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The Relationship between Energy Consumption (Renewable and Non-renewable) and Economic Growth in Northeast Asia

This thesis is submitted in partial fulfillment of the requirements for the course Senior Seminar (EC 375), during the Spring Semester of 2020

While writing this thesis, I have not witnessed any wrongdoing, nor have I personally violated any conditions of the Skidmore College Honor Code.

Name: Seung Min Park

Signature:

A handwritten signature in cursive script, appearing to read 'S M P', written in black ink.

Abstract

The worldwide environmental crisis such as climate change and global warming motivates countries to use renewable energy. Additionally, the crisis provokes the importance of energy and the appearance of ecological economic theory. The Northeast Asia region has effectively embraced renewable energy production to enhance energy independence and energy security. Countries in the region require to maintain their production level to successfully complete the transition of energy use from the non-renewables to renewables. However, renewable energy's impact on economic output in the Northeast Asia region is dubious. Moreover, only a small number of research on the availability of ecological economics in Northeast Asia has been done. The purpose of this paper is to estimate the impact of renewable and non-renewable energy consumption to economic output by employing panel data techniques. Moreover, the paper also examines the impact of total energy consumption on GDP to verify the importance of energy and the application of ecological economics. The result demonstrates that non-renewable energy influences GDP significantly more than the renewables. In this research, we have discovered that the impact of total energy consumption is similar to that of capital and labor. The policy implications of these results propose a balance of non-renewable energy consumption and renewable energy in Northeast Asia for the smooth transition of energy usage from the non-renewables to renewables due to the considerable influence of non-renewable energy consumption on GDP.

I. Introduction

The oil crisis in the 1970s threatened the energy supply of the countries in Northeast Asia. The countries realized the need of energy source diversification to prepare for the future oil crisis. Moreover, the increase of environmental crisis influenced those countries to shift their energy system from conventional resources to the renewables. These phenomena also provoked the energy's importance in GDP. Hence, ecological economics was developed. Although green energy improves energy security and environmental circumstances, it is also required to verify the power of renewable energy in terms of economic output. Does renewable energy have a significant impact on economic output? Moreover, do countries in Northeast Asia need to decouple energy like European countries have done already?

Stern (2010), an ecological economist, argued the import role of energy in economic growth. On the basis of ecological economic theory, Rath et al. (2019) investigate how renewable energy consumption affects the economic output. The empirical findings from the research reveal that the relationship between energy consumption and economic productivity can be different based on types of panels (aggregate panels, developed and developing countries panel, and all the regional panels). Hence not only Salim (2014) but also Kahia (2017) analyze the empirical findings on each country in their panel dataset. In contrast, Amri (2017) and Dogan (2016) only concentrated on one country's relationship between energy consumption and economic output.

The purpose of this paper is to investigate the relationship between economic growth and energy consumption in the Northeast Asian region over the period of 1990-2014. Moreover, the other purpose of the study is to verify which economic theory is more relevant to the countries in Northeast Asia. We utilize Ordinary Least Squares (OLS) to compare the impact of the renewables and non-renewables and the role of energy compared to capital and labor. Following Salim et al. (2014), we use a production function from the Cobb-Douglas production function by incorporating renewable and non-renewable energy consumption separately in addition to capital and labor. We also test for multicollinearity and examine the regression models to determine whether the fixed effects are suitable for the research by following Stjepanović (2018).

The research makes several important contributions towards the literature of the relationship between disaggregated energy consumption and economic output in Energy Economics. Unlike other studies, this research selected both renewable and non-renewable energy consumption to verify the relative impact of each of these sources on economic output. Second, no other study has concentrated the linkage between both renewable and non-renewable energy consumption and economic output in the Northeast Asia region. Hence, this research contributes to existing scholarship by creating a basis of understanding for study in the Northeast Asia region, specifically considering the research questions.

The findings of this research identify the impact of energy consumption compared to other inputs (capital and labor) of economic output. The amount of total energy's impact on economic output is greater than that of labor. Hence, as ecological economists argue, the role of energy is significant in economic growth. Moreover, following Salim (2014), the impact of non-renewable energy on GDP is significantly positive. However, renewable energy's negative effect on GDP indicates that policy makers should concentrate more on non-renewable energy to maintain the economic output.

The rest of this paper is structured as follows. Section 2 reviews the previous literature dealing with four hypotheses, two economic theories on the role of energy in GDP, the history of energy transition in Northeast Asia, and the linkage between energy consumption and economic output. The following section is about analytical framework. This section discusses the methodology and the data used for the econometric model. Moreover, the section includes the expectations of the research question. Next, section 4 discusses the empirical results. Finally, section 5 concludes with a discussion on future research possibilities and proposes policy implications based on the findings.

II. Literature Review

The world we live in currently faces continuous evolution and an unprecedented amount of growth in the history of global energy. Economists' perspectives on energy and its use have been changing constantly as the importance of renewable energy has been increasing day by day. Neoclassical economists claim that energy influences economic production to an insignificant degree because they claim that energy influences economic production to an insignificant degree compared to capital and labor because other inputs can substitute the role of energy readily. However, energy is crucial in economic output since no production can be carried out without the use of energy, and the possible replacement of other factors of production in place of it is limited (Stern, 1997). The other development in the history of global energy is that of renewable energy and its importance on economic growth and the surrounding environment.

More and more countries all over the world are shifting their primary source of energy model to renewable energy. This is supported by the numerous studies that exist worldwide on the linkage between energy consumptions- both renewable and non-renewable- and economic growth. The Northeast Asian region successfully adopt renewable energy for the environment and energy security. However, Northeast Asian countries try to improve the renewables for the diversification of energy sources. The countries expect to decrease the risk of energy supply shortage from the future oil crisis. Despite the recent increase in the development of renewable energy sources, research investigating the linkage between these two in the Northeast Asian countries lacks significantly. Only a few studies analyze the linkage between two sources of

energy consumptions and economic output by corroborating an importance of the role of energy in GDP.

In this research, I will examine the influence of energy- in comparison to other inputs such as capital and labor-on GDP, and the relationship between renewable and non-renewable energy's impact on economic output. Moreover, I will verify whether the ecological economists' perspectives on energy are acceptable in the Northeast Asia region. I hope this research will be a valuable indicator of energy policy decision for Northeast Asian countries, and I believe that this research can be a crucial document because it will suggest these nations with several possible ways to balance the amount of investments made between the renewable, and non-renewable energy while continuing their efforts to perform well economically for now and for the future.

I will provide a brief literature review on the relationship between energy consumption and economic growth by introducing the four subsections. The first subsection will present two differing economic perspectives on the issue. The second subsection will explain the four hypotheses which most studies have utilized to explore the direction of causality between the two subjects. Moreover, there will be an explanation on policy implications in relation to hypotheses. This section will lead to a deeper understanding of the linkage between energy consumption and economic growth. The third subsection will not only describe the transformation of the trend in global energy usage, but also introduce a brief history of clean energy usage and the reasons for this shift pertaining to each targeted country including China, Japan, Mongolia, and South Korea. Lastly, in the final subsection, I will present a number of previous studies that have dealt with the topic of relationship between energy usage and economic growth.

1. The Two Different Perspectives on Energy Consumption and Economic Growth

It has been suggested historically that economic growth and energy consumption are related phenomena; The demand for energy increases as economic growth increases. However, since an increase in energy use raises concerns about both energy and environment securities, it is the policymakers deciding on the implementation of policies who are facing great difficulties. These issues may include whether countries can decouple economic growth from energy consumption, or whether they are capable of reducing non-renewable energy consumption while maintaining the same level of economic growth as in the past. I hereby present the two different theoretical

views discussing policy implications on the relationship between economic growth and energy consumption. These two theories are Neoclassical theory and Ecological theory.

Orthodox economists argue that decoupling of energy consumption from economic growth is feasible because, based on neoclassical theory, energy plays a minor role in economic growth, and labor as well as capital, can be substituted for energy (Sorrell and Ockwell 2010). Moreover, according to the European Environmental Agency (EEA), all members of the European Union have decoupled these two since 2005 as energy intensity, a measure of energy inefficiency, continued to decrease: energy intensity decreased by an average of 2.0% per year while GDP increased by 16% (1.2% per year). Besides the decline in energy intensity of GDP, there are other factors that support the decoupling of economic growth and energy consumption such as types of economy and the growth in usage of renewables. According to *The decoupling of GDP and energy growth: A CEO guide* by Sharma, Semmets, and Tryggestad, the energy intensity of service economies is lower than that of industrial economies. Moreover, countries tend to concentrate on its service economy as they develop. Hence, developed countries' energy role on GDP is getting smaller (Sharma, Semmets, & Tryggestad 2019). According to the World Resources Institutes, it is shown that energy intensity in the developing countries such as China (231.3 tonnes of oil equivalent (toe)) and Mongolia (334.5) are much higher than energy intensity in developed countries such as South Korea (238.2 toe) and Japan (154 toe). Lastly, the growth of renewables will make the primary energy demand curve level off in 2050. The primary reason for this phenomenon can be attributed to the fact that renewable energy does not require an input when producing electricity (Sharma, Semmets, & Tryggestad 2019). Consequently, neoclassical economists argue that the role energy plays in GDP is minimal and that it should be decoupled.

The ecological economic perspective considers energy as a major player in GDP, thus reflecting the Thermodynamics laws. Ecological economists insist that the global economy is still very much dependent on energy and that decoupling of GDP and energy growth is virtual. Theoretically, thermodynamics implies that energy is crucial to all economic production because energy is necessary for every production process (Stern 2010). In addition to this, even though energy intensity decreases as a result of technological improvements, the amount of energy output cannot exceed its input, as the first law of thermodynamics claims. Therefore, the

limitation on the maximum energy efficiency of energy flows will only constrain the energy intensity rate and also trigger the substitution of labor or capital in place of energy. Decoupling economic growth and energy consumption by shifting to a service-based economy is controversial since countries with such an economy have largely been achieved by outsourcing manufacturing to countries that are heavily industrialized. (Sorrell and Ockwell 2010). Moreover, the rebound effect will further contribute to the increase of consumption of energy despite the fact that the increase of energy efficiency leads to the cost of energy, eventually resulting in a decrease of energy intensity (Berkhout et al 2000).

2. The Four Hypotheses for the Causality Relationship

There are numerous research that examine the causality relationship between energy consumption and economic growth. There are four hypotheses that explain the causal linkage between these two subjects: growth hypothesis, conservation hypothesis, feedback hypothesis, and finally, neutrality hypothesis. According to the growth hypothesis, there is a one-way causality relationship between energy consumption and economic growth. Such hypothesis supports ecological economists whose view parallel the claim that the countries with energy conservation policies will encounter negative economic growth (Kahia et al., 2015). On the contrary, the conservation hypothesis states that there exists a directional causality between economic growth and energy consumption. This hypothesis supports the neoclassical perspective by claiming that the countries with energy conservation policies will continue to maintain its policies without experiencing negative impacts on economic growth (Destek & Aslan, 2017). According to the feedback hypothesis, there is a bidirectional causality relationship between energy consumption and economic growth. Since such implies the importance of energy consumption on economic growth, the feedback hypothesis assists the ecological-economic perspective. Moreover, this particular hypothesis states that countries with energy policies concentrating on the improvement of energy consumption and efficiency will have no negative influence on economic growth (Alper & Oguz, 2016). Finally, the neutrality hypothesis states that there is no causal relationship between economic growth and energy consumption. This hypothesis emphasizes the comparatively minor role that energy plays in economic growth, while further supporting the neoclassical economic perspective. In this case, conservation energy policies do not influence economic growth of the nation at all (Salim et al., 2014).

3. Energy Transition

Conventional energy, such as coal-based energy infrastructure, has contributed to the development of our society. Nevertheless, as geopolitical and social conditions undergo a transformation, countries accordingly raise concerns for maintaining the traditional energy model. To solve environmental problems, numerous countries have boosted the development of renewable energy. In the early stages of such shifting to clean energy, its high cost and the countries' yet-to-be developed technology have slowed down the countries' movement. Despite such difficulty, and relatively high cost as well as low energy efficiency associated with it, the transition to renewable energy has continued to increase. The government funding and related policies of renewables, as well as the numerous international cooperation including The International Renewable Energy Agency's (IRENA) forum and UN's Sustainable Development Goal 7 have helped to improve the weaknesses of clean energy. Consequently, the consumption of renewable energy worldwide has risen dramatically. According to global renewable energy consumption by *Our World in Data*, for instance, the amount of consumption rate was 15,372.7 terawatt-hours (TWh) in 2000, while the amount rated 17,127.25 TWh in 2017. As illustrated above, the difference in global renewable energy consumption in 2000 and 2017 demonstrates an increased value of clean energy.

Northeast Asian countries in this research also follow an international energy trend. Each countries' distinct characteristics are particularly valuable to this study. First, China's growing demand for energy increases significantly in the amount of coal and oil product consumption. According to International Energy Agency's (IEA) China Total final consumption (TFC) by source, the country had 274,465 thousand tonnes of oil equivalent (ktoe) in 2000 and 713,000 ktoe in 2016 (IEA 2019). Although the non-renewable energy consumption has been increasing in order to meet the high energy demand, China demonstrates the fastest transition towards renewable energy, partly due to the governmental interference, among all the other countries in Northeast Asia. The government's decision to reduce its high level of dependence on coal and imported oil and to develop renewable energy is based on the rising concern of environmental protection and the two oil crises in 1973 and 1979 (Fang, 2011). For instance, China's renewable power subsidy in 2019 was 8.1 billion yuan (Xu 2019). Moreover, through a number of China's

policies regarding energy consumption, China is looking forward to achieving power grid parity in its 14th renewable energy development five-year plan (2021-2025) period (Zhihua 2020).

Japan, unlike China, is highly dependent on imports from overseas because of its lack of natural resources. An oil price fluctuation and an earthquake in 2011 damaged Japan's economy considerably. In addition, Japan is facing a decrease in population that could possibly result in changes for future energy demand. Therefore, to achieve energy transition and overcome challenges to achieve stable energy supply, the Japanese cabinet approved its new energy policy towards 2050 named "5th Strategic Energy Plan" in 2018. With the aim of reducing dependence on nuclear power and overseas energy, the country put efforts into making renewable energy as a major power source of the country. For instance, Japan's target share of renewables in the 2030 energy mix is expected to be around 22 to 24% (Power Technology 2019)

Mongolia, unlike South Korea and Japan, is a big coal producer and has most of its coal exported. Although Mongolia relies heavily on non-renewable energy, the country has adopted a law to increase and regulate the use of renewables, especially on solar, wind, and hydropower. According to "State Policy on Energy" toward 2030, the Ministry of Energy announced that as one of the government's main priorities, the government will increase the production share of renewables and reduce negative environmental impacts resulting from traditional power generation and greenhouse gases. The Mongolian Ministry of Energy expects to achieve its goal of 30% share of renewables by 2030. One of the main reasons of the government's supporting the renewable energy is based on energy supply solution for rural Soum centers (village or settled area) in the future. In Mongolia, 43% of the total population lives in remote area and they often suffer from the insufficient energy supply (Tamir et al., 2015).

South Korea, like Japan, has few natural resources. With imported fossil fuel as the country's dominant energy resource, it is also highly dependent on overseas energy and concerned with having a stable energy supply. Especially after the oil crisis in the 1970s, the Korean government recognized the necessity of energy source diversification (Lee & Huh, 2017). To enhance energy security, South Korea diversified energy resources by developing renewable energy and nuclear energy. For instance, in South Korea, the Moon administration published a Renewable Energy

3020 Plan. As the name of the plan suggests, the administration aims to increase the share of renewable energy in the generation mix by 20% until 2030.

4. The Analysis of the Energy Consumption (Renewable and Non-renewable) and Economic Growth

Most of the studies only examine the relationship between renewable energy consumption and economic growth, often failing to provide the effect of energy consumption by sources on economic output. However, there are research examining the impact of both non-renewable and renewable energy consumption on economic growth. Fethi Amri (2017) and Eyup Dogan (2016) studied the linkage between disaggregated energy consumption and economic growth in each one's target country with different approaches. Eyup Dogan (2016) concentrates on Turkey's linkage between renewable and non-renewable energy consumption and economic growth using a multivariate model with the structural break in the time-series data. Turkey, from 1961 to 2012, expanded its non-renewable energy consumption while its renewable energy consumption decreased. Eyup Dogan considers the importance of diverse research studies in energy and economic growth to maintain sustainable growth rate, which will serve to advise the policymakers and formulate various strategies and policies on energy sources. Moreover, the author used structural break estimation techniques in order to examine the relationship between energy consumption and economic growth. Also, to identify which energy source influences economic growth, Dogan divides energy consumption by sources. The result of the study presents that non-renewable energy consumption has a considerable positive effect on economic growth. Furthermore, Dogan discovered that non-renewable energy consumption and economic growth affect each other in both short run and long run. Unlike the largely contributing effect of non-renewable energy consumption, the effect of renewable energy consumption on Turkey's economic growth is insignificant. According to Dogan, it is suggested that Turkey should implement balanced consumptions on both non-renewable and renewable energy because of its energy independence, climate change, and the National Renewable Energy Action Plan.

Unlike the previous study, Fethi Amri (2017) focuses on the relationship between energy consumption- both renewable and non-renewable- and GDP in Algeria between 1980 and 2012. For the study, the author utilized three cointegration tests (Autoregressive distributed lag

(ARDL)), Gregory-Hansen and Johansen) along with vector error correction model (VECM) Granger causality. The research suggests that there is a feedback link between non-renewable energy consumption and gross domestic product in both short-run and long run. Therefore, it can be inferred that one of the implications of the study is that policymakers should control the non-renewable energy for its efficiency. As non-renewable energy consumption continues to accelerate, its positive effect will also enhance the country's economic growth. Nevertheless, due to the unidirectional relationship between renewable energy and economic growth in the long run, Amri suggests that Algeria adopt a strategy for employing renewable energy.

Besides Fethi Amri's research, there are extensive studies on several countries including those involved with OECD, ASEAN-5, and MENA net oil-importing. Ruhul A. Salim et al. (2014) examine the impact of disaggregated energy consumption- both renewable and non-renewable- on economic growth and industrial output in OECD countries using the panel cointegration technique over the period of 1980 to 2011. According to the research, there is a bidirectional relationship between non-renewable energy consumption and GDP growth in both the short run and long run. Also, the author verifies that a high level of non-renewable energy consumption leads to a high level of economic growth and vice versa. Nevertheless, due to the unidirectional causality between GDP and renewable energy consumption/ reduction of pollutant emission, the research's policy implication insists that the government should follow the policies that promote renewable energy.

Because ASEAN-5 countries' total population is less than both China and India combined and their rich natural resources attract many foreign investors, Gülfen and Vedat analyze the linkage between energy consumption and economic growth for ASEAN-5 countries. The study covers the period between 1980 and 2015. In order to yield more detailed results, the study utilizes Hacker and Hatemi-J (2006) tests for symmetric causality analysis, and Hatemi-J (2012) test for asymmetric causality. To summarize the result, the neutrality hypothesis is valid for Indonesia and Thailand in positive shocks while the hypothesis is valid for the rest of the countries in negative shocks. Moreover, from the symmetric and asymmetric causality analyses, the study suggests that non-renewable energy consumption has more effect on economic growth. Such results of energy consumption for positive and negative shocks will separately support the countries' determination on energy policies.

Montassar Kahia et al. (2017) investigates the nexus of economic growth and renewable and non-renewable energy use in eleven MENA Net Oil Importing countries during the period 1980-2012. Authors targeted the eleven countries with rich renewable resources, rapid growth of population as well as economic activity, and ineffective energy use. For the research, the authors used a multivariate panel framework for the estimation of long-run relationship and the panel Granger causality test for examining causality direction among the countries. The result of the investigation demonstrates that there exists bidirectional causality between non-renewable energy use and economic growth in both the short run and long run. Nevertheless, in the case of renewable energy use and economic growth, these two illustrated directional causality, meaning that the results were identical. Therefore, in order to protect countries from experiencing price volatility of fossil fuels and to successfully promote energy independence, the authors imply that the government should promote clean energy policies.

Among the studies that are already published, there are no studies assessing the relationship between energy consumption and economic growth. Moreover, none of the studies so far deals with the topic of which economic perspectives are suitable for application in particular areas of Northeast Asia. In order to cover this missing piece of knowledge, our research examines the nexus among energy consumption and economic growth between 1990 and 2014. Moreover, considering GDP distribution (the percentage of service and industrial base) and renewable energy growth in Northeast Asian countries, our study provides an insight into which economic theories can most suitably be applied for the particular countries. The policy implications based on our investigation on Northeast Asian countries will be discussed on the basis of the four hypotheses, making the implications more suitable for each of them.

III. Analytical Framework

The purpose of this paper is to examine the economic growth and energy consumption nexus and identify which theoretical economic theory is more relevant to the countries in Northeast Asia. A panel dataset is utilized in order to determine the existence of relationship between energy consumption by sources and economic output and the measure of elasticity of total energy consumption for choosing the appropriate economic theory for the production. By using the panel data estimation technique, we are able to identify the results that cannot be found from

employing other time series or cross-sectional data. Ordinary least squares (OLS) is not enough to determine the causality. However, it can be tested through further research in the future. Moreover, through OLS, it is possible to recognize the correlation, and it can imply the existence of causality among variables.

This section consists of three subsections. The first subsection is about data and variables that are used for the research. The second subsection deals with the descriptions for the models and methods to analyze the data. The last subsection describes the expectation of the nature of relationships and the structure of the regression model.

1. Data and variables

In this study, we use an annual panel data for Northeast Asian countries. A panel data set is based on both cross-sectional and time-series dimensions. This is why an annual panel data is suitable for use in this study measuring the causality of energy consumption by sources and economic growth over time. China, Japan, Mongolia, and South Korea are four Northeast Asian countries that we will concentrate on. All the data covers the period between 1990 to 2014, collected from the World Bank.

The World Bank open database includes the Global Tracking Framework (GTF) and World Development Indicators (WDI). Through the GTF, the World Bank measures the process of how the world transforms towards Sustainable Energy for All. The World Bank provides accurate and most up-to-date global data by using WDI. As such, by using the data from WDI and GTF, our research is certain to provide accurate and most recent data representing the macroeconomic indicators toward the changes in energy consumption in Northeast Asian countries. Total energy consumption, renewable energy consumption, and non-renewable energy consumption are the data sourced from GTF to measure the elasticity of energy consumption. The data representing macroeconomic indicators such as total labor force, real GDP, and the gross fixed capital formation are retrieved from WDI.

It is essential to comprehend the variables in the models and the theoretical framework to answer which disaggregated energy consumption affects more on economic growth and which economic production theory is the most relevant to the countries in Northeast Asia. Variables for

the research are as follow: Three economic indicators such as the gross domestic product (GDP), the gross fixed capital formation (GCF), total labor force (LF) and three types of energy consumptions such as total final energy consumption (TEC), renewable energy consumption (REC), and non-renewable energy consumption (NREC). Bhattacharya et al. (2015) also utilized GDP, GCF, and LF as three economic indicators to analyze the relationship between energy consumption and economic output. Additionally, following Zhixin and Xin (2011), all variables are expressed in natural logarithms for the research to mitigate heteroscedasticity and for the purpose of interpreting the effect of change in the variables efficiently.

The GDP of each country is measured in 2010 U.S. dollars as a measure of economic output. When our study analyzes the impact of disaggregated energy consumption on economic output for each country, GDP is used as a dependent variable. According to both neoclassical and ecological economic theory, there are other macroeconomic indicators, such as GCF and LF. Both measurements are used as independent variables. LF represents labor input, and GCF represents a proxy of capital input that is measured in current US dollars.

TEC, REC, and NREC are all driven from the World bank's GTF database, and these are all macroeconomic indicators at country-level. TEC is an indicator that measures the amount of energy consumed in a nation, quantified in terajoules (TJ). According to the IEA, one terajoule is equal to a 277778-Kilowatt hour (kWh). For the research about the nexus of economic growth and energy consumption, Brantley and Sidney (2014) and Swati et al. (2019) used TEC as an independent variable as well as an energy indicator. Following Inglesi-Lotz (2015) and Ito (2017), in this research, REC is an indicator that measures a nation's share of renewable energy in the total final energy consumption (TEC). The indicator is used to explain the influence of renewable energy among the total energy consumption. NREC is also the non-renewable energy share of TEC, analyzing the changes in the use of non-renewable energy.

2. Model and Methodology

To investigate the link between GDP and the two types of energy (renewable and non-renewable energy) and to compare the total energy consumption's level of the contribution on economic growth, the study establishes the production function by basing itself on the Cobb-Douglas production function that is proven both theoretically and empirically. This is based on

the neoclassical economy which is the mainstream model representing the relationship of input and output. The general production function form follows as Q =total production, L =labor input, and K =capital input. A represents the total factor productivity and α and β are the output elasticities of labor and capital, respectively.

$$y_{it} = AL_{it}^{\alpha}K_{it}^{\beta} \quad (1)$$

The model considers energy consumption as an additional factor that does not mainly influence the total production. Hence, there is no total energy consumption in the production function.

Our model uses GDP, total labor force, and the gross fixed capital formation to measure the total production, labor, and capital input. In fact, the model is an augmented version of the Cobb-Douglas production function. Supported by ecological economists, the model emphasizes that energy is crucial for the output just as labor and capital are crucial for an input. Consequently, the production function can be represented as

$$GDP_{it} = ALF_{it}^{\alpha}GCF_{it}^{\beta}TEC_{it}^{\gamma} \quad (2)$$

In this model, i stands for the country number (China=1, Japan=2, South Korea=3, Mongolia=4) and t represents the time period. TEC_{it} is the total energy consumption and γ is the elasticity of output with respect to the total energy consumption. Nevertheless, to analyze and figure out which energy source affects the economic output most strongly, the total energy consumption should be disaggregated. The total energy is categorized by its source: renewable energy and non-renewable energy. Therefore, instead of TEC , each REC and $NREC$ will be used as one of the energy consumptions by source. Moreover, the production function will be adjusted as follows:

$$GDP_{it} = ALF_{it}^{\alpha}GCF_{it}^{\beta}REC_{it}^{\delta_1} \quad (3)$$

$$GDP_{it} = ALF_{it}^{\alpha}GCF_{it}^{\beta}NREC_{it}^{\delta_2} \quad (4)$$

In the function, REC_{it} is the renewable energy consumption and $NREC_{it}$ is the non-renewable energy consumption. δ_1 and δ_2 represent the elasticity of output with respect to renewable and non-renewable energy.

The final form of the production function for a standard OLS model in natural logarithm form will be written as the following:

$$\ln GDP_{it} = b_{1i} \ln GCF_{it} + b_{2i} \ln LF_{it} + b_{3i} \ln TEC_{it} + \varepsilon_{it} \quad (5)$$

$$\ln GDP_{it} = b_{1i} \ln GCF_{it} + b_{2i} \ln LF_{it} + b_{3i} \ln REC_{it} + \varepsilon_{it} \quad (6)$$

$$\ln GDP_{it} = b_{1i} \ln GCF_{it} + b_{2i} \ln LF_{it} + b_{3i} \ln NREC_{it} + \varepsilon_{it} \quad (7)$$

The production function (5) in natural logarithm form is used to examine the impact of total energy consumption on economic growth compared with labor and capital. Moreover, the results from the empirical equations (6) and (7) are crucial for examining which energy source consumption is more beneficial for the production. b_{1i} , b_{2i} , and b_{3i} are elasticities of output with respect to gross fixed capital formation, labor, and energy consumption, respectively. ε_{it} is the term for an error. Our research uses the natural logarithm form in order to remove heteroscedasticity from the regression model, and to further determine the size of the change of variables' percentage using their coefficients. Since REC and NREC are already in ratio form, GDP, TEC, LF, GCF are in the natural logarithm form.

3. Expectation

In Northeast Asia, the average GDP has grown steadily with its average total energy consumption. This trend implies that the region established outstanding economic output and embraced renewable energy production successfully between 1990 and 2014 (See figures 1 & 4 in Appendix). Because the average value of GCF and LF does not often fluctuate during the period, it is expected that the energy consumption influences Northeast Asia countries' economic growth (See figures 2 & 3 in Appendix). Therefore, energy definitely is one of the inputs of the production which decides an economic output just like capital and labor in an ecological economy. The expectation would be in line with the findings of Stern (2010).

In the case of the relationship of disaggregated energy consumption and economic growth, like the feedback and growth hypothesis, the increase of GDP respect to the change in total energy consumption is expected to be identical with the result from Kahia et al. (2017). Moreover, the expectation of the separated energy consumption variables in (6) and (7) is significantly positive. The consumption of renewable slightly has decreased while the consumption of non-renewable energy has also increased. Meanwhile, the total energy

consumption increased (See figures 4, 5 & 6 in Appendix). Thus, the evidence supports the feedback or growth hypothesis on non-renewable energy consumption and economic growth. Moreover, it is expected that the evidence supports the conservation hypothesis on renewable energy consumption and economic growth. Nevertheless, the growth rate of renewable energy consumption is negatively steeper than that of non-renewable energy (See figures 5 & 6 in Appendix). Therefore, as stated by Destek and Aslan (2017), non-renewable energy consumption is expected to influence the GDP more than renewable energy consumption.

This research conducts two types of robustness checks to verify the quality of regression models. Hausman test is used to examine whether the fixed effects or random effects model is more appropriate for the panel model. Multicollinearity test is used to corroborate an unrelatedness among independent variables. In the Hausman test, the null hypothesis suggests that the random effects model is preferred, and the alternative hypothesis is that the fixed effects model should be used. A p-value that is less than 0.05 indicates that the fixed effects model is preferable to the other. A variance inflation factor (VIF) is applied to assess multicollinearity in the regression model. It verifies the correlation between independent variables and the strength of the correlation. A VIF value greater than 5 identifies the presence of imperfect multicollinearity.

From the Table 3 to Table 8 in the Appendix are results of the robustness checks. In this analysis, each model's Hausman test suggests that the fixed effects model is more efficient for each of the panel models. All the p-values from the tests are less than 2.5 %, rejecting the null hypothesis (See Table 6,7 & 8 in Appendix). In the case of a multicollinearity test, we are able to detect imperfect multicollinearity in all of the empirical models. VIF from the empirical function (5) is 125.107, which is greater than 5, and other VIF from both production functions (6) and (7) are 56.638. The results of the robustness checks can be found in the Appendix.

IV. Discussion of Results

This research applies the panel data estimation technique and estimated coefficients generated by the models to analyze the linkage between energy variables and economic output. Using panel data has significant benefits over utilizing only the cross-sectional or time-series data for the research because what we are aiming to do is analyzing the data over time. The

period of the data is between 1990 and 2014. In this research, we used Stata, a statistical software created by StataCorp, for the analysis. All variables are in the natural logarithm form to eliminate heteroscedasticity.

The production function (5) is used to analyze the relationship between economic output and total energy consumption across the Northeast Asian countries. By comparing the coefficients of each independent variable, our research analyzes the impact of each of these three factors- capital, labor, and energy consumption- on GDP. The result indicates the evidences that support either neoclassical or ecological theory, and it further illustrates which theory is more relevant to Northeast Asia society. The regression model (6) investigates the link between economic output and renewable energy consumption. Equation (7) analyzes the relationship between economic output and non-renewable energy consumption. Through the demonstration of coefficients of renewable and non-renewable energy consumption variables in the two equations (6) and (7), the study indicates which energy consumption is the most strongly associated with GDP than the other. Amri (2017) and M.Kahia et al. (2017) separate energy consumption variables by the source to investigate the impact of both renewable and non-renewable energy consumption on economic growth. This study also employs the disaggregated energy consumption measured in TJ.

1. Energy Consumption, Capital, and Labor Force

It is expected that the theory from ecological economy applies more significantly to Northeast Asia. Through the estimated coefficients of independent variables, the result from equation (5) illustrates the importance of the role of energy in economic growth. Total energy consumption has a remarkable impact on GDP, as can be seen from the results of the equation (5). A 1 percent change in the total energy consumption considerably increases GDP by 0.561 percent. Although there is a significant impact of capital that is larger to the amount of impact generated by total energy consumption, the impact of labor on economic output is less than the amount of impact generated by total energy consumption. When there is a 1 percent change in the GCF and LF, GDP rises to a very insignificant amount of 0.692 and 0.451 percent, respectively. The amount of change in GDP depends on GCF, LF, and TEC. This fact demonstrates how important an interdependency is between economy and environment.

Different research projects are required to identify the ecological economy application completely in Northeast Asia. Neoclassical economic theories identify the well-being of the economy based on particular indicators such as income or GDP. Therefore, most of the research activities are heavily concentrated on problems of economic growth and efficiency (Dzeraviaha 2016). As such, overemphasis on economic growth and efficiency has led to the environmental crisis that the modern society faces. Ecological economics is developed through diversified approaches in order to overcome the weakness of neoclassical framework. By analyzing the significant impact of energy on the economy, it is possible to enhance the neoclassical models to accommodate the greater ecological issues (Venkatachalam 2006). However, there are more issues to which the existing neoclassical model cannot be applied because of two other reasons; First, the neoclassical model overlooks the natural limits to growth and second, time plays a crucial role in the development of technology (Sollner 1997). Therefore, to apply the ecological economics perfectly onto the Northeast Asian region, further research should be conducted that is capable of managing these issues.

2. Economic Output with Renewable Energy Consumption and Non-renewable Energy Consumption

The expected relationship between both renewable and non-renewable energy consumption and economic output is significantly positive. The results from the production functions (6) and (7) suggest that the expectation is only plausible to the non-renewable energy consumption because only the amount of GDP increased by consuming non-renewable energy is significantly positive. A 1 percent increase in REC decreases GDP by 0.049 percent outstandingly. In addition, a 1 percent increase in NREC raises GDP by 0.049 percent. These estimates provide evidence to infer that consuming non-renewable energy is more beneficial for GDP. Nevertheless, additional research is needed to discover whether there exists a correlation between renewable and non-renewable energy consumption. Moreover, further research on balancing renewable and non-renewable energy consumption that can increase the GDP at the most will be essential for the Northeast Asia region's welfare.

Overall, the results from our research are in line with the findings of Salim, Hassan, and Shafiei (2014), who examined the relationship between renewable and non-renewable energy

consumption and industrial output and GDP growth in OECD countries. However, their study does not provide further details on how they could develop their production model. The study also has a greater number of countries and deals with longer duration of time. Yet, similar to our study, the production function is developed from the neoclassical model. Both South Korea and Japan are included in the target countries, and some of the time period is overlapped. Their findings also imply the greater impact of non-renewable energy consumptions on economic output, leading to an expectation that there exists a bidirectional causality between the non-renewables and GDP.

V. Conclusion and Policy Implication

This paper investigates the relationship between economic output and energy consumption by sources (both renewable and non-renewable) and further verifies the ecological economics application in Northeast Asian countries. Neoclassical and ecological perspectives on the production function support the theoretical basis of the study. The study analyzes the linkage between total energy consumption and economic output using the developed neoclassical function. Moreover, comparison of the estimated coefficients of variables suggests both renewable and non-renewable energy consumptions' influence the GDP. Although the estimated coefficient of total energy consumption is smaller than the coefficient of capital, it is greater than a coefficient of labor. Moreover, the positive impact of total energy consumption on GDP supports the ecological perspective that energy is an important input for economic output. Therefore, the correlation between these two variables-total energy consumption and GDP-implies the potential bidirectional causality.

Although non-renewable energy consumption has positive impact on GDP, renewable energy consumption contributes to the decrease of GDP. This provides a solid argument that increasing non-renewable energy consumption helps to increase an economic output. Nevertheless, for energy dependent countries like South Korea and Japan and for energy source diversification to enhance energy security, the Northeast Asia region needs to further invest in developing renewable energy to maintain energy independence. In summation, in regards to the policy implications, the overall results suggest that the policy makers in Northeast Asia should maintain a good balance of renewable and non-renewable energy consumption.

VI. Appendix

Table 1: Summary Statistics

Variable	Obs	Units	Mean	Std.Dev.	Min	Max
GDP	100	Constant 2010 US\$	2.41e+12	2.45e+12	3.09e+09	8.32e+12
TEC	100	Terajoules (TJ)	1.48e+07	1.92e+07	61259.42	7.65e+07
REC	100	% share of renewable energy in TEC	8.632	10.252	.442	34.084
NREC	100	% share of non- renewable energy in TEC	91.368	10.252	65.916	99.558
LF	100	Persons	2.06e+08	3.08e+08	737000	7.84e+08
GCF	100	Constant 2010 US\$	7.79e+11	8.58e+11	5.61e+08	3.76e+12

Table 2: Regression estimates for panel models

	(5) GDP	(6) GDP	(7) GDP
LF	0.692*** (0.168)	1.896*** (0.278)	1.896*** (0.278)
GCF	0.451*** (0.052)	0.307*** (0.073)	0.307*** (0.073)
TEC	0.561*** (0.091)		
REC		-0.049*** (0.008)	
NREC			0.049*** (0.008)
_cons	-5.151** (2.437)	-13.365*** (3.123)	-18.254*** (3.707)
Obs.	100	100	100
R-squared	0.943	0.942	0.942

Standard errors are in parenthesis

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3: Multicollinearity test (VIF value) for regression model (5)

	VIF	1/VIF
TEC	238.661	.004
LF	81.625	.012
GCF	55.035	.018
Mean VIF	125.107	.

Table 4: Multicollinearity test (VIF value) for regression model (6)

	VIF	1/VIF
LF	94.055	.011
GCF	54.119	.018
REC	21.74	.046
Mean VIF	56.638	.

Table 5: Multicollinearity test (VIF value) for regression model (7)

	VIF	1/VIF
LF	94.055	.011
GCF	54.119	.018
NREC	21.74	.046
Mean VIF	56.638	.

Table 6: Hausman Tests for Regression Model (5)

	Coefficients			
	(b) fix	(B) Ran	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
LF	.6918465	-.0659136	.7577601	.147675
GCF	.4514604	.9925015	-.5410412	.
TEC	.5606295	.043958	.5166715	.
<i>Chi</i> ²	223.21			
Prob> <i>Chi</i> ²	0			

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 7: Hausman Tests for Regression Model (5)

Coefficients				
	(b) fix	(B) Ran	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
LF	1.895787	-.1974262	2.093213	.2647086
GCF	.3068808	1.106065	-.7991844	.0500661
REC	-.048887	.0178985	-.0667855	.
Chi^2	253.42			
Prob> Chi^2	0			

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 8: Hausman Tests for Regression Model (7)

Coefficients				
	(b) fix	(B) Ran	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
LF	1.895787	-.1974262	2.093213	.2647086
GCF	.3068808	1.106065	-.7991844	.0500661
NREC	.048887	-.0178985	.0667855	.
Chi^2	253.421			
Prob> Chi^2	0			

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Figure 1: GDP Trends in Northeast Asia

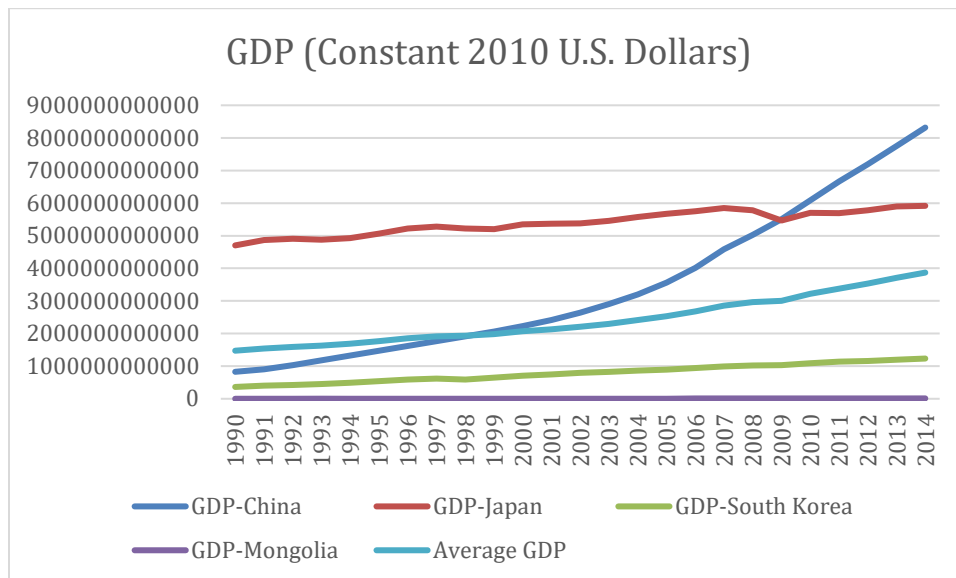


Figure 2: LF Trends in Northeast Asia

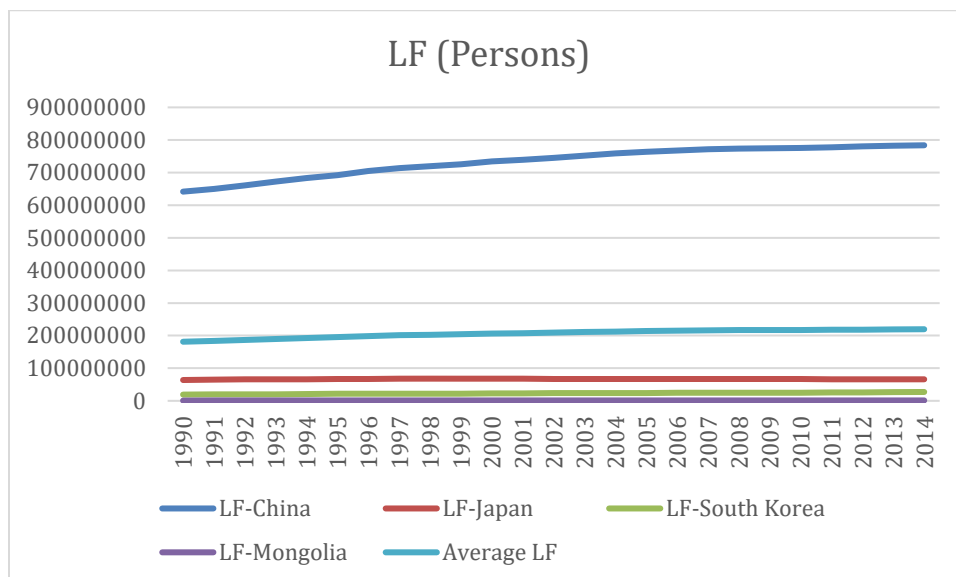


Figure 3: GCF Trends in Northeast Asia

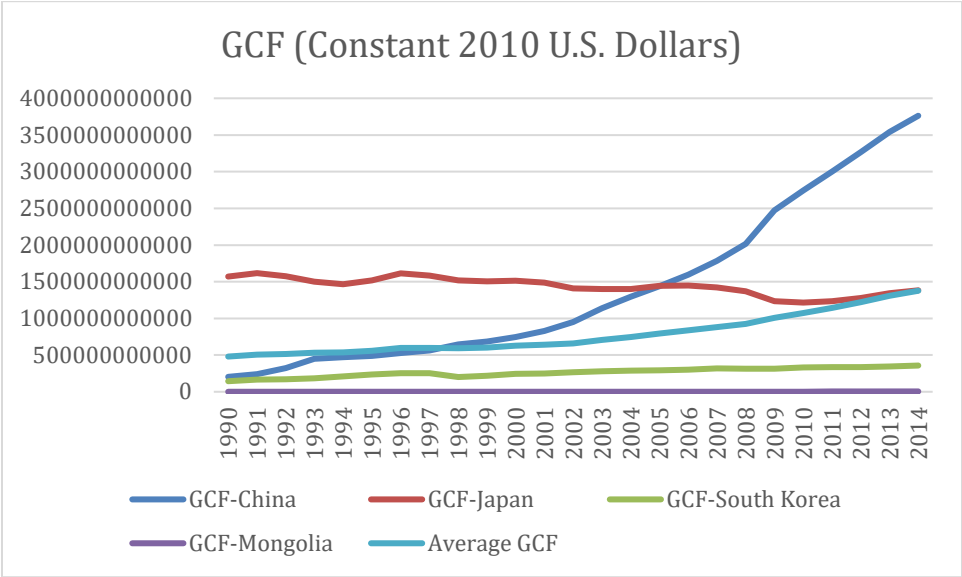


Figure 4: TEC Trends in Northeast Asia

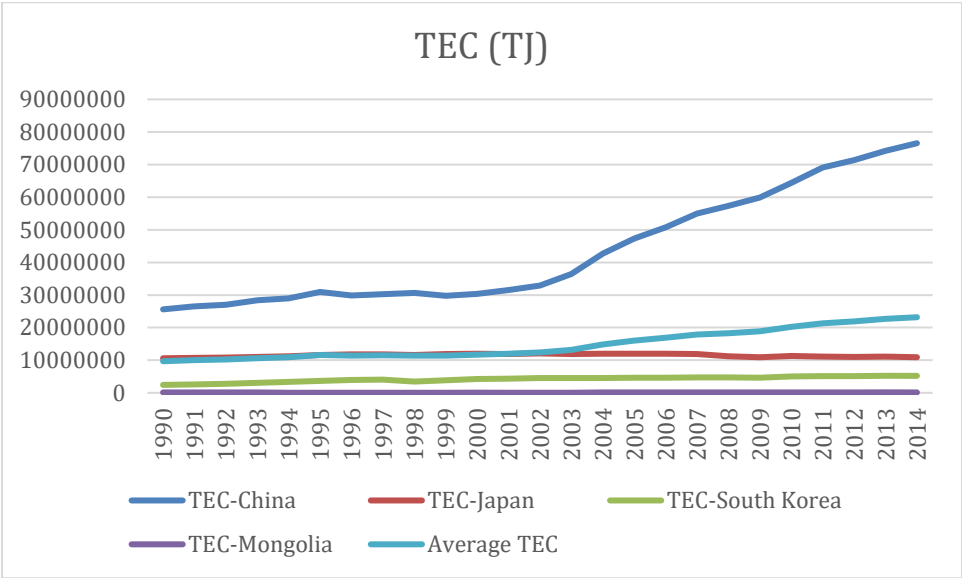


Figure 5: REC Trends in Northeast Asia

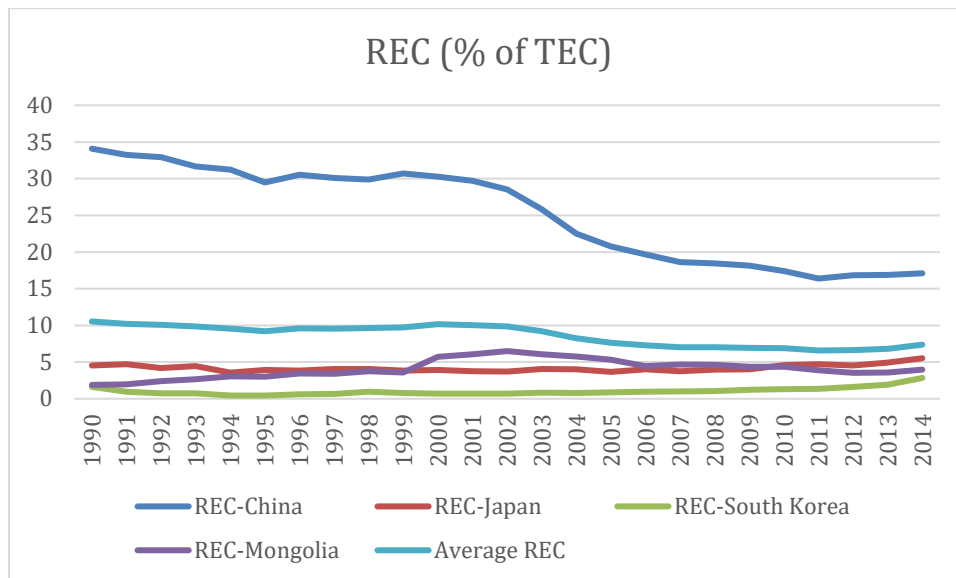
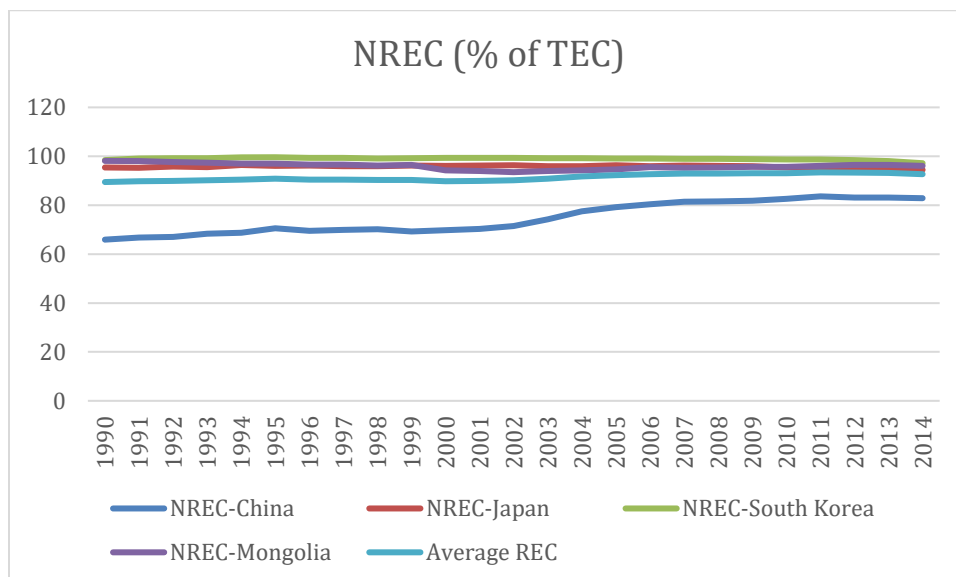


Figure 6: NREC Trends in Northeast Asia



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