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Three Essays on the Renewable Energy Policy Focusing on the Long-term Direction and Effective Implementation

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Sangmin Cho

Energy, Environmental and Engineering Economics

College of Engineering

Seoul National University

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Sangmin Cho
Department of Energy Systems Engineering
The Graduate School of Seoul National University

Abstract

This study discussed three major issues concerning long-term renewable energy policy direction at the national level and the effective implementation of policy tools in this area. First, a new viewpoint was suggested for the causal relationship between renewable energy consumption and economic growth. Then, an empirical study under the proposed and conventional viewpoints was conducted using the data of OECD and non-OECD countries, and directions for a long-term renewable energy policy were proposed. Second, a methodology was introduced for choosing optimal

renewable energy options at the national level, to achieve renewable energy policy goals efficiently. In particular, factors and criteria were derived for sectors where future expansion is expected, and an empirical analysis was conducted to select optimal alternatives. Last, with respect to public perception, which has emerged as the largest obstacle against the achievement of renewable energy policy goals, public willingness to accept (WTA) utility loss caused by renewable energy production and utilization was estimated. Factors that affect the rate of participation were analyzed to propose how public participation may be increased.

1) Causal relationship between renewable energy consumption and economic growth

This study recognized and addressed the problem posed by the previous studies and suggested a new viewpoint for addressing the causal relationship between renewable energy consumption and economic growth. The conventional viewpoint focused on the role of renewable energy as an input factor for production. However, renewable energy is more appropriately characterized as a technology or an industry rather than an energy source, when compared to conventional energy sources, especially for developed countries.

Therefore, by suggesting a new viewpoint in this regard, this paper breaks new ground.

The results of the empirical analysis for the new viewpoint revealed that for developed countries the momentum of the renewable energy industry is insufficient to lead economic growth. Rather, the industry has grown due to economic growth and the government's supporting policies. However, a very different result was obtained when the analysis targets were limited to the top five countries (USA, Japan, Germany, Denmark, and Spain) having the most mature renewable energy industries. These results showed that the growth hypothesis between renewable energy and economic growth is valid for these countries. This signifies that the renewable energy industry can play an important role in economic growth. A comparison of both analytical results shows that during the early-to-middle stages of the renewable energy industry, economic growth and the resulting fiscal expansion contributes to the industry's expansion. However, once the renewable energy industry matures to some degree, it contributes to economic growth.

2) Choosing the appropriate renewable energy source

Narrowing down the perspective to Korea, the problem is its recent economic slowdown coupled with an insufficient government budget. These factors make it difficult to attain public agreement for expanding support for the renewable energy sector. Therefore, a selection and concentration strategy is required for effective implementation of a renewable energy policy under these circumstances.

A combination of fuzzy analytic hierarchy process (fuzzy-AHP) and the benefits, opportunities, costs, risks (BOCR) approach was employed as the methodology for selecting an appropriate renewable energy option at the national level. The empirical results revealed that economic and industrial factors, such as market size and trade balance improvement, play a more significant role in effective policy implementation than energy–environmental factors such as energy cost and environmental cost. This result is in line with the new viewpoint, which focuses on the industrial aspect of renewable energy. Furthermore, the geothermal heat pump was chosen as the optimal alternative for the analyzed sectors, while the oil boiler, which is the most widely used technology at present, was revealed to be the least appropriate alternative. This result indicates that the current energy mix and energy policies are inappropriate for the studied sectors. Therefore, a paradigm shift is required in energy policy, covering not just the supply of clean and low-cost energy sources but also technological competitiveness enhancement and development of a new domestic industry.

3) Public perception of renewable energy production

It is vital to secure a minimum domestic market and construct a test bed in order to foster the renewable energy industry when it is at a nascent stage. However, the recent cases of public utility loss in the process of renewable energy deployment act as an obstacle against implementing renewable energy policies and, therefore, government choice. Accordingly, it was necessary to study public perception in terms of opportunity cost. And an empirical analysis on the feasibility of increasing waste cooking oil (WCO) collection rates for biodiesel production was conducted.

The results indicated that regular households' average WTA WCO collection was similar to or lower than the WCO market price, and if an appropriate collection system is constructed, over 40% of the households were willing to participate, provided the compensation level was comparable to the market price of the WCO. Considering that the household WCO collection rate identified by the survey was

6.9%, it is likely that appropriate compensation would raise WCO collection significantly. Therefore, the result of the empirical analysis showed that the utility loss caused by renewable energy deployment can be sufficiently overcome if a proper compensation system is constructed. In other words, to achieve the long-term renewable energy policy goals effectively, it is necessary to accurately identify the cause of the utility loss and respond to it by constructing a proper compensation system.

The overall conclusion of this study is as follows. Renewable energy should be considered as a new industry, and the industry's potential should be judged in line with the proposed selection and concentration strategies from a long-term perspective. Public utility loss, which occurs in the process of securing domestic markets for renewable energy and building test beds, can be overcome with a proper compensation system, the implementation of which will contribute to the effective implementation of renewable energy policy.

The contributions of this study are three-fold. First, it suggests a new viewpoint on the causal relationship between renewable energy consumption and economic growth and the empirical results showed

that the contribution of the renewable energy industry to economic growth depends on the phase of the renewable energy industry. Second, this paper is the first to highlight the use of fuzzy-AHP with BOCR approach toward the investigation of optimal energy alternatives for the horticulture and stockbreeding sectors and provided insights into new long-term renewable energy policy directions for these sectors. Last, this paper uses the WTA measure, instead of the willingness to pay (WTP) measure, for waste collection unlike most previous studies. Notably, this was the first attempt to study public perception of WCO collection in terms of opportunity cost.

Keywords: Panel VECM, Long-run causality between renewable energy consumption and economic growth, Fuzzy-AHP with BOCR approach, Contingent valuation, Willingness to accept

Student Number: 2010-30261

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INTRODUCTION AND RESEARCH FRAMEWORK

Intr-1. Motivation

Renewable energy supply in Organisation of Economic Co-operation and Development (OECD) member countries recorded an average annual growth rate of 2.4% from 1990 to 2012, which is three times the average annual growth rate of the total primary energy supply (0.7%) in the same period (IEA, 2014). Further, the industrial scale of renewable energy is expected to grow fast (CleanEdge, 2014). This is because many countries are competitively striving to expand renewable energy deployment and nurture the industry. Interest in renewable energy has increased in response to climate change and environmental pollution, and the industry is increasingly being looked upon as the solution to energy-related issues such as energy security and stability. Furthermore, renewable energy is believed to be the new growth engine for the future.

However, certain issues, some old and others new, have been raised, which include long-term and macroeconomic issues, such as on the casual relationship between renewable energy and economic growth, and microeconomic concerns, such as the appropriate incentive levels for renewable energy deployment. This paper aims to discuss these issues and propose possible directions for long-term renewable energy policy and effective implementation of policy tools.

The first issue concerns the contribution of renewable energy to economic growth. This discussion can significantly influence the direction of long-term renewable energy policy. Recently, many researchers investigated the casual relationship between renewable energy and economic growth, to understand whether renewable energy contributes to economic growth and to help evaluate policy directions and improve policy effectiveness (Sadorsky, 2009; Apergis and Payne, 2010, 2012; Tugcu et al., 2012; Al-mulali et al., 2013). However, these empirical analyses provided conflicting results because of the variations in research areas, periods, and/or methodologies and analysis parameters. Thus, it is difficult to arrive at specific conclusions for the question at hand (Stern, 2013). Furthermore, most researchers focus on the role of renewable energy as an energy source and overlook the fact that renewable energy should be characterized as a new industry rather than an energy source, when compared to conventional energy sources. This is especially true for developed countries (DCs). However, distinguishing whether renewable energy's contribution to economic growth should be considered an energy input or a new industry is crucial before settling on a policy direction.

The second issue concerns the selection of optimal renewable energy alternatives at the national level. Since renewable energy is dependent on the government's policy support, effective accomplishment of policy objectives requires efficient allocation of limited government resources. Hence, when selecting energy sources, a rational decision-making process considering the efficient allocation of resources must be established prior to establishing selection and concentration strategies. The issue lies in the method and process of selecting the optimal alternative. Levelized cost of energy (LCOE) analysis and benefit–cost (B/C) analysis are frequently used methods in selecting an appropriate energy source or deducing the optimal energy mix. While these evaluation methods are quantitative and objective, they do not reflect the nonmarket, qualitative, or subjective factors that must be considered in setting a policy direction. Renewable energy still has lower economic feasibility and profitability than other energy sources, but it enjoys advantages in terms of environmental performance, high industrial potential, and ripple effects on relevant industries. Moreover, renewable energy markets are new, and thus, relevant information, especially quantitative data, is lacking. Thus, qualitative evaluations, mainly experts' views, play a vital role in the government's choices. Considering these aspects, the conventional methods presented above cannot be deemed appropriate decision-making methods. Hence, rational decision-making methods should be introduced to enable the selection of the optimal renewable energy source.

The last issue concerns public perception of renewable energy. The previous two issues concerned long-term policy direction and government choices, both of which are mainly based on the positive factors about renewable energy, which were mentioned earlier. The recent emphasis on the negative nonmarket factors of renewable energy, however, indicates that the current renewable energy policies need to change. The negative nonmarket factors of renewable energy include noise, environmental destruction, and the inconvenience caused in the process of producing and utilizing renewable energy, all of which lead to public utility loss. If such utility loss becomes frequent, government support for renewable energy may be fundamentally questioned, thus becoming a major obstacle against renewable energy expansion. Therefore, by accurately identifying such negative nonmarket factors and analyzing public awareness, effective solutions can be proposed for the identified obstacles.

Addressing these issues is important because doing so can help to design more effective energy, economic, and environmental policies (Dedeoğlu and Kaya, 2013) and contribute toward identifying the measures needed for the effective implementation of these policies.

Intr-2. Research Purpose and Framework

The objective of this study is to perform an empirical analysis regarding the aforementioned three issues, so as to identify long-term renewable energy policy directions and the policy tools needed to implement it effectively. Thus, the results of this study will help derive specific implications concerning renewable energy policies.

1) First, from a long-term perspective, is renewable energy an important input for economic growth, or is it a new industry?
2) Second, which factor plays an important role in the selection of the optimal renewable energy option in a new market at the national level, and what is the optimal renewable energy source?
3) Third, how is the acceptable level of compensation for public utility loss caused by the production of renewable energy determined, and how can public participation be increased?

Let us begin with the first question. Identification of the causal relationship between renewable energy and economic growth is a recent and keenly debated topic in the field of renewable energy. Many researchers have attempted to examine the causal relationship between energy consumption and economic growth. However, as renewable energy has been recently emphasized as a core enabler for sustainable development, the scope of the researchers' interest has expanded to the causal relationship between renewable energy consumption and economic growth. Recently, therefore, several researchers have investigated the causal relationship between renewable energy consumption and economic growth, to understand whether renewable energy leads to economic growth or vice versa.

However, previous studies overlooked the fact that renewable energy can be characterized more as a new industry rather than an energy source, when compared to conventional energy sources. This is especially true for developed countries, where renewable energy accounts for a small portion of the energy mix, and it is yet to be regarded as a significant input among energy sources. Moreover, economic agents cannot discriminately select renewable electricity from all the electricity generated from various energy sources in the power grid. As such, given that it is difficult to regard renewable energy as an input (unlike conventional energy), the results of previous discussions verifying it as an essential input for economic growth are debatable, given the controversy over the assumption itself.

This study, however, suggests a new viewpoint on the causal relationship between renewable energy consumption and economic growth. In contrast to the conventional viewpoint that focuses on the role of renewable energy as an input, the new viewpoint suggests that the renewable energy industry contributes to economic growth. Moreover, unlike previous studies, the results of this study provide more informed policy implications, as it conducts an empirical analysis on DCs and less developed countries (LDCs) using the multivariate panel vector error correction model (VECM) for both the conventional and the proposed viewpoints.

Let us proceed to the second question, namely, which factor plays an important role in the selection of the optimal renewable energy option in a new market at the national level, and what is the optimal renewable energy source? According to World Energy Outlook for 2013 (WEO 2013) published by the International Energy Agency (IEA, 2013), the share of renewable energy under the "New Policies

Scenario” in world primary energy demand is projected to increase from 13.2% in 2011 to 17.6% in 2035. Despite this optimistic prospect, renewable energy is still less economically feasible and profitable than conventional energy sources, owing to its high initial investment costs as well as lower reliability with regard to technological stability. Thus, it is unlikely to be able to compete independently in the market without policy assistance from the government. Nevertheless, renewable energy provides advantages and opportunities in terms of environmental performance, high industrial potential, and ripple effects on relevant industries.

Considering that the government’s resources are limited, however, it is important to allocate them cost-effectively. Thus, it is necessary to develop a strategy that focuses on the most optimal energy option for each sector. Thus, an appropriate methodology should be selected to precisely evaluate energy options, taking into account the nonmarket and qualitative factors, by comparing renewable energy with other energy sources. Particularly, because quantitative evaluation is restricted owing to lack of information in new markets, a methodology that can overcome this problem is necessary in this field.

This study introduces an approach that presents the optimal solution at the national level by applying the fuzzy analytic hierarch process (fuzzy-AHP) with the benefits, opportunities, costs, risks (BOCR) approach. In fuzzy-AHP, the crisp AHP methodology is combined with the fuzzy theory, which can capture the vagueness of answers in the process of calculating relative weights. Furthermore, the BOCR approach suggests consistent standards for selecting criteria and factors, and it increases the rationality and convenience of selecting criteria and factors, particularly when the number of previous studies addressing the analytical targets is insufficient. In addition, the BOCR approach can consider negative priorities in decision making that were not applied in the general AHP. Thus, coupling of the fuzzy-AHP with the BOCR approach can be an appropriate methodology to evaluate the appropriateness of renewable energy for new markets in particular.

This study performed an empirical analysis on the horticulture and stockbreeding sectors in Korea. Various assistance policies, such as exemption of the tax on oil, subsidy for coal briquettes, and lower electricity tariffs, have been implemented in the Korean agriculture sector. These assistance policies can serve as opportunity factors for renewable energy. In other words, because the existent assistance measures support nonrenewable energy, additional government assistance is not as urgently required to deploy renewable energy for the agriculture sector compared to the other sectors. Particularly, because horticulture and stockbreeding are the most energy-intensive subsectors in the agriculture industry, farmers are sensitive to the assistance measures addressing energy use and energy prices.

The last question addresses acceptable level of compensation for public utility loss caused by the production of renewable energy. Previous research have focused mainly on long-term policy direction and government choice based on the positive nonmarket factors of renewable energy. However, renewable energy is not always associated with positive nonmarket factors. Indeed, the recent trend highlights the negative nonmarket factors of renewable energy, and thus, public acceptance of renewable energy is emerging as an important issue. The negative nonmarket factors of renewable energy are likely to be the main obstacles against the growth of renewable energy even as its supply increases. In particular, if these negative nonmarket factors are emphasized, policy directions on renewable energy should be comprehensively adjusted, because the promotion of renewable energy thus far has been possible only through the political will of the government and not on market choice. Thus, it is necessary to quantify these negative nonmarket factors and propose a method to solve the problems associated with them. This study provides an approach to solve these problems by considering the possibility of biodiesel production using waste cooking oil (WCO) in Korea as a case study.

Some countries, including Korea, Japan, and Austria, are already producing biodiesel by collecting and purifying WCO. In Korea, however, the WCO collection rate is significantly low in the household sector, whereas it is considerably high in restaurants and institutional food services. Households tend to avoid active participation in WCO collection, because this process requires considerable effort and time and is associated with images of filth. Subsequently, these nonmarket factors lead to a decrease in welfare. This study proposes policy directions for improving the WCO collection rate by investigating the public perception of WCO collection. The study derives the opportunity cost of such an exercise by assessing willingness to accept (WTA) using the contingent valuation (CV) method, and it also analyzes factors affecting participation. It is anticipated that this approach can be applied to propose reasonable measures to tackle the decrease in welfare, which is a primary emerging issue, in the field of renewable energy, including wind power.

Intr-3. Thesis Outline

This study consists of three essays. The figure below shows the structure of this study.

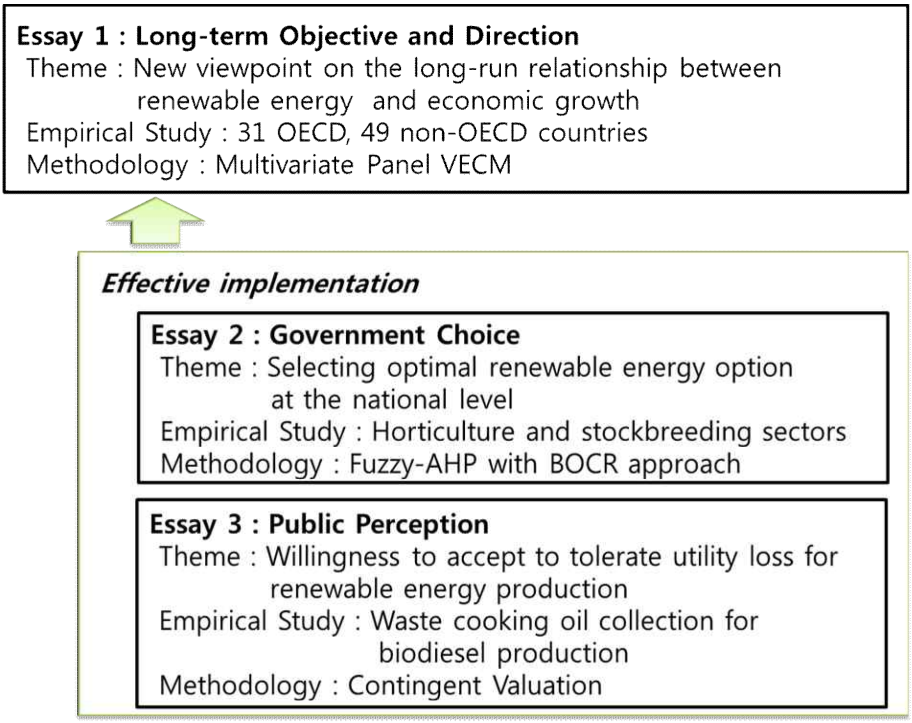

Figure Intr-1. Thesis Outline

Part I (Essay 1) suggests a novel viewpoint, which focuses on the role of renewable energy as an industry in the country's economic growth. Moreover, Essay 1 includes the results of an empirical analysis performed using the data of 31 OECD and 49 non-OECD countries and a multivariate panel VECM. Essay 1 ends with policy implications, which are more insightful than those provided by previous studies, given the benefits of adopting the abovementioned novel viewpoint.

Part II (Essay 2) introduces the methodology for selecting the optimal energy option so as to meet the national policy objective for renewable energy, namely, the fuzzy-AHP with the BOCR approach. The essay also includes an empirical analysis on renewable energy use in the horticulture and stockbreeding sectors in Korea.

Part III (Essay 3) presents a discussion on the WTA the utility loss that can be generated during the production and utilization of renewable energy, which is estimated using the CV method. Moreover, the factors that affect the rate of participation are analyzed to understand the requirements for effective implementation of the renewable energy policy. The collection of WCO for biodiesel production is selected as the target of the empirical analysis.

PART I. (ESSAY 1) A New Viewpoint on the Causal Relationship between Renewable Energy Consumption and Economic Growth

I-1. Introduction

The causal relationship between renewable energy consumption and economic growth can provide crucial implications for the long-term renewable energy policy direction. Thus, this essay suggests a new viewpoint on the causal relationship between the two, namely, it suggests the role of renewable energy as an industry. In doing so, this essay proposes a long-term energy policy direction.

The dispute concerning the causal relationship between energy consumption and economic growth has been ongoing since the study of Kraft and Kraft (1978) (Coers and Sanders, 2013). This is a controversial issue, because some arguments suggest that energy is an essential input of economic growth, whereas others state that energy is merely an insignificant input of the several input factors of production, and it does not play a crucial role in economic growth. Although many researchers have examined the causal relationship between the two variables, their results have varied according to the research areas, periods, methodologies, and/or analysis parameters focused upon/used in these studies. Thus, the dispute concerning the causal relationship between energy consumption and economic growth has not been settled (Stern, 2013). The causal relationship between energy consumption and economic growth, however, remains an interesting topic for energy policy researchers because it provides important implications for the establishment of long-term energy policy direction at the national level (Fallahi, 2010).

As seen in Table I-1, the causal relationship between energy consumption and economic growth is generally studied along the lines of one of the four following hypotheses: Growth, Conservation, Feed-back, and Neutrality (Apergis and Payne, 2012; Tugcu et al., 2012). Existing studies have examined whether energy is an essential input of economic growth by verifying these hypotheses for a specific area and/or specific period. In particular, they focused on presenting an optimal direction for energy policy based on its effects (specifically, energy conservation policies designed to reduce energy consumption) on economic growth (Coers and Sanders, 2013; Dedeoğlu and Kaya, 2013; Fallahi, 2011; Gao Lu Zou, 2012; Ozturk and Acaravci, 2010; Stern and Enflo, 2013). Recent studies on the long-run relationship between energy consumption and economic growth are summarized in Table I-2.

Table I-1. Conventional Four Hypotheses on Causal Relationship between Energy Consumption and Economic Growth

Growth	This hypothesis refers to a situation in which energy consumption plays a vital role in the economic growth process This is supported, if uni-directional causality is found from energy consumption to economic growth In this case, energy conservation policies aimed at reducing energy consumption will have negative impacts on economic growth
Conser-vation	This hypothesis means that economic growth is the dynamic which causes the consumption of energy sources This is supported if there is uni-directional causality from economic growth to energy consumption In this situation, energy conservation policies which may prevent energy consumption will not have negative impact on economic
Feed-back	This hypothesis states a mutual relationship among energy consumption and economic growth This is supported if there exists bi-directional causality between energy consumption and economic growth In case of the validity of this hypothesis, energy conservation policies designed to reduce energy consumption may decrease economic growth performance, and likewise, changes in economic growth are reflected back to energy consumption
Neutrality	This hypothesis indicates that energy consumption does not affect economic growth The absence of causality between energy consumption and economic growth provides evidence for the presence of this hypothesis In this case, energy conservation policies devoted to reducing energy consumption will not have any impact on economic growth

[a] Source: Apergis and Payne (2012), Tugcu et al. (2012)

Table I-2. Recent Literature Review for Energy Consumption and Economic Growth

Author	Country	Period	Methodology	Variable	Result
Mehrara (2007)	11 oil exporting countries	1971 -2002	Panel	GDP, EC	GDP → EC
Ozturk and Acaravci (2010)	Albania, Bulgaria, Hungary and Romania	1980 -2006	ARDL	GDP, EC	different per countries
Ozturk and Acaravci (2011)	Middle East and North Africa	1971 -2006	ARDL	GDP, EC	different per countries
Fallahi (2011)	U.S.	1960 -2005	MS-VAR	GDP, EC	different per countries
Coers and Sanders (2013)	30 OECD countries	1960 -2000	Panel	GDP, EC, K	GDP → EC
Stern and Enflo (2013)	Sweden	1850 -2000	VECM	GDP, EC, K, L etc.	different per periods
Dedeoğlu and Kaya (2013)	25 OECD countries	1980 -2010	Panel	GDP, EC, EXP, IMP	GDP ↔ EC

[a] GDP; gross domestic production, EC; energy consumption, K; gross fixed capital formation, L; labor force, EXP; export, IMP; import

Ever since climate change has been recognized as an emerging global issue, however, many countries have been facing the pressure to balance their energy policy and energy mix to reduce greenhouse gas (GHG) emissions and maintain economic growth simultaneously. Thus, efforts to reduce GHG emissions have escalated to a war of nerves among countries or groups of countries in the international arena wishing to avoid or minimize their obligations to reduce GHG emissions. In other words, there are clear concerns about the adverse effects of GHG emissions reductions on economic growth. Conversely, international pressure to commit to GHG reductions continues to grow. To address this need, the development of the renewable energy industry and expansion of renewable energy supply are recognized as important elements of not just energy but also environmental and industrial policy.

Renewable energy appears to be the most viable alternative, not just for reducing GHGs and air pollutant emissions (e.g., sulfur oxides or SOx and nitrogen oxides or NOx) but also for enhancing energy security and creating a new growth engine. According to the IEA (2014), renewable energy supply in OECD countries showed an average annual growth rate of 2.4% from 1990 to 2012, which is thrice the average annual growth rate of the total primary energy supply in the same period (0.7%). Furthermore, according to WEO 2013 published by IEA (2013), the share of renewable energy as an energy source in world primary energy demand is expected to increase very rapidly in the future, from 13.2% in 2011 to 17.6% in 2035 (New Policies Scenario). Notably, as renewable power generation increases more rapidly, its share in overall world electric power generation is projected to increase from 20% in 2011 to 31% in 2035 (IEA, 2013).

Table I-3. World Primary Energy Demand Forecast

	Current		New Policies Scenario		Current Policies Scenario		450 Scenario	
	2010	2011	2020	2035	2020	2035	2020	2035
Coal	2,357	3,773	4,202	4,428	4,483	5,435	3,715	2,533
Oil	366	4,108	4,470	4,661	4,546	5,094	4,264	3,577
Gas	2,073	2,787	3,273	4,119	3,335	4,369	3,148	3,357
Nuclear	676	674	886	1,119	866	1,020	924	1,521
Hydro	225	300	392	501	379	471	401	550
Bio	1,016	1,300	1,493	1,847	1,472	1,729	1,522	2,205
Other renewables	60	127	309	711	278	528	342	1,164
Total (MTOE)	10,071	13,070	15,025	17,387	15,359	18,646	14,316	14,908

[a] Source : IEA (2013)

Thus, the discussion on the causal relationship between energy consumption and economic growth has changed imperceptibly to that between the causal relationship between renewable energy consumption and economic growth. Thus, many researchers are currently studying the causal relationship between renewable energy consumption and economic growth. However, this shift in the topic of debate does not differ considerably from the conventional focus (namely, the causal relationship between energy consumption and economic growth). This shift is also studied in line with the four hypotheses presented in Table I-1, namely, by analyzing the long-run equilibrium and causal relationship between the two variables (Al-mulali et al., 2013; Apergis and Payne, 2010, 2012; Sadorsky, 2009, Tugcu et al., 2012). Recent studies on the long-run relationship between renewable energy consumption and economic growth are summarized in Table I-4.

Table I-4. Recent Literature Review for Renewable Energy Consumption and Economic Growth

Author	Country	Period	Methodology	Variable	Result
Sadorsky (2009)	G7 countries	1985-2005	Panel, FMOLS	GDP, CO2, OP	GDP → RE
Apergis and Payne (2010)	20 OECD countries	1985-2005	Panel	GDP, RE, K, L	GDP ↔ RE
Apergis and Payne (2012)	80 countries	1990-2007	Panel	GDP, EC, K, L	GDP ↔ EC (RE, NRE)
Tugcu et al. (2012)	G7 countries	1980-2009	ARDL	GDP, RE, L, RD, HC	different per countries and model specification
Al-mulali et al. (2013)	108 countries	1980-2009	FMOLS	GDP, RE	79% feed-back, 2% conservation, 19% neutrality

[a] GDP; gross domestic production, CO2; CO_2 emission, OP; oil price, RE; renewable energy consumption, K; gross fixed capital formation, L; labor force, EC; energy consumption, RD; R&D expenditure, HC; human capital

However, previous studies have exposed one problem in conducting such an analysis and interpreting its results. For most countries, especially developed ones, a substantial amount of renewable energy is supplied and consumed in the form of electricity.[1] With regard to electricity consumption, economic agents still cannot or do not distinguish between electricity from renewable and non-renewable sources. Moreover, renewable energy comprises a small percentage of electricity generation. Unlike total energy, which is recognized as an input of production by economic agents and can be used selectively as an input, renewable energy is not recognized as an input of production. Thus, although it is possible to verify whether renewable energy consumption leads to economic growth by analyzing the relationship between these two elements, it is hard to conclude whether renewable energy is an important input to economic growth based on the results of the analysis.

As mentioned earlier, addressing environmental problems, such as the reduction of GHGs and pollutant emissions, and solving energy problems, such as enhancement of energy security, do not constitute

[1] Most studies that analyze the causal relationship between renewable energy consumption and economic growth use renewable electricity consumption as a variable to represent renewable energy consumption.

the only reasons for many countries, particularly DCs, to expand their renewable energy consumption. By converting non-renewable energy to renewable energy in the course of fostering sustainable growth, countries actually focus on promoting renewable energy as a new growth engine. Unlike non-renewable energy, renewable energy provides many more advantages in fostering industries (including facility construction, manufacturing, and provision of services), because the share of initial investment is high compared to the fuel cost.[2] In addition, the countries expect to reap synergy effects as relatively new technology is applied and convergence with other fields, like information technology (IT), is easily facilitated. Therefore, many countries, especially developed ones, are committed to expand their renewable energy supply to build a test bed or to secure the domestic market to foster the renewable energy industry.

When the characteristics of renewable energy as an energy source and the technological and industrial traits are considered in the interpretation of the causal relationship between renewable energy consumption and economic growth, the study should focus not only

[2] Because most countries, especially DCs, rely on imports for a significant percentage of their energy needs, it may be advantageous to not only develop a new industry in the long term but also to improve trade balance in the short term.

on the role of renewable energy as an input of production or economic growth but also on renewable energy as a new industry for future growth. In other words, renewable energy consumption used in the analysis of this causal relationship could be regarded as a proxy variable of the “scale of the renewable energy industry.”

This viewpoint may invite debate, because distinguishing the effects of renewable energy on economic growth is practically difficult, and the effect pathway of the renewable energy industry on economic growth is vague. However, the new viewpoint is clearly justified considering the characteristics of renewable energy as an energy source and its abovementioned effects on technological and industrial traits.

The suggested viewpoint, however, is more suitable for DCs, which have advanced renewable energy technology and industries. Then, this study suggested revising the traditional viewpoint regarding the hypotheses for the causal relationship between renewable energy consumption and economic growth in the following manner.

Table I-5. New and Conventional Viewpoints on Causal Relationship between Renewable Energy Consumption and Economic Growth

Hypothesis	Test of hypothesis	Interpretation	
Growth	RE→GDP	Conventional	▶ Renewable energy consumption plays a vital role in the economic growth process
		New	▶ Renewable energy industry plays an important role in the economic growth.
Feed-back	RE↔GDP	Conventional	▶ Renewable consumption plays a vital role in the economic growth process, and economic growth leads to input of the renewable energy.
		New	▶ Renewable energy industry significantly affects economic growth, and economic growth leads to that of the renewable energy industry.
Conservation	GDP→RE	Conventional	▶ Economic growth is the dynamic which causes the consumption of energy sources
		New	▶ Growth of the renewable energy industry is induced by economic growth.
Neutrality	none	Conventional	▶ Renewable energy consumption does not affect economic growth, and economic growth does not lead to input of the renewable energy.
		New	▶ Renewable energy industry does not contribute to economic growth, and growth of the renewable energy industry is not induced by economic growth.

However, it will be difficult for LDCs to adopt the new viewpoint suggested in this study, the first reason being the share of renewable energy in the countries' energy mix. Between 1990 and 2010, the average percentage of electricity generated from renewable energy was 27.6% for OECD countries[3] and 42.4% (1.5 times higher) for non-OECD countries.[4] This indicates that unlike DCs, renewable energy has been a key energy source for LDCs. Accordingly, renewable energy can represent total energy, even though it is not possible to distinguish electricity generated from renewable and non-renewable energy sources. The second reason lies in the structure of the renewable energy industry. The average percentage of non-conventional renewable energy generation (excluding hydroelectric power, which is conventionally considered as traditional renewable energy) was 25.4% in OECD countries and 10.6% in non-OECD countries (i.e., less than half that of OECD countries) from 1990 to 2010. In other words, technology pertaining to non-traditional renewable energy industries in LDCs is relatively less developed compared to that in DCs. Overall, unlike DCs, which mostly regard

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[3] In total, 31 countries were analyzed. See Section 2.1 for more details.

[4] In total, 49 countries were analyzed. See Section 2.1 for more details.

renewable energy as a new industry, LDCs regard renewable energy as an important energy source because of the economic burden of fossil fuel imports or the relative immaturity of the energy industry. Thus, it is reasonable to apply the conventional viewpoint, which focuses on the role of renewable energy as an energy source, to LDCs rather than the new one.

Table I-6. Characteristics of Renewable Energy Consumption by Economic Scale

	Share of elec. from renewable energy sources	**Share of non-conventional[c)] renewable energy sources**
Developed Countries[a)]	27.6%	25.4%
Less Developed Countries[b)]	42.4%	10.6%

[a] Developed Countries : 31 OECD countries, 1990-2010

[b] Less Developed Countries : 49 non-OECD countries, 1990-2010

[c] Except hydropower

By suggesting the new viewpoint, and applying the conventional and the new viewpoint to the causal relationship between renewable energy consumption and economic growth, this study attempted to provide deeper insights into the causal relationship between economic growth and renewable energy consumption.

The rest of this essay is organized as follows. Chapter 2 describes the data and methodology used in the study. Chapter 3 presents the analytical results of the causal relationship between renewable energy consumption and economic growth. Chapter 4 provides policy implications based on these results.

I-2. Data and research methodologies

Mehrara (2007) categorized the study on the causal relationship between energy consumption and economic growth by methodology into the following four generations.

1st Generation : Vector autoregressive (VAR) – Studies : Sims(1972) Kraft and Kraft(1978), Yu and Wang(1984) et al. – Features : stationary time series
2nd Generation: ECM, Granger causality test – Studies : Nachane et al.(1988), Glasure and Lee (1997), et al. – Features : non-stationary time series
3rd Generation: multivariate ECM, Johansen causality test – Studies : Masih and Masih (1996, 1997, 1998), Stern (2000) et al. – Features: address omitted variable bias
4th Generation: panel cointegration, panel ECM – Studies : Mehrara (2007), Lee (2005) – Features: consider country and time specific (or dimension) effect, and unobserved heterogeneity. improve power

[a] Source : Mehrara (2007), Cores and Sanders (2013)

Of these, the third-generation multivariate methodology added economic variables, such as capital and labor, which differed from the variables used in the existing analyses (i.e., economic growth (or production) and energy consumption). The advantage of this multivariate methodology is that it can address omitted variable bias and analyze the indirect effects between economic growth and energy consumption through other variables.

The panel cointegration and panel VECM tests have recently been introduced by these studies as analysis methodologies using panel data. The advantage of the panel analysis is that it can increase the statistical power and consider interdependence between time series.

Accordingly, this study analyzed the causal relationship between energy consumption and economic growth by applying a multivariate panel VECM, which combines the advantages of the third-generation and fourth-generation methodologies. First, it includes capital and labor as variables in the model in accordance with previous studies (Apergis and Payne, 2010, 2012; Cores and Sanders, 2013) based on the traditional KLE production function. Also, this study sought to improve the statistical power of the model by introducing panel analysis.

5th Generation: multivariate panel ECM – Studies : Lee and Chang (2007), Narayan and Smyth (2008) et al. – Features: address omitted variable bias, improve power

[a] Source : Cores and Sanders (2013)

I-2-1. Data

This study used the data of 31 OECD countries[5] and 49 non-OECD countries[6] from 1990 to 2010. These data are sourced from World Development Indicators (World Bank, 2013). Variables used in the analysis are real GDP in constant 2005 USD (GDP), real growth fixed capital formation in constant 2005 USD (GFCF), labor force in

[5] The 31 countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxemburg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States of America.

[6] The 49 countries are Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Bolivia, Brazil, Bulgaria, Cameroon, China, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Gabon, Guatemala, Honduras, India, Indonesia, Jordan, Kenya, Kyrgyz Republic, Macedonia, Malaysia, Morocco, Mozambique, Nicaragua, Pakistan, Panama, Peru, Philippines, Romania, Russian Federation, Senegal, Singapore, South Africa, Sri Lanka, Tajikistan, Tanzania, Thailand, Togo, Tunisia, Ukraine, Uruguay, Uzbekistan, Venezuela, and Zambia.

millions (LABOR), renewable electricity consumption in GWh (RE), and renewable electricity consumption, except hydropower, in GWh (REN).[7] GFCF, LABOR, and REN are variables representing capital, labor, and non-conventional renewable energy, respectively. All variables were converted to their natural logarithmic form before use in order to explore their elasticities (i.e., LGDP, LGFCF, LLABOR, LRE, and LREN).

The multivariate panel cointegration and panel VECM methodologies applied in this study typically involve the following three steps: 1) panel unit root test, 2) panel cointegration test, and 3) panel causality test. All variables must be non-stationary if they are to be applied to the selected model in the study. Thus, the variables must first undergo the panel unit root test and be confirmed to be I(1). Next, the existence of a long-run equilibrium relationship among the key variables must be confirmed using the panel cointegration test. Lastly, if a long-run equilibrium relationship does exist, the causal relationship among the main variables must be examined after building a panel VECM model.

7 See Appendix A for more details about the data.

I-2-2. Panel unit root test

The panel unit root test is typically conducted using Im, Pesaran, and Shin's (1997, 2003) test (hereafter, IPS); Levin, Lin, and Chu's (2002) test (hereafter, LLC); and the Fisher-type tests. LLC (2002) were the first to study the panel unit root and suggested obtaining the t value by applying the augmented Dickey–Fuller (ADF) test to each time series under the assumption that a unit root of each time series shares the same autoregressive (AR) coefficient. Furthermore, they presented the panel unit root test as a methodology to standardize it. However, given that LLC used the alternative hypothesis that all of time series share the same AR coefficient, their methodology poses somewhat strong constraints. IPS (1997, 2003) mitigated these constraints by presenting a new methodology that allows for heterogeneity of the AR coefficients in each time series. The panel unit root test methodology of IPS presents test results on the basis of the group mean of the ADF t-statistic of each time series. In addition to the LLC and IPS methodologies, the Fisher-type tests proposed by Maddala and Wu (1999) and Choi (2001) tests for the existence of the panel unit root by combining the *p*-value of the statistic gained from the unit root test on each time series.

The LLC, IPS, and Fisher-type tests were conducted in this study. Model equations for the panel unit root tests are as follows.

$$y_{it} = \rho_i y_{it-1} + \delta_i X_{it} + \varepsilon_{it} \tag{I-1}$$

where $i = 1,...,N$ denote the country; $t = 1,...,T$ denotes the time period; X_{it} refers to the exogenous variables in the model including fixed effects or individual time trend; δ_i denotes autoregressive coefficients; and ε_{it} is the stationary error term.

I-2-3. Panel cointegration test

A panel cointegration technique that tests the long-run causal relationship among panel variables with unit roots is a popular method. The test methodologies proposed by Kao (1999), Pedroni (1999, 2004), and Westerlund (2007) are often used in this context. The methodology proposed by Pedroni (1999, 2004) is the most commonly used because it considers heterogeneous short-run dynamics between time series. Pedroni (1999, 2004) presented two types of cointegration tests. The first is the within-dimension approach, which assumes that a panel group shares the same AR process in the residual, and it includes four statistics: panel v-statistic, panel rho-statistic, panel PP-statistic, and panel ADF-statistic (Apergis and Payne, 2012). The second is the between-dimension approach, which allows for heterogeneity between groups and comprises three statistics: group rho-statistic, group PP-statistic, and group ADF-statistic (Apergis and Payne, 2012).

To address omitted variable bias, this study added variables representing capital (*K*) and labor (*L*) in addition to GDP and renewable energy consumption. To examine the possibility of additional variables, this study estimated four panel cointegration equations in the following manner.

$$LRE_{it} = \alpha_{ai} + \beta_{a1i} LGDP_{it} + \varepsilon_{ait} \quad \text{(I-2)}$$

$$LRE_{it} = \alpha_{bi} + \beta_{b1i} LGDP_{it} + \beta_{b2i} LGFCF_{it} + \varepsilon_{bit} \quad \text{(I-3)}$$

$$LRE_{it} = \alpha_{ci} + \beta_{c1i} LGDP_{it} + \beta_{c2i} LLABOR_{it} + \varepsilon_{cit} \quad \text{(I-4)}$$

$$LRE_{it} = \alpha_{di} + \beta_{d1i} LGDP_{it} + \beta_{d2i} LGFCF_{it} + \beta_{d3i} LGFCF_{it} + \varepsilon_{dit} \quad \text{(I-5)}$$

where the subscripts for *i* and *t* have the same meaning as in Eq. (I-1), α_i denotes country-specific fixed effects, and ε_{it} is the estimated residual.

The following unit root tests on the residuals estimated through the cointegration equations were conducted in order to verify the null hypothesis, which claims that cointegration does not exist.

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + \mu_{it} \tag{I-6}$$

where μ_{it} is a stationary error term.

I-2-4. Panel causality test

Panel causality analysis was conducted after the panel cointegration analysis confirmed long-run equilibrium relationships among the variables. This study tested the causal relationship among the main variables using the process presented by Engle and Granger (1987). That is, an estimation of the long-run equilibrium equation and the second step of the VECM estimation were applied.

First, concerning the estimation of the long-run equilibrium equation, pooled-panel fully-modified OLS (FMOLS) by Pedroni (2000) was applied, and the estimation was conducted by developing various regression equations for each country group. This is because selecting the best error correction term (ECT) is important, as the estimation result of the causal relationship can vary depending on the

ECT (Coers and Sanders, 2013). First, as this study established the following two regression equations as standard regression equations and added explanatory variables (*LABOR*, *GFCF*) one at a time, the optimal regression equation was chosen based on the significance of the explanatory variables.

$$LRE_{it} = \alpha_{ai} + \beta_a LGDP_{it} + \varepsilon_{ait} \tag{I-7}$$

$$LGDP_{it} = \alpha_{bi} + \beta_b LRE_{it} + \varepsilon_{bit} \tag{I-8}$$

where α_i denotes country-specific fixed effects, and ε_{it} is the estimated residual.

Next, a VECM equation was constructed using the residual estimated in the former stage, that is, ECT (ε_{it}), as a regression variable. For the estimation of the VECM coefficients, a least square methodology was used. VECMs were built with the two selected ECTs for OECD and non-OECD countries, and then, the optimal model was selected after reviewing the sign of the estimated ECT coefficients.[8]

[8] A case in which the ECT coefficient is positive was excluded.

Model A (OECD countries)

$$\Delta LGDP_{it} = \alpha_{ait} + \gamma_{ai} ECT_{ait-1} + \sum_{p} \beta_{a1ip} \Delta LGDP_{it-p} + \sum_{p} \beta_{a2ip} LGFCF_{it-p} + \sum_{p} \beta_{a3ip} LLABOR_{it-p} + \sum_{p} \beta_{a4ip} LRE_{it-p} \tag{I-9}$$

Model B (OECD countries)

$$\Delta LRE_{it} = \alpha_{bit} + \gamma_{bi} ECT_{bit-1} + \sum_{p} \beta_{b1ip} \Delta LGDP_{it-p} + \sum_{p} \beta_{b2ip} LGFCF_{it-p} + \sum_{p} \beta_{b3ip} LLABOR_{it-p} + \sum_{p} \beta_{b4ip} LRE_{it-p} \tag{I-10}$$

Model C (non-OECD countries)

$$\Delta LGDP_{it} = \alpha_{cit} + \gamma_{ci} ECT_{cit-1} + \sum_{p} \beta_{c1ip} \Delta LGDP_{it-p} + \sum_{p} \beta_{c2ip} LGFCF_{it-p} + \sum_{p} \beta_{c3ip} LLABOR_{it-p} + \sum_{p} \beta_{c4ip} LRE_{it-p} \tag{I-11}$$

Model D (non-OECD countries)

$$\Delta LRE_{it} = \alpha_{dit} + \gamma_{di} ECT_{dit-1} + \sum_{p} \beta_{d1ip} \Delta LGDP_{it-p} + \sum_{p} \beta_{d2ip} LGFCF_{it-p} + \sum_{p} \beta_{d3ip} LLABOR_{it-p} + \sum_{p} \beta_{d4ip} LRE_{it-p} \tag{I-12}$$

I-3. Empirical results and discussion

I-3-1. Panel unit root test

The panel unit root test results are shown in Tables I-7 to I-10. The test results showed that the level variables of OECD and non-OECD countries do not reject the null hypothesis that a unit root exists (Tables I-7 and I-9), whereas the differentiated variables reject it (Tables I-8 and I-10). Thus, all the time series are I(1).

Table I-7. Panel Unit-root Test Results, Level - OECD

Variables	Test statistics	
LGDP	LLC	-6.525***
	IPS	1.013
	ADF-Fisher	59.18
	PP-Fisher	48.43
LGFCF	LLC	-2.828
	IPS	1.537
	ADF-Fisher	43.03
	PP-Fisher	32.74
LLABOR	LLC	-0.8161
	IPS	4.858
	ADF-Fisher	55.35
	PP-Fisher	62.17
LRE	LLC	0.1390
	IPS	0.4119
	ADF-Fisher	90.29**
	PP-Fisher	89.83**

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-8. Panel Unit-root Test Results, Differentiated - OECD

Variables	Test statistics	
ΔLGDP	LLC	-10.68***
	IPS	-10.35***
	ADF-Fisher	225.7***
	PP-Fisher	256.4***
ΔLGFCF	LLC	-9.162***
	IPS	-11.51***
	ADF-Fisher	246.3***
	PP-Fisher	242.2***
ΔLLABOR	LLC	-15.06***
	IPS	-11.96***
	ADF-Fisher	312.7***
	PP-Fisher	320.3***
ΔLRE	LLC	-20.61***
	IPS	-21.11***
	ADF-Fisher	450.2***
	PP-Fisher	784.8***

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-9. Panel Unit-root Test Results, Level - non-OECD

Variables	Test statistics	
LGDP	LLC	5.469
	IPS	10.16
	ADF-Fisher	45.67
	PP-Fisher	32.30
LGFCF	LLC	0.8015
	IPS	1.000
	ADF-Fisher	0.9949
	PP-Fisher	0.9343
LLABOR	LLC	0.0386**
	IPS	4.807
	ADF-Fisher	100.4
	PP-Fisher	171.3***
LRE	LLC	0.257
	IPS	1.237
	ADF-Fisher	106.6
	PP-Fisher	113.6

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-10. Panel Unit-root Test Results, Differentiated - non-OECD

Variables	Test statistics	
ΔLGDP	LLC	-13.40***
	IPS	-12.97***
	ADF-Fisher	351.0***
	PP-Fisher	321.4***
ΔLGFCF	LLC	-15.72***
	IPS	-15.29***
	ADF-Fisher	405.8***
	PP-Fisher	436.4***
ΔLLABOR	LLC	-7.584***
	IPS	-8.605***
	ADF-Fisher	267.2***
	PP-Fisher	267.0***
ΔLRE	LLC	-25.55***
	IPS	-25.50***
	ADF-Fisher	692.7***
	PP-Fisher	1354.6***

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

I-3-2. Panel cointegration test

As shown in Tables I-11 and I-12, the results of the analysis of panel cointegration showed that the null hypothesis that cointegration does not exist is rejected in all cointegration equations. Thus, cointegration relationships exist among the variables.

Table I-11. Panel Cointegration Test Results with LRE – OECD

Covariates	Test statistics						
	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
LGDP	4.397***	-3.932***	-4.217***	-4.857***	-3.715***	-6.787***	-8.436***
LGDP, LGFCF	1.196	-2.435***	-5.889***	-6.586***	-1.275	-7.793***	-7.597***
LGDP, LABOR	2.055*	-2.608***	-5.211***	-5.374***	-1.747**	-8.128***	-9.109***
LGDP, LGFCF, LLABOR	0.3099	-1.620**	-7.713***	-7.861***	0.5249	-9.383***	-8.533***

[a] Null hypothesis of no cointegration

[b] Assume no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively

Table I-12. Panel Cointegration Test Results with LRE – non-OECD

Covariates	Test statistics						
	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
LGDP	5.155***	-7.005***	-8.457***	-9.525***	-3.995***	-8.369***	-9.067***
LGDP, LGFCF	2.197	-2.903***	-6.539***	-7.847***	-1.140	-9.543***	-10.68***
LGDP, LABOR	2.460	-2.249***	-6.286***	-9.710***	-1.045	-11.14***	-12.23***
LGDP, LGFCF, LLABOR	0.4920	0.6333	-4.962***	-7.008***	1.517	-12.47***	-11.69***

[a] Null hypothesis of no cointegration

[b] Assume no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively

I-3-3. Panel causality test

The estimated results of the FMOLS are shown in Tables I-15 and I-16. Because the natural logarithm of all variables was taken, the coefficients of the estimated regression equation indicate long-run elasticity. For OECD countries, renewable energy consumption increases by 1.41% when GDP increases by 1%. However, for non-OECD countries, when GDP increases by 1%, renewable energy consumption increases by 0.71%, whereas when renewable energy consumption increases by 1%, GDP increases by 0.34%.

Table I-13. FMOLS Test Results – OECD

Dependent Variable	Variable	Coefficient	t-Statistic	R-squared
LRE	**LGDP[a)]**	**1.413**	**12.25*****	**0.9676**
	LGDP	1.721	5.984**	0.9682
	LGFCF	-0.2530	-1.241	
	LGDP	1.687	7.749***	0.9677
	LLABOR	-0.8305	-1.589	
	LGDP	2.008	5.764***	0.9682
	LGFCF	-0.2589	-1.273	
	LLABOR	-0.8282	-1.595	
LGDP	LRE	0.2859	12.58***	0.9903
	LRE	0.0570	5.153***	0.9979
	LGFCF	0.6288	34.83**	
	LRE	0.1180	7.568***	0.9964
	LLABOR	1.734	20.14***	
	LRE[a)]	**0.0537**	**5.352****	**0.9985**
	LGFCF[a)]	**0.4689**	**21.16*****	
	LLABOR[a)]	**0.6629**	**9.007*****	

[a] Denotes finally selected regression equation

[b] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-14. FMOLS Test Results – non-OECD

Dependent Variable	Variable	Coefficient	t-Statistic	R-squared
LRE	LGDP	0.9230	15.517***	0.9736
	LGDP	1.065	10.37***	0.9738
	LGFCF	-0.1123	-1.749*	
	LGDP[a)]	**0.7116**	**7.800*** **	**0.9742**
	LLABOR[a)]	**0.5055**	**2.851*** **	
	LGDP	0.8485	6.722***	0.9743
	LGFCF	-0.1037	-1.633	
	LLABOR	0.4863	2.745***	
LGDP	LRE	0.4661	17.09***	0.9810
	LRE	0.2256	11.62***	0.9923
	LGFCF	0.4344	23.60	
	LRE	0.2123	8.657**	0.9895
	LLABOR	1.160	16.05***	
	LRE[a)]	**0.3370**	**18.55** **	**0.9944**
	LGFCF[a)]	**0.6507**	**10.87** **	
	LLABOR[a)]	**0.1380**	**7.645*** **	

[a] Denotes finally selected regression equation

[b] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

The estimated results of the chosen VECMs are shown in Tables I-15 and I-16. Among the models that targeted OECD countries, only the coefficient of LLABOR was significant in Model A, which means that LLABOR granger-causes LGDP in the short run, whereas economic growth did not have any causal relationship with renewable energy in both the short- and long-run. In Model B, only the ECT coefficient was significant, implying that LGDP granger-causes LRE in the long-run, and all variables, including LGDP, do not granger-cause LRE in the short run. These results mean that the conservation hypothesis is valid in the long-run for OECD countries.

Among the models that targeted non-OECD countries, the coefficients ECT, LGFCF, and LLABOR were significant in Model C. This indicates that LRE granger-causes LGDP in the long-run only. Meanwhile, only ECT was estimated to be significant in Model D, reflecting that LGDP granger-causes LRE in the long-run, whereas all variables, including LGDP, do not granger-cause LRE in the short run. These results show that the feed-back hypothesis is valid in the long-run for non-OECD countries.

Table I-15. Panel VECM Results – OECD

Variable	Coefficient	t-statistics
Model A : LRE → LGDP		
Constant	0.0150	9.079***
ECT	-0.0005	-0.1377
ΔLGFCF	-0.0107	-0.5505
ΔLLABOR	0.1645	2.121**
ΔLRE	-0.0028	-0.4229
Model B : LGDP → LRE		
Constant	0.0553	5.317***
ECT	-0.0991	-4.332***
ΔLGDP	-0.2964	-0.8049
ΔLGFCF	-0.0082	-0.0668
ΔLLABOR	0.4156	0.8487**

[a] Lag length is one. There is no qualitative difference with lag 2

[b] **, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-16. Panel VECM Results – non-OECD

Variable	Coefficient	t-statistics
Model C : LRE → LGDP		
Constant	0.0136	5.563***
ECT	-0.0652	-4.965***
ΔLGFCF	-0.0253	-2.172**
ΔLLABOR	0.1416	1.707*
ΔLRE	-0.0039	-0.6276
Model D : LGDP → LRE		
Constant	0.0359	3.001***
ECT	-0.2838	-11.44***
ΔLGDP	0.0627	0.3748
ΔLGFCF	-0.0183	-0.3238
ΔLLABOR	0.0087	0.0212

[a] Lag length is one. There is no qualitative difference with lag 2

[b] **, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

I-3-4. Empirical results with non-conventional renewable energy

As shown above, in the case of OECD countries, the conservation hypothesis is valid in the long-run. This implies that economic growth has been leading the growth of the renewable energy industry. Here, the causal relationship between non-conventional renewable energy and economic growth was verified again by substituting "renewable energy consumption (LRE)" with "non-conventional renewable energy consumption (LREN)." The methodology and analysis process are the same as explained in the previous sections. The panel unit root test results are shown in the following tables. The test results show that all the time series are I(1).

Table I-17. Panel Unit-root Test Results for LREN – OECD

Variables	Test statistics	
LREN	LLC	0.7729
	IPS	8.112
	ADF-Fisher	44.91
	PP-Fisher	45.21
ΔLREN	LLC	-14.04***
	IPS	-12.77***
	ADF-Fisher	272.2***
	PP-Fisher	312.1***

Table I-18. Panel Cointegration Test Results with LREN – OECD

Covariates	Test statistics						
	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
LGDP	4.316***	-2.573***	-2.340***	-3.142***	-1.788*	-4.966***	-5.094***
LGDP, LGFCF	1.704	0.2319***	-0.5155***	-1.609***	0.0004	-5.181***	-5.799***
LGDP, LABOR	3.744*	-1.228***	-2.917***	-4.939***	-0.4959	-5.593***	-6.760***
LGDP, LGFCF, LLABOR	1.528	1.076*	-1.289***	-3.908***	1.116	-6.159***	-8.198***

[a] Null hypothesis of no cointegration

[b] Assume no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively

Table I-19. Panel VECM Results between LREN and LGDP – OECD

Variable	Coefficient	t-statistics
Model A : LREN → LGDP		
Constant	0.0140	8.152***
ECT	0.0119	0.5103
ΔLGFCF	-0.0060	-0.2954
ΔLLABOR	0.1857	2.254**
ΔLREN	0.0052	1.429
Model B : LGDP → LRE		
Constant	0.0945	5.187***
ECT	-0.1751	-8.755***
ΔLGDP	0.0381	0.0585
ΔLGFCF	0.0686	0.3231
ΔLLABOR	1.4936	1.725*

[a] Lag length is one. There is no qualitative difference with lag 2

[b] **, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

The analysis of the causal relationship between non-conventional renewable energy consumption and economic growth confirms that the conservation hypothesis is valid in the long-run, which is consistent with the causal relationship between renewable energy consumption and economic growth, as shown above. This finding also supports the validity of the analysis results presented earlier, namely that economic growth leads to growth in the renewable energy industry. Indeed, because the new viewpoint focuses on the role of renewable energy in the industry, it might be more appropriate to select non-conventional renewable energy consumption rather than renewable energy consumption as a variable.

I-3-5. Empirical results on top five OECD countries

On the other hand, even among DCs, the progress achieved by the renewable energy industry varies. In this section, the causal relationship between non-conventional renewable energy and economic growth was verified by targeting the top five OECD countries (the USA, Japan, Germany, Denmark, and Spain) in terms of solar and wind power.[9] The results of the unit-root test and cointegration test respectively showed that all variables except LABOR are I(1), and there are long-run equilibrium relationships among LREN, LGDP, and LGFCF (Tables I-20 to I-22).

However, a very different result was obtained when the causality analysis targets were limited to the top five countries. The results show that the growth hypothesis between renewable energy and

[9] China and India are excluded despite doing well in the areas of solar and wind power generation, as they are non-OECD countries.

economic growth is valid in these countries (Table I-23). According to the new viewpoint, this signifies that the renewable energy industry plays an important role in economic growth.

Table I-20. Panel Unit-root Test Results for LREN – Top 5

Variables	Test statistics	
LGDP	LLC	-2.616***
	IPS	-0.0331
	ADF-Fisher	7.434
	PP-Fisher	8.835
LGFCF	LLC	-1.949**
	IPS	-0.0613
	ADF-Fisher	10.56
	PP-Fisher	7.317
LLABOR	LLC	-1.750**
	IPS	-0.5586
	ADF-Fisher	19.34**
	PP-Fisher	23.28***
LREN	LLC	-1.393*
	IPS	3.540
	ADF-Fisher	8.769
	PP-Fisher	4.317

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-21. Panel Unit-root Test Results for LREN, Differentiated – Top 5

Variables	Test statistics	
ΔLGDP	LLC	-3.849***
	IPS	-4.798***
	ADF-Fisher	41.11***
	PP-Fisher	52.06***
ΔLGFCF	LLC	-3.766***
	IPS	-3.923***
	ADF-Fisher	33.74***
	PP-Fisher	31.77***
ΔLLABOR	LLC	-10.47***
	IPS	-8.710***
	ADF-Fisher	121.4***
	PP-Fisher	121.9***
ΔLREN	LLC	0.2098
	IPS	-2.159**
	ADF-Fisher	24.61***
	PP-Fisher	52.15***

[a] Null hypothesis of no unit root

[b] Assume individual intercepts but no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Table I-22. Panel Cointegration Test Results with LREN – Top 5

Covariates	Test statistics						
	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
LGDP	4.262***	-1.884**	-1.788**	-4.407***	0.1330	0.0850	-4.452***
LGDP, LGFCF	2.694***	-2.023**	-3.531***	-3.430***	-1.012	-3.887***	-4.646***

[a] Null hypothesis of no cointegration

[b] Assume no deterministic trend

[c] Length selection used based on SIC with a maximum lag of 4

[d] ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively

Table I-23. Panel VECM Results between LREN and LGDP – Top 5

Variable	Coefficient	t-statistics
Model A : LREN → LGDP		
Constant	0.0158	4.006***
ECT	-0.0864	-3.085***
ΔLGFCF	0.1575	1.899*
ΔLLABOR	0.0978	0.5757
ΔLREN	0.0140	0.8690
Model B : LGDP → LREN		
Constant	0.1187	5.344***
ECT	-0.0311	-1.463
ΔLGDP	-2.712	-2.054*
ΔLGFCF	0.5914	1.267
ΔLLABOR	1.107	1.153

[a] Lag length is one. There is no qualitative difference with lag 2

[b] **, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

However, the causal relationship between non-traditional renewable energy consumption and economic growth in non-OECD countries was not analyzed in the present study. Non-traditional renewable energy consumption comprised an insignificant proportion of total energy consumption during the analysis period in these nations, thus preventing meaningful conclusions from being drawn from the analysis results. Indeed, a number of nations did not use non-traditional renewable energy during several periods. Hence, it is not possible to verify whether the new viewpoint holds for LDCs.

I-3-6. Summary

An analysis of the causal relationship between renewable energy consumption and economic growth showed that the conservation hypothesis is valid in the long-run for OECD countries. This implies that, according to the new viewpoint, economic growth is responsible for the growth of the renewable energy industry. However, when the analysis targets are limited to the top five countries having the most advanced renewable energy industries, the results showed that the growth hypothesis is valid, which signifies that the renewable energy industry plays an important role in economic growth.

On the other hand, the analysis of the causal relationship between renewable energy consumption and economic growth showed that the feed-back hypothesis is valid for non-OECD countries, indicating that renewable energy plays an important role as an input of production in economic growth. Similarly, economic growth has increased inputs of renewable energy for these countries.

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I-4. Conclusion and policy implications

By considering the characteristics of renewable energy as an energy source and the technological and industrial traits in the interpretation of the causal relationship between renewable energy consumption and economic growth, this study suggested the adoption of a viewpoint different from the existing viewpoint about the causal relationship between renewable energy consumption and economic growth. In addition, an empirical analysis of the causal relationship between renewable energy consumption and economic growth in OECD and non-OECD countries was conducted, and implications were drawn based on the results of the analyses based on the new and conventional viewpoints.

The panel cointegration and panel causality test were used to analyze the causal relationship between renewable energy consumption and economic growth. To address omitted variable bias and improve statistical power, the multivariate panel VECM, which combines the third-generation and fourth-generation methodologies classified by Mehrara (2007), was built.

The results of the empirical analysis showed that the conservation hypothesis of the causal relationship between renewable energy consumption and economic growth is valid in the long-run for OECD countries. From the perspective of the new viewpoint, this result indicates that the renewable energy industry has not sufficiently grown to induce economic growth and instead has been growing by leaning on economic growth. Thus, any reduction in the rate of economic growth may negatively affect the growth of the renewable energy industry.

However, a different result was obtained when the causality analysis targets were limited to the top five renewable energy-producing countries. The result showed that the growth hypothesis between renewable energy and economic growth is valid for these countries. According to the new viewpoint, this signifies that the renewable energy industry plays an important role in economic growth.

A comparison of both analytical results showed that during its early-to-middle stages, economic growth and the resulting governmental fiscal expansion contributes to the renewable energy industry's expansion. However, in contrast, once the renewable energy industry matures to some degree, it contributes to economic growth. Therefore, it is expected that in the long-term perspective, fostering the renewable energy industry will contribute to solving energy and environmental problems, such as energy security and climate change, respectively. Additionally, the renewable energy industry will contribute toward economic growth as a new growth engine. Therefore, it will be necessary to implement step-by-step development strategies, such as selection and concentration, to encourage the growth of the renewable energy industry and deployment expansion.

On the other hand, the test results of the causal relationship between renewable energy consumption and economic growth showed that the feed-back hypothesis is valid for non-OECD countries: In LDCs, renewable energy has been playing an important role as an input of production or economic growth; similarly, economic growth has caused increased inputs of renewable energy. As the economy grows, renewable energy consumption will increase and various policies for increasing renewable energy consumption such as feed-in tariffs, renewable energy certificate (REC) trading schemes, and investment tax credits, will encourage economic growth.

Meanwhile, renewable energy support from the DCs in the form of grants, such as official development assistance (ODA), for the LDCs is expected to not only solve the energy problem faced by the LDCs but also positively affect their economic growth. Therefore, DCs should promote renewable energy expansion policies that secure energy supply and promote economic growth in LDCs. Considering the positive effects of ODA of renewable energy, DCs should increase the proportion of ODA to the renewable energy sector, to ensure global sustainable growth. It is anticipated that these beneficial efforts will build momentum for LDCs aiming to develop renewable energy technologies and industries in their countries.

Future research may build on the results of this study in the following ways. This study suggested a new viewpoint on the causal relationship between renewable energy consumption and economic growth, focusing on the role of renewable energy as a new industry. However, this study did not quantitatively separate the two effects of renewable energy on economic growth. The introduction and quantification of the variables that represent these particular effects in the analytical model will help derive more specific and useful policy implications.

PART II. (ESSAY 2) Selecting Optimal Renewable Energy Option in New Markets using Fuzzy Analytic Hierarchy Process (fuzzy-AHP) with Benefits, Opportunities, Costs, and Risks (BOCR) Approach : Case Study on Horticulture and Stockbreeding Sectors[10]

II-1. Introduction

Essay 1 discussed setting long-term objective and direction for renewable energy policy that consider economic growth. For DCs, those have insufficiently grown renewable energy industry, the renewable energy industry has been found to be dependent on economic growth and expansion of government support based on that growth. Hence, a strategy of effectively allocating limited government resources is needed for growth and survival of the renewable energy industry especially during recessions such as those

[10] The rivised version of this essay was submitted to the *Renewable and Sustainable Energy Reviews*. The authors and the title of the submitted paper is as follows :

Cho S, Kim J, Heo E. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors.

that have been recently observed. For efficient allocation of resources in the process of utilizing renewable energy, selection and concentration of the optimal renewable energy source is required, but first, a series of processes for selecting appropriate evaluation factors to determine the optimal solution must be established. New markets, whose information is limited and unreliable, make quantitative evaluation difficult. This means qualitative evaluation and experts' view are significant in decision making.

This essay introduces an approach to evaluate renewable energy for new markets by comparing it with other energy sources or alternative renewable energy sources at the national level. Then empirical analysis is performed on the horticulture and stockbreeding sectors.

II-1-1. Overview

This essay introduces a fuzzy analytic hierarchy process (fuzzy-AHP) with the benefits, opportunities, costs, and risks (BOCR) approach to select optimal heating alternatives for the horticulture and stockbreeding sectors, those are one of the most energy intensive sectors within the agriculture industry. The fuzzy AHP method can capture the vagueness of answers in crisp AHP, and the BOCR approach can consider negative priorities in decision making (Heo et al., 2012). This study set 11 factors based on the BOCR approach and evaluate 6 heating alternatives, namely the oil-fired boiler, the coal-fired boiler, the electricity heater, the geothermal heat pump, the aero-thermal heat pump, and the wood pallet-fired boiler, for comparison between conventional fuels and renewable energy as heating alternatives.

The remainder of the essay is organized as follows. Section 1.2 introduces the current status of energy use in horticulture sector in Korea. Chapter 2 introduces the fuzzy-AHP with BOCR approach used in this study, and suggests hierarchy and a set of selected criteria and factors. Analysis results are explained in Chapter 3, and conclusion and implications in Chapter 4.

II-1-2. Current status of energy use in horticulture sector in Korea

The final energy consumption of the Korean agriculture, forestry, and fishery industries increased 1.7 times from 1,813,000 TOE to 3,082,000 TOE between 1990 and 2011 (KEEI, 2012). The growth rate was relatively low compared to the combined average growth rate of all industries, which increased by 3.5 times during the same period. However, horticulture and stockbreeding are energy-intensive sectors and have grown fast due to the restructuring of the agriculture, forestry, and fishery industries since the 1990s (Cho, 2011). Furthermore, the energy dependence of these industries has increased alongside the increase in respective their energy intensities (Table II-1).

Table II-1. Changes of Energy Consumption and Energy intensity of Horticulture Sector in Korea

Year	1995	2007
Energy consumption (kTOE)	67	514
Proportion in agricultural energy consumption	9.2%	32.2%
Energy intensity of floriculture sector (kTOE/million Won)	0.274	0.653
Energy intensity of vegetable sector (kTOE/million Won)	0.022	0.105

As of 2011, the agriculture, forestry, and fishery industries were found to be heavily dependent on oil, given that petroleum products accounted for 70.3% of the total energy source requirement of these industries (KEEI, 2012). In particular, oil-fired boilers accounted for 71.0% of heating applications used in the horticulture and stockbreeding sectors (Cho, 2011). Due to heavy dependence on oil and the high oil prices that prevailed over a considerable number of years, the profitability of farm houses has deteriorated. In addition, electricity consumption has substantially increased in the agriculture, forestry, and fishery industries, wherein the ratio of electricity to the total energy mix jumped from merely 6.9% in the 1990s to 29.5% in 2011. This trend is confirmed by the choice of heating facilities made by horticulture and stockbreeding businesses, where the use of electricity heaters has increased rapidly.

Table II-2. Current Status of Heating Facility for Horticulture and Stockbreeding in Korea

Equipment	Number of farms	Ratio (%)
Oil-fired boiler	213	71.0
Coal-fired boiler	8	2.7
Electricity heater	73	24.3
Geothermal heat pump	2	0.7
Aero-thermal heat pump	0	-
Wood pallet-fired boiler	2	0.7
Others	2	0.7
Total	300	100.0

[a] Source : Cho, 2011

The changing pattern of energy consumption in the agriculture industry is attributable to government policies. As an economic incentive to farmers, the Korean government grants tax exemptions on petroleum products used in the agriculture industry. The consumption of tax-free petroleum products stood at 1,761,000 kL in 2012, which means that the agriculture industry received tax breaks worth 1.04 trillion KRW. The Korean government also grants farmers discounts on electricity. For instance, horticulture and stockbreeding farmers pay 38.4~39.1 KRW/kWh for electricity, which is only one-half to one-third of the rates paid by other industries, such as the manufacturing industry. In particular, the price of electricity has been controlled while those of energy sources, such as oil, gas, and coal, have increased (IEA, 2013).

For the farmers, the easiest way to make profits would be to tap into the cheapest source of energy. However, it is necessary that the government encourage the optimal use of energy sources by considering economic feasibility and profitability, environmental friendliness, and industrial ripple effects at the national level. Previous government policies for the agriculture industry focused on providing economic support and, accordingly, the government granted tax exemptions on petroleum products and price cuts on electricity, which were two main energy sources used by the agriculture industry. However, it is crucial to investigate whether such policies resulted in distortions of resource allocation. Renewable energy has recently shown substantial improvement in economic feasibility and offers more advantages, such as reduced social costs, than conventional energy sources. However, the share of renewable energy is still too low in the agriculture industry, as excessive benefits are granted to conventional energy sources (Table II-2). Thus, it is necessary to evaluate renewable energy by comparing it with other energy sources or alternative renewable energy sources to derive optimal energy source for horticulture and stockbreeding sectors.

II-2. Research methodologies

II-2-1. Fuzzy AHP

The AHP, generally used in decision-making research for policy issues, has been employed in optimal energy source selection problem. For example Yi et al. (2011), Sánchez-Lozano et al. (2013), and Uyan (2013) applied the general AHP approach for decision making in this field.

The AHP method proposed by Saaty (1980) is based on crisp appraisal. However, because all human preferences have a degree of uncertainty, it is very hard to derive precise judgment in the real world. In addition, as Heo et al. (2012) mentioned, it is more preferable for decision makers to use familiar language expressions over numbers when assessing criteria or alternatives. In this regard, the fuzzy AHP approach, which effectively represents human perceptions and uncertainty, has been applied by various researchers. Lee et al. (2008), Heo et al. (2010), and Lee et al. (2013) applied the fuzzy AHP method.

Chang's approach (1996) for fuzzy AHP is the most popular among the various AHP methods concerning fuzziness (Bozdağ et al, 2003, Chang, 1996, Sheu, 2004, Wang et el., 2006, Weck et al., 1997). Chang (1996) used triangular fuzzy numbers (TFNs) for a pairwise comparison and proposed the extent analysis method (EAM) for synthetic extent values of the comparisons. In this essay, following Heo et al. (2012), a modified method of Chang's approach (1996) is used, incorporating the arguments of Zhu et al. (1999) and Wang and Elhag (2006).

The original EAM for fuzzy AHP by Chang (1996) is as follows.

Assume $X = \{x_1, x_2, \ldots, x_n\}$ is an object set, and $U = \{u_1, u_2, \ldots, u_m\}$, a goal set. An extent analysis should be performed individually for each goal (g_i) considering each object. Then, the extent analysis value for each object (m) can be obtained with the following symbols:

$$M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, \quad i = 1,2,\ldots,n, \tag{II-1}$$

where all $M_{g_i}^j$ $(\mathrm{j} = 1,2,\ldots,m)$ are TFNs, represented as (a_{ij}, b_{ij}, c_{ij}). These parameters denote the least possible value (a), the most possible value (b), and the highest possible value (c). According to the EAM, the value of a fuzzy synthetic extent for the i^{th} object is defined as follows:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \tag{II-2}$$

However, Wang and Elhag (2006) argued that the Eq. (II-2) is not a true synthetic extent value and proposed a modified normalization formula for the synthetic extent like Eq. (II-3).

$$\tilde{S}_i = \left(\frac{\sum_{j=1}^{m} a_{ij}}{\sum_{j=1}^{m} a_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{m} c_{kj}}, \frac{\sum_{j=1}^{m} b_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{m} b_{kj}}, \frac{\sum_{j=1}^{m} c_{ij}}{\sum_{j=1}^{m} c_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{m} a_{ij}} \right) \quad \text{(II-3)}$$

This essay applies Wang and Elhag's (2006) formula for fuzzy AHP calculation. With these fuzzy synthetic extents, the degree of possibility of $S_i = (a_i, b_i, c_i) \geq S_j = (a_j, b_j, c_j)$ can be defined as follows:

$$V(S_i \geq S_j) = \mathrm{hgt}(S_i \cap S_j) = \mu_{S_i}(d) = \begin{cases} 1, & \text{if } b_i \geq b_j \\ \dfrac{a_j - c_i}{(b_i - c_i) - (b_j - a_j)}, & \text{otherwise} \\ 0, & \text{if } a_j \geq c_i \end{cases} \quad \text{(II-4)}$$

where d is the ordinate of the highest intersection point between μ_{S_i} and μ_{S_j}. The degree of possibility for a fuzzy number to be greater than k convex fuzzy numbers $S_i\ (\mathrm{i} = 1,2,\ldots,k)$ is expressed as follows:

$$\begin{aligned} V(S \geq S_1, S_2, \ldots, S_k) &= V[(S \geq S_1) \text{ and } (S \geq S_2) \text{ and} \ldots \text{and } (S \geq S_k)] \\ &= \min V(S \geq S_i), \quad i = 1,2,3,\ldots,k \end{aligned} \quad \text{(II-5)}$$

Suppose that $d'(A_i) = \min V(S_i \geq S_k), \quad for\ k = 1,2,\ldots,n; k \neq i$.

Then, the fuzzy AHP weight vector is derived from the following equation:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{II-6}$$

where A_i $(\mathrm{i} = 1,2,\ldots,n)$ are n elements. The normalized weight vectors can be obtained after normalization:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{II-7}$$

where W is a non-fuzzy number. Following Heo et al.'s (2012) argument, the triangular fuzzy conversion scale presented in Table II-3 is applied in this essay.

Table II-3. Triangular Fuzzy Conversion Scale

Linguistic scale	**Triangular fuzzy scale**
Equally important	(1, 1, 1)
Weakly important	(4/7, 1, 7/4)
Strongly more important	(5/4, 2, 11/4)
Very strongly more important	(9/4, 3, 15/4)
Absolutely more important	(13/4, 4, 19/4)

II-2-2. BOCR Approach

Selection of the appropriate assessment factors and criteria is the major difficulties faced by researchers. Moreover, if a researcher tries to setup factors for a new field that is not previously examined, the selection will be more difficult. In this case, the BOCR approach by Saaty and Ozdemir (2003) provides a useful guide to select the factors and criteria. In addition, investigating the criteria crucial towards the establishment of an optimal heating facility for the horticulture and stockbreeding sectors requires an assessment of the benefits and costs, which are already included in the BOCR approach.

As mention in Heo et al. (2012), the BOCR approach has another advantage that can consider negative priorities, while general AHP analyses generally consider the positive aspects only. We may easily face a decision-making problem in which negative aspects must be taken into account and the costs and risks of some heating facilities for the horticulture and stockbreeding sectors are definitely negative aspects. In this regard, this essay applies the BOCR approach to select an optimal heating facility for the horticulture and stockbreeding sectors. The typical BOCR approach can be organized into ten steps (Heo et al., 2012, Saaty, 2004) (Table II-4).

Table II-4. 10 Steps of the BOCR approach

Step	Action	Details
1	Identify a problem	Identify a problem and model it as a hierarchy.
2	Construct a control hierarchy	A control hierarchy includes the strategic criteria and the BOCR. The strategic criteria are used to appraise the weights of the BOCR. These criteria should be chosen with regard to the aim and characteristics of the research.
3	Evaluate the priorities of the strategic criteria	The priorities of the strategic criteria could be evaluated through the AHP.
4	Appraise the importance of the BOCR to each strategic criterion	In this step, one should appraise the importance of BOCR to each strategic criterion. A five-step scale is generally applied—very high: 0.42, high: 0.26, medium: 0.16, low: 0.10, and very low: 0.06.
5	Evaluate the priorities of the BOCR	By multiplying the scores obtained from the appraisal (step 4) with the priority of each strategic criterion (step 3), we can evaluate the priority of the BOCR. Normalization is needed for summing up the calculation results.

Step	Action	Details
6	Determine the criteria	Determine the criteria and, if needed, the sub-criteria for the BOCR. To achieve the overall goal of the research, it is crucial to conduct a vast literature survey and examine numerous expert reviews.
7	Formulate a questionnaire	Formulate a questionnaire based on the BOCR scheme. The pairwise comparison questionnaire will be devised as in the case of the AHP.
8	Evaluate the relative priorities	Evaluate the priority of each criterion. A procedure similar to step 3 is applied to evaluate the weights.
9	Calculate the priorities of the alternatives	Synthesize the relative weights with respect to the upper-level criterion.
10	Calculate the overall priorities	Synthesize the priorities of each alternative from step 9. Using the corresponding normalized weights of the BOCR from step 5, we can obtain the overall priority.

As Lee et al. (2009) remarked, there are five methods for the BOCR approach to combine the scores of each alternative.

1) Additive:

$$P_i = bB_i + oO_i + c(1/C_i)_{normalized} + r(1/R_i)_{normalized} \qquad \text{(II-8)}$$

where B_i, O_i, C_i, and R_i are the synthesized results of alternative i, and *b*, *o*, *c*, and *r* are the normalized weights of merits B, O, C, and R, respectively.

2) Probabilistic additive:

$$P_i = bB_i + oO_i + c(1 - C_i) + r(1 - R_i) \qquad \text{(II-9)}$$

3) Subtractive:

$$P_i = bB_i + oO_i - cC_i - rR_i \qquad \text{(II-10)}$$

4) Multiplicative priority powers:

$$P_i = B_i^b O_i^o \left[(1/C_i)_{normalized}\right]^c \left[(1/R_i)_{normalized}\right]^r \qquad \text{(II-11)}$$

5) Multiplicative:

$$P_i = \frac{B_i O_i}{C_i R_i} \qquad \text{(II-12)}$$

Wijnmalen (2007) argued that the commensurability of priorities in the BOCR approach. This essay applied the revised multiplicative method to combine the scores in accordance with Wijnmalen's (2007) argument. The formula of the revised method is as follows:

$$P_i = \frac{bB_i^* + oO_i^*}{cC_i^* + rR_i^*} \tag{II-13}$$

where, B_i^*, O_i^*, C_i^*, and R_i^* are the normalized overall priorities of alternative i.

II-2-3. Criteria and alternatives

In accordance with the arguments of the BOCR framework, this study set up strategic criteria, BOCR criteria, and factors. The selection of criteria and factors is important in the AHP analysis. Generally, criteria and factors are chosen using the following steps: 1) review preceding research, 2) draft the criteria and factors, 3) seek experts' advice, and 4) confirm the criteria and factors.

In this essay, the criteria and factors were drafted on the basis of Saaty and Ozdemir (2003), Wijnmalen (2007), and preceding research, including Yi et al. (2011) and Heo et al. (2012). Especially, this study adopted the definition of costs and risks in BOCR analysis as follow, which was suggested by Wijnmalen (2007).

***Risks** in BOCR analysis are supposed to catch the expected consequences of future negative developments, whereas **Costs** represent (current) losses and efforts and consequences of negative developments one is relatively certain of.*

Then the final list of criteria and factors was determined after seeking experts' advice. The experts included the government officials of related ministries with a bearing on government decision making regarding the distribution of agricultural heating facilities, researchers of government-funded research institutes related to the energy and agricultural industries, and officials of public energy and agricultural corporations undertaking activities on behalf of the government. A total of 20 experts were short-listed, including 12 energy experts and 8 agricultural experts (Table II-5).

Based on their advice, this study finalized the reviewed criteria and factors as seen in Table II-6.

Table II-5. Description of Experts

Field	Organization[a]	
Energy	Ministry	Ministry of Knowledge Economy
	Public corporation	Korean Energy Management Corporation
	Government-funded research institute	Korea Energy Economics Institute Korea Institute of Energy Research
	Others	Hanyang University
Agriculture	Ministry	Ministry of Agriculture and Marine Forest Service
	Public corporation	Korea Rural Corporation
	Government-funded research institute	Korea Rural Economic Institute

[a] Organization names are on the basis of 2011, when the survey was conducted

Table II-6. Criteria and Factors

Criteria	Factors
B. Benefits	B1. Increase in sales for farmers B2. Trade balance improvement
O. Opportunities	O1. Market size O2. Cultivation of related industries and ripple effect to other industries O3. Improvement of eco-friendly image
C. Costs	C1. Initial investment cost C2. Fuel cost C3. Operation cost C4. Environmental cost
R. Risks	R1. Technical credibility R2. Fuel supply reliability

The description of selected factors is as follows.

1) Regarding “Benefits”,

(B1) *Increase in sales for farmers* refers to the growth in sales revenue resulting from production increase or quality improvement associated with the additional functions of a heating facility, such as convenient temperature control, cooling, and dehumidification.

(B2) *Trade balance improvement* refers to import reduction resulting from the localization of a heating facility and fuel.

2) Regarding "Opportunities",

(O1) *Market size* refers to the domestic/overseas market potential and the possibility of attaining economies of scale.

(O2) *Cultivation of related industries and ripple effect to other industries* denotes the induced development of domestic technologies and the cultivation of related and other industries associated with a particular heating facility and fuel.

(O3) *Improvement of eco-friendly image* refers to improvements in the image of the product, that of the producers' regions, and that of the nation associated with the use of an eco-friendly heating facility and fuel.

3) Regarding "Costs",

(C1) *Initial investment cost* refers to the expense incurred to purchase land and install heating facilities.

(C2) *Fuel cost* is the cost of purchasing heating fuel.

(C3) *Operation cost* includes a set of expenses associated with the operation/maintenance of a heating facility, fuel storage/supply, and residue (e.g., coal ash) disposal.

(C4) *Environmental cost* refers to the social costs caused by pollution and the greenhouse gas emissions associated with the installation and operation of a heating facility.

4) Regarding “Risks”,

(R1) *Technical credibility* denotes risks associated with the degree of technical maturity, reliability, and credibility of a heating facility.

(R2) *Fuel supply reliability* indicates risks associated with fuel price volatility and supply disruption.

Using the abovementioned criteria and factors, this study evaluated six alternatives for heating facilities; the oil-fired boiler (OB), the coal-fired boiler (CB), the electricity heater (EH), the geothermal heat pump (GH), the aero-thermal heat pump (AH), and the wood pallet-fired boiler (WB). While the types of heating facilities can be further subdivided into more specific sub-categories, this study grouped them into six categories as per the type of fuel used by them. In the surveys, this study provided respondents information on each type of heating facility along with the questionnaire.

II-3. Empirical results and discussion

II-3-1. Weights of factors and criteria

The first survey aimed to appraise the importance of strategic criteria, BOCR criteria, and the factors chosen on the basis of the experts' advice. For the survey, this study contacted 20 energy and agricultural experts, of whom 19 (95%) responded (11 energy experts and 8 agricultural experts). In the second survey, to appraise the weights of the factors, six types of energy facilities were chosen as per the criteria and factors and evaluated. The same 19 experts provided responses for the second survey. However, the responses of two experts were excluded from the AHP analysis because their consistency ratio (CR) exceeded 0.15.

The estimated result for the three strategic criteria is shown in Figure II-1. The weighting for *Economic feasibility* was the highest (49.7%), followed by that for *Spillover effect* (35.3%), and *Vitalization of the agricultural economy* (15.0%).

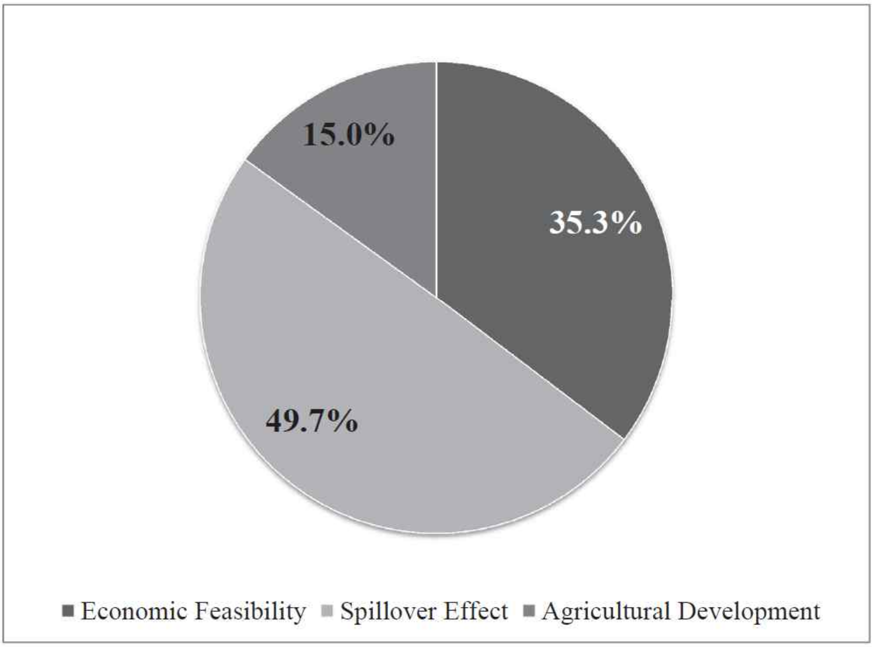

Figure II-1. Weights of Strategic Criteria

Based on these strategic criteria, the importance of benefits, opportunities, costs, and risks was estimated as per the method suggested by Saaty and Ozdemir (2003). As shown in Figure II-2, benefits, opportunities, and costs are estimated as having a similar level of importance, while risks are estimated as being relatively less important. Both energy and agricultural experts assigned the highest priority to costs. While energy experts thought more highly of opportunities than agricultural experts, agricultural experts assigned more priority to benefits.

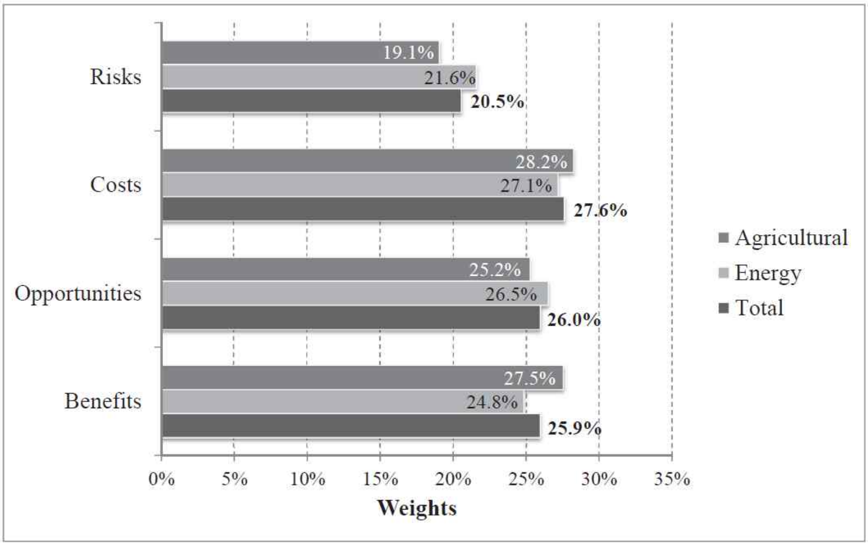

Figure II-2. Weights of Criteria - BOCR

In terms of benefits, *Trade balance improvement* (B2) was estimated as 55.9%, relatively higher than *Increase in sales of farmers* (B1, 44.1%) (Figure II-3). Among the opportunity factors, *Market size* (O1, 61.2%) showed a predominantly higher importance than the other two factors (*Cultivation of related industries and ripple effect to other industries* (O2, 13.0%) and *Improvement of eco-friendly image* (O3, 25.8%)) (Figure II-4). In terms of costs, no substantial difference was found among the importance of factors. *Environmental cost* (C4) was the highest (29.6%) followed by *Fuel cost* (C2, 25.0%). *Operation cost* (C3) and *Initial investment cost* (C1) scored 23.4% and 22.0% respectively, relatively lower than the remaining two factors (Figure II-5). In terms of risks, *Fuel supply reliability* (R2) posted a higher importance (60.1%) than *Technical credibility* (R1, 40.0%) (Figure II-6).

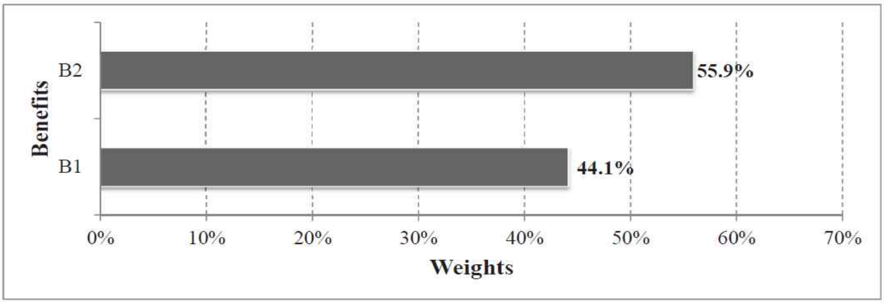

Figure II-3. Weights of Benefits

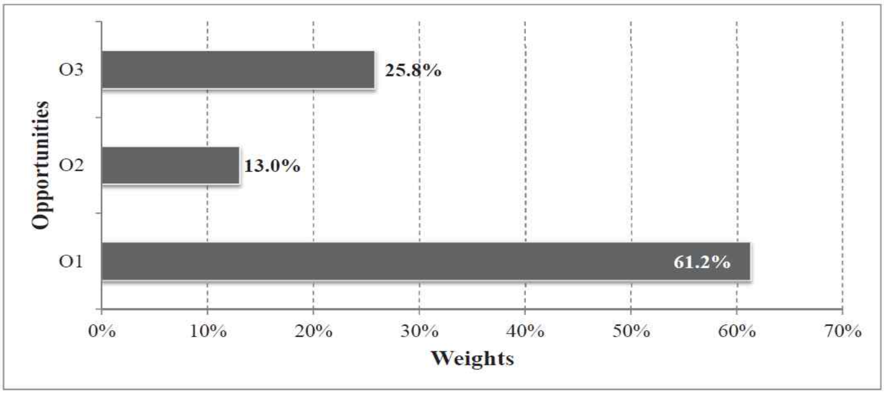

Figure II-4. Weights of Opportunities

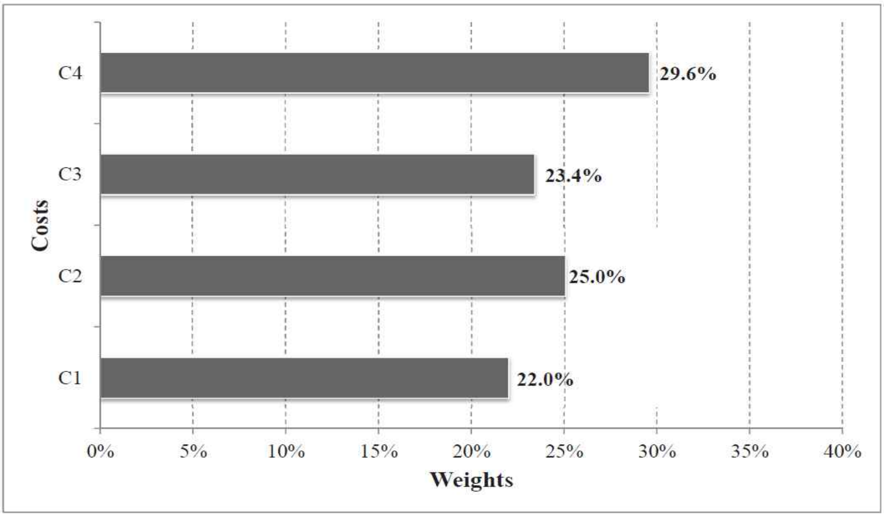

Figure II-5. Weights of Costs

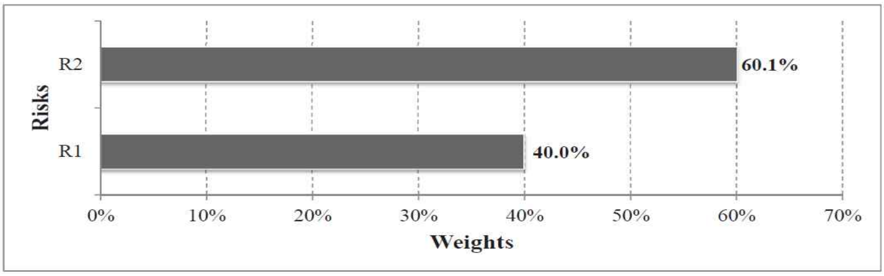

Figure II-6. Weights of Risks

Table II-7 shows the weights of the factors. Opportunity associated with *Market size* (O1) was estimated as the most important factor (15.9%) followed by *Trade balance improvement* (B2, 14.5%). In contrast, *Cultivation of related industries and ripple effect to other industries* (O2) was estimated as having a very low importance of only 3.4%. Energy experts ascribed a relatively higher priority to *Technical credibility* (R1) and *Cultivation of related industries and* *ripple effect to other industries* (O2), while agricultural experts regarded *Market size* (O1) and *Fuel supply reliability* (R2) highly.

Table II-7. The Results of the Weights of Each Factor

Factors	Total	Energy	Agricultural
B1	11.4%	12.1%	10.9%
B2	14.5%	12.7%	16.6%
O1	15.9%	9.4%	21.8%
O2	3.4%	8.5%	0.0%
O3	6.7%	8.5%	3.5%
C1	6.1%	6.3%	5.4%
C2	6.9%	7.0%	6.7%
C3	6.5%	6.5%	6.3%
C4	8.2%	7.4%	9.8%
R1	8.2%	11.8%	0.0%
R2	12.3%	9.8%	19.1%

II-3-2. Evaluation results for alternatives

Six heating facility alternatives were prioritized based on the calculated weights. The comparative evaluation of these alternatives was done on a 9-point scale by the same experts. The evaluation results appear in Figure II-7 – Figure II-10.

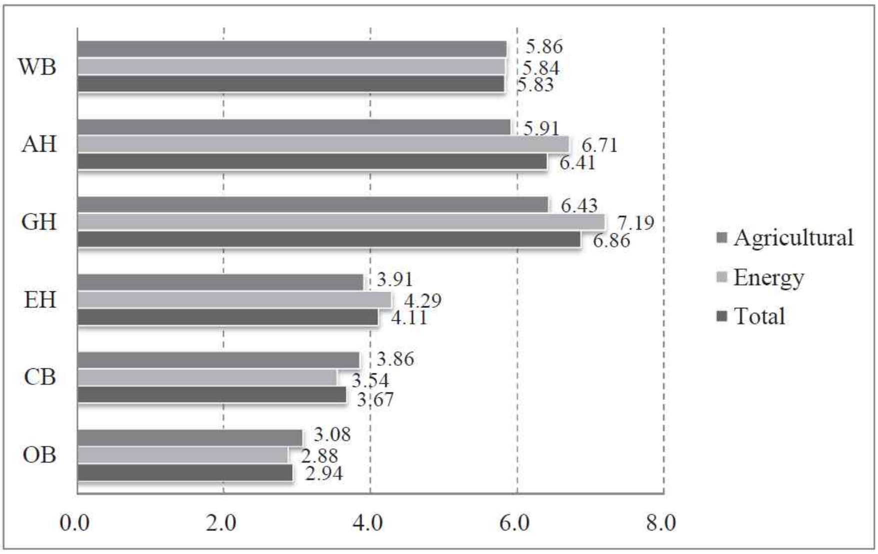

Figure II-7. Evaluation Results for Benefits

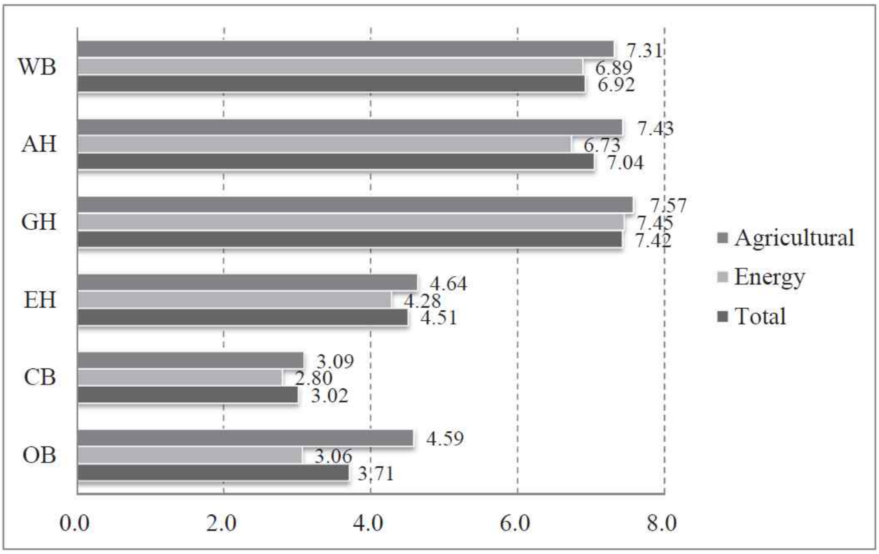

Figure II-8. Evaluation Results for Opportunities

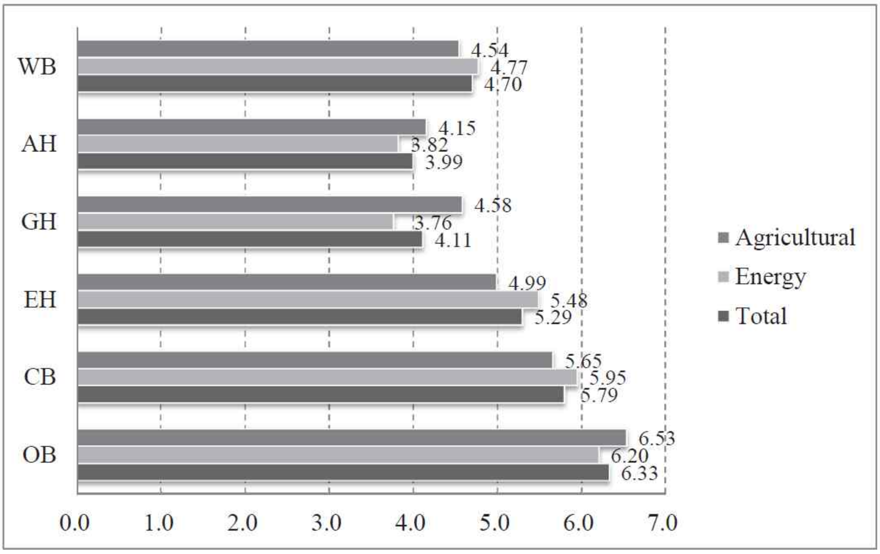

Figure II-9. Evaluation Results for Costs

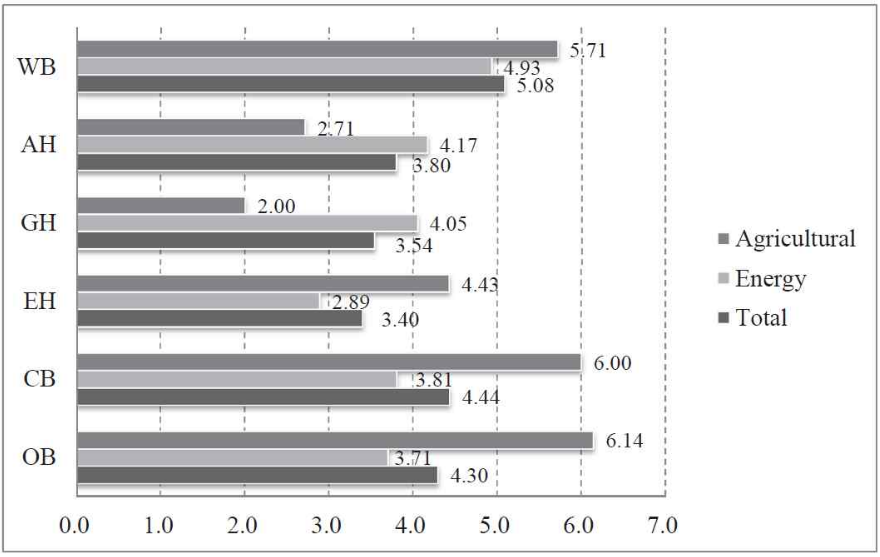

Figure II-10. Evaluation Results for Risks

In terms of benefits, the geothermal heat pump (GH) earned the highest score (6.86), followed by aero-thermal heat pump (AH) (6.41). The oil-fired boiler (OB), coal-fired boiler (CB), and electricity heater (EH) scored relatively low. The evaluation result for opportunity was similar to that for benefit. Alternatives that adopt relatively newer technologies or use renewable energy as fuel, such as the geothermal heat pump (GH), the aero-thermal heat pump (AH), and the wood pallet-fired boiler (WB), earned higher scores, while the coal-fired boiler (CB), a mature technology that uses fossil fuel, acquired a very low score (3.09).

In terms of costs, a higher score entails a greater cost, since cost factors have negative implications. The oil-fired boiler (OB) scored the highest at 6.33, followed by the coal-fired boiler (CB, 5.79), and the electricity heater (EH, 5.29). The geothermal heat pump (GH) and the aero-thermal heat pump (AH) earned a higher score on *Initial investment cost* (C1) but scored low on *Fuel cost* (C2) and *Environmental cost* (C4). These technologies posted overall low scores for cost.

Similar to costs, a higher score on risks entails greater risk exposure. Unlike the other criteria, the evaluation result for risks did not show much difference among the alternatives. However, there were substantial differences among the evaluation results of expert groups. In general, facilities using electricity, such as the electricity heater (EH), geothermal heat pump (GH), and aero-thermal heat pump (AH), were evaluated as being less risky, mainly due to the reliability of Korea's power grid and the assured and stable availability of geothermal and aero-thermal heat. The wood-pallet fired boiler (WB) scored high on risk as opposed to the other renewable energy facilities; Korea imports most of the wood pallets it consumes, and hence, its risk concerning *Fuel supply reliability* (R2) was assessed as being higher.

The rankings of the alternatives were decided based on these evaluations (Figure II-11). The experts chose the geothermal heat pump (GH, 1.992) as the most appropriate heating facility for the horticulture and stockbreeding sectors in Korea. It was evaluated highly for most criteria. The aero-thermal heat pump (AH, 1.855) was also evaluated highly, almost on par with the geothermal heat pump (GH). Conversely, the scores for the oil-fired boiler (OB, 0.657) and the coal-fired boiler (CB, 0.692) were less than half the scores of the abovementioned two alternatives. The evaluation results showed slight differences between expert groups. The evaluation result of the agricultural experts' group had substantial deviations among the alternatives, and the geothermal heat pump (GH) and aero-thermal heat pump (AH) earned high scores.

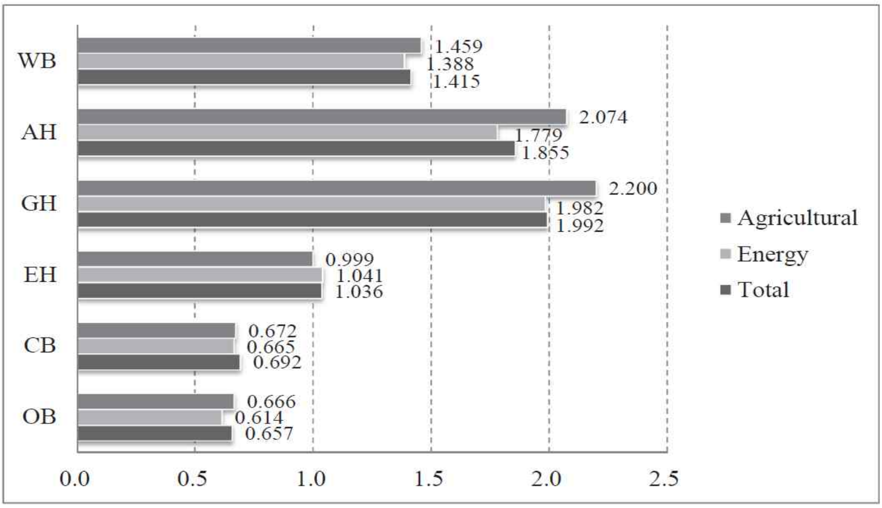

Figure II-11. Overall Evaluation Results

II-4. Conclusion and policy implications

The purpose of this essay was to suggest an approach to evaluate energy options for a new market at the national level with an empirical study on the horticulture and stockbreeding sectors in Korea, those consume the major share of energy in the country's agriculture industry. The analyses were conducted by combining the fuzzy AHP with the BOCR approach, and the following conclusions and policy implications were drawn from the results.

First, *Market size* and *Trade balance improvement* posted higher importance. This means that a paradigm shift, from low-cost energy supply to technological competitiveness enhancement, is required for the current energy policies applicable to the agricultural industry. Korean enterprises could then increase their share in domestic/ overseas heating facility markets, thus pushing down facility prices and creating added value. This result is also a reflection on the current Korean energy supply structure; the country imports most of its energy sources, and there is an urgent need to rectify such a structure. Although consumers typically attach the highest importance to cost, the results from the expert evaluation at national the national perspective offer different and meaningful insights, with implications on government policy making.

Second, experts evaluated the geothermal heat pump as being the most appropriate alternative for the horticulture and stockbreeding sectors in Korea. While it entails the highest initial investment cost of all the alternatives, the geothermal heat pump earned high scores for most factors and criteria. The heat pump uses electricity and geothermal heat, and therefore supplies heating in a more eco-friendly and reliable manner. It is easy to control the temperature, and the technology offers cooling and dehumidification functions that help stimulate the growth of crops and livestock, especially in the summer season. More efficient energy policies for the agriculture industry are likely to result in a speedy migration from the mix of existing energy facilities to the geothermal heat pump. However, as the geothermal heat pump entails a relatively higher initial investment cost, it poses a high entry barrier for small farm houses. Given that the aero-thermal heat pump requires a relatively lower initial investment cost and scored almost as highly as its geothermal counterpart, it could provide a viable alternative to the geothermal heat pump for smaller farms and in areas that do not have ready access to geothermal energy.

Third, the oil-fired boiler, which currently accounts for the predominant share of the horticulture and stockbreeding heating facilities in Korea, ranked the lowest in the expert evaluation. It was scored relatively highly in terms of the initial investment cost and technical credibility, unlike its lower scores for the other factors and criteria. Notably, it earned the highest score for fuel cost. These results suggest that that the Korean government's energy policies for the agriculture industry have resulted in a distortion of resource allocation. This fact and the lower scores for the other criteria and factors for this particular technology lead us to conclude that the tax exemption on petroleum products enjoyed by the agricultural industry needs to be phased out. Simultaneously, subsidies or loans for the installation of geothermal and aero-thermal heat pumps should be introduced, thus lowering their initial investment costs and promoting the use of such renewable energy facilities.

Fourth, other than the results for the risk factors, there was no noticeable discrepancy between the evaluation results of the two expert groups. The agricultural experts assigned priority to fuel supply reliability and accordingly determined the geothermal and aero-thermal heat pumps as better alternatives. In contrast, the energy experts evaluated technical credibility highly and appraised the electricity heater as the best alternative associated with that factor, while regarding the aerothermal and geothermal heat pumps as the two worst alternatives. These differences may be attributed to the fact that agricultural experts are exposed to a relatively greater extent to the workings at farm houses, and hence, they considered reliable fuel supply, which is a major concern for most farmers who depend heavily on oil-fired boilers, as a bigger priority. On the other hand, energy experts have a relatively closer relationship with technology developers or facility makers than with farmers, and therefore, may have assigned more importance to the technological capability rather than fuel.

As analyzed above, technical or industrial aspects such as the size of the market, trade balance improvement effects, and industry ripple effects need to be considered more than energy aspects such as costs or price volatility when selecting an energy source from the national perspective. From this perspective, the heat pump was selected as the optimal solution. As analyzed in Essay 1, considering how the renewable energy industry still relies on economic growth and government funds in developing countries such as Korea, the technical and industrial aspects need to be emphasized even more from the selection and concentration perspective. The present study selected the horticulture and stockbreeding sectors as the new market where renewable energy can expand. It is expected that this methodology and point of view will also be valid in other markets and industries (Heo et al., 2012, 2010).

This study, meanwhile, was conducted based on expert survey, and hence could not reflect the preferences of farm houses who are the actual consumers. Therefore, it is necessary to examine farm houses' preferences on the values of heating facilities and to compare the result with this study, in order to suggest more realistic policy suggestions.

PART III. (ESSAY 3) Public's Willingness to Accept for Utility Loss from Renewable Energy Production: Case Study on Waste Cooking Oil Collection for Biodiesel[11]

III-1. Introduction

Essay 2 discussed about the government choice for effective accomplishment of long-term renewable energy policy objectives. Recently, however, public perception and public acceptance of renewable energy has been emerging as an important influencing factor on renewable energy policy and renewable energy growth. This is because cases of public's utility loss with the deployment of renewable energy have been increasingly reported currently. Such loss in utility may lead to failure of government choice. The reason behind this is that, as analyzed in Essay 1, the renewable energy industry is dependent on economic growth and expansion of

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[11] The rivised version of this essay was submitted to the *Resources, Conservation & Recycling*. The authors and the title of the submitted paper is as follows :
Cho S, Kim J, Park H, Heo E. Provision of an incentive for waste cooking oil collection in South Korea: A contingent valuation approach.

government support that is based on growth in most developed countries. If public’s utility loss is frequently occur with the deployment of renewable energy, questions may be raised about the appropriateness of government support. In short, while the debate on the utility loss due to the deployment of renewable energy and the public perception of renewable energy may seem minor, it can significantly affect long-term renewable energy policy directions.

Thus, this essay aims to propose an approach for the public perception of the utility loss caused by production of renewable energy and a solution to improve it, with an empirical study on the WCO collection for biodiesel.

III-1-1. Overview

WCO has been one of the major feedstock for biodiesel production in Korea. The Korean government is considering providing positive incentives to enhance the rate of participation in WCO collection from households. Before implementing such a policy, it is necessary to examine the appropriate incentive level, the way in which the incentive should be provided, and the effects of the incentive. Motivated by this necessity, by using the CV, this essay investigates public perception of WCO collection and recycling from Korean households.

This essay examines three issues related to the public perception of WCO collection. First, this study investigates the factors that can effect participation in WCO collection, including socio-economic factors, awareness, and the collection systems used. Specifically, a drop-off system in which WCO is collected from central town points, such as supermarkets and religious facilities and a curbside system in which WCO is collected via door-to-door visits by local recyclers are compared with each other. This study then analyze the average incentive level, approximated by the WTA, needed to attract household participation in WCO collection and whether it is appropriate, given the current WCO market price. The WTA for drop-off system and the WTA for curbside system is also compared with each other. Finally, this study calculates the effect of such an incentive, as shown by the maximum amount of WCO collected if an incentive is provided.

The contributions of this essay are two-fold. First, this essay is the first to study the public perception of WCO collection in terms of opportunity cost. Public perceptions of WCO collection have seldom been investigated, since most of countries have not been interested in WCO collection and policies regarding WCO collection and recycling for biodiesel production are at a nascent stage. For that reason prior researches have mostly investigated public perception of municipal solid waste (MSW) collection and recycling (Ajzen, 1991; Basili et al., 2006; Gillespie and Bennett, 2011; Jones et al., 2010; Keramitsoglou and Tsagarakis, 2013; Matsumoto, 2011; Nixon and Saphores, 2007; Tiller et al., 1997). Second, this study uses WTA measure instead of willingness to pay (WTP) for waste collection. Most previous studies have analyzed the public's WTP for waste collection systems by using stated preference methods such CV and conjoint analysis. Except for Basili et al. (2006), past works have focused only on valuing the environmental benefits of waste collection and recycling from the public's perspective; little attention has been paid to the accompanying opportunity cost. However, the Korean public has been participated in MSW collection for several years, and most Korean households have disposed of WCO by wiping it, which does not place a large burden on the environment (KEEI, 2011). In this circumstance, it seems unlikely that the utility gains from WCO collection would exceed the associated utility losses. For those reasons, this study focuses on the opportunity cost of WCO collection to select WTA measure instead of WTP.

The remainder of the essay is organized as follows. Section 1.2

introduces the current status of WCO collection and recycling in Korea. Chapter 2 discusses theoretical approach to measuring WTA for WCO collection and questionnaire design. Chapter 3 describes the CV data, such as basic information from the survey and responses to the value-eliciting questions. Chapter 4 presents the WTA estimation results and discusses policy implications of providing an incentive for WCO collection. Finally, Chapter 5 concludes the study.

III-1-2. Current status of WCO collection and recycling in Korea

Since 2002, the Korean government has promoted biodiesel as a means of meeting joint goals of decreasing greenhouse gas emissions, enhancing energy security, and increasing air quality. Contrary to the government's expectation, however, biodiesel promotion has not contributed to enhancing Korean energy security because over 60% of the feedstock used in biodiesel production since 2006 has come from imported vegetable oils (KBEA, 2013). To examine the potential for cultivating biodiesel crops domestically, the Korean government implemented a pilot project for cultivating canola, a key biodiesel crop, from 2007 to 2010 (MAFRA, 2011). However, this pilot project failed due to low productivity and economic infeasibility, revealing that Korea's inappropriate soil and weather conditions render it much less competitive than other countries in cultivating biodiesel crops. After the failure of the pilot project, the government has been promoting biodiesel more passively. For example, although the government initially announced that fuel blends including 3.0% biodiesel would be compulsory in 2012 (KEEI and MOTIE, 2008), this target was later revised downward to 2.0% based on both the high price and insufficient supply of domestic feedstock for biodiesel production (MOTIE, 2010).

Given these circumstances, WCO has been proposed as an alternative feedstock for biodiesel production in Korea. As shown in Figure III-1, WCO accounts for the majority of the domestic materials used in biodiesel, with its share gradually increasing from 26% to 31% over the last seven years. The sources of WCO in Korea are classified into the residential, restaurant business, and institutional food service sectors[12].

The WCO collection rate is 78.6% from restaurant businesses and 98.0% from institutional food service but a mere 18.6% in the residential sector (KEEI, 2011). Thus, it is necessary to raise the

[12] The food manufacturing sector is excluded from the sources of WCO because it has rarely produced WCO due to recent changes in manufacturin g processes (KEEI, 2011).

WCO collection rate in the residential sector in order to procure the domestic feedstock needed for biodiesel production.

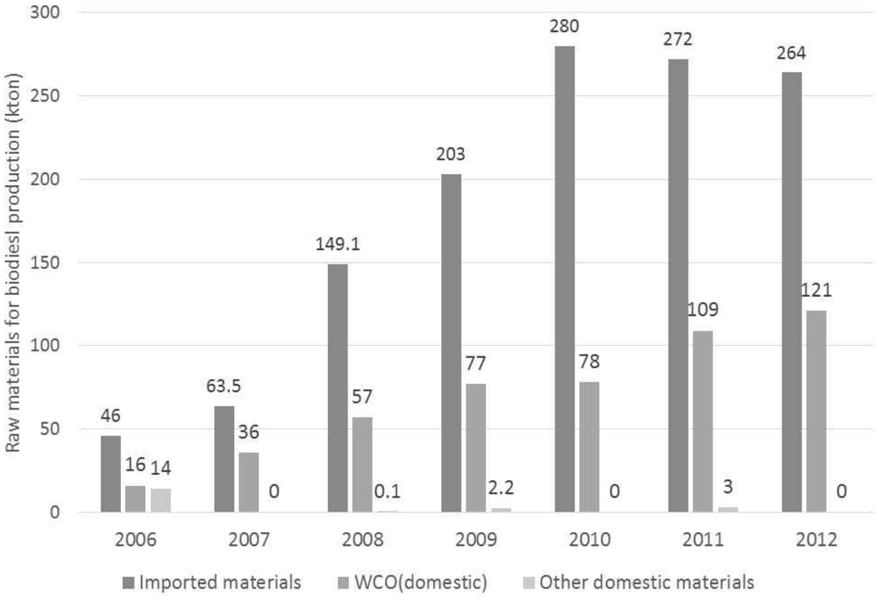

Figure III-1. Feedstock for Biodiesel Production in South Korea (2006-2012)

[a] Source : Korea Bio-energy Association (http://www.kbea.or.kr)

Currently, policies regarding WCO collection from Korean households are based on "command and control" instruments. The government has legally designated WCO as a recyclable resource and has mandated that it must be collected separately from other wastes and recyclables (ME, 2011). Households are required to dispose WCO in garbage cans for WCO near their residence; these are later collected by authorized local recyclers that can resell the collected WCO to biodiesel producers.[13] This policy is not accompanied by any specific non-compliance penalties, as it is almost impossible for the government to monitor WCO collection from households. Korean households have thus been known to pour WCO down the drain or absorb it with paper rubbish; such disposal methods are difficult to control. Local recyclers have even avoided collecting WCO from households since the amount collected is too small to make collection profitable.[14] As such, WCO collection policies have thus far not yielded significant effects. Given this, the government is considering providing positive incentives (Jones et al., 2010) to households for participating in WCO collection.

[13] Specifically, local recyclers can sell collected WCO to refining compan ies, which eventually sell the refined WCO to biodiesel producers.

[14] Thus, these garbage cans containing WCO collected from households may not have been delivered to biodiesel producers. Actually, in Korea, ther e is no official statistics of the share of WCO collected from households.

III-2. Research methodologies

III-2-1. Measuring household WTA for WCO collection

Participation in WCO collection can cause utility losses for individuals because the WCO collection process entails opportunity cost. Consider, for example, an individual who collects WCO in a bottle as it is generated. When the bottle is full, it is collected by via either a drop-off or curbside system. To perform this activity, the individual must devote some of his or her time and endure inconveniences (Matsumoto, 2014). The opportunity cost of WCO collection in terms of both time and inconvenience can be estimated by measuring the individual's WTA for the WCO collection (Basili et al., 2006). This study thus hypothesizes that Korean households will participate in WCO collection if they receive financial incentives equal to their WTA. Among the four welfare change measures[15] defined by Freeman (2003), financial incentives can be regarded as WTA to tolerate loss. Incentive levels have been approximated using

[15] Freeman (2003) classified welfare changes into the following four type s: WTP to secure a gain; WTP to avoid a loss; WTA to tolerate loss; and WTA to forgo a gain.

WTA in many previous studies (Cultice et al., 2013; Groothuis et al., 1998).

To model WTA to tolerate loss, suppose that an individual gains utility from the amount of goods and service purchased x, convenience q, and leisure time t. Then, the utility function of a typical individual is given by $u(x,q,t)$. This utility function is assumed to be monotonically increasing in x, q, and t. If an individual participates in WCO collection, as described above, he or she will exert time and effort to collect WCO, causing both q and t to decrease. Solving the utility maximization problem yields the following state-dependent indirect function with the price term suppressed (Groothuis et al., 1998):

$$U = v(q,t;m), \qquad \text{(III-1)}$$

where U is the reference utility level, $v(\cdot)$ the indirect utility function, and m is income.

Suppose that an individual's convenience and leisure time, respectively, decrease from q^0 to $q^1(<q^0)$ and from t^0 to $t^1(<t^0)$ due to his or her participation in the WCO collection scheme, whereas his or her income does not change. Then, the individual's

utility will change from U^0 to U^1. The relationship between U^0 and U^1 is

$$U^1 = v(q^1, t^1; m) \leq U^0 = v(q^0, t^0; m). \tag{III-2}$$

Then, the compensating surplus (CS) associated with a change in q and t is

$$v(q^1, t^1; m + CS) = v(q^0, t^0; m). \tag{III-3}$$

The CS refers to the amount of additional money an individual would need to reach the initial utility U^0 after a change in his or her convenience and leisure time. In this context, the CS measures the minimum amount of money an individual will accept to bear the inconvenience and time losses engendered by participation in WCO collection—i.e., the WTA.

The choice of WTA as a measure of the CS has been widely disputed. The NOAA (National Oceanic and Atmospheric Administration) panel (Arrow et al., 1993) strongly recommended to use the WTP measure rather than the WTA measure because the WTA measure tends to exceed the WTP measure. However, despite the many problems with the WTA measure (Hanemann, 1991; Zhao and Kling, 2001), this study uses the WTA measure for three reasons. First, households may value participation in WCO collection in terms of utility losses (Matsumoto, 2014). Kahneman et al. (1990) suggested that the WTP measure could severely understate value if individuals value losses more highly than gains. The Korean public has been participating in solid waste collection using a volume-based fee system since 1995 (Lee and Paik, 2011). Most Korean households have disposed of WCO by wiping it up (i.e., absorbing it into paper), which does not place a large burden on the environment (KEEI, 2011). In this circumstance, it seems unlikely that the utility gains from WCO collection would exceed the associated utility losses. Second, WCO collection may not be an alien concept to the Korean public, which has had its solid waste collected for years. Horowitz and McConnell (2000) showed that the WTA/WTP ratio decreases as the respondents' familiarity with the associated practice increases. Thus, the WTA measure is not expected to distort the true utility changes. Third, it is almost impossible to directly calculate the opportunity cost of participation in WCO collection, making WTA a useful reference for determining incentive levels.

III-2-2. Questionnaire design

The design of the questionnaire in this study was based on a CV approach, which elicits public preferences for non-market goods by measuring individuals' WTP or WTA (Mitchell and Carson, 1989). To compare the Korean public's preferences for two different WCO collection systems, this study designed two questionnaires types: A and B. Questionnaire A assumed a drop-off system and questionnaire B assumed a curbside system. Except for the difference in the collection system, the two questionnaires contained identical questions.

The questionnaire consisted of three sections (Bateman et al., 2002). The first presented questions about perception, attitudes, and awareness of WCO collection; it was designed to help respondents consider how they would be affected by participating in WCO collection and to prepare them to respond to later value-eliciting questions based on a hypothetical scenario. The second section presented the hypothetical scenario, the value-eliciting questions, and follow-up questions. In this section, respondents were asked to make a monetary valuation of the utility losses they would incur by participating in a hypothetical WCO collection scheme. The third section collected information on the respondents' socio-economic characteristics, such as education, income, and number of family members.

In the hypothetical scenarios participants of WCO collection get incentives: a bottle of WCO can be exchanged for cash. These scenarios also presented the positive and negative attributes of WCO collection. Concerning positive attributes, the questionnaire explained that WCO collection helps to supply materials for biodiesel production and to prevent soil and water pollution. Concerning negative attributes, the questionnaire noted that it is laborious to collect WCO in the home. After presenting the hypothetical scenarios, the questionnaire asked respondents to state their average annual expenditures on cooking oil. This question was presented to help respondents sensibly respond to the subsequent value-eliciting questions on acceptable levels of financial compensation and to allow a comparison between their WTA and their cooking oil expenditures (Bateman, 1996). Immediately after this question were the value-eliciting questions. On questionnaire A, these solicited the respondent's WTA for participation in WCO collection under the drop-off system, whereas those on questionnaire B referred to the curbside collection system.

The value-eliciting questions followed the form required for the double-bounded dichotomous choice (DBDC) model (Hanemann et al., 1991). As such, the second dichotomous choice question posed was dependent on the response to the first question. A respondent was first asked if he or she would accept the initial bid amount (B_i). If he or she responded "yes," the second bid (B_i^L) was a set amount smaller than the initial bid ($B_i^L < B_i$); if he or she responded "no," the second bid (B_i^U) was a set amount larger than the initial bid ($B_i^U > B_i$). The bidding unit was the cash received in exchange for a 1-liter of WCO. Three initial bid amounts were provided on each questionnaire: KRW 1,000 (USD 0.91), KRW 1,500 (USD 1.37), and KRW 2,000 (USD 1.83). The bid amounts, by questionnaire type, are presented in Table III-1. They were selected based on the WCO processing cost and the WCO price in the feedstock market for biodiesel production (KEEI, 2011). Finally, follow-up questions were posed to respondents stating zero WTA or that they would not participate in the WCO collection scheme.

Table III-1. Questionnaire Type by WCO Collection System and Bid Amount

Collection System	B = KRW 1,000 B^U = KRW 1,500 B^L = KRW 500	B = KRW 1,500 B^U = KRW 2,000 B^L = KRW 1,000	B = KRW 2,000 B^U = KRW 2,500 B^L = KRW 1,500
Questionnaire A: Drop-off system	Type A1	Type A2	Type A3
Questionnaire B: Curbside system	Type B1	Type B3	Type B3

[a] KRW 1 million = USD 913.24 (BOK, 2013).

III-3. Data description

The population surveyed was homemakers aged from 20 to 65 in Korea. A sample of 420 individuals was selected via stratified random sampling (Mitchell and Carson, 1989) to enable generalization of the effects of socio-economic factors. Each type of questionnaire was administered to 70 individuals. The survey was conducted via face-to-face interviews in May 2011. In line with the recommendation of the NOAA Panel (Arrow et al., 1993), interviewees were carefully informed about the background of the questionnaire. Sampling and fieldwork were carried out by a professional polling firm.

III-3-1. Socio-economic characteristics

Table III-2 summarizes the socio-economic characteristics of the respondents. As the target population was homemakers, the sample was 98.1% female and 1.9% male. Respondents' ages ranged from 20 to 65, with the majority (72.4%) between 31 and 50. More than half of the respondents were high-school graduates, followed by 41.7% with bachelor's degrees. Most of the respondents (78.1%) had monthly household incomes ranging from KRW 2 million (USD 1,826) to KRW 5 million (USD 4,566) [16]. More than half of the respondents' families consisted of 4 members.

[16] The average standard exchange rate (KRW 1,095=USD 1.00), as provided by the Bank of Korea (BOK, 2013), was applied in this study.

Table III-2. Descriptive Statistics for Respondents' Socio-economic Characteristics

Characteristic	Number of respondents
Gender	
Female	412 (98.1%)
Male	8 (1.9%)
Age	
20-30	15 (3.6%)
31-40	132 (31.4%)
41-50	172 (41.0%)
51-60	81 (19.3%)
61-65	20 (4.8%)
Education	
Middle school graduate	21 (5.0%)
High school graduate	220 (52.4%)
Bachelor's degree	175 (41.7%)
Master's degree or Ph.D.	4 (1.0%)
Household monthly income [a]	
Less than KRW 2 million	34 (8.1%)
KRW 2 million - 3 million	86 (20.5%)
KRW 3 million - 4 million	142 (33.8%)
KRW 4 million - 5 million	100 (23.8%)
KRW 5 million - 7 million	50 (11.9%)
More than KRW 7 million	8 (1.9%)
Number of family members	
Less than 2	55 (13.1%)
3	78 (18.6%)
4	236 (56.2%)
More than 5	51 (12.1%)

III-3-2. Awareness of and attitudes towards WCO recycling

The majority (71.2%) of the respondents stated that they knew that WCO has been designated as a recyclable resource, like paper, metal, and plastic; only 28.8% stated that they were not aware of this fact. 56.4% of the respondents stated that they had seen a garbage can for WCO collection near their residence; the remainder stated that they had not. Most of the respondents (91.0%) reported having heard that collected WCO is recycled into soap, automotive biodiesel, and industrial materials; only a few (9.0%) had not heard this.

The respondents were generally concerned about the environmental effects of pouring WCO down the drain or absorbing it with paper (Table III-3). Five ordered response levels, from “Not concerned at all” to “Very concerned,” were used to measure this. More than 80% and about 50% of the respondents reported that being (very) concerned about the environmental effects of pouring WCO down the drain and absorbing it with paper, respectively. The environmental cost of pouring WCO down the drain is, in fact, much greater than that of disposing of it via paper (Kim et al., 2007; ME, 2010); the Korean public thus appears to recognize that the environmental cost of WCO varies depending on how it is disposed.

Table III-3. Awareness of the Environmental Effects of WCO

	Disposal via drain	Disposal via paper
Very concerned	174 (41.4%)	61 (14.5%)
Concerned	178 (42.4%)	165 (39.3%)
Neutral	36 (8.6%)	135 (32.1%)
Slightly concerned	32 (7.6%)	58 (13.8%)
Not at all concerned	0 (0.0%)	1 (0.2%)
Total	420 (100)%	420 (100%)

Most respondents (76.9%) reported that they mainly had wiped WCO up with paper, 10.2% had poured it down drain, and only 6.9% had participated in WCO collection. A small fraction (3.3%) had personally recycled WCO, such as by transforming it into recycled soap. The remainder (1.9%) had poured WCO into the soil. Thus the majority of respondents (89.8%) did not engage in collecting and recycling of WCO[17]. However, only a small minority (12.1%)

[17] This figure is far from that derived by KEEI (2011), which reported t hat the residential WCO collection rate is 18.6%. Unfortunately, it is hard to determine which figure is correct because there are no formal statistics regar ding WCO collection rates in the residential sector. One can do expect, howe

disposed of WCO in a way that imposed serious environmental burdens, such as pouring it down the drain or into the soil. This implies that policy approaches to WCO collection are better framed in terms of economic feasibility for biodiesel production rather than in terms of environmental protection.

III-3-3. Cooking oil consumption behavior

Respondents reported, on average, consuming 5 liters of cooking oil per year and spending KRW 22,896 (USD 20.90) per year to purchase it. Their stated amounts of cooking oil consumed do not correspond with their stated cooking oil expenditures: dividing the stated cooking oil expenditure by the average per-liter price of cooking oil (KPRC, 2011)[18] implies that the average household consumes 6.6 liters of cooking oil per year. Their statements on cooking oil consumption thus seem unreliable; this is unsurprising, as respondents are unlikely to precisely measure their cooking oil

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ver, that survey of this study (based on face-to-face interviews) is more accurate than that of KEEI (2011), which relied on phone interviews.

[18] The Korea Price Research Center (KPRC, 2011) reported the average price of cooking oil per liter to be KRW 3,466 (USD 3.12) in 2011.

consumption. Respondents are homemakers, however, this study assumes that they can estimate expenses more precisely. Thus, this study considers the 6.6-liter annual consumption amount derived from the respondents' statement on cooking oil expenditures to be a more realistic figure.

The respondents estimated the WCO generation rate as 10.0% of cooking oil consumption. This figure exceeds that presented by KEEI (2011) (7.7%) but is smaller than those presented by Korea Zero Waste Movement Network (2009) and Kim et al. (2007) (25.7% and 50.0%, respectively). As the latter two studies' information is derived from very small samples with potential estimation biases, KEEI (2011) argued that the figures suggested by the Korea Zero Waste Movement Network (2009) and Kim et al. (2007) exaggerated the actual WCO generation rate. This argument seems reasonable, given that the WCO generation rate for the Korean restaurant business is just 7.3%. As such, the WCO generation rate (10.0%) revealed by survey of this study seems to be reasonable.

III-3-4. Responses to value-eliciting questions

Responses to the value-eliciting questions are presented in Table

III-4. Unlike for the other questions, responses to the value-eliciting questions may vary by questionnaire type because the hypothetical scenarios and initial bid amounts are different across the questionnaires. This study classified respondents into six groups based on their answers to the sequential bid and follow-up questions

Table III-4. Responses to Value-eliciting Questions

Type	Initial bid	Yes–Yes	Yes–No	No–Yes	No-No	Zero WTA	Protest bid	Total
WTA interval		$(0, B_i^L]$	$(B_i^L, B_i]$	$(B_i, B_i^U]$	(B_i^U, ∞)	0	-	
Questionnaire A: drop-off system								
Type A1	KRW 1,000	1	12	6	8	20	23	70
		(1.4%)	(17.1%)	(8.6%)	(11.4%)	(28.6%)	(32.9%)	(100%)
Type A2	KRW 1,500	8	1	6	9	28	18	70
		(11.4%)	(1.4%)	(8.6%)	(12.9%)	(40.0%)	(25.7%)	(100%)
Type A3	KRW 2,000	11	3	6	4	30	16	70
		(15.7%)	(4.3%)	(8.5%)	(5.7%)	(42.9%)	(22.9%)	(100%)
Total		20	16	18	21	78	57	210
		(9.5%)	(7.6%)	(8.6%)	(10.0%)	(37.1%)	(27.1%)	(100%)

Type	Initial bid	Yes–Yes	Yes–No	No–Yes	No-No	Zero WTA	Protest bid	Total
Questionnaire B: curbside system								
Type B1	KRW 1,000	3	6	3	4	25	29	70
		(4.3%)	(8.6%)	(4.3%)	(5.7%)	(35.7%)	(41.4%)	(100%)
Type B2	KRW 1,500	9	2	4	3	28	24	70
		(12.9%)	(2.9%)	(5.7%)	(4.3%)	(40.0%)	(34.3%)	(100%)
Type B3	KRW 2,000	9	4	4	3	28	22	70
		(12.9%)	(5.7%)	(5.7%)	(4.3%)	(40.0%)	(31.4%)	(100%)
Total		21	12	11	10	81	75	210
		(10.0%)	(5.7%)	(5.2%)	(4.8%)	(38.6%)	(35.7%)	(100%)

The first group referred to respondents who answered “yes” and “yes” to the two sequential bid questions while stating a positive WTA. This group included 20 and 21 respondents to questionnaires A and B, respectively. The second group referred to respondents who answered “yes” to the first bid question and “no” to the second bid question; 16 and 12 respondents questionnaires A and B, respectively, were classified within this group. The third group referred to respondents who answered “no” to the first bid question and “yes” to the second one and included 18 respondents to questionnaire A and 11 respondents to questionnaire B. The fourth group included respondents answering “no” to both sequential bid questions while stating a willingness to participate in WCO collection if the incentive were greater than the second bid (B_i^U). This group included 21 and 10 respondents to questionnaires A and B, respectively.

The fifth group referred to respondents who did not want to be compensated in exchange for their participation in WCO collection and were thus considered as having zero WTA. To identify the respondents with zero WTA, this study included a follow-up question for respondents replying “yes” to both bid questions. They were asked whether they would participate in WCO collection without any compensation; those who answered “yes” were categorized into the fifth group. A full 37.1% and 38.6% of respondents to questionnaires A and B, respectively, were categorized into this group. Given this high ratio of respondents reporting zero WTA, it is unlikely that respondents overstated their WTA. To the respondents with zero WTA, this study asked why they would participate in WCO collection without any compensation. For questionnaires A and B, respectively, 67% and 68.3% of respondents claimed this was motivated by a desire to protect the environment, 13.8% and 11.9% stated that it was their obligation under the law, and 18.1% and 17.8% answered that they did not require any compensation because WCO collection would save them money on the paper normally used to absorb WCO.

The sixth group refers to respondents who were identified as placing protest bids—i.e., those who did not want to participate in WCO collection, regardless of the cash incentive. Protest bids usually occur when respondents oppose or disapprove of the survey (Halstead et al., 1992). To identify protest bids, this study asked a follow-up question only to the respondents replying “no” to both bid questions. They were asked whether they would participate in WCO collection if the incentives provided were greater than the one presented (B_i^U); those answering “no” were categorized into the protest bid group. For questionnaires A and B, 27.1% and 35.7% of respondents, respectively, were classified in this group; thus, more respondents protested the curbside system than did the drop-off system.

The respondents belonging to the protest bid group were asked to state why they would not participate in WCO collection, even with a large incentive. The respondents were allowed to choose plural responses among examples. For questionnaire A and B, respectively, 51 and 66 respondents answered that they would not participate because the amount of WCO generated was too small, and 7 and 1 respondents did not consider the environmental impact of disposing of WCO via paper to be serious. Only 2 and 2 respondents did not like the WCO collection system proposed.

III-4. Empirical results and discussion

III-4-1. Factors influencing participation in WCO collection

This study hypothesizes that participation in WCO collection is influenced by socio-economic factors, awareness of WCO collection, initial bid amount, and the WCO collection system. These potential determinants are examined by estimating the following binomial logit model (Ek, 2005):

$$P[Y=1] = \frac{\exp(\beta' X)}{1+\exp(\beta' X)} = \Omega(\beta' X) \qquad \text{(III-4)}$$

In Eq. (III-4), β is the vector of parameters to be estimated. The dependent variable, Y, participation in WCO collection, equals one if the respondent stated willingness to participate in WCO collection with a positive or zero incentive. That is, it equals one for all respondents except those belonging to the sixth group, the protest bids, for whom it was set equal to zero. X is a vector of explanatory variables: socio-economic factors, awareness of and WCO recycling, initial bid amount, and the WCO collection system. Definitions and descriptive statistics for these explanatory variables are summarized in Table III-5.

Table III-5. Definitions and Descriptive Statistics for Explanatory Variables

Variable	Definition	Mean (S.D.)
TYPE	WCO collection system (0 = drop-off system; 1 = curbside system)	0.500 (0.501)
BID	Initial bid amount	1500 (108.735)
AWARENESS 1	Awareness of the legal designation of WCO as a recyclable resource (0 = no; 1 = yes)	0.712 (0.453)
AWARENESS 2	Awareness of the environmental effects of pouring WCO down the drain (1–5: 1 = not at all concerned; 5 = very concerned)	4.716 (0.881)
AWARENESS 3	Awareness of the environmental effects of absorbing WCO with paper rubbish (1–5: 1 = not at all concerned; 5 = very concerned)	3.540 (0.912)
EXPENSE	Yearly expense of cooking oil (0–9: 0=non-response; 1=below KRW 10,000; 9=over KRW 45,000)	4.229 (2.469)
AGE	Respondent's age	44.650 (8.429)
GENDER	0 = female; 1 = male	0.019 (0.137)
FAMILY	Number of family members	3.681 (0.974)
EDUCATION	Education level (1 = middle school graduate; 2 = high school graduate; 3 = bachelor's degree; 4 = master's degree or doctorate)	2.386 (0.597)
INCOME	Monthly household income (1–10: 1 = below KRW 1 million; 10 = over KRW 10 million)	5.945 (1.577)

Results from estimating the binominal logit model (Eq. III-4) are given in Table III-6. The likelihood ratio test rejected the joint hypothesis that all coefficients equal to zero at the 1% significance level, but among the 11 variables, only four are statistically significant at the 10% level. That is, the explanatory variables, such as income, gender, education, and awareness, do not appear to influence a given respondent's participation in WCO collection, even though they have been shown to influence public preferences for MSW collection (Afroz et al., 2009; Basili et al., 2006). This implies that public preference for WCO collection is differentiated from that for MSW collection.

Table III-6. Determinants of Participation in WCO Collection

Variable	Parameter estimate [a]	t-value
TYPE	-0.3959*	-1.840
BID	0.0005*	1.791
AWARENESS 1	-0.3838	-1.494
AWARENESS 2	-0.0263	-0.1749
AWARENESS 3	-0.0019	-0.0129
EXPENSE	0.1172**	2.338
AGE	-0.0123	-1.059
GENDER	0.4941	0.5813
FAMILY	0.2027*	1.648
EDUCATION	0.0937	0.4918
INCOME	0.0332	0.4224

Sample size: 420

Log-likelihood: -246.8

LR ratio (χ^2): 29.20***

[a] ****, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.*

The negative sign on the coefficient for the TYPE variable suggests that the rate of participation in WCO collection is likely to be higher under the drop-off system than under the curbside system. This result corresponds with the survey result (Table III-4) that protest bids are more common for the curbside system than for the drop-off system. To explain this intuitively: the curbside system and its accompanying visit to the home by unknown recyclers may reduce participation in WCO collection, even though it may be more convenient than the drop-off system. The positive coefficient on the BID variable indicates that the greater the incentive, the higher the rate of participation in WCO collection, which is consistent with previous studies (Basili et al., 2006; Groothuis et al., 1998; Kim et al., 2013). The positive coefficient for the EXPENSE variable suggests that households spending higher-than-average amounts on cooking oil are more likely to participate in WCO collection. This result is reasonable, since households spending more money on cooking oil likely generate larger amounts of WCO. As mentioned in Section 3.4, most of the respondents protesting against participating in WCO collection did so because too little WCO was being generated in their households. The positive coefficient on the FAMILY variable indicates that the greater the number of family members, the higher the rate of participation in WCO collection.

III-4-2. WTA to participate in WCO collection

This study hypothesizes that the WTA to participate in WCO collection can approximate the necessary incentive level. To derive the WTA for the respondents willing to participate in WCO collection (Halstead et al., 1992), this study exclude the respondents protesting against WCO collection and analyze the CV data for the 153 respondents to questionnaire A (drop-off system) and 135 respondents to questionnaire B (curbside system). To calculate WTA, the maximum likelihood estimators of ρ, θ_1, and θ_2 in Eq. (B.6), are first derived[19]. Then, the mean WTA is calculated, substituting these estimates into Eq. (B.8)[20]. The difference between the WTA under the drop-off system and the WTA under the curbside system is estimated using the method proposed by Kim et al. (2012). The mean WTA, confidence intervals, and the WTA difference are calculated by the delta method (Greene, 2002) and presented in Table III-7. All the estimates are statistically significant at the 1% level.

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[19] This study applied the mixture model (An and Ayala, 1996; Werner, 1999) to estimate these parameters. See Appendix B for detail.

[20] The method for calculating WTA is explained in Appendix B.

Table III-7. Estimates of Parameters, Mean WTA, and Difference in WTA

Variable	Parameter estimate [a, b]	t-value
Questionnaire A: drop-off system		
ρ	0.5098***	12.61
θ_1	1768.0***	12.78
θ_2	0.5689***	6.832
Mean WTA (WTA_A)	KRW 772 (USD 0.70)***	8.782
Log-likelihood	-206.4	
Questionnaire A: curbside system		
ρ	0.6000***	14.23
θ_1	1513.0***	6.836
θ_2	0.6621***	5.705
Mean WTA (WTA_B)	KRW 546 (USD 0.50)***	6.836
Log-likelihood	-163.6	
WTA difference between two systems		
WTA_A - WTA_B	KRW 226 (USD 0.21)***	2.831

[a] ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

[b] KRW 1 million = USD 913.24 (BOK, 2013).

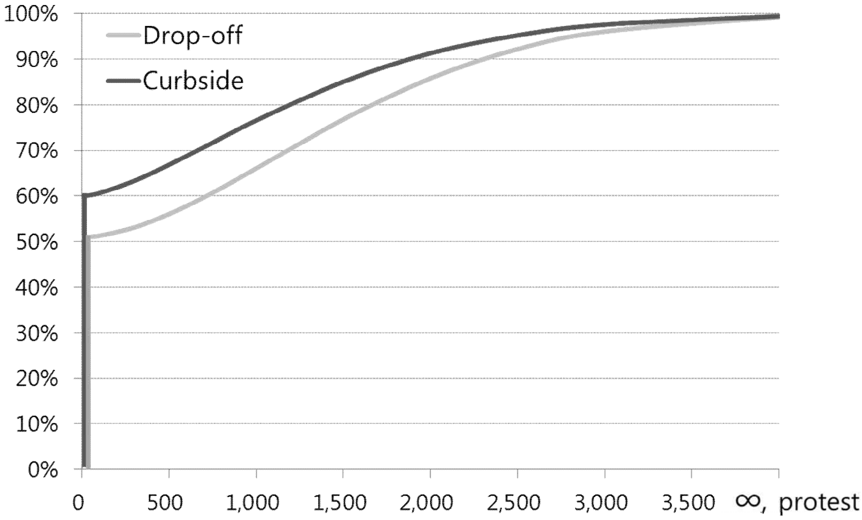

Figure III-2. Cumulative Distribution of WTA (KRW/liter of WCO) – Exclude Protest Bids

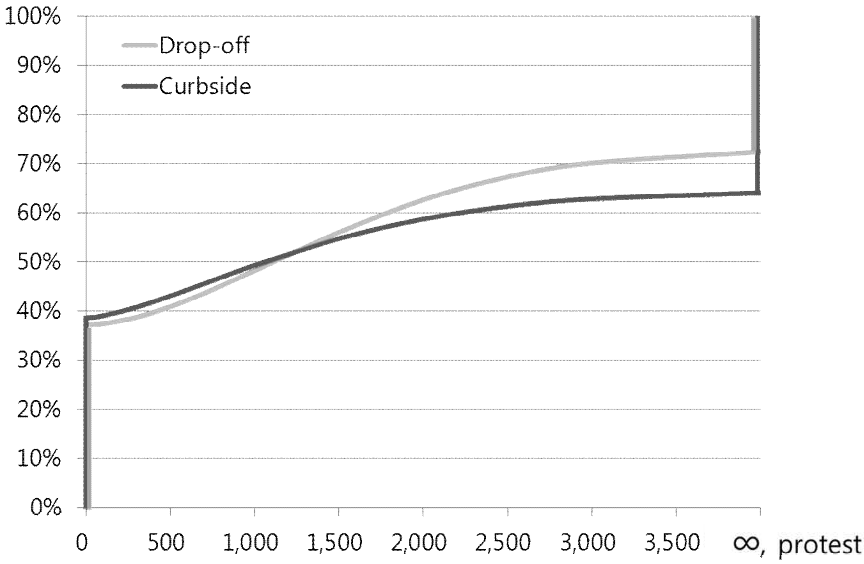

Figure III-3. Cumulative Distribution of WTA (KRW/liter of WCO) – Include Protest Bids

The mean WTA to participate in WCO collection under the drop-off system is KRW 772 (USD 0.70) per liter of WCO. The mean WTA under the curbside system is KRW 546 (USD 0.50) per liter of WCO. The difference between these two WTAs is KRW 226 (USD 0.21) and is statistically significant. This indicates that the WTA under the curbside system is smaller than that under the drop-off system, even though the participation rate is smaller under the curbside system. A possible explanation for this is that for the respondents allowing recyclers to visit, the curbside system is more convenient than the drop-off system.

KEEI (2011) proposed that an incentive of KRW 700 (USD 0.64) per liter of WCO would be appropriate, given WCO prices in markets for biodiesel feedstock. The mean WTA under the drop-off system is greater than this proposed incentive level, but that under the curbside system is not. If an incentive of KRW 700 (USD 0.64) per liter of WCO is provided at a flat rate, people with a WTA greater than this will not participate in WCO collection. Eq. (B.7) reveals that 43.5% of respondents would participate in WCO collection under the drop-off system while 45.5% would participate under the curbside system.

III-4-3. Expected amount of WCO collected

To estimate the amounts of WCO collected when an incentive is provided to participants, this study considers four cases. Case A-a refers to providing an incentive equal to each participant's WTA under the drop-off system. Case A-b refers to providing an incentive of KRW 700 (USD 0.64) under the drop-off system. Case B-a refers to providing an incentive equal to each participant's WTA under the curbside system. Finally, Case B-b refers to providing an incentive of KRW 700 (USD 0.64) under the curbside system.

As the population surveyed was homemakers aged 20 to 65 in Korea, this study assumes that the WCO collection participation rate derived via survey of this study approximates the WCO collection participation rate for the general Korean public. The participation rate in Case A-a is approximated by the portion of questionnaire A respondents stating that they would participate in WCO collection, whereas that for Case A-b is approximated by the portion of respondents affirming participation with a WTA less than KRW 700 (USD 0.64) per liter of WCO. The participation rates for Cases B-a and B-b are approximated in similar ways using questionnaire B responses.

Table III-8. Amount of WCO Collected - By Case

Case description	Participation rate	Amount of WCO collection
Drop-off collection system		
Case A-a. An incentive equal to each participant's WTA is provided.	72.9%	8,518 kilo liter (7,836 ton)
Case A-b. An incentive of KRW 700 (USD 0.64) is provided.	43.5%	5,086 kilo liter (4,679 ton)
Curbside collection system		
Case B-a. An incentive equal to each participant's WTA is provided.	64.3%	7,513 kilo liter (6,912 ton)
Case B-b. An incentive of KRW 700 (USD 0.64) is provided.	45.5%	5,313 kilo liter (4,888 ton)

[a] The total number of Korean households in 2011 is estimated as 17,687,001 by the Korean government (KOSIS, 2011). The density of WCO is assumed to be 0.92 kg per liter (KEEI, 2011).

Table III-8 presents the participation rate and amount of WCO collected in each case. As noted in Section 3.3, 11,684 kilo liters (10,749 tons) of WCO will be generated by Korean households each year if the average household consumes 6.6 liters of cooking oil annually and generates WCO of 10.0% of cooking oil consumed. The amount of WCO collected can be calculated by multiplying the total amount of WCO generated and the WCO collection participation rate. Table III-8 shows that between 5,086 and 8,518 kilo liters (4,679 and 7,836 tons) of WCO could be collected annually if an incentive were provided to participants. These amounts correspond to 3.9–6.5% of the total amount of WCO used in biodiesel production in Korea in 2012 (Figure III-1).

III-4-4. Summary

The results shown in Table III-6 indicate that the drop-off system is more effective than the curbside system in promoting WCO collection if there is no upper limit on incentives. However, if the incentive satisfying the economic feasibility condition is provided (KRW 700 or USD 0.64 per liter), the participation rate under the curbside system is only slightly higher than that under the drop-off system. In reality, it is likely that participants would be provided with the incentive satisfying the economic feasibility condition; this study thus concludes that the collection system chosen will not have a large impact on the participation rate. About 45% of the population is expected to participate in WCO collection at this incentive level (Table III-8).

At the time of the survey, only 6.9% of respondents stated that they had participated in WCO collection without any compensation. Providing an incentive of KRW 700 (USD 0.64) per liter of WCO thus increases the participation rate more than six-fold. However, incentive provision is unlikely to effectively increase the share of domestic feedstock used in biodiesel production. The share of biodiesel feedstock that came from domestic sources in 2012 was 31.4% (Figure III-1). This share would increase to only 32.6–33.5% if the amount of WCO collection increased due to the incentive. This increase is slight because the total amount of WCO generated by Korean households is a mere 8.9% of the amount of WCO used as a feedstock for biodiesel production.

Consequently, while an incentive would be very effective at increasing the amount of WCO collected, it would be insufficient to increase the proportion of biodiesel production feedstock that is sourced domestically. It must be noted, however, that this study overlooks animal-source oils and fats generated by Korean households; it may thus underestimate the amount of biodiesel feedstock that could be generated in the domestic residential sector. Considering the eating habits of the average Korean household, animal-source oils and fats, in addition to WCO, may be desirable sources of biodiesel feedstock. If sufficient public relation activities related to WCO collection are conducted, the amount of animal-source fats and WCO collected from households should increase, eventually leading to an increase in domestically sourced materials for biodiesel production.

III-5. Conclusion and policy implications

By applying the CV method, this study has examined the Korean public's participation in WCO collection when an incentive is provided. It identified key factors for promoting participation in WCO collection, derived the incentive level (approximated by the WTA) appropriate to encourage participation in WCO collection, and calculated the amount of WCO that would be collected, when an incentive provided. The results showed that incentive provision would contribute greatly to increasing WCO collection but do little to increase the portion of biodiesel feedstock that are domestically sourced. Providing an incentive that satisfied the economic feasibility conditions would likely attract over 40% of Korean households to participate in WCO collection, regardless of the collection system used.

Most research to date on public preferences for waste collection services has focused on the benefits of these services. In the current context, however, many governments already provide waste collection services; as such, collection of an additional substance that must be gathered separately, like WCO, may have a negative influence on participants' utilities. Complementing previous studies on the opportunity cost of waste collection, such as Basili et al. (2006) and Matsumoto (2014), this essay has modeled the utility losses caused by WCO collection and calculated these losses in terms of WTA. This extends the existing literature on public perception of waste collection, and the results have shed much needed light on WCO collection policies; they can thus act as useful references for governments planning WCO collection and biodiesel production.

This essay has shown that public's utility loss during the production of renewable energy affects deployment of renewable energy and that deployment may increase considerably if utility loss is appropriately compensated. This empirically shows that, while selection and concentration by the government, as discussed in Essay 2, are crucial for effective achievement of long-term renewable energy policy objectives, it is also important to ensure public acceptance of government policy or government choice. Hence, for sustainable growth of renewable energy, it is necessary to minimize public utility loss during the deployment of renewable energy and establish an appropriate compensation system for utility loss.

Meanwhile, the result of this study can be more practical with the following further study. The rates of protest bid of both collection systems, especially the curbside system, are somewhat high. But the reason why the respondents protest to the bid is not clear. Therefore, it is necessary to analyze factors that affect protest bids in depth and figure out how to reduce protest bid group for suggesting more appropriate WCO collection system.

PART IV. OVERALL CONCLUSION

Renewable energy supply in member countries of the OECD recorded an average annual growth rate of 2.4% from 1990 to 2012, thrice the average annual growth rate of the total primary energy supply (0.7%) in the same period (IEA, 2014). Further, the industrial scale of renewable energy is expected to grow fast (CleanEdge, 2014). This is because many countries are competitively striving to expand renewable energy deployment and nurture the industry.

Several policy-centric issues, therefore, have been raised, and the topics of discussion vary from long-term and macroeconomic issues, such as on the relationship between renewable energy and economic growth, to microeconomic concerns, such as the appropriate incentive levels for renewable energy deployment. This paper presents an empirical analysis on the following three issues concerning renewable energy policy.

1) Essay 1 suggests a new viewpoint regarding the causal relationship between renewable energy consumption and economic growth. A possible long-term renewable energy policy direction is proposed accordingly.

2) Essay 2 presents the results of an empirical study on choosing optimal renewable energy options at the national level, to help achieve renewable energy policy goals efficiently.
3) Essay 3 focuses on the public perception of utility loss caused by renewable energy production and its utilization. Further, it analyzes the factors affecting the rate of participation and proposes ways to increase it.

It is crucial to address these issues because doing so can help derive more effective energy, economic, and environmental policies (Dedeoğlu and Kaya, 2013) and contribute to the understanding of the factors necessary for their effective implementation. Moreover, addressing these issues is a prerequisite to the sustainable growth of the renewable energy industry.

Essay 1. Causal relationships between renewable energy consumption and economic growth

The causal relationship between energy consumption and economic growth has been actively researched. Due to the recent expansion in renewable energy, however, the interest in the causal relationship between energy consumption and economic growth has naturally expanded into an interest in the causal relationship between *renewable* energy consumption and economic growth. However, fundamentally, these discussions have not deviated from the convention.

This paper underscores the problem posed by previous studies, which were based on a specific viewpoint, and suggests a novel viewpoint for addressing the causal relationship between renewable energy consumption and economic growth. The existing viewpoint focuses mainly on the role of renewable energy as an energy input for production. However, when compared to conventional energy sources, renewable energy is more suitably characterized as a new industry than an energy source, particularly for countries with robust renewable energy industries. Therefore, this paper suggests a new viewpoint that focuses on the role of renewable energy as an industry.

The results of the empirical analysis undertaken using the new viewpoint revealed that the momentum of the renewable energy industry in OECD countries is not sufficient to lead economic growth; rather, the industry has grown due to economic growth and the government's supporting policies. Therefore, economic growth and government support continue to be necessary conditions for the advancement of the renewable energy industry. In particular, during periods of economic recession, like the present situation, because the renewable energy industry is expected to record slow growth, or even, reverse growth, a national strategy is required to help this industry to survive. A typical example is the selection and concentration strategy for the effective distribution of resources.

However, a very different result was obtained when the analysis targets were limited to the top five OECD countries (USA, Japan, Germany, Denmark, and Spain) with the most advanced renewable energy industries; the results showed that the growth hypothesis regarding renewable energy and economic growth is valid in these countries. Under the new viewpoint, this signifies that the renewable energy industry plays an important role in economic growth.

A comparison of both analytical results showed that during its early and middle stages, economic growth and the resulting fiscal expansion contributes to the renewable energy industry's expansion. However, in contrast, once the renewable energy industry matures to some degree, it can lead economic growth. These results signify the industrial potential of renewable energy in the long-term. Thus, it is expected that from a long-term perspective, fostering the renewable energy industry will help create a new growth engine, which will contribute to solving energy, environmental, and economic problems. Therefore, it will be necessary to implement development strategies to encourage the growth of the renewable energy industry and its deployment expansion.

On the other hand, renewable energy constitutes a high proportion of the energy mix in LDCs. Therefore, the conventional viewpoint, which focuses on the role of renewable energy as an energy source, will remain valid. The result of the empirical analysis of the causal relationship between renewable energy consumption and economic growth in non-OECD countries showed that the feed-back hypothesis is valid. That is, renewable energy is an important input factor in production or economic growth, and conversely, economic growth has also led to increasing renewable energy consumption in these countries. Therefore, it will be necessary to implement aggressive renewable energy deployment policies for LDCs, since such government policies will not only solve energy problems but also contribute to economic growth.

Essay 2. Choosing the appropriate renewable energy source

Narrowing down the perspective to Korea, the domestic renewable energy industry is still growing and relies on the support provided by government policies. The issues faced by the Korean renewable energy industry are the country's recent economic slowdown coupled with an insufficient government budget. These issues lower public acceptance for expanding support for the renewable energy sector. Therefore, to foster renewable energy development under these circumstances, a selection and concentration strategy is required to ensure effective allocation of limited financial resources. The AHP is a widely used methodology used for the selection of appropriate energy sources at the national level, and recent advances to this methodology include the adoption of the fuzzy theory and the BOCR approach. Thus, this study chose a fuzzy-AHP with the BOCR approach as the methodology for selecting an appropriate renewable energy option at the national level. An empirical analysis was conducted by targeting the horticulture and stockbreeding sectors, where possibilities for the future expansion of renewable energy are likely to be high.

The results of the weight evaluation of the factors and criteria revealed the importance of economic and industrial factors, such as market size and trade balance improvement, which were assessed to be higher than that of the energy–environmental factors such as energy cost and environmental cost. This result is in line with the new viewpoint suggested in Essay 1, which focuses on the industrial aspect of renewable energy. Therefore, renewable energy policies should focus on technological competitiveness enhancement and development of new and domestic industry rather than the supply of clean and low-cost energy sources.

Optimal renewable energy sources for the horticulture and stockbreeding sectors were then selected and analyzed. The results indicated that the geothermal heat pump is the optimal alternative, while the oil boiler, which is most widely used, is the least appropriate alternative. This result showed that the energy mix and energy policies in the Korean agriculture sector require to be modified.

Essay 3. Public perception of renewable energy production

It is vital to secure a minimum domestic market and construct a test bed in order to help the renewable energy industry grow beyond a nascent stage. However, recently, recurring cases of public utility loss have hampered renewable energy deployment; utility loss acts as an obstacle in implementing renewable energy policies. Therefore, it is necessary to consider utility loss and public perception as important factors when designing renewable energy policies. Thus, public perception in terms of opportunity cost was studied, and a method for ensuring public acceptance was proposed. Collection of WCO for biodiesel production in Korea was selected as the target of the empirical analysis, because the biofuels sector has received the most passive response from the Korean government, given the insufficiency of biofuels as a domestic raw material. Thus, deployment and industrialization have been delayed for this sector in Korea. Increased WCO collection from households is necessary to overcome these problems. However, households tend to avoid active participation in WCO collection, because this process requires considerable effort and time and is generally considered as filthy. This study used the CV methodology to estimate Korean households'

WTA WCO collection and analyzed the participation rate for a certain incentive level. The results indicated that the average WTA of regular households for WCO collection is similar to or lower than the WCO market price, and if an appropriate collection system is constructed, over 40% of households are willing to participate, provided the compensation level is comparable to the market price of the WCO. Considering that the household WCO collection rate identified by the survey was 6.9%, it is likely that appropriate compensation would raise WCO collection significantly, by about six-fold. The result of the empirical analysis showed that the utility loss caused by renewable energy deployment can be sufficiently overcome if a proper compensation system is constructed. Therefore, to achieve long-term renewable energy policy goals effectively, it is necessary to accurately identify the cause of the utility loss and respond to it by constructing a selective compensation system as soon as possible.

To sum up, the conclusions of this paper are as follows. The renewable energy sector needs to be viewed as a new industry, and its potential should be tapped via a concerted long-term selection and concentration strategy. Public utility loss, which occurs in the process of securing domestic markets and building test beds, can be overcome with a proper compensation system. These initiatives can contribute to the effective implementation of renewable energy policy.

The contributions of this paper are three-fold.

1) First, it suggests a new viewpoint on the causal relationship between renewable energy consumption and economic growth, so as to overcome the limitations of previous studies and offer a fresh perspective. Furthermore, the empirical results showed that the extent of contribution of the renewable energy industry to economic growth depends on the phase of the renewable energy industry.
2) Second, this paper is the first to highlight the use of fuzzy-AHP toward the investigation of optimal energy alternatives for the horticulture and stockbreeding sectors, which are the most energy-intensive sectors in the agriculture, forestry, and fishery industries. The study provided insights into new long-term renewable energy policy directions for these industries.
3) Last, this highlights the use of the WTA measure, instead of the WTP measure, for waste collection unlike most previous studies that focused only on valuing the environmental benefits of waste collection and recycling from the public's perspective.

Notably, this was the first attempt to study public perception of WCO collection in terms of opportunity cost.

APPENDIX A. Descriptive Statistics for Part I (Essay 1)

A-1. Descriptive Statistics By Country

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Country	**Mean**	**St. Dev.**	**Median**	**Mean**	**St. Dev.**	**Median**	**Mean**	**St. Dev.**	**Median**
Australia	591,868	126,636	590,962	18,083	1,853	17,590	2,770	2,645	1,230
Austria	274,535	38,383	280,623	39,749	3,992	39,771	2,835	2,005	1,777
Belgium	341,426	42,526	348,630	1,766	1,765	1,044	1,434	1,754	584
Canada	972,997	171,400	999,930	351,158	22,947	354,220	8,601	3,536	8,484
Chile	102,193	27,996	101,251	21,542	5,317	20,689	1,887	803	1,786
Czech Republic	113,782	21,437	106,434	2,618	1,169	2,360	751	773	516
Denmark	232,445	27,442	242,097	5,688	3,824	5,572	5,662	3,826	5,542
Finland	168,380	30,691	171,939	21,346	2,948	21,193	8,262	2,059	8,710
France	1,933,349	221,194	1,973,041	68,229	6,999	66,951	4,804	3,799	3,135
Germany	2,631,244	228,528	2,685,203	45,585	28,202	35,475	25,878	27,587	13,743

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Greece	203,401	38,299	196,958	4,670	2,197	4,144	876	1,018	451
Hungary	93,229	14,965	89,959	846	974	257	658	962	65
Iceland	13,410	2,891	13,213	8,301	4,094	7,679	1,531	1,462	1,323
Ireland	150,422	52,778	159,642	1,584	1,086	1,138	828	1,078	339
Italy	1,658,870	133,654	1,700,991	50,324	9,014	48,240	9,017	6,296	6,680
Japan	4,318,233	257,612	4,308,101	103,896	9,012	103,187	19,154	7,441	16,748
Korea, Rep.	688,469	198,138	678,268	4,109	1,017	4,230	447	673	201
Luxembourg	30,691	7,722	31,586	160	71	143	65	56	49
Mexico	769,700	127,915	797,403	35,992	5,646	36,007	8,344	1,354	8,102
Netherlands	572,616	87,463	597,952	4,253	3,443	2,973	4,153	3,442	2,831
New Zealand	95,375	18,400	93,734	27,889	2,149	28,114	3,840	1,500	3,358
Norway	264,494	43,954	272,720	120,876	10,895	120,393	550	409	299
Poland	260,355	68,516	261,095	3,424	2,515	2,352	1,409	2,243	226
Portugal	173,316	22,453	184,100	13,257	4,892	12,868	3,052	3,291	1,545
Slovenia	30,450	6,557	29,900	3,655	529	3,575	75	85	70

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Spain	963,155	179,231	963,134	43,049	19,136	36,971	14,269	16,857	6,238
Sweden	322,180	52,805	324,508	73,390	8,214	74,747	5,815	4,376	4,261
Switzerland	361,079	37,277	360,564	35,519	3,243	35,788	852	309	857
Turkey	397,598	96,114	374,661	35,814	8,036	35,559	560	901	275
United Kingdom	1,974,079	348,129	2,005,800	11,960	6,677	9,616	7,286	6,674	4,884
United States	11,162,793	1,964,762	11,558,791	366,852	39,977	361,814	90,627	30,577	77,160
Argentina	169,675	37,900	166,007	29,219	6,810	29,484	820	655	673
Armenia	3,721	1,578	3,416	1,966	794	1,799	1	2	-
Azerbaijan	11,905	7,546	9,183	2,078	558	1,951	-	-	-
Bangladesh	49,326	16,191	46,269	754	147	749	-	-	-
Belarus	25,437	8,378	23,138	37	30	28	10	23	0
Bolivia	8,376	1,862	8,201	1,851	414	1,999	50	9	52
Brazil	792,840	147,067	768,993	307,313	65,008	298,979	11,236	7,614	8,368
Bulgaria	25,183	4,994	23,042	2,876	1,007	2,754	56	165	0

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Cameroon	14,263	2,850	13,827	3,389	612	3,334	44	140	0
China	1,698,295	993,958	1,417,048	312,801	191,252	225,472	10,137	18,042	3,058
Costa Rica	16,679	4,855	16,341	6,296	1,941	6,645	976	545	1,176
Dominican Republic	28,763	9,657	28,565	1,073	473	910	36	10	37
Ecuador	35,962	6,890	34,012	7,203	1,763	7,071	149	283	0
Egypt, Arab Rep.	77,208	22,016	75,403	12,814	1,968	13,167	345	472	137
El Salvador	14,844	2,823	15,219	2,441	665	2,132	882	499	786
Ethiopia	10,317	4,169	8,912	2,162	1,034	1,651	5	9	0
Gabon	8,228	811	8,133	824	75	818	8	1	8
Guatemala	23,603	5,356	23,442	3,341	1,377	2,810	965	750	606
Honduras	8,202	1,947	7,705	2,131	398	2,136	50	70	1
India	664,357	269,891	602,654	93,875	29,639	80,809	8,884	13,248	3,038
Indonesia	249,036	62,669	235,915	13,995	5,262	14,891	4,596	2,876	4,875
Jordan	10,298	3,527	9,239	40	24	42	6	4	3

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Kenya	16,689	3,313	15,673	3,779	717	3,786	884	462	702
Kyrgyz Republic	2,327	495	2,302	11,226	1,257	11,118	-	-	-
Macedonia, FYR	5,675	756	5,482	1,073	456	900	-	-	-
Malaysia	115,585	36,561	113,868	5,895	1,324	5,831	131	413	0
Morocco	51,374	12,408	46,686	1,430	817	1,194	137	173	64
Mozambique	4,959	2,135	4,311	7,973	6,574	9,652	-	-	-
Nicaragua	5,369	1,202	5,413	858	214	854	500	161	489
Pakistan	90,477	22,933	85,822	23,657	4,796	22,449	-	-	-
Panama	13,419	4,465	12,524	3,044	717	3,021	26	11	23
Peru	69,240	20,159	64,654	15,858	3,543	16,327	245	171	159
Philippines	87,419	21,995	82,354	15,932	3,591	17,546	8,718	2,137	9,921
Romania	88,678	16,950	82,787	15,898	2,558	16,004	26	90	3
Russian Federation	686,988	152,899	670,119	167,768	7,542	167,639	230	206	82
Senegal	7,211	1,738	6,934	155	131	53	49	8	48

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Singapore	100,981	35,496	98,204	421	294	245	421	294	245
South Africa	215,323	42,651	204,703	1,546	758	1,408	206	154	307
Sri Lanka	20,530	6,263	19,780	3,692	716	3,471	14	23	11
Tajikistan	2,170	786	2,099	15,697	1,081	15,845	-	-	-
Tanzania	11,477	3,924	10,061	2,053	473	2,078	-	-	-
Thailand	148,289	35,160	140,496	7,032	2,075	7,322	987	1,025	688
Togo	1,939	315	2,001	124	54	100	1	2	-
Tunisia	26,738	7,627	25,946	102	55	87	26	36	23
Ukraine	83,449	23,264	83,877	11,364	1,885	11,710	46	86	6
Uruguay	16,731	2,706	16,544	7,046	1,643	7,068	169	298	47
Uzbekistan	12,679	3,673	11,221	7,323	1,724	6,525	-	-	-
Venezuela, RB	135,878	23,551	128,279	62,552	14,546	60,441	-	-	-
Zambia	6,404	1,448	5,675	8,482	1,149	8,102	-	-	-

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Country	Mean	St. Dev.	Median	Mean	St. Dev.	Median
Australia	147,223	54,067	130,489	9,806,404	1,016,291	9,624,371
Austria	62,208	5,336	63,072	3,931,461	233,776	3,854,452
Belgium	68,542	9,717	67,877	4,384,374	272,081	4,361,766
Canada	188,505	51,893	182,805	16,493,976	1,478,924	16,240,679
Chile	19,984	8,184	18,352	6,250,625	839,106	6,104,930
Czech Republic	29,216	6,917	29,197	5,147,341	78,991	5,160,445
Denmark	42,612	9,250	45,587	2,888,576	45,734	2,896,373
Finland	33,380	6,987	35,364	2,604,446	76,557	2,615,122
France	360,451	57,143	373,895	27,554,879	1,355,184	27,303,844
Germany	489,475	30,179	478,100	40,486,370	1,087,738	40,355,557
Greece	41,309	13,147	41,250	4,768,407	346,905	4,840,264
Hungary	19,261	4,640	20,189	4,259,146	136,181	4,240,969
Iceland	2,680	1,227	2,396	164,980	15,101	165,913

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Ireland	34,925	13,919	37,089	1,766,744	317,312	1,756,229
Italy	332,407	38,285	334,505	23,854,992	862,299	23,736,125
Japan	1,063,694	80,940	1,074,438	66,704,516	988,736	66,634,318
Korea, Rep.	212,861	40,255	223,062	22,527,615	1,755,969	22,664,926
Luxembourg	6,187	1,924	6,300	190,892	23,388	188,849
Mexico	153,266	40,036	156,235	40,741,897	5,707,492	40,810,790
Netherlands	111,458	18,872	116,425	8,030,020	705,169	8,157,730
New Zealand	19,301	5,676	18,025	1,987,131	226,068	1,931,619
Norway	48,054	13,309	46,448	2,352,055	152,819	2,374,610
Poland	49,884	19,385	52,015	17,530,839	290,445	17,393,291
Portugal	40,119	6,769	43,459	5,189,090	335,424	5,253,013
Slovenia	7,168	2,580	7,674	963,713	64,768	965,827
Spain	253,092	67,557	257,484	18,893,799	2,683,851	18,185,883
Sweden	56,983	12,386	57,116	4,647,126	165,974	4,607,053
Switzerland	77,659	7,945	77,447	4,078,243	210,054	3,997,815

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Turkey	76,080	24,142	67,680	21,780,246	1,615,130	21,750,853
United Kingdom	319,979	69,215	336,985	29,896,500	1,152,898	29,529,666
United States	2,320,569	530,576	2,488,477	144,841,370	9,936,895	147,134,193
Argentina	35,111	12,992	32,183	15,752,623	1,809,953	15,373,642
Armenia	1,184	958	745	1,486,126	84,019	1,471,444
Azerbaijan	2,503	2,189	1,480	3,625,874	488,556	3,556,038
Bangladesh	10,691	5,153	9,914	59,708,081	8,112,919	58,986,696
Belarus	7,530	4,448	5,739	4,788,449	256,181	4,753,813
Bolivia	1,297	368	1,241	3,624,960	626,993	3,604,562
Brazil	141,124	31,985	135,688	83,868,710	11,661,496	83,788,912
Bulgaria	5,036	2,810	4,120	3,617,847	223,061	3,511,993
Cameroon	2,184	752	1,863	6,093,786	1,164,390	6,005,388
China	656,381	465,074	500,789	715,986,861	47,180,651	724,325,746
Costa Rica	3,277	1,102	3,157	1,651,166	342,378	1,605,371

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Dominican Republic	5,132	1,943	5,474	3,629,873	510,138	3,568,036
Ecuador	6,930	2,044	6,065	5,533,140	1,062,777	5,480,252
Egypt, Arab Rep.	14,456	5,609	13,859	20,290,712	3,094,170	19,687,527
El Salvador	2,248	500	2,369	2,235,390	193,708	2,224,359
Ethiopia	2,366	1,389	2,059	29,666,747	6,143,396	28,753,049
Gabon	1,797	423	1,587	445,426	69,002	438,059
Guatemala	4,256	1,139	4,644	4,130,501	789,865	3,954,632
Honduras	2,084	644	2,013	2,272,652	419,892	2,358,620
India	184,691	107,141	140,338	409,212,288	48,104,860	405,190,192
Indonesia	59,843	16,608	53,142	95,715,884	12,721,792	97,648,031
Jordan	2,850	965	2,626	1,205,914	268,263	1,218,806
Kenya	2,968	1,287	2,554	12,028,859	1,949,042	11,913,757
Kyrgyz Republic	417	168	351	2,102,919	240,590	2,067,014

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Macedonia, FYR	1,026	155	977	863,056	52,009	852,481
Malaysia	30,798	7,453	29,728	9,616,038	1,611,963	9,808,007
Morocco	13,421	5,387	12,071	9,858,486	1,159,071	10,043,844
Mozambique	994	442	969	8,665,912	1,569,099	8,770,875
Nicaragua	1,320	392	1,399	1,818,248	339,528	1,805,496
Pakistan	18,240	3,234	17,139	43,910,925	9,201,946	42,944,914
Panama	2,617	1,367	2,234	1,318,243	235,661	1,314,543
Peru	14,774	6,840	12,996	11,858,903	2,239,917	12,112,966
Philippines	18,508	3,861	18,375	31,495,047	4,611,580	31,131,874
Romania	19,284	9,260	15,017	10,731,957	814,859	10,536,224
Russian Federation	154,436	91,395	122,650	73,325,407	2,922,913	73,946,212
Senegal	1,646	590	1,552	4,176,978	783,461	4,091,979
Singapore	26,419	8,102	26,411	2,074,986	369,172	2,068,866
South Africa	33,932	13,150	28,784	15,866,696	2,466,433	16,750,867
Sri Lanka	4,493	1,855	3,873	7,722,791	646,947	7,909,059

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Tajikistan	927	881	555	2,481,789	408,062	2,349,255
Tanzania	2,779	1,426	2,058	16,922,611	3,004,637	16,682,945
Thailand	49,393	11,865	50,965	34,782,172	2,710,188	34,413,726
Togo	291	102	272	2,176,861	449,471	2,135,436
Tunisia	6,291	1,507	6,343	3,157,132	401,446	3,200,864
Ukraine	20,573	13,130	14,355	24,024,248	940,294	23,539,373
Uruguay	3,163	791	3,270	1,565,999	89,330	1,578,912
Uzbekistan	2,546	982	2,183	9,340,240	1,520,562	9,213,324
Venezuela, RB	25,822	12,162	23,740	10,488,318	2,032,410	10,611,258
Zambia	1,034	819	802	4,395,990	662,714	4,390,754

A-2. Descriptive Statistics By Year – OECD

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Year	Mean	St. Dev.	Median	Mean	St. Dev.	Median	Mean	St. Dev.	Median
1990	804,176	1,600,598	263,849	42,600	83,877	14,898	4,543	17,151	695
1991	814,352	1,611,388	260,826	42,727	82,395	16,590	3,554	11,117	769
1992	831,525	1,659,798	257,804	42,904	80,295	18,493	3,940	12,523	875
1993	843,182	1,695,148	252,479	45,412	84,989	19,439	4,120	12,925	917
1994	869,641	1,754,368	262,610	44,034	82,743	18,260	4,289	13,183	985
1995	892,394	1,798,922	272,953	46,954	89,711	19,545	4,369	12,604	1,296
1996	919,117	1,860,869	277,353	48,217	96,109	17,761	4,465	12,908	1,459
1997	951,646	1,934,233	284,865	48,393	93,526	20,151	4,693	12,591	1,714
1998	976,771	2,002,851	296,844	47,381	86,944	17,105	4,946	12,509	1,170
1999	1,009,164	2,085,907	310,676	47,671	87,111	17,398	5,289	13,186	1,364
2000	1,049,031	2,166,127	324,508	48,952	86,753	19,457	5,813	13,875	1,545
2001	1,062,480	2,186,203	328,604	45,874	75,791	21,541	5,951	13,037	1,777

2002	1,079,026	2,219,901	336,765	48,189	87,203	19,818	6,788	14,776	1,951
2003	1,101,195	2,277,149	344,631	48,142	86,636	19,049	7,414	15,198	2,099
2004	1,136,523	2,357,851	359,225	50,134	86,588	24,017	8,469	16,456	2,573
2005	1,166,914	2,429,947	370,580	51,514	90,830	23,457	9,721	18,044	3,935
2006	1,201,556	2,492,184	386,504	53,245	92,595	22,452	10,798	20,051	4,720
2007	1,232,596	2,537,903	398,583	53,643	90,743	24,312	12,361	22,588	6,126
2008	1,233,683	2,528,509	396,864	56,829	94,848	27,314	13,981	26,211	6,344
2009	1,188,844	2,449,116	376,911	58,520	98,705	25,260	15,870	29,688	6,799
2010	1,222,922	2,514,967	400,326	62,129	98,864	25,844	18,696	34,522	8,113

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Year	Mean	St. Dev.	Median	Mean	St. Dev.	Median
1990	169,929	335,056	50,951	15,900,778	25,121,070	4,923,222
1991	169,049	330,178	50,052	16,126,569	25,387,901	4,994,693
1992	170,275	336,358	50,614	16,276,280	25,796,389	5,045,288
1993	169,077	343,211	54,589	16,367,530	26,051,952	5,088,850
1994	175,234	356,218	53,146	16,567,643	26,448,152	5,144,757
1995	181,531	369,839	57,508	16,712,394	26,762,674	5,159,906
1996	191,452	394,067	59,558	16,910,370	27,143,279	5,160,445
1997	200,703	415,023	60,348	17,126,376	27,595,040	5,175,174
1998	208,604	438,433	62,331	17,289,461	27,930,492	5,196,678
1999	219,470	468,774	62,587	17,441,394	28,207,107	5,216,521
2000	230,507	494,386	66,367	17,575,123	28,489,262	5,253,013
2001	228,473	490,906	57,885	17,682,196	28,667,366	5,353,699
2002	225,935	480,002	59,044	17,832,595	28,784,750	5,426,638
2003	232,065	496,198	66,062	17,951,924	28,888,906	5,453,429

2004	242,247	521,483	66,452	18,151,393	29,094,314	5,454,126
2005	253,126	547,740	66,828	18,364,734	29,420,158	5,504,806
2006	263,544	559,440	72,440	18,595,482	29,781,019	5,546,703
2007	269,790	553,434	78,876	18,788,686	30,021,320	5,580,983
2008	262,892	527,039	81,990	19,015,738	30,319,703	5,586,043
2009	231,842	459,295	79,385	19,094,127	30,333,377	5,543,982
2010	235,194	464,486	78,502	19,231,569	30,335,820	5,553,291

A-3. Descriptive Statistics By Year – non-OECD

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
Year	**Mean**	**St. Dev.**	**Median**	**Mean**	**St. Dev.**	**Median**	**Mean**	**St. Dev.**	**Median**
1990	78,511	164,456	15,661	16,451	41,612	2,656	270	1,002	-
1991	79,661	164,136	16,000	17,007	42,840	2,671	275	995	-
1992	79,936	160,523	17,020	17,287	44,190	2,900	303	1,064	-
1993	82,349	166,210	17,688	18,321	46,538	3,485	302	1,065	-
1994	85,004	173,521	17,286	19,465	48,771	3,451	350	1,190	-
1995	88,948	184,530	15,714	19,988	51,413	2,753	425	1,253	-
1996	93,088	195,519	16,311	19,720	51,046	3,021	457	1,361	-
1997	97,519	208,073	17,737	20,553	53,485	3,092	516	1,524	-
1998	98,804	216,977	19,226	21,667	55,833	3,786	550	1,698	3
1999	102,942	230,126	19,880	21,733	55,891	3,334	658	1,970	3
2000	108,960	246,897	21,033	22,494	58,435	3,442	745	2,121	11
2001	113,714	262,817	22,027	23,428	59,996	3,199	808	2,171	16

	Real GDP in Constant 2005 Million USD			Renewable Electricity Consumption in GWh			Non-Conventional Renewable Electricity Consumption in GWh		
2002	118,906	281,773	23,138	23,659	61,943	3,419	863	2,286	18
2003	126,334	305,365	24,768	24,259	63,478	3,528	962	2,442	31
2004	136,338	333,228	26,352	26,945	72,430	4,220	1,036	2,592	33
2005	146,849	366,043	27,211	29,136	78,845	4,345	1,173	2,874	38
2006	159,719	407,128	28,675	30,984	84,567	4,606	1,400	3,413	38
2007	175,165	459,190	30,483	33,015	93,177	4,824	1,896	5,184	45
2008	186,552	498,482	31,483	35,092	105,036	4,344	2,356	6,630	62
2009	192,857	536,474	31,649	36,925	112,667	4,087	3,079	9,256	97
2010	208,350	590,180	32,992	40,639	129,321	5,788	3,892	12,413	139

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
Year	**Mean**	**St. Dev.**	**Median**	**Mean**	**St. Dev.**	**Median**
1990	22,124	64,048	3,523	31,417,025	100,492,276	5,267,274
1991	21,087	56,280	2,895	31,998,500	102,137,955	5,198,128
1992	19,101	42,222	2,708	32,592,739	103,766,979	5,149,406
1993	19,553	44,345	2,850	33,135,368	105,359,548	5,097,670
1994	20,284	47,697	3,065	33,686,789	106,886,194	5,041,576
1995	21,787	52,312	3,132	34,297,094	108,455,305	5,150,486
1996	22,696	56,172	3,229	34,868,165	110,030,699	5,314,733
1997	24,185	60,202	3,801	35,446,332	111,663,813	5,477,619
1998	23,932	65,179	4,094	36,032,784	113,289,621	5,646,077
1999	24,037	68,805	4,087	36,822,788	114,963,102	5,819,291
2000	25,833	75,332	4,446	37,422,430	116,662,567	6,005,388
2001	27,485	82,170	4,120	38,082,056	118,313,670	6,187,051
2002	28,773	91,602	4,433	38,729,913	120,040,103	6,372,967
2003	31,691	106,045	4,831	39,426,782	121,757,820	6,563,363

	Real Growth Fixed Capital Formation in Constant 2005 Million USD			Labor Force in Millions		
2004	35,946	119,540	5,194	40,133,649	123,364,900	6,768,447
2005	40,111	133,869	5,559	40,843,689	124,983,682	6,979,295
2006	45,248	150,970	6,438	41,256,349	125,665,108	7,196,140
2007	51,747	171,806	7,027	41,645,242	126,240,110	7,429,725
2008	56,433	187,764	7,399	42,007,313	126,618,208	7,658,877
2009	60,947	227,668	7,057	42,357,215	127,009,459	7,905,165
2010	67,465	254,201	7,720	42,646,556	127,053,801	8,157,901

APPENDIX B. The DBDC Value-elicitation Method

Contingent valuation (CV) data analysis is founded on the random utility model. Based on this model, Eq. (III-1) can be rewritten as

$$U = v(q^j, t^j; m) + \varepsilon_j, \quad j = 0, \quad 1. \tag{B.1}$$

in which $j = 1$ if the individual participates in WCO collection and $j = 0$ if he or she does not. As one cannot observe the individual's true utility level, it must be represented by the sum of the indirect utility function $v(q^j, t^j; m)$ and the error term ε_j. This study assume that $v(q^j, t^j; m)$ is monotonically decreasing in j. That is, participation in separate WCO collection reduces the individual's utility because it decreases his or her convenience and leisure time.

When offered financial compensation, B, to participate in WCO collection, the individual will accept the offer if

$$v(q^1, t^1; m + B) + \varepsilon_1 \geq v(q^0, t^0; m) + \varepsilon_0 \tag{B.2}$$

Then, the probability that the individual will agree to participate in WCO collection is given by

$$
\begin{aligned}
&\Pr[v(q^1, t^1; m + B) + \varepsilon_1 \geq v(q^0, t^0; m) + \varepsilon_0] \\
&= \Pr[B \geq C] = F_C[B; \theta]
\end{aligned}
\tag{B.3}
$$

Here, the acceptance of the offer demonstrates that the WTA compensation required by the individual, C, is not larger than B. $F_C[B;\theta]$ is the cumulative distribution function of C, and θ is its parameter vector.

In the DBDC model, the range of WTA values is defined based on the responses to the bid values (Krishna et al., 2013); for "yes"-"yes" responses the range is $(0, B_i^L]$; for "yes"-"no" it is $(B_i^L, B_i]$; for "no"-"yes" it is $(B_i, B_i^U]$; and for "no"-"no" it is $(B_i^U, +\infty)$.

This study also applied the mixture model (An and Ayala, 1996; Werner, 1999) to reflect the preferences of respondents with zero WTA. As a result, for each individual i, a binary-valued indicator designates the group to which the individual belongs:

$$I_i^0 = 1 \ \text{ if } \ WTA = 0 \ \ \text{(0 otherwise)}$$

$$I_i^{YY} = 1 \ \text{ if } \ 0 < WTA \le B_i^L \ \ \text{(0 otherwise)}$$

$$I_i^{YN} = 1 \ \text{ if } \ B_i^L < WTA \le B_i \ \ \text{(0 otherwise)}$$

$$I_i^{NY} = 1 \ \text{ if } \ B_i < WTA \le B_i^U \ \ \text{(0 otherwise)}$$

$$I_i^{NN} = 1 \ \text{ if } \ B_i^U < WTA \ \ \text{(0 otherwise).} \tag{B.4}$$

Given the classifications in Eq. (B.4), the cumulative distribution of WTA can be represented as

$$G_C(B;\rho,\theta) = \begin{cases} 0, & if \quad C < 0 \\ \rho, & if \quad C = 0 \\ \rho + (1-\rho)F_C(B;\boldsymbol{\theta}), & if \quad C > 0 \end{cases} \tag{B.5}$$

where $F_C(\cdot)$ is an absolutely continuous cumulative distribution function such that $F_C(0;\boldsymbol{\theta}) = 0$. As shown in Eq. (B.5), $G_C(\cdot)$ has a point mass at $C = 0$, represented by the parameter ρ. To restrict the probability that WTA lies between 0 and 1, ρ is fitted using a logistic distribution: $\rho = \exp(\sigma)/(1+\exp(\sigma))$ (Werner, 1999). Then, the log-likelihood function (Cameron, 1988) of the above model is

$$
\begin{aligned}
\ln L = \sum_{i=1}^{N} \{ & I_i^0 \ln \rho + I_i^{YY} \ln(1-\rho) F_C(B_i^L; \boldsymbol{\theta}) \\
& + I_i^{YN} \ln(1-\rho)[F_C(B_i; \boldsymbol{\theta}) - F_C(B_i^L; \boldsymbol{\theta})] \\
& + I_i^{NY} \ln(1-\rho)[F_C(B_i^U; \boldsymbol{\theta}) - F_C(B_i; \boldsymbol{\theta})] \\
& + I_i^{NN} \ln(1-\rho)[1 - F_C(B_i^U; \boldsymbol{\theta})]
\end{aligned} \tag{B.6}
$$

Assuming the Weibull distribution, $F_C(\cdot)$ is given by

$$
F_C(B_i, \boldsymbol{\theta}) = 1 - \exp\left[-\left(\frac{B_i}{\theta_1} \right)^{\theta_2} \right], \tag{B.7}
$$

where $\boldsymbol{\theta}$ is a vector of parameters θ_1 and θ_2. In case of the covariate model for assessing the effects of the respondents' attitudes, knowledge, and socio-economic characteristics, θ_1 is replaced with γZ_i, where Z_i is the covariate vector for the i-th individual. Then, the mean WTA, C^+, is given by

$$
C^+ = (1-\rho)\theta_1 \Gamma(1 + 1/\theta_2) \tag{B.8}
$$

REFERENCES

Afroz R, Hanaki K, Hasegawa-Kurisu K. Willingness to pay for waste management improvement in Dhaka city, Bangladesh. Journal of Environmental Management 2009; 90:492–503.

Ajzen I. The theory of planned behavior. Organizational Behavior and Human Decision Processes 1991; 50:179–211.

Al-mulali U et al.. Examining the bi-directional long run relationship between renewable energy consumption and GDP growth, Renewable and Sustainable Energy Reviews 2013; 22:209–222.

An Y, Ayala RA. A mixture model of willingness to apy distribution. Working paper. Durham: Duke University; 1996.

Apergis N, Payne JE. Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. Energy Policy 2010; 38:656–660

Apergis N, Payne JE. Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model, Energy Economics 2012; 34:733–738

Arrow K, Solow R, Portney PR, Leamer EE, Radner R, Schuman H. Report of the NOAA panel on contingent valuation. Washington DC: Resources for the Future; 1993.

Basili M, Di Matteo M, Ferrini S. Analysing demand for environmental quality: A willingness to pay/accept study in the province of Siena (Italy). Waste Management 2006; 26:209–219.

Bateman IJ. Household willingness to pay and farmers' willingness to accept compensation for establishing a recreational woodland. Journal of Environmental Planning and Management 1996; 39:21–44.

Bateman IJ, Carson RT, Day B, Hanemann M, Hanley N, Hett T, Jones-Lee M, Loomes G, Mourato S, Özdemiroglu E, Pearce DW. Economic valuation with stated preference techniques: A manual. Cheltenham: Edward Elgar; 2002.

BOK. Bank of Korea; 2013. Available at http://ecos.bok.or.kr/

Bozdağ CE, Kahraman C, Ruan D. Fuzzy group decision making for selection among computer integrated manufacturing systems. Computers in Industry. 2003;51:13-29.

Cameron TA. A new paradigm for valuing non-market goods using referendum data: Maximum likelihood estimation by censored logistic regression. Journal of Environmental Economics and Management 1988; 15:355–379.

Chang D-Y. Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research 1996;95:649-55.

Cheng C-H. Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function. European Journal of Operational Research. 1996;96:343-50.

Cho S. A study on the alteration of energy sources for facility agriculture (in Korean), KEEI occasional research 2011; 11-03

Cho S, Kim J, Heo E (in revision). Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. Renewable and Sustainable Energy Reviews.

Cho S, Kim J, Park H, Heo E (in revision). Provision of an incentive for waste cooking oil collection in South Korea: A contingent valuation approach. Resources, Conservation & Recycling.

Choi I. Unit root tests for panel data. Journal of International Money and Finance 2001; 20:249–272.

CleanEdge. Clean Energy Trends 2014; 2014..

Coers R, Sanders M. The energy–GDP nexus; addressing an old question with new methods, Energy Economics 2013; 36:708–715.

Cultice AK, Bosch DJ, Pease JW, Boyle KJ. Horticultural producers' willingness to adopt water recirculation technology in Mid-Atlantic region, Washington DC: 2013 AAEA & CAES Joint Annual Meeting; 2013. Available at http://ageconsearch.umn.edu/handle/150409

Dedeoğlu D, Kaya H. Energy use, exports, imports and GDP: New evidence from the OECD countries. Energy Policy 2013; 57:469–476

Ek K. Public and private attitudes towards “green” electricity: the case of Swedish wind power. Energy Policy 2005; 33:1677–1689.

Engle RF, Granger CWJ. Co-integration and error correction: representation, estimation, and testing. Econometrica 1987; 55: 51–276.

Fallahi F. Causal relationship between energy consumption (EC) and GDP: A Markov-switching (MS) causality. Energy 2011; 36:4165–4170

Freeman AM. The measurement of environmental and resource values: Theory and Methods. 2nd Ed. Washington DC: Resources for the Fugure; 2003.

Gillespie R. Bennett J. Willingness to pay for recycling food waste in the Brisbane region. Environmental economics researach hub research reports. Melbourne: The Australian National University; 2011.

Glasure YU, Lee A-R. Cointegration, error correction and the relationship between GDP and energy: the case of South Korea and Singapore. Resource and Energy Economics 1997; 20:17–25.

Greene W. Econometric analysis. 5th ed. New York: Prentice Hall; 2002.

Groothuis PA, Van Houtven G, Whitehead JC. Using contingent valuation to measure the compensation required to gain community acceptance of a lulu: The case of a hazardous waste disposal facility. Public Finance Review 1998; 26:231–249.

Halstead J, Luloff A, Stevens T. Protest bidders in contingent valuation. Northeastern Journal of Agricultural and Resource Economics 1992; 21:160–169.

Hanemann WM, Loomis J, Kanninen B. Statistical efficiency of double-bounded dichotomous choice contingent valuation. American Journal of Agricultural Economics 1991; 73:1255–1263.

Hanemann WM. Willingness to pay and willingness to accept: How much can they differ? American Economic Review 1991; 81: 635–347.

Heo E, Kim J, Boo K-J. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. Renewable and Sustainable Energy Reviews 2010;14:2214-20.

Heo E, Kim J, Cho S. Selecting hydrogen production methods using fuzzy analytic hierarchy process with opportunities, costs, and risks. International Journal of Hydrogen Energy 2012; 37(23):17655-17662.

Horowitz JK, McConnell KE. A review of WTA/WTP studies. Journal of Environmental Economics and Management 2000; 44:426–447.

IEA. Energy prices and taxes, first quarter 2013. International Energy Agency(IEA); 2013.

IEA. Renewables Information (2014 Edition). International Energy Agency(IEA); 2014.

IEA. World Energy Outlook 2013. International Energy Agency(IEA); 2013.

Im KS, Pesaran MH, Shin Y. Testing for unit roots in heterogeneous panels. Journal of Econometrics 2003; 115:53–74.

Im KS, Pesaran MH, Shin Y. Testing for unit roots in heterogeneous panels. Working Paper, University of Cambridge; 1997.

Jones N, Evangelinos K, Halvadakis CP, Iosifides T, Sophoulis CM. Social factors influencing perceptions and willingness to pay for a market-based policy aiming on solid waste management. Resources, Conservation and Recycling 2010; 54:533–540.

Kahneman D, Knetsch JL, Thaler RH. Experimental tests of the endowment effect and the Coase theorem. The Journal of Political Economy 1990; 98:1325–1348.

Kao C. Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics 1999; 90:1–44.

KBEA. Korea Bio-Energy Association. Available at http://www.kbea.or.kr/

KEEI. Yearbook of energy statistic (in Korean). Korea Energy Economics Institute (KEEI); 2012.

KEEI. Policy measures on building a domestic supply and demand system for biodiesel material (in Korean). Korea Energy Economics Institute (KEEI); 2011.

KEEI, MOTIE. 2008. The 1st national energy master plan (in Korean). Korea Energy Economics Institute (KEEI) / Korean Ministry of Trade, Industry and Economy (MOTIE); 2008.

Keramitsoglou KM, Tsagarakis KP. Public participation in designing a recycling scheme towards maximum public acceptance. Resources, Conservation and Recycling 2013; 70:55–67.

Kim J-W, Kim M-H, Yoo H-R. Utilization plan of waste cooking oil. Gyeonggi-Do (in Korean): Korean Studies Information; 2007.

Kim J, Park J, Kim H, Heo E. Assessment of Korean customers' willingness to pay with RPS. Renewable and Sustainable Energy Reviews 2012; 16:695–703.

Kim J, Park J, Kim J, Heo E. Renewable electricity as a differentiated good? the case of the Republic of Korea. Energy Policy 2013; 54:327–334.

KOSIS. Korean Statistical Information Service; 2011. Avaliable at http://www.kosis.kr/

KPRC. Korea Price Research Center; 2011. Available at https://www.kprc.or.kr

Kraft J, Kraft A. On the relationship between energy and GNP. Journal of Energy and Development 1978; 3:401–3.

Krishna VV, Drucker AG, Pascual U, Raghu PT, King EDIO. Estimating compensation payments for on-farm conservation of agricultural biodiversity in developing countries. Ecological Economics 2013; 87:110–123.

KZWMN. Investiation into disposal and recycling of waste cooking oil. Korea Zero Waste Movement Network (KZWMN); 2009.

Lee AHI, Chen HH, Kang H-Y. Multi-criteria decision making on strategic selection of wind farms. Renewable Energy 2009;34:120-6.

Lee C-C. Energy consumption and GDP in developing countries: a cointegrated panel analysis. Energy Economics 2005; 27:415–427.

Lee SK, Mogi G, Kim JW, Gim BJ. A fuzzy analytic hierarchy process approach for assessing national competitiveness in the hydrogen technology sector. International Journal of Hydrogen Energy 2008;33:6840-8.

Lee SK, Mogi G, Hui KS. A fuzzy analytic hierarchy process (AHP)/data envelopment analysis (DEA) hybrid model for efficiently allocating energy R&D resources: In the case of energy technologies against high oil prices. Renewable and Sustainable Energy Reviews 2013; 21: 347-55.

Lee S, Paik HS. Korean household waste management and recycling behavior. Building and Environment 2011; 46:1159–1166.

Levin A, Lin C-F, Chu C-H J. Unit root tests in panel data: asymptotic and finite sample properties. Journal of Econometrics

2002; 108:1–24.

Maddala G.S, Wu S. 1999. A comparative study of unit root tests with panel data and a new simple test. Oxford Bulletin of Economics and Statistics 61, 631–652.

MAFRA, Press releases at 12. 07, 2011. Sejong-si: Korean Ministry of Agriculture, Food and Rural Affairs (MAFRA); 2011.

Masih A M.M., Masih R. Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modeling techniques. Energy Economics 1996; 18:165–183.

Masih A M.M., Masih R. On the temporal causal relationship between energy consumption, real income and prices: some new evidence from Asian-energy dependent NICs based on a multivariate cointegration/vector error-correction approach. Journal of Policy Modeling 1997; 19:417–440.

Masih A M.M., Masih R. A multivariate cointegrated modeling approach in testing temporal causality between energy consumption, real income and prices with an application to two Asian LDCs. Applied Economics 1998; 30:1287–1298.

Matsumoto S. Waste separation at home: Are Japanese municipal curbside recycling policies efficient? Resources, Conservation and Recycling 2011; 55:325–334.

Matsumoto S. The opportunity cost of pro-environmental activities: Spending time to promote the environment. Journal of Family and Economic Issues 2014; 35:119–130.

Mehrara M. Energy consumption and economic growth: the case of oil exporting countries. Energy Policy 2007; 35:2939–2945.

ME. Report on operation and management of public sewage treatment plant in 2009 (in Korean). Korean Ministry of Environment (ME); 2010.

ME. Guidlines for separate collection of recyclable resources (in Korean). Korean Ministry of Environment (ME); 2011.

Mitchell R, Carson R. Using surveys to value public good: The contingent valuation method. Resources for the Future; 1989.

MOTIE. The 2nd mid- and long-term strategy for biodiesel promotion (in Korean). Korean Ministry of Trade, Industry and Energy (MOTIE); 2010.

Narayan PK, Smyth R. Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. Energy Economics 2008; 30:2331–2341.

Nixon H, Saphores JDM. Financing electronic waste recycling Californian households' willingness to pay advanced recycling fees. Journal of Environmental Management 2007; 84:547–559.

OzturkvvI, Acaravci A. The causal relationship between energy consumption and GDP in Albania, Bulgaria, Hungary and Romania: Evidence from ARDL bound testing approach. Applied Energy 2010; 87:1938–1943

OzturkvvI, Acaravci A. Electricity consumption and real GDP causality nexus: Evidence from ARDL bounds testing approach for 11 MENA countries. Applied Energy 2011; 88:2885–2892

Pedroni P. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economics and Statistics 1999; 61(S1):653-670.

Pedroni P. Fully modified OLS for heterogeneous cointegrated panels. Advanced in Econometrics 2000; 15:93–130.

Pedroni P. Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the ppp hypothesis: new results. Econometric Theory 2004; 20:597–627.

Saaty TL. The analytic hierarchy process : planning, priority setting, resource allocation. New York ; London: McGraw-Hill International Book Co.; 1980.

Saaty TL, Ozdemir M. Negative priorities in the analytic hierarchy process. Mathematical and Computer Modelling 2003;37:1063-75.

Saaty TL. Fundamentals of the analytic network process — multiple networks with benefits, costs, opportunities and risks. Journal of Systems Science and Systems Engineering 2004;13:348-79.

Sadorsky P. Renewable energy consumption and income in emerging economies, Energy Policy 2009; 37:4021–4028

Sánchez-Lozano JM, Teruel-Solano J, Soto-Elvira PL, García-Cascales MS. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. Renewable and Sustainable Energy Reviews 2013; 24: 544-56.

Sheu J-B. A hybrid fuzzy-based approach for identifying global logistics strategies. Transportation Research Part E: Logistics and Transportation Review. 2004;40:39-61.

Sims CA. Money, income and causality. American Economic Review 1972; 62:540–552.

Stern DI. A multivariate cointegration analysis of the role of energy in the US economy. Energy Economics 2000; 22:267–283.

Stern DI, Enflo K. Causality between energy and output in the long-run. Energy Economics 2013; 39:135–146.

Tiller KH, Jakus PM, Park WM. Household willingness to pay for dropoff recycling. Journal of Agricultural and Resource Economics 1997; 22:310–320.

Tugcu CT, Ozturk I, Aslan A. Renewable and non-renewable energy consumption and economic growth relationship revisited: Evidence from G7 countries. Energy Economics 2012; 34:1942–1950.

Uyan M. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. Renewable and Sustainable Energy Reviews 2013; 28: 11-7.

Wang Y-M, Elhag TMS. On the normalization of interval and fuzzy weights. Fuzzy Sets and Systems 2006;157:2456-71.

Wang Y-M, Elhag TMS, Hua Z. A modified fuzzy logarithmic least squares method for fuzzy analytic hierarchy process. Fuzzy Sets and Systems. 2006;157:3055-71.

Weck M, Klocke F, Schell H, Ruenauver E. Evaluating alternative production cycles using the extended fuzzy AHP method. European Journal of Operational Research. 1997;100:351-66.

Werner M. Allowing for zeros in dichotomous-choice contingent-valuation models. Journal of Business & Economic Statistics 1999; 17:479–486.

Westerlund J. Testing for Error Correction in Panel Data. Oxford Bulletin of Economics and Statistics 2007; 69(6):709-748

Wijnmalen DJD. Analysis of benefits, opportunities, costs, and risks (BOCR) with the AHP–ANP: A critical validation. Mathematical and Computer Modelling 2007;46:892-905.

World Bank. World Development Indicators; 2013. Available at: http://www.worldbank.org/data .

Yi SK, Sin HY, Heo E. Selecting sustainable renewable energy source for energy assistance to North Korea. Renewable and Sustainable Energy Reviews 2011; 15:554-63.

Yu ESH, Hwang BK. The relationship between energy and GNP, further results. Energy Economics 1984; 6:186–190.

Zhao J, Kling CL. A new explanation for the WTP/WTA disparity. Economics Letters 2001; 73:293–300

Zhu K-J, Jing Y, Chang D-Y. A discussion on Extent Analysis Method and applications of fuzzy AHP. European Journal of Operational Research 1999;116:450-6.

Zou GL. The long-term relationships among China's energy consumption sources and adjustments to its renewable energy policy. Energy Policy 2012; 47:456–467

Three Essays on the Renewable Energy Policy Focusing on the Long-term Direction and Effective Implementation

재생에너지 정책의 장기 방향 설정과 효과적인 이행에 관한 세 편의 에세이

조 상 민
에너지시스템공학부 (지구환경경제학 전공)
서울대학교 대학원

요약 (국문 초록)

본 논문은 재생에너지 정책의 장기 방향 설정 및 관련 정책 수단의 효과적인 이행에 관한 세 가지 이슈에 대한 연구로 구성되어있다. 첫 번째 에세이는 재생에너지 소비와 경제성장간 인과관계를 접근하는 새로운 시각을 제기하였다. 그리고 이러한 새로운 시각과 기존의 시각에 기반하여 OECD 국가 및 non-OECD 국가를 대상으로 실증분석을 수행하고, 장기 재생에너지 정책 방향을 제시하였다. 두 번째 에세이는

재생에너지 정책의 효율적인 이행을 위한 국가 차원에서의 최적 재생에너지원 선택에 관해 실증 연구를 수행하였다. 특히, 추후 재생에너지의 확대가 예상되는 분야를 대상으로 의사결정 영향요인을 도출하고 이에 기반하여 최적 대안을 도출하였다. 세 번째 에세이는 최근 재생에너지 정책 목표 달성에 있어 가장 큰 장애요인 중 하나로 부각되고 있는 대중의 인식과 관련하여 재생에너지의 생산과 이용 과정에서 발생하는 효용감소에 대한 대중의 지불의사액을 추정하였다. 또한, 대중의 참여에 영향을 미치는 요인을 분석하여, 참여 확대를 위한 방안을 제시하였다.

1) 재생에너지 소비와 경제성장간 인과관계에 대한 새로운 접근

본 논문에서는 우선 특정한 시각에서 재생에너지 소비와 경제성장간 인과관계에 접근한 기존 연구들의 문제점을 지적하고, 둘간의 인과관계에 대한 새로운 시각을 제기하였다. 기존의 연구들은 재생에너지소비와 경제성장간 인과관계를 주로 생산을 위한 에너지 투입으로서의 재생에너지의 역할에 초점을 맞추고 있다. 하지만 재생에너지의 경우 전통적 에너지원과 달리 기술 혹은 산업적 측면이 강하며, 실제로 많은 국가들, 특히 개발국들의 경우 재생에너지를 성장동력으로 육성하기 위한 노력을 기울이고 있다. 따라서 본 논문에서는

재생에너지소비와 경제성장간의 인과관계를 산업으로서의 재생에너지의 역할에 초점을 맞춰 접근하는 새로운 시각을 제기함으로써 관련 연구의 새로운 지평을 제시하고자 하였다.

패널벡터오차수정모형(Panel VECM)을 활용하여 OECD국가를 대상으로 실증 분석을 수행한 결과 재생에너지 산업은 아직까지 경제성장을 선도할 만큼 성장하지 못하였고, 경제성장에 힘입어 성장하여 왔음이 밝혀졌다. 하지만 분석대상을 재생에너지산업이 가장 발달한 상위 5개 국가 (미국, 일본, 독일, 덴마크, 그리고 스페인)로 한정할 경우 이전 분석과 상반된 결과가 도출되었다. 이들 국가들의 경우 재생에너지소비와 경제성장 간 성장가설(Growth hypothesis)이 유효한 것으로 나타나 재생에너지 산업이 경제성장에 있어 중요한 역할을 담당하는 것으로 밝혀졌다.

결국, 재생에너지 산업의 경우 초기 단계에는 경제성장과 이에 기반한 재정 확대에 의존하여 성장하지만, 일정 수준 이상으로 성숙하게 되면 경제성장을 선도할 수 있는 잠재력을 보유하고 있음을 의미한다.

2) 국가차원의 최적 에너지원 선택

시야를 우리나라로 좁혀보면, 최근 경제성장이 둔화되고 정부의 재원이 부족하여 재생에너지 분야에 대한 정부의 전

폭적인 지원이 국민적 합의를 이끌어 내는 것이 쉽지 않을 것으로 예상된다. 따라서, 효과적으로 재생에너지 산업을 성장시키기 위해서는 장기적 비전 하에서 국가적 차원에서의 최적 재생에너지에 대한 선택과 집중의 전략이 요구된다.

계층분석법(Analytic Hierarchy Process: AHP)은 국가적 차원의 대안 선택에 관한 의사결정을 지원함에 있어 널리 활용되고 있는 방법론이며, 최근에는 퍼지이론(fuzzy theory)과 BOCR 접근법의 도입으로 방법론적으로 보다 발전하였다. 따라서 본 연구에서는 BOCR 접근법을 적용한 퍼지-계층분석법(Fuzzy-AHP with BOCR approach)을 도입하고, 추후 재생에너지 확대 가능성이 높은 시설원예 및 축산농가를 대상으로 실증분석을 수행하였다.

평가요인에 대한 가중치 분석 결과, 시장규모나 무역수지 개선효과와 같은 거시경제·산업적 요인들의 중요도가 에너지-환경적 요인들보다 높게 평가되었다. 이는 첫 번째 에세이에서 제시한 바 있는, 재생에너지를 산업의 측면에서 접근해야 한다는 시각과 일맥상통한다. 따라서 재생에너지 정책이 친환경적이고 저렴한 에너지원의 공급보다는 기술경쟁력 강화, 신산업 육성, 경제성장 등에 높은 가중치를 두고 결정될 필요가 있으며, 이러한 기준 하에서 최적의 대안이 선택되어야 할 것이다.

한편, 최적에너지 대안에 대한 실증분석 결과 현재까지 보급이 가장 미미한 대안 중 하나인 지열히트펌프가 최적 대안으로 선택된 반면, 현재 가장 널리 이용되고 있는 유류보일러는 우선순위가 가장 낮은 대안으로 평가되었다. 이러한 결과는 앞서 논의한 바와 같이 현재의 에너지믹스와 에너지정책에 근본적인 변화가 필요함을 보여준다.

3) 재생에너지 생산에 대한 대중의 인식

아직 초기단계인 재생에너지 산업을 육성하기 위해서는 테스트베드 구축, 실증사업 추진, 그리고 최소한의 내수시장 확보 등이 요구되고, 이는 RD&D와 더불어 적절한 보급정책이 동반될 필요가 있음을 의미한다. 문제는 최근 들어 재생에너지의 생산과 이용 과정에서 일반 대중들의 효용감소가 종종 관찰되고 있으며, 이러한 효용감소가 재생에너지 정책 추진에 있어 주요한 장애요인으로 부각되고 있다는 것이다. 따라서 정부의 재생에너지 정책 수립에 있어 이러한 효용감소와 대중의 인식이 중요한 요소로 고려될 필요가 있다. 본 논문에서는 재생에너지 생산에 대한 대중의 인식을 기회비용으로 인한 효용감소의 측면에서 접근하고 이를 기반으로 대중의 참여를 확대하기 위한 방안을 제시하였다.

본 연구에서는 조건부 가치평가법(Contingent Valuation

Method: CVM)을 활용하여 바이오디젤 생산을 위한 폐식용유 수거를 대상으로 일반 가정의 수용의사액(Willingness to Accept: WTA)을 추정하고, 특정 인센티브 수준에서의 참여율을 분석하였다. 그 결과, 폐식용유 수거에 대한 일반 가정의 평균 수용의사액은 폐식용유 시장가격과 유사하거나 다소 낮은 것으로 났다. 즉, 적절한 수거시스템이 구축된다면 폐식용유의 시장가격 수준의 보상 하에서도 일반가정의 폐식용유 수거참여가 확대될 수 있음을 의미한다. 추정결과 그 비중은 현재 가정부문의 폐식용유 수거율(6.9%)의 약 6배인 40% 이상이 될 것으로 나타났다.

실증분석 결과에서 알 수 있듯이 재생에너지 보급으로 인한 대중의 효용감소는 적절한 보상체계가 구축되면 충분히 극복될 수 있다. 따라서 중장기 재생에너지 정책목표의 효과적인 달성을 위해서는 이러한 효용감소의 원인을 정확하게 파악하고 보상체계를 즉각적으로 구축하여 대응할 필요가 있을 것이다.

이상의 에세이들을 종합하여 결론을 내리면 다음과 같다. 재생에너지의 경우 신산업 육성을 통한 경제성장의 관점에서 정책적으로 접근할 필요가 있다. 그리고, 재생에너지 산업의 잠재력을 고려할 때, 초기단계에는 장기적인 비전 하에 선택

과 집중을 통한 효율적인 산업 육성 전략이 요구된다. 그리고 재생에너지 산업 육성을 위해 요구되는 테스트베드 구축 및 내수시장 확보 등의 과정에서 발생할 수 있는 대중의 효용감소는 적절한 보상체계를 통해 극복될 수 있으므로, 이를 통해 재생에너지 보급 및 산업육성 정책의 효과를 높일 필요가 있다.

본 논문이 가지는 의의는 크게 세 가지 측면으로 구분할 수 있을 것이다. 우선, 본 논문은 재생에너지 소비와 경제성장간의 인과관계에 대한 새로운 시각을 제기함으로써, 기존의 연구들의 한계를 지적하고 관련 연구의 새로운 방향성을 제시하였다. 둘째, 본 연구는 퍼지-계층분석법을 활용하여 시설원예 및 축산부문의 최적 에너지원 선택에 관한 연구를 수행한 최초의 연구로, 해당분야 에너지정책의 새로운 방향성을 제시하였다. 셋째, 본 논문은 지불의사액(Willingness to Pay: WTP)을 활용한 기존의 대부분의 연구들과 달리, 수용의사액을 통해 폐기물 수거에 대한 대중의 인식을 측정하였다는 점에서 의의를 가진다. 특히, 폐식용유수거를 대상으로 한 대중의 인식에 관한 연구는 본 연구가 최초인 것으로 파악된다.

본 논문은 다음과 같은 후속연구를 통해 학술적, 정책적 기여도를 높일 수 있을 것으로 판단된다. 우선, 재생에너지가 에너지원으로써, 그리고 산업으로써 경제성장에 기여하는 경로에 대한 추가적인 연구가 필요하다. 이를 통해 본 논문에서 제기한 새로운 시각의 적정성과, 재생에너지 각각의 속성이 경제성장에 미치는 기여의 정도를 파악함으로써 보다 발전된 시사점을 제시할 수 있을 것이다. 다음으로, 일반 소비자의 입장에서의 최적 에너지원에 대한 분석이 추가될 필요가 있다. 이를 국가적 차원의 대안과 비교함으로써, 연구결과의 정책적 기여를 높일 수 있을 것으로 기대된다. 마지막으로, 폐식용유 수거 참여에 대한 저항적 지불의사(protest bids)가 높게 나타나는 원인을 심층적으로 분석하여, 대중의 참여율을 높일 수 있는 방안을 도출할 필요가 있을 것이다.

주요어: 패널벡터오차수정모형, 재생에너지소비와 경제성장 간 장기인과관계, 퍼지-계층분석법, 조건부 가치평가법, 수용의사액

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