ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF ARTS AND SOCIAL SCIENCES

THE IMPACT OF ENERGY INDEPENDENCE AND SECURITY ACT OF 2007 ON RENEWABLE ENERGY CONSUMPTION IN THE UNITED STATES

M.A. THESIS

Abdul Baghı NABIYEV

Department of Economics

Economics M.A. Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ SOSYAL BİLİMLER ENSTİTÜSÜ

2007 YILINDAKİ ENERJİ BAĞIMSIZLIĞI VE GÜVENLİĞİ YASASININ AMERİKA BİRLEŞİK DEVLETLERİNDE YENİLENEBİLİR ENERJİ TÜKETİMİ ÜZERİNDEKİ ETKİSİ

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To my family,

FOREWORD

Since my Bachelor period, I am interested in Economics and always want to give an academic contribution to the economics literature. This thesis is the final work of my Master study at the Istanbul Technical University of Social Sciences.

I am extremly grateful to my advisor Assist. Prof. Dr. Shourjo CHAKRAVORTY for his support during my M.A thesis study. I am also grateful for Prof. Bülent GULOGLU and Res.Asst.Murat GUVEN for their support and valuable suggestions. I would like to thank to my family; my mother Gultakin, my father Maharram and my sister Aytac for their sıpport during this process.

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ABBREVIATIONS

ADF	:	Augmented Dickey - Fuller
AIC	:	Akaike Information Criteria
BIC	:	Bayesian Information Criteria
BTU	:	British Thermal Unit
CAFE	:	Corporate Average Fuel Economy
DF- GLS	:	Dickey-Fuller with Generalized Least Squares
DOLS	:	Dynamic Ordinary Least Squares
EIA	:	Energy Information Administration
EISA 2007	:	Energy Independence and Security Act of 2007
EPA	:	Environmental Protection Agency
FMOLS	:	Fully Modified Ordinary Least Squares
FPE	:	Final Prediction Error
FRED	:	Federal Reserve Economic Data
GHG	:	Greenhouse Gas
GLS	:	Generalized Least Squares
HQ	:	Hannan-Quinn Information Criteria
HAC	:	Heteroskedasticity and Autocorrelation Consistent
LR	:	Sequential Modified LR Test Statistic
MGPO	:	Mandatory Green Power Option
OLS	:	Ordinary Least Squares
PP	:	Phillips- Perron
PURPA	:	Public Utilities Regulatory Policy Act
RET	:	Retail choice
RFS	:	Renewable Fuels Standard
RPS	:	Renewable Portfolio Standards
VAR	:	Vector Autoregessive Model

SYMBOLS

LCO_2	**:** Natural Logarithm of CO_2 emission
LOP	**:** Natural Logarithm of Oil Price
LREC	**:** Natural Logarithm of Renewable Energy Consumption
LRGDP	**:** Natural Logarithm of GDP
D2008	**:** Dummy variable of EISA (2007)
ε_t	**:** Error term
t	**:** Time
α	**:** An Intercept Constant
β_t	**:** The Coefficient on a Time Trend
β'	**:** Co-integration Vector
k	**:** Dimensional Vector
θ	**:** Co-integrating Coefficient
d	**:** Integrated of Order
y_t	**:** The variable of Interest (LRGDP, LREC, LCO_2, LREC)
δ	**:** The Coefficient Presenting Process Root
B	**:** Co-integration Matrix
A_j	**:** Matrix of VAR
λ_{max}	**:** Max- Eigen Statistic
r	**:** Positive Eigenvalue
Tr	**:** Trace Test Value

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THE IMPACT OF ENERGY INDEPENDENCE AND SECURITY ACT OF 2007 ON RENEWABLE ENERGY CONSUMPTION IN THE UNITED STATES

SUMMARY

In recent years, global warming, climate change, increase in CO_2 levels in the atmosphere, fluctuations in oil prices and countries' reliance on imported energy resources have increased the number of studies in the renewable energy field. Recognition of renewable energy sources as the main energy source coincided with the 1970s, and the number of studies carried out in this area is steadily increasing.

In the literature, there are several studies in relation to the association between the renewable energy consumption and economic growth. Differently from other studies, the contribution of existing empirical study to the economic literature addresses the effectiveness of implemented sustainable energy policies. This study examines the impact of the Energy Independence and Security Act of 2007 (EISA 2007) on renewable energy consumption in the US. The results obtained from this study are important for the countries that support renewable energy investments such as Turkey, India, China and aims to provide guidance for future studies.

In this study, independent variables GDP, oil price and CO_2 emissions which affect renewable energy consumption were introduced. Then our control variable which is EISA(2007) was explained. A set of time series consisting of total renewable energy consumption and CO_2 emissions were chosen from the Energy Information Agency (EIA), and real GDP and oil prices were obtained from the Federal Reserve Economy Database (FRED). This dataset covers the first quarter of 1990 and the last quarter of 2017. First, to test the stability of these time series, ADF, PP, DF-GLS stationarity tests were employed and according to the obtained results it was understood that the series were stationary at their first differences. After the Johansen Cointegration test was performed, the model was estimated with Dynamic OLS and Fully Modified OLS estimators. According to the results obtained from both estimators, EISA (2007) positively and statistically significantly affects renewable energy consumption from 2008 to 2017 in the US.

2007 YILINDAKİ ENERJİ BAĞIMSIZLIĞI VE GÜVENLİĞİ YASASININ AMERİKA BİRLEŞİK DEVLETLERİNDE YENİLENEBİLİR ENERJİ TÜKETİMİ ÜZERİNDE ETKİSİ

ÖZET

Son yıllarda dünya genelinde küresel ısınma, iklim değişikliği, atmosferdeki CO_2 seviyelerinin artışı, ayrıca petrol fiyatlarındaki dalgalanmalar ve ülkelerin yabancı enerji kaynaklarına bağımlılığı gibi faktörler ekonomi literatüründe yenilenebilir enerji alanında yapılan çalışmaların sayısını arttırmıştır.Yenilenebilir enerji kaynaklarının ana enerji kaynağı olarak kabul görmesi 1970'lerden sonraya tesadüf etmektedirki nitekim bu alanda yapılan çalışmaların sayısı giderek artmaktadır.

Literatürde genellikle yenilenebilir enerji tüketimiyle ekonomik büyüme arasındaki ilişki bağlamında birçok çalışma mevcuttur. Bu çalışmanın diğer çalışmalardan farklı olarak literatüre katkısı uygulanmakta olan yenilenebilir enerji politikalarının etkinliğini ele almaktadır. Mevcut çalışma ABD 'de 2007 yılında uygulanmaya konulan Enerji Bağımsızlığı ve Güvenliği Yasasının yenilenebilir enerji tüketimi üzerindeki etkisini incelemektedir. Bu çalışmadan elde edilen sonuçlar Türkiye, Çin, Hindistan gibi yenilenebilir enerji yatırımlarına destek veren gelişmekte olan ülkeler açısından önemlidir ve gelecek çalışmalara yol gösterici olmayı amaçlamaktadır.

Çalışmada öncelikle bağımlı değişkenimiz olan yenilenebilir enerji tüketimini etkileyen önemli bağımsız değişkenler GSYH, petrol fiyatları ve CO_2 emisyonları tanımlanmıştır. Daha sonra kukla değişkenimiz olan 2007 yılındaki Enerji Bağımsızlığı ve Güvenliği yasası değişkeni açıklanmıştır. Enerji Bilgi Yönetim İdaresinden (EIA) toplam yenilenebilir enerji tüketimi ve CO_2 emisyonlarından oluşan zaman serileri ver seti alınmış, real GSYH ve petrol fiyatları ise Federal Rezerv Ekonomi Data (FRED) sisteminden elde edilmiştir. Bu veri seti 1990 yılının ilk çeyreği ile 2017 yılının son çeyreğini kapsamaktadır. İlk olarak bu zaman serilerinin durağanlığını test etmek amacıyla ADF, PP, DF-GLS durağanlık testleri yapılmş ve elde edilen sonuçlara göre serilerin birinci dereceden durağan olduğu anlaşılmıştır. Daha sonra Johansen Eşbütünleşme testleri yapıldıktan sonra Dinamik EKK ve Tam Değiştirilmiş EKK tahmin edicileriyle model tahmin edilmiştir. Her iki tahminediciden elde edilen sonuçlara göre 2007 yılındaki Enerji Bağımsızlığı ve Güvenliği Yasasının 2008'den 2017'ye kadar ABD'de yenilenebilir enerji tüketimi üzerinde istatistiksel olarak anlamlı ve pozitif etkisi bulunmaktadır.

1. INTRODUCTION

It is now widely recognized that renewable energy needs are among the most critical issues of our century. It was expressed in the 2009 International Energy Outlook that, "Renewables are the fastest growing source of world energy with consumption increasing by 3.0 per cent per year" (EIA, 2009). There are several factors that lead governments to be more concerned about renewable energy sources in recent years. These reasons are global warming, climate change, price fluctuations of raw petroleum, the reliance on imported energy resources, the ecological effects of carbon dioxide emanation, Kyoto Protocol and so on (Omri & Nguyen, 2014).

The main driver of global warming is economic growth that relies mainly on traditional energy sources such as fossil fuels. Carbon dioxide (CO_2) emissions released into the atmosphere through the consumption of this kind of energy sources. The increasing level of CO_2 will lead to catastrophic ecological issues, for example, rising ocean levels, climate change, and expanded intensity of storms. This will influence all parts of our environment. One of the most important solutions to dealing with climate change is finding alternative energy sources and decreasing reliance on traditional fossil fuels. Both sustainable (for example, wind, hydro, sun-powered, biomass and geothermal) and nuclear power sources can give some remedies to the issues of energy security and global warming (Menyah & Wolde-Rufael, 2010). The United States (US) has been increasing investment expenditures in nuclear and alternative energy sources in order to decrease reliance on imported oil as well as to expand the amount of secure power, also limit price instability related with petroleum imports and diminish greenhouse gas (GHG) emanation (Toth, 2006; Vaillancourt, Labriet, & Loulou, 2008; Adamantiades & Kessides, 2009). Another main driver of consuming renewable energy is the Kyoto Protocol. The Kyoto Protocol sets obligations to signatories in order to reduce their CO_2 emissions significantly as well as to lessen climate change (Becker & Posner, 2005)

For these reasons, investigating the main factors of sustainable energy utilization is very critical. It is essential that there should be a more reliance on sustainable energy sources in the following years.

Although there are many studies of renewable energy, it is less common to find papers investigating the influence of regulations that support alternative energy consumption. To address the concerned issue in the economic literature, this study looks at the key drivers of renewable energy use and, specifically, the effectiveness of the Energy Independence and Security Act of 2007 (EISA 2007) in bumping up renewable energy production and utilization in the US from 1990 to 2017. Specific determinants impact renewable energy utilization and these components vary from country to country. These variables are collected into three groups: a) political components; b) socioeconomic factors and c) country-specific factors (Marques, Fuinhas, & Manso, 2010). In this paper, the variables that influence sustainable energy consumption are CO_2 emissions, real gross domestic product (GDP), oil price and EISA 2007. The initial three components are socioeconomic determinants while EISA 2007 is a political factor. In the economic literature, the common approach indicates that the level of renewable energy use is mainly affected by the political factors. The main driver behind this approach is that alternative energy sources are more costly than traditional energy sources because firms have not internalized the environmental costs of non-renewable sources. Being of more expensive renewable energy leads to a market failure. One of the effective ways to solve this market failure is legislative policies that can reduce high dependence on traditional energy sources and support an expansion of alternative energy sources (Popp, Hascic, & Medhi, 2011). These legislative regulations will support alternative energy sources compete with non-renewable energy sources (Carley, 2009). Moreover, when the generation of fossil fuels are restricted by the emerging of an emissions-constrained environment, alternative sources can compete with traditional energy sources without any legislative mechanism (Ibikunle & Okereke, 2014). The empirical results of this paper also support the consensus that political factors are the most important determinant of renewable energy utilization. I found that EISA 2007 positively affects renewable energy consumption.

After the explanation of the introduction part, the literature review was introduced in the second part. Our data and methodology were explained in part 3 then our empirical

results were interpreted in section 4. Section 5 is the final part of this study and this section summarizes our findings and touches on some limitations of this study.

2. LITERATURE REVIEW

It will be useful to examine the influence of renewable energy programs on renewable energy consumption. While the greater part of the studies and papers about the effectiveness of energy policies are qualitative and hypothetical, experimental work on this field is insufficient. I believe that the present paper will give a contribution to the empirical side of the energy policy literature.

Menz and Vachon (2006) examined the impact of some state-level regulations on wind power improvement from 1998 to 2003 in the US. These policies are renewable portfolio standards (RPS), retail choice (RET), fuel generation disclosure rules (FGD), mandatory green power options (MGPO) and public benefit funds (PBF), respectively. Using Ordinary Least Squares (OLS) method, the empirical outcomes figure out that the implementation of RPS policies has a positive impact on wind power deployment. Another finding is that RET negatively affects the improvement of wind energy and PBF is not a statistically significant factor in this analysis. The key restrictions of Menz and Vachon (2006)'s study are the small data set and the likelihood of excluded factors.

Carley (2009) analyzed the association between regional renewable portfolio standards (RPS) execution and the share of renewable power electricity production across 50 states. RPS is a regulation which requires to promote the production of energy from alternative energy sources. To check the effectiveness of RPS implementation, the fixed effects model and the fixed effects vector decomposition (FEVD) model were employed by using data between the years of 1998 and 2006. According to both models, there is a small, negative and statistically insignificant association between RPS regulations and the share of renewable energy electricity generation. On the other hand, RPS regulations have positive impacts on particular states. Another main result is that other variables such as gross state product per person, electrical energy consumption per person, the price of electricity are correlated to renewable energy development statistically significantly.

Delmas and Montes-Sacho (2011) examined the influence of two main policies, Renewable Portfolio Standards (RPS) and Mandatory Green Power Options (MGPO), on the capacity of renewable energy from 1998 to 2007 across 48 states. MGPO offers clients the choice to purchase electricity produced from alternative power sources by selecting a green power supplier or obtaining of renewable energy credits (RECs) (Menz & Vachon, 2006). Differently, from previous studies, the natural, social and policy context of regulations are integrated into the model for measuring real effectiveness policies. Secondly, while other studies focused on the portion of renewables in the aggregate energy generation, the present study examines renewable energy capacity development. Using Binomial logit and Tobit model, two-stage modelling methodology was employed for evaluating the effectiveness of selected regulations. According to the results, RPS negatively affects renewable capacity investments while MGPO has a positive and statistically significant effect on renewable capacity.

Payne (2012) studied the causal relationship between renewable energy utilization, carbon emissions, real GDP, real oil prices and the Public Utilities Regulatory Policy Act (PURPA). To test the causality, the Toda- Yamomoto long-causality test technique was employed by using data from 1949 to 2009. The results from the Toda- Yamomoto long-causality test shows that the implementation of PURPA and other alternative energy regulations from 1978 to 2009 impacts renewable energy consumption positively and statistically significantly. Furthermore, the oil prices, output, carbon dioxide emanation did not have a causal effect on renewable energy use. Another main finding is that unpredictable shocks to carbon emissions and real GDP affected positively on renewable energy consumption.

Meade, 2016 examined two main provisions of the EISA and their macroeconomic impacts on the economy with different scenarios. The primary target of this Act is to decrease U.S. reliance on imported petroleum. Two main provisions were assessed: (*i*) reforming the Corporate Average Fuel Economy (CAFE) standards and (*ii*) setting Renewable Fuel Standard (RFS) for promoting the generation and using of renewable fuels. Two scenarios, “EISA” case and the without the implementation of EISA were compared by using Long-term Interindustry Forecasting Tool (LIFT) model. The

results indicate that EISA negatively affects real GDP. While the EISA reduce dependence on imported oil by almost 14% by 2030, it is not sufficient to balance the negative effects on GDP, employment and so on.

3. DATA and METHODOLOGY

3.1 Data Source and Description

This empirical analysis examines the quarterly impacts of EISA 2007 and other factors such as GDP, CO_2 emissions and oil price on renewable energy eonsumption between the years 1990 and 2017 in the US. Data taken from the Energy Information Administration (EIA) includes all renewable energy sources (LREC) measured in quadrillion British thermal units (Btu) and carbon emissions (LCO_2) measured in million metric tons. Real GDP (LRGDP) is in 2009 US dollars and oil prices (LOP) are West Texas Intermediate (WTI) crude oil prices per barrel. Both LRGDP and LOP were obtained from Federal Reserve Economic Data (FRED). Also, a dummy variable D2008 indicates the introduction of EISA 2007 and is equal to 1 from the first quarter of 2008 to the last quarter of 2017 and 0 otherwise. All variables are used in natural logarithms in the econometric tests. Table 3.1 figures out the summary statistics of variables in the United States from 1990 Q1 to 2017 Q4.

Table 3.1: Summary statistics of the variables.

	LRGDP	**LREC**	**LOP**	**LCO_2**	**D2008**
Mean	13113.76	1.798208	46.78995	1378.504	0.357143
Median	13567.60	1.658920	33.64500	1377.072	0.000000
Maximum	17261.00	2.965379	123.9700	1579.768	1.000000
Minimum	8865.600	1.108124	12.90000	1174.052	0.000000
Std. Dev.	2507.724	0.389566	29.88977	96.23037	0.481311
Skewness	-0.249475	0.905955	0.766820	0.030321	0.596285
Kurtosis	1.816464	2.820862	2.316054	2.251035	1.355556
Jarque-Bera	7.698641	15.47050	13.15922	2.634920	19.25663
Probability	0.021294	0.000437	0.001388	0.267815	0.000066
Sum	1468741.	201.3993	5240.475	154392.4	40.00000
Sum Sq. Dev.	6.98E+08	16.84552	99167.22	1027892.	25.71429
Observations	112	112	112	112	112

3.2 Variables

It will be useful to investigate key factors of renewable energy deployment and the relationship among these factors. There are three types of factors such as *political, socioeconomic and country-specific factors* as classified by Ibikunle and Okereke (2014) and Antonio C.Marques (2010). Political factors include public policies, institutional variable and energy security. Socioeconomic factors are CO_2 emissions, prices (oil, natural gas, coal and so on), income (GDP), the percentage of traditional energy resources for electricity generation and energy consumption. The last group, country-related variables contain country size or geographic area, deregulation of the electricity market and continuous commitment. Country size or geographic area is used instead of the production potential of renewables. The variables in the model are chosen based on the theory and previous empirical studies.

I want to give a brief information about renewable energy sources and its role in the United States. Unlike non-renewable energy resources, for example, coal, fuel oil, natural gas, renewable energy sources are not limited. Wind, biomass, solar, geothermal and hydropower are widely known types of renewable energy sources. Biomass is the most consumed source and there are four types of biomass sources widely used today. They are ethanol and biodiesel, hardwood and agrarian products, solid garbage and landfill gas and biogas, respectively. The greater part of countries' energy needs had been met by wood till the 1800s. When coal, oil, natural gas were started to use broadly, the consumption of wood as an energy source was decreased significantly in the US (EIA, 2009). The consumption of renewables is expanding particularly solar, biofuels, and wind in recent years. The amount of energy consumption by main resources from 1949 to 2017 in the US is shown in Figure 3.1.

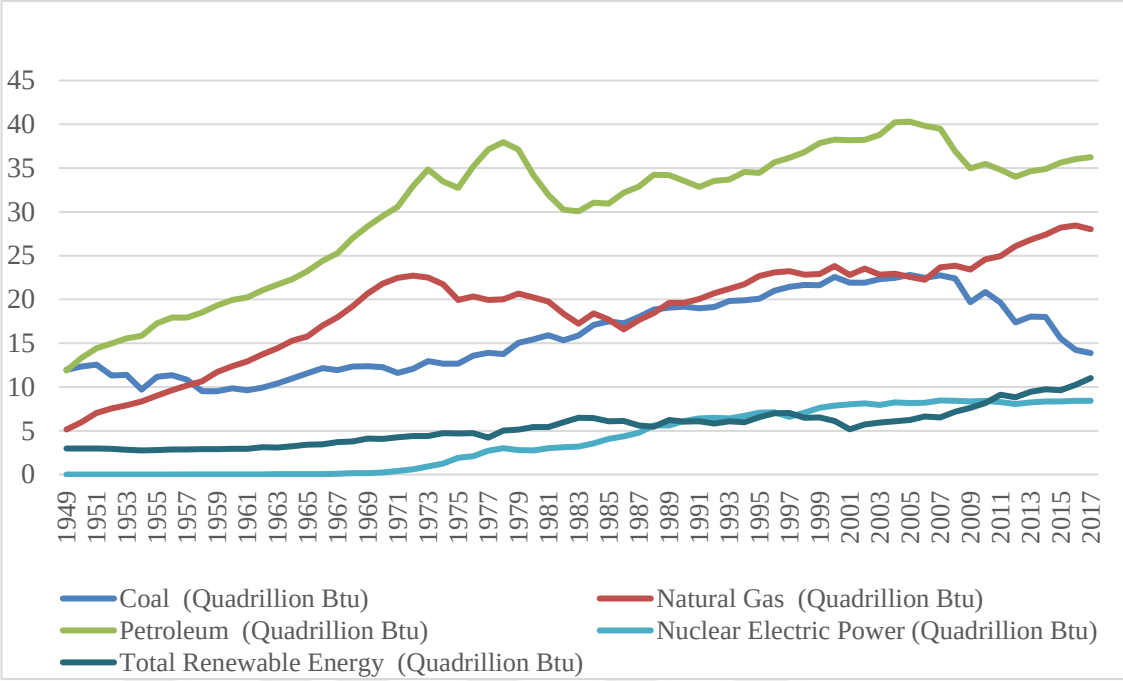

Figure 3.1: Share of U.S. energy consumption by major sources, 1949 -2017

Source: Energy Information Administration, (EIA)

Figure 3.2 figures out that 10% of aggregate energy utilization comes from renewable energy sources with 10.2 quadrillion Btu. The use of renewable energy increased by about 57% from 2007 to 2016.

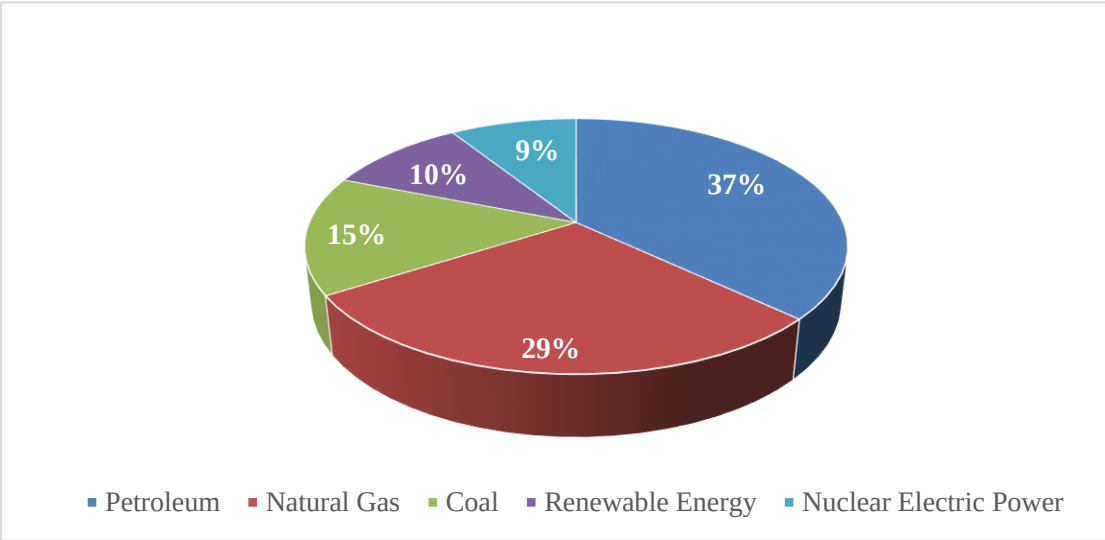

Figure 3.2: U.S. energy consumption by energy source, 2016

Source: Energy Information Administration, (EIA)

When it comes to share of renewables, Figure 3.3 shows that biomass is the most consumed renewables with 46%. Solar and geothermal are the least used renewables at 6% and 2%, respectively.

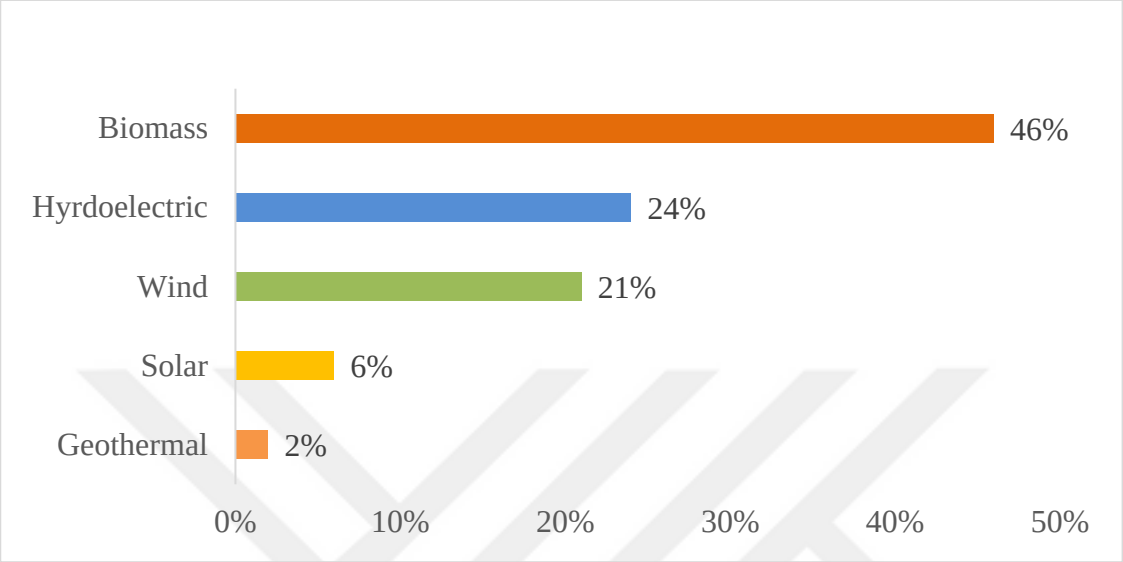

Figure 3.3: Share of Renewables Energy Sources, 2016
Source: Energy Information Administration, (EIA)

Clean energy sources have a very crucial role in diminishing CO_2 emissions. The increased level of sustainable energy consumption leads to a decrease in demand for traditional fossil fuels. Differently from fossil fuels, clean energy sources except for biomass, do not exude emissions directly. As a result of the implementation of state and federal level clean energy policies and incentives, the use of alternative energy supplies increased higher than twice between the years 2000 and 2016. According to EIA, the consumption of renewable energy will increase in the US by 2040.

Although clean energy sources have many benefits, the generation and the consumption of this kind of energy sources are more costly than traditional energy sources. Another disadvantage of renewable energy deployment is that this kind of energy sources are located far from cities and the installation of renewables is more expensive. Moreover, the generated electricity from renewables is not always existed and it mainly depends on weather and climate conditions. For instance, adverse weather conditions such as more cloudy and low windy days decrease electricity production from solar and wind, respectively. Likewise, drier climate conditions negatively affect hydroelectric energy generation. It is useful to give some details

about the explanatory variables after explaining renewable energy, the dependent variable.

First, the CO_2 emission level is a crucial factor that affects alternative energy utilization. According to EIA estimation, a CO_2 emanation from energy use fell down about 861 million metric tons between the years 2005 and 2017. Also, it is estimated that energy-based CO_2 emission level will be lower about at 13% in 2019 than it was in 2005.

Both Marques et al. (2010) and Sadorsky (2009) proxy CO_2 emissions as environmental concerns in their analysis. To deal with environmental concerns such as climate change, governments have to reduce reliance on traditional fuels and increase renewable energy production. Therefore, global warming in other words greater level of CO_2 emissions requires to increase renewable consumption and it is believed that CO_2 emissions will affect renewable energy use positively. CO_2 emission levels were put as a representative of environmental concerns in this analysis.

Second, the price of renewable energy is higher than non-renewable energy sources, because ecological costs are not contained by non-renewable energy sources (Menz & Vachon, 2006). Therefore, renewable energy prices are less competitive than traditional energy prices in the short run. There are quite a lot of studies that investigated the association between energy prices and economic growth. Chang et. al. (2009) analyzed that regions with high income and growth can meet easily the costs related to using of renewable energy technologies and energy prices are found to be positively and statistically significantly related to renewable energy production. Following Sadorsky (2009) and Omri & Nguyen (2014), renewable energy was taken into account as a substitution for oil and oil-based products. If renewable energy is a substitute for oil, it is believed that increased oil price will reduce households' oil consumption and the use of clean energy sources tends to be more attractive (The Annual Report of Council of Economic Advisers, 2006). Based on the demand theory, rising oil price negatively affects oil consumption and increase the consumption of renewables, in other words, there is a negative association between renewable energy and oil products (Sadorsky, 2009). Oil price was considered as a price of a substitute in this study.

Third, the main driver of renewable consumption is income and the impact of income on renewable energy consumption was tested by several studies (Chang et al., (2009); Sadorsky (2009); Antonio C. Marques (2010); Ibikunle & Okereke, (2014) and so on). Generally, income effect can be calculated by using GDP or GDP per capita. For instance, Huang, (2007), put GDP in their analysis. In the most studies, when modelling energy demand, GDP is usually employed as a substitution for revenue and GDP has a positive impact on renewable energy consumption. Countries with higher income and growth can afford easily the costs related to renewable energy installation (higher prices and taxes) and can give more incentives to promote clean energy production (Antonio C.Marques, 2010).

Finally, I discuss the political factor which is the Energy Independence and Security Act 2007 (EISA 2007). This act was signed on December 19, 2007. The main targets of this act are reducing energy dependence on the foreign energy source, providing energy security, increase the generation of renewable fuels, protect customers, promoting renewable fuel generation and consumption, improve the productivity of goods, houses and means of transportation and so on (United States Environmental Protection Agency, 2007). Key provisions of this Act are briefly explained in this manner:

- Corporate Average Fuel Economy (CAFE). It is expected that cars and light lorries will consume 35 miles per gallon by the year 2020.
- Renewable Fuels Standard (RFS). The law targets an adjusted standard which increases from 9.0 billion gallons to 36 billion gallons between the years of 2008 and 2022.
- Energy Efficiency Equipment Standards. There are several renewed standards for lighting and for selected devices such as freezers, metal halide lamps, residential freezers and so on.
- Repeal of Oil and Gas Tax Incentives. Two tax subsidies are cancelled in order to balance the predicted cost to carry out CAFE provision.

3.3 Methodology

To examine the effect of EISA2007 on renewable energy consumption in the US, the explanatory variables are put in this empirical analysis. We estimated the following equation:

$$LREC_t = \alpha + \beta_1 (LRGDP)_t + \beta_2 (LCO_2)_t + \beta_3 (LOP)_t + \beta_4 (D2008)_t + \varepsilon_t \quad (3.1)$$

where LREC is a renewable energy consumption, LRGDP is a real GDP, LOP is the oil price, LCO_2 is a CO_2 emission. Except for D2008 variable, other variables in the model are expressed as natural logarithms. D2008 is a dummy variable with the introduction of the Energy Independence and Security Act 2007 (EISA 2007) and ε_t is an error term.

3.3.1 Stationary test

Firstly, the stationary condition of these variables was checked. To check this condition, we can see the graphs of these variables and then run some stationarity tests. Figure 3.4 shows time series of renewable energy consumption from 1990 to2017.

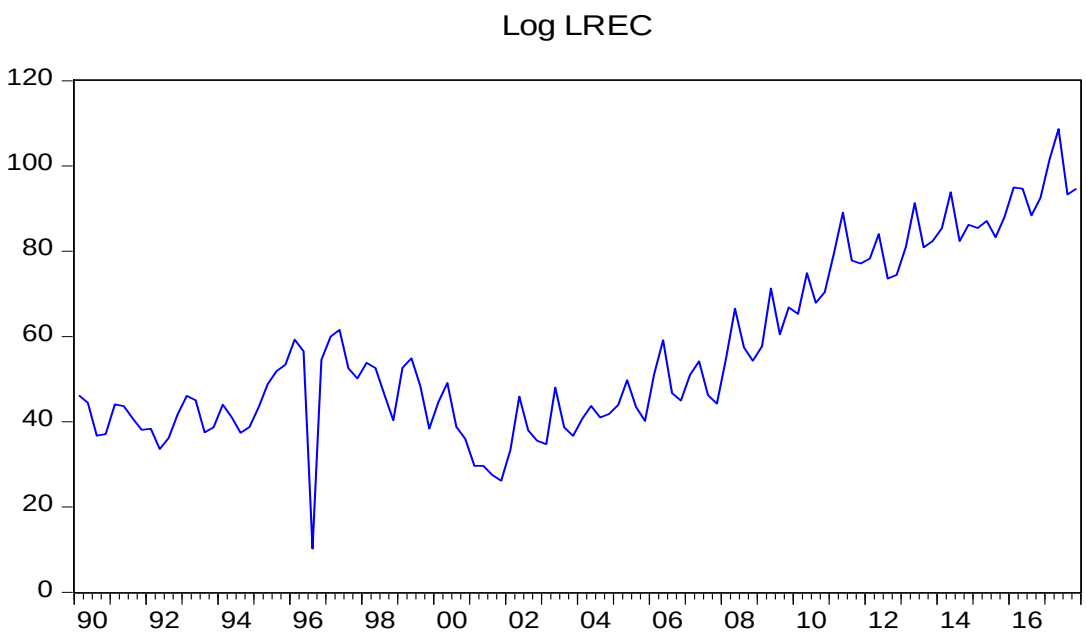

Figure 3.4: Renewable energy consumption

Seasonally adjusted CO_2 emission time series is shown in the Figure 3.5.

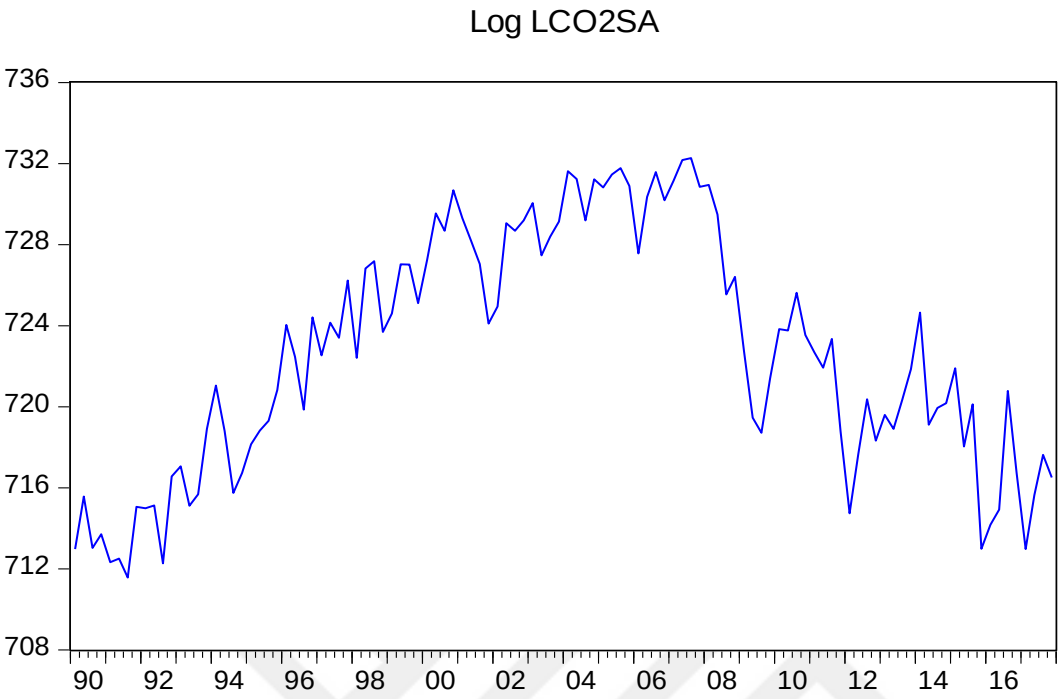

Figure 3.5: CO_2 Emissions

Figure 3.6 figures out oil prices per barrel from 1990 to 2017.

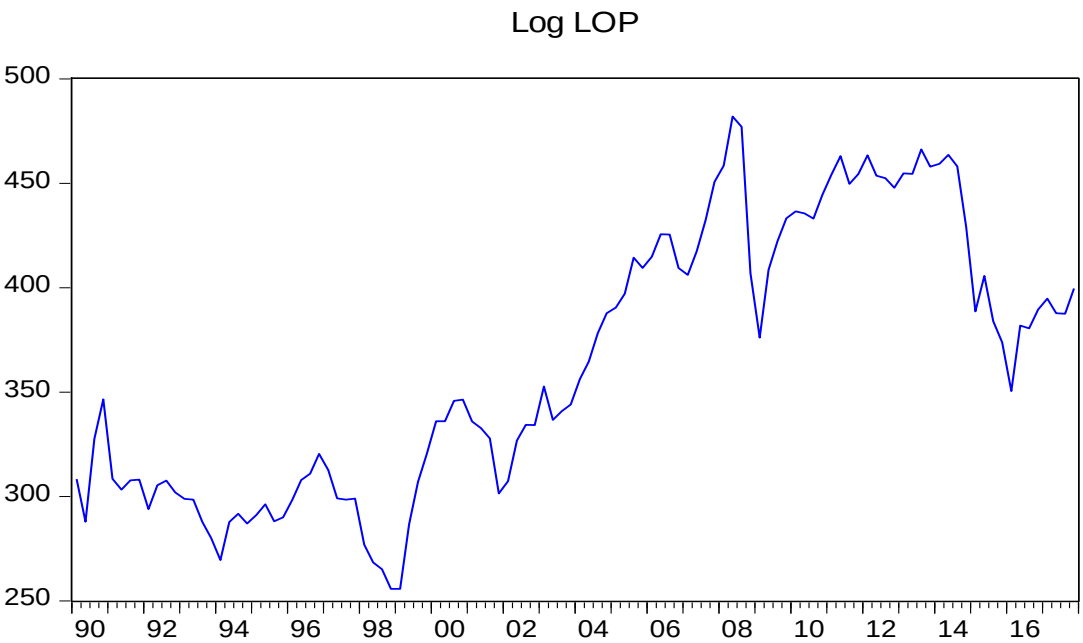

Figure 3.6: Oil Price

Lastly, time series of real GDP is shown in Figure 3.7.

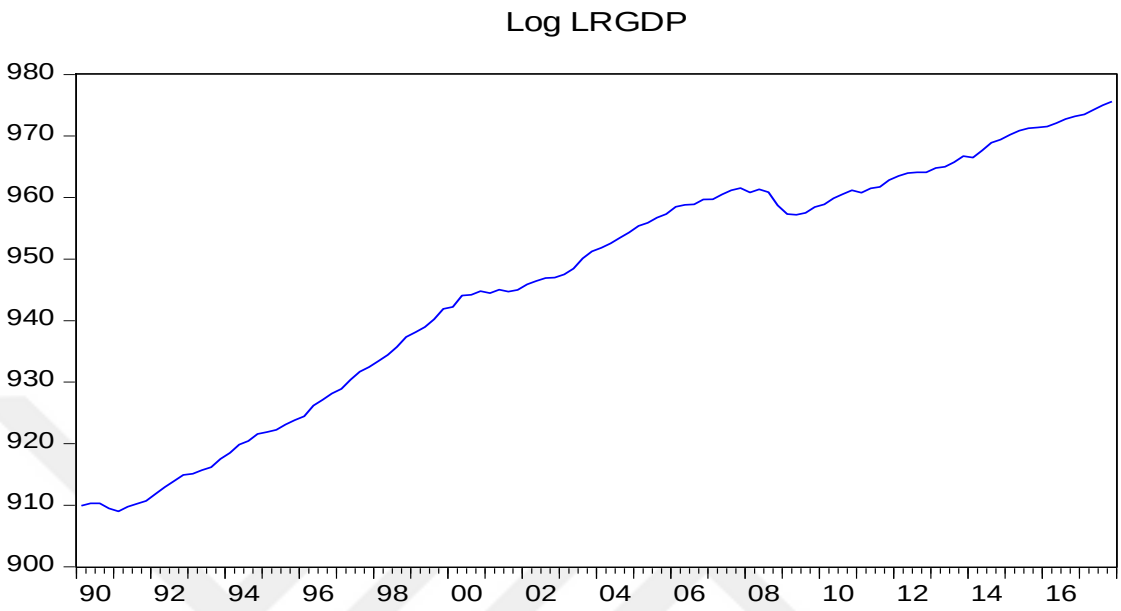

Figure 3.7: Real GDP

While examining the above graphs, it is revealed that the variables are not stationary. The graphical review does not give exact results. It can only give you an idea. For this reason, various methods have been developed to analyze the stability. Applying stationary tests, we can find out the maximum degree of integration of selected variables. If these variables are not stationary that means each variable has a unit root, their variance and covariance are not constant. Therefore, the estimated regression results would be spurious and incorrect. To check stationary, several stationary tests can be used. Augmented Dickey-Fuller (ADF), Phillips Perron (PP) and Dickey-Fuller with Generalized Least Squares (DF- GLS) were performed in the existent analysis.

3.3.2 Augmented Dickey-Fuller (ADF) test

This test was improved by Dicky and Fuller in 1981. Dickey-Fuller test applies only to an AR(1). Differently from normal Dickey-Fuller test ADF test allows for higher-order autoregressive processes. Studies of ADF suggest that it is better for a bigger and more complex set of time series model. The formulation of the ADF test is written as follow:

$$\Delta y_t = \alpha + \beta t + \delta y_{t-1} + \sum_{i=1}^{P} \gamma_i \Delta y_{t-i} + \varepsilon_t \qquad (3.2)$$

In the Equation (3.2), α is an intercept, β is the coefficient of *t*, δ is the estimated value of the coefficient of y_{t-1} , y_t is our interest variable that they are LRGDP, LCO_2, LREC, LOP, ε_t is an error term which is i.i.d. The null hypothesis of ADF test is the the that δ=0 , $\beta \neq 0$ and y_t is not stationary. The alternative hypothesisis that δ < 0, $\beta \neq 0$, and y_t is stationary. If the value of the ADF test statistic is bigger than its table value, then the alternative hypothesis that y_t is stationary is not rejected.

3.3.3 Phillips-Perron (PP) test

$$\Delta y_t = \alpha + \beta t + \delta y_{t-1} + \varepsilon_t \qquad (3.3)$$

Another important unit root test is the Phillips-Perron test which was developed by Peter C.B Phillips and Pierro Perron (1988). Differently, from ADF, Phillips and Perron use non-parametric statistical techniques to take into account the autocorrelation in the residual terms without adding past period difference terms (Damodar & Dawn, 2009). Also, the ADF and Phillips-Perron tests have the same asymptotic distribution. The null hypothesis of the Phillips-Perron test is that δ=0, y_t is not stationary, against the alternative hypothesis δ < 0, y_t is stationary. When the value of the Phillips-Perron test statistic is bigger than its table value, then the alternative hypothesis that y_t is stationary is not rejected.

3.3.4 Dickey-Fuller with Generalized Least Squares (DF-GLS) test:

The DF-GLS test was introduced by Elliott, Rothenberg, and Stock (1996). This test is robust than the ADF test. There are two steps in order to calculate the DF-GLS test. First, the constant and trend are approximated by the Generalized Least Squares (GLS) method. In the second step, the Dickey-Fuller test is employed to test for a unit autoregressive root in "detrended" version of y_t (y_t^d) where Dickey-Fuller regression does not include an intercept or a time trend (James & Mark, 2011). If the value of the DF-GLS test statistic is bigger than its critical value, then the alternative hypothesis that y_t is stationary is not rejected (James & Mark, 2011). Table 3.2 shows the results of all three stationary tests.

Table 3.2: Unit root tests from 1990Q1 to 2017Q4

Variable Unit Root Test	Levels	First differences
LREC		
ADF	-0,57	-13,67*
PP	-3,60	-18,20*
DF-GLS	-0,25	-13,48*
LROP		
ADF	-2,13	-8,75*
PP	-2,30	-8,22*
DF-GLS	-2,10	-8,43*
LRGDP		
ADF	-1,58	-6,83*
PP	-1,62	-6,99*
DF-GLS	-1,60	-6,72*
LCO_2		
ADF	-2,16	-9,96*
PP	-1,74	-13,27*
DF-GLS	-1,74	-11,75*

Note: Unit root tests above include a constant and trend. Critical values for the unit root tests as follows: ADF and PP: *(1%) -4,04. DF-GLS:* (1%) -3,57.

"There is a unit root" is the null hypothesis of the above tests. All series have a unit root which means that all variables are not stationary in their levels whereas they are stationary after taking their first difference. According to results, the null hypothesis is rejected at the significance level of 1%. Therefore, all series LREC, LROP, LRGDP, LCO_2 are integrated of order one.

3.3.5 Cointegration test

In the economic theory, there are can be a long-run economic correlation between certain economic and financial variables and there might be the same stochastic trend among these variables. For instance, the permanent income hypothesis (PIH) indicates cointegration between income and consumption, money demand models mean co-integration between money, nominal income, prices and interest rates. This case is characterised as a cointegration. "Assume that X_t and Y_t are integrated of order one and if for some coefficient θ, Y_t - θ X_t is integrated of order zero, then X_t and Y_t are said to be cointegrated" (James & Mark, 2011). The cointegrating coefficient is θ and calculating the difference Y_t - θ X_t gets rid of this common stochastic trend.

There are several approaches to test co-integration. Firstly, the definition of cointegration was introduced by Engle and Granger (1987) as below. In the Equation (3.4), Y_t is a k-dimensional vector and the element of Y_t are cointegrated of order (d,c), Y~ CI (d, c). "If the integrated order of Y_t elements is d, I(d), and if there exists at least one non-trivial linear combination z of these variables, which is I (d-c), where $d \geq c > 0$ holds, i.e. iff" (Kirchgässner & Wolters, 2007).

$$\beta' Y_t = z_t \sim I(d - c) \tag{3.4}$$

Where β' is a cointegration vector and r is a cointegration rank that equals the number of linearly explanatory co-integration vectors. B is denoted as a cointegration matrix:

$$B' Y_t = Z_t \tag{3.5}$$

If the integrated order of variables is 1, it supports that $0 \leq r < k$. When r equals the 0, there is no co-integration between elements of Y (Kirchgässner & Wolters, 2007).

Another most commonly used method to test co-integration is Vector Autoregressive (VAR) based Johansen (1988) test. While Engle-Granger test allows just one co-

integrating association, Johansen methodology allows further than one cointegrating association and this test is more appropriate for this study. We can write general VAR(p) model as follows:

$$y_t = \alpha_0 + \sum_{j=1}^{p} A_j y_{t-j} + \varepsilon_t \tag{3.6}$$

In the Equation (3.6), y_t is our variable of interest *LREC, LRGDP, LCO$_2$, LOP, D2008*. α_0 is an interception vector or (α_{LREC} , α_{LRGDP} α_{LCO2}, α_{LOP}, α_{D2008}), and A_j is a VAR parameters matrix for lag j, ε_t is a residual term vector (ε_{LREC} , ε_{LRGDP} ε_{LCO2}, ε_{LOP}, ε_{D2008}). To employ Johansen test, firstly, we have to choose lag order of the VAR. Table 3.3 shows the values of Sequential Modified LR Test Statistic (LR), Final Prediction Error (FPE), Akaike Information Criteria (AIC), Schwarz Information Criteria (SC) and Hannan-Quinn Information Criteria (HQ). Schwarz Information Criterion was selected with lag order 1 because there are few parameters.

Table 3.3: VAR lag order selection criteria.

Endogenous variables:	LREC LRGDP LOP LCO2 D2008					
Exogenous variables:	C					
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1940,22	NA	1,21E+10	37,408	37,535	37,459
1	-1279,37	1245,44	59370,31	25,18	25,943*	25,489*
2	-1257,23	39,607	62929,33	25,23	26,633	25,801
3	-1231,07	44,269	62057,78	25,21	27,247	26,036
4	-1172,88	92,88*	33302,04*	24,57*	27,244	25,656
5	-1156,44	24,657	40296,46	24,74	28,044	26,078
6	-1142,16	20.041	51504,63	24,94	28,886	26,542
7	-1129,37	16,727	68873,5	25,18	29,757	27,034
8	-1104,44	30,207	74448,08	25,181	30,394	27,293

Next step for employing the Johansen test is selecting appropriate deterministic elements (intercept, trend, both and none). To choose deterministic components, Pantula principle introduced by Pantula (1989) was suggested by Johansen. The method includes the forecasting of three models, beginning from the most restricted model 2 to the minimum restricted model 4 comparing the trace test statistic to its table value. When the null hypothesis is not rejected for the first time, this test is finished. Another way of choosing the correct model is using Akaike Information Criteria (AIC)

and Schwarz Information Criteria (SC) values. The smallest values of both criteria are chosen and this value shows which model is the correct. Table 3.4 examines which test types are appropriate to our data and model.

Table 3.4: Johansen Cointegration test summary

Series: LREC LRGDP LOP LCO2 D2008 Lags interval: 1 to 1					
Selected (0.05 level*) Number of Cointegrating Relations by Model					
Data Trend :	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No trend	Intercept No trend	Intercept No trend	Intercept Trend	Intercept Trend
Trace	2	4	1	2	2
Max-Eig	1	1	1	2	2
*Critical values based on MacKinnon-Haug-Michelis (1999)					
Information Criteria by Rank and Model					
Data Trend :	None	None	Linear	Linear	Quadratic
Rank or No. Of Ces	No Intercept No trend	Intercept No trend	Intercept No trend	Intercept Trend	Intercept Trend
Log Likelihood by Rank (rows) and Model (columns)					
0	-1.384.229	-1.384.229	-1.367.434	-1.367.434	-1.365.990
1	-1.364.400	-1.359.563	-1.347.466	-1.339.689	-1.338.244
2	-1.355.094	-1.345.557	-1.338.078	-1.319.720	-1.318.298
3	-1.346.848	-1.336.839	-1.329.843	-1.311.486	-1.310.076
4	-1.342.987	-1.329.024	-1.326.944	-1.306.805	-1.306.751
5	-1.342.987	-1.326.568	-1.326.568	-1.304.910	-1.304.910
Akaike Information Criteria by Rank (rows) and Model (columns)					
0	25.62234	25.62234	25.40790	25.40790	25.47254
1	25.44363	25.37388	25.22665	25.10344	25.14990
2	25.45626	25.31923	25.23778	24.94037*	24.96906
3	25.48815	25.36070	25.26988	24.99065	25.00138
4	25.59976	25.41862	25.39899	25.10555	25.12274
5	25.78158	25.57396	25.57396	25.27109	25.27109
Schwarz Criteria by Rank (rows) and Model (columns)					
0	26.23608	26.23608	26.14439	26.14439	26.33178
1	26.30287	26.25767	26.20864	26.10998*	26.25464
2	26.56100	26.47307	26.46527	26.21696	26.31930
3	26.83839	26.78459	26.74287	26.53729	26.59712
4	27.19550	27.11256	27.11747	26.92224	26.96397
5	27.62282	27.53795	27.53795	27.35783	27.35783

According to the values of AIC and SC, model 4 which is Linear (Intercept and Trend) is chosen. After determining the appropriate model, the Johansen test is employed and test outputs are reported in Table 3.5.

Table 3.5: Johansen Cointegration Test.

Trend assumption: Linear determinants trend (restricted)
Series: LREC LRGDP LOP LCO2 D2008
Lags interval (in first differences): 1 to 1

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.396170	125.0486	88.80380	0.0000
At most 1 *	0.304459	69.55778	63.87610	0.0154
At most 2	0.139055	29.62055	42.91525	0.5248
At most 3	0.081575	13.15087	25.87211	0.7264
At most 4	0.033872	3.790441	12.51798	0.7722

Trace test indicates 2 cointegrating eqn (s) at the 0.05 level

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.396170	55.49081	38.33101	0.0002
At most 1 *	0.304459	39.93723	32.11832	0.0045
At most 2	0.139055	16.46968	25.82321	0.5032
At most 3	0.081575	9.360433	19.38704	0.6869
At most 4	0.033872	3.790441	12.51798	0.7722

Max-eigenvalue test indicates 2 cointegrating eqn (s) at the 0.05 level

Table 3.5 summarizes Johansen co-integration test in light of the above assumptions such as lag order selection criteria and model types. Johansen Approach includes 2 types of likelihood tests such as Trace Test and Maximum Eigenvalue Test.

(i) " There are at most r positive eigenvalues" is the null hypothesis of Trace test while "There are more than r positive eigenvalues" is the alternative hypothesis (Kirchgässner & Wolters, 2007). The Trace test formulation is written as follow:

$$\mathrm{Tr}(r) = -T \sum_{i=r_{+1}}^{k} \ln\left(1 - \hat{\lambda}_i\right) \tag{3.7}$$

When we look at Trace test values, Table 3.5 shows that Trace Statistic values are bigger than its critical values (69,55 > 63,87) at the significance level of 5% also p values are smaller than 0.05 level. It means that there are at least 2 cointegrating equations at the 0.05 level.

(ii) The Maximum Eigenvalue (λmax) test examines whether there are r or r+1 cointegrating vectors."There are exactly r positive eigenvalues" is the null hypothesis for λmax while the alternative hypothesis is that "There are exactly r+1 positive eigenvalues" (Kirchgässner & Wolters, 2007). The λmax test statistic is written as follow:

$$\lambda max = (r, r+1) = -T \ln\left(1 - \hat{\lambda}_{r+1}\right) \tag{3.8}$$

When we look at Max-Eigen test values, Table 3.5 shows that Max-Eigen Statistic values are bigger than its critical values (39,93> 32,11) at the significance level of 5% also p values are smaller than 0.05. It means that there are at least 2 cointegrating equations at the 0.05 level.

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3.3.6 Estimation of cointegrating coefficients

$$Y_t = \alpha + \theta X_t + z_t \tag{3.9}$$

In Equation (3.9), if dependent and explanatory variables are cointegrated, the OLS estimator of θ is consistent. On the other hand, the distribution of OLS estimator is non-normal, and the results of *t*-statistics can be misinforming whether or not those *t*-statistics are calculated employing Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors (James & Mark, 2011). Therefore, several other cointegrating coefficient estimators were improved due to these problems of the OLS estimator of θ. One of the most commonly used estimator of θ *is Dynamic OLS (DOLS)* estimator introduced by Stock and Watson (1993). The DOLS estimator is written as follow:

$$Y_t = \beta_0 + \theta X_t + \sum_{j=-p}^{p} \delta_j \Delta X_{t-j} + u_t \tag{3.10}$$

In Equation (3.10), the regressors are X_t, $\Delta X_{t+p}, \ldots\ldots, \Delta X_{t-p}$ that they are present, future and past values of change in X_t, respectively. When there is a cointegrating relationship between dependent and explanatory variables, then the DOLS estimator is efficient in big samples. Moreover, statistical results of θ and δ' s based on HAC standard errors are valid and t-statistic computed with DOLS estimator with HAC standard errors has a normal distribution (James & Mark, 2011).

Another method of estimating co-integration coefficients is Fully Modified OLS (FMOLS) suggested by Phillips and Hansen (1990). This estimator eliminates endogeneity and serial correlation problems that caused by the OLS estimator. Moreover, "FMOLS estimator is asymptotically unbiased and has fully efficient mixture normal asymptotics that permits to employ standard Wald tests by using Chi-square statistical inference" (Phillips & Hansen, 1990).

4. EMPIRICAL RESULTS AND DISCUSSION

Both DOLS and FMOLS estimates of Equation (3.10) are shown in Table 4.1 and Table 4.2.

Table 4.1: Dynamic OLS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LRGDP	9.95E-05	1.99E-05	4.995153	0.0000
LOP	-0.000917	0.000911	-1.007074	0.3163
LCO2	-0.002013	0.000427	-4.713527	0.0000
D2008	0.278425	0.121724	2.287343	0.0242
C	3.166363	0.396487	7.986037	0.0000
R-squared	0.867677	Mean dependent var		1.800105
Adjusted R-squared	0.857298	S.D. dependent var		0.390812
S.E. of regression	0.147633	Sum squared resid		2.223131

Table 4.2: Fully- Modified OLS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LRGDP	0.000109	2.06E-05	5.310667	0.0000
LOP	-0.002095	0.001383	-1.515349	0.1327
LCO2	-0.002032	0.000482	-4.215486	0.0001
D2008	0.318920	0.131663	2.422246	0.0171
C	3.138081	0.525237	5.974596	0.0000
R-squared	0.826189	Mean dependent var		1.800105
Adjusted R-squared	0.819630	S.D. dependent var		0.390812
S.E. of regression	0.165978	Sum squared resid		2.920158

All variables except D2008 are in their natural logarithms so that we can interpret the coefficients as elasticity estimates. The test outputs illustrate that all variables in the model are statistically significant except Oil Price (LOP) at the 5% level of significance. EISA(2007) from 2008 to 2017 as the dummy variable D2008 has a positive impact on renewable energy consumption about 0.27% increase when using Dynamic OLS technique. When using FMOLS estimation method, there is about 0.31% increase in renewable energy consumption. Similarly, Payne (2012), Menz & Vachon (2006) found that there is a positive association between policy implications and renewable energy utilization, while Carley (2009) shows that RPS policies negatively affect the share of renewable energy electricity generation. Next, real GDP has a positive and statistically significant impact on renewable energy consumption when employing both estimation techniques. This result is verified by Menz & Vachon (2006), Carley (2009), Sadorsky (2009) and so on. The reason is that it is easy for wealthier countries to afford the costs of renewable installations and technologies and to give more contribution to renewable energy policies and incentives. Another result is that CO_2 has a negative and statistically significant impact on renewable energy consumption. While CO_2 emission has a negative impact on the contribution of renewables to energy production in the study of Marques (2010), CO_2 has a positive and significant influence on renewable energy consumption in the studies of Sadorsky (2009), Ibikunle & Okereke, (2014) and Omri & Nguyen (2014), respectively. In order to check the association between CO_2 emissions and renewable energy consumption, I take the lag value of CO_2 emissions using DOLS and FMOLS methods. Table 4.3 shows that there is again a negative association between the lag value of CO_2 emissions and renewable energy consumption when using both FMOLS and DOLS estimation methods.

Table 4.3: FMOLS and DOLS with a lag value of CO_2 emissions

	FMOLS			DOLS		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
LRGDP	0.000109	2.06E-05	0.0000	9.95E-05	1.99E-05	0.0000
LOP	-0.002095	0.001383	0.1327	-0.000917	0.000911	0.3163
LCO2	-0.002032	0.000482	0.0001	-0.002013	0.000427	0.0000
D2008	0.318920	0.131663	0.0171	0.278425	0.121724	0.0242
C	3.138081	0.525237	0.0000	3.166363	0.396487	0.0000

Lastly, there is a negative and statistically insignificant association between oil price and renewable energy use. The impact of oil price shows considerable variability across the studies. As a high-income country, the U.S. can easily diversify the oil price risk through derivatives markets and particular energy regulations. The R-square is 86.76% for Dynamic OLS and 82.6% for FMOLS. This reveals that GDP, Oil Price, CO_2 emissions and EISA (2007) explain about 86.76% and 82.61%, respectively of the variation in renewable energy consumption in the US. The remaining 13.24% and 17.39% is determined by other components which are not included in this empirical analysis.

5. CONCLUSION

This study gives a good chance to investigate the impact of renewable energy policy implementation on renewable energy consumption. According to the present study, the main finding is that EISA (2007) affects positively and statistically significantly renewable energy consumption in the US between the first quarter of 2008 and the last quarter of 2017. Similar results verified by Payne (2012), Menz & Vachon (2006). Another result is that real GDP is still the main driver of renewable energy use and this result is verified by Sadorsky (2009), Marques et al. (2010), Chang et al. (2009), and so on.

This study reveals that governments have to give more importance in sustainable energy policies to promote both renewable energy consumption and production. By implementing energy policies, renewables can be more competitive in the energy market. Furthermore, these policies need to be revised for changing economic conditions regularly.

There are a few critical limitations to this studies. Firstly, the sample size of this empirical analysis is small. Because renewable energy was considered as a primary energy source recently so that there is no available long period data about renewables. However, using of quarterly data makes this analysis more consistent. Secondly, it is possible that omitted variables bias problem can occur. However, this problem did not occur. Moreover, this model could be developed by adding other policy variables including marketplace-based renewable power regulations, clean power investments and so on. Finally, results are only relevant to the US. Therefore the findings can not be generalized. The study can be developed by investigating more states in a panel data framework. For instance, we can choose at least 2 states and examine the changes in the amount of renewable energy consumption or production caused by the implementation of this Act using Difference in Difference methods.

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