ANALYSIS OF ENERGY CONSUMPTION ON THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS IN THE UNITED STATES: DOES RENEWABLE ENERGY PLAY A ROLE?

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ABSTRACT

Using CO_2 emissions as a representation of environmental degradation an empirical econometric analysis is conducted to see if there is evidence of an Environmental Kuznets Curve in the United States and if renewable energy consumption plays a significant role in CO_2 emission mitigation. The renewable energy consumption variable was broken down further to isolate geothermal, hydroelectric, biomass, solar, and wind energy consumption and explore their role in the analysis. An Auto-Regressive Distributed Lag approach to cointegration with Pooled Mean Groups and Mean Groups estimations was used on U.S. state (including District of Columbia) specific data from 1987 to 2015 to calculate the long and short run results that would support an Environmental Kuznets Curve hypothesis. The panel of states was divided into low, medium, and high GDP brackets as disaggregate models and those were examined along with a model of the entire United States. Evidence for an Environmental Kuznets Curve for the United States could not be established in the aggregate model, however it was found that renewable energy consumption did have a negative coefficient, which indicates CO_2 emission mitigation through renewable energy consumption. Out of the individual renewable energy consumption variables tested, only wind energy consumption was found to be statistically significant while the model also exhibited evidence to support an Environmental Kuznets Curve hypothesis in this aggregate model. Looking at the different GDP state brackets, low GDP states were the only bracket that yielded evidence of an Environmental Kuznets Curve in the disaggregate models. For estimations with the low GDP states bracket looking at the individual renewable energy consumption variables, hydroelectric, biomass, solar, and wind energy consumption variables were statistically significant as well. The medium GDP bracket states aggregate model did not yield conclusive results, stemming from the lack of slope in the GDP variable for this model. Out of the individual renewable energy consumption variables tested in the subset, biomass was the

only energy consumption to be statistically significant while the model exhibited evidence of an Environmental Kuznets Curve. The high GDP bracket aggregate model did not yield results showing evidence of an Environmental Kuznets Curve, while the individual renewable energy consumption variable subset models geothermal and wind energy consumption were statistically significant within models showing evidence of an Environmental Kuznets Curve. Breaking out these separate renewable energy consumption variables in an Environmental Kuznets Curve analysis can provide empirical support for policy and investment in specific renewable energy technology.

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Introduction

Climate change is at the forefront of controversial topics today, specifically in political and scientific discussions. Focus is on what the consequences are and most importantly what actions, if any, should be pursued. Carbon dioxide (CO_2) emissions are the most significant greenhouse gas emissions affecting climate change representing 65% of emissions by gas with 36,138,285 kiloton produced in 2014 on a global scale, 5,254,279 kiloton in the United States alone in 2014 (U.S. Environmental Protection Agency, "Global Greenhouse Gas Emissions Data", 2017; World Bank, 2017). These emissions are directly linked to energy consumption in our society. The growing energy consumption is a problem with no clear solution, though its consequences are obvious. The U.S. Energy Information Administration (EIA) has forecast a 28% increase in world energy consumption between 2015 and 2040 from 575 quadrillion Btu (British thermal unit) in 2015 to 736 quadrillion Btu in 2040 (U.S. Energy Information Administration, "Annual Energy Outlook 2017", 2017).

Carbon dioxide emissions are from an ever increasing industrialized economy that is reliant on fossil fuels. The contributors are not only large developed countries, but also developing ones that are increasing their industrial sectors to improve their economy and eventually the quality of life of its citizens. The EIA has forecast that the increase in energy demand will be greater from non-Organization for Economic Co-operation and Development (OECD) countries than OECD countries (U.S. Energy Information Administration, "Annual Energy Outlook 2017", 2017). With all types of countries increasing their greenhouse gas emissions, increasing world population also starts to play a role, as population is an important driver of energy demand (U.S. Energy Information Administration, "Annual Energy Outlook 2017", 2017). Connecting to the 1972 publication *Limits to Growth,* which warned that even then the rates of resource use and industrial output along with population growth patterns could not be sustained and would end in catastrophe (Meadows, Meadows, Randers, & Behrens, 1972). This shocking conclusion was derived with computer modeling and even defended by 20 and 30 year updates concluding in the same catastrophe. The increasing levels of production and output lead a discussion about increasing economic growth and the effect it has on the environment.

A hypothesized relationship between indicators of environmental degradation and income per capita is titled the Environmental Kuznets Curve (EKC), seen in *Figure 1*. The curve is named after Simon Kuznets (1955) who first hypothesized that income inequality would rise in the beginning and then fall as economic growth increased. The argument of renewable energy's involvement in this EKC curve will be examined in this paper. Energy production and through it consumption in an economy represents a significant portion of the natural resources used in a society. With the increasing trend of the implementation of renewable energy technologies compared to those technologies sourced with fossil fuels, a division in this category of energy consumption could help explain an EKC for the United States. If renewable energy consumption is a statistically significant variable this could lead to advancements in policy for increased renewable energy use to help move towards a sustainable future.

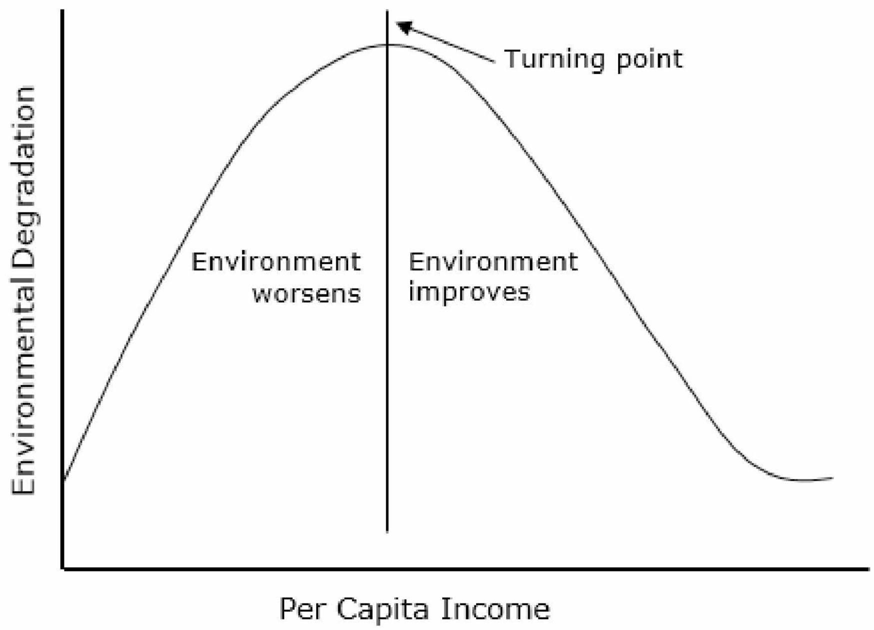

Figure 1: Environmental Kuznets Curve
Source: https://en.wikipedia.org/wiki/Kuznets_curve

This study sets out to examine the hypothesis of an EKC for the United States using an empirical analysis with state (including District of Columbia) level panel data with aggregate and disaggregate models based on low, medium, and high GDP states. This economic growth and environmental degradation relationship will try to be explained with energy consumption variables, specifically the differences between non-renewable and renewable energy consumption. The renewable energy variable will be separated to try to examine the significance, if any, of different specific renewable energy consumptions in the United States. To examine the hypothesis and the significance of these variables an autoregressive distributed lag (ARDL) approach to cointegration will be utilized as proposed by Blackburne & Frank. (2007 & Pesaran, Shin, & Smith, 1999). This ARDL approach using Pooled Mean Groups (PMG) and Mean Groups (MG) allows us to create an error-correction model (ECM) that estimates both the short and long run parameters of the model. This dynamic approach will help explain the significance in the different types of energy consumption variables, especially different types of specific renewable energy consumption that have not been studied before in this context, as well as the overall EKC hypothesis for the United States in both aggregate and disaggregate models.

Literature Review

The EKC has been a popular topic in scientific literature with an increasing interest in the empirical models and their findings. According to Panayotou the empirical literature is centered on five questions (2003). First, whether the actual inverted U-shaped relationship between environmental degradation and income exists. Second, what other factors or variables can be included and explained by the model. Third, the relationship, if any, between the results from panel estimations and individual country projections. Fourth, can a statistical relationship be defined by carrying capacity or ecological thresholds in relation to the EKC? Finally, what role environmental policy has in explaining or changing the curve?

With these five questions at the forefront of EKC research there are many angles and perspectives taken on this topic throughout the years. This literature review will cover some research from the beginning that builds the foundation of the EKC relationship, as well as recent studies that contain variables such as renewable energy consumption. No study could be found that specifically discussed the role of individual renewable energy consumption on an EKC for the United States, a subject this study will try to identify.

One of the frequently cited works with regards to EKC is a working paper that first modeled economic growth and environmental degradation (Grossman & Krueger, 1991). The context of this model was in the North American Free Trade Agreement in that many worried that competition would drive companies to Mexico to escape strict environmental standards of business. However, Grossman and Krueger believed that this free trade would actually help protect the environment. To prove this they developed a model of cross-country panel data of air pollution in urban areas. Their evidence showed an increase in air pollution at per capita GDP at lower levels of national income and a decrease in air pollution per capita GDP at higher levels of income. Therefore, those bringing trade and income into Mexico would be helping decrease emissions and environmental degradation in the long run. These findings were the starting point for the next decades of research on EKC.

A recent study looked at energy consumption in the United States and the impacts of GDP shocks on energy consumption and vice versa. They broke down those two variables even further to inspect the relationship in different economic sectors (commercial, industrial, residential, and transportation) and different energy sources (fossil fuels, nuclear, and renewable). The methodology applied was a time series approach with a Granger causality analysis to find asymmetries of the bidirectional relationship. The conclusions from this type of analysis was that the United States is highly dependent on petroleum consumption and renewable energy sources do not have relationship with economic growth. Looking specifically into the different economic sectors the industrial sector is very significant to economic growth and very sensitive to GDP shocks. In an overall conclusion, this study found that its empirical results suggested evidence that GDP growth causes energy consumption (Carmona, Feria, Golpe, and Iglesias, 2017). While this study does not test specifically the EKC hypothesis, it does contribute results to the renewable energy consumption significance argument and the directional relationship between GDP changes and energy consumption.

Looking at studies that specifically test the EKC hypothesis, the first study uses panel data from 17 different OECD countries from 1977-2010 in a fully modified least squares

(FMOLS) and dynamic ordinary least squares (DOLS) estimation (Bilgili, Koçak, & Bulut, 2016). Their findings of an EKC hypothesis on a country level differed with each country; however, on the panel level the findings did support an overall EKC hypothesis. The panel coefficient estimates yield evidence for an EKC with a negative coefficient of renewable energy on CO_2 emissions and positive and negative coefficients on GDP per capita and GDP per capita squared respectively. These authors' attempt to test the EKC at a country-by-country basis for those in their sample, found that the individual countries did not yield robust estimations for evidence of an EKC. For the United States, the study showed that the EKC hypothesis did not hold and there were disagreeing coefficients between the FMOLS and DOLS estimations. This study represents a large number of studies' findings in the literature, that panel data sets across many countries would more often than not show an EKC, while individual countries tested would not show evidence to support the EKC hypothesis (Jebli, Pzturk, & Youssef, 2016; Dogan & Seker, 2016; Bilgili, Koçak, & Bulut, 2016)

Moving into studies that look at specific countries, the role of renewable energy and non-renewable energy consumption on an EKC for Pakistan is examined (D, Zhang, Wang, & Wang, 2017). A time period of 1970-2012 was used with an autoregressive distributive lag (ARDL) bounding testing, a sensitivity analysis using FMOLS and DOLS, a canonical cointegrating regression (CCR), and VECM granger causality approach. The results supported the EKC hypothesis for the country of Pakistan, including that renewable energy consumption playing a significant role in reducing CO_2 emissions and non-renewable energy consumption has a positive impact on CO_2 emissions, indicating the bi-directional causality relationship. Policy implications discussed in the study with these conclusions suggest an expansion in the investment in renewable energy. This study is one of the few studies that establishes a statistically significant relationship of renewable energy consumption with the EKC.

Another study employed ARDL to examine energy consumption in Algeria from 1980-2012 (Amri, 2017). For this specific country only non-renewable energy consumption contributed to economic growth, renewable energy consumption showed no effect on economic growth. A unidirectional link was also found going from non-renewable energy to renewable energy in the short run, meaning the demand of non-renewable energy stimulates renewable energy in the short run. The policy discussions for this country are unique since there is that second unidirectional link in the short run, so they do not discourage the implementation of non-renewable energies just suggest and increase in their efficiency.

Analytical Framework of an Environmental Kuznets Curve Hypothesis

The Environmental Kuznets Curve implies the variable for environmental degradation creates an inverted U-shaped function of income per capita (Stern, 2003). The most used variable to represent the environmental degradation is carbon dioxide emissions, although other indicators have been used to represent environmental degradation such as deforestation and other specific air pollutants. The hypothesis of this curve implies that once there has been enough economic growth and expansion in a country there will be a turning point in which environmental degradation starts to decrease as economic growth continues to grow, thus depicting the inverted U-shaped curve. Before this hypothesis, the common understanding was that high-income societies actually destroyed their natural resources at a higher rate than lower-income societies (Yandle, Bhattarai & Vijayaraghavan, 2002). However countries that are in the growing stages, often at lower-income, are those that are starting industrialization, switching their energy use to sources that are often dirtier when it comes to pollution (Panayotou, 1993).

The theoretical explanation of the EKC can be described in three effects: the scale effect, the structure effect, and the abatement effect (Jaunky, 2011). The scale effect in the initial stages represent the industrialization of an early economy and the fact that this often requires high levels of input for output and manufacturing, depleting natural resources and creating the by-product of pollution. The structure effect represents the gradual shift in economies toward better and cleaner technologies that are often more efficient. The abatement effect represents a time in an economy when high-income countries become focused on the importance of environmental preservation. These three effects create the positive slope at the beginning of the EKC, the middle turning point, and the negative slope for the higher-income economy (Jaunky, 2011).

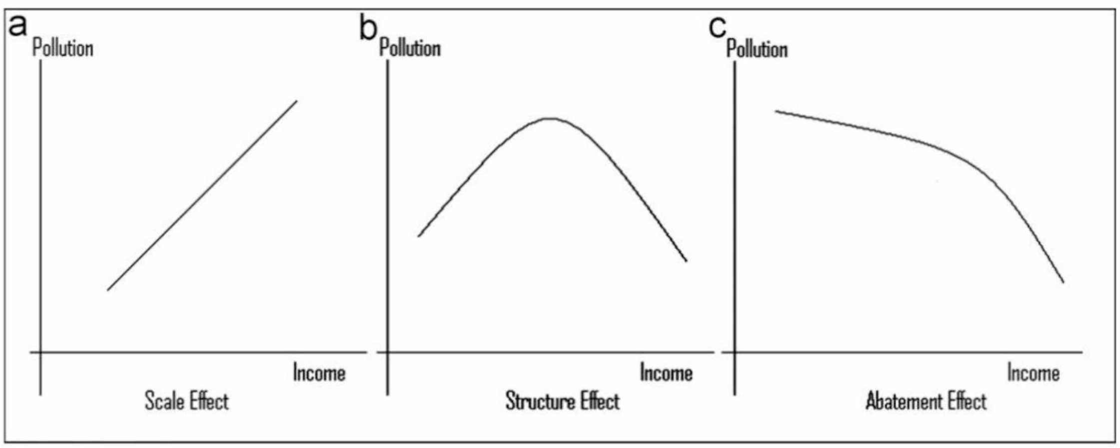

Figure 2: Different Effects of Income on Pollution
Source: Islam et al. (1999).

The explanation for this curve is not to imply that there are no environmental limits to growth or that there are "optimal" patterns of environmental degradation (Shafik & Bandyopadhyay, 1992). More specifically that once an economy reaches a certain level of growth and advancement in technology it will decrease its general pollution to the environment. The World Bank's *World Development Report 1992* examined the EKC hypothesis without using such specific terminology (World Bank, 1992). They determined factors that can effect environmental impact per unit of economic activity (Stern, Common, & Barbier, 1996). These factors include: structure, efficiency, clean technologies, and management practices. While the report did not claim that economic growth was the solution to environmental degradation, it did defend the previously mentioned factors and their benefits to the environment as a whole and how these factors would be increased with an increase in economic growth.

Models and Methods

In order to examine whether an EKC is shown to be present in the United States, panel data at a state level was obtained. Before moving forward with the models, it is necessary to determine the presence of unit roots in the data set to check for stationarity. According to Kim et al. (2010) estimators can be applied at I(0) and I(1) variables but not I(2) or higher. This unit root testing will ensure all variables are not I(2) by implementing the panel unit root tests of LLC, Breitung, IPS, Fisher ADF and Fisher PP.

An empirical approach, presented in Equation (1), is used to estimate the log-log quadratic model to estimate the relationship between GDP per capita and CO_2 emissions per capita taking into consideration energy consumption for Model 1A.

$$\ln((CO_2)_{it}) = \beta_{0t} + \beta_1 \ln(GDP_{it}) + \beta_2(\ln(GDP_{it}))^2 + \beta_3 \ln(NRE_{it}) + \beta_4 \ln(RE_{it}) + \mu_i + u_{it} \quad (1)$$

where $(CO_2)_t$ is CO_2 emissions per capita; GDP_t is per capita gross domestic product, NRE_t is non-renewable energy consumption, RE_t is renewable energy consumption, *i* being the number of states, *t* being the number of periods, and u_t represents errors that could be other causes of environmental degradation that are not taken into consideration in the model.

The different models in this study will be specified as the notation laid out in *Table 1*, which describes the sample size for each model and the important variables included. Subset models B through F for each model are those at specify a certain renewable energy broken out from the overall renewable energy consumption variable. The medthodology, results, and discussion of these subset models can be found in *Appendix B*. The specific GDP brackets are discussed in the next section, *Data Description* and a complete list can be found in *Appendix A*.

Table 1: Model Descriptions

Model	Part of Sample
1A	Aggregate model, 50 states plus D.C. and all renewables
2A	Disaggregate model, low GDP states, and all renewables
3A	Disaggregate model, medium GDP states, and all renewables
4A	Disaggregate model, high GDP states, and all renewables

According to the EKC hypothesis β_1 should be positive while β_2 should be a negative (Baek, 2015). This difference in signs represents the hypothesis that economic growth, here represented by per capita GDP, increase CO_2 emissions in the beginnings stages of industrialization and after a turning point, the continued growth after industrialization starts to decrease CO_2 emissions. The coefficient on non-renewable energy consumption is expected to positive since those energy sources are from fossil fuels. A negative coefficient for renewable energy consumption is the desired outcome of this study, which would indicate that renewable energy consumption is mitigating CO_2 emissions (Baek, 2016).

The ARDL(1,1,1,1) dynamic panel specification of Equation (1) is shown in Equation (2).

$$\Delta \ln(CO_{2it}) = \delta_{10i} \ln(GDP_{it}) + \delta_{11i} \ln\left(GDP_{i,t-1}\right) + \delta_{20i}(\ln(GDP_{it}))^2 + \delta_{21i}\left(\ln\left(GDP_{i,t-1}\right)\right)^2 + \delta_{30i} \ln(NRE_{it}) + \delta_{31i} \ln\left(NRE_{i,t-1}\right) + \delta_{40i} \ln(RE_{it}) + \delta_{41i} \ln\left(RE_{i,t-1}\right) + \lambda_i \ln\left(CO_{2i,t-1}\right) \mu_i + u_{it} \quad (2)$$

If the variables in either Equation (2) are I(1) and cointegrated, then the error term is an I(0) process for all variables (Blackburne & Frank, 2007). Cointegrated variables show responsiveness to any deviation from long run equilibrium, therefore an error correction model shows the short run dynamics of the variables in the model that are influenced by the deviation from equilibrium (Blackburne & Frank, 2007). This error correction reparameterization is shown in Equation (3) for the model in Equation (2).

$$\Delta \ln(CO_{2it}) = \phi_i\left[\ln\left(CO_{2i,t-1}\right) - \theta_{0i} - \theta_{1i} \ln(GDP_{it}) - \theta_{2i} \ln(GDP_{it})^2 - \theta_{3i} \ln(NRE_{it}) - \theta_{4i}\ln(RE_{it})\right] + \delta_{11i}\Delta \ln(GDP_{it}) + \delta_{21i}\Delta \ln(GDP_{it})^2 + \delta_{31i}\Delta \ln(NRE_{it}) + \delta_{41i}\Delta \ln(RE_{it}) + u_{it} \quad (3)$$

Where:

$$\phi_i = -(1-\lambda_i), \theta_{0i} = \frac{\mu_i}{1-\lambda_i}, \theta_{1i} = \frac{\delta_{10i}+\delta_{11i}}{1-\lambda_i}, \theta_{2i} = \frac{\delta_{20i}+\delta_{21i}}{1-\lambda_i}, \theta_{3i} = \frac{\delta_{30i}+\delta_{31i}}{1-\lambda_i}, \theta_{4i} = \frac{\delta_{40i}+\delta_{41i}}{1-\lambda_i}$$

The ϕ_i parameter is the error correction speed of adjustment, this along with the long run coefficients, $\theta_{1i}, \theta_{2i}, \theta_{3i}, \theta_{4i}, \theta_{5i}$ are of interest. With the inclusion of θ_{0i}, a non-zero mean of cointegration is allowed. For variables to exhibit a return to long run equilibrium ϕ_i is expected to be negative. These equations will be ran through the dynamic heterogeneous panel estimations of pooled and mean group calculations.

Data Description

The data used in this analysis was obtained from the following source: the Energy Information Administration (EIA), the Bureau of Economic Analysis (BEA), and the Federal Reserve Bank of St. Louis Economic Data (FRED). The dependent variable of CO_2 emissions from fossil fuels for each state was obtained from the EIA measured in million metric tons, which was then converted into per capita units with FRED estimates of annual population state per state. Annual gross domestic product (GDP) per capita for each state (including District of Columbia) was obtained from BEA data and represents the monetary value of all finished goods and serviced produced in each state divided by total midyear population in current dollars. The GDP data aggregated by state was only available back to 1987. For this analysis the time period of 1987-2015 was used. All GDP data was converted to constant dollars using the Consumer Price Index.

In order to try to tease out aggregate bias in the sample of states GDP brackets were formed. These were created by taking an average of the state's GDP over our time period, ranking them, and then dividing the sample into thirds to create three brackets. The low GDP bracket ranges from $36,274.00-$48,157.00, the middle GDP bracket from $48,157.01-$55,111.00, and the high GDP from $55,111.01-$176,089.00. The specific states that fall into these brackets can be found in the *Appendix A*.

The energy consumption variables, both renewable and non-renewable energy consumption data were obtained from EIA data. The non-renewable energy consumption variable represents energy that is sourced from fossil fuels. This variable includes coal, natural gas (excluding supplemental gaseous fuels), distillate fuel oil, jet fuel, LPG, motor gasoline (excluding fuel ethanol), residual fuel oil, and other. The renewable energy consumption variable includes energy from many different sources as well. These sources are hydroelectric power, biomass; which is further broken down to differentiate between wood and waste, fuel ethanol, and losses and co-products, geothermal, solar, and wind. Both energy consumption variables are measured in trillion Btus (British thermal units) and were converted to per capita units using the FRED annual population per state data. The renewable energy consumption variable was broken down further into geothermal, hydroelectric, biomass, solar, and wind to explore the significance of the individual energy consumptions in the United States. This dichotomy created of each renewable variable. For example for geothermal there were two variables one, of strictly just geothermal energy consumption, and then a variable that contained the rest of the renewable energy consumption from the sources of hydroelectric, biomass, solar, and wind. This structure is repeated for all of the types of renewables.

Descriptive statistics for each variable are provided in the following tables. *Table 2* for the aggregate model 1A, and *Tables 3, 4, & 5* for the disaggregate models 2A, 3A, and 4A. The difference between the non-renewable energy and renewable energy consumption for California is shown in *Figure 3*. *Figure 4* shows the percentage contribution of various fuel sources to US energy consumption, including geothermal energy. This provides the scale at which renewable energy consumption is utilized at a national level in comparison to other fuel sources.

Table 2: Descriptive Statistics for Aggregate Model 1A: All Renewables & All States

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	24.594 (19.465)	2.33	132.904	Tons per capita
GDP	Gross Domestic Product	54,906.83 (20,196.22)	32,018.05	195,488.60	Constant dollars per capita
NRE	Non-Renewable energy consumption	339,000,000 (247,000,000)	22,000,000	1,590,000,000	Btu per capita
RE	Renewable energy consumption	33,700,000 (38,700,000)	515,420.50	207,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 3: Descriptive Statistics for Aggregate Model 2A: All Renewables & Low GDP States

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	23.943 (11.509	2.33	65.192	Tons per capita
GDP	Gross Domestic Product	43,425.81 (4,666.91)	32,018.05	55,561.71	Constant dollars per capita
NRE	Non-Renewable energy consumption	320,000,000 (131,000,000)	223,100,000	763,000,000	Btu per capita
RE	Renewable energy consumption	46,100,000 (42,100,000)	3,389,634	188,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 4: Descriptive Statistics for Aggregate Model 3A: All Renewables & Medium GDP States

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	25.804 (15.482)	8.858	81.103	Tons per capita
GDP	Gross Domestic Product	50,938.00 (4,928.855)	36,403.50	81,300.59	Constant dollars per capita
NRE	Non-Renewable energy consumption	362,000,000 (208,000,000)	47,600,000	980,000,000	Btu per capita
RE	Renewable energy consumption	30,000,000 (34,600,000)	1,779,166	179,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 5: Descriptive Statistics for Aggregate Model 4A: All Renewables & High GDP States

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	24.040 (27.638)	4.249	132.904	Tons per capita
GDP	Gross Domestic Product	70,356.68 (28,146.02)	47,352.62	195,488.60	Constant dollars per capita
NRE	Non-Renewable energy consumption	334,000,000 (348,000,000)	22,000,000	1,590,000,000	Btu per capita
RE	Renewable energy consumption	248,000,000 (35,700,000)	515,420.50	207,000,000	Btu per capita

Note: Standard deviations in parentheses.

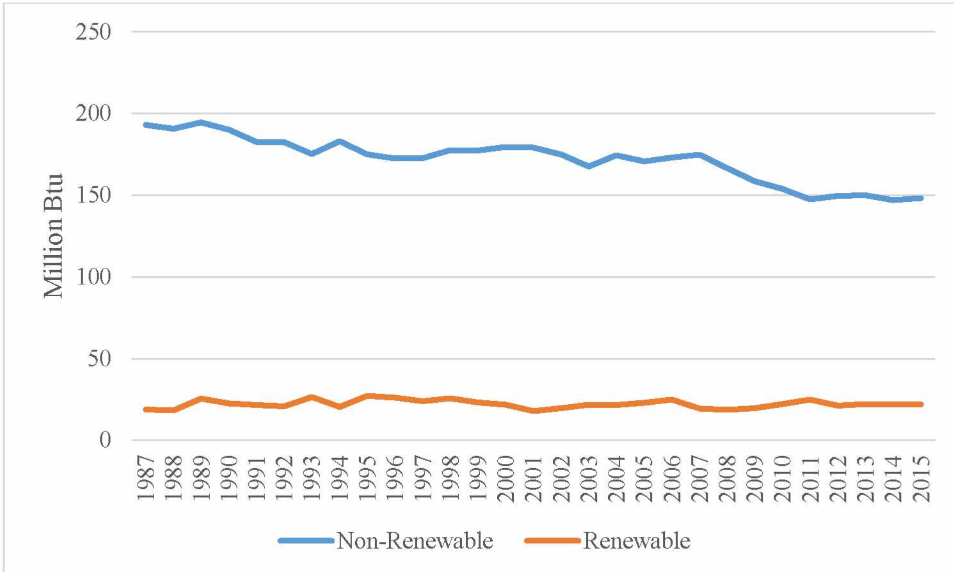

Figure 3: California's Energy Consumption between the years of 1987-2015, EIA.

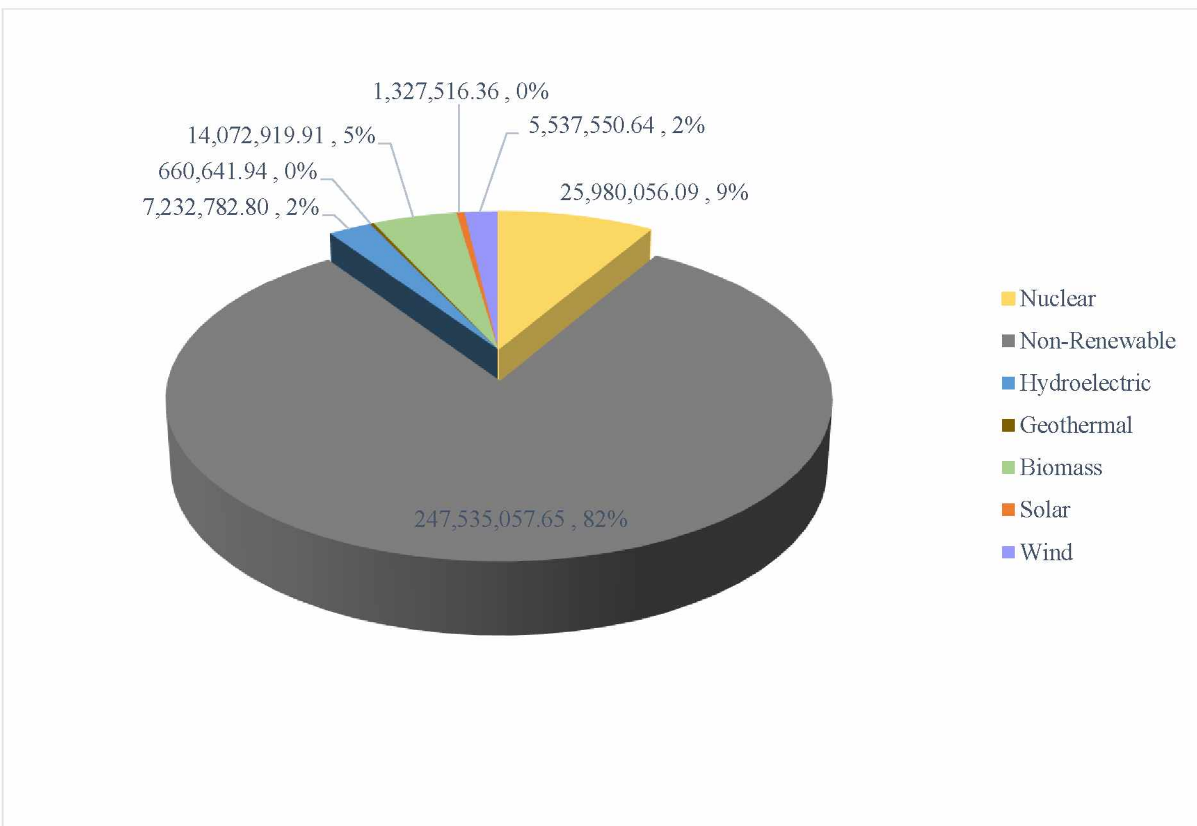

Figure 4: Energy Consumption for the United States by fuel sources in 2015, Btu per capita, EIA.

Estimation Results and Discussion

Testing for unit roots, they were found in all variables except those concerning the renewable energy consumption, including when it was broken out into the specific renewable energy consumption and other renewable energy consumption. For those variables where a unit root was found the variable was first differenced and then re-tested for a unit root. The renewable energy consumption variables were found to not have a unit root, however, will be first differenced along with the other variables as convergence is not achievable in the model without this step. All variables now can reject the null hypothesis at a 1% level of significance, so no unit roots going forward will affect the results. Results for these unit root tests separated by models can be seen in *Tables 6, 7, 8, & 9*.

Table 6: Results of panel unit root test with the Model 1: All Renewables & All States

Variable	Common Unit Root				Individual Unit Root					
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	-3.703	-17.335	3.453	-12.932	-1.089	-23.9941	283.079	845.839	319.012	4923.90
	(0.0001)	(0.0000)***	(0.9997)	(0.0000)***	(0.1381)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
GDP	2.356	-3.833	0.632	-11.9833	6.769	7.423	26.7826	216.933	22.875	551.655
	(0.9908)	(0.0001)***	(0.7364)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
GDP^2	2.330	-3.946	0.503	-11.929	6.655	-7.387	27.881	216.193	22.555	595.355
	(0.9901)	(0.0000)***	(0.6925)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
NRE	-0.832	-16.022	3.117	-9.860	1.67	-21.459	100.064	661.458	251.827	3892.99
	(0.2026)	(0.0000)***	(0.9991)	(0.0000)***	(0.9526)	(0.0000)***	(0.5357)	(0.0000)***	(0.0000)	(0.0000)***
RE	-3.834	-16.543	-0.203	-14.184	3.484	-19.321	168.606	252.177	226.905	2951.37
	(0.0001)	(0.0000)***	(0.4194)	(0.0000)***	(0.0002)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 7: Results of panel unit root test with the Model 2: All Renewables & Low GDP States

Variable	Common Unit Root				Individual Unit Root					
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	1.126	-7.426	3.462	-7.047	2.576	-12.127	22.733	187.508	73.474	1197.42
	(0.8700)	(0.0000)***	(0.9997)	(0.0000)***	(0.9950)	(0.0000)***	(0.9295)	(0.0000)***	(0.0001)	(0.0000)***
GDP	1.044	-1.837	1.255	-4.608	4.462	-5.348	7.971	86.505	4.544	165.238
	(0.8517)	(0.0331)**	(0.8953)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
GDP^2	1.044	-1.84	1.255	-7.601	4.462	-5.348	7.971	86.505	4.544	165.238
	(0.8517)	(0.0331)**	(0.8953)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
NRE	0.399	-6.797	2.894	-3.359	1.838	10.772	28.282	168.688	88.337	1265.54
	(0.6550)	(0.0000)***	(0.9981)	(0.0004)***	(0.9670)	(0.0000)***	(0.7436)	(0.0000)***	(0.0000)	(0.0000)***
RE	-0.994	-10.717	-1.184	-7.171	-2.134	-11.198	56.0015	175.351	90.108	1012.04
	(0.1600)	(0.0000)***	(0.1181)	(0.0000)***	(0.0164)	(0.0000)***	(0.0101)	(0.0000)***	(0.0000)	(0.0000)**

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 8: Results of panel unit root test with the Model 3: All Renewables & Medium GDP States

Variable	Common Unit Root					Individual Unit Root				
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	1.518	-10.466	2.543	-6.866	2.826	-14.013	17.167	219.501	47.739*	1279.59
	(0.9355)	(0.0000)***	(0.9945)	(0.0000)***	(0.9976)	(0.0000)***	(0.9928)	(0.0000)***	(0.0592)	(0.0000)***
GDP	-3.518***	-9.282***	-5.148***	-11.531***	-1.422*	-8.534***	41.164	129.233***	44.111	275.090***
	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0774)	(0.0000)	(0.1857)	(0.0000)	(0.1148)	(0.0000)
GDP^2	-3.493***	-9.283***	-5.068***	-11.491***	-1.411*	-8.525***	41.126	129.110***	44.011	274.929***
	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0791)	(0.0000)	(0.1867)	(0.0000)	(0.1168)	(0.0000)
NRE	0.663	-9.764***	1.624	-8.854***	1.355	12.435***	31.086	192.430***	107.203***	1403.66***
	(0.7466)	(0.0000)	(0.9478)	(0.0000)	(0.9124)	(0.0000)	(0.6112)	(0.0000)	(0.0000)	(0.0000)
RE	-1.917**	-8.705***	1.684	-8.636***	-0.634	-9.000***	38.341	139.705***	31.228	319.371***
	(0.0276)	(0.0000)	(0.9540)	(0.0000)	(0.2628)	(0.0000)	(0.2790)	(0.0000)	(0.6042)	(0.0000)

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 9: Results of panel unit root test with the Model 4: All Renewables & High GDP States

Variable	Common Unit Root					Individual Unit Root				
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	-0.294	-8.632***	1.103	-7.995***	1.260	-11.012***	26.057	169.956***	49.220**	1003.64***
	(0.3842)	(0.0000)	(0.8651)	(0.0000)	(0.8962)	(0.0000)	(0.8334)	(0.0000)	(0.0442)	(0.0000)
GDP	-3.096***	-10.407***	-4.410***	-11.270***	-1.382*	-8.644***	41.357	131.688***	50.493**	274.825***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0834)	(0.0000)	(0.1802)	(0.0000)	(0.0341)	(0.0000)
GDP^2	-3.114***	-10.404***	-4.389***	-11.252***	-1.377*	-8.642***	41.335	131.670***	50.413**	274.796***
	(0.0009)	(0.0000)	(0.0000)	(0.0000)	(0.0841)	(0.0000)	(0.1808)	(0.0000)	(0.0347)	(0.0000)
NRE	-2.357***	-10.977***	0.794	-7.098***	-0.299	-13.959***	40.695	300.341***	56.246***	1223.79***
	(0.0092)	(0.0000)	(0.7865)	(0.0000)	(0.3824)	(0.0000)	(0.1994)	(0.0000)	(0.0096)	(0.0000)
RE	-0.820	-7.481***	0.016	-9.336***	0.115	-8.628***	34.249	135.939***	32.662	342.954***
	(0.2060)	(0.0000)	(0.5064)	(0.0000)	(0.5461)	(0.0000)	(0.4558)	(0.0000)	(0.5331)	(0.0000)

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

To test whether there is evidence of a cointegration relationship between the variables, multiple panel cointegration tests were applied, suggested by Pedroni (1999). These results are presented in *Table 10*, divided by model. However, mixed results seen from these Pedroni's tests are not uncommon. To combat these contradicting results from Pedroni's tests an error correction term, ϕ_i in Equations (3), is used as an alternative criterion to explore a cointegration relationship between the variables (Baek & Choi, 2017) . These error correction terms are reported in the *Appendix B&C* with each model and in every case were negative and statistically significant, which provide evidence that there is a cointegration relationship between the variables in all models. Using an ARDL framework, the long and short run relationships established with the coefficients are only meaningful if cointegration is present. In a sense this is interpreted as any deviation in the variables of the models is not expected to remain and will eventually return to the trend of the variable in the long run

Table 10: Panel Cointegration test results for Models 1A, 2A, 3A, & 4A

Pedroni test	**1A**	**2A**	**3A**	**4A**
Panel $\boldsymbol{\upsilon}$–Statistic	-4.3778	2.3487	1.4389*	0.2034
Panel rho-Statistic	-0.3370	0.4734	-1.5595*	-2.2692**
Panel PP-Statistic	-31.7082***	-18.8992***	-12.4702***	-10.1744***
Panel ADF-Statistic	-16.5377***	-5.8515**	-2.4547***	-3.9566***
Group rho-Statistic	3.2834	1.79447	2.1923	2.4220
Group PP-Statistic	-23.9146***	-9.0342***	-15.2359***	-7.4675***
Group ADF-Statistic	-3.8550	-0.7464	-0.4131	-0.013

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Estimation results for the model represented in Equation (3) are presented in *Table 11* for both the Pooled Mean Group (PMG) regressions and the Mean Group (MG) regressions. The Hausman test was used to determine which method to efficiently estimate Equation (3). A Hausman test p-value greater than 0.05 indicates that the PMG model is efficient and its estimates should be used. The estimated Hausman test p-value of 0.5282 and a Chi squared value of 3.18, which means the efficient estimator under the null hypothesis, is the PMG estimator. However the coefficients do not yield evidence of an EKC at this aggregate model.

Table 11: MG and PMG Estimation results for Model 1A: All Renewables & All States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	15.786 (17.495)	4.698 (14.666)
$(\ln(GDP_t))^2$	-0.741 (0.807)	-0.232 (0.680)
$\ln(NRE_t)$	0.497*** (0.158)	0.681*** (0.112)
$\ln(RE_t)$	-0.014 (0.024)	-0.022 (0.021)
Constant	-6.942 (75.752)	-4.043*** (0.702)
Error-Correction Term	-0.474*** (0.054)	-0.253*** (0.044)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-41.104 (83.026)	-0.344 (0.713)
$(\ln(GDP_t))^2$	2.048 (3.906)	0.0135 (0.032)
$\ln(NRE_t)$	1.115*** (0.088)	1.096*** (0.009)
$\ln(RE_t)$	0.057 (0.055)	-0.016*** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

The intention of this model is to see a negative coefficient on renewable energy consumption, which would have meant that renewable energy consumption was significant in mitigating CO_2 emissions. While the correct sign is seen on the renewable energy variable, the overall model does not exhibit an EKC. With the results of Equation (3) result in statistically significant coefficients for renewable energy consumption, Equation (6) was modeled to further explore if the individual renewable energy consumptions had any significance. Full results and discussion for Models 1B-F can be found in the *Appendix B1*. Renewable energy not having a significant impact on CO_2 emissions is not necessarily inconsistent with the literature; in fact, the past studies have had contradictory results on this topic with similar time periods but slightly different panel structures.

To see if there is aggregate bias affecting the evidence of the EKC hypothesis the analysis continues with the separate GDP brackets. For the low GDP bracket states in Model 2 the same estimation tests are run as Model 1, with each type of renewable energy consumption separated. A list of the exact low GDP bracket states is in the *Appendix A*. For Model 2A the renewable energy variable was left in the general form only separating out from the non-renewable energy consumption. The results follow in *Table 12* showing both results from the MG and PMG estimators. A Hausman test resulted in a p-value of 0.3796 and a Chi squared value of 3.08, which indicate that the PMG estimator is the most efficient estimator under the null hypothesis for this model. Looking at the long run estimations for the PMG results all variables are statistically significant and the signs of the coefficients indicate the presence of an EKC. Like all the models in Model 1A-F the short run results are not statistically significant, which is a reasonable outcome when considering the benefits of renewable energy consumption will be seen over time. Full results and discussion for Models 2B-F can be found in the *Appendix B2*.

Table 12: MG and PMG Estimation results for Model 2A: All Renewable & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	36.931 (29.709)	4.666 (15.282)
$(\ln(GDP_t))^2$	-1.736 (1.400)	-0.219 (0.722)
$\ln(NRE_t)$	0.311* (0.177)	0.410** (0.199)
$\ln(RE_t)$	-0.034 (0.057)	0.003 (0.056)
Constant	111.649 (110.470)	-16.781*** (4.284)
Error-Correction Term	-0.481*** (0.081)	-0.303*** (0.077)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-240.050 (203.018)	6.984** (2.940)
$(\ln(GDP_t))^2$	11.469 (9.711)	-0.329** (0.137)
$\ln(NRE_t)$	0.962*** (0.128)	1.109*** (0.013)
$\ln(RE_t)$	-0.049 (0.080)	-0.024*** (0.005)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

While the low GDP bracket models were the most significant in interest and statistically, the medium and high GDP bracket states were also modeled. Most resulted in either inconclusive results or no statistical significance. *Table 13* presents the results for the medium GDP bracket states. This particular model does not reveal conclusive results. The PMG estimator would not converge so only MG results are presented. Since PMG could not run a Hausman test cannot be run either, therefore an efficient estimator cannot be chosen. Looking at the MG results in *Table*

7 the long run coefficients are not statistically significant and do not exhibit evidence of an EKC. Results for models 3B-F can be found in *Appendix B3*.

Table 13: MG and PMG Estimation results for Model 3A: All Renewables & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	120.155 (96.240)	-
$(\ln(GDP_t))^2$	-5.564 (4.444)	-
$\ln(NRE_t)$	0.323 (0.291)	-
$\ln(RE_t)$	-0.098 (0.112)	-
Constant	242.602 (455.277)	-
Error-Correction Term	-0.493** (0.168)	-
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-48.723 (118.249)	-
$(\ln(GDP_t))^2$	2.276 (5.451)	-
$\ln(NRE_t)$	0.953** (0.289)	-
$\ln(RE_t)$	0.056 (0.138)	-

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

The high GDP bracket results, seen in *Table 14*, represent a unique result in this analysis in that the Huasman test, with a p-value of 0.0149 and a Chi squared value of 12.35, indicates that the most efficient estimator in this model is the MG over the PMG results. Focusing on these MG results, there is only one statistically significant coefficient, non-renewable energy consumption, and the combination of all the coefficients do not yield evidence of an EKC for these high GDP bracket states. Results for models 4B-F can be found in *Appendix B4*.

Table 14: MG and PMG Estimation results for Model 4A: All Renewables & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-72.750 (57.491)	-41.189* (21.998)
$(\ln(GDP_t))^2$	3.280 (2.600)	1.865* (0.997)
$\ln(NRE_t)$	0.592 (0.466)	0.683** (0.304)
$\ln(RE_t)$	-0.465** (0.231)	-0.330* (0.193)
Constant	-595.095 (484.948)	-3.875** (1.087)
Error-Correction Term	-0.615*** (0.092)	-0.351** (0.099)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	74.235 (84.669)	-2.257 (2.688)
$(\ln(GDP_t))^2$	-3.386 (3.829)	0.099 (0.119)
$\ln(NRE_t)$	0.953*** (0.122)	1.392*** (0.049)
$\ln(RE_t)$	0.212 (0.183)	-0.005 (0.013)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

These results can be explained with the GDP categories themselves. They were created to represent thirds of the sample size, however this created a very narrow bracket for the medium bracket, $48,157.01 to $55,111.00, and an exceedingly large high GDP bracket, $55,111.01 to $176,089.00. *Figure 5* displays the medium GDP bracket states average GDP over the sample time period, 1987-2015, in comparison with the Y-axis representing the full range of values in the aggregate model. With this middle third of the data the slope between the GDP values is very small, which is likely to be the reason the medium GDP bracket states model would not converge with the PMG estimator. With future work on this subject and with this data these GDP brackets could be reconfigured, or even drop the District of Columbia as it could be considered an outlier.

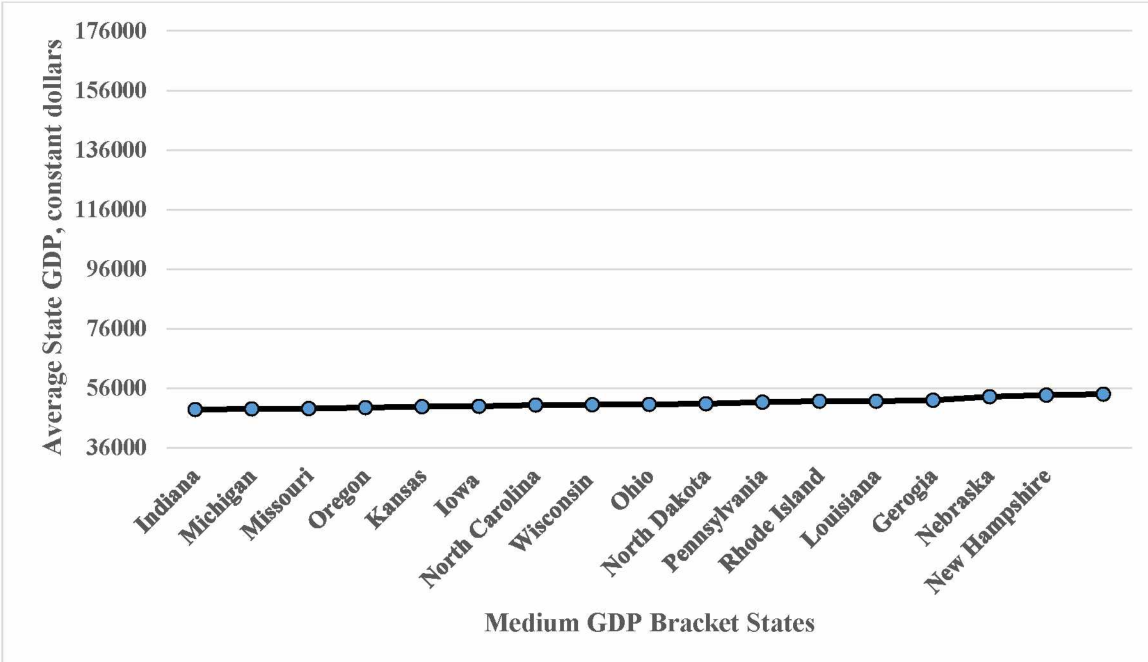

Figure 5: Average GDP in Medium GDP Bracket States for 1987-2015, EIA

While literature has shown contrasting results for an EKC in the United States this study shows that with a PMG estimation in the long run there is statistically significant evidence of an EKC where renewable energy consumption plays a role in mitigating the CO_2 emissions and that the variables are cointegrated. While the second model with only low GDP states was expected to have weak results, the results do mirror the first model and strengthen the results in that the coefficients still exhibit the correct signs for an EKC. With the EKC hypothesis more prominent in low GDP/income countries it also follows logic that the medium and high GDP brackets in this analysis did not yield conclusive results.

EKC research has been around for quite some time and those who criticize the hypothesis present many arguments. A common one is that this relationship is based on correlation but not causation. That if CO_2 emissions decline in the long run, that doesn't dismiss what damage has been done in the past for what has accumulated. More econometric criticisms focus on issues in: heteroskedasticity, omitted variable bias, simultaneity, and problems with cointegration (Stern, 2004). Different post estimation tests can be done to work with the data to alleviate some of these issues. Further research and analysis in this topic could be expanding into different type of environmental degradation for the United States. Other studies have used variables such as water pollution, deforestation, etc. In a study by Caviglia-Harris, Chambers, & Kahn (2009) they looked at the ecological footprint of a country as the measure of environmental degradation. Exploring this type of dependent variable could open new insight into different aspect of the relationship between the environment and economic growth.

Conclusions and Policy Implications

According to the estimates from the Equation (3) model, there is not evidence of an Environmental Kuznets Curve in the United States at an aggregate level when concerning state GDP. Out of the models tested with specific renewable energies, only wind energy consumption yielded statistically significant results for the aggregate model while holding evidence for an EKC. Looking at the three disaggregate models with low, medium, and high GDP bracket categorization only the low GDP bracket model yielded results of an Environmental Kuznets Curve hypothesis, with the subset testing showing biomass, solar, and wind having individual statistical significance. With the EKC hypothesis more prominent in low GDP/income countries it also follows logic that the medium and high GDP brackets in this analysis did not yield conclusive results.

The findings of this study have significant policy implications that could assist in the funding and implementation of renewable energy technologies. While CO_2 emissions are a popular measure of environmental quality, an increase in the implementation of renewable energy technologies would help mitigate pollution and other types of environmental degradation that occur when sourcing fossil fuels. An empirical study can help persuade policy makers and key energy industry stakeholders with sound evidence that is based not only on theory but data and facts, to increase policy and investment. With the topic of CO_2 emissions and other greenhouse gas emissions, and climate change in general, empirical analyses should be conducted and used to educate and induce behavioral changes in our society.

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Appendix A

GDP Brackets

Low GDP States: Alabama, Arizona, Arkansas, Florida, Idaho, Kentucky, Maine, Mississippi, Montana, New Mexico, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, Vermont, and West Virginia

Middle GDP States: Georgia, Indiana, Iowa, Kansas, Louisiana, Michigan, Missouri, Nebraska, New Hampshire, North Carolina, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, and Wisconsin

High GDP States: Alaska, California, Colorado, Connecticut, Delaware, District of Columbia, Hawaii, Illinois, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New York, Texas, Virginia, Washington, and Wyoming

Appendix B

B1: Results for Models 1B-F

Modeling the subsets of the main models, models B-F for each will estimate with the individual GDP bracket state and different renewable energy consumption variables broken out of the total renewable energy consumption variable, *Table 15* showing the exact variables in each subset. Descriptive statistics for models 1B-F are shown in *Table 16*. Following the same methodology as the main models unit root testing was conducted, *Table 17*, followed by cointegration testing, *Table 18*, before the MG and PMG estimators were applied.

Table 15: Model 1 Subset Descriptions

Model 1	50 States plus D.C.
1A	CO_2, GDP, GDP^2, NRE, & RE
1B	CO_2, GDP, GDP^2, NRE, ORG, & GE
1C	CO_2, GDP, GDP^2, NRE, ORH, & HE
1D	CO_2, GDP, GDP^2, NRE, ORB, & BE
1E	CO_2, GDP, GDP^2, NRE, ORS, & SE
1F	CO_2, GDP, GDP^2, NRE, ORW, & WE

Table 16: Descriptive Statistics for Disaggregate Models 1B-F

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	24.594 (19.465)	2.33	132.904	Tons per capita
GDP	Gross Domestic Product	54,906.83 (20,196.22)	32,018.05	195,488.60	Constant dollars per capita
NRE	Non-Renewable energy consumption	339,000,000 (247,000,000)	22,000,000	1,590,000,000	Btu per capita
RE	Renewable energy consumption	33,700,000 (38,700,000)	515,420.50	207,000,000	Btu per capita
GE	Geothermal energy consumption	432,798.9 (1,269,582)	0	12,200,000	Btu per capita
ORG	All other renewable energy consumption expect geothermal	33,300,000 (38,700,000)	515,420.50	207,000,000	Btu per capita
HE	Hydroelectric energy consumption	15,900,000 (30,800,000)	-417,169.6	190,000,000	Btu per capita
ORH	All other renewable energy consumption expect hydroelectric	17,800,000 (18,900,000)	35,45473	130,000,000	Btu per capita
BE	Biomass energy consumption	15,100,000 (15,700,000)	515,420.5	106,000,000	Btu per capita
ORB	All other renewable energy consumption expect biomass	18,700,000 (32,400,000)	-926,509.2	190,000,000	Btu per capita
SE	Solar energy consumption	193,313.7 (586,435)	0	7,069,973	Btu per capita
ORS	All other renewable energy consumption expect solar	33,500,000 (38,800,000)	515,420.5	207,000,000	Btu per capita
WE	Wind Energy	2,115,512 (8,015,354)	0	80,100,000	Btu per capita
ORW	All other renewable energy consumption expect wind	31,600,000 (36,800,000)	515,420.5	207,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 17: Results of panel unit root test with the Models 1B-F

	Common Unit Root				Individual Unit Root					
Variable	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	-3.703	-17.335	3.453	-12.932	-1.089	-23.9941	283.079	845.839	319.012	4923.90
	(0.0001)	(0.0000)***	(0.9997)	(0.0000)***	(0.1381)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
GDP	2.356	-3.833	0.632	-11.9833	6.769	7.423	26.7826	216.933	22.875	551.655
	(0.9908)	(0.0001)***	(0.7364)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
GDP^2	2.330	-3.946	0.503	-11.929	6.655	-7.387	27.881	216.193	22.555	595.355
	(0.9901)	(0.0000)***	(0.6925)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***	(1.0000)	(0.0000)***
NRE	-0.832	-16.022	3.117	-9.860	1.67	-21.459	100.064	661.458	251.827	3892.99
	(0.2026)	(0.0000)***	(0.9991)	(0.0000)***	(0.9526)	(0.0000)***	(0.5357)	(0.0000)***	(0.0000)	(0.0000)***
RE	-3.834	-16.543	-0.203	-14.184	3.484	-19.321	168.606	252.177	226.905	2951.37
	(0.0001)	(0.0000)***	(0.4194)	(0.0000)***	(0.0002)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
GE	-324.202	-306.636	0.841	-2.296	-291.648	-252.510	8478.78	7661.69	6793.14	757.066
	(0.0000)	(0.0000)***	(0.7999)	(0.0108)**	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
ORG	-3.826	-16.057	-0.167	-14.212	-3.408	-19.245	167.314	523.101	237.735	2971.45
	(0.0001)	(0.0000)***	(0.4337)	(0.0000)***	(0.0003)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
HE	-15.437	-14.214	-4.743	-14.230	-12.654	-21.595	551.609	567.931	604.533	4014.67
	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
ORH	-5.990	-18.364	0.839	-123.779	-5.614	-21.314	208.127	584.899	475.346	4086.16
	(0.0000)	(0.0000)***	(0.7993)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
BE	-5.381	-13.289	-0.365	-12.126	-4.119	-16.820	176.933	452.778	182.465	1968.36
	(0.0000)	(0.0000)***	(0.3576)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
ORB	-69.9158	-60.364	-2.090	-10.413	-36.4383	-44.014	1789.38	2100.71	643.820	5213.77
	(0.0000)	(0.0000)***	(0.0183)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
SE	-160.236	-311.406	1.400	-0.992	-115.889	-183.990	5118.29	6233.00	1725.23	667.022
	(0.0000)	(0.0000)***	(0.9192)	(0.1606)	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
ORS	-4.274	-16.319	-0.616	-14.007	-3.954	-19.177	177.181	521.084	232.763	2980.99
	(0.0000)	(0.0000)***	(0.2691)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
WE	-39.433	-87.895	-1.775	-13.081	-9.806	-24.096	300.464	470.166	296.077	439.703
	(0.0000)	(0.0000)***	(0.0379)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***
ORW	-4.045	-17.074	-2.579	-15.124	-5.077	-19.895	194.324	537.330	257.297	3217.05
	(0.0000)	(0.0000)***	(0.0050)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***	(0.0000)	(0.0000)***

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 18: Panel Cointegration test results for Models 1B-F

Pedroni test	**1A**	**1B**	**1C**	**1D**	**1E**	**1F**
Panel v–Statistic	-4.3778	-6.5187	-6.1932	-5.1146	-6.9308	-6.8922
Panel rho-Statistic	-0.3370	2.5975	2.1492	2.2306	2.0584	1.8914
Panel PP-Statistic	-31.7082***	-40.2720***	-32.1163***	-33.4254***	-38.8477***	-31.1333***
Panel ADF-Statistic	-16.5377***	-12.5255***	-12.7513***	-13.4878***	-13.2187***	-12.0083***
Group rho-Statistic	3.2834	5.4858	4.9478	5.4195	4.5269	4.1262
Group PP-Statistic	-23.9146***	-24.3892***	-23.6972***	-25.0152***	-31.0260***	-29.0703***
Group ADF-Statistic	-3.8550	0.2166	-0.4734	-1.1865	-2.5805***	-3.9996***

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

For example, Model 1B, has geothermal energy consumption broken out into a separate variable to estimate its affect to the EKC in Equation (4).

$$\ln((CO_2)_{it}) = \beta_{0t} + \beta_1 \ln(GDP_{it}) + \beta_2(\ln(GDP_{it}))^2 + \beta_3 \ln(NRE_{it}) + \beta_4 \ln(OR_{it}) + \beta_5 \ln(GE_{it}) + \mu_i + u_{ti} \quad (4)$$

The ARDL(1,1,1,1,1) dynamic panel specification of Equation (4) is shown in Equation (5).

$$\begin{aligned}\Delta \ln(CO_{2it}) = {} & \delta_{10i} \ln(GDP_{it}) + \delta_{11i} \ln\left(GDP_{i,t-1}\right) + \delta_{20i}(\ln(GDP_{it}))^2 + \delta_{21i}\left(\ln\left(GDP_{i,t-1}\right)\right)^2 + \\ & \delta_{30i} \ln(NRE_{it}) + \delta_{31i} \ln\left(NRE_{i,t-1}\right) + \delta_{40i} \ln(OR_{it}) + \delta_{41i} \ln\left(OR_{i,t-1}\right) + \\ & \delta_{50i} \ln(GE_{it}) + \delta_{51i} \ln\left(GE_{i,t-1}\right) + \lambda_i \ln\left(CO_{2i,t-1}\right) \mu_i + u_{it} \qquad (5)\end{aligned}$$

The error correction reparameterization of Equation (5) is shown in Equation (6).

$$\begin{aligned}\Delta \ln(CO_{2it}) = {} & \phi_i\left[\ln\left(CO_{2i,t-1}\right) - \theta_{0i} - \theta_{1i} \ln(GDP_{it}) - \theta_{2i} \ln(GDP_{it})^2 - \theta_{3i} \ln(NRE_{it}) - \right. \\ & \left. \theta_{4i} \ln(OR_{it}) - \theta_{5i}\ln(GE_{it})\right] + \delta_{11i}\Delta \ln(GDP_{it}) + \delta_{21i}\Delta \ln(GDP_{it})^2 + \\ & \delta_{31i}\Delta \ln(NRE_{it}) + \delta_{41i}\Delta \ln(OR_{it}) + \delta_{51i}\Delta\ln(GE_{it}) + u_{it} \qquad (6)\end{aligned}$$

Where:

$$\phi_i = -(1-\lambda_i), \theta_{0i} = \frac{\mu_i}{1-\lambda_i}, \theta_{1i} = \frac{\delta_{10i} + \delta_{11i}}{1-\lambda_i}, \theta_{2i} = \frac{\delta_{20i} + \delta_{21i}}{1-\lambda_i}, \theta_{3i} = \frac{\delta_{30i} + \delta_{31i}}{1-\lambda_i}$$

$$\theta_{4i} = \frac{\delta_{40i}+\delta_{41i}}{1-\lambda_i}, \theta_{5i} = \frac{\delta_{50i}+\delta_{51i}}{1-\lambda_i}$$

The same methodology was used as that with Equation (3) is utilized for the individual renewable energy subsets and through a Hausman test was used to decide the efficient estimator between the MG and PMG estimators. *Table 19* shows the Hausman test results and the long run statistical significance of the important variables in each model as well if there is evidence of an EKC in the long run. These results for Equation (6) and the other renewable variables are similar in the long run to those found for Equation (5) with the signs of the coefficients indicating evidence of an EKC in the long run. Models that specified the individual renewable energy technologies of solar and wind were the only ones to exhibit evidence of an EKC through this methodology as well as exhibiting evidence of an EKC in the long run. Full tables of results can be seen in *Tables 20-24*.

Table 19: Model 1B-F Results

MODEL	IMPORTANT VARIABLE	P-VALUE	CHI SQUARED VALUE	LONG RUN EKC?
1B	Geothermal	0.5551	3.96	**NO**
1C	Hydroelectric	0.5615	1.15	**NO**
1D	Biomass	0.1954	7.36	**NO**
1E	Solar***	0.3343	4.57	**NO**
1F	Wind***	0.4083	3.98	**YES**

Note: *** represents statistical significance of that variable in the long run in the model

Wind energy is a type of renewable energy technology that is abundant and well known in society. With this technologies long history of utilization and research & design it can also be incorporated into hybrid systems to decrease the demand of fossil fuel sources, especially during peak hours for utility companies. In a regression analysis looking at factors on the price of wind energy, the authors found wind energy to be cost competitive with natural gas-fired power generation (Berry, 2009). Current policy driving wind energy implementation, the Renewable Electricity Production Tax Credit (PTC), is a phasedown program ending after 2019. While this means there are current wind farms being constructed this phasedown does create an unstable future for wind energy consumption unless more policy is enacted. These small policy changes can be driven with the evidence of an EKC curve for the United States to increase investment and policy on renewable energies while changing the shape of our curve as an example to industrializing countries.

Table 20: MG and PMG Estimation results for Model 1B: Geothermal Energy & All States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	17.110 (41.182)	-16.482 (19.762)
$(\ln(GDP_t))^2$	-0.839 (1.897)	0.751 (0.912)
$\ln(NRE_t)$	0.533** (0.222)	0.542*** (0.151)
$\ln(GE_t)$	-0.041 (0.038)	-0.023 (0.022)
$\ln(ORG_t)$	-0.156** (0.074)	-0.141* (0.073)
Constant	-70.165 (264.914)	-6.240*** (2.346)
Error-Correction Term	-0.581*** (0.071)	-0.289*** (0.108)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-110.225 (120.789)	0.681 (0.698)
$(\ln(GDP_t))^2$	5.290 (5.721)	-0.033 (0.030)
$\ln(NRE_t)$	0.849*** (0.139)	1.093*** (0.010)
$\ln(GE_t)$	0.036 (0.040)	0.0002 (0.0002)
$\ln(ORG_t)$	0.032 (0.087)	-0.009*** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 21: MG and PMG Estimation results for Model 1C: Hydroelectric Energy & All States

Short Run		
Variable	**MG**	**PMG**
$\mathbf{ln}(\boldsymbol{GDP_t})$	21.402 (54.749)	-6.726 (22.930)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-1.023 (2.524)	0.302 (1.058)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.330 (0.210)	0.534** (0.193)
$\mathbf{ln}(\boldsymbol{HE_t})$	-0.095 (0.070)	-0.046 (0.031)
$\mathbf{ln}(\boldsymbol{ORH_t})$	-0.138* (0.072)	-0.098 (0.077)
Constant	-150.570 (267.090)	-5.543** (2.362)
Error-Correction Term	-0.602*** (0.062)	-0.266** (0.113)
Long Run		
Variable	MG	PMG
$\mathbf{ln}(\boldsymbol{GDP_t})$	2668.46 (1970.519)	0.514 (0.725)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-122.310 (90.259)	-0.025 (0.033)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.875 (2.966)	1.099*** (0.011)
$\mathbf{ln}(\boldsymbol{HE_t})$	-1.320 (1.010)	-0.001 (0.001)
$\mathbf{ln}(\boldsymbol{ORH_t})$	0.427 (1.260)	-0.014** (0.001)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 22: MG and PMG Estimation results for Model 1D: Biomass Energy & All States

Short Run		
Variable	**MG**	**PMG**
$\mathbf{ln}(\boldsymbol{GDP_t})$	20.258 (55.644)	-2.394 (16.251)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-0.973 (2.563)	0.107 (0.750)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.370* (0.197)	0.518*** (0.141)
$\mathbf{ln}(\boldsymbol{BE_t})$	-0.147** (0.068)	-0.099 (0.070)
$\mathbf{ln}(\boldsymbol{ORB_t})$	-0.080 (0.078)	-0.057 (0.037)
Constant	-161.247 (244.906)	-6.810** (2.239)
Error-Correction Term	-0.613*** (0.061)	-0.266** (0.087)
Long Run		
Variable	MG	PMG
$\mathbf{ln}(\boldsymbol{GDP_t})$	24.324 (49.242)	0.993 (1.266)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-1.071 (2.258)	-0.046 (0.058)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.896 (0.144)	1.221*** (0.017)
$\mathbf{ln}(\boldsymbol{BE_t})$	0.031 (0.078)	-0.023*** (0.003)
$\mathbf{ln}(\boldsymbol{ORB_t})$	0.046 (0.069)	-0.007*** (0.001)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 23: MG and PMG Estimation results for Model 1E: Solar Energy & All States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	36.780 (35.215)	-22.694 (18.967)
$(\ln(GDP_t))^2$	-1.743 (1.620)	1.042 (0.875)
$\ln(NRE_t)$	0.348 (0.232)	0.481** (0.151)
$\ln(SE_t)$	-0.005 (0.006)	0.003 (0.003)
$\ln(ORS_t)$	-0.184** (0.087)	-0.148* (0.076)
Constant	-131.137 (240.400)	-7.355** (2.671)
Error-Correction Term	-0.596*** (0.067)	-0.303*** (0.110)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-4.184 (47.312)	1.187 (0.625)
$(\ln(GDP_t))^2$	0.251 (2.172)	-0.056 (0.010)
$\ln(NRE_t)$	0.948*** (0.125)	1.087*** (0.028)
$\ln(SE_t)$	0.002 (0.004)	-0.001*** (0.0002)
$\ln(ORS_t)$	-0.035 (0.080)	-0.008*** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 24: MG and PMG Estimation results for Model 1F: Wind Energy & All States

Short Run		
Variable	**MG**	**PMG**
$\mathbf{ln}(\boldsymbol{GDP_t})$	42.716 (43.024)	-24.410 (17.156)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-2.019 (1.986)	1.112 (0.791)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.362* (0.201)	0.509*** (0.139)
$\mathbf{ln}(\boldsymbol{WE_t})$	-0.0007 (0.001)	-0.002* (0.001)
$\mathbf{ln}(\boldsymbol{ORW_t})$	-0.187** (0.078)	-0.136** (0.064)
Constant	-81.850 (250.711)	-7.153** (2.660)
Error-Correction Term	-0.574*** (0.075)	-0.280** (0.104)
Long Run		
Variable	MG	PMG
$\mathbf{ln}(\boldsymbol{GDP_t})$	-91.664 (83.787)	1.408** (0.632)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	4.379 (3.955)	-0.067** (0.028)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.791*** (0.172)	1.104*** (0.010)
$\mathbf{ln}(\boldsymbol{WE_t})$	-0.003 (0.002)	-0.0005*** (0.0001)
$\mathbf{ln}(\boldsymbol{ORW_t})$	0.066 (0.075)	-0.017*** (0.003)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

B2: Results for Models 2B-F

Mirroring the same structure as Models 1B-F, the individual renewable energy consumption variables were broken out of the all renewable energy consumption variable specifically for the low GDP bracket states. Exact variables in each model are explained in Table 25. Descriptive statistics, unit root testing, and cointegration tests are shown in *Tables 26, 27, & 28* respectfully.

Table 25: Model 2 Subset Descriptions

Model 2	Low GDP Bracket states
2A	CO_2, GDP, GDP^2, NRE, & RE
2B	CO_2, GDP, GDP^2, NRE, ORG, & GE
2C	CO_2, GDP, GDP^2, NRE, ORH, & HE
2D	CO_2, GDP, GDP^2, NRE, ORB, & BE
2E	CO_2, GDP, GDP^2, NRE, ORS, & SE
2F	CO_2, GDP, GDP^2, NRE, ORW, & WE

Table 26: Descriptive Statistics for Disaggregate Models 2B-F

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	23.943 (11.509	2.33	65.192	Tons per capita
GDP	Gross Domestic Product	43,425.81 (4,666.91)	32,018.05	55,561.71	Constant dollars per capita
NRE	Non-Renewable energy consumption	320,000,000 (131,000,000)	223,100,000	763,000,000	Btu per capita
RE	Renewable energy consumption	46,100,000 (42,100,000)	3,389,634	188,000,000	Btu per capita
GE	Geothermal energy consumption	258,625.3 (437,101.8)	0	2,426,013	Btu per capita
ORG	All other renewable energy consumption expect geothermal	46,100,000 (42,100,000)	3,389,634	185,000,000	Btu per capita
HE	Hydroelectric energy consumption	23,600,000 (32,100,000)	0	163,000,000	Btu per capita
ORH	All other renewable energy consumption expect hydroelectric	22,800,000 (22,900,000)	2,229,140	110,000,000	Btu per capita
BE	Biomass energy consumption	20,800,000 (21,700,000)	1,499,013	106,000,000	Btu per capita
ORB	All other renewable energy consumption expect biomass	25,600,000 (33,100,000)	0	163,000,000	Btu per capita
SE	Solar energy consumption	238,721.9 (675,653.4)	0	7,069,973	Btu per capita
ORS	All other renewable energy consumption expect solar	46,100,000 (42,300,000)	4,094,579	188,000,000	Btu per capita
WE	Wind Energy	1,498,549 (4,645,062)	0	33,500,000	Btu per capita
ORW	All other renewable energy consumption expect wind	44,900,000 (41,000,000)	3,466,736	181,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 27: Results of panel unit root test with the Models 2B-F

Variable	Common Unit Root				Individual Unit Root					
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	1.126 (0.8700)	-7.426 (0.0000)***	3.462 (0.9997)	-7.047 (0.0000)***	2.576 (0.9950)	-12.127 (0.0000)***	22.733 (0.9295)	187.508 (0.0000)***	73.474 (0.0001)	1197.42 (0.0000)***
GDP	1.044 (0.8517)	-1.837 (0.0331)**	1.255 (0.8953)	-4.608 (0.0000)***	4.462 (1.0000)	-5.348 (0.0000)***	7.971 (1.0000)	86.505 (0.0000)***	4.544 (1.0000)	165.238 (0.0000)***
GDP^2	1.044 (0.8517)	-1.84 (0.0331)**	1.255 (0.8953)	-7.601 (0.0000)***	4.462 (1.0000)	-5.348 (0.0000)***	7.971 (1.0000)	86.505 (0.0000)***	4.544 (1.0000)	165.238 (0.0000)***
NRE	0.399 (0.6550)	-6.797 (0.0000)***	2.894 (0.9981)	-3.359 (0.0004)***	1.838 (0.9670)	10.772 (0.0000)***	28.282 (0.7436)	168.688 (0.0000)***	88.337 (0.0000)	1265.54 (0.0000)***
RE	-0.994 (0.1600)	-10.717 (0.0000)***	-1.184 (0.1181)	-7.171 (0.0000)***	-2.134 (0.0164)	-11.198 (0.0000)***	56.0015 (0.0101)	175.351 (0.0000)***	90.108 (0.0000)	1012.04 (0.0000)**
GE	-142.138 (0.0000)	-135.586 (0.0000)***	0.255 (0.6006)	-1.799 (0.0360)**	-122.394 (0.0000)	-98.548 (0.0000)***	2111.84 (0.0000)	1948.90 (0.0000)***	1614.68 (0.0000)	257.234 (0.0000)***
ORG	-0.998 (0.1591)	-10.168 (0.0000)***	-1.195 (0.1160)	-7.122 (0.000)***	-2.142 (0.0161)	-11.073 (0.0000)***	55.884 (0.0104)	173.688 (0.0000)***	90.356 (0.0000)	1011.96 (0.0000)***
HE	-5.507 (0.0000)	-9.440 (0.0000)***	-4.162 (0.0000)	-9.245 (0.0000)**	-5.882 (0.0000)	-11.125 (0.0000)***	92.187 (0.0000)	166.406 (0.0000)***	340.726 (0.0000)	881.671 (0.0000)***
ORH	-3.665 (0.0001)	-11.256 (0.0000)***	0.121 (0.5483)	-7.692 (0.0000)***	-4.27 (0.0000)	-11.977 (0.0000)***	81.2847 (0.0000)	188.632 (0.0000)***	184.793 (0.0000)	1263.88 (0.0000)***
BE	-4.865 (0.0000)	-8.667 (0.0000)***	-1.464 (0.0716)	-8.106 (0.0000)***	-4.539 (0.0000)	-11.098 (0.0000)***	81.937 (0.0000)	173.429 (0.0000)***	73.273 (0.0001)	790.335 (0.0000)***
ORB	-27.537 (0.0000)	-47.242 (0.0000)***	-2.081 (0.0187)	-5.894 (0.0000)***	-16.094 (0.0000)	-31.869 (0.0000)***	607.399 (0.0000)	716.052 (0.0000)***	155.215 (0.0000)	2075.33 (0.0000)***
SE	-120.174 (0.0000)	-256.083 (0.0000)***	1.036 (0.8498)	-0.94932 (0.1712)	-77.358 (0.0000)	-120.043 (0.0000)***	1393.55 (0.0000)	1640.44 (0.0000)***	756.026 (0.0000)	209.279 (0.0000)***
ORS	-1.111 (0.1332)	-10.564 (0.0000)***	-1.851 (0.0321)	-7.411 (0.0000)***	-2.303 (0.0106)	-11.031 (0.0000)***	55.902 (0.0104)	172.721 (0.0000)***	91.577 (0.0000)	1012.55 (0.0000)***
WE	0.678 (0.7511)	-7.567 (0.0000)***	-0.982 (0.0237)	-8.792 (0.0000)***	0.750 (0.7734)	-4.715 (0.0000)***	12.121 (0.9548)	58.231 (0.0000)***	10.426 (0.9820)	124.250 (0.0000)***
ORW	-0.784 (0.2164)	-11.204 (0.0000)***	-1.993 (0.0231)	-7.466 (0.0000)***	-3.181 (0.0007)	-11.706 (0.0000)***	65.091 (0.0010)	181.774 (0.0000)***	100.498 (0.0000)	1263.18 (0.0000)***

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 28: Panel Cointegration test results for Models 2B-F

Pedroni test	**2A**	**2B**	**2C**	**2D**	**2E**	**2F**
Panel v–Statistic	2.3487	-2.0797	-0.1490	0.7529	-1.9591	-2.5612
Panel rho-Statistic	0.4734	2.1421	2.0227	1.0763	2.4778	2.2192
Panel PP-Statistic	-18.8992***	-35.3843***	-16.3992***	-13.5653***	-28.5177***	-34.8927***
Panel ADF-Statistic	-5.8515**	-5.9466**	-4.5311	-2.8866	-4.9452	-6.1926
Group rho-Statistic	1.79447	3.2303	3.0595	2.9996	2.7005	2.5716
Group PP-Statistic	-9.0342***	-12.4647***	-7.9688***	-7.6428***	-15.0555***	-15.0822***
Group ADF-Statistic	-0.7464	-0.8823	0.8143	0.3870	-1.3227*	-2.0304**

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 29 summarizes the results of the Model 2 subset models 2B-F. Following the results of Model 1 there are some models that exhibit evidence of an EKC and some models where the individual renewable energy consumption variables were statistically significant. The only model to not exhibit evidence of an EKC for the low GDP bracket states while the specific renewable energy consumption variable was statistically significant, was geothermal energy consumption. Hydroelectric, biomass, solar, and wind energy consumption were statistically significant in mitigating CO_2 emissions within evidence of a long run EKC. These results closely reflect the subset results of model 1 and suggest the importance of low average GDP states implementing renewable energy technologies into their energy consumption profiles. Full tables of results can be seen in *Tables 30-34.*

Table 29: Model 2B-F Results

MODEL	IMPORTANT VARIABLE	P-VALUE	CHI SQUARED VALUE	LONG RUN EKC?
2B	Geothermal	0.4129	2.86	**NO**
2C	Hydroelectric***	0.2525	6.59	**YES**
2D	Biomass***	0.3052	6.01	**YES**
2E	Solar***	0.1275	7.16	**YES**
2F	Wind***	0.5685	2.02	**YES**

Note: *** represents statistical significance of that variable in the long run in the model

Table 30:
MG and PMG Estimation results for Model 2B: Geothermal Energy & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	49.411 (43.230)	3.270 (15.730)
$(\ln(GDP_t))^2$	-2.326 (2.039)	-0.152 (0.743)
$\ln(NRE_t)$	0.242 (0.188)	0.439** (0.215)
$\ln(GE_t)$	0.004 (0.003)	0.001 (0.001)
$\ln(ORG_t)$	-0.072 (0.058)	0.0007 (0.066)
Constant	124.677 (131.495)	-0.870*** (0.242)
Error-Correction Term	-0.526*** (0.076)	-0.242** (0.068)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-350.897 (327.073)	-2.599 (5.495)
$(\ln(GDP_t))^2$	16.740 (15.604)	0.120 (0.256)
$\ln(NRE_t)$	1.004*** (0.132)	1.118*** (0.040)
$\ln(GE_t)$	-0.011 (0.009)	-0.005*** (0.001)
$\ln(ORG_t)$	-0.084 (0.009)	-0.067*** (0.010)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 31:
MG and PMG Estimation results for Model 2C: Hydroelectric Energy & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	34.513 (29.320)	7.121 (16.458)
$(\ln(GDP_t))^2$	-1.621 (1.382)	-0.334 (0.777)
$\ln(NRE_t)$	-0.230 (0.228)	0.332 (0.235)
$\ln(HE_t)$	-0.046 (0.066)	-0.018 (0.044)
$\ln(ORH_t)$	0.023 (0.039)	0.022 (0.028)
Constant	135.183 (104.572)	-22.286*** (5.508)
Error-Correction Term	-0.512*** (0.086)	-0.334*** (0.082)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-68.486** (33.698)	9.094** (2.676)
$(\ln(GDP_t))^2$	3.235** (1.585)	-0.425** (0.124)
$\ln(NRE_t)$	0.611** (0.233)	1.109*** (0.014)
$\ln(HE_t)$	-0.023 (0.076)	-0.010** (0.004)
$\ln(ORH_t)$	-0.280 (0.212)	-0.018*** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 32: MG and PMG Estimation results for Model 2D: Biomass Energy & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	31.460 (31.584)	9.591 (16.494)
$(\ln(GDP_t))^2$	-1.475 (1.488)	-0.451 (0.778)
$\ln(NRE_t)$	0.282 (0.200)	0.373* (0.217)
$\ln(BE_t)$	-0.029 (0.024)	0.017 (0.023)
$\ln(ORB_t)$	-0.016 (0.042)	-0.009 (0.036)
Constant	139.944 (99.108)	-22.965*** (5.916)
Error-Correction Term	-0.495*** (0.091)	-0.322** (0.082)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-48.496 (35.401)	9.975** (3.144)
$(\ln(GDP_t))^2$	2.293 (1.664)	-0.466** (0.052)
$\ln(NRE_t)$	0.937*** (0.144)	1.100*** (0.012)
$\ln(BE_t)$	0.094 (0.143)	-0.019*** (0.002)
$\ln(ORB_t)$	0.003 (0.043)	-0.009** (0.003)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 33: MG and PMG Estimation results for Model 2E: Solar Energy & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	40.674 (34.107)	4.033 (14.716)
$(\ln(GDP_t))^2$	-1.914 (1.609)	-0.190 (0.695)
$\ln(NRE_t)$	0.258 (0.177)	0.377* (0.202)
$\ln(SE_t)$	0.0002 (0.002)	0.0007 (0.008)
$\ln(ORS_t)$	-0.073 (0.056)	0.011 (0.064)
Constant	114.649 (120.573)	-17.739*** (4.344)
Error-Correction Term	-0.552*** (0.082)	-0.333*** (0.081)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-53.624* (32.384)	6.581** (2.537)
$(\ln(GDP_t))^2$	2.538* (1.524)	-0.309** (0.118)
$\ln(NRE_t)$	0.824*** (0.115)	1.100*** (0.011)
$\ln(SE_t)$	-0.002 (0.002)	-0.0008** (0.0002)
$\ln(ORS_t)$	-0.103 (0.104)	-0.011** (0.004)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 34: MG and PMG Estimation results for Model 2F: Wind Energy & Low GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	46.288* (27.704)	8.084 (15.536)
$(\ln(GDP_t))^2$	-2.178* (1.305)	-0.380 (0.734)
$\ln(NRE_t)$	0.282** (0.142)	0.384* (0.201)
$\ln(WE_t)$	0.0005 (0.0003)	0.0002 (0.0007)
$\ln(ORW_t)$	-0.025 (0.048)	0.006 (0.053)
Constant	167.353 (131.531)	-21.957*** (5.500)
Error-Correction Term	-0.554*** (0.090)	-0.324*** (0.081)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-244.876 (203.175)	9.417** (2.841)
$(\ln(GDP_t))^2$	11.700 (9.719)	-0.441** (0.132)
$\ln(NRE_t)$	0.916*** (0.177)	1.082*** (0.017)
$\ln(WE_t)$	-0.0008 (0.001)	-0.001*** (0.0002)
$\ln(ORW_t)$	-0.061 (0.069)	-0.034*** (0.006)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

B3: Results for Models 3B-F

Continuing with the subset models of the aggregate model 3A, the individual renewable energy consumption variables are broken out and estimated. Specific variables in each model is explained in *Table 35*. Keeping the same methodology, *Table 36* shows the descriptive statistics, *Table 37* depicts the unit root testing for this subset, and *Table 38* displaying the results of the cointegration tests.

Table 35: Model 3 Subset Descriptions

Model 3	**Medium GDP Bracket states**
3A	CO_2, GDP, GDP^2, NRE, & RE
3B	CO_2, GDP, GDP^2, NRE, ORG, & GE
3C	CO_2, GDP, GDP^2, NRE, ORH, & HE
3D	CO_2, GDP, GDP^2, NRE, ORB, & BE
3E	CO_2, GDP, GDP^2, NRE, ORS, & SE
3F	CO_2, GDP, GDP^2, NRE, ORW, & WE

Table 36: Descriptive Statistics for Disaggregate Models 3B-F

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	25.804 (15.482)	8.858	81.103	Tons per capita
GDP	Gross Domestic Product	50,938.00 (4,928.85)	36,403.50	81,300.59	Constant dollars per capita
NRE	Non-Renewable energy consumption	362,000,000 (208,000,000)	47,600,000	980,000,000	Btu per capita
RE	Renewable energy consumption	30,000,000 (34,600,000)	1,779,166	179,000,000	Btu per capita
GE	Geothermal energy consumption	153,704.1 (230,388.2)	0	1,458,840	Btu per capita
ORG	All other renewable energy consumption expect geothermal	29,800,000 (34,500,000)	1,779,166	178,000,000	Btu per capita
HE	Hydroelectric energy consumption	11,100,000 (26,600,000)	0	150,000,000	Btu per capita
ORH	All other renewable energy consumption expect hydroelectric	18,900,000 (19,600,000)	3,545,473	130,000,000	Btu per capita
BE	Biomass energy consumption	15,900,000 (12,600,000)	1,685,526	78,400,000	Btu per capita
ORB	All other renewable energy consumption expect biomass	14,100,000 (1,080,917)	0	162,000,000	Btu per capita
SE	Solar energy consumption	4,829,568 (586,435)	0	1,385,126	Btu per capita
ORS	All other renewable energy consumption expect solar	29,900,000 (34,600,000)	1,779,166	178,000,000	Btu per capita
WE	Wind Energy	2,884,877 (10,200,000)	0	80,100,000	Btu per capita
ORW	All other renewable energy consumption expect wind	27,100,000 (30,400,000)	1,779,166	179,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 37: Results of panel unit root test with the Models 3B-F

Variable	Common Unit Root				Individual Unit Root					
	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	1.518	-10.466***	2.543	-6.866***	2.826	-14.013***	17.167	219.501***	47.739*	1279.59***
	(0.9355)	(0.0000)	(0.9945)	(0.0000)	(0.9976)	(0.0000)	(0.9928)	(0.0000)	(0.0592)	(0.0000)
GDP	-3.518***	-9.282***	-5.148***	-11.531***	-1.422*	-8.534***	41.164	129.233***	44.111	275.090***
	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0774)	(0.0000)	(0.1857)	(0.0000)	(0.1148)	(0.0000)
GDP^2	-3.493***	-9.283***	-5.068***	-11.491***	-1.411*	-8.525***	41.126	129.110***	44.011	274.929***
	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0791)	(0.0000)	(0.1867)	(0.0000)	(0.1168)	(0.0000)
NRE	0.663	-9.764***	1.624	-8.854***	1.355	12.435***	31.086	192.430***	107.203***	1403.66***
	(0.7466)	(0.0000)	(0.9478)	(0.0000)	(0.9124)	(0.0000)	(0.6112)	(0.0000)	(0.0000)	(0.0000)
RE	-1.917**	-8.705***	1.684	-8.636***	-0.634	-9.000***	38.341	139.705***	31.228	319.371***
	(0.0276)	(0.0000)	(0.9540)	(0.0000)	(0.2628)	(0.0000)	(0.2790)	(0.0000)	(0.6042)	(0.0000)
GE	-156.533***	152.535***	0.941	-1.351*	-166.594***	-140.714***	2902.92***	2704.71***	2388.34***	253.540***
	(0.0000)	(0.0000)	(0.8267)	(0.0878)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORG	-1.885**	-8.610***	1.684	-8.685***	-0.616	-9.022***	38.137	140.017***	31.258	333.055***
	(0.0297)	(0.0000)	(0.9540)	(0.0000)	(0.2688)	(0.0000)	(0.2868)	(0.0000)	(0.6027)	(0.0000)
HE	-6.717***	-10.523***	-2.933***	-9.442***	-7.098***	-13.029***	113.864***	203.277***	147.268***	1542.02***
	(0.0000)	(0.0000)	(0.0017)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORH	-2.720***	-8.564***	2.331	-9.259***	-0.883	-9.659***	40.399	151.968***	45.069*	765.414***
	(0.0033)	(0.0000)	(0.9901)	(0.0000)	(0.1884)	(0.0000)	(0.2084)	(0.0000)	(0.0971)	(0.0000)
BE	-3.620***	-7.187***	1.355	-9.845***	-2.202**	-8.857***	55.918**	136.084***	50.227**	253.687***
	(0.0001)	(0.0000)	(0.9124)	(0.0000)	(0.0138)	(0.0000)	(0.0103)	(0.0000)	(0.0360)	(0.0000)
ORB	-39.571***	-23.255***	-1.049	-6.502***	-15.203***	-14.913***	318.112***	407.786***	240.697***	511.766***
	(0.0000)	(0.0000)	(0.1470)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
SE	-57.416***	-110.594***	2.547	0.364	-40.044***	-61.881***	1350.94***	1621.25***	373.998***	179.915***
	(0.0000)	(0.0000)	(0.9946)	(0.6425)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORS	-1.995**	-8.533***	1.626	-8.514***	-0.771	-9.008***	39.558	139.859***	32.326	320.753***
	(0.0230)	(0.0000)	(0.9481)	(0.0000)	(0.2201)	(0.0000)	(0.2356)	(0.0000)	(0.5498)	(0.0000)
WE	1.504	-8.527***	-0.683	-10.036***	1.263	-5.678***	12.129	75.688***	11.428	154.077***
	(0.9337)	(0.0000)	(0.2473)	(0.0000)	(0.8968)	(0.0000)	(0.9904)	(0.0000)	(0.9940)	(0.0000)
ORW	-1.628*	-9.331***	0.129	-9.489***	-1.516*	-9.487***	45.677*	145.669***	37.323	298.677***
	(0.0517)	(0.0000)	(0.5517)	(0.0000)	(0.0647)	(0.0000)	(0.0870)	(0.0000)	(0.3188)	(0.0000)

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 38: Panel Cointegration test results for Models 3B-F

Pedroni test	**3A**	**3B**	**3C**	**3D**	**3E**	**3F**
Panel υ–Statistic	1.4389*	0.7495	0.6431	0.9131	-1.8644	0.4619
Panel rho-Statistic	-1.5595*	-0.8500	-0.3070	-0.1961	-2.7468***	0.0618
Panel PP-Statistic	-12.4702***	-16.2688***	-11.9997***	-12.2289***	-22.5154***	-10.1351***
Panel ADF-Statistic	-2.4547***	-3.0249***	-1.4703*	-1.4985*	-8.2031***	-0.8558
Group rho-Statistic	2.1923	2.6709	3.0232	3.2253	2.8498	2.3614
Group PP-Statistic	-15.2359***	-13.9066***	-14.7078***	-14.2742***	-22.5683***	-18.4919***
Group ADF-Statistic	-0.4131	-0.6264	0.7923	-0.8186	-5.4247***	-3.0840***

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 39 summarizes the results of the subset models 3B-F. Similar to the results of the aggregate model 3A, model 3C specifically looking at hydroelectric energy would not converge within the PMG estimations. Even though the aggregate model 3A which included the overarching renewable energy consumption variable, did not converge to conclusive results the individual model looking at biomass energy consumption, model 3D, showed evidence for an EKC while the specific biomass variable was statistically significant. Full tables of results can be seen in *Tables 40-44.*

Table 39: Model 3B-F Results

MODEL	IMPORTANT VARIABLE	P-VALUE	CHI SQUARED VALUE	LONG RUN EKC?
3B	Geothermal***	0.8242	1.51	**NO**
3C	Hydroelectric	-	-	-
3D	Biomass***	0.1229	6.88	**YES**
3E	Solar***	0.5251	3.20	**NO**
3F	Wind***	0.7793	1.76	**NO**

Table 40: MG and PMG Estimation results for Model 3B: Geothermal Energy & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	100.43 (96.108)	-35.674 (48.188)
$(\ln(GDP_t))^2$	-4.665 (4.437)	1.657 (2.226)
$\ln(NRE_t)$	0.324 (0.272)	0.545** (0.218)
$\ln(GE_t)$	0.001 (0.002)	-0.004** (0.001)
$\ln(ORG_t)$	-0.066 (0.119)	-0.144 (0.095)
Constant	256.675 (501.445)	-38.904** (15.705)
Error-Correction Term	-0.524** (0.178)	-0.548** (0.221)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-38.667 (124.384)	10.579* (6.388)
$(\ln(GDP_t))^2$	1.819 (5.734)	-0.493* (0.294)
$\ln(NRE_t)$	0.856** (0.312)	0.850*** (0.053)
$\ln(GE_t)$	0.005 (0.006)	0.001* (0.001)
$\ln(ORG_t)$	0.063 (0.157)	0.042*** (0.001)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 41: MG and PMG Estimation results for Model 3C: Hydroelectric Energy & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	85.533 (154.681)	-
$(\ln(GDP_t))^2$	-3.964 (7.141)	-
$\ln(NRE_t)$	0.247 (0.385)	-
$\ln(HE_t)$	-0.043 (0.110)	-
$\ln(ORH_t)$	-0.140** (0.072)	-
Constant	-111.074 (671.340)	-
Error-Correction Term	-0.596*** (0.138)	-
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	8023.163 (5805.769)	-
$(\ln(GDP_t))^2$	-367.848 (265.909)	-
$\ln(NRE_t)$	0.898 (9.080)	-
$\ln(HE_t)$	-4.053 (2.974)	-
$\ln(ORH_t)$	1.495 (3.838)	-

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 42: MG and PMG Estimation results for Model 3D: Biomass Energy & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\mathbf{ln}(\boldsymbol{GDP_t})$	111.892 (152.675)	0.275 (57.872)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-5.188 (7.045)	0.002 (0.2.671)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.142 (0.287)	0.382* (0.221)
$\mathbf{ln}(\boldsymbol{BE_t})$	-0.121 (0.117)	-0.059 (0.062)
$\mathbf{ln}(\boldsymbol{ORB_t})$	0.100 (0.110)	-0.007 (0.062)
Constant	198.915 (510.351)	-17.849 (41.605)
Error-Correction Term	-0.685*** (0.131)	0.133 (0.311)
Long Run		
Variable	MG	PMG
$\mathbf{ln}(\boldsymbol{GDP_t})$	-1.418 (111.950)	21.377*** (3.253)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	0.097 (5.164)	-0.994*** (0.150)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.915* (0.357)	1.117*** (0.014)
$\mathbf{ln}(\boldsymbol{BE_t})$	0.049 (0.163)	-0.003 (0.004)
$\mathbf{ln}(\boldsymbol{ORB_t})$	-0.135 (0.116)	-0.005** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 43: MG and PMG Estimation results for Model 3E: Solar Energy & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	150.702* (77.555)	-46.191 (56.150)
$(\ln(GDP_t))^2$	-6.967* (3.579)	2.140 (2.596)
$\ln(NRE_t)$	-0.031 (0.514)	0.476* (0.261)
$\ln(SE_t)$	-0.015 (0.017)	-0.009 (0.005)
$\ln(ORS_t)$	-0.029 (0.112)	-0.105 (0.080)
Constant	169.422 (525.046)	66.515** (27.312)
Error-Correction Term	-0.555** (0.165)	-0.582** (0.239)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	-43.226 (110.969)	-23.243 (16.202)
$(\ln(GDP_t))^2$	2.044 (519)	1.063 (0.748)
$\ln(NRE_t)$	1.135*** (0.325)	0.812*** (0.037)
$\ln(SE_t)$	0.007 (0.011)	-0.002** (0.0007)
$\ln(ORS_t)$	0.017 (0.129)	0.0002 (0.015)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 44: MG and PMG Estimation results for Model 3F: Wind Energy & Medium GDP States

Short Run		
Variable	**MG**	**PMG**
$\mathbf{ln}(\boldsymbol{GDP_t})$	158.041 (113.368)	-62.171 (0.193)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	-7.327 (5.244)	2.876 (0.1.845)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.291 (0.288)	0.446** (0.227)
$\mathbf{ln}(\boldsymbol{WE_t})$	-0.00008 (0.004)	-0.004 (0.004)
$\mathbf{ln}(\boldsymbol{ORW_t})$	-0.127 (0.097)	-0.116 (0.085)
Constant	26.388 (646.587)	20.146** (6.844)
Error-Correction Term	-0.500* (0.193)	-0.569** (0.193)
Long Run		
Variable	MG	PMG
$\mathbf{ln}(\boldsymbol{GDP_t})$	-76.635 (130.525)	-9.012 (7.772)
$(\mathbf{ln}(\boldsymbol{GDP_t}))^2$	3.567 (6.027)	0.411 (0.359)
$\mathbf{ln}(\boldsymbol{NRE_t})$	0.487 (0.476)	0.903*** (0.026)
$\mathbf{ln}(\boldsymbol{WE_t})$	-0.008 (0.007)	-0.001** (0.0004)
$\mathbf{ln}(\boldsymbol{ORW_t})$	0.079 (0.165)	-0.033** (0.010)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

B4: Results for Models 4B-F

The last subset of the disaggregate model 4, focusing on the high GDP bracket states, the impacts of the individual renewable energy consumption variables are tested. *Table 45* shows the exact variables in each subset of the model. With this final model *Table 46* depicts the descriptive statistics, *Table 47* shows the results of the unit root testing, and *Table 48* shows the mixed results of the cointegration tests that lead to the MG and PMG estimations.

Table 45: Model 4 Subset Descriptions

Model 4	High GDP Bracket states
4A	CO_2, GDP, GDP^2, NRE, & RE
4B	CO_2, GDP, GDP^2, NRE, ORG, & GE
4C	CO_2, GDP, GDP^2, NRE, ORH, & HE
4D	CO_2, GDP, GDP^2, NRE, ORB, & BE
4E	CO_2, GDP, GDP^2, NRE, ORS, & SE
4F	CO_2, GDP, GDP^2, NRE, ORW, & WE

Table 46: Descriptive Statistics for Disaggregate Models 4B-F

NOTATION	VARIABLE	MEAN	MIN.	MAX.	UNIT
CO_2	Carbon dioxide	24.040 (27.638)	4.249	132.904	Tons per capita
GDP	Gross Domestic Product	70,356.68 (28,146.02)	47,352.62	195,488.60	Constant dollars per capita
NRE	Non-Renewable energy consumption	334,000,000 (348,000,000)	22,000,000	1,590,000,000	Btu per capita
RE	Renewable energy consumption	248,000,000 (35,700,000)	515,420.50	207,000,000	Btu per capita
GE	Geothermal energy consumption	886,067.2 (2,069,689)	0	12,200,000	Btu per capita
ORG	All other renewable energy consumption expect geothermal	23,900,000 (35,800,000)	515,420.50	207,000,000	Btu per capita
HE	Hydroelectric energy consumption	13,100,000 (32,100,000)	-417,169.6	190,000,000	Btu per capita
ORH	All other renewable energy consumption expect hydroelectric	11,700,000 (10,200,000)	515,420.50	87,000,000	Btu per capita
BE	Biomass energy consumption	8,498,537 (5,667,184)	515,420.5	30,700,000	Btu per capita
ORB	All other renewable energy consumption expect biomass	16,300,000 (33,400,000)	-926,509.2	190,000,000	Btu per capita
SE	Solar energy consumption	292,923.3 (729,2759)	0	6,311,209	Btu per capita
ORS	All other renewable energy consumption expect solar	24,500,000 (35,800,000)	515,420.5	207,000,000	Btu per capita
WE	Wind Energy	1,963,109 (8,153,360)	0	78,900,000	Btu per capita
ORW	All other renewable energy consumption expect wind	22,800,000 (34,400,000)	515,420.5	207,000,000	Btu per capita

Note: Standard deviations in parentheses.

Table 47: Results of panel unit root test with the Models 4B-F

	Common Unit Root				Individual Unit Root					
Variable	LLC		Breitung		IPS		ADF		PP	
	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference	Level	First Difference
CO2	-0.294	-8.632***	1.103	-7.995***	1.260	-11.012***	26.057	169.956***	49.220**	1003.64***
	(0.3842)	(0.0000)	(0.8651)	(0.0000)	(0.8962)	(0.0000)	(0.8334)	(0.0000)	(0.0442)	(0.0000)
GDP	-3.096***	-10.407***	-4.410***	-11.270***	-1.382*	-8.644***	41.357	131.688***	50.493**	274.825***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0834)	(0.0000)	(0.1802)	(0.0000)	(0.0341)	(0.0000)
GDP²	-3.114***	-10.404***	-4.389***	-11.252***	-1.377*	-8.642***	41.335	131.670***	50.413**	274.796***
	(0.0009)	(0.0000)	(0.0000)	(0.0000)	(0.0841)	(0.0000)	(0.1808)	(0.0000)	(0.0347)	(0.0000)
NRE	-2.357***	-10.977***	0.794	-7.098***	-0.299	-13.959***	40.695	300.341***	56.246***	1223.79***
	(0.0092)	(0.0000)	(0.7865)	(0.0000)	(0.3824)	(0.0000)	(0.1994)	(0.0000)	(0.0096)	(0.0000)
RE	-0.820	-7.481***	0.016	-9.336***	0.115	-8.628***	34.249	135.939***	32.662	342.954***
	(0.2060)	(0.0000)	(0.5064)	(0.0000)	(0.5461)	(0.0000)	(0.4558)	(0.0000)	(0.5331)	(0.0000)
GE	-234.589***	-216.984***	0.3042	-1.232	-179.256***	-163.073***	2939.24***	2487.34***	2265.37***	235.859***
	(0.0000)	(0.0000)	(0.6195)	(0.1088)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORG	-0.871	-8.280***	0.067	-9.613***	0.124	-8.938***	32.837	138.921***	32.919	344.699***
	(0.1917)	(0.0000)	(0.5270)	(0.0000)	(0.5495)	(0.0000)	(0.5245)	(0.0000)	(0.5205)	(0.0000)
HE	-3.863***	-5.758***	-1.58*	-6.433***	-4.559***	-11.294***	76.013***	165.323***	99.199***	1051.93***
	(0.0001)	(0.0000)	(0.0570)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORH	-1.617*	-12.421***	0.283	-5.509***	0.009	-10.604***	32.608	166.360***	21.297	204.130***
	(0.0529)	(0.0000)	(0.6117)	(0.0000)	(0.5039)	(0.0000)	(0.5358)	(0.0000)	(0.9560)	(0.0000)
BE	-0.752	-9.568***	-2.496***	-8.645***	-0.749	-9.582***	36.081	146.628***	39.395	520.421***
	(0.2257)	(0.0000)	(0.0063)	(0.0000)	(0.2268)	(0.0000)	(0.3715)	(0.0000)	(0.2412)	(0.0000)
ORB	-12.635***	-26.252***	-0.288	-7.442***	-8.561***	-17.897***	339.814***	436.866***	110.448***	1148.77***
	(0.0000)	(0.0000)	(0.3865)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
SE	-82.673***	-139.097***	-0.377	-1.206	-72.182***	-116.641***	2109.17***	2707.93***	541.976***	269.755***
	(0.0000)	(0.0000)	(0.3531)	(0.1139)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORS	-1.134	-7.332***	-0.623	-8.792***	-0.454	-8.554***	35.535	134.297***	33.788	331.885***
	(0.1282)	(0.0000)	(0.2666)	(0.0000)	(0.3246)	(0.0000)	(0.3958)	(0.0000)	(0.4779)	(0.0000)
WE	-43.471***	-87.144***	-0.619	-5.570***	-18.496***	-30.635***	276.213***	336.247***	274.223***	161.376***
	(0.0000)	(0.0000)	(0.2678)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ORW	-0.794	-8.475***	-1.529*	-10.287***	-0.626	-8.987***	41.527	140.187***	39.391	386.311***
	(0.2135)	(0.0000)	(0.0630)	(0.0000)	(0.2654)	(0.0000)	(0.1755)	(0.0000)	(0.2413)	(0.0000)

Note: All variables are in natural logarithms. *** and ** denote rejections of the null hypotheses of a unit root at the 1% and 5% significance levels, respectively. P-values are in parentheses. All tests include a constant and a trend.

Table 48: Panel Cointegration test results for Models 4B-F

Pedroni test	4A	4B	4C	4D	4E	4F
Panel υ–Statistic	0.2034	-1.4039	-2.7313	-2.0836	-0.5883	-4.1602
Panel rho-Statistic	-2.2692**	0.3088	-0.5564	-0.6245	-1.2000	-0.3496
Panel PP-Statistic	-10.1744***	-7.2010***	-6.8188***	-8.6355***	-8.2114***	-6.5314***
Panel ADF-Statistic	-3.9566***	-1.9894**	-0.8567	-2.4163***	-1.7529**	-1.0147
Group rho-Statistic	2.4220	3.3707	3.1843	3.2769	3.1078	3.1267
Group PP-Statistic	-7.4675***	-9.3630***	-6.8360***	-6.9288***	-9.4105***	-10.9952***
Group ADF-Statistic	-0.013	-0.5026	0.8538	1.2122	-1.094	-2.6972***

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 49 summarizes the results of the last subset tests on the disaggregate model 4. Looking at the individual renewable energy consumption variables, geothermal and wind energy consumption yielded statistically significant results while their models held evidence of an EKC. While model 4D, specifically identifying biomass energy consumption, did yield evidence of an EKC in the model, the coefficient for biomass was not statistically significant. Whereas the solar energy consumption variable was statistically significant, the model it was within did not yield coefficients that showed evidence for the EKC. Full tables of these results are in *Tables 50-54*.

Table 49: Model 4B-F Results

MODEL	IMPORTANT VARIABLE	P-VALUE	CHI SQUARED VALUE	LONG RUN EKC?
4B	Geothermal***	0.8213	2.20	**YES**
4C	Hydroelectric	0.9569	1.07	**NO**
4D	Biomass	0.4219	4.95	**YES**
4E	Solar***	0.7054	2.17	**NO**
4F	Wind***	0.6492	2.47	**YES**

Table 50: MG and PMG Estimation results for Model 4B: Geothermal Energy & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-98.509*	-35.140*
	(58.816)	(19.886)
$(\ln(GDP_t))^2$	4.473*	1.574*
	(2.662)	(0.898)
$\ln(NRE_t)$	1.034*	0.791**
	(0.573)	(0.334)
$\ln(GE_t)$	-0.131	-0.068
	(0.115)	(0.068)
$\ln(ORG_t)$	-0.329**	-0.303
	(0.177)	(0.189)
Constant	-591.847	-17.574***
	(602.606)	(3.764)
Error-Correction Term	-0.692***	-0.460***
	(0.091)	(0.098)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	58.887	3.729**
	(92.773)	(1.335)
$(\ln(GDP_t))^2$	-2.689	-0.171**
	(4.194)	(0.060)
$\ln(NRE_t)$	0.687**	1.084***
	(0.251)	(0.013)
$\ln(GE_t)$	0.116	0.0007**
	(0.119)	(0.0003)
$\ln(ORG_t)$	0.117	-0.005**
	(0.192)	(0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 51: MG and PMG Estimation results for Model 4C: Hydroelectric Energy & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-55.839 (51.720)	-36.270* (20.087)
$(\ln(GDP_t))^2$	2.515 (2.342)	1.624* (0.909)
$\ln(NRE_t)$	0.514 (0.460)	0.827*** (0.297)
$\ln(HE_t)$	-0.197 (0.171)	-0.082 (0.065)
$\ln(ORH_t)$	-0.297 (0.200)	-0.247 (0.214)
Constant	-475.822 (441.974)	-7.887*** (2.387)
Error-Correction Term	-0.699*** (0.094)	-0.340*** (0.103)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	50.703 (77.576)	1.421 (3.071)
$(\ln(GDP_t))^2$	-2.320 (3.514)	-0.078 (0.138)
$\ln(NRE_t)$	1.115*** (0.114)	1.016*** (0.034)
$\ln(HE_t)$	0.113 (0.115)	0.026*** (0.007)
$\ln(ORH_t)$	0.066 (0.070)	-0.008** (0.004)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 52: MG and PMG Estimation results for Model 4D: Biomass Energy & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-82.578 (59.386)	-16.802 (12.669)
$(\ln(GDP_t))^2$	3.743 (2.685)	0.739 (0.570)
$\ln(NRE_t)$	0.687 (0.482)	0.751** (0.297)
$\ln(BE_t)$	-0.290* (0.166)	-0.272 (0.199)
$\ln(ORB_t)$	-0.324* (0.195)	-0.161* (0.083)
Constant	-822.602 (500.907)	-14.041*** (3.178)
Error-Correction Term	-0.658*** (0.088)	-0.415*** (0.094)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	122.887 (89.254)	2.963** (1.360)
$(\ln(GDP_t))^2$	-5.605 (4.036)	-0.137** (0.061)
$\ln(NRE_t)$	0.837*** (0218)	1.0761*** (0.014)
$\ln(BE_t)$	-0.049 (0.100)	0.003 (0.002)
$\ln(ORB_t)$	0.271* (0.154)	-0.005*** (0.001)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 53: MG and PMG Estimation results for Model 4E: Solar Energy & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-81.034 (52.617)	-27.419 (20.021)
$(\ln(GDP_t))^2$	3.652 (2.382)	1.231 (0.908)
$\ln(NRE_t)$	0.818* (0.435)	0.688** (0.318)
$\ln(SE_t)$	-0.004 (0.008)	0.007 (0.004)
$\ln(ORS_t)$	-0.450** (0.222)	-0.328* (0.194)
Constant	-677.485 (472.771)	-11.944*** (2.72)
Error-Correction Term	-0.680*** (0.089)	-0.440*** (0.100)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	84.297 (82.975)	1.779 (1.422)
$(\ln(GDP_t))^2$	-3.828 (3.758)	-0.083 (0.064)
$\ln(NRE_t)$	0.886*** (0.159)	1.072*** (0.019)
$\ln(SE_t)$	0.001 (0.004)	-0.004*** (0.0009)
$\ln(ORS_t)$	0.193 (0.172)	-0.007*** (0.002)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively

Table 54: MG and PMG Estimation results for Model 4F: Wind Energy & High GDP States

Short Run		
Variable	**MG**	**PMG**
$\ln(GDP_t)$	-76.181* (44.928)	-41.518* (21.497)
$(\ln(GDP_t))^2$	3.447* (2.035)	1.864* (0.972)
$\ln(NRE_t)$	0.513 (0.524)	0.697** (0.288)
$\ln(WE_t)$	-0.002** (0.001)	-0.002 (0.001)
$\ln(ORW_t)$	-0.410** (0.201)	-0.292* (0.160)
Constant	-439.293 (375.903)	-15.654*** (3.692)
Error-Correction Term	-0.669*** (0.087)	-0.413*** (0.097)
Long Run		
Variable	MG	PMG
$\ln(GDP_t)$	46.518 (69.456)	3.629*** (1.208)
$(\ln(GDP_t))^2$	-2.128 (3.143)	-0.167*** (0.054)
$\ln(NRE_t)$	0.970*** (0.107)	1.087*** (0.012)
$\ln(WE_t)$	-0.002 (0.001)	-0.0004*** (0.0001)
$\ln(ORW_t)$	0.182 (0.139)	0.003 (0.004)

Note: ***, **, * represents statistical significance at 1%, 5%, and 10% respectively