RENEWABLE ENERGY CONSUMPTION AND ECONOMIC GROWTH NEXUS: DIFFERENTIAL IMPACT BETWEEN DEVELOPED AND DEVELOPING ECONOMIES

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Lilly Schmachtenberger

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Abstract

Renewable energy is an alternative energy source that has the capability of promoting economic prosperity while ensuring the preservation of our environment. This paper seeks to examine relationships between renewable energy consumption and economic growth and the differential impact on both developed and developing economies. I employed a fixed effect co-panel regression model to a sample of the top thirty-nine renewable energy consuming countries for the period 1995–2019. Our key empirical findings reveal that renewable energy consumption is associated with a positive statistically significant impact on economic growth in developing countries; however, a negative impact was found among developed economies. This study extends investigation into possible determinants of renewable energy demand through the creation of a Cobb-Douglas production function. These findings have important implications for policymakers in revealing that renewable energy sources can offer an environmentally sustainable means of economic growth in the future, but a proper understanding of dynamics including capital and labor deepening channels is essential in developing appropriate policy.

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Signature

Lilly Schmachtenberger

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Introduction

Electricity consumption is a well investigated and influential input in furthering economic development (Apergis, Nicholas & Payne, 2009); however, non-renewable energy sources have proven to further perpetuate environmental degradation (Osobajo et al., 2020). In order to limit the progression of climate change and carbon emissions, alternative energy sources like renewables provide a global opportunity for sustainable economic growth. Renewable energy sources have been identified as the "fuel of the future," but the inter-linkages between renewable energy consumption and economic growth have not been clearly understood in the existing literature (Singh et al., 2019). This study seeks to examine relationships between renewable energy consumption and economic growth, exploring the differential impact on both developing and developed economies.

This study emphasizes the relative importance of renewable energy on economic growth by analyzing separate panels for developed and developing countries. This comparison is relevant due to the fact that developed and developing economies are projected to have separate energy needs in the future. Many developed and developing countries are moving towards a "green" growth agenda. In 2021, renewables contributed to 28.7% of global energy consumption (International Energy Agency, 2022). The United Nations, a leading global organization, declared renewable energy development as one of their main areas of focus in the future. Heavy investment with respect to renewables stems from their potential in promoting economic growth and environmental conservatism simultaneously. Interestingly in 2015, the Renewable Energy Network discovered that developing countries were investing more into renewables than developed countries for the first time. This could be explained by energy consumption in developing economies increasing by 84% between 2007 and 2035, comparative to only 14% in developed economies.

This study provides evidence that energy consumption plays a vital role in economic growth, and serves as a complement to capital and labor deepening. Importantly, I removed reverse causality in the estimation of the causal impact of renewable energy through the inclusion of a lagged renewable energy consumption variable. A majority of the literature with respect to electricity consumption (renewable or non-renewable sources) and economic development works along four well established hypotheses: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. This study's results support the growth hypothesis, indicating that a unidirectional relationship from renewable energy consumption to economic growth exists.

This study uses a co-panel data analysis of 24 developed and 15 developing economies for the period 1995–2019. This paper includes these specific countries as they were identified by Ernst and Young as holding the highest Renewable Energy Country Attractiveness Index scores (Ernst & Young, 2020). The geographical location and developmental categorization of the thirty-nine countries observed within this study vary. This study attempts to take one more step in deriving a demand function for renewable energy. Utilizing the full panel of 39 countries, this study curated a production function to expound upon indicators that can predict or change the demand for renewable energy consumption. Real GDP, the price of coal, and the price of natural gas were identified as inputs within this production function. Results could help shed light on the income and substitution effects of renewable energy consumption and other energy sources.

This paper answer four main questions:

(1) Does renewable energy consumption have a significant impact on GDP?

(2) Does renewable energy consumption have a significant impact on gross fixed capital formation?

(3) Does renewable energy consumption have a significant impact on the size of the labor force?

(4) Is there a differential impact on renewable energy consumption in developing and developed countries?

Within our first investigation, I find that renewable energy increases economic development for developing countries more than developed countries. A 1% increase in renewable energy consumption decreased real GDP by 0.045% in developed countries, but a 1% increase in renewable energy consumption increased real GDP by 0.152% in developing countries. To understand the differing dynamics between developed and developing economies gross fixed capital formation and labor force were investigated as dependent variables. These results show that renewable energy consumption impacts real GDP positively in developing countries through labor deepening channels. However, for developed economies, renewable energy consumption impacts real GDP negatively through unforeseen channels outside of the scope of this research.

With gross fixed capital formation as the dependent variable, a 1% increase in renewable energy consumption increased gross fixed capital formation by 0.044% in developed countries. Renewable energy consumption does not have statistically significantly impact on gross fixed capital formation in developing countries. Developing countries' renewable infrastructure and development opportunities often stem from private investment, and the infrastructure and distribution channels are often less capital intensive than structures utilized in developed economies. This could explain the lack of a significant relationship between renewable consumption and GFCF in developing economies.

With labor force as the dependent variable, a statistically significant coefficient was found among developing countries. A 1% increase in renewable energy consumption increased labor force by 0.144%. There was no statistically significant coefficient found among developed countries and labor force. This is intriguing as the United Nations claims that every dollar of investment in renewables creates three times more jobs than the fossil fuel industry, but this was not supported by the results for developed countries (United Nations, 2022).

In the panel of developed countries, results provide evidence that renewable energy consumption negatively impacts real GDP. The negative impact did not flow from factors such as total labor force or through positive impacts on GFCF. It can thus be inferred that the negative impact on real GDP flows through other factors such as changes in total factor productivity or trade balances. In the panel of developing countries, results provide evidence that renewable energy consumption positively impacts real GDP. The positive effect does seem to flow from factors such as total labor force; however, in the case of GFCF, the impact of renewable consumption for developing countries was insignificant.

The second probe of this study intends to measure if there is a substitution or income effect that impacts demand for renewable energy sources. Within this panel of data, it was found that a 1% increase in real GDP decreased renewable energy consumption by 0.21%; however, there was no statistically significant relationship between the price of substitutes and the impact on renewable energy demand.

The findings of this study differ from results previously published by Singh and Nyuur. Singh and Nyuur discovered that an increase in renewable energy consumption would have positive impacts on economic growth for both developed and developing countries (Singh et al., 2019). These conclusions contradict the negative unidirectional relationship between renewable energy consumption and economic growth seen amongst the developed countries within the purview of this study. Concerning the second sub-topic of this study, our findings contradict Li and Leung, who found short run causality from the price of coal and the price of natural gas to renewable energy consumption among seven European countries (Li & Leung, 2021a). The lack of similarity could be explained by the expanded geographical and developmental scopes of the countries included in observation. In order to see a more cohesive results among the literature, it may take more time and investment to define the true relationship and linkages between these variables.

Literature Review

2.1.1 Empirical Background

Renewable energy is a cost effective, sustainable, and economically sensible substitute for conventional energy sources such as coal, natural gas, oil, and other fossil fuels. Derived from natural sources such as wind and solar, renewable energy does not perpetuate growth within emissions or pollutants like fossil fuels. The International Renewable Energy Agency estimated that 90% of the world's electricity consumption can and should come from renewables by 2050 in order to mitigate climate change (United Nations, 2022). Investment into renewable energy sources would be momentously beneficial for the environment, but also cost effective. The International Renewable Energy Agency found that replacing coal-fired plants with new solar and wind projects would cut annual system costs by 32 billion per year and reduce annual CO_2 emissions by around 3 Gigatons (International Renewable Energy Agency, 2021).

Climate change and global warming are at the forefront of global concern. Direct and indirect human activities contribute to environmental deterioration, but human activities such as industrialization and globalization are often viewed as main perpetrators of climate change.

Though human activities such as industrialization have been positively related to accelerated economic growth and increasing output, it is costly in regard to the volume of pollutants and emissions. Renewable energy sources act as a suitable alternative to counteract the costs that correspond with non-renewable energy sources. Not only are renewable energy sources effective in minimizing environmental degradation, but there is limited evidence that renewable energy sources are less effective in promoting increasing levels of output or higher levels of economic growth.

Previously there has been a multitude of studies done in relation to energy consumption, economic growth, and environmental degradation; however, the affiliation between renewable energy consumption, economic growth, and environmental quality remains a bit more unclear. In the previously established literature, it has been found that increasing non-renewable energy consumption increases levels of economic growth and pollutants. The existing literature examining the associations between renewable energy consumption and economic growth fails to delineate a cohesive and reoccurring nexus. A majority of these studies differ in methodology and structural framework; however, they all emphasize the importance of sustainability within economic growth. Four differing hypotheses are often investigated within the literature: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis.

i. The **growth hypothesis** refers to a situation in which energy consumption plays a vital role in the economic growth process directly and/or as a complement to capital and labor. The growth hypothesis is supported, if unidirectional causality is found from energy consumption to economic growth. In this case, energy conservation policies aimed at reducing energy consumption will have negative impacts on economic growth (Tugcu et al., 2012).

ii. The **conservation hypothes**is means that economic growth is the dynamic which causes the consumption of energy sources. The validity of the conservation hypothesis is proved if there is unidirectional causality from economic growth to energy consumption. In this situation, energy conservation policies which may prevent energy consumption will not have negative impact on economic growth (Tugcu et al., 2012).

iii. The **feedback hypothesis** states a mutual relationship among energy consumption and economic growth. The feedback hypothesis is supported if there exists bi-directional causality between energy consumption and economic growth. In case of the validity of this hypothesis, energy conservation policies designed to reduce energy consumption may decrease economic growth performance, and likewise, changes in economic growth are reflected back to energy consumption (Tugcu et al., 2012).

iv. The **neutrality hypothesis** indicates that energy consumption does not affect economic growth. The absence of causality be- tween energy consumption and economic growth provides evidence for the presence of the neutrality hypothesis. In this case, energy conservation policies devoted to reducing energy consumption will not have any impact on economic growth (Tugcu et al., 2012).

The vision of sustainable development has captivated the world's attention. Many countries and organization have increased their regulations and policies intended to limit carbon emissions and encouraging other sustainable options. Researchers have prioritized the investigation of renewable energy consumption impacts on economic growth. This research attempts to define whether renewable energy consumption is a driver of economic growth, and if there is variation among the economic impacts between developed and developing economies.

2.1.2 Energy Consumption Growth Nexus

In 1978, Kraft and Kraft conducted one of the initial studies examining the causal relationship between energy consumption and economic growth. Utilizing gross energy consumption and gross national product as variables, Kraft found that there was a unidirectional causality from gross national product to gross energy consumption in the United States (Kraft et al., 1978). Their conclusions illuminate that policy implemented to encourage energy conservation would not have an adverse effect of economic activity; however, this is not a general consensus amongst all of the literature. Since the publication of their findings, this study has been undertaken in the context of a broad range of countries and many alternative findings have been made.

There is a lack of uniformity in regard to the directionality and magnitude of the relationship between energy consumption and economic growth. These diverging conclusions and results have been explained by heterogeneity in countries climate, energy consumption patterns, developmental classification, and many other factors that could contribute to omitted variable bias. For example, Apergis and Payne conducted a study including six countries in Central America. This study commissioned a panel data set over the period 1980-2004 to explore the relationship between energy consumption and economic growth including production factors: capital formation and labor force (Apergis & Payne, 2009). It was concluded that a long run positive unidirectional relationship exists between energy consumption, gross capital formation, and labor force in relation to economic growth. Apergis and Payne's findings in Central America provide evidence for the growth hypothesis, whereas Kraft and Kraft's findings support the conservation hypothesis. Not only is there lack of consensus within directionality, but other researchers have found there to be a bi-directional relationship between economic growth and energy consumption. Saidi and Hammami investigated this relationship within Tunisia over the period 1974-2011, and found that the casual relationship between energy consumption and economic growth was bi-directional. This result provides evidence to support the feedback hypothesis. This result indicates energy is a determinant factor of the GDP growth, and, therefore, a high-level of economic growth leads to a high level of energy demand and vice versa (Saidi & Hammami, 2014). These findings would therefore reject neo-classical assumptions of the neutrality of the effect of energy consumption on economic growth.

The direction of causality is imperative in aiding policy makers to curate the most effective climate policy. Varying conclusions within results emphasize that a policy could impact different regions in inadvertent ways. Evidence of unidirectional causality from income to energy consumption could assume full compatibility between energy conservations policy and policies for economic growth. Kraft and Kraft discovered a unidirectional relationship between gross national product to gross energy consumption; therefore, their conclusions illuminate that policy implemented to encourage energy conservation would not have an adverse effect of economic activity. This interferes with Apergis and Payne's findings that there is a unidirectional relationship from energy consumption to economic growth. Legislation curated to limit energy consumption in this case would unintentionally stunt economic growth. In the case of the bi-directional relationship between energy consumption and economic growth found by Saidi and Hammami there would be similar consequences of carbon reducing policies. In order to counteract the possible negative impacts of carbon reducing/energy conserving policies, encouragement and investment towards technological innovation for energy savings and renewable energy alternatives could simultaneously reduce environmental degrading, while simultaneously protecting economic development.

2.1.3 Environmental Quality - Economic Growth Nexus

The relationship between air quality and economic growth has also been extensively researched. In early literature regarding this topic, Grossman and Krueger studied the relationship between specific air pollutants and economic growth across forty-two countries. This was one of the original pieces of research to call into question the connection between a country's trade regimen and its rate of environmental degradation as well as the relationship between a country's stage of economic development and its output of pollution. In their study, it was found that the concentration of sulfur dioxide and smoke increased with per capita GDP at low levels of national income, but decreased with GDP growth at higher levels of income. The inverted-U shaped relationship between pollution and national income indicated peak levels of pollution to occur around per capita income of four thousand to five thousand dollars (Krueger & Grossman, 1991). Grossman and Kruger explained this divergence by claiming as economic activity expands pollutants tend to grow; however, countries with higher levels of national income often develop heightened demands for a more sustainable environment. These more developed economies are then able to allocate excess funds or resources into environmental upgrading. These findings triggered the development of the Environmental Kuznets Curve theory.

There is a plethora of creativity within literature striving to quantify the relationship between economic progress and environmental quality. Differing data intervals, methodologies, variable selections, and national or regional characteristics explain the complex and volatile linkages between economic progress and environmental quality. It is imperative to recognize that varying economic characteristics of countries could explain the complex and fluctuating results seen when defining the relationship between economic growth and environmental quality.

2.1.4 The Nexus of Energy Consumption, Economic Growth, and CO_2 Emissions

Environmental degradation and sustainability have ascended to the forefront of many academic conversations in both developing and developed economies. Several factors such as population size, the carbon intensity of energy, economic growth, clean nuclear energy use, fossil energy consumption, renewable energy consumption, and urbanization have been identified to be responsible for the growth in the global CO_2 emissions levels (Osobajo et al., 2020). CO_2 emissions have operated as a benchmark in estimations of global warming potentials. Many scholars utilize this benchmark to investigate the impacts energy consumption can have on carbon dioxide emissions.

Hossain investigated the dynamics between carbon dioxide emissions, energy consumption, economic growth, foreign trade, and urbanization within Japan (Hossain, 2012). It was discovered in Japan, higher energy consumption gave rise to more carbon emissions, resulting in a more polluted environment. However, uniquely it was found there was also a positive unidirectional causal relationship discovered between carbon emissions and economic growth**.** Though energy consumption was found to promote economic growth by increasing the amount of goods and services produced, it also left the issue of increasing greenhouse gas emissions (Hossain, 2012). This positive unidirectional relationship highlights a moral dilemma, actions or policies intended to lower carbon emissions in order to improve the health of our environment could cause slowing economic growth and raise unemployment.

Based on previous studies it can be concluded that energy consumption and economic growth are two of the most cited drivers of carbon dioxide emissions. Stolyarova examined the relationship between per capita carbon dioxide emissions, per capita GDP, and energy mix across 93 countries. This study found the main determinant of the growth rate of per capita carbon dioxide emissions was the growth rate of per capita GDP, and the percentage of alternative and nuclear energy use (Stolyarova et al., 2002). Similarly, Osobajo investigated the impact of energy consumption and economic growth on carbon dioxide emission utilizing economic growth, energy consumption, capital stock, and population as independent variables (Osobajo et al., 2020). Osobajo looked at a twenty-year period for 70 countries. It was concluded that all study variables were positively significant, and that a bidirectional causal relationship exists between the study variables and carbon dioxide emissions except for energy consumption, which has a unidirectional relationship with emissions. This differs from Stolyarova findings as Osobajo discovered a bi-directional relationship between carbon emissions and economic growth, and Stolyarova discovered a positive unidirectional causal relationship between carbon emissions and economic growth**.** A majority of the literature indicates that there is a relationship that exists between energy consumption, economic growth, and carbon emissions; however, there is a lack of consensus on the relative size or direction of these linkages. This relationship is imperative to further differentiate and specify as policy regarding economic stimulus, carbon reduction targets, or energy conservation could have unintended positive or negative impacts.

2.1.5 Renewable and Non-Renewable Electricity Consumption- Growth Nexus

There is also an abundant amount of literature comparing the varying impacts of renewable energy consumption to non-renewable energy consumption in regard to their correlation with economic growth. Apergis and Payne study investigated the relationship between renewable and non-renewable electricity consumption and economic growth for 16 emerging market economies within a time-varying coefficient cointegration model spanning the period 1990–2011 (Apergis, N. & Payne, 2014). This study was unique in finding that a large number of emerging countries are undertaking initiatives to restructure their electricity consumption profile through investing heavily in renewable energy. There results show that a 1% increase in now-renewable energy consumption increases real GDP by 0.424%, but the long-run coefficient for renewable energy consumption was positive but statistically insignificant. Though their findings were insignificant they do justify the efforts undertaken by emerging market economies to reduce their carbon intensity. In future findings, scholars anticipate the substantial increase in the share of renewable energy in the overall energy mix could possibly have a positive statistically significant impact on economic growth.

Other literature examining the causal relationship between renewable and non-renewable energy consumption on economic growth have inconsistent conclusions. There is some uniformity among multi country panel studies, as many of these studies provide statistical support for the feedback hypothesis for all energy sources. For example, Tugcu and Ozturk investigated the long-run and causal relationships between renewable and non-renewable energy consumption and economic growth in order to determine which type of energy consumption is more important for economic growth in G7 countries for 1980–2009 period. The long-run estimates showed that both renewable or non-renewable energy consumption matter for economic growth. There was little difference in the elasticity estimates between the two differing energy sources (Tugcu et al., 2012). Also, Apergis and Payne expanded upon their contributions to this literature in implementing another study within this discipline. These scholars lookes at eighty countries within a multivariate panel framework, and similarly found there was little difference in the elasticity estimates with respect to renewable and non-renewable energy consumption. Their results provided a statistically significant bidirectional causality between renewable and non-renewable energy consumption and economic growth in the short and long run. In other research, Bhattacharya and Paramati were able to differentiate the elasticity estimates between renewable versus non renewable energy sources. It was concluded that a 1% increase in renewable energy consumption increased economic output by 0.109%, while a 1% increase in non-renewable energy consumption increased economic output by 0.277% (Bhattacharya et al., 2016). Though there are varying conclusions surrounding the elasticity estimates between renewable versus nonrenewable sources, the most common conclusions support the feedback hypothesis with respect to multi country panel studies.

2.2.1 Renewable Energy: Growth Hypothesis Evidence

The rising share of renewable energy within the world's energy mix is raising many questions surrounding its possible implications to economic growth. The growth hypothesis indicates a situation in which renewable energy consumption plays a vital role in the economic growth, and is supported if unidirectional causality is found from energy consumption to economic growth. There have been a multitude of studies that have come to this conclusion, but the structure as well as the methodology applied by scholars can explain variations within the literatures support of the growth hypothesis.

Xu and Wang investigated the role of renewable energy adaptation, financial development, and globalization toward environmental quality and economic progress among the big five economies. Xu and Wang concluded that variables of interest: financial development, capital formation, natural resources, and globalization have a positive impact on economic progress, but consequential impacts on environmental quality. It was also discovered that renewable energy consumption mitigates environmental degradations while continuing to reinforce economic progress (Xu et al., 2022). These conclusions emphasize the tradeoff that occurs between the economy and the environment. Though economic growth inadvertently hinders environmental quality, the results indicate the adaptation of renewable energy sources can not only strengthen economic growth, but reduce environmental degradation simultaneously.

Region specific studies have also been conducted, and have provided support for the growth hypothesis. Scholars Qudrat-Ullah and Nevo investigated the impact of renewable energy consumption and environmental sustainability on economic growth within Africa. They were able to solidify a unidirectional relationship from renewable energy adoption to economic growth. Variables of interest included gross domestic product, renewable energy consumption, carbon emissions, gross fixed capital formation, labor force, and access to electricity. This study concluded that a 1% increase in renewable energy consumption led to a 1.9% increase in economic growth in the long run (Qudrat-Ullah & Nevo, 2021).

Further research investigates the differing impact of renewable energy consumption as a driver of economic growth for developing versus developed economies. Understanding the differing impacts for emerging market economies versus established market economies is a meaningful investigation. This methodology was utilized by Singh and Nyuur. Specifically, the sample of countries studied within this research included the top ten highest renewable energy producing developed and developing countries. This ensured that countries producing or utilizing small amounts of renewable sources were not included due to a likely negligible impact. Singh and Nyuur were able to conclude that there was a positive statistically significant unidirectional relationship between renewable energy consumption to economic growth for both developing and developed economies (Singh et al., 2019). The multivariate framework included variables for real gross domestic product, gross fixed capital formation, total labor force, renewable energy production, and fossil fuel use. Though this relationship was found to have the same directionality for both categories of countries, the impact of renewable energy production on economic growth was higher in developing economies. In developed countries, an increase in renewable energy production caused a 0.07% rise in output, compared to only 0.05 % rise in output for developing countries (Singh et al., 2019). These findings have important implications for policymakers and reveal that renewable energy production can offer an environmentally sustainable means of economic growth in the future for both developing and developed economies.

2.2.2 Renewable Energy: Conservation Hypothesis Evidence

The conservation hypothesis means that economic growth is a driver in which causes the consumption of energy sources. The validity of the conservation hypothesis is proven if a unidirectional causal relationship found from economic growth to energy consumption. The literature regarding the conservation hypothesis provides the least amount of literary support comparative to the growth, feedback, and neutrality hypotheses; however, there have been studies that have generated empirical evidence to support the conservation dynamic.

Sadorsky utilized a panel co-integration technique for eighteen emerging economies from 1994 to 2003, and found that a 1% increase in real income per capita would lead to a 3.5% increase in renewable energy consumption (Sadorsky, 2009). This finding supports the conservation hypothesis, and provides evidence that renewable energy consumption will escalate heavily when emerging economies gain momentum. In another study conducted by scholars utilizing a Granger causality test on data collected in the United States, evidence of a unidirectional relationship from GDP to renewable energy consumption was also found (Menyah et al., 2010).

2.2.3 Renewable Energy: Feedback Hypothesis Evidence

There is an excess of literature that also supports the feedback hypothesis with respect to renewable energy consumption. The feedback hypothesis is supported if there exists bi-directional causality between renewable energy consumption and economic growth. In case of the validity of this hypothesis, energy conservation policies designed to reduce energy consumption may inadvertently decrease economic growth performance.

In a country specific study of Ghana, scholars Gyimah and Yao conclusions supported the feedback effect. Ghana was selected due to its large supply of renewable energy as well as their impending energy crisis. Utilizing variables for gross domestic product, foreign direct investment, gross capital formation, and trade this study concluded that there is a bidirectional relationship between renewable energy consumption and economic growth. An important point to note within Gyimah and Yao's findings include the significant impact trade has on influencing economic growth (Gyimah et al., 2022).

In another study conducted by Apergis and Payne results supporting the feedback hypothesis were found. Apergis and Payne are leading scholars within electricity consumption and economic growth nexus literature; however, variations within methodology and areas of study explain their varying findings. Apergis and Payne investigated evidence from OECD countries utilizing real GDP, renewable energy consumption, real gross fixed capital formation, and the labor force as variables. Their Granger-causality results confirmed that a bidirectional causal relationship exists between renewable energy consumption and economic growth in both the short and long run for OECD countries. Apergis and Payne explained these findings by concluding renewable energy consumption indirectly affects economic growth through its positive impact on real gross fixed capital formation, but not through its impact on the labor force (Apergis, Nicholas & Payne, 2010).

In another study conducted by Apergis and Payne, they investigated the relationship between renewable energy consumption and economic growth within Central America. Utilizing the same variables as the study they performed on OECD countries, they found evidence to provide the same conclusion. Though both studies provide empirical evidence to support the feedback hypothesis, the results pertaining to Central American countries found a 1% increase in renewable energy consumption increases real GDP by 0.244%, whereas in the study conducted on OECD countries found a 1% increase in renewable energy consumption increases real GDP by 0.76% (Apergis, Nicholas & Payne, 2011). Thus, these results reinforce the importance of economic growth for the continued development and uses of renewables; however, differing empirical results raise questions of what regional characteristics or other external factors could cause the production of slightly differing statistical results.

In similar methodology to Singh and Nyuur's approach in clustering countries based upon level of development, Ntanos and Skordoulis investigated the relationship between renewable energy consumption and economic growth amongst 25 European countries. In order to classify these countries, this studied utilized a hierarchical cluster analysis in categorizing the examined countries based on their GDP and renewable energy consumption. Utilizing gross domestic product, gross fixed capital formation, labor force, renewable energy consumption, and nonrenewable energy consumption as variables, Ntanos and Skordoulis findings supported the feedback hypothesis for both clusters. Their investigation emphasized that the magnitude of the relationship between renewable energy consumption and economic growth was greater for the

European countries of higher GDP than those with lower GDP. For countries belonging to cluster one, the higher GDP and renewable consuming countries, if renewable energy consumption increased by 1% the country's GDP would increase by 0.603%. For countries in cluster two if renewable energy consumption increased by 1% the country's GDP would increase by 0.477% (Ntanos et al., 2018). This is similar to the findings of Singh and Nyuur indicating countries with lower levels of GDP will see a smaller impact on economic growth than developed countries.

2.2.4 Renewable Energy: Neutrality Hypothesis Evidence

The final hypothesis often investigated and supported within renewable energy consumption is the neutrality hypothesis. The neutrality hypothesis indicates that renewable energy consumption does not affect economic growth. In this case, energy conservation policies devoted to reducing energy consumption will not have any impact on economic growth. Menegaki found evidence to support this hypothesis when investigating growth and renewable energy in Europe. When looking at twenty-seven European countries in a multivariate panel framework over the period 1997-2007, Menegaki included variables of final energy consumption, greenhouse gas emissions, and employment as additional independent variables. The panel error correction model did not provide any evidence of a short- or long-term causality from renewable energy consumption to economic growth (Menegaki, 2011).

Another creative variation within the literature includes evaluating the impact of energy prices on the demand for renewable energy. Li and Leung investigated this nexus among seven European countries from 1985-2018. Weighted price indexes of coal and natural gas were included in the demand specification with real GDP to explaining renewable energy demand within a production function. It is imperative to understand the energy prices in both the short and long run provided evidence causality is found to flow from substitute energy prices and renewable energy demand. Increases in alternative energy prices indicated changing demand for renewable energy. Though their results provide empirical support to the important nature of non-renewable energy prices and its impact on the renewable energy transition, there was lack of causality from renewable energy demand and real GDP. These findings support the neutrality hypothesis (Li & Leung, 2021b).

Data & Methodology

This paper follows a panel of 39 countries identified by Ernst and Young as holding the highest Renewable Energy Country Attractiveness Index scores (RECAI). These rankings were determined based upon the evaluation of renewable energy investment and deployment opportunities within a country (Ernst & Young, 2020). Within this panel of 39 countries, two clusters were created based upon the World Bank's classification of high income, upper middle income, and lower middle income. The developed economies include: Hungary, Switzerland, Norway, Finland, Belgium, Sweden, South Korea, Poland, Portugal, Greece, Israel, Canada, Spain, Netherlands, Chile, Italy, Ireland, Denmark, France, United Kingdom, Germany, Australia, Japan, and the United States. Countries categorized as upper middle income and lower middle income, representing developing economies include the following 15 countries: Jordan, Indonesia, Kenya, Kazakhstan, Mexico, South Africa, Philippines, Turkey, Vietnam, Argentina, Egypt, Morocco, Brazil, China, and India.

This study explored the impact of renewable energy consumption on economic growth. I selected variables for real GDP, gross fixed capital formation, and labor force from The World Bank. I selected variables for renewable energy consumption and fossil fuel consumption from Our World In Data. This data was analyzed quantitatively using a Granger causality test to produce conclusive and statistically significant findings. *Table 1* provides an overview of the variables. The multivariate framework includes real GDP in constant 2015 US dollars as a proxy for economic growth, real gross fixed capital formation in constant 2015 US dollars, total labor force, renewable energy consumption, and fossil fuel use. Further details of variables explained in the table below.

This study continues to investigate into the nexus between renewable energy demand through the creation of a production function that could help shed light on the income and substitution effects that possibly impact renewable energy demand. This study obtained the geographically appropriate price indexes for coal and natural gas from the IEA Energy Prices and Taxes databases and multiplied them by each country's electricity generation share of coal and natural gas to generate the influence weighted price series of coal (PC) and natural gas (PG). Coal price indexes including the US Central Appalachian coal marker price index, Asian marker price, and the Northwest Europe marker price were utilized and assigned to the countries based upon geographical region. Following being assigned a region-specific coal price index each individual countries coal electricity share (%) was multiplied by the index in order to produce a weighted variable. The same methodology was utilized when constructing natural gas weighted indexes; however, the natural gas indexes utilized were the US Henry Hubb, OECD countries CIF (BP), LNG- Japan CIF, Netherlands TTF, and more.

3.1.2 Variables/ Summary Statistics

Table 1

Variable	Description	Period	Source
Real GDP	Real Gross Domestic Product is the market value of all final goods and services produced in the economy during a specified period of time. It is measure in billions of constant US$ (2015).	1995-2019	The World Bank

GFCF	Gross fixed capital formation includes land improvements, 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. It is measured in billions of constant US$ (2015).	1995-2019	The World Bank
LF	Labor Force refers to the supply of labor for the production of goods and services. It is measured in millions.	1995-2019	The World Bank
REC	Renewable Energy consumption is defined as electricity consumed from renewable sources such as geothermal, solar, tides, wind, biomass, and biofuels. It is measured in millions of kilowatt-hours (Twh). This variable was lagged by one year.	1995-2019	Our World in Data
FF	Fossil Fuels are defined as electricity generation that consist of electricity generated from coal, petroleum, and natural gas. It is measured in per capita of terawatt-hours (Twh).	1995-2019	Our World in Data
Coal Weighted Index	Coal Weighted Index includes the price of coal at a point in time and multiplying that value, which is in US dollars per tone (2015) by the electricity share provided by coal %. The price index and electricity share are time and country specific.	1995-2019	Our World in Data
Natural Gas Weighted Index	Natural Gas Weighted Index includes the price of natural gas at a point in time and multiplying that value, which is in US dollars per cubic meter (2015) by the electricity share provided by natural gas %. The price index and electricity share are time and country specific.	1995-2019	Our World in Data

Table 2: All Countries

All Countries	Observations	Mean	Standard Deviation	Min	Max
GDP	975	1240.97	2599.79	6.73	21372.57
GFCF	970	312.51	697.77	2.72	6115.00
LF	975	54.86	135.36	1.10	800.02
FF	965	2213.69	4983.72	5.80	33692.99
REC	975	369.3	754.10	1.24	5776.89
CoalPriceIndex	513	25.45	21.91	0.009	133.70
NaturalGasIndex	601	0.07	0.08	0.0001	0.37

Table 2 provides descriptive statistics for all countries. Table 3 and 4 separately describe the developed and developing countries.

Table 3: Summary Statistics Developed Countries

Cluster 1	Observations	Mean	Standard Deviation
GDP	600	1536.68	2957.77
GFCF	600	348.21	652.58

LF	600	20.70	31.60
FF	600	2025.46	4396.22
REC	600	228.89	392.47

Note: this table includes countries deemed high income by the World Development Index. This cluster includes 24 countries.

Table 4: Summary Statistics Developing Countries

Cluster 2	Observations	Mean	Standard Deviation
GDP	375	767.82	1796.06
GFCF	370	254.64	762.79
LF	375	109.52	203.12
FF	365	2523.11	5815.47
REC	375	593.95	1073.34

Note: this table includes countries deemed upper middle income or lower middle income by the World Development Index. This cluster includes 15 countries.

Table 5: Two Sample T Test Results

Difference Cluster 1-2	Observations	Mean
GDP	225	768.86***
GFCF	230	93.58***
LF	225	-88.81***
FF	235	-497.65
REC	225	-365.06***

Note: *** statistical significance was found with a threshold of a pvalue less that .0

The overall mean of real GDP when looking at all of the countries within the panel together was 1240.971, seen in *Table 2*. When comparing the variable means of developed versus developing countries the mean for real GDP was larger for countries within the developed country cluster. The difference between developed versus developing countries real GDP mean was 768.8634 billion seen in *Table 5*; however, it is also important to note that there was a larger standard deviation for real GDP within developed countries comparative to developing countries in cluster two.

The overall mean of gross fixed capital formation was also larger with respect to developed country cluster. The difference between the mean of developed versus developing clusters with respect to GFCF was 93.5751 billion, seen in *Table 5.* It makes sense that countries of higher development would have a larger value of GFCF, as a higher fixed capital formation indicates larger growth within the economy and aggregate income. This is conducive to the characteristics of countries within cluster one (developed countries).

The labor force mean for developing countries was greater than developed countries with a difference in mean of 88.8146 million, seen in *Table 5*. Less developed economies tend to be more labor intensive, and these summary statistics illuminate that emerging economies tend to offer lower wages or income, but businesses in these regions remain competitive by employing many workers.

The fossil fuel consumption mean was also greater for developing countries than developed by 497.653 Twh, seen in *Table 5.* The energy intensity for developing countries sectors may be more labor and energy intensive comparative to more developed countries.

Renewable energy consumption was also seen to have higher means within the developing country cluster. Developing countries had a larger mean that developed countries for renewable energy consumption by 365.06 Twh, seen in *Table 5*. These summary statistics indicate that even though developing countries have lower means for GDP and GFCF they are consuming more renewable sources.

3.1.3 Empirical Methodology

This paper establishes whether renewable energy consumption can be a driver of economic growth in a region. In order to analyze the economic benefit of renewable energy consumption its relationship with real GDP, GFCF, and total LF is investigated. We lagged renewable energy consumption by one year to eliminate the possibility of a bidirectional relationship, and to isolate the impact of renewable consumption on GDP because it is not immediate, but felt over time. These variables are relevant as labor force and gross fixed capital formation are two key macroeconomic variables in the traditional production function of GDP. In this study, we essentially wanted to measure the differential impact of renewable energy consumption across developed and developing economies following the production function below.

$$Y_{it} = f(REC_{it}, FF_{it}, GFCF_{it}, LF_{it}) \text{ …….. Equation 1}$$

Where Y is the output, and inputs come from FF, fossil fuel consumption, REC, renewable energy consumption, GFCF, gross fixed capital formation, LF, labor force

To estimate this model, I use the following regression methodology. Each regression is tested three times, first using the full panel of 39 countries and then using the developed and developing panels separately. Each of the regressions includes fixed effects for both time and country. The natural logarithms allow the coefficient to be interpreted as elasticities and also help to deal with the dynamic properties of the data.

A) $lnGDP_{it} = \beta_0 + \beta_1 lnGFCF_{it} + \beta_2 lnLF_{it} + \beta_3 lnREC_{it} + \beta_4 lnFF_{it} + \gamma_i + \alpha_t + \in$

B) $lnGFCF_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnLF_{it} + \beta_3 lnREC_{it} + \beta_4 lnFF_{it} + \gamma_i + \alpha_t + \in$

C) $lnLF_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnGFCF_{it} + \beta_3 lnREC_{it} + \beta_4 lnFF_{it} + \gamma_i + \alpha_t + \in$

Equation (2) is an estimate of a demand for renewable energy consumption. I assume factors contributing to demand originating from Y, real GDP, PC, price of coal, PG, price of natural gas. Competition between fuels and renewable sources implies the potential influence the price of these fuels may have on renewable energy consumption and production. We lagged the natural gas price weighted index and the coal price weighted index by four years. This is because we do not expect to see a change in energy price to have an immediate impact on the consumption of alternatives, but a transition and switch which occurs over time.

$$RE_{it} = f(Y_{it}, PC_{it}, PG_{it}) \quad \text{........ Equation 2}$$

To estimate this model, I use the following regression methodology. Each regression is tested one times, using the full panel of 39 countries due to a large quantity of missing data points. Differential impact between developing and developed economies was not possible due to the lack of sufficient observations. The natural logarithms allow the coefficient to be interpreted as elasticities and also help to deal with skewness due to outliers. A fixed effect model was utilized in order to capture effects specific to the observations respective time and country.

I estimated the renewable energy demand function using the following regression:

A) $lnRE_{it} = \beta_0 + \beta_1 lnY_{it} + \beta_2 lnPC_{it} + \beta_3 lnPG_{it} + \gamma_i + \alpha_t + \in$

Results

4.1.1 Hypothesis 1: Renewable energy consumption is a driver of economic growth.

Table 6 below displays the results of the full panel of countries, developed countries' panel, and the developing countries' panel. In all three panels the R^2 is approximately .9. This measures the total variance in real GDP that can be explained by GFCF, LF, REC, and FF.

Table 6: Regression Results

Variables	**All Countries**		**Developed Countries**		**Developing Countries**	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
GFCF	.578***	.025	.490***	.026	.616***	.051
LF	.030	.091	.5712***	.108	-.2867	.197
REC	-.028	.018	-.045**	.013	.152*	.080
FF	.315***	.040	.194***	.049	.238**	.096
Constant	1.350***	.269	1.585***	.272	1.647***	.794
R-Squared		.992		.996		.989
Adjusted R-Squared		.991		.995		.988

Notes *** indicated significance at the 1% level, ** indicated significance at 5% level, * indicated significance at 10% level. **Sample:** 1995-2019 **Key:** GDP: Gross Domestic Product, GFCF: Gross Fixed Capital Formation, LF: Labor Force, REC: renewable energy consumption, FF: fossil fuel consumption

The coefficient found including all countries was not statistically significant with respect to renewable energy consumption impact on economic growth, as seen in *Table 8*. This result does not match a similar study conducted by Singh and Nyuur, who discover a statistically significant positive coefficient indicating a 1% increase in renewable energy production increases real GDP by 0.06% (Singh et al., 2019). This comparative study utilized the top ten developed and developing countries in renewable energy consumption to produce this result. Within the results of this study, it was also discovered that among the panel including only developed countries a 1% increase in renewable energy consumption decreased real GDP by 0.045%, significant at the 5% level. This coefficient value is highly different than what was seen with respect to the developing countries panel. For developing countries, it was found that a 1% increase in renewable energy consumption increased real GDP by 0.15%, at the 10% significance level. Though these two panels' results provide support for a unidirectional relationship between renewable energy consumption and economic growth the sign of the relationship is different. These results indicate that an increase of renewable consumption in developed countries has a negative impact on real GDP, while an increase in renewable energy consumption in developing economies has a positive impact on real GDP. These results differ from what was found in Singh and Nyuur study. They found both positive impacts of renewable energy production on real GDP in both developed and developing countries; however, my results were different in concluding renewable energy consumption has a greater positive impact on real GDP for developing countries than developed (Singh et al., 2019).

Firstly, in the full panel including all 39 countries we can see that gross fixed capital formation and fossil fuel consumption both have statistically significant impacts on real GDP. All else kept equal, a 1% increase in GFCF increased real GDP by 0.58%. Similarly, a 1% increase in fossil fuel consumption increased real GDP by 0.32%. These coefficients are both significant at the 1% level.

Unlike many other studies that have provided statistically significant results in defense of the growth, feedback, neutrality, and conservation hypothesis the coefficient on the full panel of countries for renewable energy consumption was statistically insignificant. The coefficient on labor force was also statistically insignificant. The granger causality test was also utilized when running separate panels for developed and developing countries. The results demonstrate that renewable energy consumption has a statistically significant impact on real GDP; however, the magnitude and sign of the relationship varies between the two panels.

The findings for developed economies, found statistical significance for all variables investigated within the relationship at the 5% level. A 1% increase in gross fixed capital formation increased real GDP by 0.49%, a 1% increase in labor force increased real GDP by 0.57%. A 1% increase in fossil fuel consumption increased real GDP by 0 .19%. Most importantly, a 1% increase in renewable energy consumption decreased real GDP by 0.045% in for developed countries.

Within the third panel, including only developing countries as determined by the World Development Index, all variables investigated had statistically significant coefficients except for labor force. A 1% increase in gross fixed capital formation increased real GDP by 0.62%. A 1% increase in fossil fuel consumption increased real GDP by 0.24%. Most importantly, a 1%

increase in renewable energy consumption increased real GDP by .024% for developed countries.

For all three panels gross fixed capital formation has a positive statistically significant impact on real GDP at the 1% level; however, a 1% increase in gross fixed capital formation has the largest impact on real GDP for the panel including only developing countries. Labor force only provided a statistically significant coefficient amongst developed economies with respect to real GDP. The panel including all countries and solely developed economies did not find a statically significant coefficient for labor force at the 10% level of significance. Fossil fuel consumption was also found to have a positive statistically significant coefficient among all three panels; however, the largest impact within the magnitude of the coefficient was found along the panel which included all thirty-nine countries.

4.1.2 Hypothesis 2: Renewable energy consumption increases gross fixed capital formation.

Table 7 below displays the results of the full panel of countries, developed countries' panel, and the developing countries' panel. In all three panels the R^2 is approximately .9. This measures the total variance in GFCF that can be explained by GDP, LF, REC, and FF.

Table 7: Regression Results

Variables	**All Countries**		**Developed Countries**		**Developing Countries**	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
GDP	.658***	.029	.830***	.044	.523***	.044
LF	-.058	.097	.398***	.144	-.599***	.179
REC	-.016	.019	.044**	.018	-.061	.074
FF	.493***	.041	.122*	.065	.680***	.081
Constant	-2.484***	.278	-2.290***	.351	-.700	.735
R-Squared		.991		.992		.990
Adjusted R-Squared		.990		.991		.990

Notes *** indicated significance at the 1% level, ** indicated significance at 5% level, * indicated significance at 10% level. **Sample:** 1995-2019 **Key:** GDP: Gross Domestic Product, GFCF: Gross Fixed Capital Formation, LF: Labor Force, REC: renewable energy consumption, FF: fossil fuel consumption

Firstly, it was found that in the case of the full panel of developed and developing countries as well as the panel with only developing countries the coefficient from renewable energy consumption impact on GFCF was statistically insignificant. Though these coefficient values were insignificant, there was a statistically significant positive relationship found between renewable energy consumption and GFCF among developed countries. In the panel including only developed economies it was found that a 1% increase in renewable energy consumption increased GFCF by 0.043%, at the 5% significance level. This is similar to Apergis and Payne's findings that also supported that within a panel of developed countries, renewable energy consumption has a positive impact on GFCF (Apergis & Payne, 2010). Though the coefficient including the entire collection of countries was statistically insignificant it is possible that renewable energy consumption could have a negative impacts on gross fixed capital formation due to damage to the traditional energy sector, and high levels of investment needed to deploy the high capital needs of renewables.

Fossil fuel consumption and real GDP also had positive statistically significant coefficients with respect to GFCF for all three panels under investigation. A 1% increase in real GDP increased GFCF by 0.82% among developed countries, and a 1% increase in real GDP increased GFCF by 0.52% in developing economies. A 1% increase in fossil fuel consumption increased GFCF by 0.12% among developed countries, and a 1% increase in fossil fuel consumption increased GFCF by 0.68% for developing countries. The coefficient discovered between labor force and GFCF was not statistically significant in the panel including all thirty-nine countries, but statistically significant results were provided when separating the countries by levels of development. For developed countries a 1% increase in labor force increased GFCF by 0.39%, but for developing countries a 1% increase in labor force decreased GFCF by 0.59%.

4.1.3 Hypothesis 3: Renewable energy consumption increases labor force participation.

Table 8 below displays the results of the full panel of countries, developed countries' panel, and the developing countries' panel. In all three panels the R^2 is approximately .9. This measures the total variance in LF that can be explained by GDP, GFCF, REC, and FF.

Table 8: Regression Results

Variables	**All Countries**		**Developed Countries**		**Developing Countries**	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
GDP	.004	.013	.088***	.0167	-.024	.0166
GFCF	-.007	.012	.036***	.0131	-.059***	.018
REC	-.009	.007	.001	.005	.144***	.022
FF	.162***	.015	.188***	.018	.016	.028
Constant	1.780***	.082	.331 ***	.109	3.164***	.144
R-Squared		.999		.999		.999
Adjusted R-Squared		.999		.999		.999

Notes *** indicated significance at the 1% level, ** indicated significance at 5% level, * indicated significance at 10% level. **Sample:** 1995-2019 **Key:** GDP: Gross Domestic Product, GFCF: Gross Fixed Capital Formation, LF: Labor Force, REC: renewable energy consumption, FF: fossil fuel consumption

This section tests whether renewable energy consumption contributed to real GDP through its effect on labor. Labor is a component in the aggregate production function. In a variety of the literature, renewable energy is identified as a sector that creates large amounts of employment. There was only a statistically significant coefficient observed in the panel including developing counties linking renewable energy consumption and labor force. The coefficients on the panels including all thirty-nine countries and only developed economies were not significant even at the 10% level. In the panel including only developing economies, all else being equal, a 1% increase in renewable energy consumption increased the labor force by 0.14%.

4.1.4 Factors impacting demand of renewable energy

Table 9: Regression Results

Variables	**All Countries**	
	Coef.	Std. Err.
GDP	-.21*	.011
Coal Price Index	.032	.054

Natural Gas Price Index	-.057	.036
Constant	5.920***	.770
R-Squared		.974

Notes *** indicated significance at the 1% level, ** indicated significance at 5% level, * indicated significance at 10% level. **Sample:** 1995-2019 **Key:** GDP: Gross Domestic Product, Coal Price Index: weighted index of lagged coal price Natural Gas Price Index: weighted index of lagged natural gas price

As seen in *Table 9* there is not a statistically significant impact found among the coefficients on natural gas price index or coal price index on renewable consumption. Though there was a statistically significant finding that a 1% increase in real GDP decreased renewable energy consumption demand by 0.21%, overall, these findings disrupt common conclusions in the existing literature. Specifically, this study's findings contradict those of Li and Leung who found short run causality from the price of coal and price of natural gas to renewable energy consumption among seven European countries (Li & Leung, 2021). Lack of similarity could be explained by that expanded geographical and developmental scopes of the countries included. In order to see a more general and significant correlation between alternative prices and impacts on demand for renewables may take more time and investment to visualize.

Discussion

5.1.1 Renewable energy consumption has differential impacts in developed and developing economies.

Table 11: Summary of Hypothesis 1-3

Hypothesis	**Developed: Panel 2**	**Developing: Panel 3**
	Coefficient	Coefficient
Renewable energy consumption is one of the drivers of economic growth.	-.045**	.152*
Renewable energy consumption increases fixed capital formation.	.044**	-.061
Renewable energy consumption has a positive impact on labor force.	.001	.144***

Notes *** indicated significance at the 1% level, ** indicated significance at 5% level, * indicated significance at 10% level.

First, in the panel of developed countries it was found renewable energy consumption has a negative impact on GDP. However, the negative impact does not seem to flow from factors such as total labor force. Though renewable energy consumption in developed countries had a positive impact on GFCF, it can thus be inferred that the negative impact on GDP flows through factors like total factor productivity and trade balances. Unlike the results produced with respect to only developed economies, in the panel including developing countries a positive statistically significant relationship between renewable energy consumption and real GDP was discovered. The positive effect does seem to flow from factors such as total labor force; however, in the case of GFCF the impact of renewable consumption for developing countries was insignificant.

As seen in the results the impact of renewable energy consumption on GDP was found to be higher in developing compared to developed countries. This could be explained by the fact a majority of opportunities and investments in renewables have originated from developing countries recently.

Secondly, there was a lack of significance between renewable energy consumption and GFCF in developing countries. A positive statistically significant relationship was discovered among developed economies. This is surprising as it was expected that increased usage of renewables would be mirrored by an increase in GFCF since low wage developing countries are often the largest producers and exporters of renewables. This divergence could be explained by developing economies such as India utilizing infrastructure and distribution channels that are less capital intensive such as photovoltaic cells and mini-grids. Though these are still forms of renewable energy sources they are less capital intensive than solar and wind farms that are often utilized in developed countries (Hall et al., 2014).

Lastly, renewable energy consumption was found to have a positive impact on total labor force in developing countries and no significant impact on developed countries. This is a complete contradiction of the findings in Singh and Nyuur research. They found renewable energy production to have a positive impact on total labor force for developed countries and no significant impact on developing economies (Singh et al., 2019). This statistically significant impact on labor within developing economies could be explained by design and developmental infrastructure originating in developed economies, and lower-level higher volume work being carries out in developing countries.

Conclusion

This paper contributed to the ongoing literature investigating four hypotheses with respect to energy consumption and economic growth. As previously supported in a multitude of studies of varying frameworks energy consumption is a known driver of economic growth among all countries. Also, repeated studies have emphasized the troublesome linkage between economic growth stimulated from energy consumption impact on environmental degradation. This paper uniquely investigated the top thirty-nine renewable energy consuming countries of differing developmental stages to examine if there is a differential impact of renewable energy consumption on economic growth. It is imperative to delineate the relationship between renewable consumption and economic growth in order to formulate the correct policy to promote both environmental sustainability and economic prosperity.

My key empirical findings reveal that renewable energy consumption is associated with a statistically significant impact on economic growth in both developed and developing countries during the period 1995-2019. I find a unidirectional relationship between renewable energy consumption to economic growth, due to the lagged dynamic of the independent variable renewable energy consumption. Though the directionality identical, the results indicated that a 1% increase in renewable energy consumption decreased real GDP by 0.045% in developed countries. For developing countries, it was found that a 1% increase in renewable energy consumption increased real GDP by 0.15%. These findings have important implications for policymakers, and reveal that renewable energy production can offer an environmentally sustainable means of economic growth in the future, but effective and appropriate policy may differ based upon geographical, developmental category, or industry specific uniqueness.

These findings have contributed to the literature of the linkages between renewable energy consumption and economic growth, highlighting known as well as unknown dynamics that generate influence. Previously, the literature estimating the effects of renewable consumption on capital formation and labor force participation has been limited, but this study illuminated these channels and how they differ based upon a country's developmental categorization. Our results suggest that the stage of economic development of a country must be considered while devising policies to promote renewable energy consumption.

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