Rollins College
Rollins Scholarship Online

Honors Program Theses

Spring 2017

Examining Renewable Energy and Economic Growth: Evidence from 22 OECD Countries

David Neitzel
dneitzel@rollins.edu

Follow this and additional works at: http://scholarship.rollins.edu/honors

Part of the Econometrics Commons

Recommended Citation
Neitzel, David, "Examining Renewable Energy and Economic Growth: Evidence from 22 OECD Countries" (2017). *Honors Program Theses*. 46.
http://scholarship.rollins.edu/honors/46

This Open Access is brought to you for free and open access by Rollins Scholarship Online. It has been accepted for inclusion in Honors Program Theses by an authorized administrator of Rollins Scholarship Online. For more information, please contact rwalton@rollins.edu.

Examining Renewable Energy and Economic Growth: Evidence from 22 OECD Countries

David Neitzel

Rollins College

April 2017

Abstract

A growing amount of electricity is produced from renewable sources. For this reason, it is important to understand the effect that this developing industry has on economic growth. This paper examines this relationship between economic growth and renewable energy consumption within a multivariate framework using a panel of 22 OECD countries over the period 1995-2012. The results of the Fully-Modified Least Squares regression indicate a statistically significant, albeit small, negative relationship between real GDP and renewable energy. Granger Causality tests indicate bidirectional causality running between GDP and renewable energy. The small effect of renewable energy on growth implies that policies supporting the renewable energy industry will not have a significant impact on GDP.

Introduction

Energy sources are the driving force behind any modern economy. Because of this, fluctuations in energy prices have profound effects on economic output (Hamilton, 2005). Price spikes in oil tend to be associated with recessions because they raise shipping costs, manufacturing costs, and make certain capital stocks too expensive to use. On the other hand, low oil prices tend to produce economic expansion (Murphy & Hall, 2011). For example, a sudden drop in oil prices can also cause economic downturn. At the beginning of 2016, the price of oil fell well below $30 a barrel, causing global markets to experience large losses at the beginning of the year. This was a strong reminder of the power energy sources have over the economic system.

According to the 2014 U.S. Energy Information Administration, renewable energy accounted for 9.8% of total domestic energy consumption in 2014, and it grew an average of 5% per year over 2001-2014 from its most recent low in 2001 (Energy Information Administration, 2014). The small decline in renewable energy consumption in 2001 was due to a change in the white house policy on renewable energy upon the election of George W. Bush. Since then, renewable energy consumption levels have grown steadily each year. The 2014 report cites increased renewable capacity at both the industrial and end-user levels as the reason for the increase in national consumption levels. Particularly, the steadily dropping price of both solar and wind energy has created a larger demand for these materials. These reductions in prices have been attributed to both technological improvements and economies of scale.

Growth in the renewable energy sector has led to increased discussion of the role it will play in the future energy economy. Numerous policies, such as feed-in tariffs and subsidies, have been enacted at the expense of taxpayers worldwide to target the development of this sector.

While growth is undoubtedly occurring, the overall effects on the economy are uncertain. If an association between growth in the renewable energy sector and growth in the overall economy can be supported empirically, it would support government spending on renewable energy development. Alternatively, if no association is found, it will indicate that public funds would likely be better spent on another part of the economy. In this study, I investigate the causal relationship between renewable energy consumption and economic growth. Therefore, the results of this study will offer valuable information for policymakers.

With this in mind, I will investigate the relationship between the use of renewable energy and macroeconomic variables such as economic growth, unemployment, school enrollment, and gross capital formation. I expect to find that the use of renewable energy has a positive and statistically significant effect on economic growth. This would highlight the benefits of government policies such as renewable energy production tax credits, rebates for the installation of renewable energy systems, renewable energy portfolio standards, as well as benefits of avoiding climate change problems, reduction in dependence on foreign energy sources or volatility of prices.

Applying the fully modified OLS technique for heterogeneous cointegrated panels by Pedroni (2000), I find that renewable energy consumption does not contribute to an increase in the GDP. The most important factor for GDP growth is gross capital formation.

Current Energy Economy

The current consumption of fossil fuels presents two main problems for the future. First, fossil fuels are nonrenewable resources that will, eventually, run out. An insufficiency in the supply of energy sources would cripple development in all areas and therefore presents a relevant problem for all governments. Second, fossil fuel consumption is the largest source of pollution and contributor to climate change. While most governments worldwide agree that this is a significant problem, short term economic interests have typically trumped environmental ones in the policy arena.

Efforts have been made to curtail fossil fuel emissions, but they have not made significant progress. Most notably, the Kyoto Protocol, signed in 1997, is an international treaty designed to reduce carbon emissions to combat global warming. Countries that ratified the Protocol pledged that, starting in 2005 when it became effective, they would reduce their greenhouse emissions to 5% under 1990 levels. While this was a promising agreement at the time, it has barely made a dent in the amount of greenhouse gasses being emitted. This is due to the United States' lack of involvement. Although the agreement was signed by President Clinton in 1997, the U.S. senate failed to ratify it. Then, in 2001, executive support for the bill fell apart when President Bush entered office. The United States is by far the largest emitter of greenhouse gasses in the world, and their lack of participation prevented a large portion of world emissions from being curbed.

There are indications that economic forces are shifting to likely make changes in the energy sector in the future. Two important factors are expected to play a role in accelerating the process of adopting renewable energy sources. Firstly, the concept of peak points in oil production will have a significant impact on the price behavior of petroleum products in the future. A peak point is the point in time that an oil well has reached its peak efficiency. At that time, the well is pumping the maximum volume of oil possible. Once it reaches this point, the efficiency of the well decreases (Murphy & Hall, 2011). In order to maintain the volume necessary to meet demand, water must be pumped into the well to keep the internal pressure at an adequate level. This is an expensive process and these costs are typically transferred directly to the selling price of the oil.

Oil production increased rapidly throughout the 20th century, but has begun to taper off over the last ten years or so, indicating that many wells are nearing or have passed their peak points (Aleklett, et al., 2010). With production reaching relatively flat growth levels, a significant number of new wells with relatively low development costs would need to be found to keep up with world demand over the next few decades. If this does not happen, it could mean a significant rise in oil prices in the near future.

To put the effects of declining oil production in perspective, even if oil demand was to remain flat until 2030, 45 million barrels per day (Mb/d) of gross capacity – roughly four times the current capacity of Saudi Arabia – would be need to be found just to offset the decline from existing fields and meet the current level of demand (Birol, 2009). It is highly unlikely that this amount of new production capacity will be found and developed to meet this demand, indicating that significant changes will occur in the industry by the year 2030 (Aleklett, et al., 2010).

Chart 1: Forecasted World Oil Production

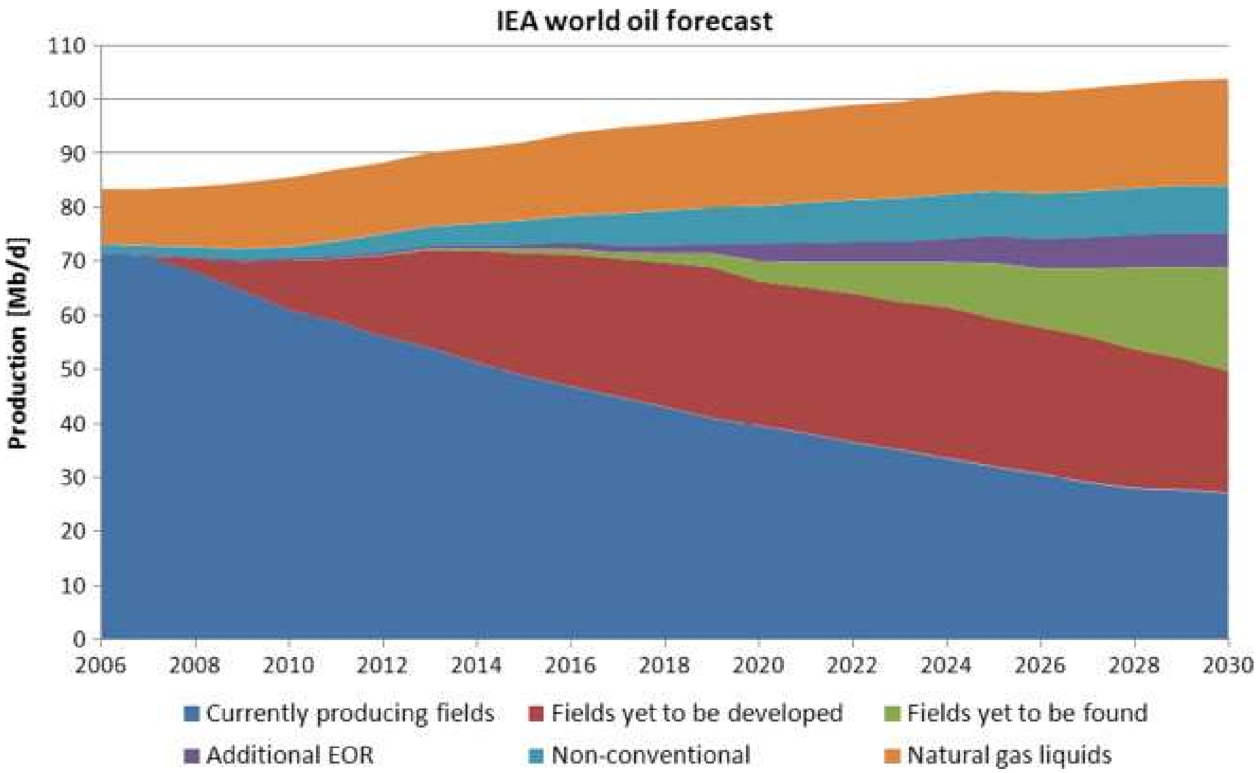

Chart 1 shows the International Energy Agency's (IEA) forecast for future fossil fuel production. It shows production levels from currently producing fields falling steadily and overall oil production also falling. While fields yet to be developed are projected to provide a large amount of oil as currently producing fields taper off, oil from these wells will be more expensive than the oil from currently producing wells. Typically, the reason that these fields have not yet been developed is because of the costs associated with development. While it is true that these fields will likely developed, this development will be costly and will contribute to rising oil prices in the future.

Secondly, the electricity grid that transports electric energy is aging. The power grid has forgone updates and has declined in quality. The lack of repairs has reduced costs to the utility companies in recent years, keeping electricity prices low for consumers. However, regulation was placed to keep the power grid in good working order so repairs did not pile up. Now, they have accumulated to such a degree that repairs will be very costly, with entire replacements are needed in many areas. These costs will make the price of traditionally generated electricity rise to historic levels and stimulate the exploration of other energy options.

There are numerous options for energy resources that can contribute to a clean energy economy. Hydroelectric power is a popular source of sustainable electricity that has gained traction all over the world. Hydroelectric dams can produce large quantities of electricity, last a long time, and are price competitive with other methods of electricity generation. However, most possible locations for large, productive dams have already been developed. This means that future growth in the hydroelectric industry is expected to be relatively slow and that it will most likely not be a major component of the world's electricity production in the future. For this reason, governments should not allocate significant funds for the development of hydroelectric technology.

Wind power is also a cost-effective alternative to fossil fuels. It is able to produce a lot of energy under the right conditions and there are many undeveloped spaces where wind farms can still be built, meaning that it is likely that this industry will still grow quite a bit in the future. However, the cost of installation is often not the only significant cost associated with wind energy. Wind mills have a lot of complex, moving parts leading to highly variable maintenance costs that can significantly raise the overall price of the energy they produce. Maintenance must be done by specialized workers, who charge more for the work they do than maintenance workers in other energy industries. Additionally, wind is often intermittent and unreliable. This means that while wind may serve as a good source of supplemental energy, it is unlikely that it will take over as a primary source of electricity in the future. Governments should support wind energy, but not as a probable primary energy source.

Solar energy is perhaps the most promising of the renewable energy sources available to us today. Firstly, there is ample sunny space to generate enough power to satisfy the entire world's electricity demand. This creates a significant growth opportunity for the industry, which currently only contributes about 1% of electricity worldwide. Solar energy systems involve no moving parts and do not require nearly the same level of maintenance as other renewable options, giving solar cost advantages.

Given the likelihood of renewable energy sources playing a major role in the future energy economy, it is important to study the causal relationships that may exist between renewable energy consumption and economic growth. Connections made in this study will have important policy implications for nations in all stages of economic development.

Government Energy Policies

Government energy policies take many forms. Since the 1990's, they have mainly targeted greenhouse emissions as a means of combatting global warming. The Kyoto Protocol was an international treaty signed in 1997 that commits its participants to reduce domestic greenhouse emissions (United Nations, 2017). The greenhouse gasses targeted by the treaty were carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, and all hydroflourocarbons and perfluorocarbons (Grubb, 2003). This agreement largely gave the responsibility of reducing carbon emissions to developed nations. This was based on the fact that, historically, these are the nations largely responsible for contributing to the problem of global warming.

Although it was signed in 1997, the Kyoto Protocol's first commitment period did not begin until 2008. In the period of 2008-2012, all member states committed to specific, quantified emission limitation and reduction objectives. Unfortunately, the first commitment period did little to slow down the global levels of harmful emissions (Clark, 2012). The Kyoto protocol was perhaps most important simply as a first step of international environmental diplomacy. While it lacked effectiveness, it made up for it by giving widespread attention to the issue of greenhouse emissions.

Governments have various policies available to them to directly stimulate the renewable energy industry. Two of the most effective are subsides and feed-in tariffs. Both subsidies and feed-in tariffs help the market develop with the help of artificial fiscal support, bringing down the natural price of solar energy to be price competitive without government aid after a certain period of time.

Subsidies for solar energy systems are payments from the government directly to the purchasers of these systems, decreasing costs to the end user. For developing markets, subsidies are particularly effective. The reduction of consumer costs increases demand, allowing firms to grow their client base and expand operations. The true value of a subsidy program lies in its ability to create expansion. As the producers of solar materials expand their business due to increased demand, economies of scale set in and create cost advantages. The larger the scale at which solar materials are produced, the more inexpensive it is to make those materials and the more inexpensive the materials for the consumer.

This has already been done successfully. In 1995, the Japanese government started the Seventy Thousand Roofs program. At the time, the unsubsidized price of solar energy was at $11,500 per kW. They set subsidy levels so that solar energy was price competitive with traditional energy options. This involved a 50% subsidy on the price of the system and created an ideal environment for solar firms to expand. Sure enough, the unsubsidized price of solar energy declined steadily over the next ten years until it became price competitive with standard utility prices, at a price of about $6,000 per kW in 2006 (International Energy Agency, 2005). This targeted subsidy program was incredibly successful in facilitating growth in the solar industry and bringing down costs. Today, Japan has the third largest installed capacity of solar energy in the world and expects 70% of new homes to have solar energy installed (Yamamoto & Osamu, 2010).

Feed-in tariffs are another way that governments can help grow their domestic solar industries. Unlike subsidies, which are used for a wide range of industries, feed-in tariffs are policy mechanisms designed specifically to stimulate the renewable energy market. They provide cash payments for electricity generated by solar panels, even if it is used directly by the consumer. Additionally, they establish a legal precedent for owners of solar systems to sell excess energy back to the utility company by connecting the solar system to the main energy grid. During the day, excess energy produced by solar panels flows out of the home to the energy grid and at night, energy flows from the grid back into the house. The price that must be paid by the utility is higher than the retail price of energy and is usually guaranteed for 15 to 25 years, creating a significant financial incentive for consumers (Couture, Cory, Kreycik, & Williams, 2010). Additionally, since feed-in tariffs are paid in part by utility companies, they use less taxpayer money than subsidies, making them generally quite popular with voters.

This relatively simple model has had far reaching effects on the solar industry. Without a grid-tied system that offers feed-in tariffs, consumers have to purchase expensive batteries to store the energy their solar panels produce. In many cases, this makes the purchase of a solar system unfeasible. Feed-in tariffs effectively reduce most households' electricity bill to zero because they end up paying for less than the net flow of electricity to the household. Since they receive a higher price for the energy produced by solar panels, they end up paying for less energy than they use. Sometimes, homeowners even receive a check from the utility company at the end of each month.

Germany is an excellent model of the effectiveness of feed-in tariffs. In 1999, Germany enacted a 50 eurocent per kWh feed-in tariff for solar energy systems as part of its Hundred Thousand Rooftops program. As a result, the installed capacity of solar energy grew by approximately 800% from 1999 to 2004 (European Renewable Energy Council, 2004). Due to its success, the program was amended in 2004, 2009, and 2012. This success was partially because Germany did not restrict the feed-in tariff to households and small businesses. Firms could create facilities with the sole purpose of generating solar electricity and selling it at the elevated rate. Many firms saw an opportunity to make a return and the significant industry growth reflects, in part, the establishment of these new firms. Unlike subsidies, feed-in tariffs create incentives for consumers and large businesses alike (Lipp, 2007).

Additionally, the increased efficiency resulting from the expansion of solar energy caused the price of electricity during the day to fall 40%, saving German consumers between €520 million and €840 million (Parkinson, 2012). Today, lobbyists for the utilities industry have worked to reduce feed-in tariffs, but the momentum gained over the last 15 years has not been easily stopped. Today, Germany has the largest installed capacity of solar energy per capita in the world.

Although there has been a lot of policy success for renewable energy sources, there have also been some failures. The case of Spain is one example. Spain invested too heavily in wind energy because they had excessive expectations of the cost benefits that it could produce. They supported a heavily subsidized approach to developing their wind energy industry. Policies such as feed-in tariffs were effective at quickly growing the industry domestically. However, while Spain did rise to the forefront of the European renewable energy sector, it did so at a considerable cost. The expensive policies that supported the growing wind industry were not supported by the low energy costs that were expected. An electricity system deficit grew quickly to the current level of 25.5 billion euros (Couture, 2013).

The case of Spain implies that legislators should not be overly optimistic about the future of renewable energy. Like any government program, excessive spending can lead to deficits. In the renewables industry, the relatively small history of government programs poses a problem for legislators. Each government must take into account their specific energy situation when determining the policy that will be effective for them.

Energy and Growth Hypotheses

The empirical studies examining the relationship between energy consumption and economic growth examined four distinct hypotheses. Each hypothesis has distinct implications for government policies that target energy consumption levels as a means of decreasing emission levels. The policy implications behind these hypotheses are the main driving factor behind research of this kind. If energy consumption is shown to be a limiting factor for economic growth, policies that limit energy consumption for environmental reasons could inadvertently lead to declines in incomes and employment rates (Ouedraogo & Diarra, 2010).

The growth hypothesis states that energy consumption is directly responsible for creating economic growth as a complement to capital and labor. This hypothesis is supported if causality is found running from energy consumption to growth, but not from growth to energy consumption. The implication of this type of unidirectional causality is that the policies that limit energy consumption as a means of decreasing emissions will negatively impact economic growth (Tugcu, Ozturk, & Aslan, 2012). In this case, a change in energy consumption can be expected to lead to a change in GDP. Alternatively, a change in GDP is not expected to have an effect on energy consumption. These policies mainly take the form of limits on carbon emissions, such as those proposed in the Kyoto protocol.

The conservation hypothesis states that economic growth is directly responsible for stimulating energy consumption. This hypothesis is supported if causality is running from economic growth to energy consumption, but not from energy consumption to growth. This means that a change in GDP will have an effect on energy consumption, but a change in energy consumption will not have an effect on GDP. In this case, it is typical that economic growth leads to greater energy consumption. However, in certain cases, economic growth can lead to a decrease in energy consumption. This typically happens in growing economies as production shifts from primarily industrial sectors to service sectors that are less energy intensive (Squalli, 2007). The implication when this hypothesis is supported is that policies that limit energy consumption, such as limits on carbon emissions, will not have a negative impact on economic growth (Tugcu, Ozturk, & Aslan, 2012).

The feedback hypothesis states that economic growth and energy consumption impact each other simultaneously. This hypothesis is supported by evidence that suggests bidirectional causality between energy consumption and economic growth. This means that a change in either GDP or energy consumption can be expected to have an effect on the other. The implication of evidence supporting this hypothesis is that policies limiting energy consumption, will negatively impact economic growth. Additionally, fluctuations in growth will be reflected in changes in energy consumption (Tugcu, Ozturk, & Aslan, 2012).

Lastly, the neutrality hypothesis means that energy consumption has no effect on economic growth. Evidence that shows no causality between energy consumption and growth in either direction. This means that a change in GDP will not have an effect on energy consumption, and that a change in energy consumption will not have an effect on GDP. The implication of evidence supporting this hypothesis, like the conservation hypothesis, is that policies that limit energy consumption, will not have a negative impact on economic growth (Tugcu, Ozturk, & Aslan, 2012).

Literature Review

Many studies have been done supporting each of the hypotheses relating to energy consumption and economic growth. The literature shows that the most popular methodologies for finding evidence of causality are based on the granger causality test (Chontanawat, Hunt, & Pierse, 2008). The granger causality test is a hypothesis test used to determine if one times series is significant in predicting another one (Granger, 1969). Typical economic regressions are only useful in measuring correlation between two variables but Granger's method can test for causality between two distinct time series variables by measuring the ability of one variable to predict the future values of another variable.

Studies that have examined the relationship between energy consumption and economic growth have not found a consensus on a single hypothesis. A 2008 study of 108 nations over the period 1971-2000 used a granger causality test to show unidirectional causality running from energy consumption to economic growth, thus supporting the growth hypothesis (Chontanawat, Hunt, & Pierse, 2008). Another 2008 study, of 82 nations over the period 1972-2000, used a different methodology and found evidence supporting the conservation hypothesis (Huang, Hwang, & Yang, 2008). These two studies used similar samples over a similar time period and made conclusions supporting very different hypotheses. This indicates that methodology may be very important to the results of this type of study.

Other studies found evidence supporting multiple hypotheses within a single study. A 2003 study examined the relationship between energy consumption and GDP growth for the top ten emerging economies and G7 economies individually (Soytas & Sari, 2003). At an individual level, they found that evidence supported differing hypotheses in different countries. For example, in Argentina, bidirectional causality was found, supporting the feedback hypothesis. In

Italy and Korea, evidence was found supporting the conservation hypothesis. In France, Germany, Turkey, and Japan, the evidence supported the growth hypothesis. This evidence implies that successful policies may vary between countries.

A 2006 study examined eleven major industrialized countries in hopes of finding a causal relationship between energy and growth in industrialized countries. The study however, did not find a consistent relationship. Analysis supported the feedback, conservation, and neutrality hypotheses among individual countries (Lee, 2006). The evidence supported the growth hypothesis in Canada, Belgium, the Netherlands, and Switzerland. In the United States, the feedback hypothesis was supported. In France, Italy, and Japan, the conservation hypothesis was supported. The differences found at an individual level suggest that there may not be an overreaching energy conservation policy that works well for every country.

This study is particularly interested in how renewable energy consumption fits into this complex system. In studies that include renewable energy consumption in their scope, the feedback hypothesis has been largely supported. In a 2014 study, Apergis and Danuletiu found evidence supporting the feedback hypothesis (Apergis & Danuletiu, 2014). They used the Canning and Pedroni long-run causality test to analyze their sample of 80 countries. The presence of bidirectional causality means that policies that limit energy consumption will likely negatively impact economic growth. Instead, governments should pursue policies that facilitate the development of the renewable energy sector (Apergis & Danuletiu, 2014). It is possible that these findings are somewhat incomplete. The omission of any variables apart from energy consumption and economic growth indicates a possible omitted variable bias. There are many other factors that influence economic growth. It is possible that other, more important, determinants of growth are correlated with energy consumption and influenced the results of this study without being mentioned.

Perhaps the most comprehensive contribution to the body of work studying renewable energy and economic growth has been made by Apergis and Payne. In 2010, the pair authored three papers on the topic, using a consistent methodology of cointegration tests, panel error correction models, and Granger-Causality tests. The first study examined 13 Eurasian countries over the period 1992-2007 (Apergis & Payne, 2010a). The second study examined a panel of 20 OECD countries from 1985-2005 (Apergis & Payne, 2010b). The third examined six countries in Central America over the 1985-2005 period (Apergis & Payne, 2010c). In all three studies, evidence supported the feedback hypothesis, indicating bidirectional causality between renewable energy consumption and GDP growth.

A 2011 study by the same authors also studied the relationship between renewable energy consumption and economic growth, including other variables that were measured over time (Apergis & Payne, 2011). Other variables included in the paper were nonrenewable energy, real fixed capital formation, and labor force. The study found a long run equilibrium relationship among the variables with each of the variables' respective coefficients positive and statistically significant. The evidence also showed bidirectional causality between renewable energy consumption and economic growth in both the short and long run, supporting the feedback hypothesis. The study also found evidence supporting the feedback hypothesis for nonrenewable resources. This indicates that renewable energy may influence growth in the same way as nonrenewable energy sources.

In 2012, Tugcu, Ozturk, and Aslan also studied the relationship between renewable energy consumption and economic growth with the addition of several additional variables. The study included real gross fixed capital formation, labor force, total number of full and part time students enrolled in public and private tertiary education, the sum of the number of patent applications domestically, and nonrenewable energy consumption. Bidirectional causality was found between both renewable energy consumption and growth and nonrenewable energy consumption and growth. These findings support the feedback hypothesis, which implies energy conservation policies will negatively impact economic growth. Alternatively, policies that promote renewable energy growth should have a positive impact on growth. These findings also imply that renewable energy influences growth in the same way as nonrenewable energy sources, similar to the 2011 study by Apergis and Payne.

While there is little consensus on how exactly energy consumption in general impacts growth, there is consensus on how renewable energy consumption and economic growth affect each other. The majority of studies found bidirectional causality between these two variables. This study will add to the current body of work in order to generate a greater understanding of how these two variables are connected. With greater understanding, policymakers will be able to create more effective policies for both the environment and growth.

Using Time Series Data to Study the Relationship Between Economic Growth and Consumption of Renewable Energy

To investigate whether renewable energy consumption influence growth, I make use of data on 22 countries that are members of the Organization of Economic Development (OECD). The countries included are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the United States. Analyzing the way that certain factors influence growth over time requires a specific type of data called time series data. Time series data refers to measurements taken over time, as opposed to cross sectional data which refers to observations at a single point in time. Analyzing time series data comes with its own challenges. This is because data from one year almost certainly influences the data from following years. Lagged independent variables can be used when it is expected that X affect Y after a period of time. More complicated cases exist when the impact of an independent variable is expected to be spread out over a number of time periods. In such case, the appropriate econometric model would be a distributed lag model:

$$Y_t = \alpha_0 + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \cdots + \beta_p X_{t-p} + \epsilon_t.$$

A distributed lag model explains the current value of Y as a function of current and past values of X, thus distributing the impact of X over a number of time periods.

There are several approaches to dealing with the challenges that time series data provides. The first approach treats the interdependence of variables among years as a result of autocorrelated errors. Error terms are described as autocorrelated if they are correlated over time. Autocorrelation is common in time-series data. Often, error terms can be correlated due to the time it takes variables to adjust, or the “stickiness” of variables. For example, if the Federal

Reserve in the United States changes interest rates suddenly, there will be a related change in exchange rates that follows. However, this change will not happen immediately, and will likely create error terms that are correlated over time.

The most common and intuitive way of modeling autocorrelation is to create an autoregressive model, or AR(1) model, for error terms. The equation for the error in an AR(1) model sets the error term for period *t* equal to ρ times the error in the previous term plus a random error, i.e. $u_t = \rho u_{t-1} + \varepsilon_t$. The error in the previous term is referred to as the lagged error. The ρ term indicates the degree to which the errors are correlated over the period. Any nonzero ρ term indicates that the errors are correlated over time. A positive value indicates that a high error in the previous term will likely lead to a high error in the following term. This means that errors will tend to be high for a time and then low for a time. Alternatively, a negative value indicates just the opposite. When there is negative autocorrelation, a high error in one year will likely lead to a low error in the following year, creating errors that bounce around from one time to the next.

In order to test for autocorrelation, two methods are generally used. It is important to test for autocorrelation because, if it exists in the data, it must be corrected in order to generate meaningful results. The first method involves running a standard OLS model, calculating residuals, and graphing the residuals over time. Residuals that change gradually over time indicate positive autocorrelation. Residuals that bounce rapidly from high to low indicate negative autocorrelation. If a pattern cannot be determined, low correlation between errors is to be assumed. This method of graphically testing for autocorrelation is effective because correlated errors only impact the OLS standard errors. They do not bias the estimation, so the standard OLS model can be used.

The graphic method of checking for autocorrelation is effective for quickly examining the type of data that is being worked with, but it is informal. The second method of testing is to use an auxiliary regression to estimate the degree of autocorrelation exactly. In the auxiliary model, the expected error is equal to expected-ρ times the expected lagged error plus a random error, i.e. $u_t = \rho u_{t-1} + \varepsilon_t$. The expected error and the expected lagged error are equal to the residuals and the lagged residuals in the initial OLS estimation. If there is a statistically significant value for expected-ρ, there is empirical evidence of autocorrelation.

Once autocorrelation is established as present, it must be removed from the dataset by transforming all variables. This process is called p-transforming the data and it is automated in most software packages. After the data has been purged of autocorrelation, OLS will produce an unbiased estimate *and* variance, giving a much more accurate analysis of the data.

A second way of dealing with time series data is to treat the dependent variable from each period as directly influencing the following period. This is called a dynamic model. Naturally, this means that changes in data at any time before any given time will have an effect on that observation. For example, in this method, a change in GDP in the United States in the year 1970 will directly affect GDP in 1971, which will directly affect GDP in 1972, and so on all the way through the period of study. Changes in the data will have effects that percolate through the dataset in a forward direction.

Dynamic models differ mathematically from OLS models in one key way. They include a lagged dependent variable as one of the independent variables.

The simplest dynamic model is:

$$Y_t = \alpha_0 + \beta_0 X_t + \lambda Y_{t-1} + u_t$$

In this model, the current value of the dependent variable Y is a function of the current value of X and a lagged value of Y itself. Thus, λ coefficient reflects the extent to which the dependent variable depends on its lagged value. By doing this, the effect that past dependent variable values have on later ones can be included in the model. The higher the value of Y, the more later values depend on past ones. If past dependent variable values do in fact influence future ones, then omitting this term would likely lead to omitted variable bias.

The inclusion of this new term leads to a few differences between dynamic models and OLS models. Firstly, the implication of coefficients changes. This is because a change in X not only has an immediate effect on Y, but an effect on future Y values. Second, autocorrelation becomes a more difficult problem to solve. In dynamic models, correlated error terms *do* bias OLS estimates. This is because the lagged dependent variable term is a function of the lagged error term in the AR(1) model. Third, if the coefficient on the lagged dependent variable is zero, a biased estimate can result. These are all things to keep in mind when deciding whether or not to create a dynamic model by including a lagged dependent variable as a control variable.

Another issue that can arise when working with dynamic time series data is the concept of stationarity. A stationary series is one whose basic properties, for example its mean and its variance, do not change over time. In contrast, a nonstationary series has one or more basic properties that do change over time. For example, the real per capita output of an economy typically increases over time, so it is nonstationary. On the other hand, the growth rate of real per capita output often does not increase over time, so this variable is stationary. Stated shortly, stationarity means that a variable keeps the same distribution through the entire period of study. If variables are nonstationary, the distribution of the variable depends on time. For example, if the mean of a variable gets bigger over time, the variable is nonstationary. Nonstationary variables can pose problems because, in certain cases, they move in trends. If two variables move in the same trend, even though they are not correlated, the regression will incorrectly show evidence of a relationship. The major consequence of nonstationarity for regression analysis is spurious correlation that inflates R^2 and the t scores of the nonstationary independent variables, which in turn leads to incorrect model specification.

Many economic time series variables are nonstationary even after the time trend is removed. This nonstationarity typically takes the form of a variable behaving as if it was random walk, which means that the variable's next period's value equals this periods value plus a stochastic error term. A random walk variable is nonstationary because it can wander up and down without an inherent equilibrium and without approaching a long-term mean.

To better understand this, consider a simple dynamic model where Y depends only on the past values of itself. That is:

$$y_t = \rho y_{t-1} + \varepsilon_t$$

If the coefficient on the lagged dependent variable is less than one in absolute value terms, $|\rho| < 1$, there is essentially no issue because the effect of the nonstationary characteristic of the variable quickly evaporates over time. The expected value of Y_t will eventually approach 0 as the sample size gets bigger. Similarly, if $|\rho| > 1$, then the expected value of Y_t will continuously increase making Y_t nonstationary. This is nonstationarity due to a trend. If $|\rho| = 1$, $y_t = y_{t-1} + \varepsilon_t$ is a random walk. The expected value of Y_t does not converge on any value and it is nonstationary. This is called unit root. Variables with unit roots run the very likely risk of generating spurious regression results. Spurious regression results falsely imply that X has an effect on Y. The presence of a unit root must be dealt with to avoid invalid results.

The most popular test for the presence of a unit root is called the Dickey-Fuller test. This is a simple hypothesis test with the null hypothesis that $\rho = 1$ against the alternative hypothesis that $\rho < 1$. The test is run to see if a unit root exists for any of the variables. If the data is nonstationary and there is a unit root, the model must be transformed from levels to differences, or changes in values.

Analysis of time series data can be very valuable for policy makers. It allows researchers to study how one variable may influence another variable over time. Evidence of causal links between variables and common economic metrics can indicate where policy makers can allocate funds to have the largest impact.

Data and Variables

I obtained annual data from 1990 to 2012 from the World Bank Development Indicators database for the 22 OECD countries. The dependent variable is the real GDP (Y), measured in constant 2010 US dollars. Real GDP is an inflation adjusted measure that reflects the value of all domestically produced goods and services within a country each year. It is the best way of measuring economic growth because it measures how the amount of goods and services within an economy change over time, adjusting for any nominal changes created by inflation.

The independent variables in this study have all been shown to be related to economic growth in previous studies. Real gross fixed capital formation (K) is measured in constant 2010 US dollars. Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. According to the 1993 SNA, net acquisitions of valuables are also considered capital formation. Total labor force, measured in millions, comprises people ages 15 and older who meet the International Labor Organization definition of the economically active population: all people who supply labor for the production of goods and services during a specified period. It includes both the employed and the unemployed. While national practices vary in the treatment of such groups as the armed forces and seasonal or part-time workers, in general the labor force includes the armed forces, the unemployed, and first-time job-seekers, but excludes homemakers and other unpaid caregivers and workers in the informal sector.

The primary purpose of this paper is to study the relationship between renewable energy consumption and real GDP. I consider three different measures of renewable energy use. One measure is renewable energy consumption as a % of total final energy consumption. Another measure of renewables is electricity production, measured in millions of kilowatt hours as a net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric. While other researchers used renewable energy consumption (see for example Apergis and Payne, 2010), this variable is not publicly available and I use renewable energy production instead. The third measure of renewables is measured in thousand tonnes (tonne of oil equivalent) and it represents the contribution of renewables to total energy supply.

All variables are in natural logarithms.

Methodology

Unit Root Tests for Stationarity

In order to investigate the possibility of panel cointegration, it is first necessary to determine the existence of unit roots in the data series. I employ the Im, Pesaran and Shin (IPS) test which is based on the well-known Dickey-Fuller procedure.

Consider a simple panel-data model with a first order autoregressive component:

$$y_{it} = \rho_i y_{i,t-1} + z'_{it}\gamma_i + \varepsilon_{it}$$

Where $i = 1,\dots,N$ indexes panels; $t = 1,\dots,T_i$ indexes time, y_{it} is the variable being tested; and ε_{it} is a stationary error term. The z'_{it} can represent panel-specific means, panel-specific means and a time trend, or nothing.

Panel unit root tests are used to test the null hypothesis $H_0\colon \rho_i = 1$ for all *i* versus the alternative $H_a\colon \rho_i < 1$.

The above equation is often written as

$$\Delta y_{it} = \phi_i y_{i,t-1} + z'_{it}\gamma_i + \varepsilon_{it}$$

so that the null hypothesis is then $H_0\colon \phi_i = 0$ for all *i* versus the alternative $H_a\colon \phi_i < 0$.

An advantage of using the IPS over other tests is that it does not assume that all panels share a common autoregressive parameter, ρ. Cultural, institutional, and other factors make such an assumption questionable. Therefore, the IPS allows for heterogeneity between units in a dynamic panel framework.

IPS begins by specifying a separate Augmented Dickey-Fuller test (ADF) regression for each cross section with individual effects and no time trend:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta y_{i,t-j} + x_{it}\delta + \varepsilon_{it}$$

where i = 1,…,N and t = 1,…,T

IPS use separate unit root tests for the N cross-section units. Their test is based on the ADF statistics averaged across groups. After estimating the separate ADF regressions, the average of the t-statistics for pi from the individual ADF regressions, $t_{iT_i}(p_i)$:

$$\bar{t}_{NT} = \frac{1}{N}\sum_{i=1}^{N} t_{iT}(p_i \beta_i)$$

The *t-bar* is then standardized and it is shown that it follows the standard normal distribution asymptotically as N and T → ∞. Im, Pesaran and Shin also proposed a cross-sectionally demeaned version of both tests to be used in the case where the errors in different regressions contain a common time-specific component.

Panel Cointegration Tests

To determine whether a cointegrating relationship exists, I employ the recently developed methodology proposed by Pedroni (1999 and 2004) is employed.

Pedroni introduced the first residual-based panel cointegration tests. The main idea behind residual-based panel cointegration tests is to test for the existence of a unit root in the residuals of a cointegrating regression equation. A unit root in the residuals implies no cointegration between the components of the model. On the contrary, the absence of a unit root in the residuals shows evidence for a cointegrating relation between the dependent and independent variables of the regression equation. Since these tests are based on the assumption that there is only one single cointegrating relation between the variables, the number of cointegrating relations cannot be detected if there are more than one.

Pedroni (1999 and 2004) suggested seven different residual-based panel cointegration tests for testing the null hypothesis of no cointegration. The four within-dimension-based (i.e. panel-v, panel-ρ, semiparametric panel-t and parametric panel-t) statistics are calculated by summing up the numerator and the denominator over N cross-sections separately. The three between-dimension-based (i.e. group-ρ, semi-parametric group-t and parametric group-t) statistics are calculated by dividing the numerator and the denominator before summing up over N cross-sections.

The procedures proposed by Pedroni make use of estimated residual from the hypothesized long-run regression of the following form:

$$y_{it} = \alpha_i + \delta_i t + x'_{Mit}\beta_{Mi} + \varepsilon_{it}$$

for $i = 1, \ldots, N$, $t = 1, \ldots, T_i$, $m = 1, \ldots, M$, where T is the number of observations over time, N is the number of cross-sections in the panel, and M is the number of regressors. In this set up, α_i is the member specific intercept or fixed effects parameter which varies across individual cross sectional units. The same is true for the slope coefficients and member specific time effects, $\delta_i t$.

The methodology employs four heterogeneous panel statistics and three heterogeneous group panel statistics to test the null hypothesis of no cointegration against the alternative hypothesis of cointegration.

The null hypothesis of no cointegration for the panel cointegration test is the same for each statistic, $H_0{:}\rho_i = 1$,for all i= 1,...,N, whereas the alternative hypotheses for the between-dimension-based and within-dimension-based panel cointegration tests differ. The alternative hypothesis for the between-dimension-based statistics is $H_1{:}\rho_i<1$, for all i= 1,...,N.

For within-dimension-based statistics the alternative hypothesis $H_1{:}\rho_i=\rho <1$, for all i= 1,...,N, assumes a common value. That is, in the case of panel statistics, the first-order autoregressive term is assumed to be the same across all the cross sections, while in the case of group panel statistics the parameter is allowed to vary over the cross sections.

Under the alternative hypothesis, the panel-v statistic diverges to positive infinity, and the right tail of the standard normal distribution is used to reject the null hypothesis. All the other panel cointegration test statistics diverge to negative infinity. Thus, the left tail of the standard normal distribution is used to reject the null hypothesis. If the null is rejected in the panel case then the variables are cointegrated for all the countries. On the other hand, if the null is rejected in the group panel case, then cointegration among the relevant variables exists for at least one of the countries.

Empirical Results

Table 1 presents the results from the IPS unit root test. I consider a model with and without the deterministic trend. The test is performed on the variables in levels as well as in first difference. The results indicate that the null hypothesis that all panels contain unit root cannot be rejected for all variables in levels with and without the trend. The results indicate the null hypothesis that all panels contain unit root can be rejected for all variables except GDP and capital formation when the variables are first differenced. This reveals that labor and variables representing renewable energy are all integrated of order one, or *I(1)*. The panel unit root results recommend the potential presence of panel cointegration which I perform next.

Table 1: Panel Unit Root Test – Im, Pesaran and Shin (IPS)

Variable	Level		First difference	
	Without trend	**With trend**	**Without trend**	**With trend**
GDP	2.6737 (0.9962)	-0.1168 (0.4535)	1.4439 (0.9256)	1.6506 (0.9506)
LABOR	2.4285 (0.9924)	-1.0574 (0.1452)	1.0238 (0.8470)	-3.1533*** (0.0008)
CAPITAL	2.6923 (0.9965)	0.4377 (0.6692)	-0.8603 (0.1948)	-1.0318 (0.1511)
RENEWABLE	7.0391 (0.9999)	-1.885** (0.0295)	5.4513 (0.9999)	-1.6585** (0.0486)
RENEW	5.1452 (0.9999)	-5.2873*** (0.0000)	4.8756 (0.9999)	-3.2400*** (0.0006)
ELECTRICITY	1.1629 (0.8776)	-1.1003 (0.1356)	-1.9348** (0.0265)	-1.8286** (0.0337)

Notes: Panel unit root tests include intercept and trend. *** indicates statistically significant at the 1% level; ** indicates statistically significant at the 5% level. Standard errors are in parentheses. RENEWABLE is renewable energy consumption as a % of total final energy consumption. RENEW is contribution of renewables to total energy supply. ELECTRICITY is net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric.

I estimate the Pedroni (1999, 2001 and 2004) heterogeneous panel cointegration test, which allows for cross-section interdependence with different individual effects in order to determine whether long-run equilibrium relationships exist among the variables. There are two sets of panel cointegrations tests. The panel tests, based on the within dimension approach, includes four statistics: panel v, panel ρ, panel PP, and panel ADF-statistics that take into account common time factors and heterogeneity across countries and the groups tests, based on the between dimension approach that include three statistics: group ρ, group PP, and group ADF-statistics. These statistics are based on averages of the individual autoregressive coefficients associated with the unit root tests of the residuals for each country in the panel. Cointegrations are carried out for intercept and intercept plus time trend. Tables 2 and 3 report both the panel and group mean cointegration test statistics. In Table 2, I measure renewable energy as renewable energy consumption as a % of total final energy consumption. In Table 3, renewable energy is electricity production, measured in millions of kilowatt hours as a net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric. The null hypothesis is that there is no cointegration. All statistics are from Pedroni's procedure (1999) where the adjusted values can be compared to the N(0,1) distribution. The Pedroni (2004) statistics are one-sided tests with a critical value of -1.64 ($k < -1.64$ implies rejection of the null), except the v statistic that has a critical value of 1.64 ($k > 1.64$ suggests rejection of the null).

Table 2: The Pedroni Cointegration Test

Test	Without trend	With trend
Panel *v* statistic	.1675	.7779
Panel *ρ* statistic	.963	1.631*
Panel *t* statistic (non-parametric)	-1.087	-1.646**
Panel *t* statistic (*adf*) (parametric)	2.038**	.1759
Group *ρ* statistic	2.753***	3.49***
Group *t* statistic (non-parametric)	-.3155	-.3232
Group *t* statistic (*adf*) (parametric)	2.473***	1.039

Note: ***, **, *, indicates rejection of the null hypothesis of no-cointegration at the 1%, 5% and the 10% significance levels, respectively. Renewable energy represents renewable energy consumption as a % of total final energy consumption.

Table 3: The Pedroni Cointegration Test

Test	Without trend	With trend
Panel *v* statistic	-0.00153	.3882
Panel *ρ* statistic	.6714	1.6106
Panel *t* statistic (non-parametric)	-1.842*	-3.936***
Panel *t* statistic (*adf*) (parametric)	.2453	1.094
Group *ρ* statistic	1.855*	2.772***
Group *t* statistic (non-parametric)	-2.634***	-3.789***
Group *t* statistic (*adf*) (parametric)	0.3619	1.25

Note: ***, **, *, indicates rejection of the null hypothesis of no-cointegration at the 1%, 5% and the 10% significance levels, respectively. Renewable energy represents electricity production, measured in millions of kilowatt hours as a net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric.

Without the trend, I find that 3 out of 7 statistics reject the null hypothesis of no cointegration at the 5% significance level for the panel *adf* statistic and at the 1% significance level for the group ρ and the group *adf* statistics (Table 2). The results for the panel cointegration test in the model with the trend again show that 3 out of 7 statistics reject the null hypothesis of no cointegration (panel ρ statistics at the 10% significance level and panel t and group ρ at the 1% significance level). Similar results are obtained in Table 3. Again 3 out of 7 statistics reject the null hypothesis of no cointegration with and without the trend. The results of the panel cointegration tests in Tables 2 and 3 indicate that independent variables do hold cointegration in the long run for the group of OECD countries with respect to GDP.

Fully Modified Ordinary Least Squares

After establishing that the variables are cointegrated, I estimated the fully modified OLS (FMOLS) technique for heterogeneous cointegrated panels (Pedroni, 2000) according to the following equation:

$$y_{it} = \alpha_i + \beta_1 L_{it} + \beta_2 K_{it} + \beta_3 RE_{it} + u_{it}$$

The results are displayed in Table 4. I estimate three models. In Model 1, renewable is renewable energy consumption as a % of total final energy consumption. In Model 2, renewable is contribution of renewables to total energy supply. In Model 3, renewable is electricity from net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric. All variables are measured in logarithms so the coefficients can be interpreted as elasticities. I expected a positive and significant effect of each variable on GDP. I find that labor force does not have an effect on GDP. Capital has a positive and statistically significant effect on GDP at the 1 percent level. Thus, the results indicate that over the long run and holding all other variables constant, a 1% increase in gross fixed capital formation increases real GDP by 1.03 to 1.05 percent. The coefficient on renewable is statistically significant only in Model 3 and has a negative sign. It indicates that a 1 percent increase in electricity production from renewable sources reduces the real GDP by 0.046 percent. This effect is negative but small. These results different from the body of work already done on this topic. Apergis and Payne (2010a, 2010b, 2010c) repeatedly found that renewable energy had a positive, but small, effect on GDP. These differences could exist for a variety of reasons including differences in methodology, sample countries, and time-period.

Table 4: Fully Modified Ordinary Least Squares

Variable	Model 1	Model 2	Model 3
Labor	-.0384 (.0621)	-.0332 (.0657)	-.0063 (.0642)
Capital	1.031*** (.0642)	1.0479*** (.0649)	1.0296*** (.0635)
Renewable	-.0296 (.0199)	-.0211 (.0189)	-.0460*** (.0170)
Trend	.0002 (.0001)	.0002 (.0001)	.0002* (.0001)
R^2	0.9917	0.9911	0.9870
Adjusted R^2	0.9916	0.9911	0.9869

Notes: *** indicates statistically significant at the 1% level; ** indicates statistically significant at the 5% level. Standard errors are in parentheses. Standard errors are in parentheses. In Model 1, renewable is renewable energy consumption as a % of total final energy consumption. In Model 2, renewable is contribution of renewables to total energy supply. In Model 3, renewable is electricity from net geothermal, solar, tides, wind, biomass, and biofuels, excluding hydroelectric.

To infer the causal relationship between the variables, I conduct a pairwise Granger Causality test. The test examines the causal effect of each variable on other variables to determine the causal relationship. The results of the Granger Causality test are displayed in Table 5.

Table 5: Pairwise Granger Causality Estimates

Null hypothesis	Number of lags determined by AIC criteria	W bar	Z bar	Z bar tilde
L does not Granger Cause Y	7	18.687	14.649***	4.878***
K does not Granger Cause Y	7	38.013	38.8774***	14.9571***
Renewable does not Granger Cause Y	7	63.0796	70.2996***	28.0295***
L does not Granger Cause K	7	537.8654	665.4756***	275.6377***
L does not Granger Cause Renewable	7	928.3612	1154.9873***	479.2869***
Renewable does not Granger Cause L	1	7.3132	20.9386***	16.9887***
Renewable does not Granger Cause K	7	279.3678	341.4311***	140.8271***
Y does not Granger Cause L	7	349.9699	429.9355***	177.6471***
Y does not Granger Cause K	7	74.9183	85.1401***	34.2035***
Y does not Granger Cause Renewable	7	439.2100	541.8039***	224.1872***

Notes: *** indicates statistically significant at the 1% level

The Granger Causality test used is based on the causality test developed by Dumitrescu and Hurlin (2012), which can return successful results, even under the conditions of cross-sectional dependence. Cross-sectional dependence occurs when multiple variables have a simultaneous, causal effect on each other. In this case, it can be difficult to isolate the relationships among variables. The test developed by Dumitrescu and Hurlin is used because it allows meaningful results to be interpreted, in spite of possible cross sectional dependence. Variable X is said to Granger Cause variable Z if the past values of X can help Z. The null hypothesis of the test is that X does not Granger Cause variable Z. Therefore, a small probability (rejection of the null) is evidence that there is a causal relationship where variable X Granger Causes variable Z. These results do not imply causation but that variable X may be causing variable Z.

The results in Table 5 indicate that there is a bidirectional relationship between all pairs of variables. These results are consistent with findings in several previous studies. For example, the three studies conducted by Apergis and Payne (2010a, 2010b, 2010c) all found bidirectional causality running between real GDP and renewable energy. Additionally, the bidirectional causality found among all tested variables is consistent with the findings of Apergis and Payne (2011).

Conclusion

This study built upon the research studying the effect of renewable energy utilization on economic growth using a panel of 22 OECD countries over the period 1990-2012. To this end I utilize fully modified OLS technique for heterogeneous cointegrated panels advanced by Pedroni (2000). Periodic studies on this topic are important due to the constantly changing nature of the world's energy economy. As the renewable energy industry continues to play a larger role in contributing to electric energy, the nature of its relationship with GDP growth can change.

The results of the FMOLS regression indicate that fixed capital formation has a positive and statistically significant effect on GDP growth. Over the long run and holding all other variables constant, a 1% increase in gross fixed capital formation increases real GDP by 1.03 to 1.05 percent. On the other hand, renewable energy reduces the real GDP growth by 0.046 percent.

Bidirectional Granger-causality indicates that the evidence in this study supports the feedback hypothesis where economic growth and renewable energy impact each other simultaneously. This adds to the already significant body of research that has supported the same conclusion. The small negative effect of renewable energy on GDP growth estimated by the FMOLS regression implies that renewable energy policies do not contribute to GDP growth at this time. This does not mean, however, that policies such as feed-in tariffs and subsidies will not have impact in the future. At the present, they are valuable for developing these industries for environmental purposes. Future research on this topic is essential as the renewable energy grows and generates a larger portion of the world's electricity supply. Updated datasets will continue to provide meaningful insight on this issue.

Appendix

Table 6: Energy Consumption-Economic Growth Literature Summary

Study	**Sample**	**Time Frame**	**Causality**	**Hypothesis Confirmed**
Apergis & Danuletiu, 2014	80 Countries	1990-2012	Renewable Energy<>Growth	Feedback Hypothesis
Apergis & Payne, 2010a	13 Eurasian Countries	1992-2007	Renewable Energy<>Growth	Feedback Hypothesis
Apergis & Payne, 2010b	20 OECD Countries	1985-2005	Renewable Energy<>Growth	Feedback Hypothesis
Apergis & Payne, 2010c	6 Central American Countries	1980-2006	Renewable Energy<>Growth	Feedback Hypothesis
Apergis & Payne, 2011	80 Countries	1990-2007	Energy<>Growth Renewable Energy<>Growth	Feedback Hypothesis
Chontanawat, et al., 2008	108 Countries	1971-2000	Energy>Growth	Growth Hypothesis
Huang, et al., 2008	82 Countries	1972-2000	Growth>Energy	Conservation Hypothesis
Lee, 2006	11 Industrialized Countries	Varied	Energy<>Growth Growth>Energy Energy>Growth	Feedback, Growth, and Conservation Hypotheses
Soytas & Sari, 2003	G7 Countries	Varied	Energy<>Growth Growth>Energy Energy>Growth	Feedback, Growth, and Conservation Hypotheses
Tugcu, et al., 2012	G7 Countries	1980-2009	Renewable Energy<>Growth	Feedback Hypothesis

References

Administration, E. I. (2014). *Annual Energy Outlook 2014 with Projections to 2040*. Retrieved from Energy Information Administration: https://www.eia.gov/outlooks/aeo/pdf/0383(2014).pdf

Akinlo, A. (2008). Energy Consumption and Economic Growth, Evidence from 11 Sub-Sahara African Countries. *Energy Economics*.

Aleklett, K., Hook, M., Jakobsson, K., Lardelli, M., Snowden, S., & Soderbergh, B. (2010). The Peak of the Oil Age - Analyzing the world oil production reference scenario in world energy outlook 2008. *Energy Policy*.

Apergis, N., & Danuletiu, D. (2014). Renewable Energy and Economic Growth: Evidence from the Sign of Panel Long-Run Causality. *International Journal of Economics and Policy*.

Apergis, N., & Payne, J. (2010a). Renewable Energy Consumption and Growth in Eurasia. *Energy Economics*.

Apergis, N., & Payne, J. (2010b). Renewable Energy and Economic Growth: Evidence from a Panel of OECD Countries. *Energy Policy*.

Apergis, N., & Payne, J. (2010c). Energy Consumption and Economic Growth in Central America: Evidence from a Panel Cointegration and Error Correction Model. *Energy Economics*.

Apergis, N., & Payne, J. (2011). Renewable and Nonrenewable Energy Consumption-Growth Nexus: Evidence from a Panel Error Correction Model. *Energy Economics*.

Bayar, Y., & Ozel, H. (2014). Electricity Consumption and Economic Growth in Emerging Economies. *Journal of Knowledge Management, Economics and Information Technology*.

Birol, F. (2009). Energy use and carbon policy. *Presentation given at the Sixth Meeting of the Global ROundtable on CLimate Change* .

Chontanawat, J., Hunt, L., & Pierse, R. (2008). Does Energy Consumption Cause Economic Growth? Evidence from a Systematic Study of Over 100 Countries. *Journal of Policy Modeling*.

Clark, D. (2012). *Has the Kyoto Protocol Made any DIfference to Carbon Emissions?* The Guardian.

Couture, T. (2013). Pain in Spain: New Retroactive Changes Hinder Renewable Energy . *Renewable Energy World*.

Couture, T., Cory, K., Kreycik, C., & Williams, E. (2010). *Policymaker's Guide to Feed-In Tariff Policy Design.* National Renewable Energy Laboratory .

European Renewable Energy Council. (2004). *Renewable Energy Policy Review: Germany.* Brussels.

Granger, C. (1969). Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Econometrica*.

Grubb, M. (2003). The Economics of the Kyoto Protocol. *World Economics*.

Hamilton, J. (2005). Oil and the Macroeconomy. *Palgrave Dictionary of Economics*.

Huang, B.-N., Hwang, M., & Yang, C. (2008). Causal Relationship between Energy Consumption and GDP Growth Revisited: A Dynamic Panel Data Approach. *Ecological Economics*.

International Energy Agency. (2005). *Key World Statistics.* Paris.

Lee, C.-C. (2006). The Causality Relationship Between Energy Consumption and GDP in G-11 Countries Revisited. *Energy Policy*.

Lipp, J. (2007). Lessons for Effective Renewable Energy Electricity Policy from Denmark, Germany, and the United Kingdom. *Energy Policy*.

Murphy, D., & Hall, C. (2011). Energy return on investment, peak oil, and the end of economic growth. *Ecological Economics Reviews*.

Ouedraogo, I., & Diarra, M. (2010). Electricity Consumption and Economic Growth in Burkina Faso: A Cointegration Analysis. *Energy Economics*.

Parkinson, G. (2012). PacHydro Sees 12GW of Solar by Mid 2020s. *Reneweconomy*.

Pedroni, P. (1999). Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. *Oxford Bulliten of Economics and Statistics*, 653-678.

Pedroni, P. (2001). Purchasing Power Parity Tests in Cointegrated Panels. *The Review of Economics and Statistics*, 727-731.

Pedroni, P. (2004). Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Test with an Application to the PPP Hypothesis. *Economic Theory*, 625-697.

Pegkas, P. (2014). The Link Between Educational Levels and Economic Growth: A Neoclassical Approach for the Case of Greece. *International Journal of Applied Economics*.

Peseran, M., Shin, Y., & Smith, R. (2001). Bound Testing Approaches to the Analysis of Level Relationships. *Journal of Applied Economics*.

Sari, R., Ewing, B., & Soytas, U. (2008). The Relationship Between Disaggregate Energy Consumption and Industrial Production in the United States: An ARDL Approach. *Energy Economics*.

Soytas, U., & Sari, R. (2003). Energy Consomption and GDP: Causality Relationship in G-7 Countries and Emerging Markets. *Energy Economics*.

Squalli, J. (2007). Electricity Consumption and Economic Growth: Bounds and Causality Analyses of OPEC Countries. *Energy Economics*.

Tugcu, C., Ozturk, I., & Aslan, A. (2012). Renewable and Non-Renewable Energy Consumption and Economic Growth Relationship Revisited: Evidence from G7 Countries. *Energy Economics*.

United Nations. (2017, March 3). *Satus of Ratification of the Kyoto Protocol*. Retrieved from UNFCCC Homepage.

Yamamoto, M., & Osamu, I. (2010). National Survey Report of PV Power Applications in Japan. *International Energy Agency*.