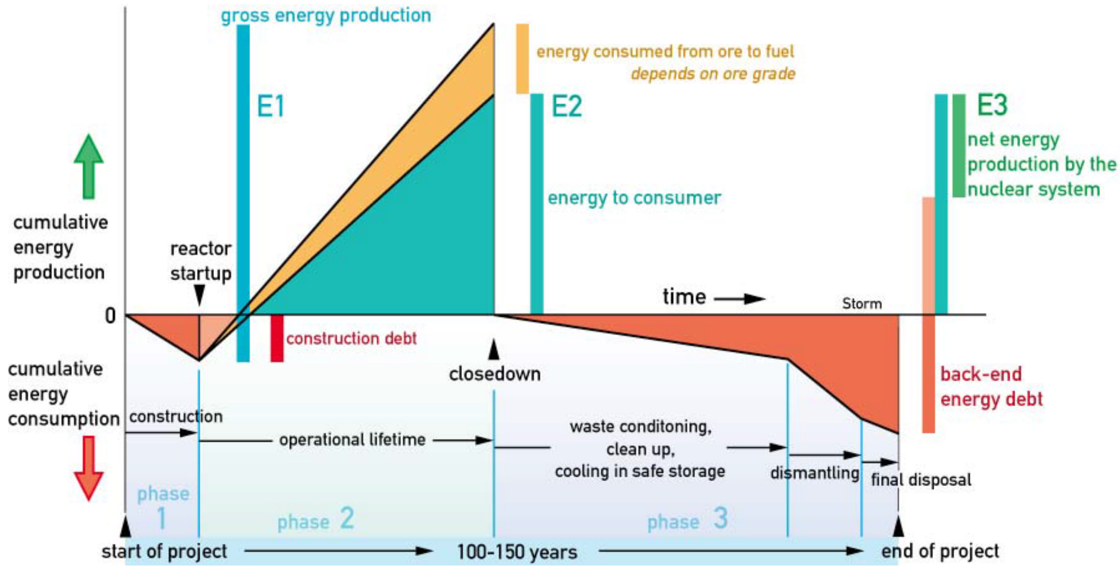


Figure 2-2: Life-time Analysis of Nuclear Power Plants.
Source: Storm van Leeuwen (2006)

power plants and nuclear wastes disposal/storage facilities. After the Fukushima nuclear accident, there are growing demands for stopping the operation of nuclear power plants when their licensed operating time is expired. Nuclear power plants can also be a serious threat to social security by being the target of (cyber-) terrorisms or wars (Whitney, 2014). After the 9.11, the threats of international terrorism have increased worldwide, regardless of nations (PSR, 2006).

In relation, many European countries such as Sweden, Switzerland, Spain, Belgium, Netherlands, Germany and the United Kingdom already gave up nuclear power generation policies (Yoon, 2003; Traber & Kemfert, 2012: 1). ‘Nuclear moratorium’ has gradually become a global trend. In this respect, this study does not include the expansion of nuclear power plants except for the ones currently being constructed and assumes that the operation of nuclear power plants would be halted after their expected lifetime.

Air Pollution Issue: In Korea, 69.8 % of air pollutants were originated from fuel combustion in 2012, as shown in Table 2-2, and this trend has since then continued without a big change (NIER, n.d.). Those categorized as 'the others' are deeply related with fuels, since they are mainly generated from manufacturing processes such as the use, storage, treatment of organic solvents. This means that impacts of energy policies are critical to air pollution in Korea. However, air pollutants can be controlled significantly by precautionary measures like the expanded use of low-sulfur oil and unleaded gasoline, and by the end-of-pipe measures such as electrostatic precipitators, cyclones, scrubbers, and three-way catalysts. That is why the overall air quality of Korea has improved or not worsened seriously, despite the continual increase in fuel combustion.

Table 2-2: Air pollutants Originated from Fuel Combustion in 2012 in Korea

(Unit: thousand ton)

Category	Sum	SOx	NOx	PM10	CO	VOC
Fuel Combustion	2,198.9 (69.8 %)	283.3 (69.0 %)	1,001.5 (93.1 %)	111.8 (93.6 %)	673.2 (96.2 %)	129.3 (15.0 %)
The Others	952.6	127.2	59.0	7.6	26.6	732.2
Sum	3,151.5	410.5	1,060.3	119.4	699.8	861.5

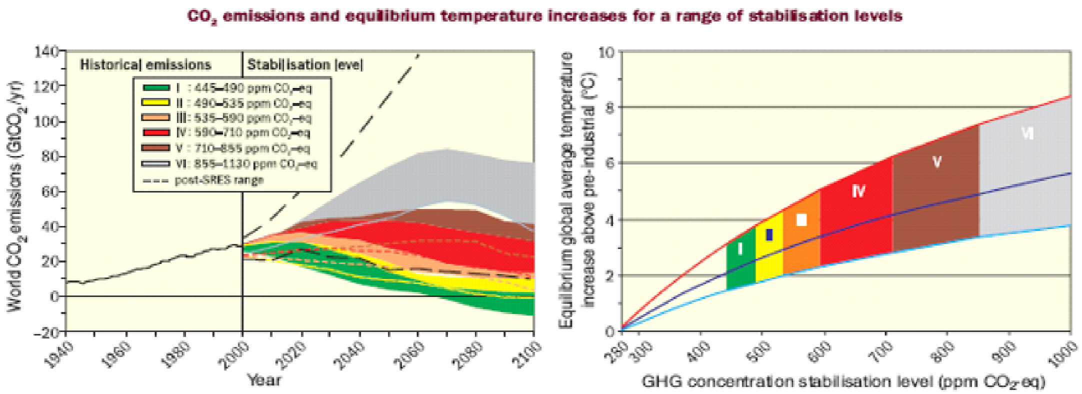
Source: NIER (n.d.)

The emitted air pollutants cause many adverse problems to people, society and natural ecosystem, which incurs additional social costs to cure, complement and prevent these problems. In this sense, this study reflects the internalization of social costs instead of directly analyzing the impacts of air pollutants.

<u>GHG Emission Issue</u>: In 2012, Korea's per capita emission from energy consumption amounted to 11.86 t_CO_2, more than 2.6 times of the global average emissions (IEA, 2014a). According to *the INDC Plan*'s BaU Propsect, per capita emission of GHG is expected to reach 13.2 t_CO_2 by 2020 and 14.2 by 2030 (PMO et al., 2015). The Korean government seems to consider that aggressive measures cannot be accomplished without compromising economic growth. However, as the international negotiations for post-Kyoto agreement proceeds, the pressures from the global society and domestic NGOs are expected to grow. With regard to the reduction principles, the reduction programs based on the global equity and responsibility are expected to gain momentum (de Araujo et al., 2007). Therefore, this study examines whether Korea delivers the global equity-based CO_2 emission goal without excessive economic losses or decrease in GDP affected by the reduction of GHG emissions.

As for the future GHG emissions, the IPCC suggested a 50-70 % reduction of CO_2 in comparison with the emissions of 1990 (1996:9-11), which corresponded to around 3.3 t_CO_2 per capita, based on the population of 1990 (Byrne & Wang et al, 1998: 335-339). Among the IPCC's six different scenarios, as shown in Figure 2-3, Category I is regarded as the case for meeting the IPCC's suggestion.

<u>Summary</u>: As a summary, this study is going to examine whether Korea has the potential to reduce GHG emissions to the level required by the international community in order to hold the global temperature rise within 2 °C.



Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Figure 2-3: GHG Emissions Scenarios by the IPCC.
Source: IPCC (2008: 66-7)

2.3.2 Energy Sustainability from Economic Point

Energy system and related policies can greatly affect the national economy. The impacts of energy on economy are examined from the point of energy weight to national economy, the relative price differences among energy sources, and carbon intensity or the amount of carbon emitted per unit GDP.

Energy Import Issue: The weight of energy on the national economy can be expressed as the ratio of energy costs to GDP. This indicator shows the overall influence of energy on the economy. This concept can be divided into two categories: the portion of imported energy costs to GDP can be an index to evaluate the impacts on both the economy and security, while the portion of total energy costs to GDP can be an indicator to evaluate the impact on the economy. In this sense, lower energy weight to GDP can be interpreted as lighter burden on the national economy. Main policies to lower energy impacts are demand management policies including energy-efficiency policy which pursues the minimum input of energy for enjoying the same or better energy services and energy consumption reduction policies to reduce the absolute amount of energy consumed. Another example is to support technology development for reducing energy production costs. The promotion of cheaper but cleaner energy technologies can relieve energy burdens on the economy.

Price Competitiveness Issue: The change in price competitiveness among energy sources can be a good economic indicator to evaluate the influence of energy on the economy. One long-term goal of many energy policies is to change the current energy mix to a more desirable one. Sustainable energy policy seeks to achieve an energy mix which is environmentally friendly, under given economic, technological, socio-political constraints. In general, conventional energy such as fossil fuels and nuclear are being considered to be more competitive, compared with renewable energy under the current energy system. However, the current system does not properly reflect price competitiveness, because energy prices have been seriously distorted by the government's subsidies and tax exemptions as well as externalities such as health costs, global warming, degradation of air quality, the reduction of agricultural products, building erosion, the increase of cleaning costs, etc[15]. One policy option to

[15] External costs are generally recognized as negative; however, they are not confined to negative impacts. Especially, the activation of renewable energy has many benefits such as positive environmental impacts, distributed generation value – electric energy value, thermal energy value, option value (rapidly building small amounts of electric

address this problem is to reform the current accounting system to a 'greener' one by internalizing the external costs (Hecht, 2005: 2). In Korea, KEI, a government-run research institute, carried out a research on the internalization of energy-related externalities (Kang et al., 2007). Other policy options are to support technology development to reduce energy costs and to grant economic incentives on specific energy sources which have potential benefits in the future.

Carbon Intensity Issue: Carbon intensity can be an index for evaluating the economic impacts of energy. However, its role is conditional and limited; in other words, carbon intensity in itself does not explain any economic influences, assuming that there is no regulation on carbon emissions. Possible policy options include the introduction of carbon tax, the adoption of carbon emissions trading system, and the imposition of economic, legal and systematic disadvantages on carbon-emitting fuels.

Summary: Based on these findings, a new economic system to correct the current energy price system by reflecting the external costs is to be designed. Secondly, change in the energy mix under the conditions of corrected price system will be examined, taking the prediction of future production and operation costs from related articles into consideration. Thirdly, if necessary, economic impacts of energy policies through which Korea does its share of international goal for GHG reduction will be analyzed by gradually increasing the rate of carbon tax. The basic structure for economic analysis is shown in Figure 2-4.

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generating capacity), deferral value (deferring infrastructure investments), engineering cost savings (reduction of O&M costs and T&D loss), customer reliability value, environmental value, – hedge value, import premium, and employment (Mosey & Laura, 2009; Sterling et al, 2013).

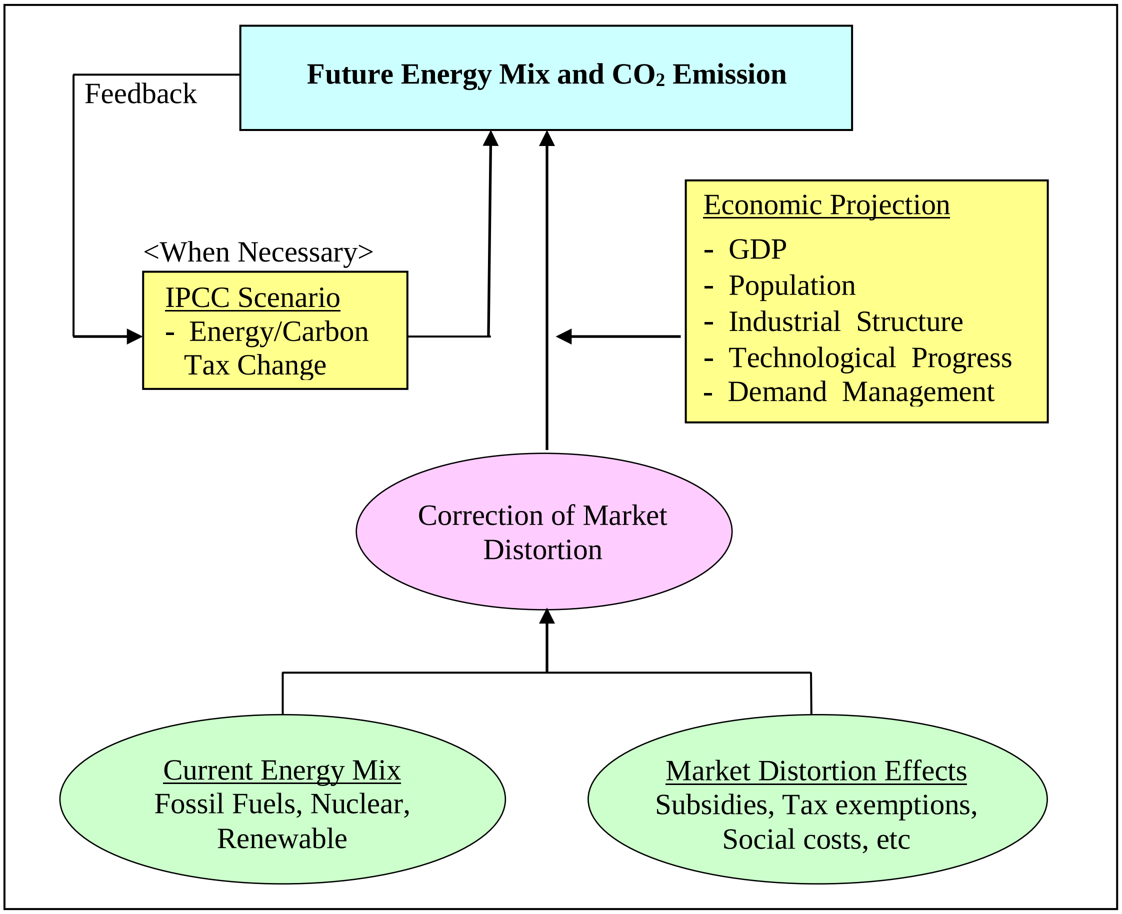

Figure 2-4: Diagram for Analyzing Economic Effects of Energy Policies.

2.3.3 Energy Sustainability from Socio-Political Point

This study classifies the impacts of energy policies on socio-political equity and security into four categories: inter-generation equity, the access of low-income group to energy, balanced regional development, and stable energy supply.

Inter-generation Issue: Assuming that the current generation excessively consumes energy resources that are limited in quantity or seriously deteriorate the environment, future generations' economic and environmental needs will be severely compromised. Though Korea lacks conventional energy resources even for the current generation to consume, it has sufficient renewable energy potential, which is also well-distributed nationwide (MOTIE/KEMCO, 2014; KEEI, 2006: 163-164). In addition, the potential of renewable energy is expected to increase rapidly thanks to the continuous technological development in the future. In this sense, the inter-generational justice is closely connected with the provision of renewable energy in Korea. In this meaning, the issue of inter-generational justice will be excluded, since the promotion of renewable energy can be the solution to inter-generational issue.

Class Issue: The issue of the poor's difficulties in accessing energy is another important social concern. According to the *National Basic Energy Plan*, an energy poverty class – households which consume more than 10 % of their income to get access to energy – is estimated to be 7.8 % of the total households in 2006 (PMO et al., 2008: 59). The government currently plans to help them to escape from this difficulty by 2030. Reflecting the plan of the Korean government, this study will exclude this issue from analysis.

Regional Development Issue: The inter-regional energy imbalance is also important in examining energy sustainability. As mentioned, Korea's energy supply structure is significantly centralized. It is understandable that the urban areas where a large population is living need to be protected from environmental pollution, but still the current energy structure causes serious distortion between energy supply and demand, especially regarding electricity. However, the current energy policies do not aim to rectify this imbalance. The situation is expected to grow even worse, as socio-political decentralization accelerates and the independence and responsibility of local governments grow.

A sustainable energy system can be achieved through "the diversification and localization of energy sources and systems" under the given environmental capacity of each region (Li, 2005). Wang & Byrne et al., in their study on '*Spatially-Integrated Electricity Resource Planning (SIERP)*', show the benefits and strengths of regionally balanced energy development compared with centralized generation system: for instance, the improvement of energy efficiency from supply, T&D, and end-use process, more flexible peak-load management, the development of local-based various energy sources, and the adoption of environmentally-friendly generation methods such as cogeneration, district heating and cooling, fuel substitution, and the use of renewable energy (1995 & n.d.).

Considering these social elements, this study concentrates on the analysis of balanced regional development as a key social consideration for energy sustainability. For this, newly suggested energy policies need to be evaluated whether or not they can contribute to the balanced regional development. First, the study examines how much renewable energy can substitute the role of conventional energy sources, considering their potential and impacts on the environment and economy. Second, the study examines the regional distribution of renewable energy in connection with the potential of the region. Through these processes, this study evaluates the ways of overcoming energy imbalance among regions.

Figure 2-5 shows the basic framework of energy sustainability based on balanced regional development. The development of renewable energy can also contribute to regional economic development by creating job opportunities and additional income for the region.

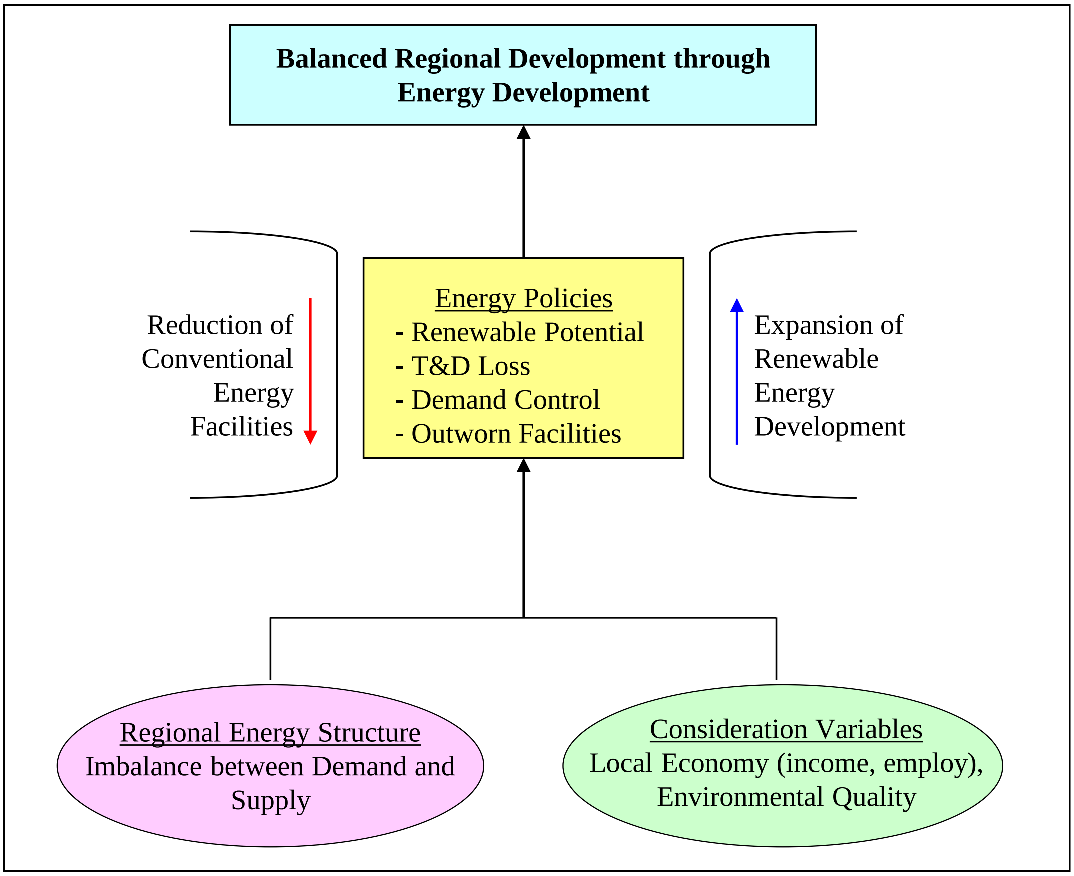

Figure 2-5: Diagram for Developing an Energy System Based on Balanced Regional Development.

Security Issue: Security is also important in energy sustainability. Energy security is greatly affected by the structure of the national energy system including the current amount of energy supply and consumption, the potential of domestic energy resources, the distribution of international energy resources[16], the dependence on

[16] 62 % of globally proved oil reserves are found in the Middle East. OECD countries' reserves account for only 7 % of the world total, despite their 60 % consumption (IEA, 2007: 36).

overseas energy, the overall possibility of energy depletion[17], the stability of energy supply, the change in energy prices, and the substitutability of energy sources, etc. (IEA, 2007: 33-34; BP, 2007; Yergin, 2006; Lee, 2013; WEC, 2013).

Energy security issue can be largely looked at from two perspectives. One is the physical stability which is linked to the amount of energy secured; for example, the security of stable suppliers, the preparedness of energy storage against emergency, the stability of energy transportation routes, and the stability of energy supply system against terrorism, wars and other political disturbances. The other is the price stability which is affected by the rapid fluctuation of energy price like the current oil price, and the capacity or vulnerability of the economy system on energy fluctuations. The IEA evaluates the international energy security using the indexes of ESMC and ESMC*pol*. For each nation, IEA analyzes energy security using the ESI (2007). Gupta designs an OVI by selecting seven indicators based on market risk and supply risk (2008). Based on these researches, this study evaluates how the energy security level changes by scenarios, using the indicators on international market share of each fuel, political stability, and the economic share of each fuel.

2.3.4 Synthesis of Energy Sustainability

Summing up, sustainable energy system can be described as one that combines the existing centralized energy system with new decentralized renewable energy system, within the capacity of ecosystem, minimizing global climate change impacts, sustaining economic soundness and competitiveness, and securing social justice, equity and security, as shown in Table 2-3.

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[17] The reserve to production (R/P) ratios of fossil fuels are 52.5 for oil, 54.1 for natural gas, and 110 for coal (BP. 2015: 6, 20, 30).

Table 2-3: Framework for Sustainable Energy System

Energy Sustainability

Environment	**1. Climate Change** □ Global GHG reduction targets □ Conventional energy vs. Renewable energy **2. Other Environmental Issues** □ Environmental pollution related with energy □ Nuclear Issues: NPT, radioactive accidents, etc
Economy	**1. Fuel Substitution** □ Domestic Anthracite vs. Natural gas **2. Energy Saving** □ Reduction of energy service necessity □ Energy efficiency improvement **3. Price competitiveness between energy sources** □ Internalization of external social costs □ Technological advancement
Socio-Politics	**1. Balanced regional development** □ Regional renewable energy potentials □ Class issues, alienation, and social barriers **2. Energy Security** □ Political stability □ Dependency on overseas energy

For this, sustainable energy system should satisfy the requirements of environment, economy and socio-political system. Therefore, sustainable energy system should meet the recommendation of the IPCC to control the global warming within 2 ℃, while preserving environment, sustaining the prospected economic development, and securing balanced regional development, social justice and national security, as shown in Table 2-4.

Table 2-4: Goals, Indicators, and Targets of Sustainable Energy System

	Conceptual Goals	Indicators	Targets
Environment	- To alleviate dangerous anthropogenic interference with climate change by stabilizing GHG concentration - Environmental pollution control	- GHG emission amounts - Air pollution management	- IPCC's recommendation to prevent excessive climate change (3.3 t_CO_2 based on 1990) - Air pollution management through internalizing the social costs of energy
Economy	- Not to cause serious damages to economic development or to improve energy-related economic condition	- Weight of energy import to GDP or GNP - Change of energy service price	- Sustaining the prospected development by coordinating energy supply and price
Society	- To improve social equity through balanced regional energy distribution and securing energy supply	- Regional energy production and consumption - Energy security index	- Balancing regional electricity supply and demand - Improving energy independence by increasing domestic energy weight

As reference, the meaning of 'sustainable energy system' also includes being 'more sustainable' in this study. That means, the increase in domestic energy production or the decrease of energy import cannot be evaluated absolutely in itself, but be estimated relatively by using the comparatives meaning such as 'better' or 'more' meanings. It also means that each country should do the best to reduce GHG emissions, even though it cannot meet the required target, based on the recommendation of the IPCC and in consideration of international justice.

Chapter 3

OVERVIEW OF ENERGY AND CLIMATE CHANGE POLICIES AND RESEARCH

During the last half century, Korea has achieved startling economic growth from the ruins of war, to become the world's 12th largest economic power. Korea's economic achievement was in tandem with the aggressive promotion of heavy and chemical industries and export-oriented policies. Economic growth led by energy intensive industries, however, has left the Korean economy heavily dependent on conventional foreign energy and, thereby, the energy system unsustainable.

In this section, this study examines Korea's energy situations and critically reviews the government's energy and climate change policies, related researches, and policy suggestions.

3.1 Korea's Energy Situations

3.1.1 Energy Supply and Consumption

Korea has a small portion of domestic conventional energy. As shown in Table 3-1, the share of internal production in TPES is 16.5 % in 2014. However, the actual portion of internal energy is less than 5.0 % because uranium, the fuel for nuclear power generation which takes up 11.7 % of TPES, is fully imported. In addition, considerable amounts of materials which usually end up as waste[18] are being

[18] Waste constitutes 76 % of new and renewable energy in 2006, and 68 % in 2012 (KEMC, 2007: 9; MOTIE, 2014b: 5).

imported or produced with imported materials. While Korea discovered natural gas reserve in the Donghae-1 gas field (KNOC, 2014), the amount is so insignificant, raising the share of domestic energy in TPES only by 0.11 % in 2014.

Table 3-1: Korea's Energy Balance in 2014

(Unit: thousand toe[19])

Category	Total	Coal	Oil	Natural gas	Hydro	Nuclear	NRE
Domestic Production	46,716	787	-	322	1,650	33,002	10,956
Import	309,511	80,460	180,663	48,388	-	-	-
Export	- 62,301	-	- 62,301	-	-	-	-
Others[1]	- 10,988	3,365	- 13,418	937	-	-	-
TPES	282,938	84,612	104,944	47,773	1,650	33,002	10,956

Note: 1. NRE means new and renewable energy. It includes solar thermal, PV, wind power, ocean energy, geothermal, bio-mass, waste energy, and fuel cells. The unit conversion factors from 'toe' to 'MWh' are 4.67 for PV, 4.74 for wind power and ocean energy, and 4.73 for fuel cells.
2. 'Others' means international bunkering, change of stock, and statistical errors.
Source: MOTIE & KEEI (Yearbook of Energy Statistics, 2015: 125, 127, 343)

Oil is by far the dominant energy source. It constitutes 37.1 % of TPES and 58.4 % of total energy imported[20]. Main suppliers of oil are the Middle East countries, which provide 85.1 % of total oil in 2012 (MOTIE/KEEI, 2013: 80-8). As shown in

[19] The term 'toe' means 'ton of oil equivalent', which amounts to 10^7 Kcal as a thermal value.

[20] If nuclear energy is included, the portion of oil falls into 52.7 % of the total energy imported.

Table 3-1, ‘new and renewable energy’[21] takes the largest share among domestic energy sources, except for nuclear energy. However, it only accounts for 3.9 % of TPES. The domestic coal, which once amounted to more than 23.7 million ton in 1987, rapidly reduced to 1.6 million ton in 2014 (MOTIE/KEEI, 2015: 10).

Figure 3-1 shows the energy transformation process that flows from primary energy to final energy by sector. According to Figure 3-1, the power generation sector consumes 107.6 Mtoe or 38.0 % of primary energy to produce 44.9 Mtoe of electricity[22] and 1.0 Mtoe of heat. To produce 0.6 Mtoe of heat[23], 3.3 Mtoe of oil, LNG and natural gas are consumed. The gas manufacturing sector consumes 23.8 Mtoe to produce 23.2 Mtoe of city gas. In sum, 282.9 Mtoe of primary energy is reduced to 213.9 Mtoe, out of the total final energy, through energy transformation process. This means that 69.0 Mtoe (24.4 %) of primary energy is being wasted or internally used during energy transformation processes. In relation, the electricity which is generated from new and renewable energy sources but does not sold to Korea Power Exchange (KPX) is included in the category of ‘NRE’, not the category of ‘electricity’ as TFC in Figure 3-1.

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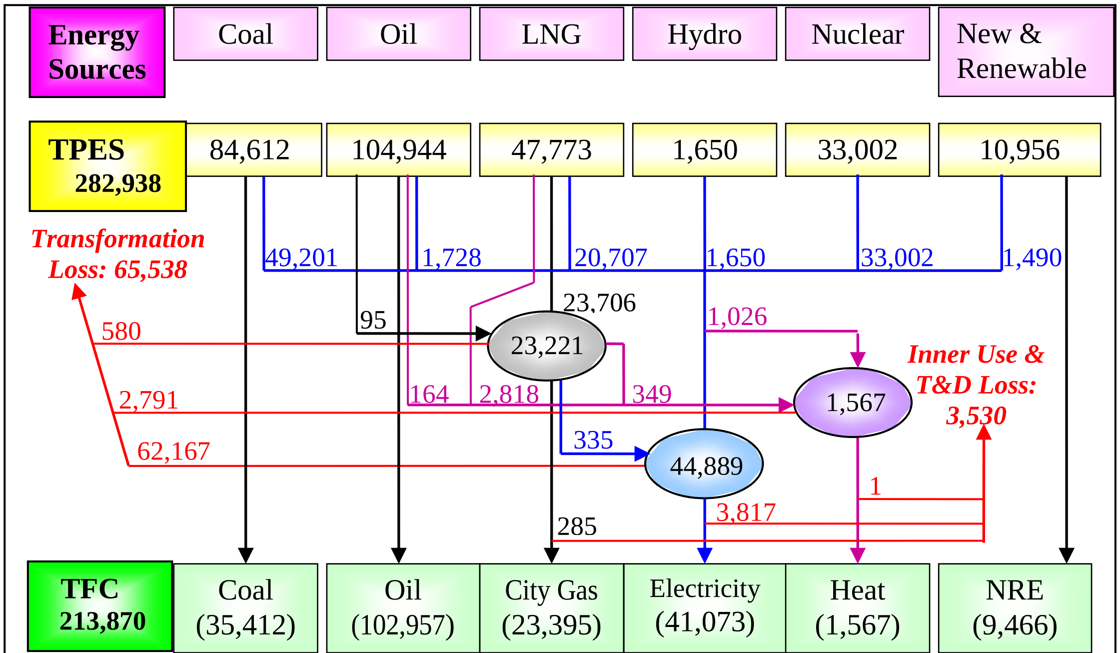
[21] The *Act on the Development, Use, and Propagation of the New and Renewable Energy* defines *new and renewable energy* as solar, bio-mass, wind, hydro, fuel cell, coal gasification and liquidation, heavy oil residue gasification, ocean energy, waste energy, geothermal, hydrogen energy, and others which are prescribed by the Presidential Order (Ministry of Government Legislation, 2015).

[22] Since 3.8 million toe of electricity is being consumed within power plants or wasted as T&D loss, the electricity supplied to consumers reduces into 41.1 million toe.

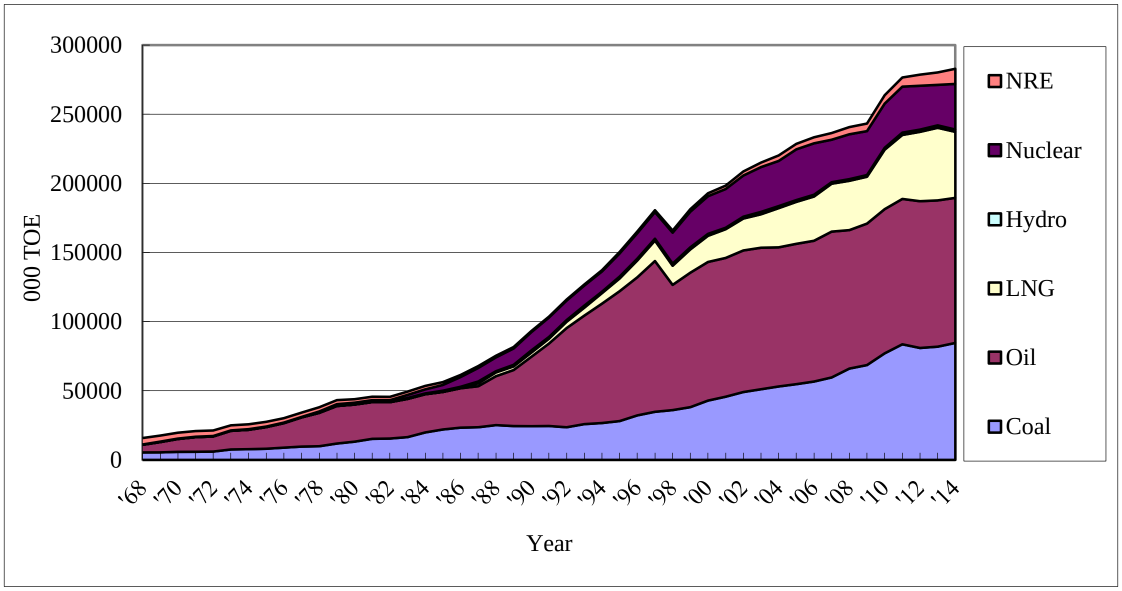
[23] According to ‘*2015 Yearbook of Energy Statistics* (MOTIE/KEEI, 2015)’, 3.3Mtoe of energy is consumed to produce 0.54 Mtoe of heat, except 1.03 Mtoe of heat produced in the process of electricity generation.



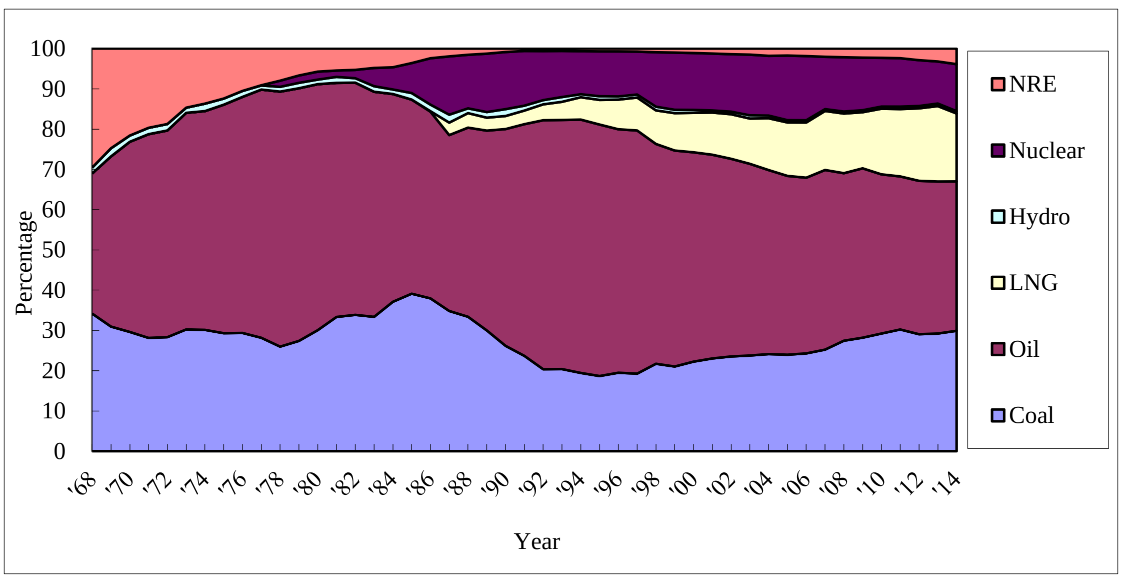
Industry	34,666	61,188	9,404	22,757	-	8,070
Transportation	-	35,761	1,307	172	-	388
Resi/Comm	745	4,701	12,600	15,706	1,528	197
Public	-	1,306	85	2,438	38	813

Figure 3-1: Energy Supply and Consumption in Korea in 2012.
Source: MOTIE & KEEI (2015: 342-343) (Unit: 1000toe)

The industrial sector, especially the manufacturing subsector, consumes the majority of final energy. The industrial sector consumes 136.1 Mtoe (63.6 %) of final energy and the manufacturing subsector 118.8 Mtoe (55.6 %); the transportation sector 37.6 Mtoe (17.6 %); the residential and commercial sectors 35.5 Mtoe (16.6 %); and the public sector 4.7 Mtoe (2.2 %). Figure 3-2 shows the trends of energy consumption by source during the recent 46 years. Figure 3-2 (a) shows that the growth rate of energy consumption has been falling continuously, even though its absolute consumption has continued to increase, except for the year of 1998 when Korea was hit by the financial crises and could not help being aided by the IMF though financial support and its supervision.



(a) Absolute Change of Primary Energy Consumption by Fuel



(b) Relative Change of Energy Constitution among Fuels

Figure 3-2**:** TPES Trends between 1968 and 2012.
Sources: MOTIE/KEEI (2014)

Of energy sources, oil consumption has increased rapidly during the period of 1988-1998, which has been gradually decreasing ever since; coal and nuclear energy have steadily increased for last 20 years; LNG and renewable energy have been increasing rapidly until present. Figure 3-2 (b) shows the decrease of traditional bio-mass like wood and the increase of new renewable energy such as waste, wind and PV.

3.1.2 Energy Related Issues in Korea

Many economic indicators show Korea's excessive addiction to conventional energy. The annual increase rate of energy consumption had been greater than that of GDP for a long time, especially during the 1990s. Even though the annual increase rate of per capita energy consumption has rapidly decreased after 2000, per capita energy consumption has increased continually, attaining to 5.61 toe in 2014 from 1.15 toe in 1980. Energy productivity, on the other hand, has not shown a rapid increase but just deteriorated during the 1990s.

Table 3-2: Trends of Energy-related Major Indicators of Korea

Category	1980	1990	2000	2014	Annual Increase Rate (%)		
					'80-'90	'90-'00	'00-'14
GDP (KRW trillion, 2010)	160.1	406.3	820.7	1426.6	9.8	7.3	4.0
Population (million)	38.1	42.9	47.0	50.4	1.2	0.9	0.5
TPES (Mtoe)	43.9	93.2	192.9	282.9	7.8	7.5	2.8
Per Capita Energy Consumption (toe)	1.15	2.17	4.10	5.61	6.6	6.6	2.3
GDP/Energy (KRW million/toe)	3.646	4.360	4.255	5.042	1.8	-0.2	1.2
Energy/GDP Elasticity	-	-	-	-	0.80	1.04	0.69

Source: MOTIE/KEEI (2014)

Energy consumption is the most important causes of air pollution. Despite the increase in energy consumption, air pollutants such as SOx, CO and Pb began to decrease considerably. They were major issues of air pollution when pollution reduction technologies were not developed yet. Their remarkable decrease was made possible with the implementation of preventive and end-use technologies as well as the application of reduction policies, including supply of low sulfur-contained oil and non-lead gasoline, distribution of three-way-catalysts, and control of coal burning in urban area. However, NOx, VOC and PM10 have not decreased yet, causing air pollution such as acid rain and photochemical smog. According to NIER, ozone alerts were issued 52 times in 2000 as the hourly mean ozone concentration reaches 0.12 ppm or more; 84 times in 2005; 83 times in 2010; 129 times in 2014 (2015b). The maximum ozone concentration has also shown the upward trend.

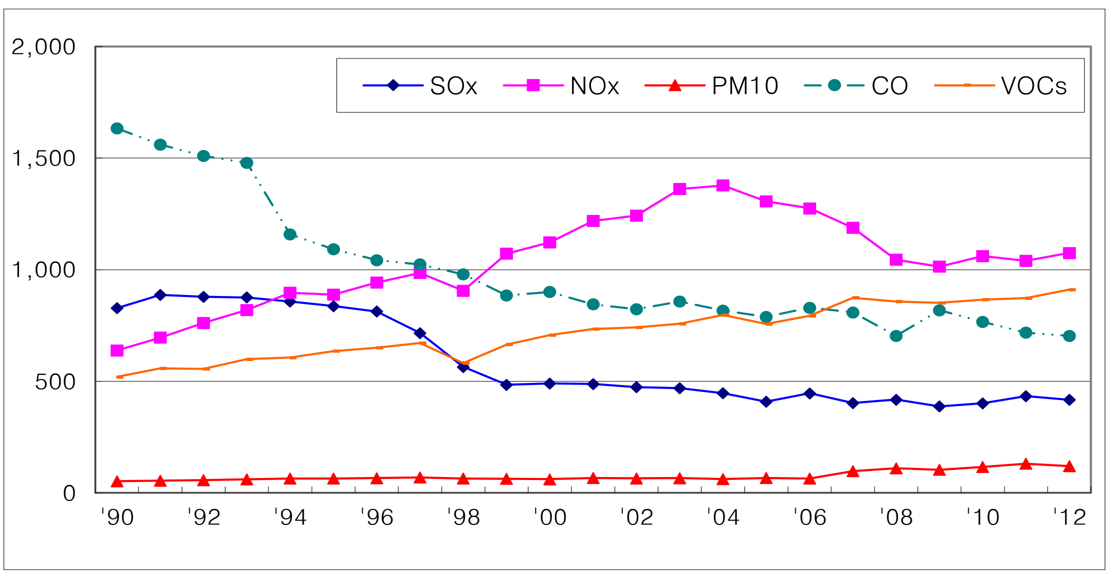


Figure 3-3**:** Air Pollutants Emissions Trends in Korea.
Note: The Unit of air pollutants is a thousand ton per year.
Source: NIER (2015a)

As energy consumption increased rapidly, so did GHG emissions. Current GHG emissions in Korea are known to be remarkable in the world and even among OECD countries, as shown in Figure 3-4. According to IEA, Korea's per capita energy consumption amounts to 5.27 toe in 2012, while that of OECD is 4.19 toe on average and 1.90 toe globally. Moreover, Korea's per capita energy consumption is 11.86 t_CO_2, while that of OECD is 9.68 t_CO_2 on average and 4.19 t_CO_2 globally (2015a).

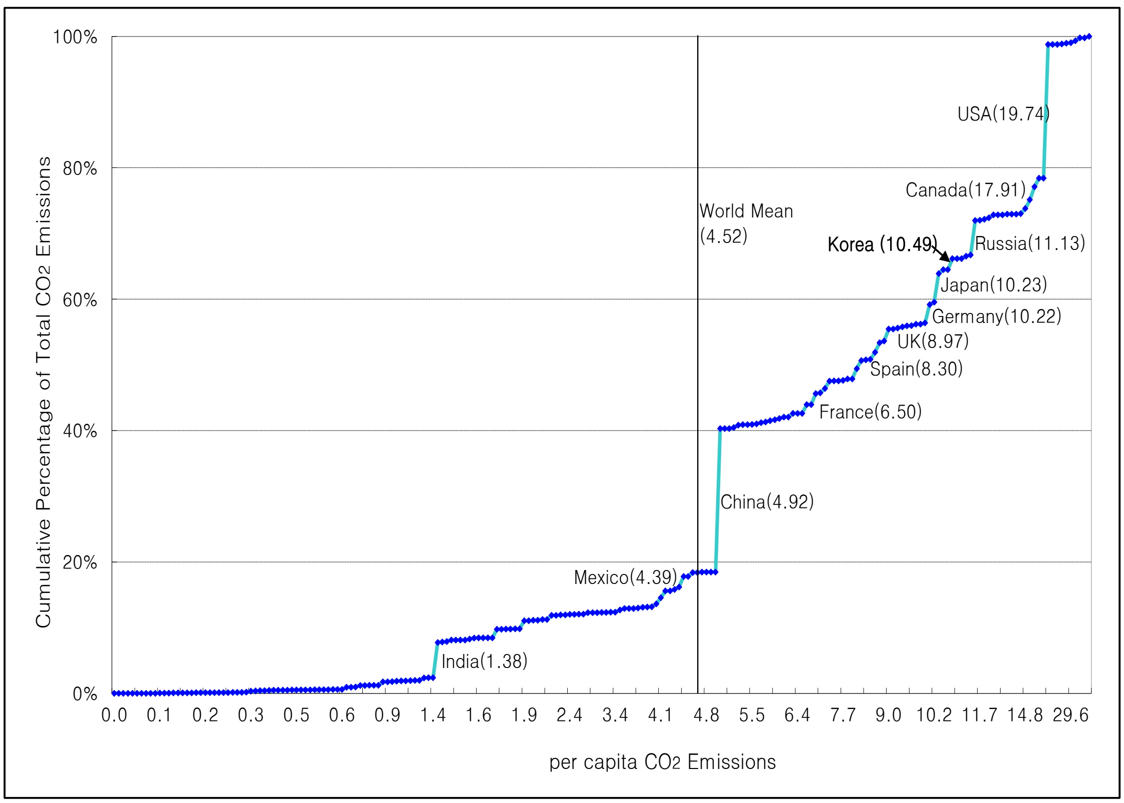


Figure 3-4: Cumulative Comparisons of CO_2 Emissions of Each Country Based on per Capita CO_2 Emissions.
Note: The number in parentheses means the per capita CO_2 emissions of each country in 2007.
Source: United Nations Statistics Division (2010)

Energy consumption also incurs social costs. Although not reflected in the current pricing system, social costs generated by energy consumption are significant. According to Kang et al., members of KEI, the overall social costs caused by energy consumption amount to KRW 67,485 billion or USD 58.9 billion in 2004, as shown in Table 3-3 (2007: 75-86). Even though Kang et al.'s analysis is rather conservative as it does not reflect the costs from water pollution and waste problems, it shows that overall social costs of fossil fuels are substantial.

Table 3-3: External Social Costs Caused by the Energy Sector in 2004

(Unit: KRW billion (USD billion))

Criteria	Sum	Air Pollutants	CO_2
Total	67,485.0 (58.9)	46,992.2 (41.0)	20,492.8 (17.9)
Electricity Sector	17.727.1 (15.5)	12, 849.6 (11.2)	4,877.5 (4.3)
Other Energy Sector	49,757.9 (43.5)	34,142.6 (29.8)	15, 615.3 (13.6)

Note: 1.The considered air pollutants are CO, NOx, SOx, PM, and VOC.

2.The annual social costs from air pollution are calculated by adopting EU's estimates on pollution cost per unit air pollutant – PM 243,972 KRW/kg, SOx 44,347, NOx 7,813, VOC 7,208 – and that of KAIST in the case of CO – 7,276 KRW/kg.

3. The annual social costs from CO_2 are calculated by adopting the analysis of Antonio Volpin and the Cambridge Econometrics who estimated the average price of carbon dioxide trade permit in EU for 2008-2012, 31,855 KRW/t_CO_2 or Euro 25.

Sources: Kang et al. (2007: 80-82)

In addition to environmental problems, energy consumption causes unbalanced regional development. Figure 3-5 shows the imbalance between electricity production and consumption by region in 2012; the positive values are net surplus compared with their consumption, while negative values are the portion supplied from other regions.

The figure shows that the ten regions generate less electricity than their consumption, and six of them produce less than 10 % of their consumption. Only six regions are net suppliers for other regions, which means that coal-fired and nuclear power plants are concentrated in these regions.

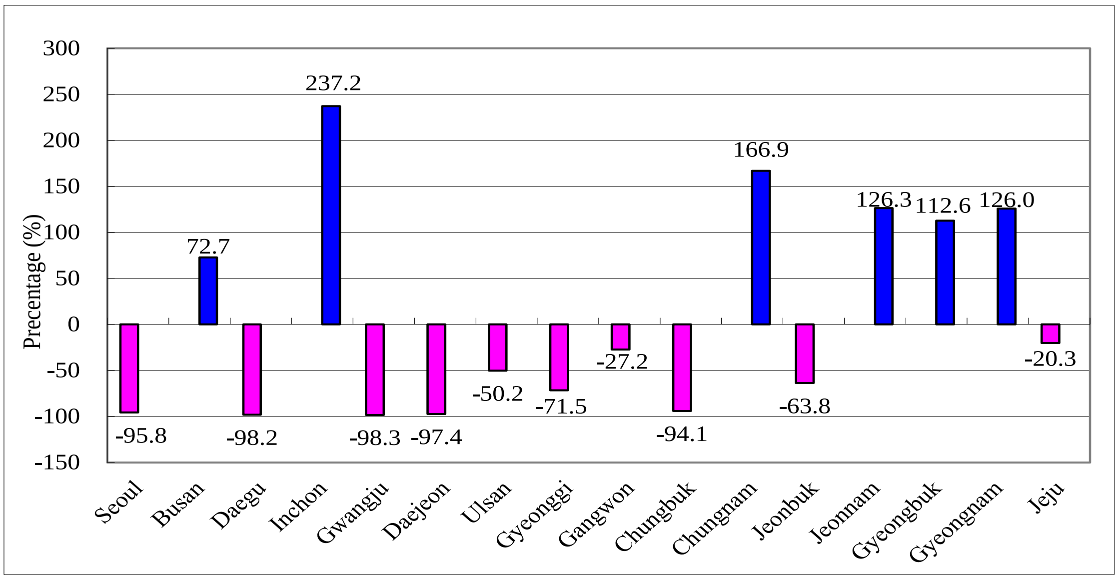


Figure 3-5: Net Electricity Production (+) and Consumption (-) Rate by Region.
Source: Hyundai Research Institute (2013)

Regional energy imbalance can cause social inequality among regions: while cities enjoy the benefits of clean energy, rural areas with large-scale power plants have to endure more environmental burdens and less development. This is proven by the frequent protests and demonstrations against coal-fired and nuclear power plants and the construction of high voltage transmission lines. Such imbalance is expected to get intensified, because the Korean government plans to construct additional large-scale power plants to those same rural areas where power plants have already been built or under operation, instead of energy consuming regions.

3.2 National Energy and Climate Change Policies

In Korea, MOTIE is the main body responsible for energy change related policies, even though the implementation of policies like *Comprehensive Countermeasure for the Convention on Climate Change (CCCCC)* has been led by inter-governmental committees or other authorities[24]. Hitherto, MOTIE has carried out major energy and climate change researches and related policies in cooperation with its research agency, KEEI, and its public enterprise, KEPCO. The basic structure of energy plans and policies is shown in Figure 3-6.

This study examines several policies, especially those considered as major energy and climate change policies, including the *First National Basic Energy Plan: 2008~2030* (PMO et al., 2008), the *Second National Basic Energy Plan: 2015~2035* (MOTIE, 2014a), the *Plan for Setting Post-2020 GHG Reduction Goals* or *the INDC Plan* (PMO et al., 2015), *the Basic Plans on Developing and Disseminating New and Renewable Energy* (MOCIE, 2003 & 2008) and the *White Paper for New and Renewable Energy* (MOCIE/KEEI, 2006), and the seven *Basic Plans for Electricity Supply and Demand* which have been established at two or three year intervals (MOCIE, 2000, 2004, 2006a, 2008; MKE, 2010, 2013; MOTIE, 2015), and the *third CCCCC* (Inter-governmental Committee on the UNFCCC of Korea, 2005).

[24] Policies on climate changes are largely implemented by two authorities in Korea: MOTIE and the Ministry of Environment (or ME). ME is mainly in charge of GHG monitoring and statistics, international climate negotiations, CO_2 emissions from vehicles, GHG emissions from non-energy related sources, etc. Other Ministries are partly in charge of climate change policies related to their responsibilities such as agriculture, forest, and R&D for technological development. However, major energy policies have been suggested and established by MOTIE.

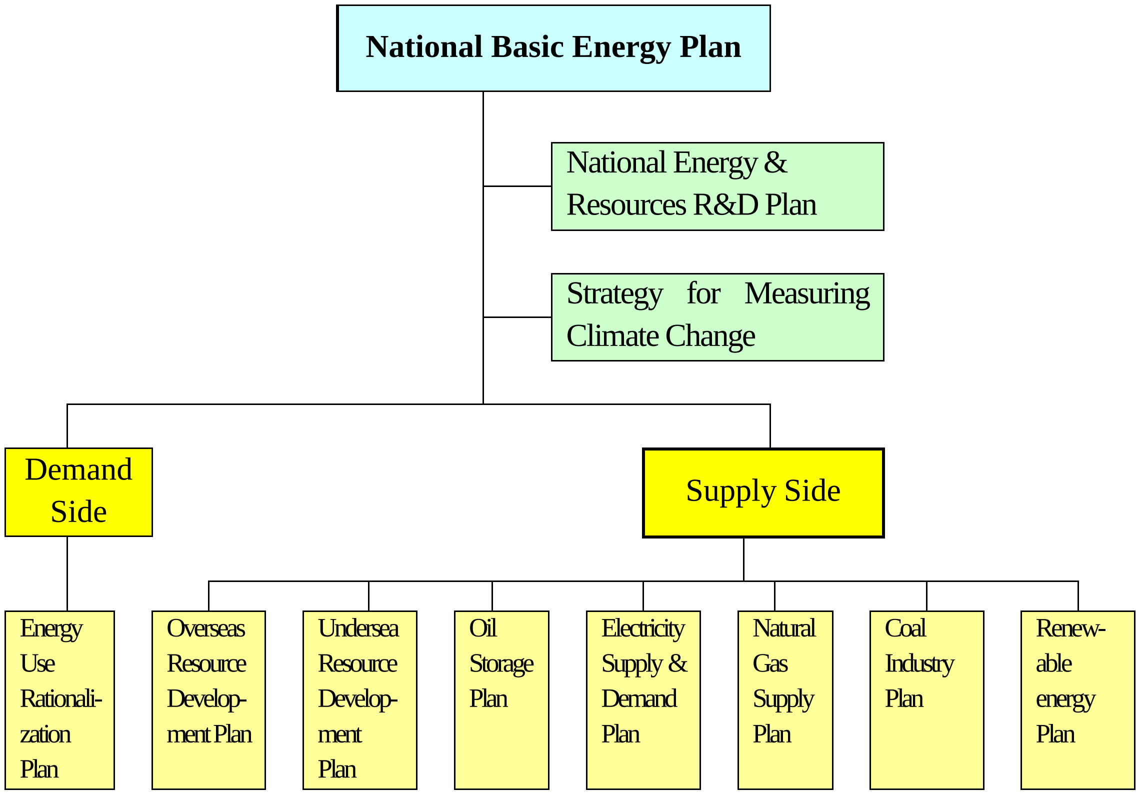


Figure 3-6: National Energy Plans Diagram.
Sources (PMO et al., 2008: 5)

3.2.1 National Basic Energy Plans (2008 & 2014)

The National Basic Energy Plan is comprehensive in nature, dealing with the whole energy sectors and sources. *The Plan* indicates long-term national energy philosophies, visions and goals. *The First Energy Plan* was announced in August 2008, and *the Second Plan* in January 2014. These plans set the directions for Korea's energy policies over the next 20 years. By 2000, Korea's main interest was to supply cheap energy in a stable manner. Beyond 2000, Korea has begun to reform its energy system to be more market-friendly. With the introduction of *the First Plan*, Korea began to reflect 3Es – energy security, economic efficiency and environmental protection. *The Second Plan* has further consolidated the importance of 3Es by focusing on energy demand policies, distributive electricity system and GHG reduction technologies.

In *the Second Plan*, MOTIE presents the BaU prospect by 2035 as follows: TPES will be 377.9 Mtoe from 275.7 in 2011; final energy 254.1 Mtoe from 205.9; and energy intensity 0.180 toe/million KRW from 0.255 (MOTIE, 2014a). The shadowed column in Table 3-4 represents the energy-related prospect by source and sector in 2035. The second BaU scenario is developed assuming that the society would be more energy intensive than the first one. For example, the second BaU scenario forecasts the electricity consumption in 2030 to be 762 TWh, while the first one predicts it to be 585TWh (PMO et al., 2008; MOTIE, 2014a).

Based on these scenarios, MOTIE[25] plans to reduce 13 % of final energy (254 → 221 Mtoe) and 15 % of electricity consumption (70 → 60 Mtoe) by 2035 (2014: 23, 36, 39). In relation to nuclear power, *the Second Plan* seeks to cut down its weight to 29 % (43 GW), while the First Plan projected 41% based on the capacity of power plants.

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25 Compared with *the First Plan*, the second one failed to adjust, converge and meet all ministries' opinions, especially the opinion of Ministry of Environment. Therefore, it was announced under the name of MOTIE, while *the First Plan* was announced under the names of PMO et al.

Table 3-4: MOTIE's 2014 BaU Scenario on TPES, Final Energy, and Sectoral Demand by 2035

(Unit: Mtoe)

Category		2011	2025	2030	2035	Annual increase rate (%)
TPES	**Sum**	**275.7**	**354.1**	**369.9**	**377.9**	**1.32**
	Coal	83.6	100.2	107.7	112.4	1.24
	Oil	105.1	111.0	107.1	101.5	-0.15
	Natural Gas	46.3	64.8	69.8	73.3	1.93
	Hydro	1.7	1.7	1.9	2.0	0.70
	Nuclear	32.3	59.6	65.3	70.0	3.28
	New/Renewable	6.6	16.8	18.0	18.8	4.44
Final Energy	**Sum**	**205.9**	**248.7**	**254.3**	**254.1**	**0.88**
	Coal	33.5	37.4	38.8	38.6	0.58
	Oil	102.0	109.1	105.1	99.3	-0.11
	City Gas	23.7	32.5	34.4	35.3	1.68
	Electricity	39.1	59.7	65.6	70.2	2.47
	Heat	1.7	2.9	3.1	3.3	2.82
	New/Renewable	5.8	7.1	7.4	7.4	1.01
Sectoral Demand	**Sum**	**205.9**	**248.7**	**254.3**	**254.1**	**0.88**
	Industry	126.9	151.6	152.3	148.4	0.66
	Transportation	36.9	44.0	45.5	46.5	0.97
	Residence	21.6	24.2	24.6	24.9	0.59
	Commercial	15.9	23.6	26.0	28.1	2.39
	Public/Others	4.6	5.4	5.8	6.2	1.31

Sources (MOTIE, 2014: 35-36)

Table 3-5: Five Visions of the First National Basic Energy Plan

Visions	Indicators	2006	2030
Improving Energy Independence	Direct exploration of Overseas Energy	3.2 %	40 %
	New/Renewable Energy	2.2 %	11 %
Construction of Low Energy Consumption Society	Energy Intensity (toe/USD thousand)	0.341	0.185
Less Oil Dependence	Oil Dependence	43.6 %	33 %
Improving Energy Accessibility	Energy Poverty	7.8 %	0 %
Green Energy Industry Support	Technology Level Compared with Developed Countries	60 %	90 %

Sources (PMO et al., 2008)

The difference between the two plans is that while *the First Plan* puts forward concrete visions, as shown in Table 3-5, the second one just shows the policy directions. *The second plan* suggests six major objectives to accomplish its goals as follows:

- To reduce 15 % of electricity demand, the plan projects to adjust the energy tax rate to narrow the relative difference among energy sources, improve electricity charge system, and establish demand management system based on ICT.

- The plan projects to increase the weight of a distributive generating system to 15 %. The plan projects to establish power plants under the lock-in of a transmitting system from existing plant-first policies, and enlarge group of energy facilities, independent power suppliers and new and renewable energy facilities.

- To address climate change issues, the plan projects to apply the latest GHGs reduction technologies and enlarge the weight of nuclear power.

- To strengthen energy security and secure stable supply, the plan projects to develop direct overseas energy resources and expand the share of new and renewable energy to 11 % of TPES by 2035, which was the goal of *the First Plan* by 2030.

- The plan projects to secure energy import by diversifying suppliers and build internal capacity to stockpile energy.

- To remove energy-poor class, the plan projects to strengthen energy well-being system by introducing new policies including Energy Boucher System.

3.2.2 Plan for Setting Post-2020 GHGs Reduction Goal (2015)

Following the Lima Decision of COP 20 in 2014, which invited each country to prepare its INDC including the reduction target for post-2020 and submit it by September 2015 to the UNCCC Secretariat, the Korean government confirmed to reduce 37 % of GHG compared with BaU Scenario based on the *Second National Basic Energy Plan* (MOTIE, 2014a) – 25.7 % reduction from domestic activities and 11.3 % reduction through purchasing international-based emission certificate.

The INDC Plan forecasts 3.08 % GDP growth on average, 0.23 % increase in population, and 1.28 % increase of oil price per annum during 2012 and 2030. Based on such prediction, the government forecasts that Korea will consume 254.4 Mtoe of final energy and 369.9 Mtoe of TPES in 2030. The projected GHG emissions amount to 850.6 Mt_CO_2 – 738.9 Mt_CO_2 from the energy sector and 111.7Mt_CO_2 from the non-energy sector, with the average annual increase rate of 1.33 %. Based on this BaU scenario, the government examines four different alternatives which would reduce GHG emissions to 14.7 %, 19.2 %, 25.7 %, and 31.3 % respectively, as shown in Table 3-6. However, the government does not provide any additional information such as the concrete methodologies and the reduction scale of TPES for extracting GHG emissions.

Table 3-6: Korea’s Four Alternatives in *the INDC Plan*

Category		BaU	The 1st Alternative	The 2nd Alternative	The 3rd Alternative	The 4th Alternative
GHG Emissions (Mtoe)		850.6	726	688	632	585
Emission Level	Against BaU	0 %	-14.7 %	-19.2 %	-25.7 %	-31.3 %
	Against 2012	23.6 %	5.5 %	0 %	-8.1 %	-15 %

Sources: PMO et al. (2015: 15)

Despite these four alternatives, the government adopts another alternative, which plans to reduce 37 % of GHG emissions by 2030, in consideration of domestic and international worries and criticisms. Nonetheless, the final decision is evaluated to select more modified option, compared with the 4th alternatives from the point of domestic reduction. Instead of planning to reduce more domestic emissions, the government decides to supplement the deficit by purchasing 11.3 % of international emission certificates.

The INDC Report plans to attain the target by expanding the distribution of new and renewable energy, adopting state-of-the-art technologies in the industrial sector, introducing average mileage system for both car and trucks, distributing LED lights, reducing the share of coal-fired power plants, expanding the share of nuclear power plants, introducing FEMS and BEMS, strengthening the insulation standard, and so on. However, the report does not include concrete methods or instruments for accomplishing the target, except those already being implemented or previously planned.

3.2.3 New and Renewable Energy Technology Development, Use, and Propagation Plans

MOTIE established *the Third Plan for New and Renewable Energy Technology Development, Use, and Propagation (2009~2030)* (hereinafter referred to as '*the Third NRE Plan*') in December 2008 and *the Fourth New and Renewable Energy Basic Plan (2014~2035)* (hereinafter referred to as '*the Fourth NRE Plan*') in September 2014 to facilitate the new and renewable energy production.

In 2014, new and renewable energy constitutes 5.4 % of TPES[26] and the power generated amounts to 2.4 % of total electricity. Energy from waste takes a lion's share, constituting 59.8 % of total new and renewable energy, as shown in Table 3-7.

Table 3-7: Distribution of New and Renewable Energy by Source in 2014

Category	Waste	Bio-mass	Hydro	Photo Voltaic	Wind	Ocean	Geo-Heat	Others
Portion (%)	59.8	24.5	5.0	4.7	2.1	1.1	0.9	1.8

Source: MOTIE/KEEI (2015: 125)

MOTIE plans to raise the share of new and renewable energy to 11 % of TPES and to 13.4 % of total electricity supply by 2035. Compared with *the Third NRE Plan* which aims to attain 7.7 % of electricity by 2030, *the Fourth* has more ambitious goal. However, *the Fourth* as a whole is evaluated to be less progressive: *the Fourth NRE*

[26] There is a difference between statistics in MOTIE/KEEI (2015): statistics for renewable energy (page 125) include hydro power in the category of renewable energy, while statistics for whole energy (page 342-343) do not include the large hydro power.

Plan projects to supply 11 % of TPES with new and renewable energy by 2035, which is the same goal of *the Third NRE Plan* in 2030; the time for accomplishing 10 % of TPES was adjusted from the year of 2022 to 2024 in *the Fourth NRE Plan*.

Major policies to promote new and renewable energy are to give strong support to three new and renewable energy sources[27] – wind, photovoltaic (PV), and hydrogen & fuel cell – and foster them as globally competitive industries, construct 1 million green homes by 2020, improve legal and tax systems for encouraging private investment and expanding its market share like RPS system, and support technological development. According to *the Third and Fourth NRE Plans*, the target price for power generation are 90 KRW/kWh for PV and 70KRW/kWh for solar heat and small hydro in 2030, and 61KRW/kWh for PV and 63~81KRW for wind in 2035 (MKE, 2008: 20, 22, 25; MOTIE, 2014b: 16).

Even though MOTIE has been trying to introduce and enlarge the provision of new and renewable energy, some policies arouse the worries. MOTIE has removed a Feed-In-Tariff System in 2011 and also has weakened and delayed the RPS by lowering mandatory allotments. MOTIE projects to switch from government-led policies into market-friendly policies to ostensibly enlarge the civil investment in the Fourth NRE Plan (2014b: 5), which is also concerned to retreat the proliferation of new and renewable energy sources, unlike the expectation of the government, since they are not price-competitive yet.

In relation to the new and renewable energy potential, MOTIE published *the 2005 New and Renewable Energy White Paper* in 2006 with KEEI and *the 2014 New*

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[27] Korea's technological levels compared with developed countries were estimated to be 50-70 % at the time of *the 3rd NRE plan* and 86 % at the time of the *4th NRE plan* (MKE, 2008: 5; MOTIE, 2014b: 3).

and Renewable Energy White Paper in 2014 with KEMCO. According to *the 2014 White Paper*, the technical potential of new and renewable energy is estimated at 1,372 Mtoe, which is about 4.9 times greater than the amount of total primary energy supply in 2012 (MOTIE/KEMCO, 2014: 97), which will be examined in more detail in Chapter Four.

3.2.4 Basic Plans for Electricity Supply and Demand

MOTIE establishes electricity demand and supply plans every two or third year, in accordance with *the Electricity Business Act*. The most recent one is the *Seventh Plan for Electricity Supply and Demand* 2015-2029(hereinafter referred to as 'the Seventh Electricity Plan') established in July 2015. According to the plan, electricity demand, which was 485 TWh in 2012, is expected to be 618 TWh in 2020 and 766 TWh in 2029, with a 3.1 % annual increase rate. Maximum power demand is expected to be 102 GW in 2020 and 127 GW in 2029, with 3.1 % annual increase rate (MOTIE, 2915: 15). Under the scenario, the plan looks to reduce 12 % of maximum power demand and 14.3 % of total electricity demand through demand management programs.

Table 3-8 shows the capacity and power generation after the demand control. Electricity demand in 2029 is expected to be 657 TWh with a 2.1 % annual increase rate, and maximum power demand 112 GW with a 2.2 % annual increase rate. The capacity includes 22 % of reserve rate – 15 % of minimum reserve rate and 7 % of demand uncertainty (MOTIE, 2015: 17). The Korean government plans to continuously increase electricity supply from conventional energy such as coal and nuclear, as shown in Table 3-8.

Table 3-8: Electricity Supply Plan during the Period of 2012 and 2029

(Unit: GW, TWh, (%))

Criteria		Total	Nuclear	Coal	LNG + C/C	Oil	Others
2012	Capacity	81.8	20.7	24.5	20.1	4.9	11.6(14.1)
	Generation	484.6	143.5	189.1	112.2	13.4	26.4
2020	Capacity	134.2	26.7	37.6	35.6	3.8	30.5(22.7)
	Generation	588.4					NRE only 50.7 (7.9)
2029	Capacity	163.9	38.3	44.0	33.8	1.2	46.6
	Generation	656.9					NRE only 83.1 (11.7)

Note: 2012 Generation is based on 'net generation'.
Source: KEPCO (2013) and MOTIE (2015: 11, 30)

The electricity consumption in Korea has kept increasing, indebted to the government's low electricity charge policy. The government continues to provide more electricity even after demand management measures, as shown in Figure 3-7.

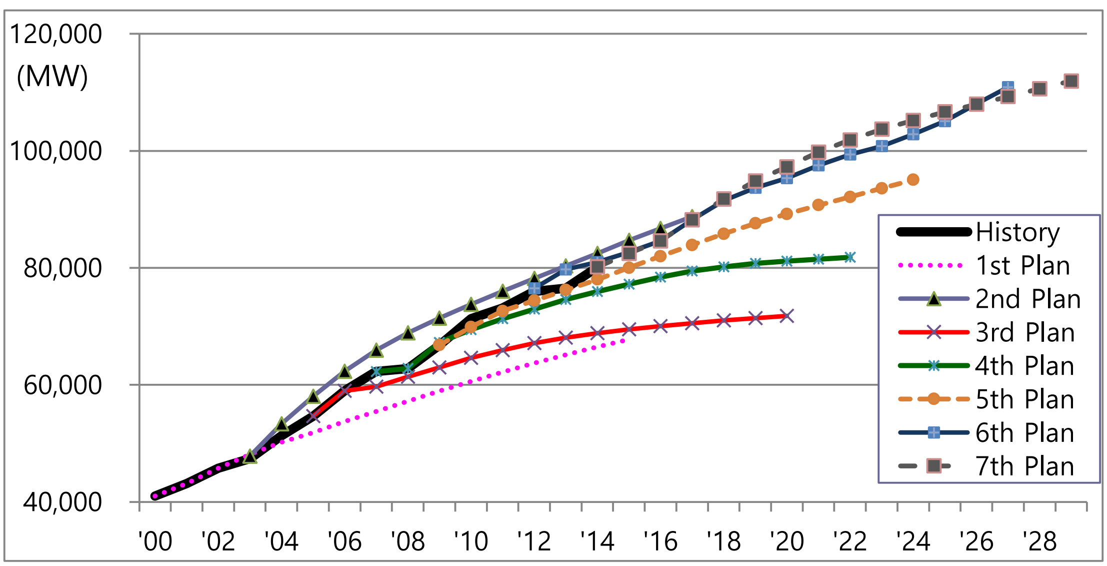

Figure 3-7: Trends of Maximum Electricity Consumption: History and Projection.
Source: MOCIE (2000, 2004, 2006a, 2008), MKE (2010, 2013), MOTIE (2015)

3.2.5 The Third Comprehensive Countermeasures on Climate Change Conventions by the Intergovernmental Committee on the UNFCCC of Korea (2005)

Korea joined the UNFCCC in December 1993 and ratified the Kyoto Protocol in February 2002. In order to fulfill such a global mandate in a more systematic way, Korea establishes an inter-governmental body which is comprised of major ministries and their subsidiary agencies, institutions and corporation, and developed three successive comprehensive countermeasures every three year: the first for 1999-2001, the second for 2002-2004, and the third for 2005-2007. *The Third CCCCC*[28] basically pursues international cooperation on climate change, transformation from a fossil fuels-centered economic system into a low-carbon economic system, and the reduction of negative impacts on public welfare to minimum (Inter-governmental Committee on the UNFCCC of Korea, 2005: 9). Figure 3-8 shows the objectives and basic structures of these measures.

Under these objectives and structures, *the Third CCCCC* includes major projects as follows:

- Projects to construct an infrastructure to measure how the climate change convention is implemented: preparing for making mandatory GHG reduction measures for post-Kyoto regime, establishing statistics and analysis system for GHG and evaluating their reduction potential, R&D on GHG reduction technologies, strengthening education and public campaign, and implementing the Kyoto mechanism such as CDM, and an emission trading system, etc.

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[28] Even being old, the *Third CCCCC* shows well the objectives, directions, and contents of energy and climate change policies. That’s why this study includes the review of this measure.

- Projects to reduce GHG emissions: comprehensive demand management (a voluntary agreement[29] targeting energy-related companies, ESCO[30] projects, and E-TOP program[31], etc), reduction of GHGs from the energy supply sector (the expansion of cogeneration, RPS, green pricing system[32], etc), improvement of energy use efficiency (average fuel mileage, standby-power reduction program, minimum efficiency permit standard, granting certification to high-efficient-equipment, energy efficiency standards & labeling program, etc), energy management in the building sector (strengthening the standard for building insulation by 20 %, granting certification to high efficiency buildings, etc), measures for the transportation sector (efficient freight transport system, electronic toll collecting system, exclusive bus-lane system, artificial intelligence-aided traffic system, tax incentives for no/low pollution vehicles, etc), the environmental sector (expansion of wastewater treatment and livestock manure treatment facilities, power generation using landfill gas, waste recycling, etc), and the agriculture/forestry sector (improving land-use for reducing GHG emissions, developing methane-reducing feed, strengthening forest management, etc).

- Projects to adapt to climate change: establishing monitoring system on climate change and resultant occurrence of natural disasters, strengthening researches and monitoring on the eco-system, and conducting impact analyses on public health caused by climate change, etc.

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[29] The central and local governments contract voluntary agreements with individual companies to reduce energy consumption from the industrial sector.

[30] An energy service company is the one which invests into energy saving facilities on behalf of users and seeks profit from the cost-reduction.

[31] An E-TOP program is the one in which the government favorably supports private companies under the agreement of accomplishing the arranged goal of energy efficiency. If the company fails to attain the goal, the government withdraws the supporting fund.

[32] A Green Pricing System is the one in which the customers voluntarily pay additional cost for green electricity generated from renewable energy sources.

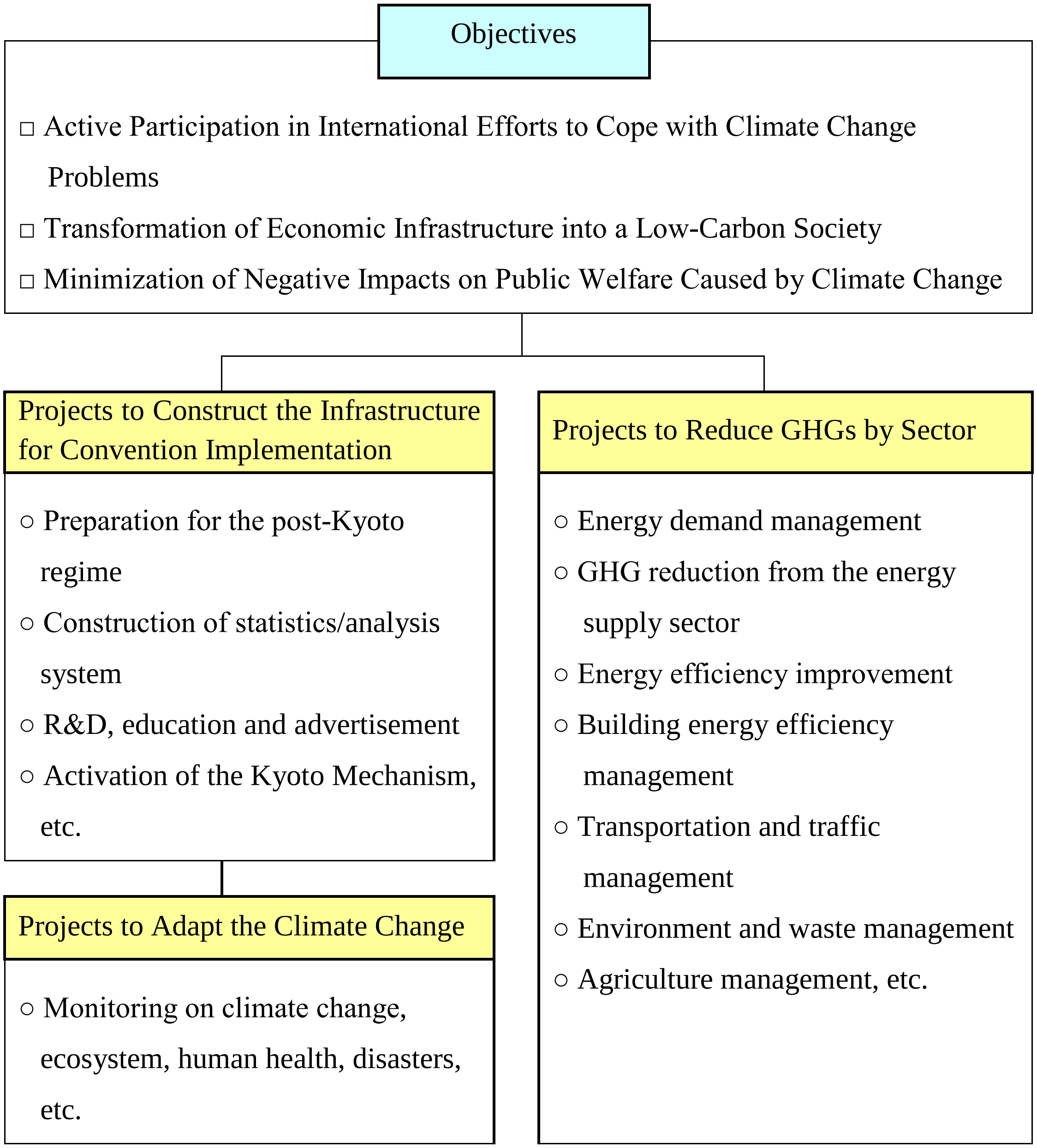

Figure 3-8: Objectives and Basic Structures of *the Third CCCCC*,
Source: Inter-governmental Committee on the UNFCCC of Korea (2005)

3.3 Critical Review on Current Energy System and Policies

As mentioned, the Korea's current energy system is found to have many problems and limitations to be called sustainable. Government's policies, therefore, should focus on building sustainable energy system by expanding the use of renewable energy, improving energy efficiency, strengthening energy security, establishing energy demand management, etc. However, the current policies still have many limitations. Firstly, they do not contribute to environmental improvement; on the contrary, they lead to the continuous increase in the number of coal and nuclear power plants which might deteriorate environmental quality in the future. Secondly, they are insufficient to secure stable energy supply. Since the dependency on imported energy is expected to continue, energy import costs would persistently be a burden on the economy. Thirdly, socio-political instability is likely to continue. The continual dependence on the Middle East oil and the successive construction of large power plants would threaten regional and national security.

3.3.1 Critique on Energy-Related Environmental Issues

As shown in Section 3.1, Korea's energy consumption keeps growing, despite the warning of air pollution and climate change. Table 3-9 shows that Korea's TPES increase rate is higher than the global average, while those of many developed countries have already shown a downward trend.

Table 3-9: Comparison of TPES Increase Rate of Some Selected Countries

Category	Korea	Japan	USA	Germany	World Average
Annual Average Increase rate ('02~'12, %)	2.86	-1.20	-0.52	-0.80	2.59

Source: IEA (2015a)

According to the national plans of Korea, the upward trend of energy consumption is likely to continue even in the future. Both of the *second National Basic Energy Plan* (2014) and the *Seventh Electricity Plan* (2015) estimate successive increase in energy consumption by the target years – 2035 and 2029 respectively. Only *the INDC Plan* (2015) projects to reduce 25.7 % of domestic emissions compared with BaU scenario, which means 8.1 % of absolute decrease compared with the 2012 emissions. Even though *the INDC Plan* presents the GHG reduction target, it does not include any concrete projects on the scale and method of reduction. In addition, the GHG reduction goal by 2030 lacks the characteristics of sustainability: even the challenging *INDC Plan* estimates Korea's GHG emissions to be 632 Mt_CO_2 or 12.11 t_CO_2 per capita in 2030 (PMO et al, 2015) which is 4.5 times higher than the global sustainable goal of 3.3 t_CO_2 per capita based on the 1990 population.

3.3.2 Critique on Energy-Related Economic Issues

Although Korea has accomplished economic growth largely thanks to energy intensive industries, excessive energy consumption will eventually become burden on the national economy. According to the IEA, Korea is among the global top ten countries in terms of conventional energy import: the fifth in crude oil, the fourth in natural gas, the fourth in coal, and the fourth in nuclear[33] (IEA, 2014a: 11-17). This means that Korea is seriously vulnerable to global energy crises or conflicts on both economic and security side.

[33] 'Nuclear' category denotes the amount of electricity from nuclear power plants. 'Nuclear' category is added to Table 3.10 because Korea imports all uranium used for power generation.

Table 3-10: Top Ten Large Energy Importers and Nuclear Producers

Crude Oil (Mt, 2012)		Natural Gas (bcm, 2013)		Coal (Mt, 2013)		Nuclear (TWh, 2012)	
USA	442	Japan	123	China	320	US	801
China	269	Germany	76	Japan	196	France	425
India	185	Italy	62	India	178	Russia	178
Japan	179	**Korea**	53	**Korea**	127	**Korea**	150
Korea	128	China	49	Taiwan	68	Germany	99
Germany	93	Turkey	45	Germany	50	China	97
Italy	74	France	43	UK	49	Canada	95
Spain	60	UK	39	Turkey	28	Ukraine	90
Netherlands	57	USA	27	Malaysia	23	UK	70
France	57	Spain	30	Italy	20	Sweden	64

Source: IEA (2014a: 11-17)

In addition, the share of energy import costs to GDP is 13 %, while that of OECD is around 2 %[34] on average, which can also be interpreted as Korea's economic instability (MOTIE/KEEI, 2015). Korea's energy import rate to GDP is 0.212 (Mtoe/billion 2005 USD) in 2012, while that of Japan whose energy import rate to TPES is similar to Korea is 0.093 (IEA, 2014a: 52). It shows how vulnerable Korea's energy dependency is relative to other countries.

These economic indicators are expected to improve in the future with the increase in GDP and the absolute decrease in energy consumption by 2030 if the expected import price does not change. However, rapid increase in energy price can possibly cause undesirable impacts, which means that Korea's energy system cannot be evaluated as sustainable in respect to economic point, even in the future.

[34] The ratio is estimated based on GDP, net energy import and import prices of Korea.

3.3.3 Critique on Energy-Related Socio-political Issue

The main energy suppliers of Korea are those located in the Middle East[35], which has been politically unstable as witnessed in recent international political issues such as the conflicts between Israel and Arab countries, frequently occurring political and military disturbances, and recurrent terrors by al-Qaeda and ISIS. Dangers exist not only in oil-exporting countries but also on oil transporting routes. The route from the Middle East to Korea is also the very place on which piracies and military threats are frequently reported (Lee, 2008; Yeoh, 2004; Lee, 2013). Figure 3-9 shows the main oil transportation route of Korea.

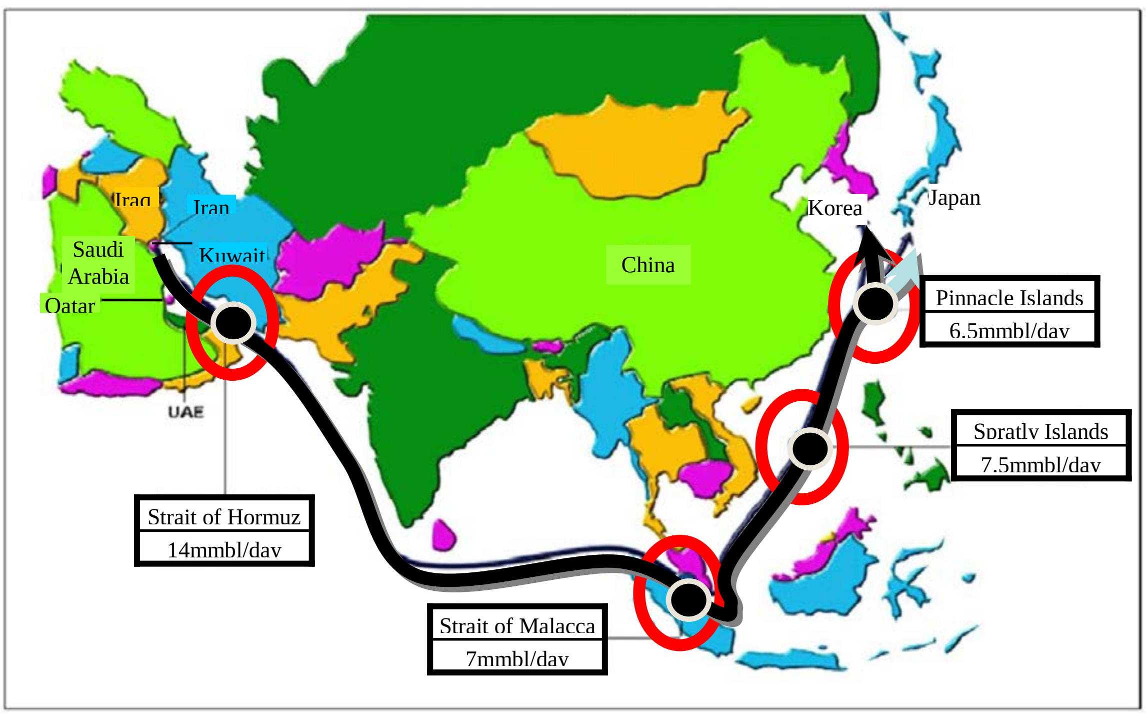

Figure 3-9: Main Oil Transportation Routes of Korea.
Source: Lee (2008)

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35 In 2006, Korea imported 82 % of its oil from the Middle East (PMO et al., 2008).

In addition, Korea faces many artificial and natural disasters. According to the *Seventh Electricity Plan*, the government is planning to establish 45 power plants including 13 nuclear power plants, the capacity of which amounts to 46,487 MW, and close down of 23 facilities with 6,760 MW (MOTIE, 2015:26). The construction and operation of large-scale nuclear power plants is vulnerable to accidents, natural disasters and socio-political threats like terrors and wars. National division and globalization also heighten political instability. Especially, Korea's plan to add 13 nuclear power plants which goes against to the international movements of 'nuclear moratorium' raises concerns in terms of national security.

According to Gupta, who assesses the vulnerability of 26 oil-importing countries using the oil vulnerability index[36] (or OVI), Korea is one of the most vulnerable countries, as shown in Table 3-11. Korea has a high risk from almost every angle; (almost) no domestic oil reserves, heavy oil-dependence on politically unstable Middle East, high oil intensity (0.19 toe/USD thousand, compared with OECD average 0.13: IEA, 2014a), large share of oil import in GDP, and large share of oil in TPES. Korea's energy security ranking estimated by WEC – the 103th among 129 countries – also shows the weakness of its energy system (2013).

[36] Gupta (2008) selects seven indicators based on market and supply risk: oil intensity or OI (oil consumption over GDP (US$2000)), net oil imports (value of oil import) as percentage of GDP or VOM/GDP, GDP per capita, and oil share in total primary energy supply or OS for market risk indicators; ratio of domestic reserves to domestic consumption or DR/DS, geographical oil market concentration risk or GOMCR, and market liquidity or ML (the ratio of world oil imports to the net oil imports of a given country) for supply risk indicators. GOMCR is calculated by combining three oil related indicators – net oil dependence, diversification of oil imports, and political risks based on the International Country Risk Guide (ICRG) risk ratings – with the methods of modified Herfindahl-Hirschman market concentration index.

Table 3-11: Classification of Oil Vulnerability of 26 Countries in 2004

Most Vulnerable (Mean OVI=1.003)	More Vulnerable (Mean OVI=.0.810)	Less Vulnerable (Mean OVI=0.562)	Least Vulnerable (Mean OVI=0.389)
Philippines (1.11) **Korea (0.98)** India (0.93)	Greece (0.89) Czech Republic (0.86) Portugal (0.83) Turkey (0.82) Poland (0.81) Slovak Republic (0.75) Spain (0.70)	China (0.66) Hungary (0.64) Belgium (0.60) Finland (0.56) New Zealand (0.56) Italy (0.55) Netherlands (0.51) Japan (0.49) Ireland (0.49) Switzerland (0.46)	Austria (0.46) France (0.45) Germany (0.44) United States (0.37) Sweden (0.37) Australia (0.24)

Source: Gupta (2008)

Main policies implemented by the Korean government are more aimed at securing physically stable energy supply rather than directly pursuing energy security by reducing fossil fuel dependency and expanding domestic energy supply.

3.3.4 Summary of Critiques

To establish a sustainable energy system is one of the goals of energy policies in Korea. However, it is found that Korea's energy policies include many unsustainable characteristics; for instance, development of makeshift strategies to minimize pressure from the international community, strengthening conventional energy infrastructures for continuous and stable energy supply, and expansion of energy storage facilities in preparation for emergency or crises. From such examples, it can be understood that the government simply interpret the concept of 'energy sustainability' as instrumental just to expand new and renewable energy portion and to improve current system instead of seeking a fundamental change. In addition, these policies do not guide to reduce GHG emissions. For example, recent plans are developed based on the assumption that the future society would become more energy intensive than previous ones. Policies also seem to have a tendency to go backward. In other words, the government plans to construct more coal-fired and nuclear power plants rather than setting an ambitious goal to reduce GHG emissions. The goal to expand new and renewable energy is hard to be considered ambitious either.

In sum, the government seems to understand the concept of 'energy sustainability' as a narrow and passive one and in an inconsistent way, which seems that the government might have used this concept as a slogan to camouflage 'unsustainable' energy policies. The following evaluation of IEA (2007), even though published in 2007, still shows well the limitations of the current energy system and related policies of Korea:

> Perhaps the greatest challenge facing the Korean government regarding its energy policy is the lack of a clear, long-term vision for its energy market. …… the government should establish a comprehensive and co-ordinated energy strategy, and a framework that involves all stakeholders, improves co-ordination across different ministries and government entities, integrates the environmental dimensions of energy consumption into energy policy. …… it has not taken any binding emissions targets under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. …… Air quality in Korea is generally poor in most of its large cities, particularly Seoul, in comparison to other OECD countries. …… The country has relatively low energy efficiency, owing in part to its rapid development and its heavy industrial base, and although declining, energy intensity is expected to remain high. …… The share of new and renewable energy sources in Korea's overall energy mix is the lowest of all IEA countries …… in Korea, certain customers, namely industrial and agricultural customers, pay energy prices that are below cost. Furthermore, subsidies are provided to domestic coal producers and customers. This encourages inefficient consumption of resources and raises the total cost of energy for Korean customers. ……(IEA, 2007: 9-14)

3.4 Review on Energy Related Researches and Policy Suggestions

Many experts have examined and suggested alternative policies to improve Korea's energy system. The major researches are carried out by KEEI, which examines the current energy situations, develops the future energy scenarios, and puts forward comprehensive strategies on energy and climate change. There are also several other research projects to address future energy-related challenges.

These studies can be classified into two; one is for comprehensive studies which include overall strategies, and the other is for partial approaches focusing on specific issues. Partial approaches, again, can be divided into five categories depending on their foci, including the improvement of economic efficiency, the expansion of renewable energy, the improvement of energy security, and the pursuit of social equity and balanced regional development.

3.4.1 KEEI's Research on Energy and Climate Change Policies

Since 1997, KEEI has carried out researches for setting up climate change strategies for Korea. These include researches on the establishment of action plans on climate change conventions (1997-1999), researches for addressing the UNFCCC and the Kyoto Protocol (2000-2003), and researches on mid- and long-term policies and strategies for post-Kyoto regime (2004-2006).

Reference Prospect (BaU Scenario): KEEI prospects that the Korean economy would keep growing, but at a slower rate compared with the past. Energy elasticity to GDP is expected to improve from 0.31 in 2005 to 0.24 in 2020 and to 0.21 in 2030, which means the increase rate of energy consumption becomes less than that of GDP, as shown in Table 3-12.

Table 3-12: Prospects of Energy-related Major Indicators of Korea

Category	2005	2010	2020	2030	Annual Increase Rate (%)		
					’05- 10	’10-‘20	’20-‘30
GDP(KRW trillion)	721.5	908.6	1345.0	1897.2	4.7	4.0	3.5
Primary Energy(Mtoe)	229.3	261.5	328.8	400.1	2.7	2.3	2.0
Per Capita Energy Consumption(toe)	4.75	5.31	6.58	8.11	2.3	2.2	2.1
Energy/GDP (toe/KRW million)	0.32	0.29	0.24	0.21	-2.0	-1.6	-1.5

Source: KEEI (2006: 89)

Under these premises, KEEI prospects that the overall primary energy consumption would increase from 229.3 Mtoe in 2005 to 400.1 in 2030, with a 2.25 % of average annual increase rate. Of energy sources, new and renewable energy are expected to increase rapidly, while oil consumption is expected to increase the least.

Table 3-13: Prospects of Energy Demand by Energy Source

(Unit: Mtoe)

Category	2005	2010	2020	2030	Annual Increase Rate (%)		
					’05-‘10	’10-‘20	’20-‘30
Coal	54.8	63.8	72.7	82.1	3.1	1.3	1.2
Oil	101.6	109.0	123.5	142.0	1.4	1.3	1.4
LNG	30.0	38.0	60.0	78.6	4.9	4.7	2.7
Hydro Energy	1.3	1.4	1.4	1.5	1.2	0.5	0.3
Nuclear Energy	36.7	41.7	56.8	74.2	2.6	3.1	2.7
New/Renewable Energy	5.0	7.7	14.4	21.8	9.0	6.5	4.3
Total (TPES)	229.3	261.5	328.8	400.1	2.7	2.3	2.0

Source: KEEI (2006: 90)

With continual growth of fossil fuel consumption, GHG emissions are projected to increase by 58 % during this period or from 136.3 Mt_C in 2005 to 184.4 in 2020 and to 215.4 in 2030, as shown in Table 3-14. The economic soundness is projected to improve: GHG emissions per unit GDP would reduce from 0.19 t_C/million KRW in 2005 to 0.11 in 2030, and GHG emission per unit primary energy consumption would decrease from 0.59 t_C in 2005 to 0.54 in 2030. However, the per capita GHG emissions would continue to increase considerably by 2030.

Table 3-14: Prospects of GHG-related Indicator

Category	2005	2010	2020	2030	Annual Increase Rate (%)		
					’05-‘10	’10-‘20	’20-‘30
GHG Emission (Mt_C)	136.3	154.8	184.4	215.4	2.6	1.8	1.6
Per capita GHGs(t_C)	2.82	3.14	3.69	4.37	2.2	1.6	1.7
GHG/GDP (t_C/KRW million)	0.19	0.17	0.14	0.11	-2.1	-2.1	-1.9
GHG/GDP elasticity	-	-	-	-	0.54	0.44	0.45

Source: KEEI (2006: 93)

GHG Reduction Scenario: In relation to future energy system influenced by policy measures, the KEEI’s 2006 report foresees that Korea would reduce its TPES by 50.8 Mtoe and cut CO_2 emissions by 27.2 Mt_C in 2030, which is around 13 % decrease respectively, compared with BaU scenario, as shown in Table 3-15.

For this, KEEI suggests the introduction of environment-friendly energy policies such as the promotion of structural change in energy demand and the introduction of carbon tax. KEEI suggests Korea’s long-term goal to be 349.3 Mtoe of TPES and 188.3 Mt_C of GHGs emissions by 2030.

Table 3-15: Analysis of the Effects of KEEI/MOCIE's GHG-Reduction Scenario

(Unit: Mtoe, Mt_C, (% with BaU))

Category		2005	2010	2020	2030
Reference (BaU)	TPES	229.3	261.5	328.8	400.1
	GHG Emission	136.3	154.8	184.4	215.4
Scenario for structural change of energy demand	Energy savings	-	6.8 (2.6)	20.5 (6.2)	33.8 (8.4)
	GHG reduction	-	4.0 (2.6)	10.6 (5.8)	18.1 (8.4)
Scenario for energy price increase by introducing the carbon tax	Energy savings	-	1.6 (0.6)	7.7 (2.3)	17.0 (4.3)
	GHG reduction	-	1.2 (0.8)	4.3 (2.3)	9.1 (4.2)
Reduction Scenario	TPES	229.3	253.2 (96.8)	300.6 (91.4)	349.3 (87.3)
	GHG Emission	136.3	149.6 (96.6)	169.5 (91.9)	188.3 (87.4)

Source: KEEI (2006: 89, 93, 159, 160, 164,167)

Evaluation of Policy Measures: KEEI report analyzes the economic effects of nine scenarios[37] based on the 2015's projection. According to the report, the introduction of emission permit trade system with credit allocation is evaluated as the most efficient, while the adoption of the same system but with free allocation as the worst (2006: 333-4). Regarding the analysis on reduction potential, the relative change of each energy source is calculated, as shown in Table 3-16. The role of renewable energy is evaluated to be tiny. In addition, nuclear energy is not included in any reduction scenario, which shows that KEEI views nuclear energy as an important instrument to address climate change.

[37] Nine scenarios are the combination of three GHG reduction amounts – 10 % reduction, 20 % reduction, and the sustenance of 2010's emission level – and three reduction instruments – carbon tax, emission permit trade system with free allotment, and emission permit trade system with credit allotment.

Table 3-16: Relative Changes of Fuel Constituents by 2006 KEEI

(Unit: %)

Fuel Type	10 % reduction Scenario			15 % reduction Scenario			20 % reduction Scenario		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
Coal	-21.2	-18.9	-15.9	-45.1	-50.5	-53.4	-50.9	-50.5	-53.5
Oil	-3.9	-3.7	-5.9	-3.9	-11.3	-10.2	-9.5	-11.6	-11.5
LNG	18.8	7.1	4.3	61.4	48.4	48.5	72.4	68.2	74.3
Others	0.0	0.0	0.0	0.0	0.0	0.0	70.4	29.3	22.8
Total	-4.7	-5.0	-5.4	-5.8	-6.5	-6.4	-6.6	-7.4	-7.2

Source: KEEI (2006: 334-340)

3.4.2 Other Comprehensive Studies

Noh, S.-U. (2014) analyzes 19 industrial sectors including 16 manufacturing industries to suggest effective green growth alternatives for the industrial sector to meet the 2020 GHG targets. Noh examines the national goal in the industrial sector based on five scenarios – production, structure, energy intensity, energy mix and GHG emissions. Major policy measures are target management system, emissions trading system, energy management system, ESCOs, energy audit and tax, RPS, the expansion of renewable energy, demand control measures, etc. According to Noh, all scenarios except for the one regarding energy mix contribute to achieving the 2020 target. Among them, structural reform of the industrial sector is expected to be the most cost-effective, based on the assumption of a full value-added transition. Noh evaluates that the policy measures based on energy intensity, energy mix and low carbon efforts on electricity production are desirable for green growth. Noh also stresses the importance of industrial structure reform based on the market.

Lee, S.-H. (2012) examines the construction of sustainable energy system based on renewable energy. By developing a referential scenario based on *the first National Basic Energy Plan* and *the third NRE Plan*, Lee analyzes the portion of renewable energy will reach 36.5 % in 2030. To minimize disadvantages of renewable energy, Lee suggests the introduction of back-up system such as electricity storage, the integration of electricity and transportation system, and the use of heat pump.

3.4.3 Studies on Energy-Economy Issues

Relationship between Energy Consumption and Economic Growth Some experts examined the relationship between energy consumption and economic growth to find out a stimulus variable, using statistical methods like Granger-causality test and error-correction modeling.

Yoo, S.-H. (2005), based on the data about GDP and electricity consumption over the period of 1970-2002, finds that there were uni-directional short-run causality from electricity consumption to GDP, and bi-directional long-run causality between electricity consumption and economic growth. That is, the increase in electricity consumption leads to economic growth and the increase in real income triggers electricity consumption. Based on these conclusions, Yoo suggests that Korea needs policies to encourage investment in electricity supply for economic growth. Oh & Lee (2004) analyze the data on energy consumption and GDP, applying multivariate model of capital, labor, energy and GDP over the period of 1970-1999. The authors lead to a similar conclusion with Yoo (2005). The analysis by Im, J. G. (2013) who examines the policies for electricity demand management in the industrial sector, shows the bi-directional causality between electricity consumption and production activities.

Narayan & Prasad (2007)[38] analyze the causal relationship between electricity consumption and GDP for 30 OECD countries. According to them, eight countries including Korea have uni-directional causality from electricity consumption to GDP, while a meaningful relationship is not found in other 22 countries. This implies that the reduction in electricity consumption through conservation policies will negatively impact real GDP in eight countries. They also show that six countries including Korea have causality from GDP to electricity consumption, which means the reduction of real GDP will decrease the consumption of electricity.

Kim, T.-H. (2014) analyzes the relationship between industrial structure and economic growth. He analyzes the increasing energy demand in energy intensive industries such as petro-chemical and metal industries, which causes the deterioration of energy efficiency. Considering the low effects on the value-added and employment status of these energy intensive industries and their negative effects on climate change, Kim proposes the reform of industrial structure into less-energy intensive.

These articles show that the increase in energy or electricity consumption causes the GDP growth, and (significantly) vice versa. Since Korea has pursued economic growth based on the supports from energy intensive industry[39], the results might be convincing. Therefore, it might say that policies based on large energy intensive industries have brought about the current economic success. However, if this

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[38] The time period that Narayan & Prasad used is 1971-2002 for Korea.

[39] According to Park and Heo's analysis on IEA statistics (2007: 2845), Korea's share of the industry in the TFC is higher than those of most OECD countries: the share is 44 % in Korea, 27.3 % in France, 30.8 % in Germany, 38 % in Japan, and 25 % in UK. They also analyze that "Korean exports (20.045kJ/Won) were more energy intensive than its imports (18.981kJ/Won) on average in 2000[,] (2007: 2846).

relationship between energy consumption and economic growth continues, it will be a great burden on Korea in the future. Kim's analysis (2014) shows these negative impacts adequately. Korea needs to transform its economic strategy from the support of energy intensive industries to the propulsion of energy saving policies.

Relationship between Energy Tax and Economy: Lee, M.-K. (2005) examines the energy tax system and how to reform the tax system to internalize externalities. He diagnoses that the current energy price system is seriously distorted because of diverse and different kinds of taxes, charges and subsidies in the energy market, in addition to lack of environmental consideration[40]. Lee suggests four principles and six constraints of energy tax reform as follows:

Four principles:

1. the internalization of congestion costs to restrain traffic volume and stimulate fair competition among transportation fuels,
2. the internalization of environmental costs,
3. the preparation for energy security and the Convention on Climate Change,
4. the rationalization of import charges on energy.

Six constraints:

1. appropriate relative price across transportation fuels,
2. the promotion of fair competition between industrial heavy oil and LNG,
3. the stability in demand for and supply of energy,

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[40] The once lower price of diesel has caused people to purchase more diesel vehicles such as jeeps and mini vans, which have become key sources of urban pollution.

4. the prevention of illegal usage of fuels,
5. gradual reform in order to give enough time for consumers to adapt to the transition and to minimize any possible negative impacts;
6. and structural change in vehicle-related tax from ownership-oriented tax to travel-oriented tax system.

Under these principles and constraints, Lee proposes to undertake reform in the energy tax system. Specifically, the relative price of gasoline, diesel and LNG should be adjusted, reflecting congestion and environmental costs. According to Lee, the reform would save 7.24 % of energy consumption and $4.3 billion of oil import and reduce 7.59 % of CO_2 emission in 2010.

Lee, J.-H. (2007) analyzes the role of carbon tax as an instrument for climate change policies. According to Lee, the levy of taxes and/or emission permit can contribute to reducing GHG emissions to a level considered to be sustainable. However, his analysis shows this could be a considerable burden for Korea to endure; 9.3(2050) ~ 8.6(2100) percentage drop in GDP compared with the reference scenario. Lee estimates the demand for fossil fuel and renewable energy separately. He assumes the consumption of fossil fuels not to affect renewable energy, and vice versa.

Lee, C.-Y. (2014) analyzes the social acceptability by estimating willingness to pay (WTP) on renewable energy, based on contingent valuation method. According to Lee, the Korean people have 3,456 KRW/month of WTP, which is more than twice compared with previous studies that estimated around 1500 KRW/month. Lee also analyzes that Korea's WTP is 20 % of Japan's, 30 % of the US's and UK's and 50 % of Italy's. Lee suggests that the Korean government should carry out more positive actions to heighten public acceptability when the internalization of energy externality is not sufficiently made yet. WTP on renewable energy indirectly demonstrates the possibility and range of carbon tax or internalization of external costs energy. Lee concludes that the acceptability of Korean people is growing.

Relationship between the Energy Pricing System and the Economy: Lee *et al.* (2005) suggest the introduction of the 'green pricing system' to meet the government's goal – supplying 7 % of electricity with new and renewable energy sources by 2011. They assert that the introduction of green pricing system contributes to preventing strong resistance from consumers by maintaining the current electricity price and encouraging voluntary participation of customers. Lee *et al*. argue that policies like Feed-in-Tariff System and RPS can generate robust resistance by increasing overall electricity fare. To establish a green pricing system, they stress the importance in choosing appropriate energy sources, gaining trust from customers through the renewable energy certificate system and effective marketing strategies.

3.4.4 Studies on Balanced Inter-regional Development

Bae *et al*. (2006) examine the expansion of new and renewable energy focusing on the balanced inter-regional development. The authors criticize existing local energy supporting policies[41] as not being cost-efficient and effective. They argue that investments[42] focusing on waste and biomass, rather than PV and wind energy, are more realistic, given regional circumstances.

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[41] The Korean government had invested KRW 171.6 billion to activate local renewable energy businesses during the period of 1996 and 2005 (Bae et al., 2006: ii).

[42] Bae et al. estimate the investment on waste to produce 91toe of energy per KRW 100 million, biomass 56, wind 28, micro-hydro 21, geothermal 15, solar thermal 12, PV 3toe, etc (2006: 20).

According to them, waste and bio-mass are more cost-effective and useful in investment than other new and renewable energy sources. They assert that waste and bio-mass – ligneous biomass, food- and organic waste for cogeneration, biomass for transportation fuel, and burnable waste – will bring considerable economic benefits for the regional development. It is estimated that the total economic benefits will be KRW 56,270 billion, as shown in Table 3-17 (2006: 113-121).

Table 3-17: Effects of Waste- and Bio-energy Investment on the Economy

(Unit: KRW billion, person)

Category	Forward[43] linkage effects	Backward[44] linkage effects	Value-added effects[45]	Employment effects
Ligneous biomass	4,679.6	3,964.2	1,598.0	2,404
Biomass for CHP	1,514.1	1,920.5	643.9	2,190
Biomass for transportation	625.5	787.6	262.8	722
Waste energy	17,405.1	16,830.0	6,038.3	16,832
Total	24,224.3	23,502.3	8,543	22,148

Source: Bae et al. (2006: 113-121)

43 'Forward linkage effect' means the impact of a specific industry's production on productivities of other industries (for example, economic impacts caused by the energy supply from a local energy facility like a waste incinerator).

44 'Backward linkage effect' means the variation of other industries' productivity to meet the demand of a specific industry (for example, the economic effects caused by the demand of a local energy facility for its operation).

45 'Value-added effect' means the variation of the value-added not only of a specific industry but also of related industries which are caused by the increase of final demand of a specific industry.

In their research, the authors estimate that additional potential of energy produced from waste and bio-mass would reach 2.184 Mtoe (biomass 1,159 and waste 1,025) – around 1 % of TPES in 2006, which contributes to meeting the objective of the new and renewable energy plan (Bae *et al*. 2006: 126; MOTIE/KEEI, 2014: 4). This research, by dealing with the issue of balanced inter-regional development that has been out of focus for many other researches, shows the importance of social equity to establish sustainable energy policies.

However, it concerns only about waste and biomass among many renewable energy sources, which limits itself in realizing balanced inter-regional development. Admitting their benefits, waste constitutes only 1 % of TPES, while the overall theoretical potential of renewable energy is more than 127 times the current TPES, as shown in the *2024 White Book on New and Renewable Energy* (MOTIE/KEMCO, 2014: 96-141).

3.4.5 Studies on Energy Efficiency Policies

Chang, H.-J. (2003) examines the possible schemes for enhancing energy efficiency and a supply security. Chang proposes market-based reform in order to prepare for future energy security challenges effectively – more efficient energy use and energy cooperation in Northeast Asia. This is in line with the direction of Korean government's energy policies. He suggests possible areas for energy cooperation in Northeast Asia as follows: strategic oil stockpile and crisis management, construction of natural gas pipeline, and building integrated electricity system. He insists that this regional cooperation could create many positive effects such as diversification of energy import sources and modes of energy supply transportation, better energy utilization and cost reduction, and financial benefits.

In terms of energy reduction, Byrne & Wang et al. (2004) stress that Korea has great potential to save energy and reduce GHG emissions, provided that Korea implements the energy efficiency policies faithfully suggested in their book, the *Energy Revolution: 21 Century Energy and Environmental Strategy*. They select[46] energy efficiency measures from the databases synthesized from the *Industrial Assessment Database*(1999) by the Office of Industrial Technologies in DOE, *National Energy Modeling System Database* (1998) by the Energy Information System, Alliance to Save Energy's *Energy Innovation: A Prosperous Path to a Clean Environment*(1997), Inter-laboratory Working Group of DOE 's *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy–Efficient and Low-Carbon Technologies by 2010 and the Beyond*(1998), and many other Korean data sources.

By applying selected technologies and methods to the majority of Korea's economic sectors, Byrne & Wang et al. assert that Korea could save 95.4Mtoe of primary energy and reduce 58.9 Mt_C of CO_2 when the suggested policies are fully implemented, and save 62.1Mtoe of primary energy and reduce 38.2Mt_C of CO_2 when 65 % of them are implemented. The expected effects from 100 % implementation of JISEEF Scenario are shown in Table 3-18. The research shows that Korea has considerable potentials to save energy and reduce GHG emissions.

46 The criteria used for selecting the necessary technologies are as follows: 10 % or more energy saving rate and five year or less recovery period of investment coats for the industrial sector; KRW 60 (USD 0.5) or less cost of conserved energy for the residential and commercial sectors; five year or less recovery period of investment coats for the transportation sector.

Table 3-18: Expected Effects of the JISEEF Scenario in 2020

(Unit: Mtoe, Mt_C)

Category	Total	Industrial Sector	Transportation Sector	Residential Sector	Commercial/ Public Sector
Electricity Saving	10.07 (29.22)	4.37	0.13	1.01	4.56
Primary Energy Saving	95.4	32.1	16.5	14.7	9.8
CO_2 Reduction	58.9	23.4	13.5	12.2	9.9

Note: The number in the parenthesis of total electricity saving is the amount of electricity converted into primary energy.
Source: Byrne & Wang et al. (2004)

3.4.6 Studies on Energy Security[47] Issues

Energy security is an important indicator to energy sustainability. Especially, it is more important to countries like Korea which are absolutely depending on foreign energy. Energy security is greatly affected by national energy structure, energy consumption, domestic energy resources, concentration of international energy resources[48], the condition of energy demand and supply, the overall energy depletion possibility, stable energy supply, change in energy prices, substitutability among energy sources, etc. (IEA, 2007: 33-4).

[47] Energy security means the relationship between energy supply and the welfare of nation. It can be defined as conversely, using the concept of 'insecurity'. Bohi and Toman define energy insecurity as "the loss of welfare that may occur as a result of a change in the price or availability of energy (1996: 32)

[48] 62 % of globally proved oil reserves - 'proved reserves' refer to fossil fuels that have been discovered and for which there is reasonable certainty that they can be extracted profitably - are found in the Middle East. The reserves of OECD countries account for only 7 % of the world total; however, these countries consume close to 60 % of world production (IEA, 2007: 36)

Of these, IEA[49] analyzes energy security using ESMC and ESMC*pol*. ESMC is expressed as $\sum_i S_{if}^2$, where S_{if} is the share of each supplier *i* in the market fuel f. ESMC*pol* is defined as $\sum_i (r_i * S_{if}^2)$, where r_i is the rating of political risk of a country ranging from 1.0 to 3.0. Therefore, the range of ESMC is between 0 (perfectly competitive market) and 10,000(purely monopoly market), while that of ESMC*pol* is between from 0 and 30,000 (politically unstable monopoly market).

For each nation, IEA analyzes energy security using ESI, which can be defined as follows: $ESI_{price} = \sum_i [ESMC_{pol-f} \times C_f / TPES]$, where $C_f / TPES$ is the share of the fuel mix and $ESMC_{pol-f}$ is the energy security market concentration of the international market for fuel f; $ESI_{volume} = PipeImp(Gas)_{oil\text{-}indexed} / TPES$, which is considered a specific structure of European gas supply based on pipeline.

IEA presents current energy stability and expected stability in 2030, as shown in Table 3-19. The ESMC of oil market in 2004 was about 3700 when OPEC countries were considered as a single-suppler, and 850 as individual suppliers. On the other hand, the ESMC*pol* of oil market is 8,730 or 1,780 for each case. Table 3-19 shows the surge of the ESI, when OPEC is considered as a single supplier, which implies OPEC's powerful influence in the oil market. The prediction shows that indexes for oil and coal increase by 2030, while that of natural gas decreases. IEA predicts the market shares of five major oil-exporting countries and coal-exporting countries to increase (86 %→88 % for oil, 83 %→88 % for coal), while the share of five major natural gas suppliers to decrease (94 % → 54 %) between 2004 and 2030.

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49 IEA's energy security is based on the concept of Herfindhal-Hirschman Index or HHI. HHI is calculated by summing the squares of the individual market shares of all the participants. It is a more elaborate measure of market concentration as it takes into account both the number of firms in the market and their respective market shares.

Table 3-19: Changes of Energy Security Indexes by Energy Market between 2004 and 2030

Category	Oil Market				Natural Gas		Coal	
	OPEC as a single supplier		OPEC as individual suppliers					
	2004	2030	2004	2030	2004	2030	2004	2030
ESMC	3,700	4,810	850	990	2,200	970	1,860	2,270
ESMC*pol*	8,730	11,440	1,780	~2,230	4,790	1,690	3,050	3,680

Source: IEA (2007: 72-82)

The IEA's report can be useful in analyzing Korea's energy security since it provides numeric information on energy security, unlike other ambiguous expressions on energy security such as the share of energy import or the dependency on the Middle East. It also reflects the uneven and imbalanced distribution of energy resources, and considers the political instability of energy exporters.

Gupta (2008) assesses the relative 'oil vulnerability index (or OVI)' of 26 net oil-importing countries. According to Gupta, Korea is one of the most vulnerable countries, the second out of 26 countries, as already shown in Table 3-11. Breaking down the indicators into individual ones, it is found that Korea runs a high risk from almost every indicator, as already examined in Section 3.3.3. Figure 3-10 also shows that Korea's oil consumption structure is very vulnerable both to market risk and supply risk.

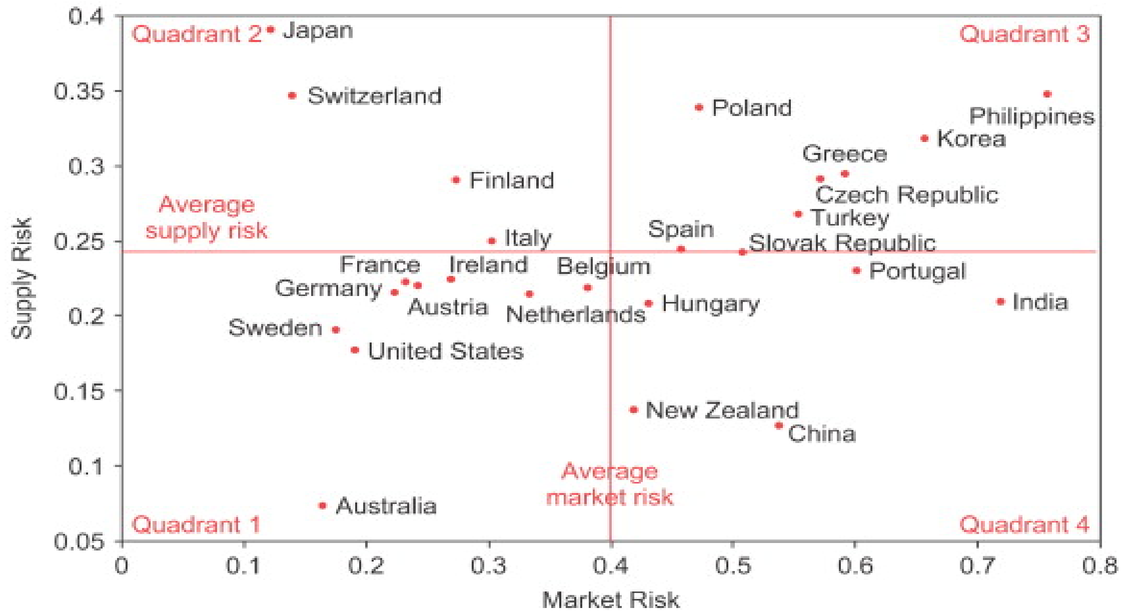

Figure 3-10: Countries in the Market Risk and Supply Risk Plane.
Source: Gupta (2008: 1207)

Lee, D.-S. (2013) analyzed the oil security vulnerability index based on supply risk variables (e.g. oil consumption over crude oil reserves, level of concentration and risk of suppliers, and net import amount over global trade) and market risk variables – per capita GDP, oil intensity, share of oil import to GDP, and the weight of oil in TPES. Lee analyzes that Korea is in a relatively good condition from the perspective of oil supply considering its efforts to diversify supply, while in very weak conditions from the perspective of demand. In sum, Korea ranks second in terms of oil vulnerability among 32 countries. According to Lee, key cause of the vulnerability is its economic structure that is prone to energy (oil) consuming. As alternatives, Lee suggests the strengthening of oil storage, international cooperation in preparation of emergencies, diversification of oil suppliers, direct overseas oil development, and demand management.

Do H.-J. (2014) focuses on the importance of differentiating the 'background elements' and 'triggering events' in considering the risks of energy security, after analyzing the political instability in the Middle East. According to Do, it should be noted to newly emerging risk-elements such as the large-scale development of non-traditional energy resource (shale gas and renewable energy), the impacts of climate change (temperature increase, sea level rise, precipitation change, the increase of extreme meteorological events, etc.), and domestic security threats like the opposition of residents against the establishment of energy-related facilities such as power plants, oil storage tanks and high voltage T&D lines.

3.4.7 Critical Examination on Previous Studies

The researches mentioned above basically aim to improve Korea's energy system or deal with energy-related security issues. Even though many studies try to suggest solutions for sustainable energy system, most of them are confined into partial improvements without suggesting fundamental and substantial recipes.

First of all, many of these researches confine their interests to the government's policies or fail to provide sufficient grounds for their alternatives in addressing the limitations of current energy system. It is found that some researches (Lee et al, 2005, Chang, 2003; KEEI, 2006; Lee 2007; Do, 2014) focus on the government policies rather than having a broader perspective that goes beyond the national policies. Although Lee (2012) analyzes the expansion of renewable system, the study has the limitation in that it does not reflect the price impacts. Such authors assume that setting the price and the share of renewable energy is decided by an external force, instead of competing with conventional energy sources. When renewable energy does not take up a significant share, there might be no competition between them, which means that renewable energy, hitherto, has been seriously dependent on the government's support. However, each energy source is inevitably going to compete against the others. Therefore, the expansion of renewable energy also needs to be analyzed under the competition-based scenario.

Second, many researches seem to have a tendency to depend on the traditional economic system in analyzing energy issues, which lacks the concept of 'sustainable development'. They analyze economic impacts based on the current pricing system which is distorted for conventional energy, or even attempts to complement this weakness (KEEI, 2006; Lee, 2005; Lee 2007). Causal analysis researches (Yoo, 2005; Oh & Lee, 2004; Narayan & Prasad, 2007; Lee, 2013) show conventional energy has played an important role until now; however, it might be difficult to expect it continues to play such a role in the future, because the increase in conventional energy consumption will be a great burden on the economy. According to Narayan & Prasad (2007), many OECD countries show the decoupling of this relationship. Korea also needs to avoid the current growth pattern in preparation for the climate change regime.

Third, domestic studies on energy security are considered to provide rather ambiguous and usually focusing on simple qualitative analysis (KEEI, 2006; Chang, 2003). These studies seem to simply conclude, without making concrete concepts, that 'more energy dependency on foreign countries' means 'more energy insecurity'. In addition, they focus mostly on oil dependence (Do, 2014; Lee 2013). On the contrary, IEA (2007) and Gupta (2008) conducted quantitative analysis using indicators related to energy concentration, political stability and other economic data. These quantitative analyses can be helpful in understanding Korea's energy security situations more concretely and finding the goals and instruments for improving the current situations, because energy security issues that Korea has to take into consideration are not confined into oil, and the comparison with other countries is also necessary.

Fourth, studies on balanced regional development require comprehensive analysis on renewable energy rather than focusing on limited sources such as waste and biomass. When available potentials considered, those of organic energy sources are relatively smaller compared with other renewable energy sources. Furthermore, energy producing facilities based on organic sources can bring on local resistance due to environmental pollution. Therefore, a comprehensive approach is required in analyzing the expansion of renewable energy.

3.5 Lessons from the Literature Review

In Chapter 3, this study has reviewed the energy situations in Korea, the government's energy policies, and related researches for improving the current energy system. This study finds that they have some limitations to accomplish the goal of sustainable energy system, despite their accomplishments and strengths for improving the current energy system, as already examined. However, both their strengths and limitations surely give lessons for building a sustainable energy system.

Firstly, comprehensive reform which changes the current energy system fundamentally would be necessary to accomplish the goals of sustainable energy system. The Korean government has established several energy policies. However, they are strongly tied up with the current energy system based on conventional energy. They just try to pursue partial improvements in the name of protecting the economy. The government mainly focuses on myopic measures; it even partly weakens the current system by protecting domestic coal mining which has already lost competitiveness, and keeps supporting conventional energy industries by providing environmentally harmful subsidies and tax-exemptions. Therefore, the limitations of the government’s policies stress the importance of fundamental reform from the current energy system. Reflecting these lessons, this study plans not to use domestic coal, to adopt structural reform in the industrial sector into a less energy-intensive one, and, especially, to internalize the social costs into their prices. As examined, many experts suggest the tax reform to make the current energy system as a greener one (KEEI, 2006; Lee, 2005).

Secondly, researches which examine the relationship between energy consumption and economic growth, give lessons to take different approaches unlike the past. The historic data shows that the increase of (conventional) energy consumption has contributed to economic growth. However, this would not be valid in the future. Under the situations in which many developed countries have been focusing on considerable reduction of energy consumption and GHG emissions, it would be hard for Korea to pursue increase of energy consumption alone. Therefore, the sustenance of the current economic structure with partial improvement should be revised for the future. In this meaning, this study tries to decouple the ‘economic development’ from ‘energy consumption’ like many other developed countries.

Thirdly, it is important to heighten the share of domestic energy production based on renewable energy. Since Korea has very limited conventional energy reserves, the options are to import foreign energy or to develop domestic renewable energy. Hitherto, the government has actively carried out the exploitation of overseas energy (PMO et al., 2008; MOTIE, 2014). However, the accomplishments are very limited. In this meaning, it is important to focus on the development of domestic renewable energy, which could bring about both increasing domestic energy production and contributing to national wealth and security by creating more jobs and stabilizing the energy supply. In addition, it is also helpful to balanced regional development. In relation, it is also important to consider the available potential of renewable energy in expanding their use, especially in developing bio-mass and waste energy.

Fourthly, it is important to protect the economy not to be seriously damaged by the reform. Since the resistance of the interested groups is always expected, the point is how to address their objections. Many policy alternatives which secure both economic soundness and environmental protection have already been suggested. The core is how to fixate them into the real policies with minimized social costs. For this, it is necessary to provide concrete benefits for offsetting inconveniences caused by new policies for eliciting the necessary supports. The gradual introduction of new policies is also needed, so as to cushion the impacts of the reform without retreatment.

In addition, it is also important to focus on eco-education and public relationship (or PR) for drawing the public support, eliciting their acceptance, and bringing about real reduction of energy consumption and expansion of renewable energy. Especially, the change of lifestyle is generally evaluated to have high potential in saving energy. However, nonetheless, it is difficult to bring out significant real saving, which stresses the importance of effective education and PR.

This study plans to construct a sustainable energy system, reflecting the lessons from previously examined the government's policies and researches.

Chapter 4

ESTABLISHMENT OF SUSTAINABLE ENERGY SYSTEM FOR KOREA

Efforts to improve national energy system require using a future energy prospect or a BaU scenario as a reference. Usually, policy scenario envisions more positive future compared with a BaU scenario. Nonetheless, policy scenarios developed by the Korean government are found to be insufficient to be called ‘sustainable’, because they are based on continuing the existing conventional energy-centered economic system than seeking a fundamental change. Therefore, it would be necessary to complement the existing energy policies with alternative policy options that are based on a more consolidated concept of ‘sustainability’.

In this chapter, an alternative policy scenario is to be established and analyzed in comparison with the existing government policies. For this, after the government’s BaU scenarios are examined, an alternative BaU scenario is developed by sharing major premises, and the results are to be examined. To examine sustainable energy scenario, an analysis on renewable energy potential is also implemented.

4.1 Prospects of Future Energy Situations

Generally, BaU scenario is developed based on the assumption that no additional specific policies or systematic measures are applied; in other words, the current energy situations and policies will continue into the future under given exogenous economic and socio-political prospects such as economic growth rate, population, industrial structure, and the limitations of available energy reserves.

The Korean government, mainly MOTIE with KEEI, has designed BaU scenarios when it established and updated energy policies. Of these, this study focuses on the scenarios which are included in *the First* and *Second National Basic Energy Plans*, *the INDC Plan*, and *the Research on Mid- and Long-Term Policies and Strategies for Measuring Climate Change Conventions*.

Since the *Second National Basic Energy Plan* provides only limited information, this study turns to the recently announced *INDC Plan,* which shares premises and prospects with the *Second National Basic Energy Plan*. At the same time, this study reflects recent data like the population trend.

4.1.1 Premises for a New BaU Scenario

This study sets 2030 as its target year for the scenario. To make economic prospects, this study adopts the growth rate used in *the INDC Plan* and *the Second National Basic Energy Plan,* based on the 2010 real GDP. In relation to the currency rate, the average value over the recent 10 years – 1,082.7 KRW/USD – is applied. For population, this study follows the prospect of KNSO (n.d.(a)).

Table 4-1: Prospects of GDP and Population

Category		2014	2020	2025	2030	Average growth rate (%)	
						'14-'20	'20-'30
GDP	KRW trillion 2010	1,319.7	1,627.7	1,888.8	2,134.8	3.56	2.75
	USD billion	1,428.8	1,762.3	2,045.0	2,311.3		
Population (1,000)		49,410	51,435	51,972	52,160	0.5	0.1

Note: 1 USD = 1,082.7 KRW (average currency rate between 2005 and 2014)
Source: PMO et al. (2015) & KNSO (n.d.(a))

In predicting future oil price, this study uses the prospects of IEA's *World Energy Outlook* which assumes 1.28 % of annual increase rate (re-cited from MOTIE, 2014 & PMO et al., 2015). It estimates that oil price would rise to USD 136.1 in 2030 from USD 112.6 in 2014. Prices are adjusted based on the 2010 value, as shown in Table 4-2.

Table 4-2: IEA's Future Oil Price Prospects

(Unit : USD/bbl)

Category	2014	2020	2025	2030
Price based on 2012	112.6	123.7	130.9	136.1
Price based on 2010	109.7	120.6	127.6	132.7

Source: IEA (2012, re-cited from PMO et al., 2015)

The Korean government uses the outlook of KIET on the change of the value-added of economic and industrial sectors respectively, as shown in Table 4-3 and Table 4-4. According to Table 4-3 and Table 4-4, the relative share of primary industrial sector decreases and that of manufacturing sector increases, while that of service sector stays around 51% in total value-added. In the manufacturing sector, the share of energy intensive industries such as oil and chemical, non-metal minerals, and primary metal industries shows a gradual decreasing trend. However, since the weight of manufacturing sector is much larger than the KEEI's 2006 BaU Scenario, the share of energy intensive industries[50] is also high. This study also examines KIET's outlook, after adjusting the projections of 2014 with the 2010 real values.

[50] While the KEEI's BaU scenario assumes the share of energy intensive industries to be 4.9 % of total value-added (KEEI/MOCIE, 2006: 88), MOTIE's 2014 BaU assumes it to be 6.2 % (2014: 34). The weight of energy consumption in these industries is

Table 4-3: Prospects of the Relative Change of Value-Added by Sector

Classification	2014	2020	2025	2030
Agriculture, Forestry, Fishery, & Mining	2.9	2.3	2.0	1.7
Manufacturing	33.2	35.0	35.7	36.1
SOC, Construction, Public	13.4	12.6	12.0	11.4
Service Sector	50.5	50.1	50.3	50.8
Total Value-Added	100.0	100.0	100.0	100.0

Source: Government's internal data (2015)

Table 4-4: Prospects of the Relative Change of Value-Added in the Manufacturing Subsector

Classification	2014	2020	2025	2030
Food & Drink	3.4 %	2.7 %	2.4 %	2.0 %
Fabric & Clothes	3.2 %	2.9 %	2.6 %	2.3 %
Wood & Papers	2.4 %	1.7 %	1.3 %	1.0 %
Oil & Chemistry	13.7 %	12.4 %	11.1 %	10.1 %
Non-metallic Ores	2.6 %	2.4 %	2.1 %	1.9 %
Primary metals	8.3 %	6.7 %	6.0 %	5.5 %
Assembly and Metals	65.1 %	70.1 %	73.4 %	76.2 %
Other Manufactures	1.3 %	1.1 %	1.0 %	0.9 %
Total	100.0 %	100.0 %	100.0 %	100.0 %

Source: Government's internal data (2015)

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gigantic: they consume 83.6 % of final energy in the manufacturing sector, while their share of value-added is just 17.5% in the manufacturing sector.

4.1.2 Process for Making a New BaU Scenario

To establish a new BaU scenario, this study applies the premises of *the INDC Plan* (the government's 2015 plan) to the method adopted in KEEI's 2006 report[51], with some additional adjustments reflecting recent data. In addition, this study calculates future energy intensity – energy consumption to value-added or GDP – by applying 0.5 % of annual AEEI, given USDOE's LBNL, KEEI and Boo et al. (re-cited from Boo and Choi, 2002: 64) and per capita energy consumption, to the given economic prospects of the government's 2015 plan, as shown in Figure 4-1.

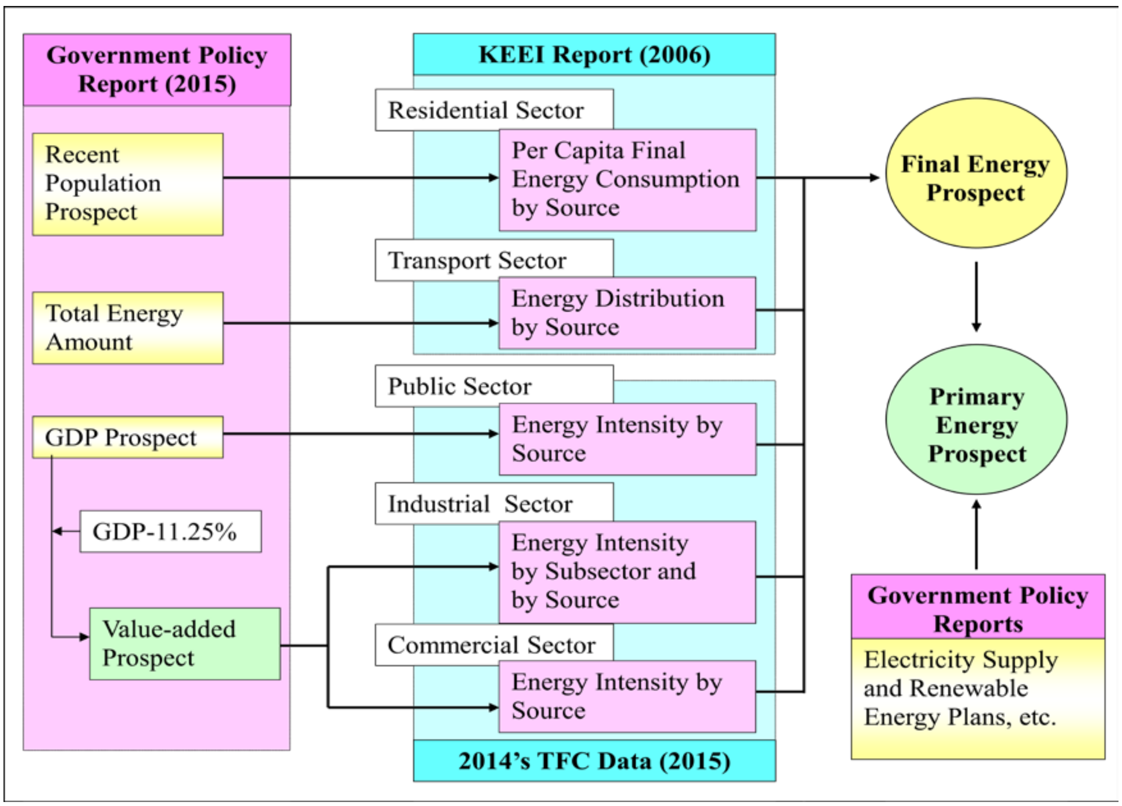

Figure 4-1: Diagram for Establishing a New BaU Scenario Using the Government's and KEEI's Modeling Data.

51 Since KEEI has played a key role in preparing government's reports, there are many similarities between government's energy scenarios and KEEI's 2006 report.

In more detail, this study establishes a BaU scenario through the following process:

1) First, the study adopts the recent KNSO population trend and the GDP prospects of the government's 2015 plan, as shown in Table 4-1. The adopted GDP prospect is then adjusted into the 2010 real value. The prospect of value-added is calculated by subtracting a net production tax, 11.25 % from GDP, reflecting historical data of the Bank of Korea (n.d.).

2) The residential final energy consumption is estimated by multiplying the population (Table 4-1) and per capita energy consumption by fuel (or energy), which is calculated based on KEEI's 2006 report for 2030 and adjusted using 2014 statistics (MOTIE/KEEI, 2015). Table 4-5 shows the corrected per capita energy consumption in the residential sector.

Table 4-5: Per Capita Energy Consumption in the Residential Sector

Category	2014	2020	2025	2030
Sum	0.391	0.436	0.473	0.510
Anthracite	0.015	0.013	0.011	0.010
Oil	0.059	0.067	0.074	0.081
Kerosene	0.029	0.039	0.047	0.055
Diesel	0.012	0.009	0.007	0.006
Heavy Oil	0.001	0.003	0.005	0.007
LPG	0.017	0.016	0.014	0.013
Non-energy Oil	0.000	0.000	0.000	0.000
City Gas	0.181	0.213	0.240	0.267
Electricity	0.107	0.106	0.106	0.106
Heat	0.027	0.030	0.033	0.036
New & Renewable	0.003	0.006	0.008	0.011

Source: KEEI (2006: 120, 128, 131, 134-136)

3) In relation to the transportation sector, the study adopts the overall energy consumption data in the government's 2015 plan. To address a lack of information, the study distributes the overall energy consumption into each fuel (or energy source) in proportion to the shares of KEEI's 2006 report, which are shown in Table 4-6

Table 4-6: Allotment of Final Energy to Each Fuel in the Transportation Sector

Category		2014	2020	2025	2030
Overall Energy Consumption (thousand toe)		37,629	41,800	44,000	45,500
Railroad	Diesel	0.35 %	0.61 %	0.83 %	1.05 %
	Electricity	0.46 %	0.57 %	0.66 %	0.75 %
Road	Gasoline	23.41 %	20.35 %	17.81 %	15.26 %
	Diesel	42.70 %	42.23 %	41.85 %	41.46 %
	LPG	11.84 %	10.77 %	9.88 %	8.99 %
	LNG	3.47 %	3.70 %	3.89 %	4.07 %
Marine	Heavy oil	5.32 %	7.83 %	9.93 %	12.02 %
	Diesel	0.83 %	1.79 %	2.59 %	3.39 %
Flight	Aviation oil	10.55 %	10.35 %	10.18 %	10.01 %
Non-energy Oil		0.04%	0.04%	0.04%	0.03%
New & Renewable		1.03 %	1.76%	2.33%	2.88%

Source: PMO el al. (2015), KEEI (2006: 118)

4) The study calculates the industrial energy consumption by multiplying the total value-added data and its distribution into each individual industry extracted from the government's internal data (Table 4-3 and Table 4-4) by the energy intensity data, which are calculated based on the 2014 real data (MOTIE/KEEI, 2015) and the application of AEEI (0.5% of annual improvement rate).

Table 4-7: Prospects for Total Value-Added and Energy Intensity in the Industrial Sector

(Unit: toe/KRW million 2010)

Category		2014	2020	2025	2030
Total Value-added (KRW trillion)		1,171.2	1,444.6	1,676.3	1,894.6
Share of Value-added	Agriculture et al.	0.090	0.087	0.085	0.083
	Mining	0.116	0.113	0.110	0.107
	Manufacturing	0.316	0.274	0.244	0.220
	Food & Beverage	0.126	0.122	0.119	0.116
	Textile & Clothes	0.128	0.124	0.121	0.118
	Wood & Paper	0.027	0.027	0.026	0.025
	Petrochemical	1.164	1.130	1.102	1.075
	Non-metal	0.508	0.493	0.481	0.469
	Primary Metal	1.000	0.970	0.946	0.923
	Assembling	0.042	0.041	0.040	0.039
	Other manufacturing	0.625	0.622	0.591	0.577
	Other energy	0.027	0.026	0.026	0.025
	Others	0.116	0.112	0.109	0.107
	Construction	0.036	0.035	0.034	0.033

Note: 1. ‘Other energy’ means energy-related industries except the transformation sector

2. ‘Others’ means the amount of energy consumption included in the manufacturing sector but not designated into specific industries in the *2015 Yearbook of Energy Statistics*.

Source: MOTIE/KEEI (2015)

5) The study induces the energy intensity data by combining the 2014 energy consumption data with the value-added of the service sector from the government’s internal data. Based on this, this study calculates the future energy intensity based on 2014’s energy intensity multiplied by the AEEI. In the case of public sector, GDP is used instead of value-added, reflecting the method of KEEI’s 2006 report. Table 4-8 and Table 4-9 show the related data.

Table 4-8: Prospects of Energy Intensity and Demand in the Commercial Sector

Category		2014	2020	2025	2030
Value-Added in the Service Sector (KRW billion 2010)		591,855	723,036	843,303	962,369
Energy Intensity by Source (toe/KRW million)	Sum	0.0266	0.0260	0.0255	0.0250
	Oil, LPG	0.0028	0.0027	0.0026	0.0026
	Natural gas	0.0059	0.0057	0.0056	0.0054
	Heat	0.0003	0.0003	0.0002	0.0002
	Electricity	0.0174	0.0169	0.0165	0.0161
	Non-energy	0.0002	0.0001	0.0001	0.0001
	NRE	0.0001	0.0003	0.0005	0.0006

Source: MOTIE/KEEI (2015)

Table 4-9: Prospects of Energy Intensity in the Public Sector

Category		2014	2020	2025	2030
GDP (KRW trillion 2010)		1319.7	1627.7	1888.8	2134.8
Energy Intensity by Source (toe/KRW billion)	Total	3.546	3.441	3.356	3.273
	Oil	0.990	0.960	0.937	0.913
	Natural gas	0.064	0.063	0.061	0.059
	Heat	0.029	0.028	0.027	0.027
	Electricity	1.847	1.793	1.748	1.705
	NRE	0.616	0.598	0.583	0.569

Source: MOTIE/KEEI (2015)

4.1.3 Results of the New BaU Scenario

Through these processes, the final energy consumption is projected to be 242.8 Mtoe in 2020 and 272.4 Mtoe in 2030, as shown in Table 4-10. The industrial sector takes 62.1 % of total final energy consumption, followed by the transportation, residential, commercial and public sectors.

Table 4-10: Prospects of TFC of the New BaU Scenario

(Unit: Thousand toe)

Category		2014	2020	2025	2030
Total		213,873	242,813	259,986	272,420
Sector	Industry	136,087	154,153	163,518	169,236
	Transportation	37,629	41,814	44,010	45,500
	Residential	19,734	22,415	24,583	26,622
	Commercial	15,743	18,831	21,537	24,076
	Public	4,680	5,601	6,339	6,987
Fuel	Coal	35,412	37,202	28,512	39,120
	Oil	102,958	115,889	121,019	123,669
	City Gas	23,396	27,599	30,735	33,448
	Electricity	41,073	47,878	53,002	57,259
	Heat	1,566	1,794	1,980	2,154
	Renewable	9,468	9,931	14,739	16,770

Based on the electricity production of the government's 2015 BaU scenario (PMO et al., 2015: 9-10), this study calculates the net energy consumption during the energy transformation process, which is 139.2 Mtoe in 2020 and 159.2 Mtoe in 2030.

Table 4-11: Estimation of Energy Consumption for the Transformation Sector

(Unit: Thousand toe)

Category	2014	2020	2025	2030
Total	111,703	139,167	147,556	159,214
Coal	49,200	57,397	54,824	59,330
Oil	1,986	2,348	1,669	1,730
Natural gas	24,377	26,728	28,369	30,615
Hydro, Renewable	3,138	8,079	10,347	11,067
Nuclear	33,002	44,614	52,347	56,473

By combining Table 4-10 and Table 4-11, TPES for the new BaU scenario is estimated to be 332.3 Mtoe in 2020 and 372.2 Mtoe in 2030, as shown in Table 4-12. According to Table 4-12, renewable energy is expected to increase rapidly compared with other energy sources; oil is expected to continue its dominant role by 2030.

Table 4-12: Estimation of TPES by Source

(Unit: Mtoe)

Category	2014	2020	2025	2030
Total	282,937	332,309	352,560	372,221
Coal	84,612	94,599	93,336	98,449
Oil	104,944	118,237	122,687	125,398
Natural gas	47,773	54,327	59,104	64,063
Nuclear	33,002	44,614	52,347	56,473
Hydro, Renewable	12,606	20,531	25,085	27,837

Based on Table 4-12, GHG emissions of the new BaU scenario are estimated to be 708.3 Mt_CO_2 in 2020 and 761.0 Mt_CO_2 in 2030. Here, GHG emissions from hydro, nuclear and renewable energy are not considered, which are also applied to both KEEI and government's reports.

Table 4-13: Estimated CO_2 Emissions of the New BaU Scenario

(Unit: Mt_CO_2)

Category	2014	2020	2025	2030
Total	631.4	708.3	723.0	761.0
Coal	329.4	368.3	363.4	383.2
Oil	190.5	213,2	221.6	228.1
Natural gas	111.6	126.9	138.0	149.6

4.1.4 Comparison of the New BaU Scenario with Other Scenarios

Table 4-14 shows the comparison of TFC among the four BaU scenarios. Since this study mainly follows the government scenario, it assumes that energy consumption will grow in the future. Among the BaU scenarios, the government's 2008 BaU predicts the lowest GHG emissions, followed by the government's 2015 BaU, this study's new BaU, and KEEI's 2006 BaU. The new BaU scenario assumes the future, which consumes 10.0 % more energy than the government's 2008 BaU; 8.3 % more energy than the government's 2015 BaU; 6.4 % less energy than KEEI's 2006 BaU. As this study tries to exclude additional political intervention in predicting future energy consumption, the results seems to be feasible. Since this study assumes lower economic growth rate compared with KEEI's 2006 scenario, reflecting recent economic situations like other government's scenarios, its BaU is expected to be lower than KEEI's 2006 BaU.

Table 4-14: Comparison of TFCs in 2030 among BaU scenarios

(Unit: Mtoe)

Category	New BaU	KEEI's 2006 BaU	Government's 2008 BaU	Government's 2015 BaU
Sum (TFC)	272.4	289.9	245.1	254.3
Industrial Sector	169.2	158.2	134.0	152.3
Transportation Sector	*45.5*	57.2	45.9	45.5
Residential & Commmercial Sectors	50.7	68.4	59.1	50.6
Public Sector	7.0	6.2	6.0	5.8

Note: 1. This study follows the government's 2015 BaU scenario in the transportation sector.

2. TFC in the government's 2015 BaU Scenario is the same with that of the government's 2014 BaU scenario, which is not included in the Table.

In relation to TPES, the new BaU scenario projects it to be 372.2 Mtoe in 2030, while the government's 2008 BaU scenario projects 342.8 Mtoe, KEEI's 2006 BaU scenario 400.2 Mtoe, and the government's 2015 BaU scenario 369.9 Mtoe, as shown in Table 4-15. Since the new BaU scenario shares much of the premises with the government's 2015 BaU scenario, the two scenarios forecast similar future energy consumption.

Table 4-15: Comparison of TPES in 2030 among BaU scenarios

(Unit: Mtoe)

Category	New BaU Scenario	KEEI's 2006 BaU Scenario	Government's 2008 BaU Scenario	Government's 2015 BaU Scenario
Total Primary Energy Supply	372.2	400.2	342.8	369.9
Coal	98.4	82.1	84.6	107.7
Oil	125.4	142.0	117.2	107.1
Natural gas	64.5	78.6	54.0	69.8
Hydro Energy	1.9	1.5	1.6	1.9
Nuclear Energy	56.5	74.2	66.8	65.3
New & Renewable Energy	25.9	21.8	18.6	18.0

In relation to GHG emissions, the new BaU scenario forecasts 761.0 Mt_CO_2 in 2030, while the government's 2015 BaU scenario forecasts 850.6 Mt_CO_2 including non-energy emissions. KEEI's 2006 BaU scenario and the government's 2008 BaU scenario do not show any information on GHG emissions, which this study estimates based on Table 4-15, as shown in Table 4-16.

Table 4-16: Comparison of GHG Emissions in 2030 among BaU scenarios

(Unit: Mt_CO_2)

Category	New BaU Scenario	KEEI's 2006 BaU Scenario	Government's 2008 BaU Scenario	Government's 2015 BaU Scenario
GHG Emissions	761.0	936.8	813.2	850.6

Note: 1.In calculating the emissions of KEEI's 2006 BaU and the government's 2008 BaU, the emission factors of bituminous, energy oil, and LNG are applied.
2. The government's 2015 BaU Scenario includes 111.7 Mt_CO_2 of non-energy emissions.

4.2 Potential of Renewable Energy

With the growing concern about climate change and air pollution, renewable energy is frequently mentioned as an alternative. This study firstly clarifies the range of renewable energy. Then, renewable energy potentials estimated by the government and some institutions are examined. Based on these, the study estimates the available potential of renewable energy by type.

4.2.1 Range of Renewable Energy

In Korea, the term 'new and renewable energy' is more frequently used than 'renewable energy', because *the Act on the Development, Use, and Propagation of New and Renewable Energy* adopts the former in analyzing the government's reports and researches; however this study uses the latter in its own analysis. Despite the difference in the meanings, they are used interchangeably in many cases. Korea is not the only country to have difficulty in defining the ambiguous term of 'renewable energy'. Many other countries and institutions define 'renewable energy' differently even though they use the same word, as shown in Table 4-17.

Table 4-17: Comparison of the Ranges of Renewable Energy

<table>
<tr><th colspan="2">Category</th><th>IEA</th><th>REN21</th><th>EU</th><th>USA</th><th>Japan</th><th>Korea</th></tr>
<tr><td rowspan="3">Hydro</td><td>Large H.</td><td>○</td><td>○</td><td>×</td><td>○</td><td>×</td><td>○</td></tr>
<tr><td>Small H.</td><td>○</td><td>○</td><td>○</td><td>○</td><td>×</td><td>○</td></tr>
<tr><td>Pumping</td><td></td><td>-</td><td>×</td><td>×</td><td>×</td><td></td></tr>
<tr><td rowspan="2">Geothermal</td><td>Generation</td><td>○</td><td>○</td><td>○</td><td>○</td><td>×</td><td rowspan="2">○</td></tr>
<tr><td>Heating/cooling</td><td></td><td>○</td><td>○</td><td>○</td><td>×</td></tr>
<tr><td rowspan="4">Solar</td><td>PV</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Heating</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td rowspan="2">○</td></tr>
<tr><td>Heat Generation</td><td>○</td><td>○</td><td>○</td><td>○</td><td></td></tr>
<tr><td>Passive Solar</td><td>×</td><td>○</td><td>○</td><td>×</td><td>○</td><td>×</td></tr>
<tr><td rowspan="3">Ocean</td><td>Tide</td><td>○</td><td>○</td><td>○</td><td>○</td><td rowspan="3">×</td><td rowspan="3">○</td></tr>
<tr><td>Wave</td><td>○</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Generation (Temp. difference)</td><td>○</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td colspan="2">Wind</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td colspan="2">Biomass</td><td>○</td><td>○</td><td>○</td><td>○</td><td>-</td><td>○</td></tr>
<tr><td rowspan="5">Waste</td><td>Recyclable municipal waste</td><td>○</td><td>○</td><td>○</td><td>○</td><td rowspan="5">-</td><td rowspan="5">○</td></tr>
<tr><td>Unrecyclable municipal waste</td><td rowspan="4">×</td><td>-</td><td rowspan="4">×</td><td>×</td></tr>
<tr><td>Industrial waste</td><td>-</td><td>-</td></tr>
<tr><td>Combustible waste</td><td>-</td><td>-</td></tr>
<tr><td>Waste heat</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Energy from temperature difference</td><td>○</td><td>×</td><td>○</td><td>×</td><td>○</td><td></td></tr>
<tr><td colspan="2">Fuel cell</td><td rowspan="3">×</td><td rowspan="3">×</td><td rowspan="3">×</td><td rowspan="3">×</td><td>○</td><td>○</td></tr>
<tr><td colspan="2">Gasification from coal and oil</td><td>×</td><td>○</td></tr>
<tr><td colspan="2">Hydrogen</td><td>○</td><td>○</td></tr>
<tr><td colspan="2">Other renewable energy</td><td></td><td></td><td></td><td></td><td>○</td><td></td></tr>
</table>

Source: Gangwon Development Research Institute (2008)

Of these, this study basically adopts the definitions of REN21 and EU. However, this study excludes ‘large hydro power’ from the category of renewable energy unlike REN21, and includes the energy acquisition method using (water or air) temperature differences. In relation to fuel cell and hydrogen, they are categorized according to their hydrogen sources: if hydrogen source is petroleum, it is classified into conventional energy, and vice versa. In case of wastes, this study classifies most of them into the category of renewable energy sources, since the combustion of waste can additionally produce heat and electricity with a similar level of air pollutants emissions compared with other treatment methods like landfills. The study, however, maintains the position that preventive methods such as reducing, reusing and recycling should take up a priority in treating wastes before they are combusted. Therefore, the expanded use of waste energy is not recommended in this paper, unlike other renewable energy sources.

In sum, renewable energy includes small hydro, geothermal, all types of solar energy, ocean energy, wind, bio-mass, combustible wastes, energy extraction from temperature differences, and renewable energy-based fuel cell and hydrogen.

4.2.2 Review of Previous Research on Renewable Energy Potential

KIER estimates Korea’s new and renewable energy potential to be 1,155Mtoe as for resources[52] and 110.7Mtoe as for available reserves (re-cited from CEA, 2003: 42). KIER also calculates the portion of solar energy by simply adding solar heat and PV without considering their exclusive relations. KIER does not include some new

[52] ‘Reserves’ refer to energy sources that have been discovered and for which there is reasonable certainty that they can be extracted profitably, while ‘resources’ means the total amounts that can be possibly (theoretically) extracted.

and renewable sources such as geothermal, offshore wind energy and ocean energy. New and renewable energy potential is estimated based on primary energy[53] rather than final energy.

Table 4-18: Estimation of New and Renewable Energy Potential by KIER

(Unit: Mtoe per year)

Category	Resources	Available Reserves	Remarks
Solar Heat	972.4	97.2	Daily average insolation: 3,079kcal/m^2 Subject area: 30,900km^2 Available reserves =10 % of resources
PV	5.9 (19.2GW)	2.9	Available reserves =50 % of resources
Biomass	11.3	2.1	Including forest and agricultural residues and organic wastes such as food wastes, livestock manure, and sludge
Wind	165.0	8.0	Wind resource distribution
Small hydro	0.6	0.2	Including (small) rivers, water purifying facilities, sewage treatment facilities, reservoirs, agricultural dams, etc.
Sum	1,155.4	110.7	

Source: CEA (2003: 42).

CEA estimates new and renewable energy potential to be 12 Mtoe for biomass and 1,506TWh of others as resources and 2.3 Mtoe of biomass and 152 TWh of others as available reserves (2003: 44-55). CEA's estimation of total available potential amounts to 40.5 Mtoe as the value of TPES. Unlike KIER, CEA does not include the portion of solar energy, which KIER estimates to be 97.2 Mtoe. In estimating the PV

53 The KIER applied energy relationship of '4 ~ 4.3 MWh = 1toe' rather than '11.63MWh = 1toe', in calculating the potential.

potential, CEA includes the whole building except for the floor, and only targeted buildings, reservoirs and roads. CEA estimates the wind energy potential to be 20 % of the 2020 electricity demand (2003: 49).

Table 4-19: Estimation of New and Renewable Energy Potential by CEA

Category	Resources	Available Reserves	Remarks
PV	380 TWh	38.7* TWh (9.7 Mtoe)	10 % of buildings (3,196 km^2) and reservoirs (160 km^2) 10 % of road length(total 91,000km)
Wind	1,069 TWh (267.3 Mtoe)	93 TWh (23.3 Mtoe)	Reserves: 26.9 % of land and shore (NREL's wind class) Available reserves: 20 % of national electricity demand by 2020 (436.6TWh)
Small hydro	-	3.9 TWh (1 Mtoe)	Capacity: 1.5GW Capacity factor: 30 %
Geothermal	-	-	Mentioned but not estimated
Biomass	12 Mtoe	2.3 Mtoe	Including forest and agricultural residues, food wastes, paper/wood wastes, livestock manure, and sludge
Ocean	57 TWh	17 TWh (4.25 Mtoe)	Tidal & wave energy capacity: 13.1MW Available reserves: 30 % of resources

Note: CEA calculated it as 38 TWh. However, this study adjusts it to 38.7 TWh (=33.6GW*24*365*0.1315). In addition, 9.7 Mtoe is calculated, based on '1toe = 4.0MWh' instead of CEA's '1toe = 4.5 MWh'(CEA, 2003: 47), to compare with other estimations.
Source: CEA (2003: 44-55).

Table 4-20 shows the estimation by MOCIE and KEEI. They includes geothermal and ocean energy, but not in counting the total potential. The potential of new and renewable energy is estimated to be 410.7 Mtoe, excluding solar heat and ocean energy. In estimating the potential for PV, their research increases the insolating solar energy unit from 3,079kcal/m^2 to 3,432kcal/m^2, considering an appropriate angle for individual solar panels. However, more caution should be taken in calculating the aggregate potential. According to their study, the total habitable land (or 31.5 % of total land) is assumed to be eligible for PV with 10 % efficiency. Even though they use a similar method with CEA in estimating wind potential, the outcome is found to be much smaller than that of CEA (267.3 Mtoe).

Table 4-20: Estimation of New and Renewable Energy Potential by MOCIE/KEEI

(Unit: Mtoe per year)

Category	Resources	Available Reserves	Remarks
Solar heat	10,100.0	3,500.0	Resources: total amount of annual insolation over Korea (3,079kcal/ m^2) Available reserves: habitable land (31.5 %)
PV		390.0	PV angle(33^{o}): insolation 3,432 kcal/ m^2 PV efficiency 10 %
Wind	161.7	16.2	Reserves: NREL's wind class 3 or more (Inland 12 %, Offshore 30 %) Available resources: 10 % of reserves
Small hydro	7.7	1.3	Capacity factor 40 %
Geothermal	-	0.9	Based on Switzerland's Geothermal use
Biomass	11.3	2.3	Forest & agricultural residues, food wastes, paper/wood wastes, livestock manure, sludge
Ocean		2,400 MW	Including four candidate's capacity
Sum	10,280.7	3,910.7 (410.7)	Ocean energy excluded. ( ) means the sum except solar heat.

Source: MOCIE/KEEI (2006: 163-4, 180)

Table 4-21 shows the renewable energy potential from *the 2014 New and Renewable Energy White Paper* by MOTIE and KEMCO. In the 2014 White Paper, the new and renewable energy potentials are classified into four categories: theoretical potential (total energy amount), geographical potential (unusable areas excluded from theoretical potential), technical potential (considering technical level or efficiency), and market potential. For convenience, in this study, technical potential is used as available reserve.

Table 4-21: Estimation of New and Renewable Energy Potential by MOTIE/KEMCO

(Unit: Mtoe/year)

Category	Theoretical Resources	Available Reserves	Remarks
Solar heat	11,371.0 (132,245 TWh)	1,160.1	Resources: total amount of annual insolation over Korea (average 3.63kWh/m^2/day) Available areas: 33.1 % × 82.3 % Efficiency: PV 16%, Solar heat 37.45%
PV		495.6 (13,503 TWh)	
Wind	172.2 (2,003TWh)	24.4 (284TWh)	Wind class : Inland 2(250W/m^2), Offshore 3(300W/m^2) Available reserves: 10 % of resources
Hydro	43.4 (505 TWh)	7.3 (84 TWh)	Small and large hydro energy
Geothermal	5,253.4	12.5	Based on EGS potential protocol
Biomass	367.1	11.5	Forest & agricultural residues, food wastes, livestock manure
Waste	14.1	10.4	
Ocean	18,203.0	144.6	Tide, tidal power, wave, water temperature
Sum	35,424.2	1,363.4	

Source: MOTIE/KEMCO (2014: 96-141)

In estimating solar energy potential, 33.1 % of land and 82.3 % of space are assumed to be available for solar energy facilities with 16 % efficiency for PV and 37.45 % for solar heat. Compared with the 2006 result, the analysis of geothermal and ocean energy showed major differences. While the figures in 2006 are limited to the existing and planned facilities' capacity, the 2014 research broadened its scope significantly based on the detailed analysis on their theoretical potentials.

4.2.3 Estimating Renewable Energy Potentials

Considering the accomplishments and limitations of previously examined four estimations, this study conducts an examination on the overall potential of renewable energy by selectively adopting the methods and adding new findings and statistics related with renewable energy, focusing on land availability and land use expandability, as follows:

Photovoltaic Electricity and Solar Thermal Energy: Solar energy, in itself, is unlimited and inexhaustible, at least, for people to use. Solar energy is more than 20,000 times the needs of people (MOCIE/KEEI, 2006: 164). The annual average intensity of solar energy in Korea is 3.55 KWh/m^2/day, and total insolating energy is 11,371 Mtoe per year or 40 times of the 2014 TPES (MOTIE/KEMCO, 2014: 97-103; MOTIE/KEEI, 2015: 343). However, this does not represent the available potential of the energy source in Korea.

To calculate available reserves, a first step needs to be taken by finding the available area for solar energy. Table 4-22 shows the land use status in Korea. The government assumes that about 33 % of land is available for solar energy, except forest which takes 64% of total land.

Table 4-22: Korea's Land Use Status

(Unit: km^2)

Total Land Area	Agricultural Land	Forest	Residential Land	Road & Rail Road	River, Others
99,678.1	21,125.6	64,730.6	3,904.2	2,747.3	7,170.4

Note: 1. Agricultural land includes rice paddy, patch, orchard, and ranch.
2. Residential land includes building sites, industrial & school sites, and area for sports and recreation, religion, parking lot, gas station and storage.
3. Others include river banks, burial sites, fishponds, lands for water service, etc.
Source: KNSA (n.d.(b))

This study basically plans to follow the government's method; however, it also adds the method that Byrne at al. applied to Seoul in calculating the potential based on available rooftop area in building area[54]. According to Byrne et al., the rooftop covers 30.9 %[55] of Seoul area, or 76.3 %[56] of the area dedicates to building usage and only 38.3 %[57] of the roof area can be covered with PV panels of 5% tilt (2015a). Combining the government method with Byrne et al.'s, this study calculates the PV potential (PV_P), as follows:

$$\mathrm{PV\_P} = \mathrm{PV\_P}_{\mathrm{BA}} + \mathrm{PV\_P}_{\mathrm{NBA}}$$

$$\mathrm{PV\_P}_{\mathrm{BA}} = \text{Insolating energy} * \text{building area} * 0.383 * 0.786 * \mathrm{PV\_ef}$$

---

54 Building area includes residential sites, industrial area, site for educational facility, land for sports/recreation/religion facilities, land for gas station, and storage area. Building area takes 3.78% of the whole land in Korea.

55 30.9 % means the rooftop area(187.05 ㎢) over Seoul area (605.33 ㎢).

56 76.3% means the rooftop area over the building area (245.3 ㎢).

57 38.3% is the ratio of finally available area for PV-panel (71.6 ㎢) over rooftop area (187.05 ㎢).

$$PV\_P_{NBA} = \text{Insolating energy} * \text{Area} * 0.412 * 0.786 * PV\_ef$$

where, 'BA' means building area, 'NBA' means non-building areas where the government regards that PV panels are installable, 0.412[58] is a suitability factor for other area, 0.383 is a combination of suitability factor, ground coverage ratio and service area, 0.786 is a tilting effect, and PV-ef is a PV-module efficiency

In addition, the study assumes that the efficiency of electricity generation from PV can reach 22 % by 2030 and 30% by 2050, up from 14~19 % of the current efficiencies, reflecting technological progress (Yoon[59], 2007; Ministry of Economy, Trade and Industry[60] of Japan, 2006: RES/COM-15; Wikipedia, 2016). Based on these premises, the available electricity potential from solar radiation would amount to 226.3 Mtoe (or 2,631 TWh) as electricity by 2030 and 308.6 Mtoe[61] (or 3,589 TWh) as electricity by 2050. Figure 4-2 shows the available PV potentials and the available land of each region. Although this study looks at the available land more limited than those of the government by applying suitability factor more strictly, it does not ignore the possibility that available land can expand in size depending on the future economic and social situations and the change of social acceptance as well as technological development.

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[58] MOTIE/KEMCO applies 0.823 as a suitability factor. However, this study applies a half of the government's factor (0.412), considering the intrinsic use of land.

[59] Yoon cited the data of NEDO (New Energy & Industrial Technology Development Organization, Japan), which prospected the power generation efficiency from the Sun to be 15~40 % by 2030: Crystalline Silicon PV 22 %, Thin Film PV 18 %, CuInSe PV 22 %, III-V PV (Concentrator type) 40 %, and Dye-sensitized PV 15 %.

[60] Ministry of Economy, Trade and Industry of Japan predicts PV efficiency to be 22 % by 2030, 30 % by 2050, and 40 % by 2100.

[61] The applied PV efficiency is 30 % according to the Ministry of Economy, Trade and Industry of Japan, with consideration of many other research results.

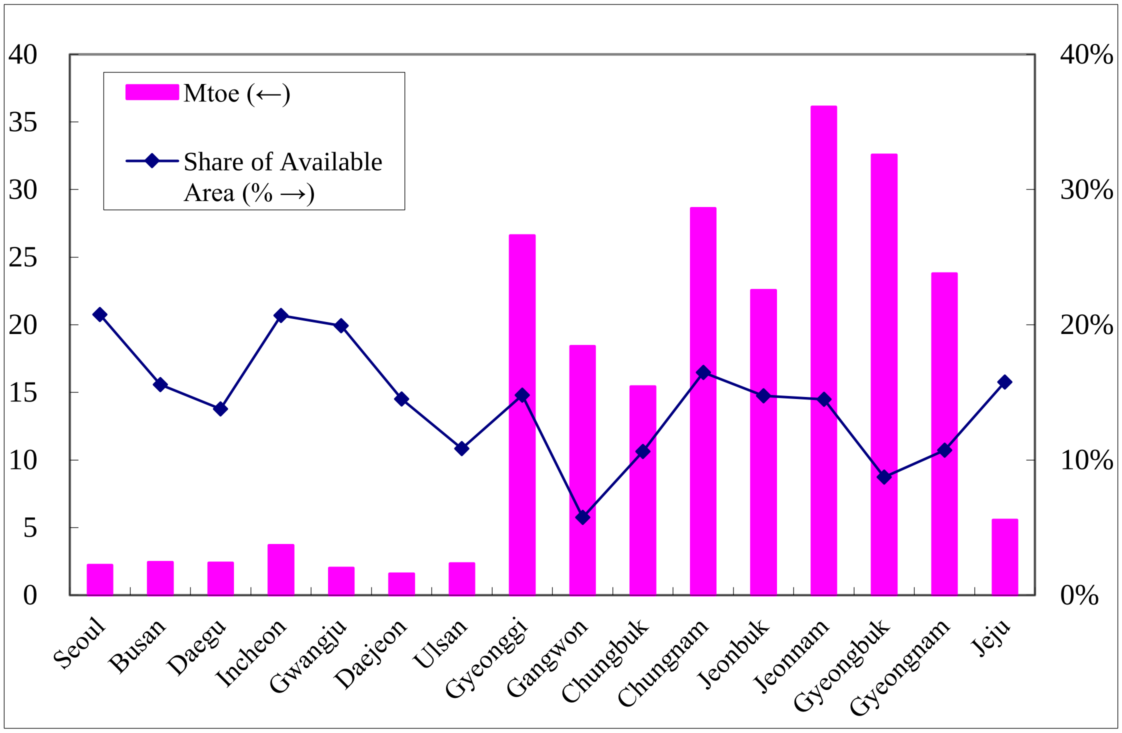

Figure 4-2: Available PV Potentials by region by 2030.

With regard to solar heat, this study estimates the potential of total solar energy would be 385.7 Mtoe by 2030 by applying 37.5 % of energy efficiency to solar heat and would be 424.9 Mtoe by 2050 by applying 41.3 % of energy efficiency to solar heat, based on the assumption that solar heat and PV are in competition with each other as the area covered with PV cannot be used for solar heat generation and vice versa.

In sum, the potential of available solar energy is between 226.3 Mtoe as electricity and 385.7 Mtoe as heat by 2030 and between 308.6 Mtoe and 424.9 Mtoe by 2050. These figures could be changed depending on how much PV and solar heat panel are established. The potential is also influenced by previously established facilities with lower efficiency compared to the estimated efficiencies.

Wind Energy: In relation to wind energy, this study follows the government estimation in 2014. The government's *White Paper* estimates the technical potential, using the wind map with 100m×100m resolution and the geographical information with 30m×30m resolution, applying 5MW/km^2 of capacity density which US NREL has suggested, but excluding unusable areas such as cities and national parks. In relation to technical potential, *the 2014 White Paper* chooses the area with 250 W/m^2 or more for in-land wind turbines, and the area with 300 W/m^2 for off-shore wind turbines based on the altitude of 100m or upper from land or sea surface (MOTIE/KEMCO, 2014: 105). The area of 50m or more below the sea level is excluded in the analysis.

Based on these premises and theoretical bases, *the 2014 White Paper* estimates the technical potential as 24.8Mtoe per year. However, since it does not include the available potential for metropolitan cities such as Busan, Incheon and Ulsan, this study adds the potential that the 2005 White Paper estimates, although their sizes are relatively small – 0.4Mtoe per year. In sum, the available potential for wind energy is estimated to be 24.8 Mtoe per year.

Table 4-23: Wind Power Potential

(Unit: Mtoe per year)

Classification	Theoretical Potential		Available Potential	
	Inland	Off-shore	Inland	Off-shore
Total	77.0	98.3	7.7	17.1

Source: MOCIE/KEEI (2006: 164, 167-170), MOTIE/KEMCO (2014: 108-9)

Bio and Waste Energy: Bio-energy refers to the energy produced from organic materials. Major sources of bio-energy are forest and agricultural residues, food waste, waste paper and wood, livestock manure, and organic sludge generated from sewage/wastewater treatment facilities. These materials can produce energy through the process of combustion and anaerobic decomposition. When burnt, they emit pollutants and GHG. However, since organic materials absorb carbon dioxide and other pollutants while growing, they are also classified as renewable energy and their net lifetime balance can be interpreted as being ‘carbon-neutral’. Organic and combustible wastes emit GHG while being disposed, regardless of what treatment methods are applied: energy production[62] or landfill treatment. According to the ME, daily generation of organic and combustible wastes in 2012 was 65,340 ton. Table 4-24 shows the generation of wastes by sector (2013). The amount of recycled materials is pre-excluded in this statistics. Daily generation of livestock manure is estimated to be 126,363 ton in 2012.

Table 4-24: Daily Generations of Organic and Combustible Wastes by Sector

(Unit: ton per day)

Category	Total	Food	Paper & Wood	Rubber & leather	Sludge	Others
Sum	65,340	16,156	11,131	14,146	15,774	8,135
Municipal	30,631	13,209	7,229	4,042		6,151
Industry	32,745	2,947	1,959	10,083	15,774	1,984
Construction	1,964		1,943	21		

Source: ME (2013)

62 For example, the landfill of wastes, and the aerobic and anaerobic decomposition of organic wastes can cause similar or more greenhouse effects by emitting CO_2 and CH_4.

Using these data, this study estimates that the annual available potential of waste energy is 6.2 Mtoe. Table 4-25 shows the potential of each waste energy. Of these, rubber-, leather- and plastic-wastes[63] constitute a significant portion because their caloric value is much higher than other materials. Agricultural residues, paper- and wood-wastes, and forest residues also constitute a large amount.

Table 4-25: Annual Energy Potential of Waste

Category	Annual Generation (1000 ton)	Caloric value (toe/ton)	Total Energy Potential (1000 toe)	Available Potential (1000 toe)	Remarks
Sum	-	-	8,824.1	6,176.9	
Paper & wood	3,602.8	0.45	1,621.3	1,134.9	Available potential = 70% of Total energy potential
Food wastes	5,892.9	0.04	235.7	165.0	
Livestock manure	46,122.5	0.0192	886.2	620.3	
Sludge	5,757.3	0.0178	102.5	71.7	
Rubber/leather/plastics	5,627.1	0.825	4,642.3	3,249.6	
Others	2,969.2	0.45	1,336.1	935.3	

Note: 1 The ratio of an available energy potential of each sector is roughly estimated, by considering the increase of recycling of wastes – paper & wood and rubber, leather & plastics – and the use of other purpose – the use of animal feeds in cases of food waste and agricultural residues.

2. Not being able to acquire necessary information on ‘Others’, this study applies the caloric value of paper and wood waste to this.

Source: MOCIE/KEEI(2006: 173, 186; MOTIE/KEMCO, 114)

[63] This study includes the rubber, leather, and plastics into the statistics for renewable energy potential. The Korean government includes them as the category of new and renewable energy and most waste incinerator combusts them with other waste such as paper and wood wastes.

In relation to forest and agricultural residues, this study adopts the estimation of *the 2014 White Paper*, which calculates the potential to be 6,200 thousand toe and 3,485 thousand toe respectively. Even though not included in the analysis of the governmental report, the cultivation of algae and energy plants for alcohol and bio-diesel can be important sources to increase the potential of renewable energy in the future.

Micro-hydro Energy: Micro-hydro energy can be generated from the sources of small rivers or streams, sewage treatment facilities, water purifying facilities, agricultural reservoirs, agricultural dams, aqueducts of multi-purpose dams, etc. According to the government's 2006 report, the technological potential of micro-hydro energy is more than 1,500 MW and the marketable potential by 2030 is 660 MW, as indicated in Table 4-26. Applying the capacity factor of 40 % (MOCIE/KEEI, 2006: 174), the electricity generation of micro-hydro is estimated to be more than 2,313 GWh or 199 thousand toe.

Table 4-26: Micro-hydro Energy Potential

(Unit: MW)

Category	Technological Potential	Marketable Potential	Electricity Generation	
			(GWh)	(1000 toe)
Total	1500.0	660.10	2313.0	198.9

Source: MOCIE/KEEI (2006: 174-5)

Other Renewable Energy Potentials: Other renewable energy sources are geothermal, ocean energy (tide and wave), landfill gas, and the temperature differences between air and (discharging) water. According to the analysis of the government, the potential of geothermal energy[64] is estimated to be 12.5 Mtoe. It is found that the regions suitable for geothermal energy development are Pohang (Gyeongbuk), Asan (Chungnam), Masan (Gyeongnam), and the Northern area of Gyeonggi (MOTIE/KEMCO, 2014: 125 & MOCIE/KEEI, 2006: 178-179).

The ocean energy has the capacity of around 4,050 MW (MOCIE, 2006: 180-185). The potential of tidal energy is estimated to be 2400 MW according to *the 2014 White Paper*. Ocean current and wave energy also have the potential of 1,650 MW. If the capacity factor of 0.24 is applied, the electricity generation from ocean energy amounts to be 8,515 GWh or 732,000 toe. Even though *the 2014 White Paper* estimates the technical potential of ocean energy as 144.6 Mtoe (MOTIE/KEMCO, 2014: 140-141), this study uses the 2006 government report as the potential for 2030, and the result of 2014 report will be considered as the potential for 2050.

According to Lee (n.d.), the amount of landfill gas (LFG) emissions is around 1,917 million m^3. Currently, only eight of 227 landfill sites are using LFG as energy source in Korea. Given that the amount of wastes that go to landfill has been decreasing rapidly and the size of landfill site needs to be large enough[65] to develop LFG, it is difficult to look into the future of LFG. Therefore, this study does not include the potential of LFG. The use of temperature differences between air and water is not only environmentally desirable but also economically efficient. However, this study does not include its potential either, considering their sizes and limitations.

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[64] The government's report estimated the potential by applying the Swiss's situation and prospects (10 % of annual increase).

[65] Lee (n.d.) estimates the minimum economic size of landfill sites for LFG use is 2 million m^3. Only 13 facilities are over 3 million m^3 and 18 are between 1~3 million m^3.

Summary of Renewable Energy Potentials: Table 4-27 summarizes the potential of major renewable energy by source. According to Table 4-27, renewable energy potentials amount to 272.4 (based on PV) ~ 439.8 as final energy in 2030 and 499.0 (based on PV) ~ 623.3 Mtoe in 2050.

Table 4-27: Estimation of Renewable Energy Potential

(Unit: Mtoe per year)

Category	Available Reserves		Remarks
	2030	2050	
Sum	272.4 ~ 439.8 (3,022 TWh)	499.0 ~ 623.3 (5,652 TWh)	
Solar (PV~ heat)	226.3 ~ 385.7 (2,631 TWh)	308.6 ~ 424.9 (3,589 TWh)	- Building area (Byrne et al., 2015a) - Other area (MOTIE/KEMCO, 2014) - Applied efficiency * PV: 0.22 ('30) ~ 0.30 ('50) * Heat: 0.375 ('30) ~ 0.413 ('50)
Wind	24.8 (288 TWh)		- In-land: 7.7 (31.2 %) - Off-shore: 17.1 (68.8 %)
Small hydro	0.20 (2.3TWh)		-MOCIE/KEEI (2006)
Geothermal	12.53		- MOTIE/KEMCO(2014)
Biomass & waste	7.93 (92.2 TWh) ~ 15.86		- Electricity is calculated by adopting 50% of efficiency compared with Heat. -Biomass: MOTIE/KEMCO (2014) -Waste: ME (2013)
Ocean	0.73 (8.5 TWh)	144.6 (1680.9 TWh)	- tide, current, and wave potential -'30: MOCIE/KEEI (2006) -'50: MOTIE/KEMCO (2014)

Note: 1. Available reserves for wind, small hydro, geothermal, biomass, and are assumed to have the same potentials between 2030 and 2050.

2. The efficiency of solar heat reflects the value of MOTIE/KEMCO (2014) for 2030, and calculates the efficiency for 2050 by multiplying AEEI of 20 years.

3. Solar heat and PV are alternatives for each other, competing in the same area.

In 2014, Korea consumed 282.9 Mtoe of TPES and 41.1 Mtoe of electricity. Compared to these values, the renewable potential in 2030 constitutes 96.3 ~ 155.5 % of 2014 TPES and 5.5 times of 2014 electricity demand, and their size would be more extended in 2050. This means that renewable energy could substitute considerable amount of conventional energy including whole electricity, provided that it satisfies the economic requirements like price competiveness.

Solar and wind energy make up large portions of renewable energy: solar energy constitutes 83.1 % of renewable energy potential based on electricity potential; 9.1 % for wind energy; 4.5 % for geothermal; and 2.9 % for biomass and waste. According to the governmental estimation, ocean energy potential is expected to increase to 144.6 Mtoe as final energy.

Compared with other potentials, the potential of this study is larger than those of KIER, CEA and MOCIE/KEEI, while smaller than that MOTIE/KEMCO, as shown in Figure 4-3

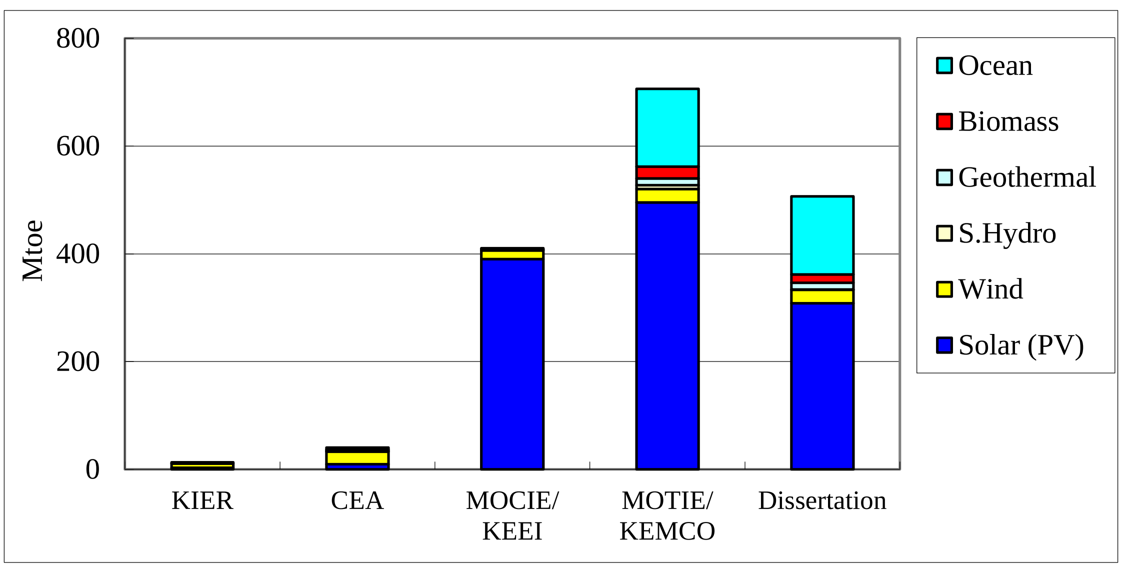

Figure 4-3: Comparisons of Renewable Energy Potential as Final Energy in 2050.

Figure 4-4 shows the regional distribution of renewable energy potential in 2050. The distribution of renewable energy potential is roughly in proportion to the size of a region, because of solar energy and geothermal. However, wind energy is concentrated to regions that are adjacent to the oceans and have proper direction of wind blowing. The distribution of renewable energy potential enables to resolve the problems of conventional energy concentration. The regions such as Jeonnam, Gyeonggi, and Chungnam in which many conventional energy facilities have been built, can have the chance for new development, provided that they can present leading strategies based on the expansion of renewable energy

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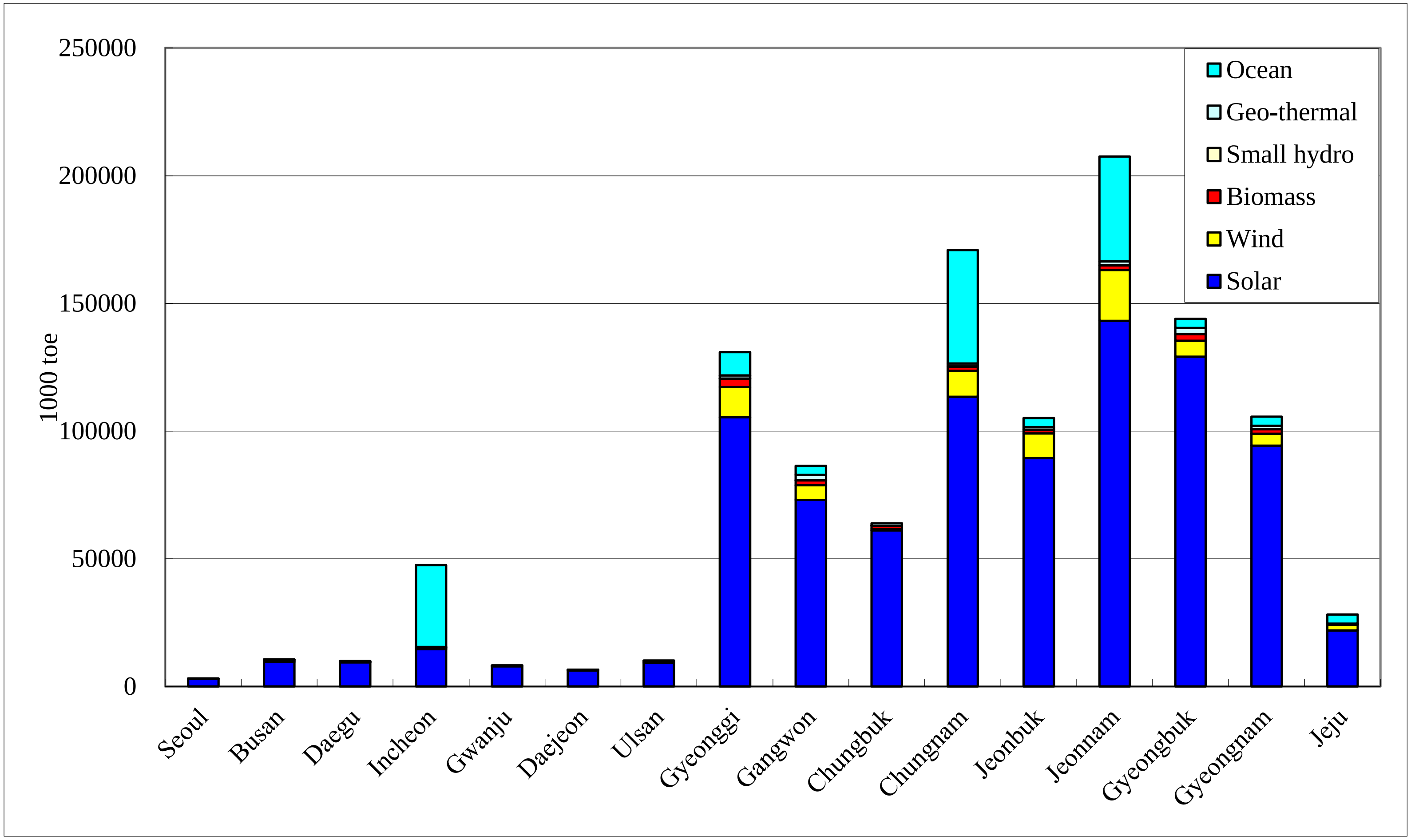

Figure 4-4: Distribution of Renewable Energy Potential by Region in 2050.

Note: 1. Geothermal energy potential is allotted in proportion to their area.

2. Ocean energy potential is distributed according to influential candidates' capacity of each region.

4.3 Energy Model for a Sustainable Energy System

Korea's economic system is based on 'free market economy'. Therefore, the excessive intervention of the government on the market can be criticized. However, certain intervention and coordination of the government is necessary in consideration of the importance of concerned policies; especially, issues that are the very influential to the entire society. To address global climate change is one of these important issues. In this stand, this study plans to deal with important energy-, environment-, economy-, and society-related major policies. Main objective is to reduce GHG and pollutants emissions through economically and socially feasible instruments. Hitherto, many policy alternatives have been recommended and implemented for this purpose, as already examined in Chapter 3.

These policies can be examined from the perspectives of price competitiveness (or economic rationality), available technology and social acceptance. In this sense, four policies are selected: the change of industrial structure, the substitution of anthracite for LNG, the improvement of energy efficiency, and the change of lifestyle. The reform of industrial structure is mainly related with adjustment of energy price, since Korea has promoted energy consuming industries based on intended low-energy price policies, as shown in the literature review on the 'relationship between energy consumption and economic growth' in Section 3.4.3. Major political instruments could be the price change of individual energy sources, the reform of direct and indirect subsidies and incentives on relevant industries. In relation to energy substitution, the effect of this policy (expected GHG reduction level) might not be significant; nonetheless, it is very important for the society. The persistent operation of environmentally harmful and economically-inefficient coal mining implies how strongly the conventional energy system is combined into our society. Without breaking off these tight relations, sustainable energy system might not be brought or be delayed significantly. In this meaning, the suspension of domestic coal mining could be a milestone of transformation from conventional energy-centered system into renewable energy-based one. The importance of development and adoption of energy efficient technologies cannot be stressed enough; many programs implemented currently are examined in Section 3.2.3. Pursuing energy-saving lifestyle is especially important from the perspective of demand management, which is one axis of energy policies in combination with supply-related policies. Since energy system is strongly connected with the society, the reform of energy system is likely to become the Sisyphus's stone without changing people's lifestyle and their actions. Considering these characteristics of energy system and its close relationship with socio-economic system, this study selects these four policies as major subjects for political recommendations.

In addition, this study examines expansion of renewable energy, basically reflecting current policy plans, and expected change of energy price according to the internalization of social costs and technological progress.

4.3.1 External Costs

To estimate external costs for energy consumption, this study uses the methods that the members of KEI, one of the government-run national research institutes, adopt in calculating the social costs of the energy and power transformation sectors. Kang et al. adopt the methods of European Union and KAIST in estimating the social costs of air pollutants, as shown in Table 4-28 (2007: 80-81).

Table 4-28: Unit External Costs of Air Pollutants

Category	CO	NOx	SOx	PM	VOC
Unit (KRW million/ton)	7.28	7.81	44.35	243.97	7.21

Source: Kang et al. (2007: 80-81)

According to NIER, air pollutants emitted from fuel combustion and industrial processes were estimated to be 3,151 thousand ton – CO 700, NOx 1,060, SOx 411, PM10 119, and VOC 862 – in 2012[66], as shown in Table 4-29. Unlike Kang et al. who excludes the VOC emissions from fuel transportation, storage process and organic solvent use (2007: 81), this study includes these processes into the category of industrial process for non-energy oil consumption. To estimate the external costs in 2012, this study combines the air pollutants and CO_2 emissions of 2012 with the external social costs of 2005, using the following method. External costs are also calculated as the real value of 2010

$$\text{External Costs in 2012} \;=\; \text{GDP deflator} \times \sum_{i} \text{UEC}_i \times \text{EA}_i \text{in 2012}$$

where UEC_i = unit external cost of air pollutant i or CO_2,

EA_i = amount of emission of i in 2012

[66] The 2012 data on air pollutants is the most recent statistic currently available.

Table 4-29: Air Pollutants Emissions in 2012

(Unit: ton per year)

Classification		CO	NOx	SOx	PM10	VOC
Anthracite	Sum	61,279	51,451	76,606	72,709	1,206
	Power Gen.	377	3,027	1,667	60	189
	Others	60,902	48,424	74,939	72,646	1,017
Bituminous	Sum	23,331	168,720	93,494	8,632	2,800
	Power Gen.	21,751	95,272	64,645	3,218	2,589
	Others	1,760	73,448	28,849	5,414	211
Oil	Sum	440,809	622,496	122,580	29,241	102,440
	Bunker-A	121	1,208	3,020	38	11
	Bunker-B	63	258	531	53	19
	Bunker-C	13,940	148,988	117,025	8,265	3,747
	Diesel	146,767	434,020	1,328	20,687	36,298
	Kerosene	2,109	7,609	21	120	114
	Gasoline	271,624	24,045	60		61,691
	Aviation oil	6,185	6,368	595	78	560
LPG		75,778	22,343	68	54	3,074
Natural Gas		71,910	136,259	567	1,143	19,833
Industrial Process (non-energy oil)		26,648	59,002	117,191	7,600	732,163
Total		699,755	1,060,271	410,506	119,379	861,516

Source: NIER (n.d.)

Table 4-30 shows that the social costs amount to KRW 89,098 billion based on the 2010 real value: KRW 68,992 billion for air pollutants and KRW 15,163 billion for GHG. External costs for air pollutants in the power generation sector are relatively smaller than those in other sectors, which mean power plants have more advanced treatment facilities to address air pollution.

Table 4-30: External Costs from Energy Consumption in 2012

(Unit: KRW billion 2010)

Criteria	Sum	Air Pollutants	CO_2
Total	89,098	68,992	20,107
Power Generation Sector	12,885	4,916	7,968
Other Energy Sector	76,213	64,075	12,138

Source: NIER (n.d.) & Kang et al (2007: 80-82)

4.3.2 Internalization of External Costs to the Current Price System

<u>Internalization of Social Costs on Fuels:</u> Air pollutants emissions are greatly affected by not only the characteristics of fuel but also the combustion methods (time, temperature, and air/fuel ratio, etc.) and end-of-pipe treatments, while the CO_2 emissions are dominantly affected by the amount of carbon in fuel[67].

The method to calculate external costs is as follows:

$$\text{External Costs for fuel}_i = FC_i \times \sum_j UC_j \times P_{ij}$$

where i means fuel kind and j means the category of air pollutants
FC_i: an amount of fuel i consumption
UC_j: unit cost for air pollutant j
P_{ij}: an amount of pollutants j emitted when fuel i burned

[67] This study does not neglect the importance of appropriate combustion methods or conditions. However, the difference of CO_2 emission levels between combustion technologies is less significant compared with other air pollutants. The CO_2 emissions, however, would be greatly affected by end-of-pipe technologies provided that CCS technologies are to be realized in the near future.

The external costs for consuming 1 toe of fuel are calculated based on the KEI's estimation of external costs per each air pollutant, the emission statistics of NIER and the fuel consumption data of KEEI[68]. This study uses the statistics data on emissions collected in 2006 and 2012. Since 2007, the Korean government has collected TMS (tele-monitoring system) data from large facilities which established TMS and reflected these data in estimating the emission statistics. Analyzing the 2012 statistics, this study finds that the data based on TMS shows very low emission rate from the bituminous-fired power plants, unlike the data of 2006. Therefore, this study re-calculates the emissions of air pollutants from unit fuel combustion by applying the average values between those of 2006 and 2012 to reduce the possible uncertainty of data precision.

Table 4-31 shows that the external costs of air pollutants range from KRW 0.14 million (bituminous used for power generation) to KRW 2.18 million (anthracite used for combustion of the non-power generation purpose). Table 4-31 shows that external cost from natural gas combustion is the lowest among fossil fuels and their usages.

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68 There are many limits in calculating precise data sets. As shown in Table 4-29, NIER statistics of air pollutants are classified differently according to fuel types – generation vs. others for coal and fuel type for oil, – while the fuel consumption statistics of KEEI are classified differently – domestic vs. import for anthracite, fuel vs. material for bituminous, and energy usage, LPG, and non-energy usage for oil. With these limitations, this study simply classifies them following to fuel types and their use, as shown in Table 4-31. This study applies the emission data of industrial process to the emission from non-energy oil consumption.

Table 4-31: External Costs of Air Pollutant and by Fuel and Usage in 2012

(Unit: KRW thousand per toe)

	Anthracite		Bituminous		Oil			Natural Gas
	Power Gen.	Others	Power Gen.	Others	Energy	LPG	Non-energy	
Total	494.2	2355.6	181.7	216.4	546.4	105.1	234.3	50.3
CO	9.0	113.3	3.4	0.7	82.3	74.5	4.3	10.6
NOx	145.7	53.4	46.0	21.4	122.9	22.7	10.7	30.0
SOx	239.5	477.5	93.4	71.9	138.2	2.1	103.3	0.5
PM-10	95.5	1710.6	38.4	122.4	184.3	1.2	44.6	6.3
VOC	4.5	0.8	0.4	0.1	18.8	4.6	71.4	2.9

Note: Gen. means ‘generation’.
Source: Kang et al. (2007), NIER (n.d.: average emission data between 2006 and 2012)

Table 4-32 shows the external costs calculated from GHG emissions, by applying the cost of 31,855 KRW/t_CO_2, the average value between 2008 and 2012 (Kang et al., 2007: 82). In relation to the external costs of GHG, the MOCIE evaluates it to be 32,000 KRW/t_CO_2 in their *Fourth Electricity Supply and Demand Plan* (2008), and KEEI 27,273 KRW/t_CO_2 (2006: 330). Comparing with these, it is considered that the application of 31,855KRW/t_CO_2 in 2010 is not overestimated. According to Table 4-32, the external costs per toe based on the 2010 real value range from KRW 17.2 thousand for non-energy oil use to KRW 96.9 thousand for anthracite combustion.

Table 4-32: External Costs of CO_2 Emission by Fuel and Usage

(Unit: KRW thousand per toe)

Fuel	Anthracite	Bituminous	Oil			LNG
			Energy	LPG	Non-energy	
Climate Change Costs	96.9	93.3	73.5	62.8	17.2	56.1

Source: Calculated based on Kang et al. (2007)

Table 4-33 presents the additional costs for social damages caused by air pollution and climate change, which are estimated by combining the figures in Table 4-31 and Table 4-32. Despite the limitations of these data in reflecting the full external costs[69], this study adopts them as internalizing the external costs. According to Table 4-33, anthracite has the largest external costs which amount to KRW 0.59 ~ 2.45 million per toe, energy oil is the second, and natural gas has the least which amount to KRW 0.11 million per toe.

Table 4-33: External Costs of Air Pollutants and CO_2 by Fuel and Usage

(Unit: KRW thousand in 2010 per toe)

	Anthracite			Bituminous			Oil			LNG
	Domestic		Import	Gen.	Fuel	Material	Energy	LPG	Non-energy	
	Gen.	Others								
External Cost	591.1	2452.5	2452.5	274.9	309.8	309.8	619.6	167.9	251.5	106.4
- CO_2	96.9	96.9	96.9	93.3	73.5	93.3	73.5	62.8	17.2	56.1
- Air pollutants	494.2	2355.6	2355.6	181.6	216.5	216.5	546.1	105.1	234.3	50.3

69 This study considers only external costs produced from direct fuel combustion or material use. External costs from mining, construction, dismantlement, and waste disposal are not reflected.

Internalization of External Social Costs into Electricity Rate: In this section, this study calculates the comprehensive costs necessary for generating 1kWh of electricity by adding external costs of fuels to their exchange rate. The necessary amount of fuel for generating 1kWh of electricity is calculated using power production efficiency data[70] from KEPCO Statistics (2014: 56-57). External costs are calculated by multiplying the necessary amount of fuel and external costs per unit fuel. Exchange rates of fuel in 2012 are sourced from KEPCO (2014: 113) and the rates are converted into the 2010 value. Table 4-34 shows basic statistics for external costs.

Table 4-34: Internalization Process of the External Costs per Unit Electricity Consumption

Category	Domestic Anthracite	Bituminous	Heavy oil	Internal Combustion	LNG-fueled	Combined Cycle
Necessary fuel for 1kWh power Production (10^4kcal)	0.271	0.241	0.262	0.230	0.261	0.195
External Costs (KRW/kWh)	160.47	66.33	162.57	142.43	27.74	20.75
2012 Exchange Rate(KRW/kWh)	92.22	58.90	224.65	224.65	186.54	147.93
Corrected Rate (KRW/kWh)	252.70	125.22	387.21	367.08	214.28	168.68

Source: Kang et al. (2007) and KEPCO (2014)

70 The efficiency data adopted are based on the spot of consumption, which means the exclusion of auxiliary use rate (3.99 % in 2014) and T&D loss (3.69 % in 2014) from gross electricity generation efficiency (MOTIE/KEEI, 2015: 161).

According to Table 4-34, external costs push up the electricity rate from KRW 20.75 (combined cycle) to KRW 162.57 (heavy oil). The cost of producing power using oil is found to be the most expensive. However, the real production cost for domestic anthracite is more expensive than that shown in Table 4-34, if the government's subsidies on domestic coal are taken into accounted. According to Table 4-34, bituminous is the most price-competitive among fossil fuels, even though the external costs caused by air pollutants emitted from bituminous-fired power plants are greater than those of combined cycles.

4.3.3 Examination on the Reform of Industrial Structure[71]

As mentioned, the government's 2015 policy scenarios look to a more energy intensive industrial structure than those of KEEI's 2006 prospect. Regarding this, the KIER, a government-supporting institute, stresses the need for a structural reorganization towards a less energy intensive energy system (2004: 18). Noh (2014) also stands in this position, as examined in Section 3.4.2. Therefore, this study suggests the reform of industrial structure, with the target suggested by KEEI (2006: 150-2). According to Lee (2008), the share of the service sector in GDP is 57.2 % in Korea, while that of Japan is 68.2 % and that of US is 76.5 %. This indirectly illustrates that the industrial structural reform will not only be capable but also necessary to advance into the group of developed economies.

[71] There could be a criticism that the change of industrial structure is not a matter of the governmental policies, since it belongs to the economy which affected by market principles such as 'demand' and 'supply'. However, there is sufficient room for the government to intervene directly or indirectly. For example, rapid growth of energy consuming industries in Korea is deeply indebted to low energy price policies. Therefore, this study addresses this topic as one of the policy recommendations to lead energy system into a sustainable one.

In this meaning, KEEI's scenario is adopted as the target for the change of industrial structure, assuming that the energy intensive industries would decrease and the commercial sector would expand, as shown in Table 4-35.

Table 4-35: Industrial Structure Included in KEEI's 2006 Scenario

Category	2012	2015	2020	2025	2030
Agriculture et al.	2.8 %	2.7 %	2.4 %	2.1 %	1.8 %
Mining	0.2 %	0.2 %	0.1 %	0.1 %	0.1 %
Manufacturing	32.6 %	31.5 %	29.8 %	28.0 %	26.3 %
Food & Beverage	3.6 %	3.4 %	3.0 %	2.7 %	2.4 %
Textile & Clothes	3.3 %	3.0 %	2.3 %	1.7 %	1.1 %
Wood & Paper	2.7 %	2.5 %	2.1 %	1.8 %	1.5 %
Petrochemical	13.9 %	13.5 %	12.6 %	11.8 %	11.0 %
Non-metal Mineral	2.6 %	2.4 %	2.1 %	1.7 %	1.4 %
Primary Metal	8.9 %	8.0 %	6.6 %	5.1 %	3.7 %
Assembling	63.7 %	66.2 %	70.3 %	74.5 %	78.6 %
Other Manufacturing	1.3 %	1.2 %	0.9 %	0.6 %	0.3 %
Construction	5.6 %	5.7 %	5.9 %	6.1 %	6.3 %
SOC	2.3 %	2.4 %	2.6 %	2.8 %	3.0 %
Service	56.5 %	57.5 %	59.2 %	60.8 %	62.5 %

Note: KEEI data were partially corrected by reflecting the real data of 2012.
Source: Unofficial Government's Data (2012 actual data) and KEEI (2006: 150-2)

Based on KEEI's 2006 data and the government's 2015 data, this study suggests a gradual transition of industrial structure from those of the government's scenario to those of KEEI's 2006 scenario, to be made in 15 years from 2015 to 2030. This study also assumes a relative decrease in the value-added of the manufacturing sector would be completely absorbed in the commercial sector, which means no additional change is expected in the government's 2015 scenario except for the manufacturing and commercial sectors. The transition equation is as follows:

$$EC_{ij} = \text{Unit\_EC}_{ij} \times \text{BaU\_VA}_{ij} \times \left(1 \pm \frac{\text{KEEI\_VA}_{ij}}{\text{BaU\_VA}_{ij}} \times \text{Year}_{ij}\right)$$

where EC*ij* means energy consumption in the sector *i* in the year *j*
Unit_EC*ij* means energy consumption per unit value-added
BaU_VA*ij* and KEEI_VAij means Sector *i*'s value-added in the year of *j* for BaU and KEEI Scenario respectively

Table 4-36 presents the distribution ratios of each industrial sub-sector and commercial sector, which this study has used, and Table 4-37 shows the relative variation ranges compared with the government's 2015 report.

Table 4-36: Industrial Structure Change Scenario Adopted by This Study

Category	2014	2015	2020	2025	2030
Agriculture et al.	2.70 %	2.63 %	2.32 %	2.04 %	1.80 %
Mining	0.15 %	0.15 %	0.13 %	0.11 %	0.09 %
Manufacturing	33.18 %	32.70 %	30.40 %	28.27 %	26.28 %
Food & Beverage	3.43 %	3.36 %	2.99 %	2.66 %	2.37 %
Textile & Clothes	3.21 %	3.01 %	2.15 %	1.54 %	1.10 %
Wood & Paper	2.37 %	2.30 %	2.00 %	1.73 %	1.50 %
Petrochemical	13.71 %	13.53 %	12.63 %	11.78 %	11.00 %
Non-metal Mineral	2.56 %	2.46 %	2.04 %	1.69 %	1.40 %
Primary Metal	8.29 %	7.88 %	6.13 %	4.76 %	3.70 %
Assembling	65.14 %	65.91 %	69.90 %	74.12 %	78.60 %
Other Manufacturing	1.27 %	1.16 %	0.74 %	0.47 %	0.30 %
Construction	5.47 %	5.52 %	5.77 %	6.03 %	6.30 %
SOC	2.28 %	2.32 %	2.53 %	2.77 %	3.03 %
Service	50.53 %	51.21 %	54.73 %	58.48 %	62.50 %

Source: Unofficial Government data (2012 actual data), PMO et al. (2008)

Table 4-37: Relative Change of Value-added in Comparison with the BaU Scenario

Category	2014	2020	2025	2030
Agriculture et al.	100.0 %	104.1 %	107.0 %	110.3 %
Mining	100.0 %	110.0 %	115.7 %	120.9 %
Manufacturing	100.0 %	86.8 %	79.1 %	73.8 %
Food & Beverage	100.0 %	94.4 %	88.7 %	84.8 %
Textile & Clothes	100.0 %	64.4 %	46.7 %	34.6 %
Wood & Paper	100.0 %	101.0 %	103.2 %	107.6 %
Petrochemical	100.0 %	88.5 %	84.0 %	79.4 %
Non-metal	100.0 %	74.9 %	62.7 %	53.2 %
Primary Metal	100.0 %	79.9 %	62.5 %	48.6 %
Assembling	100.0 %	86.5 %	79.8 %	75.1 %
Other manufacturing	100.0 %	58.2 %	37.7 %	24.9 %
Construction	100.0 %	113.1 %	128.2 %	145.3 %
SOC	100.0 %	112.3 %	126.5 %	143.3 %
Service	100.0 %	109.3 %	116.3 %	123.0 %

4.3.4 Examination on Domestic Anthracite Production and Consumption

In 2012, 1.0 Mtoe of domestic anthracite was produced and 1.1 Mtoe was consumed, while 5.3 Mtoe of anthracite was imported and 5.4 Mtoe was consumed (KEEI, n.d.). Domestic anthracite is mainly consumed as a form of briquette for heating and for electricity generation. Currently, six anthracite-fired power plants with the capacity of 1,125MW are in operation in Korea (KEPCO, 2014).

The domestic coal industry has been maintained mainly for political reason not for its economic competitiveness. A major subsidy for domestic coal is the exemption of value-added tax (VAT), financing on coal mining, subsidies for briquette production, subsidies for coal mining, and support for electricity utilities (Kang et al., 2007). First, the domestic coal is subject to VAT exemption, which amounts to KRW

73.9 billion. Second, the government's supports for coal mining amount to KRW 369.2 billion (as a financing 95.3 and as a subsidy 273.9). Third, subsidies to reduce the price for briquette for the low-income class amount to KRW 100.4 billion, which is more than half of the briquette cost. Fourth, the government also supports domestic power facilities that use coal, which amounts to KRW 177.3 billion.

Table 4-38: Subsidies for Domestic Anthracites

(Unit: KRW billion)

Total	VAT Exemption	Financing on Coal Mining	Subsidies for Briquette Production	Subsidies for Coal Mining	Support for Electricity Utilities
720.8	73.9	95.3	100.4	273.9	177.3

Note: 1. Financing includes the loan for coal mining and interest rate reduction benefits.
2. While Kang et al. only include a 'subsidy for stable production' as an environmentally harmful subsidy category among many 'subsidies for coal mining', this study additionally includes supports for preventing pollution, for education, for industrial accident compensation insurance, and for closing mine.

Source: Kang et al. (2007: 111, 116, 151)

Summing up, total subsidies for domestic coal amount to KRW 720.8 billion (720.8 million USD, provided KRW 1,000 per USD of currency rate is applied), as shown in Table 4-38 (Kang et al., 2007: 109-116, 151). Considering that Korea spends USD 407 million to import 3.1 Mtoe of anthracite, and supports USD 720.8 million to produce 1.3 Mtoe of domestic coal in 2006, the amount of total subsidies for domestic coal is more than four times compared with the import price.

Despite such a huge government's support for the domestic coal industries, the cost of power generation from domestic anthracite does not have price competitiveness compared with that of bituminous-fired power plants. According to

KPX, the BLMP of domestic coal-fired power plants was 63.94 KRW/kWh, while that of bituminous-fired power plants was 34.05 KRW/kWh (2014). The gap between them would become larger, provided that the subsidies are eradicated. When the social cost is internalized, the cost for electricity generation from domestic anthracite is expected to be the highest among fossil fuels. This analysis finds that the production of domestic coal is not only environmentally harmful but also economically inefficient.

It could be interesting to compare the economic and environmental impacts between domestic coal and natural gas. From an economic perspective, substituting natural gas for domestic coal is more cost-effective. The production cost of domestic coal is estimated to be KRW 0.178 million per toe, assuming its average caloric value as 4,500 kcal/kg and the price as 81,000 KRW/ton[72] (Kang et al., 2007: 115). Combining this cost with the overall subsidies, the actual production cost of domestic coal is estimated to be KRW 0.745 million per toe, which is 4.2 times higher than the current production cost, and two times higher than the import cost of natural gas. The total costs for production and import of anthracite are around USD 1,968 million (domestic 1,541 and import 427), while the import cost of natural gas is USD 1,896 million[73]. As already examined, external costs of anthracite are much higher than other conventional energy sources such as bituminous, oil and LNG, because briquette emits air pollutants directly while being brunt without any treatment. If external costs are considered, the gap between anthracite and natural gas becomes much wider: the social costs of anthracite are KRW 0.70~2.50 million per toe, while those of natural

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[72] The average caloric value and sale price of domestic coal are roughly estimated based on the *Bulletin of MOCIE (2006-138)* (re-cited from Kang et al., 2007: 115).

[73] The applied currency rate is 1,000 Won/USD, considering the production data of domestic coal that were gathered from 2005 to 2006.

gas are KRW 0.53 million. Even though the above analyses have limitations in representing the real price because they do not take into consideration additional costs such as replacement costs of existing infrastructure and facilities, additional costs can be minimized or removed if substitution is carried out gradually.

In this study, it is assumed that the substitution will be made from 2017 to 2026 through an annual decrease in the consumption of anthracite by 10 %. The process of substitution of LNG for anthracite is as follows:

1. Gradual ceasing of anthracite: annually 10 % decrease in anthracite consumption
2. Increase in LNG: 90 % compared with the amount of anthracite decreased considering higher efficiency of LNG

Summing up, the substitution is nationally beneficial not only from an environmental perspective but also from an economic side. This study, in this sense, assumes that anthracite production and imports would be gradually suspended and the support programs for anthracite would also be closed. It is expected that the government would be able to avoid public resistances without experiencing serious conflicts, if the government carries out appropriate measures gradually and supports the affected people with the money saved.

4.3.5 Energy Savings through Efficiency Improvement

Reducing of energy demand or service requirement can be looked at from two categories: the one is to use less energy by adopting more progressive and efficient technologies while providing the same or more energy-related services, and the other is to change the lifestyle that promotes less energy consumption, which will be examined in section 4.3.6. These two are complementary with each other.

In relation, one example is to support the use of high efficiency instruments or devices such as high-efficient motors, less energy intensive light bulbs like LED and more effective insulating materials. To reflect energy saving technologies or designs in urban development and remodeling can be another cases of these policies. The government can establish or improve the related legal and institutional systems to promote efficiency technologies that can save energy or reduce energy requirement. To strengthen a vehicle mileage standard is an example of such policies.

According to WEC, Korea's 2013 energy sustainability index ranking was 64th – energy security 103th, energy equity 49th, and environmental sustainability 85th (2013). Among indexes, 'environmental sustainability' is deeply related with 'the achievement of supply and demand-side energy efficiencies', which is much lower than developed countries. This means that Korea's energy efficiency has much room for improvement. For example, Korea's energy intensity is only 0.19 toe per USD 1000, while that of Germany 0.11 and that of Japan 0.12. To reach the current level of Japanese energy intensity, Korea has to attain 36.8% of energy efficiency improvement.

In relation, The JISEEF suggested interesting policy strategies. According to the JISEEF report, Korea's energy saving potential through efficiency improvement amounts to 70.0Mtoe as a final energy, and CO_2 reduction potential 56.7Mt_C by 2020 , which means more than 27% of efficiency improvement (Byrne & Wang et al., 2004: 264-270). This study adopts the suggestion of JISEEF report, which is shown in Table 4-39, as the target for Korea's energy efficiency improvement with some adjustments like the extension of target year into 2030, considering that Korea is still in progress without achieving the suggested policies.

Table 4-39: JISEEF's Energy Savings and CO_2 Reduction Potentials through Efficiency Improvement by 2020

Category			Energy Saving			CO_2 Reduction		
			BaU TFC	Reduction Ratio	Saving Amount	BaU Emission	Reduction Ratio	Reduction Amount
Total			257.9	27.1 %	70.0	204.4	27.7 %	56.7
Industry	Sectoral Sum		128.3	25.0 %	32.1	92.9	25.2 %	23.4
	Analyzed fields	Sub-total	110.2	25.0 %	27.5	83.1	25.2 %	20.9
		Energy intensive sub-sectors	76.9	24.4 %	18.8	50.0	24.4 %	12.2
		Other sub-sectors	33.2	26.4 %	8.8	33.1	26.4 %	8.7
	Presumed fields		18.2	25.0 %	4.5	9.8	25.2 %	2.5
Transport	Sectoral Sum		58.8	28.0 %	16.5	48.0	28.0 %	13.4
	Road	Car	25.5	34.6 %	8.8	19.7	35.7 %	7.0
		Truck	12.5	24.2 %	3.0	10.5	24.1 %	2.5
		Bus	5.7	29.0 %	1.7	4.8	28.4 %	1.4
	Railroad, marine, aviation		15.1	20.0 %	3.0	13.0	19.3 %	2.5
Commercial	Sectoral Sum		27.4	33.2 %	9.1	28.1	33.5 %	9.4
	Analyzed fields	Sub-total	22.8	35.7 %	8.2	24.8	35.3 %	8.7
		Heating	10.1	29.2 %	2.9	7.6	27.1 %	2.1
		Cooling	2.4	39.0 %	0.9	3.3	39.0 %	1.3
		Lighting	7.2	33.1 %	2.4	9.6	33.0 %	3.2
		Motor	3.2	42.0 %	1.3	4.2	42.0 %	1.8
	Presumed fields		4.6	33.2 %	1.5	3.4	33.5 %	1.1
Residential	Sectoral Sum		43.4	28.3 %	12.3	35.4	29.4 %	10.4
	Analyzed fields	Sub-total	35.0	33.8 %	11.8	27.4	34.5 %	9.5
		Heating	32.0	26.9 %	8.6	23.3	26.8 %	6.2
		Cooling	0.8	17.3 %	0.1	1.0	17.3 %	0.2
		Refrigerator	0.9	38.0 %	0.3	1.2	38.0 %	0.5
		Lighting	1.4	61.9 %	0.8	1.9	61.9 %	1.2
	Presumed fields		8.4	28.3 %	2.4	8.0	39.4 %	2.4

Source: Byrne & Wang et al.(2004: 264~270)

In addition, this study excludes the half of AEEI (or 0.5% of annual efficiency improvement) that is reflected in the BaU scenario. For example, the 25% reduction target for the industrial sector by 2020 will be changed into 21.1% reduction goal by 2030 by subtracting 3.9% of efficiency improvement, a half of AEEI accumulated for 15 years from 2016 to 2030.

According to the *Energy Technology Perspectives 2015*, efficiency technologies is evaluated to contribute to more than 38% of GHG reduction by 2050, which has similar effects with this study, as shown in Figure 4-5 (Elzinga, 2015; IEA, 2015b). The adopted saving level can be evaluated as reasonable.

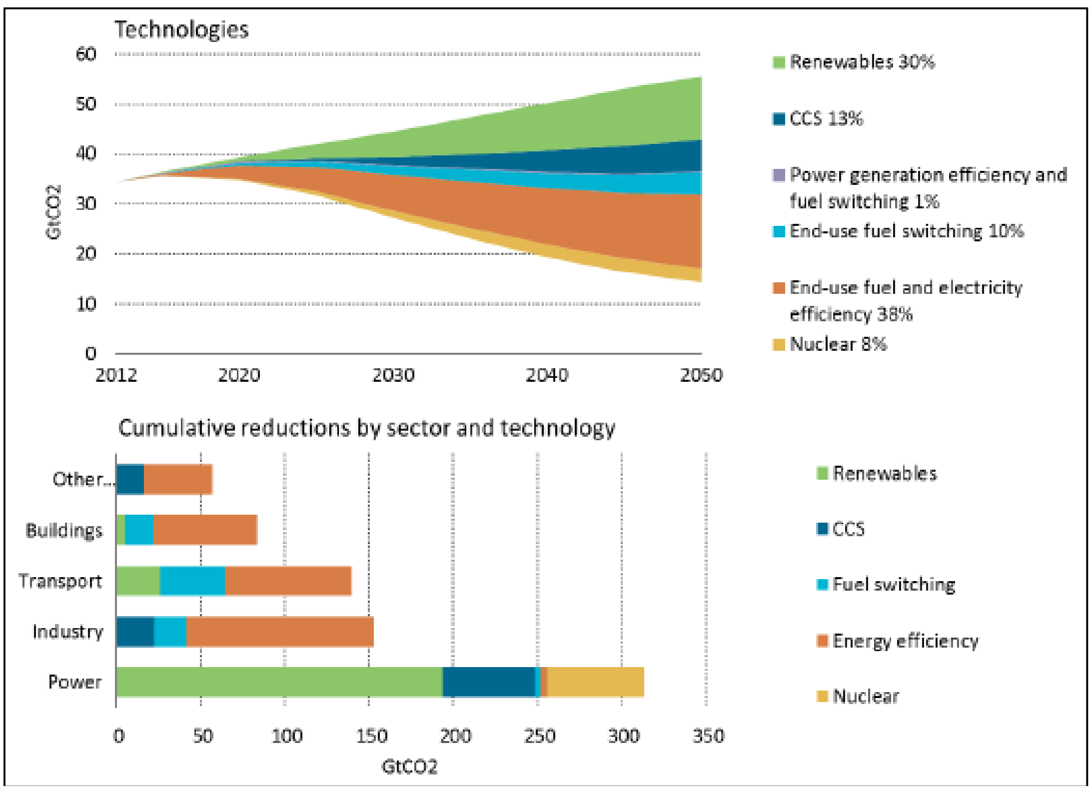

Figure 4-5 Cumulative GHG Reductions by Sector and Technology in the 2DS to 2050 by IEA.
Source: Elzinga (2015)

4.3.6 Energy Savings and CO_2 Reduction through Relieving Energy Service Requirement[74]

In addition to energy efficiency policies, the other way to reduce energy consumption is to change lifestyle into an energy-saving one. The energy saving lifestyle can be acquired by wearing underwear in winter, maintaining a narrow gap between indoor and outdoor temperatures in summer, using (electric) fans instead of air conditioners for cooling, walking or riding bicycles instead of driving within a walking distance, and using mass transportation more frequently instead of driving private automobiles. The promotion of seasonal local food ("2050 Japan Low-Carbon Society Scenario" Team, 2007 & 2008) can be another important example.

In relation, the Scenario Team of "2050 Japan Low-Carbon Society" asserts that Japan has the potential to reduce 25 ~ 29 Mt_C of GHG emissions by 2050 (2007) through energy service reduction measures such as advanced insulation technologies, HEMS, BEMS, reduction of trip distances through intensive land use and concentrated urban function, improvement of public transportation, construction of pedestrian- and bicycle rider-friendly transportation infrastructure and the promotion of seasonal local food (2007, 2008).

Considering these, this study assumes that 10 % reduction from the residential, commercial, transportation and public sectors and 5 % reduction from the industrial sector are attainable by 2030, even though actual reduction of energy service requirements is difficult to quantify due to many uncertainties.

Generally, energy saving through reducing energy service requirements is considered to be easily applicable to residential, transportation and service areas, and

74 The 'reduction of energy service' means the reduction of energy necessity, while 'efficiency improvement' means the supply of the same service with less energy.

relatively difficult to be applied in the industrial sector. However, the potential to reduce energy service requirements is not limited to specific areas. For example; the re-location of data centers which consume much electric energy to cool the system, can save much energy if they are established in the right region and designed to use natural energy for cooling instead of electricity.

In Korea, cases of wasting energy can be easily found; for example, compact car is sold just 27 % of the total vehicle models, while reaching 63 ~ 64 % in Japan and Italy; daily mileage of automobile is 57.3km, much more than those of developed countries such as Japan (25.2km), UK (41.6km) and the US (54.8km) (Chosunilbo, 2009). Recently, Japanese companies arouse controversy in Korea with their attempt to establish data centers for the purpose of taking advantage of Korea's cheaper electricity rate. Although the Korean government promotes to attract 'global cloud data center' (The Hankyoreh, 2015), these movements would cause excessive electricity consumption, and thereby, the growth of GHG emissions. On the contrary, international IT enterprises such as Apple, Google and Facebook plan to use renewable energy or to relocate their data centers to the areas where natural energy is available in cooling a system and thus saving energy (ETNEWS, 2015). Even though these are partial cases, there is much potential to reduce electricity or other energy.

Considering these various possibilities, the save of 5~10 % of final energy through reducing energy service requirements can be realized.

4.4 Forecast of Long-term Energy Costs

4.4.1 Future Fuel Costs

The Korean government adopts the IEA's high oil price prospect in predicting future oil prices. The prospect of oil price by IEA is USD 136.1 in 2030 as the 2012 value or USD 132.7 as the 2010 value, as already shown in Table 4-2. The prospect of coal (bituminous) and natural gas is somewhat disputable. When examining the historical data of Korea on fossil fuel imports, it was difficult to find any systematic relations between coal (bituminous) and natural gas: their relative range of changes is greatly affected by the period of examination.

Considering these uncertainties and difficulties, this study assumes the price change ratios of natural gas and bituminous would be the same with that of oil. For the post-2030 period, this study applies that the annual price increase rate of fossil is 1.28 % during the period of 2020 and 2030.

Table 4-40: Internalization Process of Social Costs

	2012-2016	2017-2026	2027-2050	Remarks
Climate Change Damages factor	1.00 ~ 1.13	1.17 ~ 1.54	1.94 ~ 3.23	Annual increase rate 3.13 %
Air pollution Reflected Ratio	0 %	10 % →100 %	100 %	
Climate Change Reflected Ratio	0 %	10 % → 100 % (0.12 ~ 1.54)	100 % (1.94 ~ 3.23)	Numbers in ( ) means factor values reflected

To examine the internalization of social costs, this study applies different assumption between air pollutants and CO_2: social damages caused by each unit of air pollutants are assumed not to increase in the future, while the damages caused by climate change would be exacerbated in the future. As mentioned, the price of CO_2 is estimated to be 31,855 KRW/t_CO_2 in 2012 will increase to 3.23 times in 2050 or USD 93[75] with the currency rate of 1,105KRW/USD. Considering economic effects, this study assumes no internalization by 2016, and gradual reflection by 10 % from 2017 and full reflection in 2026. Table 4-41 shows the internalized external costs of fossil fuels.

Table 4-41: Internalization of Social Costs by Fuel in 2012 Based on 2010 Value

(Unit: KRW thousand per toe)

<table>
<tr><th colspan="3" rowspan="2">Category</th><th rowspan="2">Total Costs</th><th rowspan="2">Production or Import Costs</th><th colspan="3">External Costs</th></tr>
<tr><th>Sub-total</th><th>Climate change</th><th>Air Pollution</th></tr>
<tr><td rowspan="3">Anthracite</td><td rowspan="2">Domes-tic</td><td>Gen.</td><td>849.6</td><td>258.4</td><td>591.1</td><td>96.9</td><td>494.2</td></tr>
<tr><td>Others</td><td>2710.9</td><td>258.4</td><td>2452.5</td><td>96.9</td><td>2355.6</td></tr>
<tr><td colspan="2">Import</td><td>2678.2</td><td>225.7</td><td>2452.5</td><td>96.9</td><td>2355.6</td></tr>
<tr><td rowspan="2">Bituminous</td><td colspan="2">Gen.</td><td>434.1</td><td>159.2</td><td>274.9</td><td>93.3</td><td>181.6</td></tr>
<tr><td colspan="2">Others</td><td>469.0</td><td>159.2</td><td>309.8</td><td>93.3</td><td>216.5</td></tr>
<tr><td rowspan="3">Oil</td><td colspan="2">Energy oil</td><td>1237.4</td><td>617.8</td><td>619.6</td><td>73.5</td><td>546.1</td></tr>
<tr><td colspan="2">LPG</td><td>785.7</td><td>617.8</td><td>167.8</td><td>62.8</td><td>105.1</td></tr>
<tr><td colspan="2">Non-energy oil</td><td>869.4</td><td>617.8</td><td>251.5</td><td>17.2</td><td>234.3</td></tr>
<tr><td colspan="3">Natural gas</td><td>563.3</td><td>456.9</td><td>106.4</td><td>56.1</td><td>50.3</td></tr>
</table>

Note: ‘Gen.’ means the fuels used for electricity generation.
Sources: Kang et al. (2007) and NIER (n.d.)

75 The Carbon Tax Center (2008) suggested initial CO_2 cost as 10 USD per t_CO_2 with annual increase rate of $10, which attains to 100~200 USD/t_CO_2 in 20years, while IPCC (2007: 19) prospected that carbon prices will attain to 20~80 USD/t_CO_2 by 2030 and 30~155 USD/tCO_2 by 2050. The study adopts the medium value of IPCC as the price of 2050.

4.4.2 Future Electricity Costs

Premises: In relation to the price of fossil fuel and the internalization of social costs caused by air pollutants and GHG, the premises previously mentioned will be applied. In addition, it is assumed that the fossil fuel-fired power plants and electricity transmission and distribution loss (T&D loss) would make a 0.5 % of annual progress. The value is based on the AEEI without any political intervention, the size of which was assumed by USDOE's LBNL, KEEI, and Boo et al. (Boo & Choi, 2002: 64). Applying the rate, it is found that conventional power plants are expected to have 20.3 % of efficiency improvement by 2050.

Regarding the electricity generation from renewable energy sources, this study assumes the rapid down of costs indebted to rapid technological improvement, increased economies of scale, and manufacturing experience (Byrnes & Wang 2014). Current price down trends and many research results, as shown in Table 4-42, support this position. According to Mints, the average sales price of PV module have dramatically lowered from 68.61$/Wp in 1976 to 1.47$/Wp in 2010 and 0.75$/Wp in 2012, based on 2011 USD (2013, recited from Do (2014: 169)). Based on these findings and MOTIE[76] predictions, the study, conservatively to some extent, assumes that the annual reduction rate of the price of renewable energy would be 6 % by 2020, 5 % between 2021 and 2025, 4 % between 2026 and 2030, 3 % between 2031 and 2035, and 2 % between 2036 and 2050 in case of PV and 2 % by 2050 in cases of wind and fuel cell.

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[76] MOCIE(2006b) applies the annual reduction rates of renewable energy costs to be 4 % for PV and 2 % for wind and fuel cell; the 3rd NRE plan (MKE, 2008) assumes 5% for PV, 3.4% for wind, and 9% for solar heat between 2020 and 2030; and the 4th NRE plan (MOTIE, 2014b) assumes 5% for PV and 2% for wind

Table 4-42: Trends and Prospects of Future Renewable Electricity Costs

Category	Data Sources		2010	2012	2015	2020	2030	2050
Solar	Mints (2013, $ 2011/Wp))		1.47	0.75				
	IEA (2014b: 22, $/W)		4('08)	0.8			0.3-0.47('35)	
	CLSA (2004)		Decrease of 20 % for every doubling output, more than 5 % annual cost reduction					
	IEA (2000)		Decrease of 18 % for every doubling output					
			Decrease of ~35 % for every doubling output (Europe, '85-'95)					
	EERE (2012)		$1/Wp for Utility-scale PV system, $1.25/Wp for comer-cial PV, and $1.5 for residential rooftop PV by 2020					
	Mckinsey Global Institute (2008)		Decrease of 23 % for every doubling output (1975-2003)					
	DOE/EERE (2006)	PV	13-22 (2011)			5-10		
		CSP	8-10 (2011)			3.5-6		
	DOE (2007)				5-7(CSP)	5(CSP)		
Wind	IEA (2000)		Decrease of 18 % for every doubling output (Europe, '80-'95)					
	Mckinsey Global Institute (2008)		Decrease of 13 % for every doubling output (1981-2001)					
Hydro	IEA (2005)		2					
Biomass	IEA (2005)		2					
	IEA (2000)		Decrease of 15 % for every doubling output					
	Mckinsey Global Institute (2008)		Decrease of 15 % for every doubling output (Ethanol, 1978-1996)					
Geo-thermal	IEA (2005)		2-3					

1. 'CSP' means 'concentrating solar power'.
Sources: Included in the Table.

Figure 4-6 shows that the expected PV efficiency of this study is somewhat conservative. Figure 4-7, the summary of the worldwide electricity generation costs for fossil fuels and renewable energy sources, shows that many renewable energy sources have already gained price-competitiveness in terms of electricity generation costs, compared with fossil fuels (2014, recited from Do (2014)).

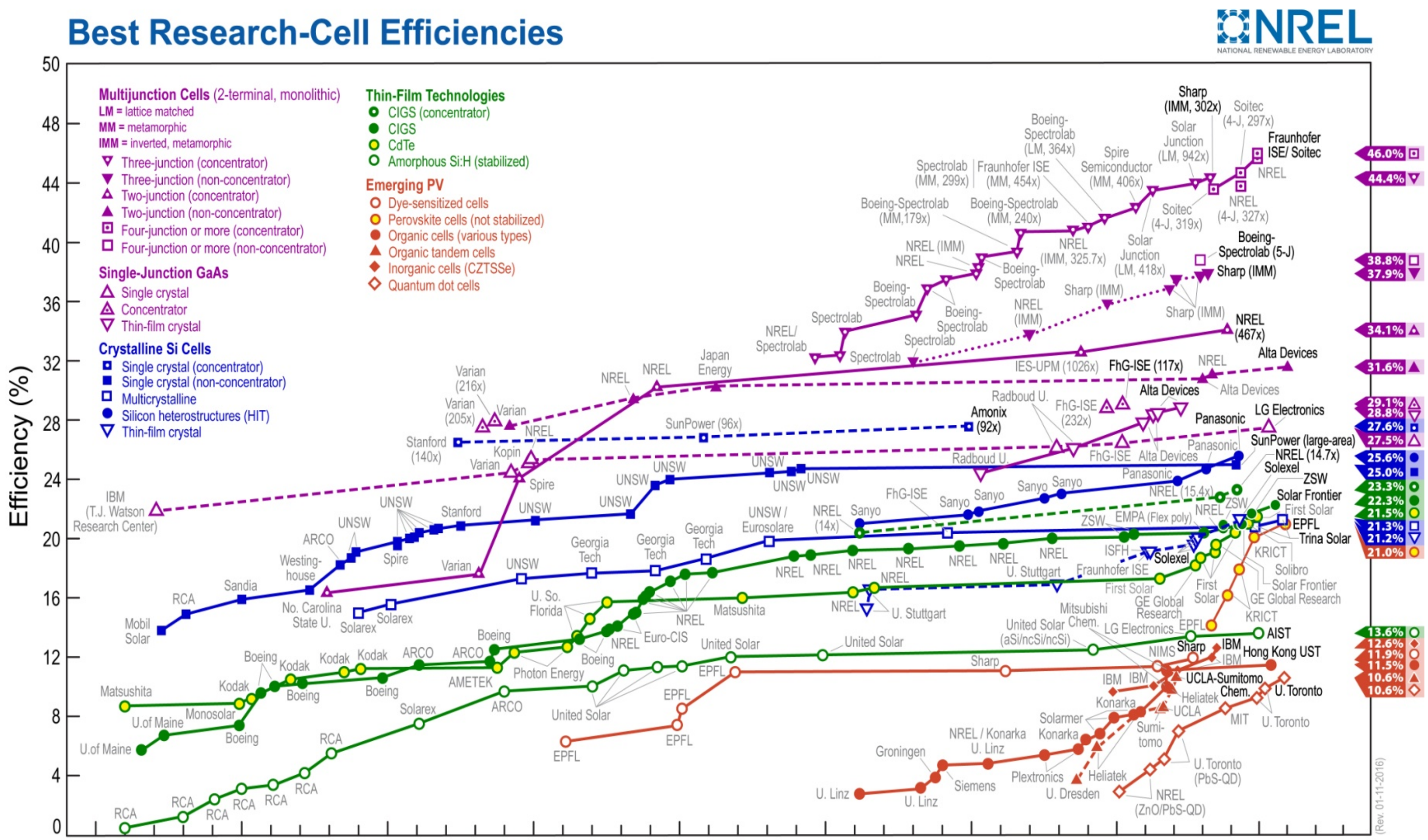


Figure 4-6: Best Research-Cell Efficiencies.
Source: NREL (2016)

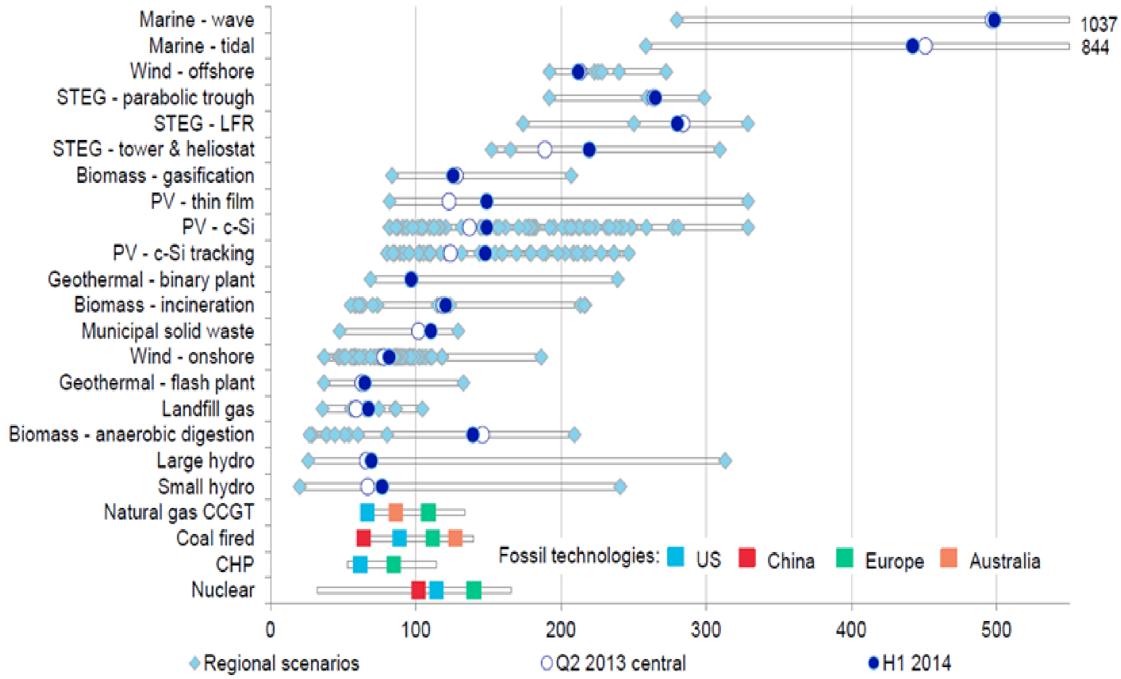


Figure 4-7: Electricity Generation Costs by Source and Fuel.
Source: BNEF (2014), recited from Do (2014)

Delivery Charge: The delivery charge was around 14.1 KRW/kWh in 2013 and 17.1 KRW/kWh[77] in 2014 (KEPCO, 2014 & 2015; MOTIE/KEEI, 2015). In the future, it is predicted that the annual increase rate would be 1.59 %, reflecting the average increase rate of the US from 1998 to 2007. The reason not to use Korea's historical data is that the Korean government has been controlling the electricity market strongly to prevent the increase of electricity rate. When this rate is applied, the delivery charge in 2050 is expected to be 25.3 KRW/kWh given the 2010 value.

[77] Average exchange rate in the Korea Power Exchange was 93.70 Won/kWh and sales price 111.28 Won/kWh in 2014. This study assumes the difference is due to the average delivery charge, and corrects the charge with the 2010 value.

Initial Price: According to MOTIE/KEEI, the average exchange rate in 2012 is 89.62KRW/kWh (2015: 197), as shown in Table 4-43. Provided that externalities are not considered, the electricity generated from nuclear is found to be the most competitive, followed by bituminous. When it comes to renewable energy sources, the generation cost was 325.67 KRW/kWh for solar energy, 155.22 for wind, and 300.93 for fuel cell in 2013 and 237.29 KRW/kWh for solar energy, 146.14 for wind, and 270.29 for fuel cell in 2014 (KEPCO, 2015: 114 & 2015: 114). This study analyzes the future price based on the above exchange rates, but as the value of 2010. Subjective sources are confined to bituminous, heavy oil, natural gas, PV, wind, and fuel cell. Initial price or exchange rate may be divided into two elements – fuel costs (or import costs) and operation and maintenance costs (or O&M costs).

Table 4-43: Electricity Exchange Amounts and Rate in 2012

Electricity Source	Electricity Exchanged (GWH)	Exchange Amount (KRW billion)	Exchange Rate (KRW/kWh)
Hydro	2,071	333	160.91
Hydro (Pumping)	5,041	866	171.82
Natural Gas, Combined Cycle	114.940	18,482	160.80
Heavy Oil	7,565	1,671	220.86
Domestic Anthracite	7,752	707	91.19
Bituminous	189,471	12,004	63.36
Nuclear	149,165	8,199	54.96
Others	14,336	1,687	117.68
Sum or Average	490,372	43,948	89.62

Source: MOTIE/KEEI (2015: 197)

Import Costs of Fossil Fuel: Figure 4-8 shows the prospects of import prices of fossil fuels by 2050, given their amount necessary for generating 1kWh of electricity. The increase rate is expected to be more or less the same among fuels per unit caloric value. However, the change in the amount of fossil fuels needed, influenced by the current efficiencies and technological progress, can affect the price prospects. Figure 4-8 shows that the increase size of heavy oil and LNG are much larger than that of bituminous. That is why the current import prices per unit caloric value of the formers are higher than that of the latter. Even though the increase rates are the same, their arithmetic differences would go up over time.

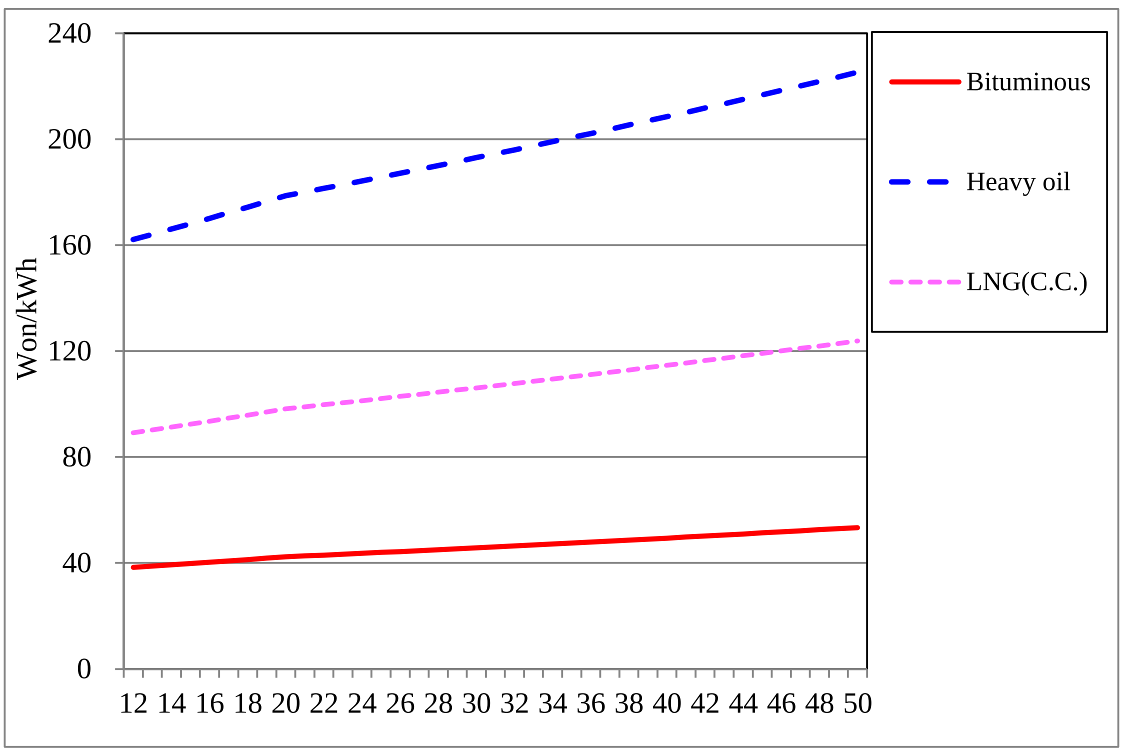


Figure 4-8: Prospects of Major Fossil Fuels' Imported Price.

Analysis of Cost Elements on Fossil Fuel Based on Electricity Production:

Figure 4-9 shows the changes in the price elements for bituminous-fired power plants. This study differentiates the price elements into five categories: fuel import price, operation and maintenance costs (O&M costs), social costs from air pollution, social costs by CO_2, and delivery charge (or T&D costs). In bituminous-fired power plants, total generation costs in 2050 are expected to be KRW 212.8 per kWh: fuel import price constitutes 25.1 % (KRW 53.4), O&M cost 17.5 % (KRW 37.3), the cost for air pollution cost 17.1 % (KRW 36.4), the cost for climate change 28.4 % (KRW 60.4), and delivery charge 11.9 % (KRW 25.3). As a result, the share of social costs by climate change is analyzed as the most influential in bituminous-fired power plants. The portion of fuel price is relatively small.

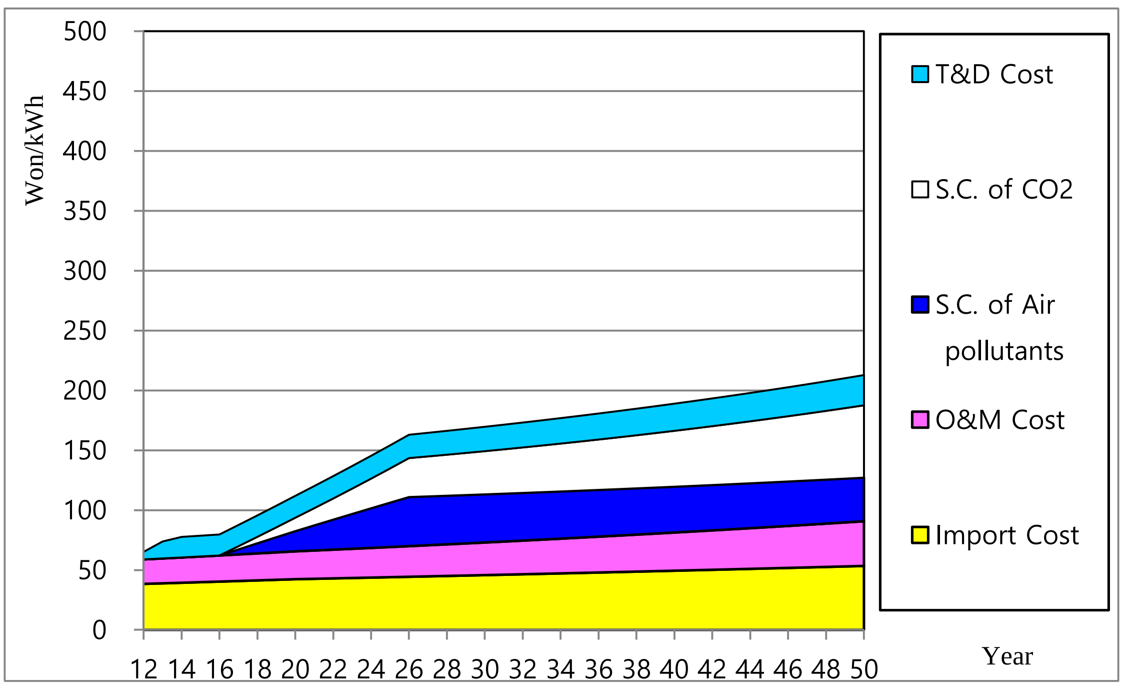


Figure 4-9: Prospects of Price Elements Change for Bituminous-fired Power Plants.

Figure 4-10 shows the changes in the price elements for natural gas-fired power plants as a form of combined cycle type. For natural gas-fired power plants, total generation costs in 2050 are expected to be KRW 293.7 per kWh: fuel import price constitutes 42.2 % (KRW 123.9), O&M cost 36.5 % (KRW 107.1), the cost for air pollution 2.8 % (KRW 8.2), the cost for climate change 10.0 % (KRW 29.4), and delivery charge 8.6 % (KRW 25.3). According to the analysis, it is found that the share of fuel price is the most influential factor in natural gas-fired power plants. However, the cost generated from air pollution takes a very small portion, with only 2.8 %. The portion of social costs caused by climate change is also low, but larger than those of air pollution. The figure also presents that supplying low-priced natural gas has the possibility to reduce the costs.

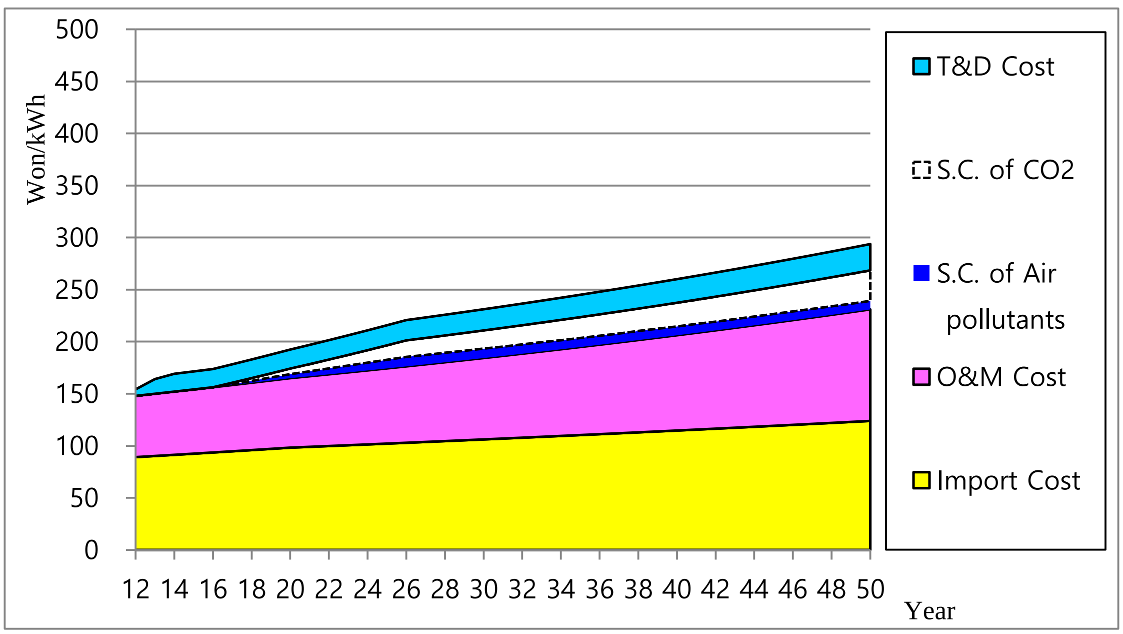


Figure 4-10: Prospects of Price Elements Change for Natural Gas-fired Power Plants.

The changes in the price elements for (heavy) oil-fired power plants are indicated in Figure 4-11. For oil-fired power plants, total generation costs in 2050 are expected to be KRW 423.3 per kWh, which is the most expensive among fossil fuel sources: fuel import price constitutes 53.2 % (KRW 225.3), O&M cost 26.9 % (KRW 113.9), the cost for air pollution 4.7 % (KRW 20.1), the cost for climate change 9.1 % (KRW 38.7), and delivery charge 6.0 % (KRW 25.3).

The analysis shows that the share of fuel price is the most influential factor in oil-fired power plants, even more than the case of natural gas. The costs for both air pollution and climate change are between the portions taken by natural gas- and bituminous-fired power plants.

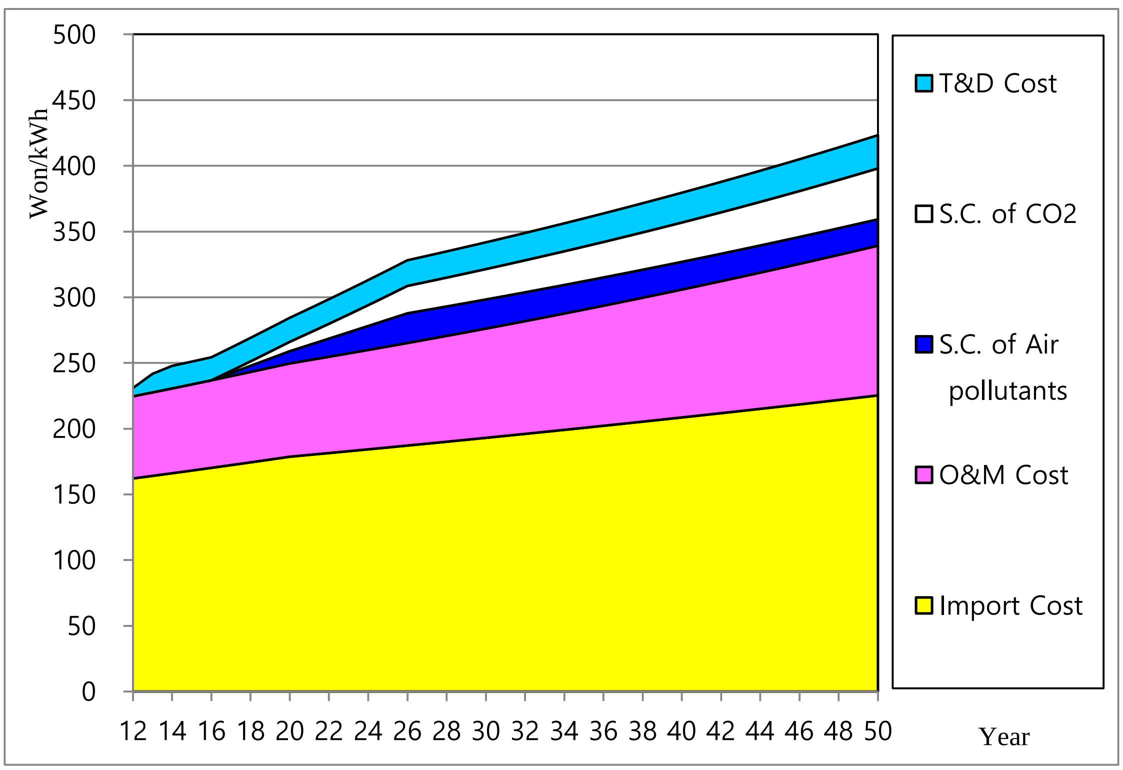


Figure 4-11: Prospects of Price Elements Change for Oil-fired Power Plants.

To sum up, the analysis shows that bituminous is the most price competitive fuel among fossil fuels, under the given IEA's oil price scenario. The price advantage of bituminous does not change with the inclusion of social costs, because of its price advantage and gradual reflection of social costs. The electricity production from oil is expected to lose its competiveness. Figure 4-12 shows price prospects of bituminous-, heavy oil-, and natural gas-fired power plants.

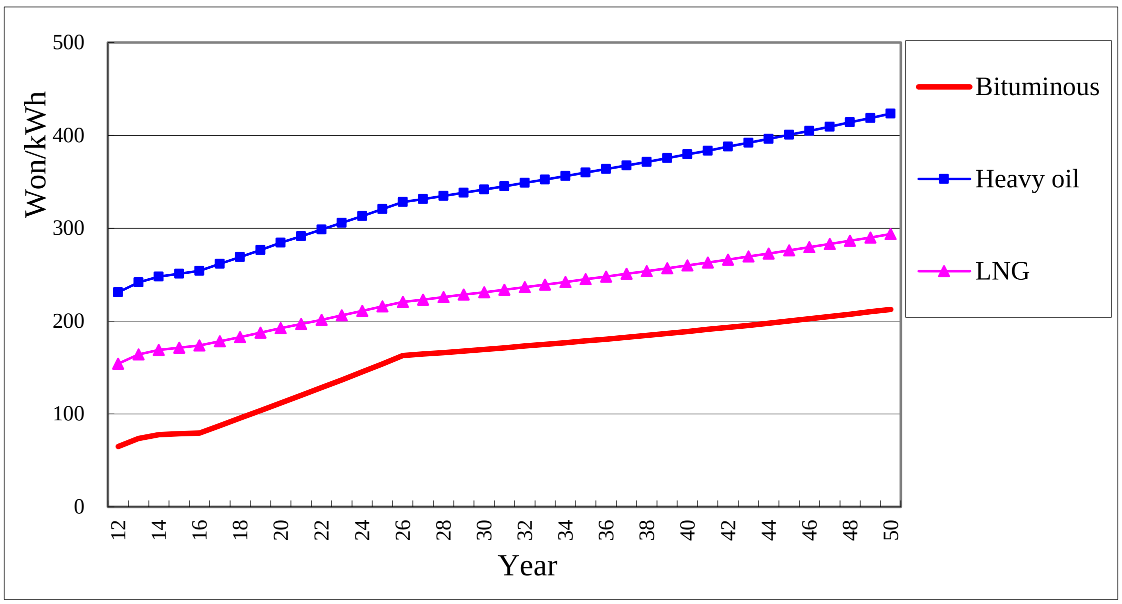


Figure 4-12: Prospects of Price Change for Conventional Power Plants.

Costs Comparison between Renewable Electricity Sources: Electricity generated from wind[78] would continue to remain as most competitive among renewable energy sources by 2029 as shown in Figure 4-13. This study considers two

[78] The production cost difference between in-land and off-shore wind mills is not considered.

cases regarding PV: one is what is connected to general T&D system, and the other is what is directly used on the spot. Direct use of electricity generated from PV (the PV-T&D case in the figure above) has the price advantage than conventional electricity consumption pattern as it saves delivery charge and prevents T&D loss. Considering this differentiation, ‘PV-T&D’ case is expected to become most price-competitive from 2030 among renewable energy sources. According to Figure 4-13, PV is less competitive than wind over the whole period of analysis, but eventually PV approaches to a similar level with wind in terms of competitiveness. Fuel cell is expected to be less competitive before 2020 in both cases of PV-T&D and PV. Considering that the current source of hydrogen is conventional, the cost of fuel cell is expected to be higher than the current price, and additional technological development is needed for securing price competitiveness.

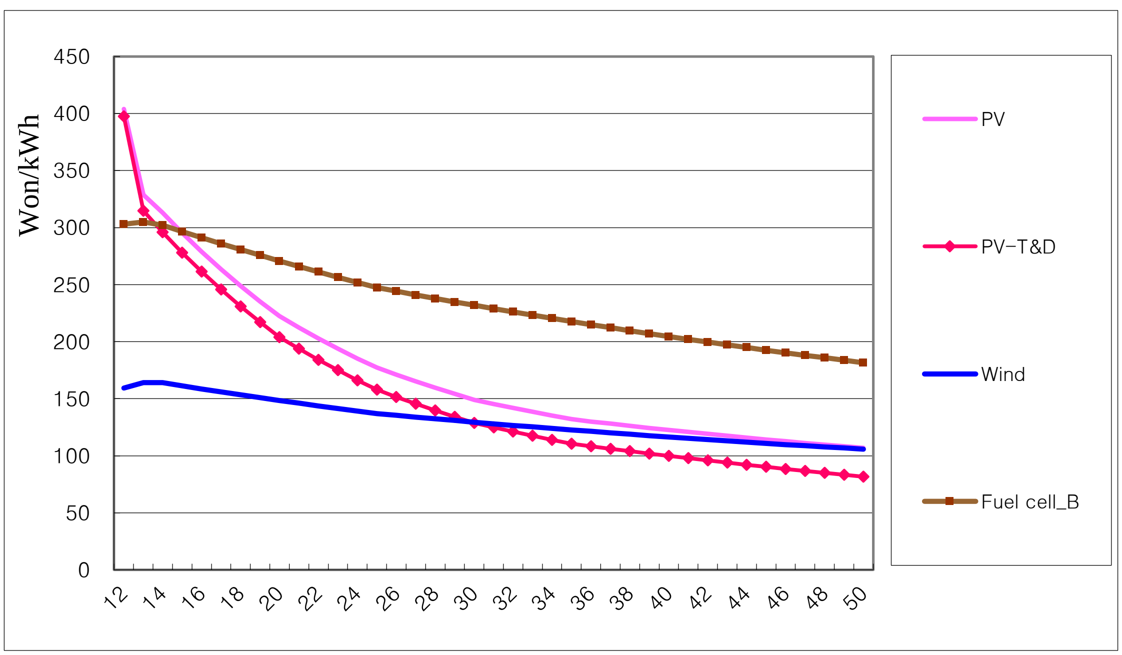
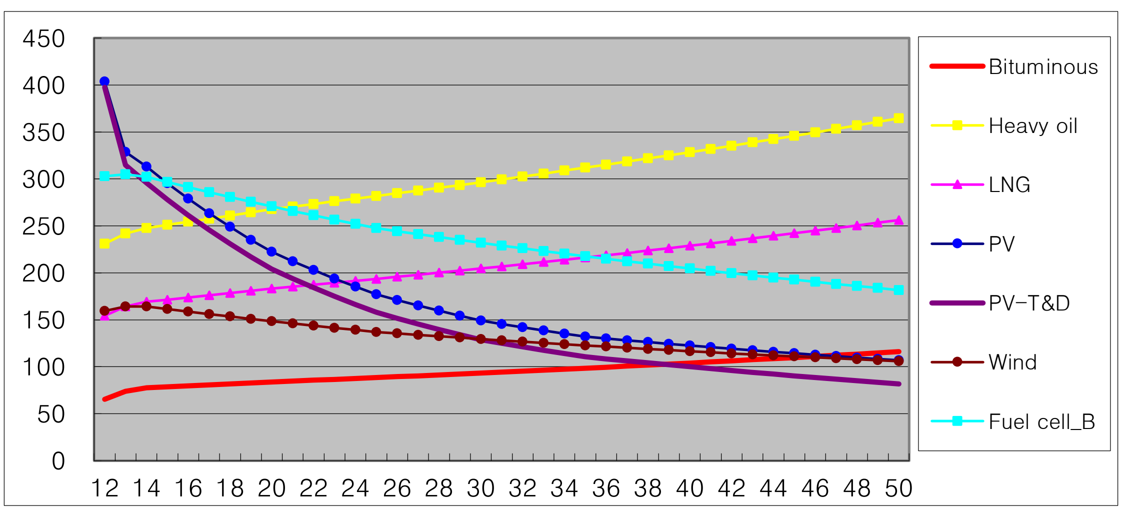


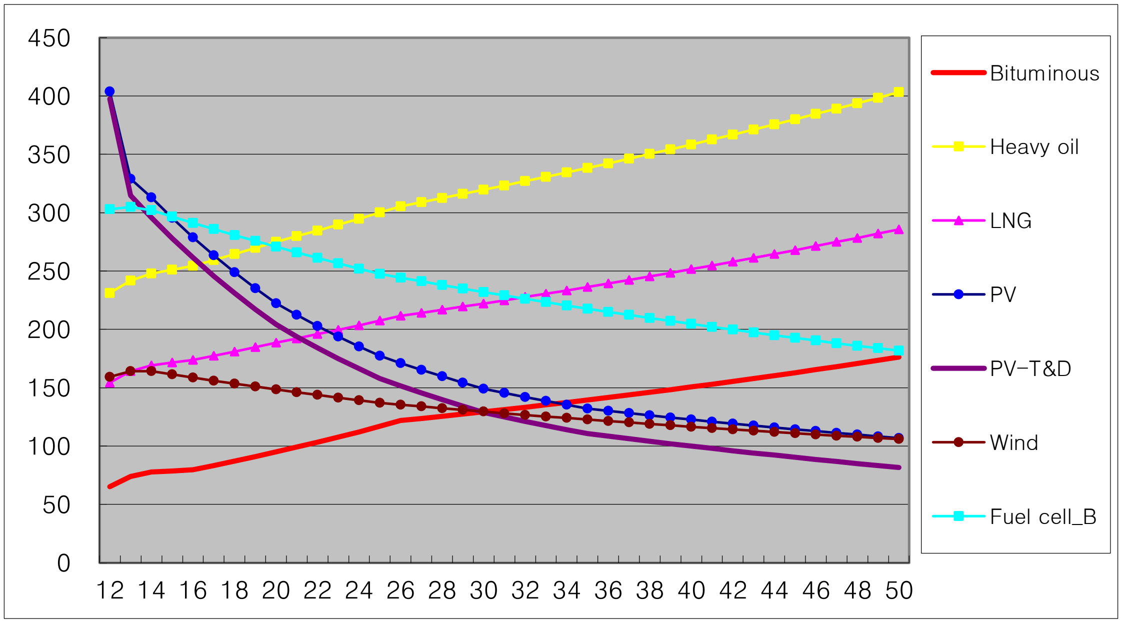
Figure 4-13: Future Price Prospects of Electricity from Renewable Energy Sources.

Costs Comparison between Fossil Fuel- and Renewable Energy-Based Electricity: Figure 4-14 shows three cases of future electricity price changes: Figure 4-14 (a) shows the price changes without any internalization of social costs; Figure 4-14 (b) includes the internalization of climate change effects; and, Figure 4-14 (c) contains the internalization of social costs caused by air pollution and climate change.

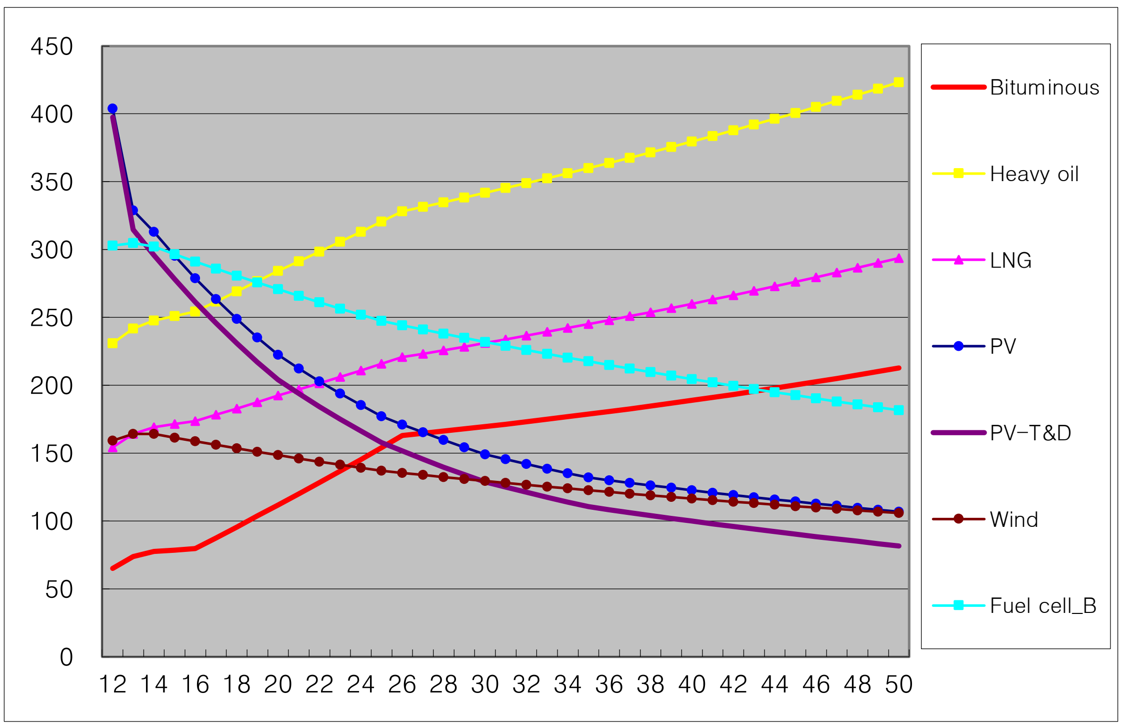
The figures all show that electricity generated from renewable energy, in the long-run, will gain price competiveness over fossil fuel. However, the timing when the renewable energy would overtake fossil fuel significantly varies. According to Figure 4-14 (a), PV-T&D acquires competitiveness over bituminous from 2037, wind from 2046, and PV from 2047. Fuel cell never becomes competitive compared with bituminous until 2050. When the social costs of climate change are reflected, PV-T&D will be more competitive over bituminous from 2030, wind from 2031, PV from 2034. The internalization of both air pollution and climate change externalities brings more affirmative results; wind acquires competiveness from 2024, PV-T&D from 2026, PV from 2028, and fuel cell from 2044.



(a) Future Generation Costs without Internalization of External Costs



(b) Future Generation Costs with Reflecting Climate Change Impacts



(c) Future Generation Costs with Reflecting Air Pollution and Climate Change Impacts

Figure 4-14: Comparison of Future Electricity Prices among Energy Sources.

Chapter 5

RESULTS

In Chapter IV, the establishment of sustainable energy system has been examined. As demand management policies, the change of industrial structure, the improvement of energy efficiency, and the reduction of energy service requirements have been dealt with. As supply-side polices, fuel substitution of LNG for anthracite and the possible expansion of renewable energy after internalizing external costs into fuel price have been looked at.

Based on these, the impacts of these policies will be analyzed and examined more deeply in this chapter. This study, firstly, examines their effects on final energy consumption by sector and by source. Second, it analyzes the impacts of price internalization on each sector including the transformation sector, especially electricity generation sector. Third, it investigates the change of primary energy supply by combining the change of final energy and the loss generated during the process of energy transformation. Fourth, it analyzes the change of GHG emissions caused by energy mix change and estimates their potential up to 2050 to examine the possibility of achieving the given goal of the global average emissions. Fifth, it investigates the renewable energy development potential of each region and divides the energy demand aligning to their energy production potential. Sixth, it analyzes the change in the national security by comparing the results with the current status of energy, the BaU scenario, and the government’s policy scenarios.

5.1 Estimation of Final Energy Consumption

As previously examined, the TFC of new BaU scenario is expected to be 272.4 Mtoe in 2030, as shown in Table 5-1. Table 5-1 serves as the base for analyzing energy saving and GHG reduction effects suggested by the policies of this study.

Table 5-1: Prospects of TFC of New BaU Scenario

(Unit: Thousand toe)

Category		2014	2020	2025	2030
Total		213,873	242,813	259,986	272,420
Sector	Industry	136,087	154,153	163,518	169,236
	Transportation	37,629	41,814	44,010	45,500
	Residential	19,734	22,415	24,583	26,622
	Commercial	15,743	18,831	21,537	24,076
	Public	4,680	5,601	6,339	6,987
Fuel	Coal	35,412	37,202	28,512	39,120
	Oil	102,958	115,889	121,019	123,669
	City Gas	23,396	27,599	30,735	33,448
	Electricity	41,073	47,878	53,002	57,259
	Heat	1,566	1,794	1,980	2,154
	Renewable	9,468	9,931	14,739	16,770

* Table 5-1 is the same as Table 4-10.

As examined, this study applies following policies to TFC of new BaU scenario: ① industry's structural change into less energy intensive industries, ② substitution of natural gas for anthracite, ③ adoption of aggressive energy efficiency technologies, and ④ reduction of energy service requirements. In addition, the study examines the expanded use of renewable energy by 2050. Renewable energy is presumed not to decrease during the above process of policy application, since their increase is caused by political intervention. Instead, the share of renewable energy reduction is allotted to other energy sources in proportion to their amounts. This presumption is applied to the whole processes.

Transition of industrial sector into a less energy-demanding structure would contribute to saving energy from the industrial sector, even though it could increase the energy consumption in the commercial sector. The transition would bring about 29.5 % reductions from the industrial sector and 23.0 % increase from the commercial sector. By fuel, coal consumption would decrease by 52.8 %, followed by oil 11.6 %, electricity 11.5 %, and city gas 9.3 %, while heat consumption is expected to increase by 2.5 %. The analysis shows that the transformation of industrial structure would make a 16.9 % net reduction in TFC. As examined, domestic coal has already lost its competitiveness. Therefore, this study suggests substituting it with city gas. The substitution would bring about 0.2 % reduction of TFC. By fuel, coal would decrease by 14.0 %, while natural gas increases by 7.7 %.

Policies for supporting efficiency technologies have great potential in reducing TFC, despite providing the same energy service. Based on the accomplishments of JISEEF (Byrne & Wang et al., 2004: 264~270), the effects of efficiency improvement policies are expected to be 23.1 % of TFC in 2030: the industrial sector 20.7 %; the transportation sector 24.0 %; the residential sector 24.2 %; the commercial sector 29.5 %; and the public sector 28.7 %. By fuel, coal is expected to decrease by 23.3 %, oil 24.0 %, city gas 24.1 %, electricity 28.2 %, and heat 24.1 %.

The reduction of energy service requirements would lead to 5 % reduction from the industrial sector and 10 % from the other sectors. By fuel, coal would decrease by 5.8 %, oil 8.0 %, city gas 8.9 %, electricity 8.4 %, and heat 10.4 %. The total energy reduction is expected to be 7.3 % of TFC.

Based on these four energy policies, this study puts forward Korea's TFC reduction potential; Korea has the potential to reduce 40.9 % of TFC by 2030. Examined by sector, the reduction potential of the industrial sector is 47.0 % compared with BaU, followed by the public sector 35.8 %, the residential sector 31.9 %, the transportation sector 31.6 %, and the commercial sector 21.9 %. Examined by fuel, coal demand would decrease to 29.3 % of the BaU, oil 61.8 %, city gas 67.5 %, electricity 59.2 %, heat 69.8 %, and renewable energy 100.7 %. Table 5-2 shows the energy reduction effects by sector and by fuel.

Table 5-2: Energy Saving Effects of Four Policy Measures in 2030

(Unit: reduction rate %, BaU & Results Mtoe)

Category		BaU Scenario	Structural Change	Fuel Substitution	Efficiency Improvement	Voluntary Reduction	Results
Total		**272.4**	**Δ16.9 %**	**Δ0.1 %**	**Δ23.1 %**	**Δ7.3 %**	**162.2**
Sector	Industrial	169.2	Δ29.5 %	Δ0.2 %	Δ20.7 %	Δ5.0 %	**89.6**
	Transportation	45.5	–	–	Δ24.0 %	Δ10.0 %	**31.1**
	Residential	26.6	–	Δ0.2 %	Δ24.2 %	Δ10.0 %	**18.1**
	Commercial	24.1	23.0 %	–	Δ29.5 %	Δ10.0 %	**18.8**
	Public	7.0	–	–	Δ28.7 %	Δ10.0 %	**4.5**
Source	Coal	39.1	Δ52.8 %	Δ14.0 %	Δ23.3 %	Δ5.8 %	**11.5**
	Oil	123.7	Δ11.6 %	–	Δ24.1 %	Δ8.0 %	**76.4**
	City gas	33.4	Δ9.3 %	7.7 %	Δ24.1 %	Δ8.9 %	**22.6**
	Electricity	57.3	Δ11.5 %	–	Δ28.2 %	Δ8.4 %	**33.3**
	Heat	2.2	2.5 %	–	Δ24.1 %	Δ10.4%	**1.5**
	Renewable	16.8	0.7 %	–	–	–	**16.9**

5.2 Prospects of Future Electricity Mix

Analysis of Government's Electricity Mix by 2030: The Korean government plans to establish electricity supply system based on nuclear and coal-fired power plants. Table 5-3 shows the electricity mix based on *the 7th Plan for Electricity Supply and Demand 2015-2029*. The share of nuclear power is estimated to be 29.0 % and that of coal 39.3 %. To realize the electricity mix projected by the government, the government plans to build 46,487MW of conventional power facilities including 13 nuclear power plants and 20 coal-fired power plants, and 30,925MW of new and renewable energy power plants, while closing power facilities with 6,760MW including one nuclear power plant (MOTIE, 2015: 26).

Table 5-3: Prospects of Electricity Mix by the Government in 2029

Category	Sum	Nuclear	Coal	Oil	LNG & Group	Hydro	NRE
Capacity (MW)	163,868	38,329	44,018	1,195	42,736	4,700	32,890
Electricity (Mtoe, TWh)	56.5 (656.9)	16.4 (190.5)	22.2 (258.4)	0.2 (2.5)	10.0 (116.6)	0.5 (5.9)	7.1 (83.1)
Primary Energy (Mtoe)	158.5	47.3	61.2	0.6	27.2	1.5	20.6

Note: 1. Electricity except nuclear and renewable, which was suggested by *the 7th Electricity Plan*, was allotted based on 2012 capacity and generation data. The used capacity factors are 0.690 for coal, 0.243 for oil, 0.321 for LNG, and 0.147 for hydro.
2. Primary energy was calculated based on 2013 net efficiencies: nuclear, hydro, and NRE 35 %; coal 36.7 %; oil 34.1 %; LNG 34.8 %; and group energy 44.3 %.
Source: KEPCO (2014: 56-57) & MOTIE (2015: 11, 30, 58, 59)

Analysis of Alternative Electricity Mix by 2030: On the other hand, the necessary electricity is estimated to be 33.3 Mtoe or 387.5 TWh in 2030, based on the suggested alternative scenario. Table 5-4 shows the electricity mix of the alternative scenario for 2030. It is assumed that electricity generated from renewable energy sources would be the same as that of the government plan. In addition, the capacity factor for nuclear is assumed to be 0.70, more than that of the government plan (0.57). To other electricity sources, the capacity factors are assigned, in consideration of their size and characteristics. In calculating primary energy, this study assumes that oil-fired power plants would not be used and the operation of coal-fired power plants would reduce to a minimum. The efficiency in electricity generation is expected to improve by 8.8% thanks to technological progress (0.5% of annual increase rate). Since most of heat energy is the by-product of electricity process, it is included in this transformation.

Table 5-4: Electricity Mix based on the Alternative Scenario in 2030

	Sum	Nuclear	Coal	Oil	LNG & Group	Hydro	NRE
Capacity (MW)	131,610	24,450	23,804	1,195	42,736	4,700	34,725
Electricity (Mtoe, TWh)	33.3 (387.6)	**12.4** (144.4)	6.4 (74.5)	-	6.7 (78.3)	**0.5** (5.8)	**7.2** (84.5)
Primary Energy (Mtoe)	49.6	**12.4**	16.0	-	13.5	**0.5**	**7.2**

Note: The primary energy of nuclear, new & renewable, and hydro for electricity is estimated to be the amount of electricity produced, unlike the government's method which applies a 'loss factor' in estimating primary energy like the case of fossil fuel.

Compared with the government's plan[79] described above, the alternative scenario requires 36.9 ~ 53.4 % less electricity, which can be supplied with the

[79] The government's plan 1 is calculated based on 2006 (nuclear only) and 2012 capacity factors – nuclear 0.805(mean of 2006 [0.879] and 2012 [0.730]), coal 0.888, oil 0.243, LNG 0.364, Group 0.595, hydro 0.147, NRE data included in the 7th

currently operating power plants and those under construction, as shown in Figure 5-1. The government could scrap the construction of newly planned power facilities and decide not to extend the lifetimes of nuclear and coal-fired power plants. The surplus in the capacity of power plants is expected to continue, as shown in Figure 5-1 (the difference between ‘No entry, Exit only’ and ‘Alternative Scenario’).

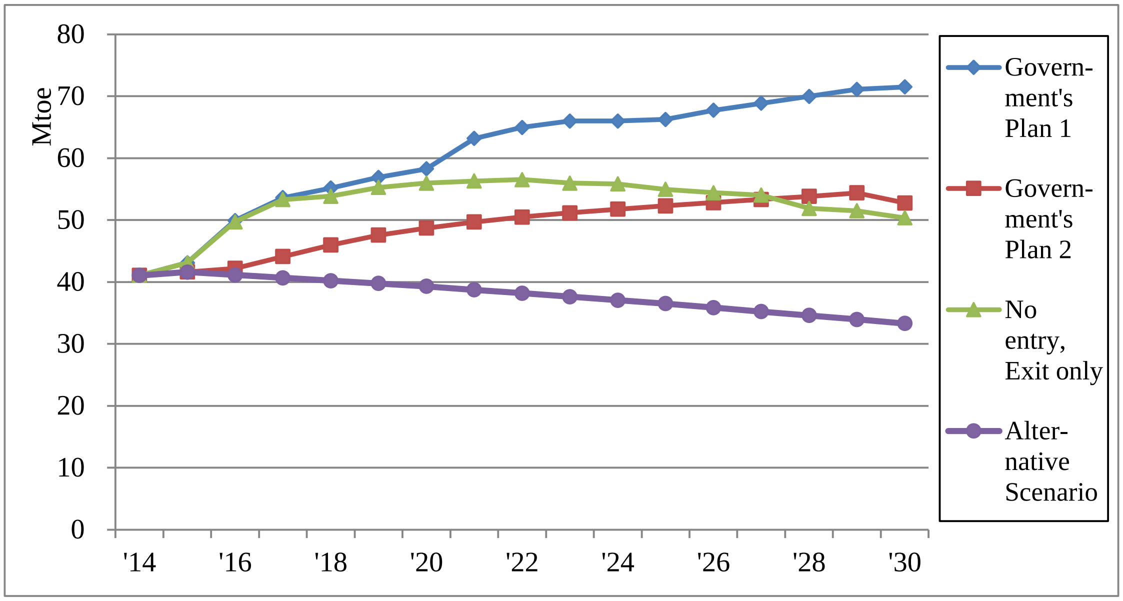


Figure 5-1: Comparison of Electricity Demand Prospects among Three Scenarios. Sources: 7th Electricity Plan (MOTIE, 2015), Others (Projected by this study)

5.3 Prospects of Energy Mix Except for Electricity

The expansion of renewable energy is also observed in the field of bio-fuels. Provided that fuels for transportation and heating are replaced with renewable energy, it could contribute to reducing GHG emissions. Currently, some bio-fuels have already acquired price-competitive (MKE, 2008: 23); however, most of them are depending on

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electricity plan (MOTIE, 2015: 59), – while the government’s plan 2 is based on the 7th electricity plan’s capacity factors, which are much less than current ones.

political interventions such as subsidies and tax exemption. The internalization of external costs brings an opportunity. By changing its current status with a lack of competitiveness, renewable energy could generate real and substantial benefits in a stable manner. In this context, the alternative scenario proposed by this study can give opportunity to reduce fossil fuel demands from the transportation and heating energy sectors. Figure 5-2 shows the availability of renewable energy for various energy services.

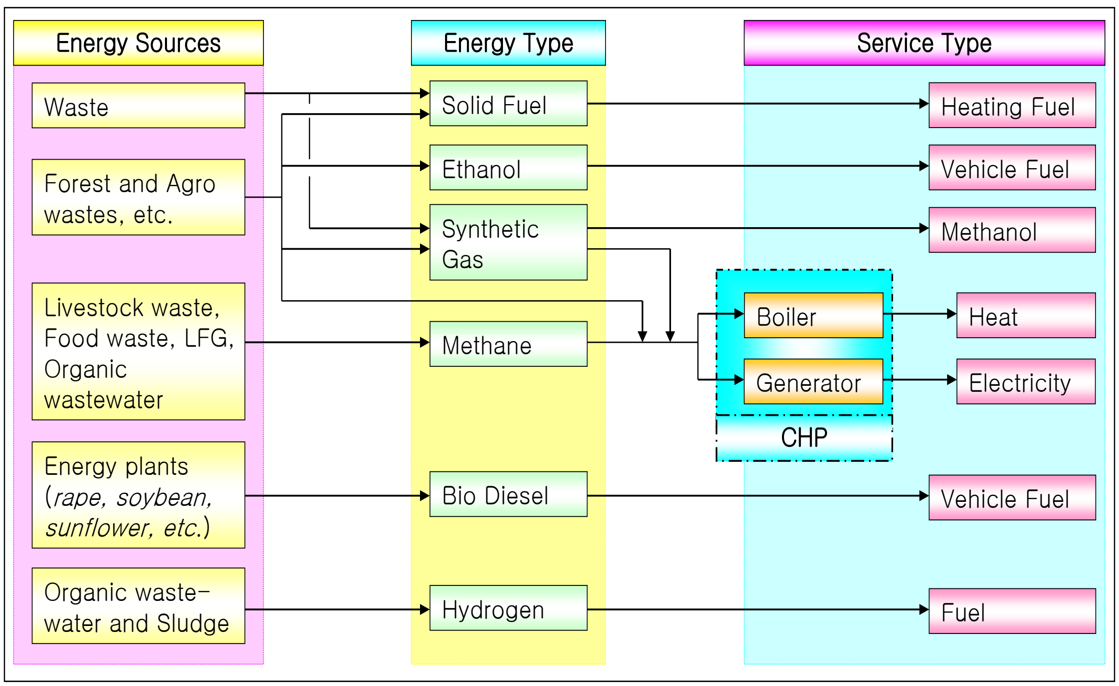


Figure 5-2: Bio Energy Types and their Availability.
Source: MOCIE (2006: 404)

This study also assumes that bio-fuels such as ethanol and bio-diesel can cover certain portion of oil demands by 2030. In addition, renewable energy sources such as solar heat, geothermal, biomass, and waste can greatly contribute to reducing the consumption of fossil fuels for heating energy. According to *the Fourth NRE Plan*, the share of renewable energy is expected to be 11% of TPES in 2035 (MOTIE, 2014). Provided the interim goal for 2030 is 10% of TPES, the share of renewable energy would be 19.5 Mtoe as TFC. Since heat generated during the process of energy transformation can be recycled, it is assumed that 0.7 Mtoe of heat – the difference between new BaU and alternative scenario – could be additionally used by 2030.

Table 5-5: Change of Energy Mix through the Expansion of Renewable Energy in 2030.

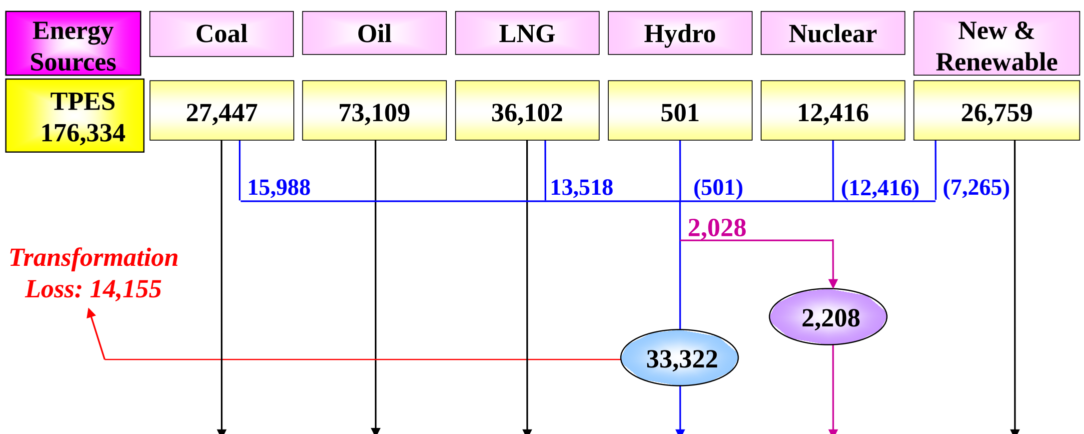
(Unit: Mtoe)

	Sum	Coal	Oil	City Gas	Electri-city	Heat	Renew-able
After Demand Control	162.2	11.5	76.4	22.6	33.3	1.5	16.9
Expansion of Renewable	162.2	11.5	73.1	22.6	33.3	2.2	19.5
Energy Change Effects	-	-	-3.3	-		+0.7	+2.6

Since renewable energy sources like wind and solar energy begin to gain competitiveness from the mid-2020s and their potential can cover the whole demand of electricity and heat by 2030, they can be the sources for additional electricity and heat. However, this study distributes the share of electricity generation evenly to each facility, considering the capacity by 2030. This means that Korea has the potential to reduce more GHG emissions, provided that the government determines not to operate more plants within their lifetime. After 2030, renewable energy supply is assumed to be greater due to their price competitiveness and rapid closing down of the existing conventional energy facilities.

5.4 Prospects of Total Primary Energy Supply

By combining the TFC (Table 5-5) and transformation process (Table 5-4), the TPES for 2030 is found to be 176.3 Mtoe, as shown in Figure 5-3. To generate 33.3 Mtoe of electricity and 2.2 Mtoe of heat, 49.6 Mtoe of energy – 16.0 Mtoe of coal, 13.5 Mtoe of natural gas, 12.4 Mtoe of nuclear, 0.5 Mtoe of hydro, and 7.3 Mtoe of renewable energy – is expected to be consumed. Since this study applies the electricity generated to primary energy in the cases of nuclear, hydro, and renewable energy, unlike the government's method which focuses on input energy. In relation, the electricity generated from renewable energy but not sold to KPX, is included in 'NRE' as final energy, following the government's method, as shown in Figure 5-3.



TFC 162,176	Coal (11,459)	Oil (73,109)	City Gas (22,583)	Electricity (33,322)	Heat (2,208)	NRE (19,494)
Industry	11,459	39,913	7,145	16,003	-	15,124
Transportation	-	28,075	1,231	253	-	1,556
Others	-	5,121	14,207	17,067	2,208	2,814

Figure 5-3: Diagram for Energy Conversion from TFC to TPES in 2030.

Compared with the government's and KEEI' scenarios, the alternative scenario is more energy effective, as shown in Table 5-6: even though following the current governmental methods (213.8 Mtoe), it is 38.8 % energy saving compared with KEEI's 2006 policy scenario, 28.8 % energy saving compared with government's 2008 policy scenario, and 34.4 % energy saving compared with government's 2014 policy scenario. One thing that needs to mention is that the government's 2015 scenario is not included in the comparison because of insufficient information.

Table 5-6: Comparison of TPES among Scenarios in 2030

(Unit: Mtoe)

Alternative scenario	KEEI's 2006Policy scenario	Government's 2008 Policy Scenario	Government's 2014 Policy Scenario
176.3 (213.8)	349.3	300.4	326.0

Note: Government's 2014 policy scenario is calculated combining the data of TFC and energy consumed during the process of transformation.

In 2050, the energy mix will have a great change, as shown in Figure 5-4. As examined, the drastic decrease of conventional power plants is expected once after their operation span. This study, additionally, assumes the end of coal-fired power plants and heat use and applies the effect of AEEI (annually 0.5% for 20 years). This study also reflects the long-term decrease of population[80], the rapid propagation of electric car[81], and the annual expansion[82] of new and renewable energy (MOTIE,

80 According to the trend analysis of KNSO (n.d.(a)), the population of Korea is expected to decrease to 52.16 million in 2030, and to 48,12 million in 2050.

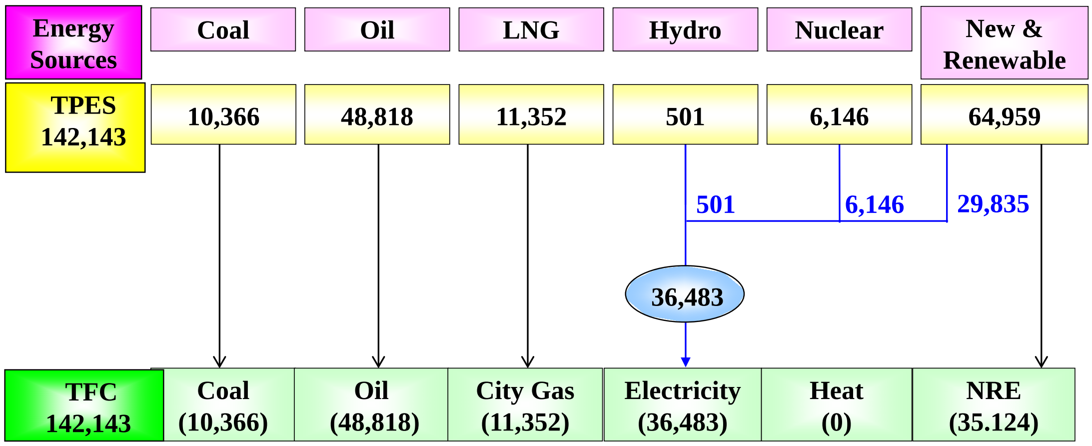
81 According to Choi et al. (2012), electric cars are expected to increase to 7 million vehicles, sharing 33% of registered car in 2035. As assuming that this trend will

2014). According to Figure 5-4, the amount of total primary energy is equivalent to that of total final energy because fossil fuel[83] would not be used any more for generating electricity. The share of renewable energy in TPES amounts to 45.7% and the energy dependence on foreign countries decreases to 53.9 % from current 95%.

continue still in 2050, this study forecasts that electric cars will takes more than 50% of registered cars. In addition, it also assumes that 50 % of transportation oil consumption will be replaced by electricity with 1.5 times more efficient mileage.

82 According to *the Fourth NRE Plan* (MOTIE, 2014), MOTIE estimates the annual increase rate of new and renewable energy to be 6.2%. This study assumes that this trend will continue still in 2050, with some adjustment. For example, it just applies the effects of AEEI to the cases of electricity, coal used in the primary industries and non-energy use. In addition, when the expected reduction of other energy source is bigger than the current consumption by sector, renewable energy is assumed to stay on.

83 Coal is assumed to be mainly used as material in the primary metal industries, while oil as fuels in the transportation sector. The production ratio of fossil fuels is prospected to exceed 50, without causing any serious physical problems in supplying them (BP, 2015).



	Coal	Oil	City Gas	Electricity	Heat	NRE
Industry	10,366	33,271	-	14,476	-	22,980
Transportation	-	12,428	430	6,814	-	5,182
Others	-	3,120	10,921	15,193	-	6,962

Figure 5-4: Diagram for Energy Conversion from TFC to TPES in 2050.

5.5 Prospects of Greenhouse Gases Emissions

The GHG emissions from the alternative scenario are expected to be 325.4 Mt_CO_2 in 2030. According to the government's 2015 scenario[84], GHG emissions in 2030 are expected to be 850.6 Mt_CO_2 based on its BaU scenario, and 535.9 Mt_CO_2 following to its policy scenario. Estimated GHG emissions by the KEEI's 2006 scenario are 690.4Mt_CO_2 in 2030. Since the government's 2008 policy scenario does not provide any information on GHG emissions and the government's 2014 scenario shares premises with the government's 2015 scenario, they will be excluded from this comparison. Figure 5-5 shows the GHG emissions of these scenarios. According to

[84] The government's 2015 report estimated non-energy GHG emissions as 111.7 Mt_CO_2 for 2030, which are comprised of industrial process 75.6 Mt_CO_2, waste treatment 15.5 Mt_CO_2, non-energy agricultural emission 20.7 Mt_CO_2.

Figure 5-5, GHG emissions of the alternative scenario are less than half the government's 2015 BaU scenario and 60.7 % of Korea's INDC plan.

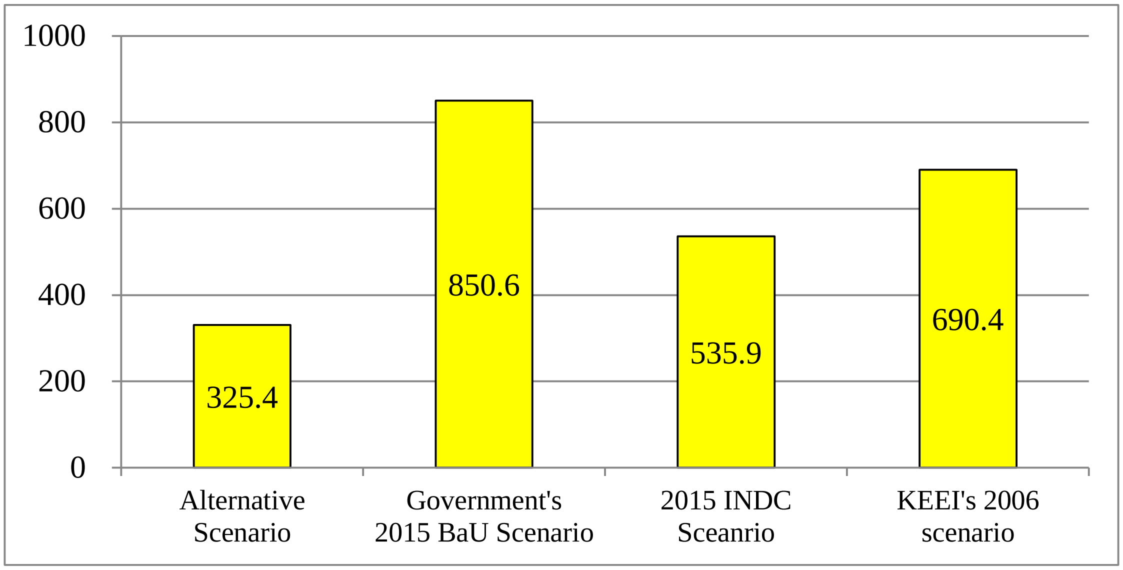


Figure 5-5: Comparison of GHGs Emission among Scenarios in 2030.

If the GHGs emissions for the alternative scenario are converted into per capita basis, the emissions reach 6.2 t_CO_2, which is about two times compared with what is necessary globally. However, there are hopeful signs for satisfying the sustainable energy policy goal; if the amount of overseas credits that the government planned to purchase are reflected, Korea's emissions would reduce to 231.8 Mt_CO_2 or 4.4 t_CO_2 per capita in 2030. In addition, renewable energy is expected to get price-competitive after the mid-2020s. This is also another positive sign to Korea, since additional reduction can be expected with the substitution of renewable energy for fossil fuels that has economic advantages. In sum, Korea has more potential in reducing GHG emissions than the government predicted, with less economic loss and more stability.

As already shown, the BaU and government policy scenarios are based on the assumption that the role of renewable energy in TPES and TFC is limited. However, Figure 4-14 has shown that the internalization of social costs could turn renewable energy more competitive from the mid-2020s. In addition, the available potential of renewable energy surpasses the national demand for electricity, as shown in Table 4-27. This means the electricity demand can be covered with renewable energy, even when nuclear and coal-fired power plants are not in operation after they are used up to their lifetime. According to Figure 5-4, GHG emissions in 2050 would decrease to less than 137.0 Mt_CO_2. This means that the per capita emission would be 2.8 t_CO_2, based on the population projected for 2050 – 48,121 thousand. If the population of 1990 – 43,411 thousand – is applied, the per capita emission would stand at 3.2 t_CO_2 in 2050, which shows that Korea could attain the sustainable goal of GHG emissions by 2050 without purchasing the overseas emission credits that the government has planned in its *INDC Plan*. Korea could achieve the goal by extending the use of renewable energy – the substitution of renewable energy for fossil fuels in all sectors. The successive development of renewable technology will contribute to enhancing energy production efficiency, lowering production costs, and increasing available potential of renewable energy.

5.6 Regional Development based on Balanced Energy Distribution

Energy supply by region has been carried out in accordance with the government plan. The Korean government has constructed the centralized energy system to cater to the national needs, without having consideration of the local demands. Therefore, many large-scale coal-fired and nuclear power plants have been and are going to be constructed in the rural areas, where large-scaled conventional power plants have already been constructed and being operated. The major candidate regions for those plants are to be constructed include Gangwon, Chungnam, Jeonnam, Gyeongnam, and Gyeongbuk (MOTIE, 2015: 26). Except Gangwon, four provinces are the regions which already have many power plants. In addition, these provinces are geographically far from the metropolitan areas where electricity consumption is relatively greater. As a result, to realize the government plans, it requires additional facilities for long-range electricity transmission, which has the possibility to weaken the balanced regional development and social equity by deteriorating environmental quality in the rural areas.

However, the alternative energy policies suggested by this study will contribute to attaining regional balanced development. As shown in Table 4-27, the available potential of renewable energy surpasses the national electricity demand, which means the demand for electricity can be fully covered with renewable energy sources even when nuclear and coal-fired power plants are not in operation after they are used up to their lifetime. As shown in Figure 5-6, renewable energy is well distributed across the regions. Therefore, it can contribute to securing regional needs by relieving the level of pollution and improving its environmental quality and equity. Especially, the metropolitan cities, which are totally dependent on surrounding regions for their electricity supply, could accomplish the “green shift” – the realization of sustainable cities which produce significant amount of PV electricity by using their own buildings and available spaces while creating more jobs and heightening environmental amenity at the same time (Byrne & Wang, 2014).

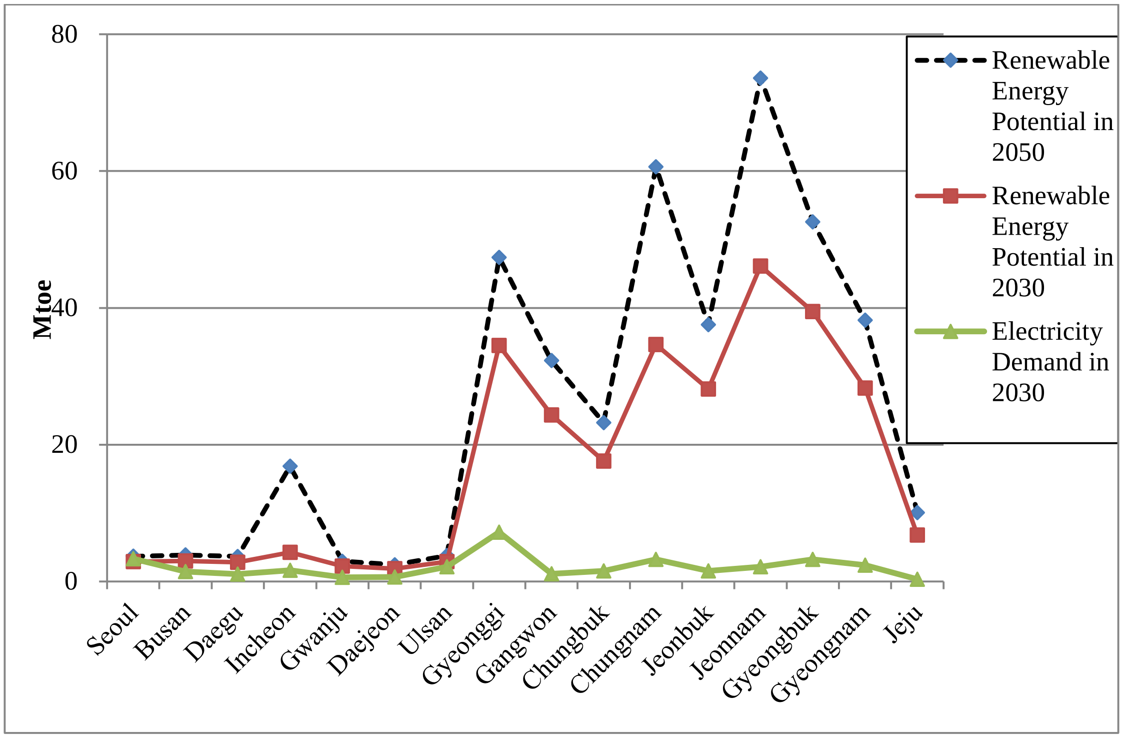


Figure 5-6: Regional Electricity Demand and Renewable Energy Potentials based on Final Energy.

Note: 1. Renewable energy potential is the available potential of PV, wind, biomass, small-hydro, geo-thermal, and ocean energy.
2. Electricity demand is the combination of 2013 distribution and 2030 total amount.

Even knowing that the whole regions would not be able to resolve energy deficiency in 2030, Figure 5-6 shows a highly improved and evenly distributed electricity demand-supply relation, compared with the current situation which is shown in Figure 3-5. Since the price competitiveness of renewable energy is expected to be stronger and continuous improvement of energy efficiency is predicted, the available potential of renewable energy in the region will increase persistently, improving the regional energy independency. In addition, the regions with high renewable energy potentials are likely to have a chance for development by supplying clean renewable energy, unlike the conventional energy facilities that have caused regional pollution and environmental degradation.

5.7 Examination on National Economy and Security

In section 5.6, this study has examined that the expansion of renewable energy would be able to contribute to not only improving social equity but also improving national security. As examined, Korea imports around 95 % of its energy consumed. Therefore, Korea's energy security is very vulnerable to the changes of international politics.

According to Figure 5-3, the alternative scenario shows that Korea's energy dependency on foreign countries will drop to 84.5 %[85,86] from the current 95 %, which means around 2 times increase in domestic energy production compared with 2014, despite the ceasing of domestic coal production. Since renewable energy potential is expected to be 272.4 Mtoe in 2030, which is higher than the necessary TPES, and is also expected to gain price competitiveness from the mid-2020s, Korea's energy independency will improve greatly, provided that the Korean government promotes renewable energy with the implementation of relevant supporting policies. If Korea successfully implements these related policies, Korea possibly supply the whole energy it needs without relying on overseas energy market by 2050, excluding indispensible materials for the economy and safety.

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[85] The study assumes 0.5Mtoe of natural gas production, the current production size.

[86] There are certain limitations in directly comparing the 2014 historical data with 2030 or 2050 estimated data. While the government applies different factors in estimating the primary energy (1 toe = 4.74GWh) and final energy (1 toe = 11.63 GWh) for renewable-based electricity, this study applies the same factor (1 toe = 11.63 GWh) not in considering the transformation loss, unlike the cases of fossil-fuel based electricity.

IEA designed the ESI for each country as ESI = $\sum_i [ESMC_{sol-i} \times C_i / TPES]$ (refer to the section 3.4.6 and Table 3-19). If the index is applied to the case of Korea, the ESI for the alternative scenario in 2030 is calculated to be 4,668, while the ESI for the government's 2015 BaU scenario in 2030 is 4,703 and the ESI in 2012 is 5,529. This shows that both scenarios would contribute to securing national security, despite the increase in international political instability. However, IEA's ESI has a limitation in that it does not reflect the absolute change of TPES, as it only considers the relative change. In other words, the relative increase of energy import weakens national security even if the absolute amount of a fuel falls down, and vice versa. Therefore, this study re-designs ESI as follows:

$\mathrm{ESI_t} = \mathrm{ESI_{IEA}} \times \left(\frac{\mathrm{TPES_t}}{\mathrm{TPES_{2012}}}\right)$ where, t means time or the expected year

The adjusted ESI shows that the government's scenario would deteriorate Korea's energy security as the ESI will reach 6,242 in 2030, while the alternative scenario improves the energy security by decreasing the ESI to 3,581.

In addition, energy productivity is also important to estimate the national energy security. According to the alternative scenario, the energy productivity, a relative value of GDP over TPES, is improved to KRW 9.99 million per toe in 2030, up from KRW 4.66 million per toe in 2014. The alternative scenario also shows the improvement in terms of energy import burdens; energy import costs as a percentage of GDP are improved from 12.9 % in 2014 into 5.9 % in 2030, while energy consumption decreases and fuel prices increase by 30.3 %.

Table 5-7: Change of Key Indicators in the Alternative Energy Scenario

Category	2014	2030
GDP (KRW trillion 2010)	1319.7	2134.8
TPES (Mtoe)	282.9	213.8
GHGs (Mt_CO_2)	631.4	325.4
GDP/TPES (KRW million/toe)	4.66	9.99
GHGs/GDP (t_CO_2/KRW million)	0.478	0.152
Energy Import Costs/GDP (%)	12.9 %	5.9 %

Chapter 6

CONCLUSION

This study has examined Korea's energy situations and analyzed its future according to the newly designed BaU scenario, the government's policy scenarios, and alternative scenario based on energy sustainability. The government's scenarios are surely more sustainable than their BaU scenarios when looking at GHG reduction. However, it does not make the Korean energy system sufficiently sustainable from the point of environment, economy, and socio-politics. Therefore, this study develops a new alternative scenario for improving energy sustainability of Korea, which is harmonized with the international justice and contributable to reducing the impacts of climate change across the globe.

6.1 Political Consideration

This study finds the possibility that Korea, the domestic energy resources of which are limited in terms of the capacity compared with the demand, could meet the goal of addressing climate change, with environmentally sound, economically beneficent and socio-politically equitable methods. However, it would not be easy to accomplish the goal of sustainable energy system. To achieve the goal, Korea has to overcome many resistances and barriers. The major issues are the reform of the current tax system, adoption of more aggressive renewable energy support, and the change in life pattern through education and public campaigns, etc.

6.1.1 Reform of the Current Taxation and Subsidy System

This study found that the alternative scenario could be realized without sacrificing economic benefits, through the abolishment of domestic coal production support and the internalization of social costs related to fossil fuels combustion. From a comprehensive perspective that integrates economic, environmental, and socio-political dimensions, this is obvious because social costs are eventually internalized in various forms of social costs such as medical costs, increase of mortality, agricultural loss, ecosystem destruction, and natural disasters caused by climate change, even though they are not directly added to energy costs. However, from the mainstream economic viewpoint, for the vested interest groups who get benefits under the current energy regime, the internalization of social costs obviously generates additional costs, increasing their economic burdens. Even if environmentally harmful subsides on domestic coal are to be abolished, which is obviously inefficient even from the perspective of mainstream economy, it is expected to bring about strong political resistances.

To relieve these resistances, this study suggests the adoption of balanced tax by trading off the increase of carbon and environmental tax with the reduction of income-based tax such as labor tax. This is also suggested by many experts because it can contribute to achieving a ‘double dividend’; that is both the reduction of environmental damages and the achievement of higher employment, and thereby creating more economic benefits (McEvoy et al., 2000; Metcalf, 2007; Shapiro et al., 2008; Komanoff, 2008; Swiss Agency for Development and Cooperation SDC, 2012; Jorgenson, 2014). In addition, the study suggests the gradual transition into a new tax system between 2017 and 2026, to reduce negative effects, provide time for preparation, and accelerate the development of new energy technologies.

Second, this study suggests converting direct support on energy consumption costs for the energy poor class to indirect support. Currently, the government prefers direct support; the subsidies for domestic anthracite and briquette are provided to lower their prices. These supports are likely to cause energy waste. Provided that the government provides the low income people with the overall living costs instead of direct energy support or having price control measures, the people would try to reduce their energy consumption and choose cheaper energy sources[87] such as city gas or renewable energy, not the currently price-distorted briquette. These measures will improve the soundness of energy system by reducing energy consumption and GHG emissions.

In relation, the government recently started to discount the special consumption tax temporarily for promoting automobile sales, allowing more advantages on heavier vehicles (Joongang-ilbo, 2016). Generally, vehicles are used more than 10 years. This means the vehicles purchased affect for a long time. It is quite worrisome that the government promotes such policy possibly leading to the increase of GHG emissions, an antinomy that contradicts to on-going GHG reduction policies including the INDC Plan.

6.1.2 Adoption of More Aggressive Renewable Energy Support Policies

Once, the Korean government had been strongly supporting the development of renewable energy through the application of FIT system, ESCOs and many other

[87] 'Cheaper' means the price after the taxation on climate change and air pollutants and the abolishment of environmentally harmful subsidies. Under the current situation, briquette is the cheapest fuel. However, after examined measures are carried out, its price will rise enough not to be selected as a common fuel.

instruments and measures, which was examined in Chapter 3. However, the government began to scrap these supporting policies to relieve the burdens of electricity generating companies, which has caused hardships for the renewable energy industries due to the reduced price of SMP and REC (Hankookilbo, 2015). On the contrary, many developed countries such as Japan, Germany, the Netherlands, and the US are supporting the renewable energy industries to ‘grasp two hares’; the reduction in GHG emissions and new economic security in the future. Even China, a representative developing country with fewer burdens compared with Korea, has been aggressively supporting the renewable energy industries. Moreover, many experts do not deny the importance of renewable energy industries as for preparing future economic development. To advance price competitiveness of renewable energy, aggressive support for renewable energy would be indispensable.

Nonetheless, the Korean government has a tendency to reducing the supports. Recently, the dependency of the Korean economy on energy intensive industries such as petro-chemical and metal/non-metal manufacturing industries has become heavier, compared with previous prediction. From a long-term perspective, this is not only environmentally burdensome but also is economically undesirable. Therefore, the Korean government should try to convert its policies to provide stronger supports for the renewable energy industries and less energy intensive industries, instead of supporting traditional energy intensive industries.

As a first transition, the concept of sustainable energy system needs to be re-established. The government should guide, support and facilitate such a change to accomplish a successful transition. For this, it is important to overcome the barriers from the existing vested interest groups. Once a certain system becomes stabilized, it is difficult to change it with another, as van den Bergh et al. (2007) mentioned as follows:

> Lock-in of technology and organizational structures implies that once a configuration becomes dominant as a result of increasing returns to scale, it is very difficult to break it out. Price corrections to incorporate the external costs of environmental damage in prices are a necessary but usually insufficient condition for undoing the lock-in of a system. Additional policy measures are thus needed, notably stimulating alternatives through subsidies, creation of niche markets, setting clear long-run objectives, providing information, educating consumers and so on. (46-7)

As mentioned, renewable energy is expected to get more price-competitiveness in the near future. However, it cannot be achieved without addressing the current price barriers. The future price competitiveness of renewable energy does not come without political intervention. The most important thing is to make a ‘political push’ on the development and promotion of renewable energy technology from the beginning. Only after the renewable technologies enter a stable stage, they would be automatically penetrated into the market. For this, this study suggests the internalization of external social costs. However, this alone cannot be a total solution. Even though the cost-internalization can relieve difficulties drastically, price disadvantage still remains for a time, as shown in the previous section. Therefore, continuous ‘pushing’ policies such as the support for R&D on renewable technologies and the institutional and financial supports for renewable energy expansion are necessary. Figure 6-1 shows the importance and process of policy-making in promoting renewable energy expansion.

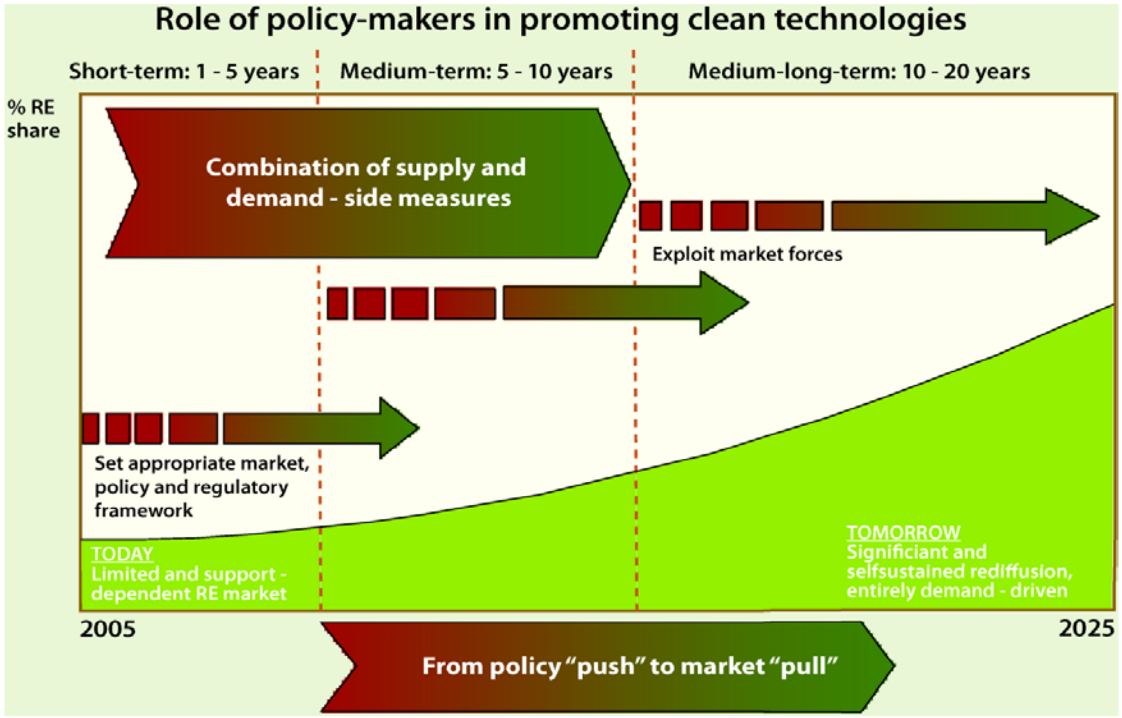
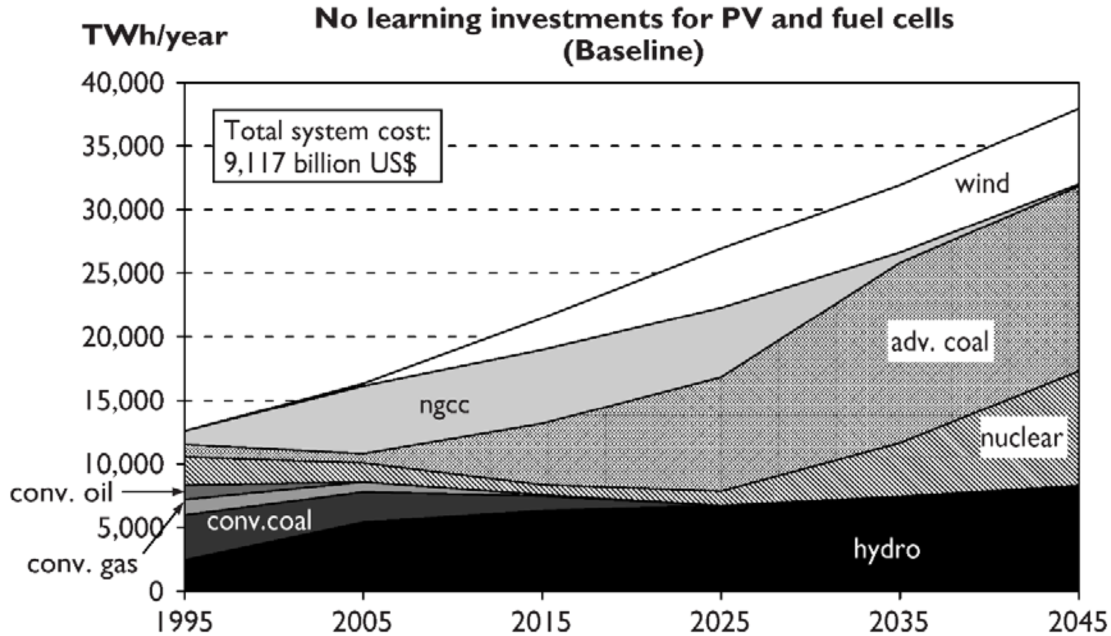


Figure 6-1: Role of Policy-makers in Promoting Clean Technologies.
Source: EU, REMAC project, 2003 (Re-cited from European Commission, 2008: 37)

Renewable technologies are generally regarded as 'young' and have much potential for cost reduction compared with conventional energy technologies. This study has shown the possibility of their market dominance potential. However, the current energy system, in which conventional energy dominates, is likely to undermine the growth of renewable technologies if no systematic actions such as re-introduction of 'FIT system' are not in place at the initial stage. Figure 6-2 shows this clearly; the future with 'no learning investments for PV and fuel' will only lead to a future with conventional energy as a dominant energy source (IEA, 2000: 87). Only with the protection and support measures, renewable technologies can permeate into the energy market and become dominant in the future, thereby reducing environmental burdens.



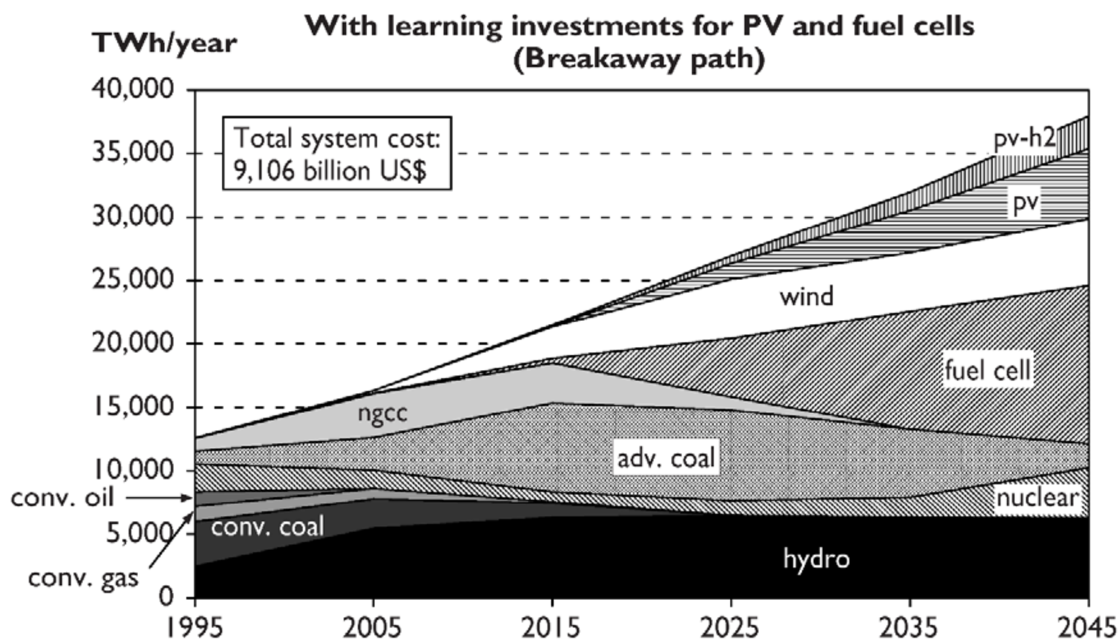


Figure 6-2: Comparison between with and without Learning Investment for Two Renewable Technologies in the Projection of Global Electricity Technology Paths.

Source: IEA(2000)

6.1.3 Diffusion of Energy Efficiency Technologies

Energy efficiency improvement can contribute to more job opportunities and higher incomes, in addition to saving consumers' money, reducing imports and cutting pollutant emissions associated with energy supply (Geller et al., 1992; recited from McEvoy et al., 2000). However, despite these theoretical benefits, many experts indicate the issues of 'energy efficiency gap'. The phenomena are that energy efficient technologies cannot penetrate into the market due to the barriers or because their actual effects are much less or even negative than the expectation (Jaffe & Stavins, 1994; Levine et al., 1996: 536-8; Gererden et al., 2015).

Some barriers block energy efficient technologies to penetrate into the market. Generally, energy efficient devices are more expensive in purchasing stage, but less expensive in the stage of operation or maintenance compared with their counterparts. Therefore, people tend to avoid buying such devices since they had acquired misleading information or they do not want to pay more at the point of purchase, while neglecting their overall benefits. 'Reduced level of service' for energy-efficient appliances (e.g., lower quality of lighting or service) and 'irreducible private costs' (e.g., the inconvenience of installing efficient equipment) can also be barriers (Levine et al., 1996; Gillingham & Palmer, 2013). The current social system also can be another barrier. For example, it is difficult to promote energy efficient appliances under the current lease system where there are gaps between the burdens at the time of purchase and the benefits generated while using a device. As a case in point, landlords are generally more interested in buying cheaper appliances to equip the building, because energy efficient appliances are more burdensome whereas the benefits of using them go to the lessees not to the landlords themselves. The following case study by Levine et al. (1996) shows this characteristic distinctively.

> The price of the higher efficiency model, which used 410kWh/year less electricity, was $60 more than the less efficient one. …… The high efficiency model was advertised widely and a prominent customer magazine recommended it. …… Because the more efficient refrigerator provided service identical to the less efficient refrigerator at a lower life-cycle cost, one might expect purchasers to choose the more efficient refrigerator. However, from 1977-1979, the inefficient model was still purchased by around 45 % of purchasers of either refrigerator in the Mideast, 35-40 % in the East, 54-69 % in the South, and 57-67 % in the Pacific region. Thus, 35-70 % of the purchasers of these two models chose the inefficient model, in spite of the low cost of conserved energy (Levine et al., 1996).

Therefore, these disadvantages or barriers must be considered in designing energy policies. The establishment of ‘standard system’ is essential for the wide use of energy efficient goods. Some additional policy considerations are also necessary for better and faster promotion of such appliances. Firstly, necessary information should be provided in a systematic way to promote eco-conscious purchase and to prevent lack of information or wrong information. Currently, energy-related polices to provide efficiency information such as carbon-labeling (or carbon footprint), low-carbon certificate, and carbon-neutral certificate systems have already been implemented. These policies need to be enhanced for expanding their effects. Secondly, the quality of energy efficiency appliances must be enhanced to survive in the market. It is important to aware that customers’ interest is not just confined on energy efficiency. Additional support for R&D is also necessary to reduce the inconvenience generated from the process of efficiency improvement. For example, the facts that some people prefer incandescent light to fluorescent light and that sports utility vehicles (SUV) are in fashion despite their gigantic fuel demand show how various customers’ desires are. Therefore, it is important to give additional support for improving the quality of energy efficient goods to compete with others from various sides including convenience and design. Thirdly, efforts have to be made for harmonizing the purchase burdens of energy efficient goods (of facility owners) and the benefits of using them (of facility renters). In this context, it can be suggested that financial benefits like tax reduction be provided in return for the mandatory purchase of energy efficient goods for leasing service.

As mentioned, Korea's energy intensity is higher than developed countries such as Japan, German and the US (Lee, 2008; PMO et al., 2008). However, it is also true that Korea's manufacturing system is considerably efficient, which means that, in many cases, the input energy per unit production of goods are not higher than many other developed countries. For example, the amount of energy consumed in producing a car is 2.34 toe in Korea, while that is 1.15 toe in Japan, and 2.75 toe in the US (Lee, 2008). Energy inputs for unit productions of iron and sodium hydroxide are similar to the levels with developed countries such as Japan, the US and EU (PMO et al., 2008: 76)[88]. These contrasts show that the general evaluation on the quality and price of Korean products is lower than those of developed countries. Therefore, it is necessary for Korea to improve its products' quality to increase the overall value-added. In this meaning, it is noteworthy that the technologies enabling the production of high quality goods are also regarded as environmentally sound and economically efficient.

6.1.4 Change of Lifestyle into Energy Saving Patterns

As mentioned, broadly, there are two categories in reducing energy consumption and, thereby, greenhouse gas emissions; one is to reduce the energy

[88] According to PMO et al., the relative energy input for iron-making is 105 in Korea, 100 in Japan, 120 in US, and 110 in EU, while that for sodium hydroxide is 100 in Korea, 100 in Japan, 110 in US, and 119 in EU, which are based on the 2003 data.

service demand and the other is to improve energy production efficiency. They are usually referred to as ‘demand control management’. This study has examined the reform of industrial structure, the reduction of energy requirement through the change in lifestyle and the development of insulation technologies, and the development of energy efficiency technologies as the instruments for demand control management. Of these, the reform of industrial structure is more closely related to industrial policies and the improvement of insulation, and energy efficiency is more related with technological advance.

However, energy demand can be reduced without industrial policies and technology development. What people should do is to simply change their lifestyle following the necessary information. The mention by Block (2004) can be considered in examining the effects of public relation and education. Being informed, customers can save considerable amount of energy.

> It is interesting to note a Dutch experiment according to which households were given information on how much energy use by consuming (purchasing) individual goods and services. Fourteen Dutch households under experiment could cut in two years direct energy requirement by 16.7 % from 60 to 50GJ and indirect energy requirement by 34 % from 200 to 132GJ while spending 20 % more income for consumption (Block, 2004; recited from Park & Heo, 2007)

Salon et al. asserts that the introduction of ‘city carbon budgets’, which includes reduced vehicle travel, more livable communities, more efficient use of land, and reduced fuel need for buildings and vehicles, would result in substantial cost savings, increase energy security, and lower energy prices (2008).

6.2 Political Implications and Suggestions

The findings, that Korea's energy system which is deeply dependent on conventional energy can be transformed into a sustainable one, deliver important political implications. Korea is the country which has very limited energy resources. As examined, it imports more than 95% of energy consumed. Korea's current energy system does not satisfy any premises of sustainability, from the point of environment, economy, and socio-politics. If Korea could attain the target for energy sustainability using accessible measures examined, many other countries, which have better conditions compared with Korea, can also attain the similar goals, contributing to binding global climate change issues under control with economically sound and environmentally friendly methods. Therefore, the findings of this study can be suggestive and applicable to many other countries, especially for developing countries.

Even though this study shows the possibility, it is not easy to attain the goal actually. There are many barriers to cope with. In relation, Geller made a short indication to the problems of the inefficient policy initiatives. According to him, "those policies that failed usually lack some, if not many, of the characteristics of successful efforts: they do not remove or overcome all of the major barriers, they are not part of an integrated market transformation strategy, they lack continuity or a high-level government commitment, they do not engage the private sector, and/or they do not develop a favorable market environment" (2003: 219). Geller's indication is believed to be applicable to energy policies. The energy system established in this study would not be realized if the characteristics of the successful efforts are not included. To avoid these problems, some considerations are suggested as follows:

Firstly, it is required to eradicate existing economic and non-economic barriers. In relation, IEA analyzes market barriers, their characteristics, and measures for overcoming them, as shown in Table 6-1 (IEA, 2003; re-cited from Owen, 2006). Around the current energy system which was constructed based on the use of fossil fuels and nuclear energy, vested interests groups have been created, and their power over the society is strongly influential. Therefore, the market barriers and alleviation methods shown in Table 6-1 can be suggestive in controlling to address these resistances.

Table 6-1: Types of Market Barriers and Measures That Can Alleviate Them

Barrier	Key Characteristics	Typical Measures
Uncompetitive market price	Scale economies and learning benefits have not yet been realized	Learning investments Additional technical development
Price distortion	Costs associated with incumbent technologies may not be included in their prices; incumbent technologies may be subsidized	Regulation to internalize ‘externalities’ or remove subsidies Special offsetting taxes or levies Removal of subsidies
Information	Availability and nature of a product must be understood at the time of investment	Standardization Labeling
Transaction costs	Costs of administering a decision to purchase and use equipment	Reliable independent information sources Convenient & transparent calculation methods for decision making
Buyer’s risk	Perception of risk may differ from actual risk (e.g., pay-back gap) Difficulty in forecasting over an appropriate time period	Demonstration Routines to make life-cycle cost calculations easy
Finance	Initial cost may be high threshold Imperfections in market access to Funds	Third party financing options Special funding Adjust financial structure

Inefficient market organization in relation to new technologies	Incentives inappropriately split – owner/designer/user not the same Traditional business boundaries may be inappropriate Established companies may have market power to guard their positions	Restructure markets Market liberalization could force market participants to find new solution
Excessive/inefficient regulation	Regulation based on industry tradition laid down in standards and codes not in pace with developments	Regulatory reform Performance based regulation
Capital stock turn-over rates	Sunk costs, tax rules that require long depreciation and inertia	Adjust tax rules Capital subsidies
Technology-specific barriers	Often related to existing infra-structures in regard to hardware and the institutional skill to handle it	Focus on system aspects in use of technology Connect measures to other important business issues (productivity, environment)

Source: IEA (2003; re-cited from Owen, 2006)

Secondly, it is necessary to balance the uses of 'carrot' and 'stick' to guide people to understand the necessity of change based on the objective scientific facts and long-term prospects and to control excessive resistances through legal and institutional policies. While overcoming resistances is more related with the 'stick' policies, accelerating the distribution of local renewable energy is more related with the 'carrot' policies.

Thirdly, it is important to provide the appropriate incentives for local people or societies to move. Kates et al. (1998) indicate that "abatement actually occurs at the local level when people and their organizations modify their behavior, change their activities, and employ different technologies" (recited from Salon et al., 2008). The society that facilitates renewable energy regime can be realized when local communities actually take actions. For this, the political and financial supports from the central government are indispensable. First of all, the government, again, should strengthen the incentives such as restoration of FiT system or re-design of RPS system to ‘push’ and ‘pull’ a nationwide growth of renewable energy market (The Kyunghyang Shinmun, 2015; Kim et al., n.d.). Second, the government should provide a distinct policy direction. On the surface, the Korean government recommends the establishment of renewable energy facilities; however, large-scale PV complexes and wind mills are often denied while conducting environmental impacts assessment for the purpose of environmental preservation, falling into the dilemma between preservation and sustainability. Therefore, the government should provide local governments and communities with distinctive directives like a ‘renewable energy development potential map’, or allow local governments and communities to select necessary candidate areas, taking their own responsibilities. Third, the government should support the capacity-building of local governments and communities. Most local governments and communities generally lack financial and organizational capacities. For example, Jeju Island ambitiously declared its vision of ‘carbon-free island by 2030, which, unfortunately, would be impossible without the support of the central government (Chosun Biz, 2015; Committee on Green Growth, 2015). In this sense, the government’s support is indispensable to balanced regional development.

Fourthly, local governments and communities, also, should adopt aggressive strategies for their own sustainable development. Recently, many policy alternatives based on renewable energy are suggested for local development. Sustainable energy utility (SEU) – a community-based development reflecting the concepts of less energy, ESCOs and renewable energy deployment – is evaluated to be contributable to local economy by creating jobs as well as improving energy service (Byrne et al., 2009; Byrne & Wang et al., 2014). The policies such as ‘Solar City Strategy’ and ‘Solar City Daegu 2050 Project’ are also applicable to local communities like metropolitan cities, in which many buildings can be candidates for PV installation (Byrne et al., 2015a & 2015b; Kim et al., 2006).

Through these policies and the collaboration between the central government and local governments and communities, the construction of sustainable energy system based on renewable energy would be realized more effectively and rapidly, relieving the transitional burden caused by energy system transformation.

6.3 Limitations of the Study and Future Research Directions

Even though this study tries to describe the future situations precisely, it also has limitations: for example, not reflecting the whole external costs for each energy source, not covering the whole subsidy and tax issues, limitations in predicting future energy prices, and imperfect approaches in treating nuclear issues.

Not Reflecting the Whole External Costs: Even though this study internalizes the external costs caused from the process of fuel burning, it does not include the whole external costs such as the costs generated from the processes of exploitation and transport of fuel, the construction and closing down of facilities, and wastes disposal. Provided that these costs are also internalized, the price competitiveness of renewable energy will be enhanced than the study analyzed. This study does not analyze the external costs of nuclear energy and renewable energy because they do not directly emit GHGs while generating electricity. Even though the analysis of external costs is incomplete, the real impacts are regarded as so little to accept the results of the analysis, since major external costs are related with GHGs and air pollutants.

Limitations in Analyzing the Effects of Internalization: This study internalizes social costs into energy price, under the assumption that there is no net effect on the economic system because the additional costs are imposed to the society through various paths such as medical expenses, property loss and reduction of life span. However, there might be additional economic effects as their functions are different according to their impact fields, the disagreement between victims and polluters, and the different influence among interest groups. Generally, the direct costs like energy tax and carbon tax imposed to the polluters are easily identified, while the indirect costs that victims defray are not regarded as energy costs. With these disadvantages of the internalization of external costs, it might cause severe social resistances despite their potential benefits on the society. However, since the internalization has considerable advantages in cost savings such as the decrease of construction costs for large-scale conventional energy facilities, the creation of more jobs, and the improvement of public health. Therefore, effects are not confined into negative impacts on the economy and the society, as this study assumes.

In addition, even though air pollution and GHG emissions are generated in Korea, their costs are not confined to Korea itself but its neighboring countries. Korea also cannot avoid the impact of pollution occurred in adjacent countries, and relevant pollution costs are shared. The previously-analyzed social costs in this study do not reflect the costs which have been imposed to Korea in this regard.

Limitations in Predicting Future Energy Prices: This study has been carried out based on the assumption of continuous increase in the future oil price and the same increase rate of coal and natural gas prices, which is quite different from the forecasts of IEA, DOE/EIA, and Korea's historical data trends. When the increase ratio of bituminous price is lower than those of oil and natural gas, the price competitiveness of coal-fired power plants will be maintained longer than this study expects. In addition, the prices of fossil fuels are unpredictable, as shown in the recent price fluctuations and rapid drops, unlike the assumption of this study. Unexpected price drops of fossil fuels will weaken the basis for the estimations and suggestions in this study. The study assumes that the current low energy prices are not normal but a temporal phenomenon, caused by international political instabilities.

Restrictions in Approaching Nuclear Power Plants: Reflecting many environmental and socio-political problems, this study suggests that additional construction of nuclear power plants would not be needed, except for the ones currently under construction, and that they be closed down after 40 years in operation. However, this study assumes that GHG emissions from nuclear power plants would be zero as it does not reflect the indirect GHG emissions caused by exploitation, transport, construction, operation, waste treatment and de-construction process. Therefore, significant reduction of GHG emissions could be achieved by operating nuclear power plants by 2050 within their expected lifetime. Since this study assumes automatic disappearance of nuclear power plants after their expected operation life, the decrease of nuclear power electricity might cause the rise of overall electricity rate in the future, which is not examined in this study. However, even if this is being occurred, its results would be witnessed after the 2030s. At that time, it is foreseen that renewable energy already gets price competitiveness compared with fossil fuels. Therefore, there are additional opportunities to offset the increase of electricity rate by substituting inefficient fossil fuel power plants with renewable energy ones. And, the future generation's costs for nuclear power plants cannot forecast to be stable, as already examined in Section 2.3.1.

Limitations of Assumptions: To address the limitations of data deficiencies, this study has applied several assumptions. Some major assumptions are as follows; KEEI's 2006 prospects could complement the data deficiency of recent predictions made by the government; the price changes of coal and natural gas would be similar to that of oil; the external costs used by KEEI would reflect the indirect costs that put the burdens on the society and the eco-system; and the R/P ratios suggested by BP contribute to predicting the available span of fossil fuel. These assumptions could seriously affect energy situations in the future. This means that small difference or mal-applications could change the future differently. Even though this study tries to apply exact and reasonable assumptions, there is always the possibility to face unexpected situation unlike this study's prediction. For example, the real external costs of coal might be higher than those of other fossil fuels. This means that their price competitiveness would weaken, and therefore, the use of oil or natural gas would increase as it substitutes coal. Hence, the critical review on these assumptions is necessary in applying the result of this study.

6.4 Concluding Remarks

This study has examined whether Korea has the potential to meet the global goal of addressing climate change based on the principles of general equity and full participation of the international community. The methodologies considered in this study are designed to be environmentally sound, economically efficient and socio-economically equitable: from an environmental perspective, it designs the methods to reflect social costs caused by air pollution and climate change; from an economic perspective, it includes both supply-side and demand-side instruments to find economically efficient methods to attain the GHG reduction goal by changing the energy mix and reducing the energy demand; from a socio-political perspective, it examines how the energy policy can contribute to regional energy balance and thereby to social equity improvement. In addition, this study also analyzes the change in the level of national energy security with the adoption of new energy scenario compared with the government's scenarios.

The Korean government has continuously examined GHG reduction plans in cooperation with KEEI, which usually aim at reducing 20 ~ 30 % of GHG emissions compared with BaU scenario. In 2015, the government has updated previous plans to extend the reduction volume. According to the plan, the government plans to reduce 37 % of GHG. Even though it is considered an ambitious plan compared with previous ones, it is far from meeting the international needs and justice which the IPCC has recommended to avoid serious worldwide climate change.

On the contrary, the alternative reduction scenario suggested by this study shows the possibility to fulfill the international needs and equity. Even though Korea is not able to meet the recommended target by 2030, Korea has additional reduction potential by making renewable energy price competitive after the mid-2020s. Since renewable energy potential is expected to increase with the advance of technology and the change of public acceptance, Korea could meet the suggested goal by 2050, as examined in section 4.2. In addition, Korea can use nuclear power plants transitionally, because many nuclear power plants are expected to be in operation by 2050. Through these policies, Korea is likely to satisfy the criteria of world average per capita GHG emissions by 2050.

In sum, Korea has a chance to transform its energy system into a sustainable one through the conversion of industrial structure into less energy intensive one, aggressive supports for efficiency improvement technologies and nurturing energy saving culture and the reform of energy pricing system; including the internalization of social costs, the eradication of environmentally harmful subsidies, and the adjustment of tax system. These measures, while being practical in theory, would not be able to easily resolve the existing problems in reality. However, the reform will, eventually, bring on economic benefits by reducing social costs and improving environmental quality, social equity and national security. In other words, a set of policy recommendations suggested by this study would enable the transition of Korea's economy toward the 'green energy economy' (Wang, 2010).

The policy recommendations in this study can be also helpful to many other countries, especially to developing countries. Compared with Korea, many other developing countries have higher potentials in relation to natural and social conditions: less population density, better natural conditions including solar energy and natural resources, and wide available land. Although they have different capacities, all countries have to contribute to addressing global climate change together. In this regard, it is important to transform the conventional energy system to renewable-based sustainable energy system. For converting into sustainable energy system, it is very significant to overcome the resistances of interested groups, especially those who are related with the conventional energy industries. Therefore, the earlier transition would cause less resistance and bring better chance. As admitting the concrete political instruments being different according to their situations, the basic approach would be similar: pursuing higher energy efficiency and changing into energy saving lifestyle will be fundamental measures for all countries. In addition, the adjustment of energy-consuming industrial and social structures is also necessary. Many socio-economic phenomena are likely to be irreversible or hard to replace. The introduction of unsustainable measures would make it difficult to suspend them afterward, as shown in Korea's example on the difficulties to abolish environmentally harmful subsidies and tax exemption, and suspend the coal mining industries. Therefore, these measures should be avoided from the scratch. By taking the strengths and avoiding the short-comings of Korea, other developing countries could have better opportunities in constructing a sustainable energy system.

Recently, the world has agreed to take actions to hold the temperature increase within 2 °C. Korea, as a responsible member of the global society, should carry out more aggressive energy and climate change policies. The policy alternatives suggested by this study would be helpful for Korea and many other countries to change their energy system into a sustainable one.

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Appendix A

RESEARCH ON MID- AND LONG- TERM POLICIES AND STRATEGIES FOR MEASURING CLIMATE CHANGE CONVENTIONS (KEEI, 2006)

1. Population and Household Prospect

Category	2005	2010	2015	2020	2025	2030
Population (million)	48.3	49.2	49.8	50.0	49.8	49.3
Households (million)	15.8	16.9	17.6	18.2	18.2	18.4

2. Final Energy Prospect for the Transportation Sector

(Unit: thousand toe)

Category	2005	2010	2015	2020	2025	2030
Sum	35,441	40,120	44,827	49,614	53,344	57,230
Rail	505	687	788	880	986	1,061
Road	28,030	31,197	34,316	37,220	39,406	41,172
Ocean	4,179	5,204	6,237	7,115	8,338	9,090
Aviation	2,727	3,032	3,486	4,399	4,614	5,907
Gasoline	7,476	7,843	8,641	8,673	8,801	9,004
Diesel	16,326	18,925	20,864	23,400	25,592	27,083
LPG	4,702	4,792	4,954	5,071	5,140	5,300
Heavy oil	3,659	4,232	4,956	5,523	6,496	7,091
Aviation oil	2,727	3,032	3,486	4,399	4,614	5,907
City Gas	337	994	1,581	2,169	2,287	2,404
Electricity	214	302	345	379	414	441

3. Final Energy Prospect for the Residential Sector

(Unit: thousand toe)

Category		2005	2010	2015	2020	2025	2030
Sum		24,335	27,893	30,519	33,071	35,022	37,161
Heating	Sub-sum	18,169	20,803	22,647	24,463	25,869	27,332
	Coal	1,072	266	66	16	4	1
	Oil	7,066	6,590	6,046	5,828	5,723	5,794
	- Kerosene	4,200	4,685	4,299	4,144	4,069	4,120
	- Diesel	800	467	428	413	405	410
	- Heavy oil	800	563	517	498	489	495
	- Propane	1,253	875	802	773	760	769
	- Butane	13	-	-	-	-	-
	City Gas	8,133	11,599	13,822	15,602	16,897	18,080
	Heat	1,281	1,698	2,028	2,296	2,485	2,657
	NRE	617	650	685	721	760	800
Cooking	Sub-sum	1,791	1,873	1,928	1,968	1,968	1,971
	Propane	566	432	333	274	237	17
	Butane	12	9	7	6	5	4
	City Gas	1,213	1,432	1,588	1,688	1,726	1,750
Sum of Electricity		4,375	5,217	5,944	6,640	7,185	7,858
Cooling		314	419	537	667	792	937
Light		896	1,045	1,192	1,332	1,417	1,480
Other Electricity		3,166	3,753	4,215	4,641	4,976	5,441

Persons per household	3.06	2.92	2.83	2.75	2.74	2.68
Toe per capita	0.50	0.57	0.61	0.66	0.70	0.75
Toe per household	1.54	1.65	1.74	1.82	1.92	2.02

4. Final Energy Prospect for the Commercial Sector

(Unit: thousand toe)

Category	2005	2010	2015	2020	2025	2030
Value-added (KRW trillion)	338.7	429.2	528.5	651.6	787.9	958.1
Building's Area (million m^2)	316	427	556	726	924	1184
Sum	13,501	16,729	19,677	23,173	26,818	31,190
Oil	2,188	2,081	1,983	1,941	1,906	1,859
City gas	3,245	4,227	5,043	5,943	6,795	7,802
Heat	210	318	409	524	653	812
Electricity	7,858	10,103	12,242	14,765	17,464	20,717
Heating	4,410	5,191	5,801	6,490	7,136	7,884
Cooling	2,363	3,220	4,091	5,106	6,146	7,362
Cooking	1,829	2,133	2,361	2,616	2,850	3,119
Power Supply	1,650	2,079	2,488	2,980	3,507	4,148
Others	3,249	4,105	4,937	5,981	7,180	8,677

5. Final Energy Prospect for the Public Sector

(Unit: thousand toe)

Category	2005	2010	2015	2020	2025	2030
GDP (KRW trillion)	721.2	908.6	1,105.5	1,345.0	1,597.4	1,897.2
Sum	3,806	4,542	5015	5,420	5,800	6,182
Oil	1,361	1,190	1,090	1,050	1,020	1,010
City gas	320	454	552	650	725	804
Heat	39	55	70	87	104	124
Electricity	1,785	2,389	2,701	2,928	3,139	3,348
Others	301	454	602	705	812	896

6. Final Energy Prospect for the Industrial Sector

(Unit: thousand toe)

Category		2005	2010	2015	2020	2025	2030
Industrial Sum	Sum	90,970	98,749	105,884	117,667	127,628	138,061
	Electricity	14,347	16,851	19,166	22,194	25,045	28,083
	Fuel	23,907	25,278	26,584	28,829	30,712	32,791
	Material	52,716	56,620	60,134	66,644	71,871	77,187
Agriculture, Forestry, Fishery	Sub-sum	3,408	3,805	4,130	4,657	5,256	6,071
	Electricity	603	690	770	889	1,024	1,205
	Fuel	2,805	3,115	3,360	3,768	4,232	4,866
Mining	Sub-sum	176	144	138	138	142	150
	Electricity	113	91	87	87	89	94
	Fuel	63	53	51	51	53	56
Manu-facturing	Sub-sum	85,147	91,766	97,942	108,674	117,640	126,849
	Electricity	13,631	16,070	18,309	21,218	23,932	26,784
	Fuel	18,800	19,076	19,499	20,812	21,837	22,878
	Material	52,716	56,620	60,134	66,644	71,871	77,187
Food & Beverage	Sub-sum	1,606	1,613	1,624	1,722	1,786	1,852
	Electricity	643	664	678	728	763	799
	Fuel	963	949	946	994	1,023	1,053
Textile & Clothes	Sub-sum	2,632	2,493	2,323	2,338	2,366	2,447
	Electricity	1,120	1,041	970	977	989	1,023
	Fuel	1,512	1,452	1,353	1,361	1,377	1,424
Wood & Paper	Sub-sum	2,024	2,198	2,240	2,389	2,493	2,598
	Electricity	962	1,014	1,039	1,114	1,168	1,222
	Fuel	1,062	1,184	1,201	1,275	1,325	1,376
Petro-Chemical	Sub-sum	42,623	45,802	49,009	54,949	60,197	65,727
	Electricity	2,923	3,267	3,579	4,125	4647	5,209

	Fuel	3,447	2,960	3,027	3,297	3522	3,761
	Material	36,253	39,575	42,403	47,527	52,028	56,757
Non-Metal	Sub-sum	5,401	5,761	5,677	5,845	5,874	5,884
	Electricity	845	880	855	863	850	836
	Fuel	4,556	4,881	4,822	4,982	5,024	5,048
Primary Metal	Sub-sum	20,576	21,135	21,978	23,692	24,589	25,314
	Electricity	2,419	2,422	2,537	2,752	2,873	2,973
	Fuel	1,694	1,668	1,710	1,823	1,873	1,911
	Material	16,463	17,045	17,731	19,117	19,843	20,430
Assembling	Sub-sum	6,193	8,789	11,110	13,565	15,956	18,444
	Electricity	4,535	6,642	8,518	10,525	12,507	14,585
	Fuel	1,658	2,147	2,592	3,040	3,449	3,859
Other Manu-facturing	Sub-sum	4,092	3,975	3,981	4,174	4,379	4,583
	Electricity	184	140	133	134	135	137
	Fuel	3,908	3,835	3,848	4,040	4,244	4,446
Construc-tion	Fuel	2,239	3,034	3,674	4,198	4,590	4,991

Coal	Sub-sum	21,244	22,000	22,562	24,079	24,857	25,468
	Anthracite	2,806	2,895	3,007	3,239	3,362	3,461
	Bituminous	18,438	19,105	19,555	20,840	21,495	22,007
Oil	Sub-sum	50,727	54,328	57,933	64,340	69,912	75,858
	Energy	10,238	10,235	10,545	11,306	11,977	12,792
	LPG	2,062	2,181	2,306	2,550	2,761	2,979
	Non-energy	38,427	41,912	45,082	50,484	55,174	60,087
City Gas		4,654	5,572	6,223	7,054	7,815	8,652
Electricity		14,346	16,851	19,167	22,195	25,046	28,084
Others		4,089	6,585	9,236	12,954	16,533	20,114

7. Final Energy Prospect

(Unit: thousand toe)

Category	2005	2010	2015	2020	2025	2030
Sum	172,143	194,620	215,159	241,900	265,147	289,939
Industry	95,060	105,336	115,121	130,622	144,163	158,176
Transportation	35,441	40,120	44,827	49,614	53,344	57,230
Residential	24,335	27,893	30,519	33,071	35,022	37,161
Commercial	13,501	16,729	19,677	23,173	26,818	31,190
Public & Others	3,806	4,542	5,015	5,420	5,800	6,182

Appendix B

THE FIRST NATIONAL BASIC ENERGY PLAN (PMO ET AL., 2008. 8)

1. Premises

Category	2006	2020	2025	2030	Annual Increase Rate (%)
GDP (KRW trillion 2000)	760.3	1,396.2	1,634.3	1,836.0	3.70
Population (million)	48.3	49.3	49.1	48.6	0.03
Oil Price (USD 2006/bbl)	66.0	102.1	109.3	118.7	2.48

Note: Oil price was predicted based on Annual Energy Outlook (DOE/EIA, 2008)

2. Prospect of Value-Added Share by the Sector

(Unit: %)

Category	2011	2020	2025	2030
Primary Industry	4.0	2.3	2.1	1.9
Manufacturing Industry	33.5	33.2	32.5	31.3
- Petro-chemistry, Non-metal, Primary Metal	9.1	7.6	7.2	6.5
- Assembly	20.1	22.7	22.8	22.6
SOC	10.4	10.0	9.7	9.3
Service Industry	52.1	54.4	55.7	57.4

Note: Value-added share was calculated based on 2000 real price value.

3. Final Energy Consumption Prospect (BaU)

(Unit: Mtoe)

Category	2006	2020	2025	2030	Annual Increase Rate (%)
Coal	22.7	27.2	28.3	27.6	0.8
Oil	97.0	112.4	117.0	114.7	0.7
City Gas	18.4	29.2	32.2	33.9	2.6
Electricity	30.0	43.9	47.9	50.3	2.2
Heat	1.4	2.9	3.4	3.9	4.3
New and Renewable	4.1	9.8	12.2	14.6	5.4
Sum	173.6	225.4	241.0	245.1	1.4

Note: Sectoral distribution Change from 2016 to 2030 (Industry 97.2 → 134.0, Transportation 36.5 → 45.9, Residential &Commercial 36.0 → 59.1, Public & Others 3.8 → 6.0)

4. Total Primary Energy Supply Prospect (BaU)

(Unit: Mtoe)

Category	2006	2020	2025	2030	Annual Increase Rate (%)
Coal	56.7	79.5	83.8	84.6	1.7
Oil	101.8	115.1	119.7	117.2	0.6
LNGs	32.0	46.1	51.5	54.0	2.2
Hydro	1.3	1.3	1.5	1.6	0.7
Nuclear	37.2	57.2	62.5	66.8	2.5
New and Renewable	4.4	12.3	15.4	18.6	6.2
Sum	233.4	311.6	334.3	342.8	1.6

5. TFC Reduction Objective in 2030

(Unit: Mtoe)

Category	2006	2020	2030	Annual Increase Rate (%)
Coal	22.7	20.8	**8.2**	-4.2
Oil	97.0	102.9	98.7	0.1
City Gas	18.4	27.0	29.7	2.0
Electricity	30.0	40.6	44.1	1.6
Heat	1.4	2.7	3.4	3.7
New and Renewable	4.1	12.0	23.4	7.5
Sum	173.6	205.9	207.5	0.7

6. TPES Reduction Objective in 2030

(Unit: Mtoe)

Category	2006	2020	2030	Annual Increase Rate (%)
Coal	56.7	66.8	47.2	-0.8
Oil	101.8	104.3	99.1	-0.1
LNG	32.0	34.3	36.2	0.5
Hydro	1.3	2.4	2.4	2.6
Nuclear	37.2	63.6	83.4	3.4
New and Renewable	4.4	16.6	32.1	8.7
Sum	233.4	288.0	300.4	1.1

7. Demand Management Objective

Category	2006	2020	2030	Annual Increase Rate (%)
Per capita Energy (toe)	4.83	5.84	6.18	1.0
Energy Intensity (toe/USD thousand)	0.347	0.233	0.185	-2.6

Note: Applied currency rate (1130.6 KRW per USD)

Appendix C

THE SECOND NATIONAL BASIC ENERGY PLAN (MOTIE, 2014)

1. Premises

Category	2011	2020	2030	2035	Annual Increase Rate (%)
GDP (KRW trillion 2005)	1,082			2,101	2.80
Population (million)	49.8	51.4	52.2	51.9	0.17
Dubai Oil Price (USD 2011/bbl)	106.0	123.7	136.1	139.8	1.16

2. Prospect of Industrial Value-Added

(Unit: KRW trillion 2005)

Category	2011	2025	2030	2035	Annual Increase Rate (%)
Primary Industry	31.3	32.1	31.0	29.3	-0.27
Manufacturing Industry	351.6	600.0	685.1	761.9	3.28
- Petro-chemistry, Non-metal, Primary Metal	87.1	112.7	117.5	118.8	1.30
- Assembly	221.2	440.7	522.2	600.5	4.25
SOC	87.6	115.8	122.5	127.0	1.56
Service Industry	610.0	929.7	1,057.9	1,182.0	2.79

3. Final Energy Consumption Prospect (BaU)

(Unit: Mtoe)

Category	2011	2025	2030	2035	Annual Increase Rate (%)
Coal	33.5	37.4	38.8	38.6	0.58
Oil	102.0	109.1	105.1	99.3	-0.11
City Gas	23.7	32.5	34.4	35.3	1.68
Electricity	39.1	59.7	65.6	70.2	2.47
Heat	1.7	2.9	3.1	3.3	2.82
New and Renewable	5.8	7.1	7.4	7.4	1.01
Sum	205.9	248.7	254.3	254.1	0.88

Note: Sectoral distribution Change from 2011 to 2030 (Industry 126.9 → 152.3, Transportation 36.9 → **45.5**, Residential 21.6 → 24.6, Commercial 15.9 → 26.0, Public & Others 4.6 → 5.8)

4. Total Primary Energy Supply Prospect (BaU)

(Unit: Mtoe)

Category	2011	2025	2030	2035	Annual Increase Rate (%)
Coal	83.6	100.2	107.7	112.4	1.24
Oil	105.1	111.0	107.1	101.5	-0.15
LNGs	46.3	64.8	69.8	73.3	1.93
Hydro	1.7	1.7	1.9	2.0	0.70
Nuclear	32.3	59.6	65.3	70.0	3.28
New and Renewable	6.6	16.8	18.0	18.8	4.44
Sum	275.7	354.1	369.9	377.9	1.32

5. TFC Reduction Objective in 2035

(Unit: Mtoe)

Category	2011	2025	2030	2035	Annual Increase Rate (%)
Coal	33.5	34.7	35.3	34.4	0.10
Oil	102.0	96.2	88.8	80.3	-0.99
City Gas	23.7	31.4	33.0	33.8	1.50
Electricity	39.1	53.3	57.1	59.9	1.79
Heat	1.7	2.8	3.0	3.2	2.72
New and Renewable	5.8	8.3	8.7	8.8	1.71
Sum	205.9	226.7	226.0	220.5	0.29

6. Share of Nuclear in Electricity Generation Sector: 29%

※ The First National Basic Energy Plan (2008): 41% (based on Capacity)

Appendix D

PLAN FOR SETTING POST-2020 GHGS REDUCTION GOALS (PMO ET AL., 2015)

1. Premises

Category	2013	2020	2025	2030	Annual Increase Rate (%)	
					’13-‘20	’13-‘30
GDP (KRW trillion 2005)	1,132.9	1.447.0	1,679.1	1,897.8	3.56	3.08
Population (million)	50.2	51.4	52.0	52.2	0.34	0.23
Households (million)	18.2	19.9	20.9	21.7	1.28	1.04
Dubai Oil Price (USD 2011/bbl)	109.7	123.7	130.9	136.1	1.73	1.28

2. Prospect of Industrial Value-Added

(Unit: KRW trillion 2005)

Category	2013	2020	2025	2030	Annual Increase Rate (%)	
					’13-‘20	’13-‘30
Primary Industry	31.5	32.3	32.2	31.0	0.37	-0.09
Manufacturing Industry	372.5	506.9	600.0	685.1	4.50	3.65
- Petro-chemistry, Non-metal, Primary Metal	89.8	105.3	112.7	117.5	2.30	1.59
- Assembly	239.8	355.5	440.7	522.2	5.79	4.68
SOC	88.5	106.4	115.8	122.5	2.67	1.93
Service Industry	638.6	799.8	929.7	1,057.9	3.27	3.01

3. Final Energy Consumption Prospect (BaU)

(Unit: Mtoe)

Category	2013	2020	2025	2030	Annual Increase Rate (%)	
					’13-‘20	’13-‘30
Coal	33.5	35.5	37.4	38.8	0.83	0.87
Oil	104.3	110.5	109.1	105.1	0.83	0.04
City Gas	24.6	29.9	32.5	34.4	2.79	1.97
Electricity	40.9	52.5	59.7	65.6	3.62	2.81
Heat	1.9	2.5	2.9	3.1	3.89	2.86
New and Renewable	6.3	6.7	7.1	7.4	0.96	0.97
Sum	211.6	237.6	248.7	254.3	1.67	1.09

Note: Sectoral distribution Change from 2013 to 2030 (Industry 131.1 → 152.3, Transportation 37.7 → 45.5, Residential 22.0 → 24.6, Commercial 16.3 → 26.0, Public & Others 4.5 → 5.8)

4. Total Primary Energy Supply Prospect (BaU)

(Unit: Mtoe)

Category	2013	2020	2025	2030	Annual Increase Rate (%)	
					’13-‘20	’13-‘30
Coal	78.1	99.3	100.2	107.7	3.48	1.90
Oil	108.6	113.1	111.0	107.1	0.59	-0.08
LNGs	51.7	55.0	64.8	69.8	0.89	1.79
Hydro	1.6	1.7	1.7	1.9	0.96	1.17
Nuclear	36.5	49.4	59.6	65.3	4.44	3.49
New and Renewable	7.8	13.7	16.8	18.0	8.48	5.08
Sum	284.2	332.2	354.1	369.9	2.26	1.56

5. GHG Emissions Prospect (BaU)

(Unit: Mt_CO_2)

Category	2013	2020	2025	2030	Annual Increase Rate (%)	
					'13-'20	'13-'30
Energy	592.2	677.5	700.5	738.9	1.94	1.32
Non-energy	87.7	104.9	109.1	111.7	2.59	1.43
Sum	679.8	782.5	809.7	850.6	2.03	1.33

6. Policy Scenario Alternatives for GHG Reduction in 2030

2030 Reduction GHG Goal		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Final GHG Emissions (Mt_CO_2)		726	688	632	585
Reduction Rate (%)	BaU versus	-14.7%	-19.2%	**-25.7%**	-31.3%
	2012 versus	5.5%	0%	-8.1%	-15.0%
Indicators Improvement Rate	t_CO_2/KRW million	-37.8%	-40.7%	-44.9%	-48.3%
	per capita T_CO_2	-0.9%	-4.4%	-12.3%	-18.8%
GDP Reduction Rate (Based on 2030 Data)		0.22%	-0.33%	-0.54%	-0.78%