RENEWABLE ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH NEXUS – EVIDENCE FROM HIGH-, MIDDLE- AND LOW-INCOME COUNTRIES

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ABSTRACT

Recent decades have witnessed growing concerns over sources of energy consumption and their role in economic development. Renewable energy and electrification have been touted by experts as a solution to mitigate these global issues. Considering this, the study investigates the intricate relationship between economic growth and renewable electricity consumption between the years 2000 to 2021 across a diverse spectrum of countries categorized by income levels. Renewable electricity consumption and economic growth data was collected for 48 countries. These countries were then further divided according to their income levels. The current study examines the relationship between renewable electricity consumption and economic growth through the lens of four distinct perspectives: the feedback hypothesis, the neutrality hypothesis, the growth hypothesis, and the conservation hypothesis. The Panel ARDL methods including the PMG, MG and DFE were employed to explore the presence of cointegration and the impact of renewable electricity usage on economic growth. The outcome of the methods indicate clearly that green electricity usage has a positive impact on economic growth across all income levels albeit at varying magnitudes. The findings contribute to the understanding of sustainable development and energy policies tailored to the specific economic contexts of countries at various income levels.

Keywords: Renewable Electricity, Economic Growth, Panel ARDL

YENİLENEBİLİR ELEKTRİK TÜKETİMİ VE EKONOMİK BÜYÜME BAĞLANTISI – YÜKSEK, ORTA VE DÜŞÜK GELİRLİ ÜLKELERDEN KANITLAR

ÖZET

Son yıllarda, enerji tüketiminde meydana gelen hızlı yükseliş ve bu yükselişin iktisadi kalkınma üzerindeki etkisi konusunda endişeler artmaktadır. Yenilenebilir enerji ve elektrifikasyon, uzmanlar tarafından konuyla ilgili küresel sorunları hafifletmeye yönelik bir çözüm olarak öne sürülmektedir. Bunu göz önünde bulundurarak çalışmada, gelir düzeylerine göre sınıflandırılan çeşitli ülkelerde 2000-2021 yıllarına ait veriler kullanılarak iktisadi büyüme ile yenilenebilir elektrik tüketimi arasındaki ilişki araştırılmaktadır. 48 ülke için yenilenebilir elektrik tüketimi ve iktisadi büyüme verileri toplandı. Bu ülkeler daha sonra gelir düzeylerine göre daha da bölündü. Bu doğrultuda, söz konusu ilişki geri besleme hipotezi, tarafsızlık hipotezi, büyüme hipotezi ve koruma hipotezi olmak üzere dört farklı perspektiften ele alınmıştır. Eşbütünleşmenin varlığını ve yenilenebilir elektrik kullanımının iktisadi büyüme üzerindeki etkisini araştırmak için PMG, MG ve DFE ile panel ARDL yöntemleri kullanılmıştır. Sonuçlar, yeşil elektrik kullanımının, değişen oranlarda da olsa, tüm gelir düzeylerinde iktisadi büyüme üzerinde olumlu bir etkiye sahip olduğunu açıkça göstermektedir. Bulgular, farklı gelir seviyelerinden ülkelerin özgün iktisadi koşullarına göre uyarlanabilecek sürdürülebilir kalkınma ve enerji politikalarının anlaşılmasına katkıda bulunmaktadır.

Anahtar Kelimeler: Yenilenebilir Elektrik, İktisadi Büyüme, Panel ARDL

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Mustapha ABEKAH-BROWN

DEDICATION

I dedicate this work to the loving memory of my dear grandmother.

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ABBREVIATIONS LIST

ADF-WS – Augmented Dickey Fuller – Wald Statistic

APS – Announced Pledges Scenario

ARDL – Autoregressive Distributive Lag

CES – Constant Elasticity of Consumption

DFE – Dynamic Fixed Effects

DOLS – Dynamic Ordinary Least Squares

EC – Energy consumption

ECM – Error Correction Model

FMOLS – Fully Modified Ordinary Least Squares

GC – Granger Causality

GDP – Gross Domestic Product

GMM – General Method of Movements

GNI – Gross National Income

GWh – Giga Watt Hours

GNP – Gross National Product

IEA – International Energy Agency

KPSS – Kwiatkowski–Phillips–Schmidt–Shin

LLC – Levin, Lin, Chu

MG – Mean Group

NARDL – Non-Linear Autoregressive Distributive Lag

NIC – Newly Industrialised Countries

NREC – Non-Renewable Energy Consumption

NZE – Net Zero Emissions

OECD – Organisation for Economic Cooperation and Development

PMG – Pooled Mean Group

REC – Renewable Energy Consumption

RELC- Renewable Electricity Consumption

STEPS – Stated Energy Policies Scenario

VECM – Vector Error Correction Model

CHAPTER 1

1. INTRODUCTION

In an era marked by ominous environmental concerns and an increasingly pressing need to foster sustainable development, the connection between the utilisation of renewable power and economic growth has bubbled to a topic of paramount significance. The global pursuit of transitioning to cleaner, more sustainable energy sources has intensified in response to growing evidence of climate change and resource depletion challenges.

Consequently, this research work endeavours to reveal the interaction between the adoption of renewable electricity and a nation's economic prosperity. The study delves into empirical evidence, and policy implications that underpin the connection between RELC and economic advancement. With the escalating need for a greener and more prosperous future, the research contributes to a deeper understanding of the potential synergies between RELC and economic growth, ultimately paving the way for informed decision-making and the promotion of a sustainable global economy.

The urgent need to address climate change is driving a shift towards electrification across various sectors, ranging from transportation to industrial processes. This underscores the crucial role of electricity in modern societies, a role set to expand as electric vehicles and heat pumps become more prevalent for transportation and heating. Presently, the generation of electrical power significantly contributes to global carbon dioxide (CO_2) emissions. However, efforts to mitigate climate impact are reshaping the trajectory of power generation, emphasizing the transition to cleaner sources and sustainable practices. Its adoption not only offers significant potential for reducing greenhouse gas emissions but also enhances energy security and promotes sustainable economic growth (Wilkinson, Smith, Joffe, & Haines, 2007).

Recent energy-growth literature acknowledges the role energy plays in the production process. Countries in the world are diverse, with glaring disparities among countries regarding their levels of development. One notable difference among countries is level of income, which also serves as a veritable way of assessing the level of development of a nation’s economy. In the adoption of renewable electricity, the transition must also be in line with the ultimate economic goal of growth. An overview of the available literature on the energy-growth nexus reveals a plethora of work on the interaction between these two factors. Nonetheless, the literature available on the interaction between renewable energy and economic growth are far much less and even much smaller when renewable electricity is considered but none have focused on RELC and economic growth nexus across different income levels. This thesis aims to tackle this gap in the literature.

The research has a primary objective, which is to delve into the intricate relationship between RELC and how it relates to countries at varying stages of development. This exploration will extend to two critical timeframes: the short-run and the long-run. The research will focus on how changes in RELC impacts a country's economic prosperity in the immediate term. This can shed light on the more immediate effects and responses of nations to changes in their use of renewable electricity. In the long run, the study will zoom out to assess how the relationship between RELC and development evolves over extended periods. This approach provides insights into the sustained influence of renewable energy practices on a nation's development.

The outcome of the research will provide an in-depth comprehension on how disparities in income and development stages affect the dynamics of the GDP-REC nexus, particularly with regards to RELC. Additionally, the outcome of the research will provide a nuanced understanding on how different ranked countries can leverage on renewable electricity to enhance the effectiveness of policy while spurring sustainable economic progression concurrently. It also provides a reference point for policy makers especially within the international bodies to create a blueprint for the adoption of green electricity and promotion of sustainable economic development that can be bespoke based on the development level of a country.

The intricate dynamic on the synergy between renewable electricity and economic growth could have different implications on policy formulation and implementation to foster the goal of sustainable economic growth. From the literature exploring the nexus between EC and economic growth, there are four potential linkages that could exist between RELC and economic expansion. These are the energy conservation hypothesis, the neutrality hypothesis, the growth hypothesis, and the feedback hypothesis. An outcome of this study in favour of the energy conservation hypothesis implies that RELC has no impact on economic growth, but economic growth has an impact on RELC instead. An outcome favouring the growth hypothesis indicates that RELC has an impact on economic growth. Furthermore, if the results of the study turn out in favour of the feedback hypothesis, it implies both RELC and economic growth have a simultaneous impact on each other while a result favouring the neutrality hypothesis indicates that RELC has no significant impact on economic growth.

This study assesses the interaction between renewable electricity usage and economic growth at diverse levels of development by selecting countries categorized according to their income levels as determined by the World Bank. Every country at a stage of development is characterized by varying socio-economic contexts, infrastructure, and energy needs. An analysis across countries at different income levels on the impact of RELC on economic growth leads to a more comprehensive grasp of the context-specific challenges and opportunities that may result from the adoption of renewable energy sources.

The transition to renewable electricity generation is undeniably challenging, requiring significant investment in infrastructure, policy frameworks, and technological advancements. Yet, it also opens a myriad of opportunities for fostering innovation, creating new industries, and promoting green job growth.

This study seeks to answer three key questions regarding the REC-economic growth linkage which are as follows:

1. Is there a long-run relationship between renewable electricity consumption and economic growth among countries at different stages of development?

2. What are the short-run and long-run impacts of RELC on economic growth among countries of different income brackets?

3. How does the impact vary at different stages of development?

To address these questions posed, the study applies panel ARDL methodology to analyse the data. In particular, the MG, PMG and DFE estimations were applied to the dataset. These three model estimations provided error correction terms, which are useful in inferring cointegration among the variables of interest, long run as well as short run coefficient estimates.

The subsequent sections of this work are structured as follows: Chapter 2 illuminates the concept of renewable energy, it's sources and discusses electrical energy. Chapter 3 gives insight into the theoretical background underpinning the role of energy in the economy. Chapter 4 conducts a literature review on the current literature on the energy-growth nexus in terms of the four main hypotheses posited so far regarding the linkage. The chapter reviews available empirical literature on the nexus as it applies to conventional energy and renewable energy. Chapter 5 introduces the data and sets up the model to be used for the study. It also discusses the methodologies to be followed in analysing the data in an attempt to find answers to the research questions posed above. Chapter 6 discusses the outcome of the analysis, and the subsequent and final chapter offers some policy discussion and addresses some of the shortcomings of this study and suggests potential ways of addressing them in further studies.

CHAPTER 2

2. RENEWABLE ENERGY

Throughout early human civilisations, renewable energy was the main source of energy available to meet man's energy demands (Sørensen, 1991). For instance, solar radiation was used as a source of heat for homes and to grow food, and wind energy was used for wind mills and sail ships(Singer et al., 1954). Renewable energy encompasses energy derived from sources that are naturally replenished relatively quickly on a human timescale, making them sustainable and environmentally friendly alternatives to finite fossil fuels which cannot be replenished quickly on a human timescale. These sources harness energy from natural processes of the Earth, such as sunlight, wind, rain, tides, waves, and geothermal heat to generate power. Unlike non-renewable resources like coal, oil, and natural gas, which are finite and contribute to environmental degradation, renewable energy sources are considered cleaner and have a lower environmental impact.

In early human civilisations, there weren't many alternatives to renewable energy sources, so the cost of extraction and conversion was not considered a hindrance to its use. However, when fossil energy became a commercially feasible enterprise, renewable energy sources could not match up. Fossil energy was about ten times cheaper than solar energy by 1900 and wind energy was comparably priced to fossil energy. However, fossil energy could be produced constantly while the cost of storing renewable energy for periods constituting its down time made it less appealing (Jensen & Sørensen, 1984). Nonetheless, in light of more recent knowledge, it appears that those valuations were not as accurate as was perceived then, as they ignored the indirect costs especially accruing to the environment associated with fossil EC.

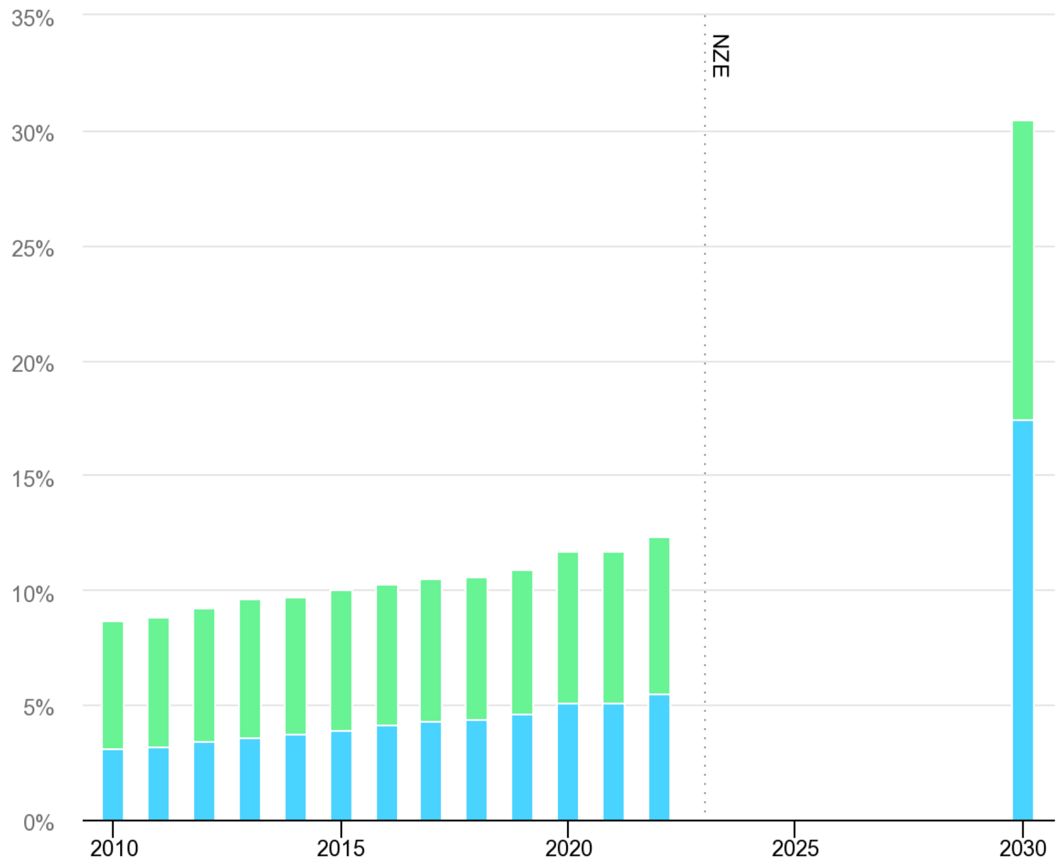

Figure 2.1 Renewables share of total energy supply. Source: IEA, Renewables share of total energy supply in the Net Zero Scenario, 2010-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/renewables-share-of-total-energy-supply-in-the-net-zero-scenario-2010-2030-2, IEA. Licence: CC BY 4.0

The share of renewable energy in total energy supply has steadily increased from 8.7% in 2010 to 12.3% in 2022 as seen in figure 2.1. The contribution from modern bioenergy (represented in green) has grown from 5.6% to 6.8% while that from hydro, wind, ocean, geothermal, and solar (represented in blue) rose from 3.1% to 5.5% in 2022. The IEA projects that renewables' share in total energy supply could exceed 30% if the NZE scenario conditions are met.

Renewable energy offers a myriad of benefits, making it a cornerstone of sustainable development. First and foremost, it represents a clean and environmentally friendly alternative to traditional fossil fuels, significantly reducing harmful emissions and mitigating climate change. Harnessing renewable sources also contributes to improved air and water quality, fostering healthier ecosystems. Moreover, the infinite nature of renewable energy resources ensures a long-term and dependable energy supply, reducing our dependence on finite and depleting fossil fuel reserves. Economically, the green energy sector stimulates job creation, innovation, and investment. Embracing renewable energy not only aligns with environmental conservation but also promotes energy security, affordability, and a sustainable future for generations to come.

2.1 Types of renewable energy

2.1.1 Solar energy

The use of the sun's energy to meet heating needs or electricity production using solar systems is classified as solar energy (Ellabban, Abu-Rub, & Blaabjerg, 2014). Electricity from solar systems can be achieved with either a concentrating solar power (CSP) system or a photovoltaic (PV) system. Thermal heating solutions involve using heat energy from the sun to heat water for residential, commercial, or recreational purposes. The amount of sunlight that reaches the Earth is much more than all the energy people use. The sun provides about 10,000 times more energy than the entire world needs or uses (United Nations, n.d.). It shows that there's a lot of solar energy available for us to tap into. In more recent decades, the cost of solar panels gone done down quite drastically, which makes them highly appealing as a renewable energy generation option.

2.1.2 Biomass energy

Biomass refers to all the natural material that comes from animals and plants. It's like a way of collecting and storing the sun's energy that plants absorb during photosynthesis (Ellabban et al., 2014). Biomass energy is derived by burning biomass which releases heat that can generate electricity. Alternatively, it can also be converted to gas or liquid that can be stored and transported and could produce energy on demand (Hall & Scrase, 1998). Even though biomass energy production involves the release of greenhouse gases, those emissions are much less compared to fossil fuel alternatives and so it is considered a low emission source of energy.

2.1.3 Hydropower

Hydro power is energy obtained from moving water. Running water from bodies such as rivers can be barricaded by building a dam, and in a controlled manner be flown to turn a turbine that generates electricity. More recently new technologies have been developed to also harness energy from the tides and waves of the sea and rivers. Hydro energy is one of the most developed and widely used renewable sources of electricity.

2.1.4 Geothermal energy

This source of power is derived from heat that occurs naturally below the surface of the Earth. It is usually heat energy trapped in rocks or liquids deep underground. It can either be used to produce electricity commercially with the use of geothermal power plants or it can be used directly for heating purposes in homes using a geothermal heat pump. Geothermal power has been proven to be an economical, dependable, and eco-friendly energy option (Hammons, 2003). Nevertheless, geothermal energy is not available everywhere and can only be harnessed in geographical locations where geothermal energy is abundant in reserves such as Iceland. Edenhofer et al. (2012) predict that total geothermal energy capacity in use could reach 800GWh by 2050.

2.1.5 Wind energy

Power from the wind can be applied to do useful things. This could be using windmills to power machines, generating electricity with wind turbines, using sails to make ships move, or using wind pumps to move water. The use of wind turbines for electricity generation was first discovered in the 1970s and had morphed in to a viable alternative energy source by the 1990s (Kaygusuz, 2009). Wind energy remains one of the most used renewable energy sources across the world.

2.2 Electrical energy

Electricity is a form of energy resulting from the existence of charged particles (such as electrons or protons), either statically as an accumulation of charge or dynamically as a current. It is a secondary energy source because it is converted from another primary source of energy, such as coal, natural gas, oil, nuclear, or renewable sources. In practical terms, electricity powers various devices and systems, providing the energy needed for lighting, heating, cooling, electronic devices, and countless other applications in our daily lives.

In the push to achieve zero emissions by 2050, a crucial strategy is electrification. Electrification involves substituting technologies reliant on fossil fuels, such as traditional engines and gas heating systems, with electric alternatives like electric vehicles for transportation or heat pumps for heating buildings. These electric alternatives tend to be more efficient, reducing overall EC. To fully reap the benefits of electrification and cutting down carbon emissions, it is imperative that the electricity we use is generated from clean and renewable sources. As we shift to cleaner sources of electricity, this transition to electrification also contributes to lowering overall emissions and mitigating environmental impact.

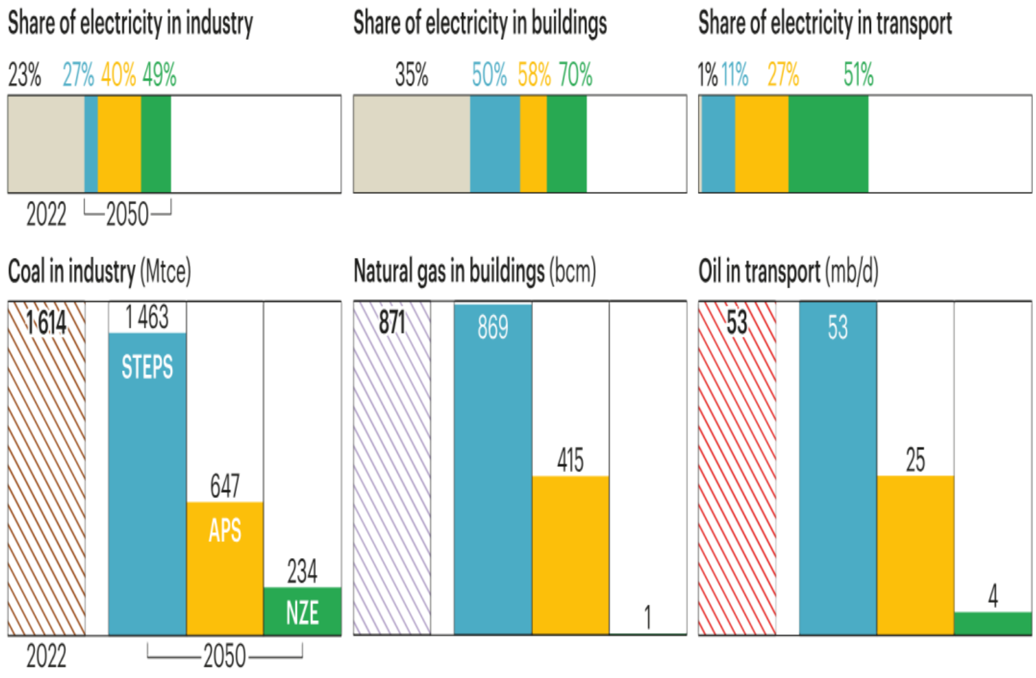

Figure 2.2 Share of electricity by category Source: IEA (2023), World Energy Outlook 2023, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2023, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

In the next three decades the IEA estimates that the share of electricity usage in the transport sector, industry and in buildings could dramatically rise. Figure 2.2 shows projections based on the STEPS (labelled in blue), APS (labelled in yellow) and NZE (labelled in green). These are agreements on implementing policies that would reduce emission and limit the rate of global temperature rises. The most ambitious of the policies if implemented would see 49% of energy used in manufacturing from electricity from the prevailing 23%. The same agreement could also cause a doubling in electricity's share in buildings use from 35% to 70% by 2050. The most dramatic of all changes would be experienced in the transportation sector where electricity would account for 51% of energy use from a prevailing 1%.

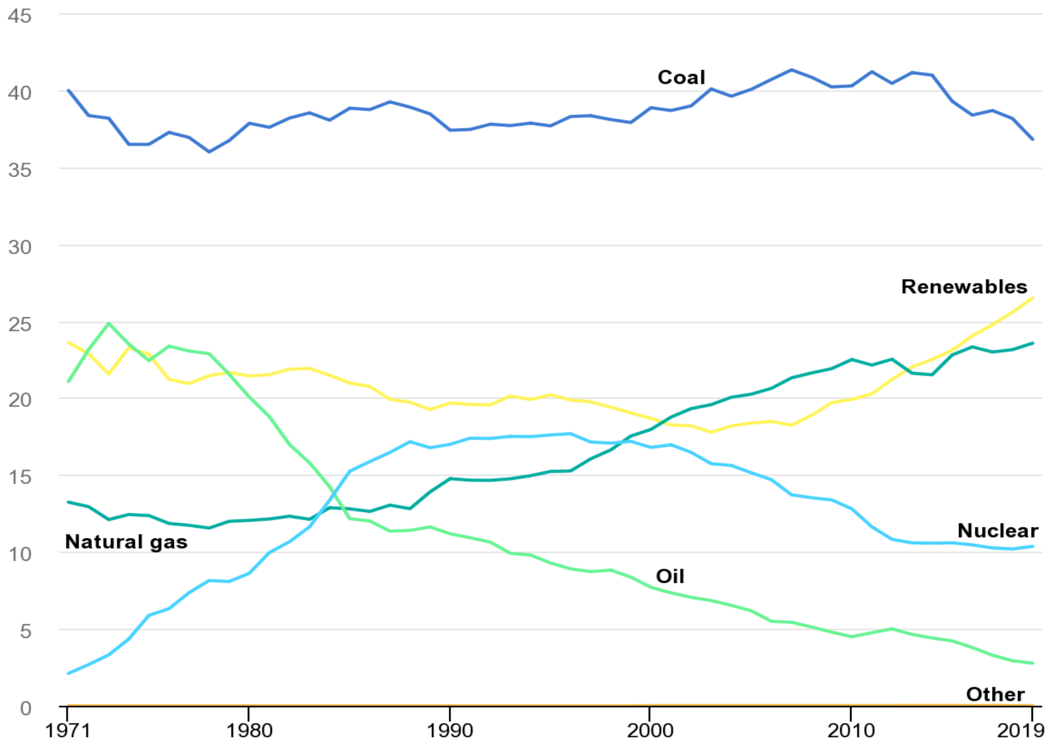

Figure 2.3 Share of electricity by category. Source: IEA, World electricity generation mix by fuel, 1971-2019, IEA, Paris https://www.iea.org/data-and-statistics/charts/world-electricity-generation-mix-by-fuel-1971-2019, IEA. Licence: CC BY 4.0

According to data from the IEA (2021), over the past five decades, coal has been the most dominant source of electricity production with its share in world electricity production oscillating between 41%-35%. However, it has begun to slowly decline with a concurrent sharp rise in electricity production from renewable sources since 2007. Renewable sources currently account for the second largest share (26.49%) in electricity production in the world. The share of oil in world electricity production started expanding at the start of the 1970s. When the oil crisis in 1973 hit, governments around the world took note of the vulnerability and potential challenges they faced with continued reliance on oil as a major source of electricity. Thus, other sources were pursued and the share of oil in electricity production began and has continued to drop since then. Nuclear energy for electricity production began to gain traction from the 1970s with its share reaching a high of 17.68% in 1996 but has kept falling ever since.

Renewable energy and electricity play a crucial role in addressing climate change, reducing dependence on fossil fuels, and ensuring a sustainable energy future. Governments, businesses, and individuals worldwide are increasingly investing in and adopting renewable energy technologies as part of a broader strategy to transition towards more environmentally friendly and resilient energy systems.

CHAPTER 3

3. THEORETICAL BACKGROUND

Although macroeconomics has always taken keen interest in the fluctuations of oil prices on the global market and its impact on economic activity, traditional growth models have excluded energy as a component that could facilitate or hinder economic growth. Meanwhile, ecological economists have always maintained that energy makes a key contribution to economic development, and they have rightly so criticized mainstream growth models that refuse to acknowledge this in that regard (Stern, 2016).

According to the efficiency law in thermodynamics, to transform production inputs into output, work is required, and work cannot take place without energy. Energy must therefore be a necessary component of all economic operations, and there must be restrictions on how often energy can be replaced by other factors of production to produce a given output in a way that energy is always necessary (Stern, 1997).

Classical economics often ascribes prices that are supposed to accrue to energy as payments to the primary factors of production because energy isn't rightly deemed a primary input in production but an intermediate factor. Consequently, the role and importance of energy in the whole production process is undermined and largely ignored in classical growth models as we know them to be (Stern, 1999; Stern, 2016). However, output is only limited to the amount of energy available and how it can be substituted between other factors of production with available technology. The energy available for production in an economy is a function of local natural resource endowment, extraction and refining capacity and generating capacity and thus is endogenous. While most mainstream economic perspective undermine the contribution of energy to economic progression, ecological economists have always maintained the essentiality of energy in development with some even going as far as championing the ideology that even technological improvement only helps improve production efficiency through increased use of energy. Thus, energy is the sole major propeller of growth (Cleveland, Costanza, Hall, & Kaufmann, 1984; C. A. S. Hall, Cleveland, & Kaufmann, 1986; C. Hall, Tharakan, Hallock, Cleveland, & Jefferson, 2003).

From this juncture, it is crucial to examine the evolution of the theoretical framework that encompasses the connection between input and output, known as the production function. This examination will enable us comprehend the significance assigned to natural resources and energy in production and its subsequent association with income growth.

3.1 Economic growth

The age-old problem of why different countries have grown differently over time has always been an enigma that has plagued the field of economic even as far back as Adam Smith’s era. The reason why two countries, for instance, Ghana and Malaysia who both gained liberation from the British in the same year and at the time had similar wealth and economic structure but are now light years apart in terms of quality of life can simply be attributed to economic growth. A simple definition of economic growth can be given as an increase in the value of products produced in a country over a measured time. The ultimate aim of all countries is to achieve economic growth. It is believed that economic growth translates to higher income and thereby people are able to afford at least the basics required for decent living and beyond. Given this analogy, it becomes apparent how valuable economic growth is, at least for what it could potentially signify to a country, that its citizens are able to improve on their living standards when growth is achieved.

3.2 Measuring economic growth

A corollary question of the previous highlight on economic growth is how to measure it. Is there any single factor that can be looked at and instantly know if an economy is growing? There are measures that are known to give a reasonably accurate indication of growth. The two most widely known factors are Gross National Product (GNP) and Gross Domestic Product (GDP).

The GNP as an economic performance metric was standardized by Simon Kuznets who happened to invent the GDP metric as well during the great depression era in the USA. It served as a way for the government to assess how bad the depression was and a barometer of how well their interventions were performing. GNP is the final value of goods and services produced by the nationals of a country. Meanwhile, GDP is defined as the total value of goods and services produced within an economy in a specified period. It doesn’t necessarily have to be produced by the citizens of the country. The works of foreign nationals in a country is included in the computation of GDP but not GNP. Value created by nationals of country abroad are included in GNP but not GDP. However, in recent times, GDP has dominated in practical use than GNP.

Three main methods of estimating GDP have been developed over the years. The expenditure approach to calculating GDP involves the summation of all final expenditures incurred in an economy in a defined period. These expenditure components are investment, government expenses, consumption, and net exports. The income approach involves summing all incomes accrued in a country over a period. These income sources include rents, profit, interest and wages. The third approach is the value-added approach. This process involves summing up all the additional value generated on a product at different stages in the production process.

Despite the numerous benefits of GDP, it does not go without any shortcomings. GDP can estimate the incomes earned in an economy, but it doesn’t indicate to whom those incomes accrued to, whether income inequality is rising or falling. It is unable to indicate the quality-of-life benefits to society from government expenditures. It can measure production, but that output excludes the cost of damages to the environment incurred in that process, a poor measure of sustainable development. The sole fixation on GDP does little to indicate the overall welfare of individuals in the country.

3.3 Main sources of economic growth

Sources of economic growth are multifaceted and fundamental to understanding a nation's economic advancement. These sources represent the essential elements that drive an economy forward, generating wealth and improving living standards. Economic growth is not a uniform process but rather a composite outcome of various contributing factors. These factors cover a wide range of elements, from labour, natural resources, technological innovation including research and development, human capital, natural resources, and government policies being some of the most notable sources of economic prosperity. Understanding some of these sources is essential for examining the key drivers that fuel a nation's economic progress.

3.3.1 Natural resources

Natural resources are non-man-made materials found in the environment that can be used for production activities. They include resources such as arable land, precious minerals, forests, water bodies, to mention but a few. Natural resources are classified as renewable if they can be replenished relatively quickly through natural occurrence. These include wind, freshwater and sunlight. Natural resources that are finite and cannot be regenerated within human timescales are considered non-renewable. These include precious minerals and fossil fuels. Natural resources can be used as capital items or inputs to produce goods. Before the industrial revolution, land was the most important factor of production (Weil, 2013). All things equal, the more natural resources available to an economy, the more output it can produce. The rapid growth of the Persian-gulf countries after their discovery of oil is a testament to this fact. However, there are instances where countries may be abundantly endowed with natural resources but not grow rapidly. Countries in sub-Saharan Africa are examples of this case.

3.3.2 Capital

The ability to get work done is enhanced by capital. Capital usually refers to physical (tangible) assets and infrastructure used in the production process. They include machinery, buildings, and many more of such that enhance the production of goods and services. Physical capital often exhibits five characteristics (Weil, 2013). Capital is produced and its production requires that the consumption of a portion of current output is forgone (investment). Also, the use of capital improves how much each worker can output. Thirdly, there is a limit on how much labour can be employed on a piece of capital at a given time. Also, given that capital improves output and there is a limit to how many people can use it at a given time, it is able to earn its owner a return (rent). Finally, using capital makes it subject to wearing out over time (depreciation).

3.3.3 Human capital

Human capital, put in a nutshell is the collective knowledge, skills, experience, and expertise of an economy's workforce. It is an intangible yet invaluable asset. Well-educated and skilled individuals are better equipped to adapt to changing technologies, make informed decisions, and contribute more effectively to an economy's overall output. Investment in human capital could take the form of education, training, and lifelong learning and healthcare, making it a driving force behind economic growth and innovation. An economy with a well-developed human capital base can adapt to changing technologies, develop cutting-edge solutions, and maximize its productivity.

3.3.4 Labour

In economics, labour is often said to be the effort exerted by individuals in the production of economic outputs. It is measured by the labour force, which is the sum of people actively working and people actively seeking to work. Labour uses capital to produce goods and services. Individuals who engage in work are rewarded by receiving wages for their efforts. Typically, the more labour available to an economy, the higher the output the economy is able to achieve. Two distinctions in labour can be made: skilled and unskilled labour. Unskilled labour is the contribution a person can make to a production process with minimal or no training. Skilled labour refers to the part of the labour force that has gained some education or specialised training. The more skilled a labour force is, the more efficient and effective they can use the capital available to them in an economy. Skilled labour contributes more to economic output is thus more valuable and typically receives much more wages than unskilled labour. An economy can increase the amount of labour available to it by increasing its population, the number of hours people work or by accumulating human capital.

3.3.5 Technological advancements

Production takes place with a set of instructions that indicates how the inputs should be applied in order to achieve the desired product. Technology is the set of instructions that shows how to apply the inputs to achieve the desired product. Technological advancements are improvements in how inputs are used to achieve the desired product. Technological advancement is not tangible but a very essential source of economic prosperity. It is the reason the same quantity of inputs can be used to achieve greater output than before. Technological advancements often result from research and development activities. Technological advancements is a function of the resources available that are committed to R&D and the available stock of human capital (Romer, 2019). The more research and development activities undertaken in an economy, the more technological progress there would be and hence that economy will grow output faster.

3.4 Growth theories

3.4.1 Classical economic growth theory

This is a school of economic thought that rose to prominence in Great Britan in the late 18th century during the industrial revolution. The front runners of these types of theories were Adam Smith and David Ricardo. Before classical economics, the mercantile system was the dominant perspective in determining how wealthy a nation is. The mercantilists considered the money supply or the treasure of the nation as a measure of its wealth. Basically, a rich nation was interpreted as one that had enough assets to survive in case of a war and not from the perspective of the welfare of its citizens.

The pulse of the reasoning of behind Adam Smith's theory was to redefine growth to match what was thought to be a burgeoning new era. He emphasized and advocated a limited government involvement in the market, favouring allowing market forces to determine the ideal distribution of resources. He believed that accumulation of capital and the portion of the population engaged in productive work were the key proponents of economic growth. He posited that high capital accumulation leads to higher labour force engaged in productive work and lays the foundation for labour specialisation. He also advocated that a large market would result in lower costs and facilitate an increase in labour productivity. Thus, it was essential to have free trade among countries so firms would have access to larger markets thereby promoting international specialisation and labour productivity. As labour gets specialised, they can earn higher wages to live satisfy their needs beyond survival.

According to this theory, accumulation of capital leads to labour specialisation which causes an increase in wages. This then leads to population growth and the availability of a larger market. Smith assumed that the population would grow at the same rate as the demand for labour. The larger market means production output can increase and the average cost of producing a unit of output will fall leading to a fall in prices of manufactured goods. This leads to a fall in profits of businesses at the steady state. If this goes on, businesses will have to cut wages in order to enjoy profits which will lead to wages falling back to subsistence levels. One of the reasons Smith was an advent proposer of limited restrictions on international was because he believed the solution to the fall in wages was to open up firms to larger markets.

3.4.2 Keynesian Growth Theory

The Keynesian theory of economic growth was developed by John Maynard Keynes during the great depression. It is notably a theory centred on the short-run path of economic growth. It became a notable school of thought as it was more effective at dealing with high unemployment that came with the great depression as previous policy attempts at it proved futile. The Keynesian theory of growth harbours two main tenets. The first is that government spending was a key component of aggregate demand, and the second core principle is that government intervention was necessary to keep the economy running at full employment.

While classical economics focused on the supply side of the economy, that is classicals thought that government should give incentives to firms to accumulate capital and make investment decisions, Keynesian economists focused on the demand side of the economy. They believe that money in an economy flows in a cycle. One economic entity's expenditure becomes income for another entity. Thus, a rise in consumption will cause a rise in income which will induce more spending and thus more income as well (Mankiw, 2006).

From the Keynesian theory on economic growth, four main sources of economic growth are identified which can be summarised in the expression:

$$AD = Y = C + I + G + X\text{-}M \qquad - \qquad (3.1)$$

Where *AD* is Aggregate Demand

Y is output or income

C is consumption

I is investment

G is government spending

(X-M) is net exports

According to Keynes, the economy runs on the level of demand in the economy and this sets income. In recessionary period, uncertainty leads to a drop in private sector spending. Thus, government spending is needed to counter this market failure to shore up income in the economy. The government's expenditures will create jobs and increase income which will in turn make business more profitable and thus more willing to engage in investment activities, thus driving economic growth.

3.4.3 Neo-Keynesian Growth Model -The Harrod-Domar Model

The Harrod-Domer model was developed by two different economists: Roy Harrod (1939) and Evsey Domar (1946). They worked separately on their models but ultimately had the same objective: to define the path of long-run growth of developed nations. It is generally considered a neo-Keynesian growth model. The model posits that economic progression in the long-run is an outcome of the economy's savings level and the productivity of capital investment. The model assumes a closed economy with an initial full employment income level. The average propensity to save equals the marginal propensity to save. Another assumption is the factors have no adjustment lags. The capital-output ratio and the savings rate are considered fixed.

Thus, the model exhibits constant returns to scale. The model fixates on a duality in the purpose of investment. These are that investment raises the output productivity capacity in the economy and it also generates income (Vandenberg & Rosete, 2019).

The model can be stated with the following two equations:

$$Y_d = \frac{I}{d} \qquad - \qquad (3.2)$$

$$Y_s = \sigma K \qquad - \qquad (3.3)$$

Y_d is the effective demand at full employment

Y_s is the productive capacity of the economy at full employment

I is net investment

σ is the productivity of capital

d is the marginal propensity to save

K is real capital

Equation 1 implies that effective demand is directly related to investment but is inversely related to the marginal propensity to save. Equation 2 also implies that aggregate supply is directly proportional to the productivity of capital and the level of capital stock. At equilibrium, demand should equal supply which after simplifying brings us the following equations:

$$\frac{I}{d} = \frac{\sigma}{K} \qquad - \qquad (3.4)$$

$$I = d\sigma K \qquad - \qquad (3.5)$$

Equation 3.5 brings forth the condition for steady state growth. It implies that, in the steady state investment should equal the product of the saving-income ratio, the productivity of capital and the capital stock. In incremental form, equation 3.5 can be derived as follows:

$$\frac{\Delta I}{I} = \sigma d \qquad - \qquad (3.6)$$

By the assumptions of the model, equation 3.6 can be rewritten as

$$\frac{\Delta I}{I} = \frac{\Delta Y}{Y} = \sigma d \qquad - \qquad (3.7)$$

This equation means that the net addition to the existing capital stock must equal the productivity of capital and the marginal propensity to save. According to Domar, equation 3.7 is the golden path an economy should follow in the steady state to maintain stability. When the net addition to capital exceeds the right side of equation 3.7, it will lead to higher income. The increased income level will lead to aggregate demand exceeding the supply capacity of the economy thereby causing a boom and inflation which is unstable. When the net addition to capital falls short of the right side, incomes will fall and thus there will be excess supply of goods beyond the demands of the economy, thus prices will fall, and the economy will run in to a depressionary state which is also unstable. Any deviations from the golden path breeds room for unstable growth.

The Harrod Domar model provides useful insight on determinants of growth in the long run. However, it doesn't come without some criticisms. The model has been criticised over its assumption of a lack of substitutability between inputs. It has also been criticised for assuming the propensities to save and the capital-output ratio as constant. These assumptions are thought of as unrealistic. The model has also been criticised for its focus on the requirement for steady state growth and not the rate of growth. Critics argue that while stable growth might be the focus of developing countries, the rate of growth is more pertinent to developed countries.

3.4.4 Neo-Classical Growth Theory: Solow Growth Model

Although there had been attempts to establish the relationship between input and output as early as the nineteenth century, it was until Cobb & Douglas (1928) introduced their ground-breaking paper that formally gave an econometrically estimated production function (Felipe & Adams, 2005). Production in its simplest definition would be the combining given inputs to generate a certain level of output. Total output generated in the whole economy is equivalent to income in the economy. A production function can be said to be the empirical relationship that defines the relationship between a given quantity of inputs and the resulting outputs. One of the most widely used production functions is the Cobb-Douglas production function widely specified as

$$Y = AK^{\alpha}L^{\beta}, (\alpha + \beta = 1) \quad - \quad (3.8)$$

where: Y is the total output in the economy.

K is the capital input

L is the labour input

A is the total factor productivity or the productivity of existing technology.

α and β refer to the sensitivity of output (output elasticity) to changes in capital and labour respectively

According to this model, output is determined by two main inputs which are capital and labour, making the model simple and easy to work with. However, this assumption in the model is criticised as one the model's flaws (Liao, Wu, & Xu, 2010). The model ignores all contributions of other inputs in production such as raw materials and energy.

Solow (1956) introduced what has now become known as one of the most prominent neoclassical growth models in economics, the Solow Growth model. According to this model, output is generated using labour denoted as L, capital labelled as *K*, and knowledge represented by *A* over a period of time(*t*) in a production function:

$$Y(t) = F(K(t), A(t)L(t)) \qquad - \qquad (3.9)$$

Technology is assumed to be labour augmenting in this model. Thus, it multiplies labour in the function. The time variable does not change output directly and only affects output through the inputs when they change over time. The model also assumes the production function maintains constant returns to scale. This means when each of the inputs are varied by a constant factor output in turn varies by the same factor. Thus,

$$F\,(cK, cAL) = cF(K, AL) \text{ for all } c \geq 0 \qquad - \qquad (3.10)$$

With the assumption that the production function exhibits constant returns to scale, the intensive form of the function modelling production can be expressed as:

$$y = f(k) \qquad - \qquad (3.11)$$

With capital per effective labour(k) = K/AL and output per effective labour(y) = Y/AL. This restatement implies output per effective labour is proportional to capital per effective labour.

Another essential assumption of the model is that the production function exhibits diminishing but positive marginal product to capital *(i.e.`(k)>0,f``(k)<0)* and it also satisfies the Inada conditions (Inada, 1964):

$$\lim_{k\to 0} f`(k) = \infty \;,\; \lim_{k\to \infty} f`(k) = 0 \qquad - \qquad (3.12)$$

Therefore, as capital increases, the marginal product of capital decreases, and conversely, as capital decreases, the marginal product of capital increases. Output is either invested or consumed. Hence, new addition to capital (investment) denoted by *I*, is the difference between output and consumption (*C*) which is also equal to how much of output is saved. The fraction of how much of output is invested, the savings rate(s) is considered exogenous and constant. Thus,

$$I = Y - C = sY \quad - \qquad (3.13)$$

Capital is assumed to depreciate at a given and constant rate *δ*. Thus, net change in capital ($\dot{K}$) is investment less how much capital stock has depreciated which can be written from (4) as

$$\dot{K} = sY - \delta K \quad - \qquad (3.14)$$

The growth rate of labour (*n*), the growth rate of knowledge (*g*), depreciation (*d*), and the savings rate (*s*) are assumed to be constant and given.

From equations (3.9) and (3.14), we can obtain the equation:

$$\dot{K} = sF(K, AL) - \delta K \qquad - \qquad (3.15)$$

Given that *k = K/L* and using the chain rule, we can obtain

$$\dot{k}(t) = \frac{\dot{K}(t)}{A(t)L(t)} - \left(\frac{K(t)}{A(t)L(t)}\right)\left(\frac{\dot{L}}{L} - \frac{K}{AL}\frac{\dot{A}}{A}\right) \quad - \qquad (3.16)$$

After some substitutions, we can obtain the expression:

$$\dot{k}(t) = s\left(\frac{Y}{AL}\right) - dk - nk - gk \quad - \qquad (3.17)$$

Given that *Y/AL = f(k)* we can rewrite as:

$$\dot{k} = sf(k) - (n + g + \delta)k \quad - \qquad (3.18)$$

The above equation is an important and rudimentary equation of the Solow growth model. It states that the rate at which capital per worker grows is the difference between the two terms on the right side of the equation. The term *sf(k)* is actual investment, the portion of output that is not consumed but rather invested to further production. The second term *(n+g+δ)k* is breakeven investment, the amount of investment needed to maintain capital per worker at its existing level. This is necessary because effective labour is growing at the rate *(n+g)* and capital is assumed to depreciate at the rate δ. Consequently, capital per effective labour must growth at this rate so there will enough for new workers as well as to replace worn-out capital. When actual investment is greater than breakeven investment, capital per effective worker rises and capital per effective worker falls when actual investment is less than breakeven investment. When the two terms are equal, capital per effective worker remains constant. The condition where actual investment equals breakeven investment is known as the steady state. From the equation, when actual investment exceeds breakeven investment $\dot{k}$ is positive and k will rise until it reaches its steady state level. On the other hand, when $\dot{k}$ is negative, k will fall until it reaches its steady state level. The variables of the model exhibit a constant growth rate in the steady state.

Even though the rate of savings doesn't affect growth when the economy is in the steady state, output per worker's level changes with changes to the savings rate. For instance, a permanent rise in the savings rate causes a temporary spike in the growth rate of output per worker and growth rate of capital per worker but permanently changes capital per worker and output per worker's levels. Suppose the savings rate were to rise until it reaches 100%, the rate of growth for output per worker will eventually stop rising, a consequence of the diminishing returns to capital assumption. The change in savings rate only has a level effect and not a growth effect.

The Solow growth model proposes that the savings rate cannot be the main driver of the growth in an economy but rather technological growth – producing more and better output with the same input - is the only way to have a perpetual change in the rate of growth of output per labour. One mainstream criticism of this growth theory is that even though it highlighted the role of technology in economic growth, it treated it as a mystery variable that is determined outside the model. Also, the model implies that incomes observed across different economies should ideally converge due to diminishing marginal returns to capital. However, this was not accurate in reality. A class of models emerged that escaped this inherent limitation by considering capital in a broader sense of human and physical capital and assumed that diminishing returns did not apply to this broader sense of capital. They ultimately became known as endogenous growth models.

3.4.5 Endogenous Economic Growth Theory

Endogenous growth models began to emerge due to the limitations of the Solow growth theory. These models aimed to demonstrate that economic growth stems from within the economy itself, rather than external factors. One crucial question raised was how to incorporate technology into these models. Gong et al. (2004) emphasize that Romer (1986) played a pivotal role in popularizing endogenous growth models. Romer's work highlighted the impact of externalities such as learning by doing and previous knowledge on macro-level labour productivity—a concept initially proposed by (Arrow, 1962). Prior to Romer's contributions, a body of work commonly referred to as *AK* models, named after their formulation, as '*Y=AK*' began to gain traction. They are considered the foundational basis of endogenous growth models.

Frankel (1962) has been credited for expounding the first known version of the AK model. He argued that improvements in human capital from accumulating more capital leads to technological advancements(A) that counteract the declines in marginal product to capital. This allows the production function potentially demonstrate increasing marginal product or constant returns to capital. When the marginal return to capital is constant, it allows the level of Y to vary in direct proportion of changes to the entire available stock of K, making the production function:

$$Y=AK \qquad - \qquad (3.19)$$

An implication of this model was that the savings rate could be used to affect the growth rate making the theory popular among policy makers at the time since policy could be used to significantly impact output growth rates.

Romer (1990) introduced perhaps the best way to define technology or knowledge, a factor in economic growth that is in some way universally agreed influences growth but no one until then had as much insight into how it affects growth (Jones, 2019). The key to Romer's success is his differentiation of ideas from all other conventional economic goods. According to Romer (1990), knowledge is different from all other economic goods in that it is nonrival. Nonrival here means that the use of an idea in one place does not make it impossible to use it in another place at the same time. For instance, the use of Newton's laws of motion in one factory does not affect it being used in any other place at the same time. In contrast, economic goods are rival. The use of my laptop in writing this thesis prevents it from being used in another other place at the same time. So, as soon as an idea is brought forth, it is not restricted by scarcity unlike normal economic goods as we know them to be (Jones, 2019).

The model uses four variables as inputs for production. These are capital(K), labour(L), human capital(H) and technology(A). Human capital is a measure of education and work-related training while technology is a measure of designs for a new product. The model assumes that the stock of labour and human capital available to the economy is fixed. His model has three sectors – the intermediate goods sector, the final goods sector, and the research sector. Human capital and the current stock of knowledge are used by the research sector to develop new designs for producer durables. These designs are then used by the intermediate sector in combination with previously saved output to manufacture producer durables. The output of the intermediate sector is also used alongside labour and human capital to make final products. A portion of human capital is dedicated to research, to produce new knowledge and the other portion is dedicated to producing final output. The final output and knowledge functions are given as

$$Y = (H_Y A)^{\alpha}(LA)^{\beta}(K)^{1-\alpha-\beta}\eta^{\alpha-\beta-1} \quad - \quad (3.20)$$

$$\dot{A} = BH_A A \quad - \quad (3.21)$$

H_Y and H_A are human capital dedicated to final output and technology respectively.

B is a productivity parameter

H refers to the units of deferred consumption needed to create one unit of output.

In equation 3.20, output is expressed as function of the basic inputs of the model with technology augmenting labour and human capital and output exhibiting diminishing returns to capital, quite similar to the Solow model. Equation 3.21 shows that the growth of knowledge is increasing in both human capitals dedicated to knowledge and the available stock of designs. Romer gave an analogy of this where he said that an engineer working today and one working about a hundred years ago may have the same level of human capital but the engineer working today may be more productive because they have more stock of knowledge to draw on to make new designs.

Romer (1990) concludes that, when an economy has a bigger stock of human capital compared to another country, that country will have bigger growth in knowledge and thus larger economic growth, giving some justification to the observed trend of developed countries growing at much higher rates than their less developed counterparts.

In spite of the genius of conventional growth theories, they still have major shortcomings. Young (1995), using growth accounting techniques notes that endogenous growth models fail to explain the rapid rise of the newly industrialised countries (NICs) of East Asia. He finds that during the period of the rapid growth in t economies, investment in capital accumulation, rises in human capital and an increased labour force involvement underpinned the process with less contribution coming from technology. Jones (1995) observes that even though the average years of education and investment has increased in OECD countries, there has not been any significant rise in growth observed over those periods as endogenous growth models predict and even argues that there might be decreasing returns to knowledge.

3.4.6 Energy as a factor of production

Despite economists having dedicated their studies to the analysis of global resources since the inception of economics as a discipline, it was not until a profound realization dawned upon North America in the 1950s during the regime of Dwight Eisenhower that the management of natural resource assets was far from satisfactory (Castle, Kelso, Stevens, & Stoevener, 1981). This awakening served as the impetus for the birth of environmental and natural resource economics as a specialised area of study. However, it was only in the early twentieth century that economists began to systematically delve into the intricate tensions that exist between the pursuit of present value maximization, and the indifference towards the reduction of future options, depletion, and non-market aspects encompassing natural resource matters.

Consequently, as the 1960s unfolded, the discipline of economics witnessed the emergence of environmental and natural resources economics as a distinct field, marking the foundation of an innovative perspective purposely to examine the intricate link between economic progression and energy.

Even though it might have not been obvious then, energy was at the heart of the enormous success of the industrial revolution (Green & Zhang, 2013). The oil crises of the 1970s as well as growing evidence of global warming has given rise to a new wave of deeper investigations into how energy and energy shocks affect the economy especially in the post-World War II period (Hamilton, 1983; Kilian, 2008; van de Ven & Fouquet, 2017). Hamilton (1983) found that seven in eight of the recessions observed in the USA between 1948 to 1972 were preceded by steep rises in the price of oil. Nordhaus et al. (1980) also noted that the demand for oil is relatively price inelastic in the short-run and an increase in oil prices increases energy expenditure, causes inflationary pressures, and reduces spending on other goods thereby hurting economic activity and growth. A later investigation by Kilian (2008) revealed that the source of an oil shock – demand side or supply side – is key to determining its impact on economic activity. The results of Darby (1982) presented a contradictory perspective to Hamilton's findings, as it failed to establish a similar correlation between GDP and the oil price shocks. However, subsequent studies conducted by (Burbidge & Harrison, 1984; Ferderer, 1996; Gisser & Goodwin, 1986; Mork, 1989) corroborated Hamilton's findings. These investigations aligned with Hamilton's outcome, thus reinforcing the link between GDP and oil price shocks. (Cunado & Perez De Gracia, 2005; Jiménez-Rodríguez & Sanchez, 2005; Lardic & Mignon, 2006; Mork, Olsen, & Mysen, 1994; Papapetrou, 2001) performed similar studies on OECD countries and found the same negative relationship between oil prices and GDP, further underscoring the role of energy in growth.

Stern (2011) modifies the Solow growth model by including energy as in input. In his model, energy has limited substitutability with capital and labour. The elasticity of substitution between labour and capital is also set to 1. Energy's impact on economic growth is contingent upon two key factors: the availability of energy and the state of technological advancements. Depending on these factors, energy can either hinder growth by imposing constraints or stimulate growth by providing enabling conditions. The model consists of two equations:

$$Y = \left[(1-\gamma)\left(A_L^{\beta} L^{\beta} K^{1-\beta}\right)^{\phi} + \gamma (A_E E)^{\phi}\right]^{\frac{1}{\phi}} \ , \ \phi = \frac{\sigma - 1}{\sigma} \quad \text{- (3.22)}$$

$$\Delta K = s(Y - p_E E) - \delta K \qquad \text{– (3.23)}$$

Y = gross output

K = capital

L = labour

E = energy

σ = elasticity of substitution between the value-added aggregate and energy

p_E= price of energy

γ= parameter reflecting the relative importance of energy and value added

A_E = Augmentation index for energy

A_L = Augmentation index for labour

Equation 3.22 represents the production function and incorporates a Cobb-Douglas function of capital and labour, along with a constant elasticity of substitution (CES) function of value added and energy. The equation reflects the relative importance of energy and value added, with parameters representing the elasticity of substitution between value added and energy, and energy price. The second equation is the equation of motion for capital, assuming a fixed savings rate and a constant depreciation rate. It ignores land and assumes that materials can be aggregated with energy.

When σ approaches unity and γ approaches zero, the model reduces to the Solow model. Contingent on the scarcity of energy, the model can exhibit either Solow-style growth or energy-constrained behaviour. In the steady state, the level of capital stock and output are determined by factors such as the savings rate, labour-augmenting technology, and depreciation, like the Solow model. However, when energy is relatively scarce, the steady state hangs on the level of energy supply and energy-augmenting technology. To account for empirical findings that demonstrate a decline in the cost share of energy over time, an assumption is introduced that the elasticity of substitution between energy and capital-labour is less than unity. This suggests that energy has become less constraining as it has become more abundant, resembling the behaviour of the Solow model where output growth is determined by labour augmentation.

Despite the enormous role of energy in economic development, it also comes at a cost. There is a general consensus amongst most scientists that the environmental crises we see today due to climate change and global warming are a result of rapid industrialization and an expansion in economic activities among others (Destek & Aslan, 2020; Ehigiamusoe, Guptan, & Lean, 2019; Mohsin, Kamran, Atif Nawaz, Sajjad Hussain, & Dahri, 2021; Usman, Alola, & Sarkodie, 2020). According to estimates, approximately 80% of greenhouse gas emissions in the European region can be attributed to energy production and consumption (Akpan & Akpan, 2012). Globally, energy alone is responsible for about 67% of total greenhouse gas emissions.

3.5 Causality hypothesis to identify the energy growth nexus

After examining the available body of work on the EC-growth correlation, two overarching themes become evident. The apparent first theme realised is the lack of consensus regarding the character of the nexus and how it manifests. The second theme observed is that most of the literature falls within four groups of hypotheses which researchers have arrived at through thorough analysis. These findings relate to whether there exists a one-way, two-way, or neutral association between economic growth and EC.

The notion of a one-way linkage can be further subdivided into two causal directions. The first suggests that EC serves as a catalyst for the growth of GDP. In other words, an increase in EC is believed to directly contribute to economic expansion. Conversely, the second direction posits that GDP growth leads to a subsequent rise in EC. Hence, there is a reciprocal cause-and-effect relationship between economic growth and EC.

3.5.1 Conservation hypothesis

The conservation hypothesis in the energy-growth nexus relationship posits that there is a unidirectional causality running from economic growth to EC. According to this hypothesis, economic growth drives an increase in EC. Under the conservation hypothesis, as an economy expands and develops, income grows and sparks a growing demand for energy. Also, as industries expand and businesses thrive, the demand for energy-intensive activities and services rises, resulting in an augmented need for energy resources. Overall, this hypothesis asserts that economic growth drives increased EC due to the expanding needs from income growth. The implication of this hypothesis is that energy conservation policies can be implemented with no significant effect on economic growth.

3.5.2 Growth hypothesis

In the energy-growth nexus relationship, the growth hypothesis posits that a one-way causality flows from EC to economic growth. In other words, increased use of energy results in more economic prosperity. As energy resources are utilized in various sectors such as industry, transportation, and households, it provides the necessary input for economic activities to expand and thrive. The availability and utilization of energy resources contribute to higher productivity, increased production output, and overall economic development. The EC to economic growth causality hypothesis acknowledges the significant role that energy plays as a fundamental input in the production process. It suggests that a sufficient and reliable supply of energy is essential for powering economic activities and supporting the infrastructure required for sustained economic growth. A consequence of this hypothesis from a policy-making perspective is that policies that seek to reduce EC in such an economy may end up hampering economic growth. Thus, policymakers ought to exercise a great deal of caution if and when they want to implement energy conserving policies.

3.5.3 Feedback hypothesis

The feedback hypothesis in the energy-growth nexus relationship suggests that there is a two-way causality or feedback loop between economic progression and EC. It suggests that EC has an impact on economic growth, and conversely, economic growth is influenced by EC. Per this proposition, an increase in EC can stimulate economic growth. As energy resources are utilized to power industries, transportation, and various economic activities, it can lead to higher productivity, increased production output, and economic expansion. This is the direct effect of EC on economic growth. However, the feedback hypothesis also highlights the seeming reverse causality, suggesting that economic growth can drive increased EC. As economies grow, there is a greater demand for energy to sustain and support the expanding economic activities. Industries, businesses, and households require more energy to power their operations, leading to an increase in EC. The feedback hypothesis acknowledges that EC and economic growth are interconnected, with each factor influencing and being influenced by the other. The relationship is not unidirectional as the others suggest but rather a dynamic feedback loop where EC can contribute to income growth, and this in turn can drive even more energy use.

3.5.4 Neutrality hypothesis

The neutrality hypothesis in the energy-growth relationship suggests there is no meaningful causal association between EC and economic expansion. According to this hypothesis, changes in EC doesn't have a substantial impact on economic expansion, and economic growth does not significantly affect EC. Under this hypothesis, EC and economic growth are considered unconnected to each other. Simultaneously, the neutrality hypothesis implies that economic growth doesn't substantially impact EC. Economic growth is perceived as an effect of various factors unrelated to EC. Other factors play a more dominant role in driving economic growth and determining EC patterns.

In summary, while traditional growth models have overlooked the role of energy in production, ecological growth models have shed light on their importance. The Solow Growth model, a prominent neoclassical growth model, focuses on capital and labour inputs while assuming constant returns to scale. However, this model falls short in explaining what accounts for majority of the variations we see in output growth. To address these limitations, endogenous growth models emerged underlined the role of technology and knowledge in promoting growth. Energy augmented growth models have illuminated the rudimentary role of energy in modelling growth with wider applicability to pre- and post-industrial revolution growth observed.

CHAPTER 4

4. LITERATURE REVIEW

A closer look on the relevant empirical literature shows that researchers have not reached a consensus regarding the relationship under consideration. This lack of agreement can largely be attributed to significant disparities in timeframes, analytical methodologies, and the various countries and groups of countries observed. Nevertheless, there has been an increasing number of findings that support either unidirectional or bidirectional causality directions, while fewer findings support the notion of neutrality. This trend may be attributed to the global shift from labour-intensive to capital-intensive methods, which rely on energy and prioritize EC as a central component of economic growth. Additionally, as the world continues to transition from analogue to digital technologies, energy and electricity consumption increasingly emerge as key drivers of economic progress.

4.1 Work validating the conservation hypothesis

4.1.1 Economic growth - conventional energy nexus

Kraft & Kraft (1978) led the way with their study of the causal relationship between gross energy inputs and Gross National Product (GNP) in their work, "On the relationship between Energy and GNP". They used data for the above-mentioned variables that started from the post second world war period from 1947 to 1974 to test for a unidirectional causality nexus between GNP and gross energy inputs by employing the method Sims (1972) had developed to test for a unidirectional causality relationship between money and GNP. Based on their work, they established that a strong statistical relationship exists between GNP and gross energy inputs which is also a unidirectional causality relationship that runs from GNP to energy exists for the USA in the period after the World War II. Thus, they determined that it is feasible to enact energy policies with a conservative approach without adversely affecting economic activity.

Cheng & Lai (1997) applied cointegration and Hsiao's GC techniques on yearly Taiwanese data from 1955 to 1993 on CPI, GDP, EC and employment. Per their findings, there is no cointegration between EC and GDP over the period studied for Taiwan. Furthermore, it was found that there was a unidirectional causality relationship that ran from economic growth to EC, and a unidirectional causality from EC to employment. Thus, economic growth boosts employment through EC.

Yoo & Kim (2006) applied unit root and cointegration tests on time series data covering 1971 to 2002 for Indonesia for the variables electricity consumption and real GDP. After that they executed the GC test on it and ascertained that in the case of Indonesia, there is a one-way causality relationship running from GDP to electricity usage implying that Indonesia could safely implement policies that curbs excessive use of electricity without hampering the economy's ability to growth. They went further to suggest that as income grew, households had more disposable income to consume more electricity probably because they could buy more electrical appliances. Also, as the economy grows the manufacturing sector also grows and needs more electricity because of their expansion.

In another paper, Narayan & Smyth (2005) investigated the role of electricity consumption, income, and a third variable, employment in a multivariate model for Australia in attempt to seek and establish the nature of the relationship between the three variables for the Australian economy. After analysing data from 1966 to 1999, for the variables of interest, they found that all three variables are cointegrated. Also, while a weak unidirectional GC relationship runs from real income to electricity consumption then to employment in the immediate term, the linkage morphs into one where real income and employment Granger cause electricity in the long run.

In a first for Cyprus, Zachariadis & Pashourtidou (2007) applied GC tests and impulse response functions to household and commercial electricity consumption, incomes, prices and weather data from 1960 to 2004 to ascertain the existence of causality relationships between them as well as analyse the impact of shocks to them. They discovered that, income Granger causes electricity usage even though a feedback causality linkage between household electricity utilisation and private income is present.

After collecting data from Bangladesh spanning 1971 to 1999 on the variables income per capita and electricity utilisation, Mozumder & Marathe (2007) applied cointegration and a vector error model on them in an attempt to explore the causality relationship between them in a bivariate model. According to the outcome of their work, a one-way relationship that runs from GDP per capita to electricity usage per capita exists for Bangladesh. This implies it is safe for the Bangladeshi government to implement policies that help conserve electricity consumption with no adverse consequences on the economy.

In 2006, the research conducted by Yoo & Kim (2006) explored the causal relationship between per capita electricity consumption and per capita real GDP across four Asian countries: Thailand, Singapore, Malaysia and Indonesia covering the period 1971 to 2002. To enhance the statistical analysis, both variables underwent logarithmic transformation. Following the logarithmic transformation, unit root tests, such as the Dickey-Fuller and Phillips-Perron tests, were applied to the data series. These tests revealed that the data became stationary at the first difference. However, the data for Thailand was only stationary at second difference. Subsequently, a GC test on the transformed, stationary logarithmic series were performed. The results of this test confirmed that causality run from economic growth to electricity consumption in Indonesia and Thailand. However, the other two countries did not receive substantial support for this hypothesis as the Engle-Granger cointegration test and the Johansen cointegration test revealed a lack of long-term equilibrium connection between their data series.

In a study for Uganda, Sekantsi & Okot (2016) examined the electricity consumption and real GDP nexus between the years 1981 to 2013. They expressed the collected data as natural logarithm values and conducted the two unit root tests on them. The Dickey-Fuller unit root test revealed that both variables were stationary only at first difference. The Phillips-Perron unit root test also indicated the same outcome. In addition, an ARDL cointegration bound test was applied on the data and it revealed the presence of cointegration among the variables. GC tests then revealed that in the short-run, causality run from GDP growth to electricity consumption as far as Uganda is concerned over the period observed.

An inquest into the nexus in Pakistan led Balcilar et al. (2019) to collected data on electricity consumption and real GDP between 1971 to 2014. In their study, they included carbon dioxide emissions as a third variable to measure the impact of carbon dioxide on the relationship. After logarithmic transformations and applying the Toda-Yamamoto causality test, it was unveiled that for Pakistan, causality runs from real GDP to electricity consumption over the observed period.

In a similar manner, Bekun & Agboola (2019) employed a tri-variate model to observe the link between the two variables of interest in Nigeria between. The third variable included was carbon dioxide emissions. They sampled data from 1971 to 2014 to analyse the relationship. According to their findings, all three variables were not stationary at level but at first difference. They then employed the Maki cointegration test which then revealed that the variables had a long-run equilibrium relationship. By using the Fully Modified Ordinary Least Squares (FMOLS) methods, the researchers discovered evidence for the conservation hypothesis and that a statistically significant income elasticity of electricity consumption was estimated to be 0.70.

Furthermore, Samu et al. (2019) replicated the earlier study by Bekun & Agboola (2019) for Zimbabwe by collecting data for the same variables over the period 1971 to 2014. They also applied the cointegration test proposed by Maki and verified that there was causality that ran from real GDP to electricity consumption. Next, they made an estimation of the income elasticity of electricity consumption in the context of a long-term equilibrium which they found be 0.78, significant at a 5% level. Another discovery from the study was that electricity consumption is unresponsive to the measured value of carbon dioxide released into the atmosphere in Zimbabwe.

For Tunisia, Mighri & Ragoubi (2020) investigated the linkage between electricity consumption and real GDP in a bivariate model with data from 1971 to 2013. The researchers then determined the Phillips-Perron unit root test as ideal for their course. From the results of the unit root test, they used after expressing the variables in natural logarithms, the two variables were not stationarity at level. They however became stationary when they were expressed as first differences. They then set electricity consumption as the dependent variable and used the ARDL bounds test for cointegration. The results confirmed that electricity consumption and real GDP had long-run cointegration. Additionally, a VECM-based GC test was conducted which revealed causality ran from GDP to electricity consumption in the long-run for Tunisia. Nevertheless, the work verified the credibility of the growth hypothesis in the short run for the Tunisian economy.

4.1.2 Renewable energy – economic growth nexus

Sadorsky (2009) employed a panel model to investigate the impact of renewable energy on income in 18 emerging economies from 1994 to 2003. The study applies five tests of stationarity on the data after they had been expressed in logarithmic forms. After the tests revealed both variables were integrated of the first order, the Pedroni panel cointegration test is then applied to the data which produced mixed results, but the study resolved that there is at least some cointegration among the factors. The FMOLS and DOLS models were estimated to obtain the elasticities of the relationship between the variables. The results from both models suggest that a percentage rise in real income increases clean energy consumed by about 3.39% to 3.45%.

Leitão (2014) probed the income-renewable energy nexus for Portugal spanning the period 1970-2010. The study estimated a multivariate model with economic growth as the dependent variable and carbon dioxide emissions, aggregate EC, globalisation, and renewable energy as the regressors. An OLS model was first estimated which revealed a positive and significant coefficient for green energy. The GMM model estimated also indicated that renewable energy has a positive effect on income growth. The ADF, PP and KPSS unit root tests were then performed on the data to confirm they were all integrated of the first order. Subsequently, the Johansen test for cointegration showed cointegration was present among the variables. From the GC tests performed, the authors deduced that economic growth unidirectionally causes green energy usage.

Ocal & Aslan (2013) in a country-specific study for Turkey between 1990 to 2010, assessed the causality link between GDP and green energy usage. The study included capital, percentage of combustible renewables and waste in aggregate energy and labour as control variables. The ADF-WS was used to check the presence of unit root in the data which confirmed all variables in the study were not non-stationary after first difference. The researchers then proceeded with an ARDL model to test for cointegration between the factors. The ARDL model unveiled an inverse relationship between renewable energy and economic growth in Turkey. Specifically, GDP plummets by 0.3% for every percentage point increase in green energy usage. The Toda Yamamoto test also revealed a one-way causal link from GDP to renewable energy.

Following their initial work a year earlier Sari et al. (2008) reanalysed the impact of EC from disaggregated sources of energy on industrial output using the data they collected for the USA from January 2001 to June 2005 using the ARDL approach. However, a variable for non-farm employment was included in the study based on the role of labour in accounting for variations in industrial output uncovered in their previous work. Again, six unit root tests were applied to the data to ascertain their stationarity and the ARDL bounds testing approach was used to test for cointegration. This revealed cointegration exists between the disaggregated sources of EC, output in the industrial sector and employment. Specifically, labour and industrial output are key factors of wind, solar and hydro in the long run.

4.2. Work validating the growth hypothesis

4.2.1 Conventional energy – economic growth nexus

Using a multivariate version of the test-vector autoregression, Stern (1993) tested for a causal relationship between GDP, EC and capital stock using data from the USA spanning 1947 to 1990. His results indicated that EC does not Granger cause GDP. However, after he adopted a quality weighted final EC measure that accounts for different mixes of fuel used to generate energy, he found that new adopted measure of energy Granger causes GDP.

Stern (2000) adds multivariate cointegration relationship between EC and GDP to his earlier analysis of USA in the period following the war and draws the conclusion that there is a unidirectional causality from EC to GDP. This finding is consistent with that of his conclusion from his earlier multivariate model work when he used a modified measure of energy.

Masih & Masih (1996) test GC for six Asian nations from 1955 to 1990 using the cointegration method between energy use and economic growth. Cointegration and VECM analysis were employed to establish causation and cointegration. According to their findings, only Indonesia, Pakistan, and India have a long-term energy-income link; Singapore Malaysia, and the Philippines do not. They discover there is unidirectional causation from EC to GDP for India. However, the conservation hypothesis dominated in Indonesia. For Pakistan, the VECM provided an indication of prevalence of the feedback hypothesis whereas variance decomposition analysis indicated that income caused EC.

Masih & Masih (1998) used multivariate cointegration and ECM techniques to approximate the causal relationship for Sri Lanka and Thailand from 1955 to 1991 and they discovered that EC, real income, and price were cointegrated and there is one-way causality from EC to real income and price, and its effect is seemingly more enhanced in Thailand than in Sri Lanka. Hence, EC is largely an independent variable not Granger caused by either price or real income.

Based on a 1960-1995 series, Soytas et al. (2001) investigate the relationship between energy use and GDP for Turkey. The authors applied cointegration and the VECM to analyse the data gathered. The cointegration analysis confirmed cointegration was valid for both factors. VECM GC analysis was then applied to probe the direction of causality. It was concluded the growth hypothesis was prevalent. Thus, EC in Turkey Granger caused income over the period observed.

Ghosh (2002) studied the link between electricity usage and GDP per capita between 1950 to 1997 employing yearly Indian data and running the GC test on the data he collected. He discovers there exists only a unidirectional GC relationship from income progression to electricity use. He also uncovers that a long-run equilibrium relationship between electricity and GDP is non-existent.

In the works of Shiu & Lam (2004) took a look at GDP and electricity consumption data between 1971 to 2000, realised that the two variables of interest are cointegrated. They then applied the error-correction model to the data which unveiled a unidirectional relationship from electricity consumption to GDP with no reverse. They further suggested that over the period observed, a significant portion of electricity generated in China was for industrial purposes, thus electricity consumption affects GDP through industrial demand for electricity.

Kumar Narayan & Singh (2007) used a tri-variate model with the variables electric power consumption, labour force and economic growth. According to their work, cointegration is only present in the model when economic is the endogenous variable and both exogenous variables statistically significantly stimulate income growth using the OLS, FMOLS and ARDL analysis to the data. They further used the GC test to ascertain if a causality relationship exists between them. They found that electricity stimulated economic growth over the period 1971 to 2002 for Fiji observed with no feedback in the long run. Thus, it would not be advisable for the government to implement policies that would limit electricity usage while pursuing economic growth policies as well. Their analysis also revealed a two-way relationship between income and labour force in the short run.

In another bivariate model, Ho & Siu, (2007) analysed electricity consumption and real GDP data from 1966 to 2002 for Hong Kong. First, the variables were expressed in logarithmic form and then stationarity was tested using the Dickey Fuller and Philips-Perron tests for unit root. The variables turned out to be stationary at first difference. The Johansen cointegration test revealed confirmed that the variables had a long run cointegration relationship. They also found that electricity causes real GDP with no feedback.

Yuan et al. (2007) also investigate the causality between real income and electricity utilisation for China. They considered data covering 1978 to 2004. After applying cointegration analysis, they found the presence of a long-run equilibrium relationship between the variables. A causality analysis reinforced the validity of the growth hypothesis revealing a unidirectional relationship that runs electricity consumption to real income. Hence, shortage in supply of electricity in China could hinder economic growth.

In the case of developing countries, Lee (2005) pooled a sample of 18 countries across different regions of the world and collected data relating to them on real GDP, energy usage and capital stock from 1975 to 2001. He used the Pedroni panel cointegration and GC tests to show that there is a cointegration relationship between EC and economic growth. His estimates reveal that EC and economic growth have and long and short-run relationship with causality running from energy to GDP with no feedback for developing countries. He suggests that this could be due to the industrial growth phase of development that these countries are usually in.

In Narayan & Smyth (2008) a causal linkage from EC to GDP was found to hold for G7 countries, they used the Westerlund (2007) cointegration method to find that there is a long-run relationship between EC, GDP and capital formation for the period 1972 to 2002. The causality found in the short-run was reportedly weak but there was strong significance for the long-run causality. It was estimated that a 100-basis point increase in EC nudges real GDP by about 12 to 39 basis points higher.

Odhiambo (2009) compiled data on Tanzania's EC, economic growth, and electricity consumption from 1971 to 2006 to examine the EC-growth nexus for the nation. He applied an ARDL bounds test as well as the Granger test for causality to probe cointegration and the causal relationship direction. After proving the factors of interest had a long-run relationship, the GC tests went on to further reveal that in both the short and long-run, electricity and EC each Granger cause economic growth in Tanzania with no feedback. This contrasts Ebohon (1996) who found a two way causality direction albeit over a different time period.

Wang et al. (2011) adopted a multivariate model with EC, economic growth, capital, and labour in a one-sector neo-classical growth model from 1972 to 2006. Again, after establishing long-run cointegration, the GC reveals that for China over the period under consideration, EC unidirectionally Granger causes economic growth in the long-run. Nonetheless, in the short run a weak two-way causation between was found between energy and economic progression.

Soytas & Sari (2007) investigated the growth hypothesis for the Turkish economy using data from 1968 to 2002 in a multivariate model with value added in the manufacturing sector, electricity consumption, fixed investment and employment in the manufacturing sector. They sought to study how electricity consumption relates to how much value is added at the manufacturing level in Turkey and in what direction the relationship runs. After establishing the variables are integrated at first difference, the Johansen cointegration was applied to reveal the existence of a long-run relationship between the variables of interest. A long-run relationship was confirmed. The GC method was applied to a VECM specification to ascertain the path causality follows. The outcome of this test indicated a unidirectional GC from electricity usage to manufacturing output in the long run. Nonetheless, the short-run tests suggested electricity does not have any significant impact on manufacturing output. The paper moreover revealed that in the long-run electricity utilisation also Granger causes labour and fixed investment in the sector in the long-run.

Warr & Ayres (2010) split the measure of energy in to two distinct variables. One was the total supply of energy which was termed ‘exergy’, and the other was output form energy inputs termed as useful work. Along with these two distinct measures of energy, two multivariate models with GDP, capital, and labour to reexamine the nexus for the USA between 1946 to 2000. Cointegration was found among the variables in both models using the using the Johansen and the Johansen and Julius techniques. Then, GC tests were applied to vector error correction models of the two sets of variables. The results pointed to quite distinct influences of both measures of energy on income, although in the same direction. Useful work Granger caused GDP in the long run alone. Exergy on the other hand Granger caused GDP in both the short and long-run. No feedback causality was found in this research. This work suggests that economic growth can also be achieved with improvements in energy efficiency.

Awodumi & Adewuyi (2020) examined the effects of NREC on economic expansion and CO_2 emanations in the top five oil-producing African nations from 1980 to 2015. Non-renewable energy was categorized into natural gas and petroleum categories. After identifying structural breaks and nonlinearity in the data, the researchers employed NARDL approach for their analysis. The findings indicated that per capita NREC of both types of energy had varying impacts on economic growth and carbon emissions across the nations, except for Algeria. In Nigeria, an expansion in NREC slowed economic growth but bettered environmental quality. For Angola, NREC stimulated economic growth, but its influence on environmental conditions was mixed and depended on the type of energy consumed. However, the study did not find a significant relationship between the growth of these energy types and environmental pollution, as they primarily contributed to economic growth.

Yoo & Kwak (2010) explored the nexus between the variables of interest in some South American nations namely: Venezuela, Peru, Ecuador, Colombia, Brazil, and Argentina. They collected 32 years of annual data from 1975 for the variables and analysed them. The test for stationarity using the Phillips-Perron methodology revealed both series were only stationary at first difference but for Peru, Chile, and Colombia. Long-term cointegration for the series was confirmed for Venezuela using the Johansen cointegration technique but cointegration for Peru, Ecuador, Chile, Brazil and Argentina was absent. A causal linkage to economic prosperity from electricity consumption was confirmed for Ecuador, Chile, Brazil and Argentina through the Granger method of testing for causality.

In another study Chouaibi & Abdessalem (2011) examined the nexus for Tunisia for the period between 1971 to 2007. After expressing the variables into natural logarithm values, they conducted Dickey-Fuller and Phillips-Perron tests for stationarity on the data. The tests verified that both variables became stationary at first difference. Then, Engle-Granger and Johansen tests for stationarity were applied to the data and they both revealed that there was no cointegration between the series. Using a VAR (4) model the GC test was then conducted which indicated that for Tunisia over the period examined, causality begins from electricity utilisation to GDP over the observed period.

In Pata & Yurtkuran (2017) a study examining the association for the two variables in five European countries: the USA, the UK, Turkey, Spain and Belgium was conducted. The study utilized yearly data spanning 1964 to 2014 for the two variables. To ascertain the stationarity of both variables, two-unit root tests were used: the Phillips-Perron and the Dickey-Fuller tests. The results showed that both variables were integrated of order I(1) in Spain and Belgium. In contrast, for the UK, Turkey, and the USA, data on GDP became stationary after their first differences were taken while data for electric power consumption was stationary at level based on stationarity tests. Furthermore, to investigate the cointegration, the researchers applied ARDL bounds test using various models for different countries as appropriate. They used an ARDL (1, 4) for Turkey, an ARDL (2, 1) for the USA, an ARDL (2, 1) for the UK, an ARDL (1, 2) for Belgium, and an ARDL (4, 1) for Spain. The study established statistically significant cointegration relationship for all the countries tested significant at the 5% level. Specifically, the impact that electricity consumption had on income growth were estimated to be 0.15, 0.41, 0.37, 1.10, and 0.38 for the respective countries mentioned above. Additionally, the research explored the immediate effects on real GDP of electricity consumption through the utilization of an error correction mechanism (ECM). The results indicated that at a 5% significance level, the short-run impacts were statistically significant. The estimated short-run impacts were 0.75, 0.56, 0.50, 0.39, and 0.41 for the five countries in the same order as previously mentioned.

Using a multivariate model, Hossen & Hasan (2018) sought the possibility of the presence of an existing link among the economic variables electricity-induced carbon dioxide emissions, electricity consumption, real GDP, and heat production in Bangladesh from 1972 to 2011. It was found that all three time series variables were integrated of order I (1) based on the estimations of stationarity tests of the Phillips-Perron and Dickey-Fuller methods. In order to investigate the equilibrium connection between the variables, the researchers utilized the Johansen test for stationarity, employing both the maximum eigenvalue statistic and the trace eigenvalue statistic. The test outcomes revealed the existence of a sustained equilibrium relationship among the three variables in the long term. In addition, the investigators executed a GC test to scrutinize the direction of causation. The test findings confirmed the presence of GC in support of the growth hypothesis.

In another multivariate model for India, Bekun & Agboola (2019) investigated the mutual influence of electricity consumption and real GDP from 1990 to 2016. The third variable included in the study was a measure of carbon dioxide emissions. To analyse the relationship, the researchers transformed the variables into their natural logarithms. The study utilized the Toda-Yamamoto test for causality investigate the presence of the growth hypothesis in India. The test outcome affirmed the presence of causation, demonstrating that electricity consumption influences real GDP at a significance level of 5%.

Another investigation on the link between electric power utilization and real GDP led Samu et al. (2019) to collate data on electricity use, real GDP and carbon dioxide emissions in Zimbabwe from 1971 to 2014 using a different method from their earlier work. Upon transforming the three variables into natural logarithms, the researchers subsequently applied the Zivot-Andrews test for stationarity, which in turn, showed that stationarity was attained only after implementing the first difference of the series. Thus, all three variables were integrated of order I (1). In order to explore and ascertain the causal relationship between the variables under scrutiny, the researchers decided to employ the Toda-Yamamoto causality test in their investigation.

The test results confirmed that over the 44-year period observed, the growth hypothesis prevailed. Thus, for Zimbabwe, electricity consumption caused growth in recorded GDP.

Zhong et al. (2019) conducted an inquest on the relationship between electricity utilization, real GDP, and total employment in China between 1971 to 2009. After stating the variables in their natural logarithms, and it was found that they exhibited non-stationarity at level. However, they became stationary after their first differences were taken. This was confirmed by conducting four unit root tests. These were the Zivot-Andrews, Kwiatkowski-Phillips-Schmidt-Shin, Dickey-Fuller and the Phillips-Perron stationarity tests. In their quest to investigate the enduring equilibrium relationship, the researchers opted to employ an ARDL (4, 4, 1) model for the cointegration test, with the natural logarithm of GDP serving as the regressand. The findings of the test pointed to a significant long-term equilibrium connection among the three variables examined in the research. Specifically, it was observed that real GDP exhibited a substantial long-term equilibrium connection with electricity consumption at a 5% significance level. Furthermore, a robust error correction model (ECM) established within the ARDL (4, 4, 1) framework revealed that causation from ran from GDP to electricity utilisation in the immediate term, reinforcing the credibility of the growth hypothesis.

In a separate study, Ha & Ngoc (2021) delved into the possibility of a non-linear influence of electricity consumption on the economic growth of the Vietnamese economy, covering the period from 1971 to 2017. The variables examined in the study encompassed four research variables: real GDP, FDI, the urbanisation rate and aggregate electricity utilisation. With the exception of the urbanisation rate variables, all other variables in the study were expressed into logarithm form and stationarity tests were run on them. It was found that all variables were integrated of order I (1). The researchers applied cointegration bounds testing procedure using the NARDL (3, 2) model to investigate cointegration in the data with the dependent variable being GDP. The findings revealed the existence of a cointegration relationship among the regressor alongside the regressors. Furthermore, a statistically significant causation from GDP to electricity utilisation in the immediate term and the long run as well was found based on the results from the ECM of the GC test used, further supporting the growth hypothesis.

In two distinct groups of countries, Eggoh et al. (2011) conducted a study to investigate the differential impression of EC on economic expansion. The two groups of countries considered were net energy-importing and net energy-exporting nations. They first tested for cross sectional dependence in the data then performed structural break tests. After that, they used the DOLS and PMG approaches to ascertain the character of the association existing for both factors based on the classifications they had defined earlier. They found the presence of a cointegration relationship between real GDP and EC for each distinct group of countries as well as for all the countries put together. However, there were differences in the magnitude of the impacts. A percentage rise in energy usage in the entire sample of countries led to a 0.36% stimulation in GDP. For the next energy-exporting countries sample, a 0.57% growth in GDP was observed with a 1% growth in electricity use while the effect reduced to 0.27 percent for the net energy-importing sample of countries. In investigating the converse relationship, the findings leaned in favour of net energy-importing countries, suggesting that their economic growth demonstrated a higher degree of responsiveness to EC.

(Nondo & Kahsai, 2009) provided additional evidence at the sub-regional level, focusing on 19 COMESA countries from 1980 to 2005. Panel unit root tests and panel Granger causality tests established a long-term relationship between energy consumption and economic growth. Moreover, the findings revealed a unidirectional causality from energy consumption to economic growth, in line with the growth hypothesis. Based on these findings and considering the abundance of renewable energy sources in COMESA, the authors recommended the promotion and development of an expanded supply of clean energy in the region.

4.2.2 Renewable energy – economic growth nexus

Payne (2011) examined the nexus that lies between real GDP and a singular source of renewable energy, biomass, capital, and labour in the United States of America using data he collected up to 2007 from 1949 and transformed them into natural logarithms. The PP test, the ADF and the DFGLS tests for stationarity were then used to ascertain the maximum integration order of the factors for a VAR model estimation. They deduced from the tests that all variables have a maximum integration of order one. Subsequently, the Schwartz, Akaike and Hannan-Quinn information criteria were then used to establish the ideal lag-length of the model which was 2. This was followed by using the Toda-Yamamoto technique to test for GC. The outcome of the test revealed that REC (biomass) causes income growth unidirectionally.

Ewing et al. (2007) collected monthly data on employment, industrial output, aggregate EC, aggregate REC, and disaggregated sources including geothermal, biomass, wind, fossil fuels, solar and hydro. The aim was to probe the impact of these sources of energy on variations in industrial output in the United States from January 2001 to June 2005. The series were outputted into natural logarithms and six unit root tests were employed on the data. The data for geothermal energy was not stationary even after second difference and was then dropped. Generalised Forecast Error Variance Decomposition analysis was then run on the data. this revealed that 16% of variations in industrial output in the USA could be accounted for by biomass while about 6% could be accounted for by wind energy, emphasizing the key role of renewable energy in the US economy.

Yildirim et al. (2012) also followed path of his predecessors by examining the income-renewable energy nexus for the USA using data from 1949 to 2010. He includes employment, and capital as control variables in the study. The PP and the Kwiatkowski tests for stationarity were applied to the data which indicated that the series were integrated of order one at maximum. The Hannan Quinn and Schwartz Bayesian information criteria were then used to obtain the maximum lag length of the data. A bootstrap corrected Toda Yamamoto causality technique is then run on the variables. The conclusion of the test uncovered a one-way causation relationship to GDP from biomass (waste) but found no causality from the other sources of renewable energy despite biomass only contributing 6% of aggregate renewable energy consumed over the period studied.

Twerefou et al. (2018) conducted a study to examine the effect of aggregate energy, petroleum, and electricity consumption on economic growth in West African nations over 36 years from 1980. They employed the FMOLS approach to analyse the data collected. According to their study, a causality relationship that runs to economic growth from total EC and petroleum consumption does not exist. However, a unidirectional causation from economic prosperity to electricity utilisation was discovered, confirming the conservation hypothesis. They also discovered that total

EC had negative and significant effect on economic growth in the region. A percentage increase in aggregate EC resulted in a 0.14% decrease in economic growth. This negative effect on economic growth was ascribed to the region's heavy reliance on biomass. However, when the energy sources were analysed separately, statistically significant positive impacts were observed. Also, it was found that RELC had a larger impact of 0.107% on economic expansion than non-renewable energy from petroleum which stood at 0.058%.

Maji et al. (2019) collated data covering the period 1995 to 2014 for countries in the West African subregion and then applied the DOLS, FMOLS, and OLS estimations on the data. Similar to the finding of Twerefou et al. (2018), they found renewable energy and biomass were limiting factors on income growth in the region. This was also attributed to the predominant use of wood biomass as a renewable energy source in West Africa and the limited utilization of greener sources of energy such as solar, wind, and hydropower.

For countries in BRICS, Banday & Aneja (2020) used data from 1990 to 2017 to investigate the causal nexus between economic growth, carbon dioxide emissions and REC and NREC. The study applied bootstrap causality test of Dumitrescu and Hurlin to the data of BRICS. According to their findings, a feedback linkage exists between REC and GDP for Brazil and China. Also, for Russia, their estimations indicated that the growth hypothesis prevailed while they found no causality between the two factors for India. Furthermore, in the case of South Africa, they found that economic growth caused REC. In addition, for NREC, they found no causality between the two factors for South Africa. Causality from NREC to income growth was nonetheless affirmed for the rest of the block.

Shahbaz et al. (2020) assessed the growth implications of using renewable versus non-renewable energy sources usual annual data from 1990 to 2018. This research encompassed 38 nations with a significant reliance on REC. In analysing the data collected they first used the DOLS and FMOLS approaches and then used heterogenous non-causality tests. For the complete set of countries in the sample, the empirical results confirmed a significant association between economic prosperity and the utilization of both conventional and renewable energy. From the individual country estimations, interesting findings came to light. There was evident heterogeneity in various facets of the relationship. In 27 countries, NREC demonstrated a more substantial influence compared to renewable energy consumption on real GDP. Furthermore, non-renewable energy was noted to yield a positive effect in 81.6% of the countries, while REC exhibited a positive impact in a much less 68.4% of the nations. However, the impact of renewable energy was significant in thirty nations compared to twenty-one countries for NREC. France, Turkey, the United Kingdom, and India all exhibited a negative impact when both REC and NREC were considered in these European countries and India. It was observed that in six countries, including the USA, Israel, Belgium, Morocco, and South Africa the influence of both types of energy utilisation was insignificant on real GDP growth.

Chen et al. (2020) conducted a separate study where they showcased how the effect of REC on economic growth can vary between helpful and adverse outcomes, contingent on the volume of REC. This investigation involved a threshold model and encompassed annual data from 103 countries spanning 21 years from 1995 to 2015. The study revealed that, initially, the effect of green energy on economic expansion was adverse, but it transitioned to become favourable after crossing a specific consumption threshold. This discovery was especially noticeable in developing and/or non-OECD nations. Moreover, the study indicated that the association was inconsequential in developed countries but positive in the case of OECD countries.

Adams, Klobodu, & Apio (2018) took into account regime type while investigating the effects of renewable and non-renewable energy on economic growth in 30 sub-Saharan African countries from 1980 to 2012. The study found significant long-run relationships among the variables based on heterogeneous panel cointegration and panel-based error correction tests. However, the short-run relationship was not found to be robust. The study indicated that non-renewable energy had a more significant impact than renewable energy. Specifically, a 10% increase in renewable and non-renewable energy was associated with a 0.27% and 2.11% increase in economic growth, respectively. When controlling for democracy, the impact of both energy source consumption on economic growth was enhanced. Thus, the study also captured the effect of governance on the nexus.

For Pakistan, Abbasi et al., (2020) investigated the effects of renewable energy and non-renewable energy on GDP growth for the period 1970 to 2018 using NARDL and taking into consideration governance factors as a third variable in the study. Findings from the Nonlinear Autoregressive Distributed Lag (NARDL) modelling unveiled distinct effects stemming from the two energy sources. While renewable energy showcased favourable outcomes, non-renewable energy was identified as having an adverse influence on economic growth. Parallel to the observations made by Adams et al. (2018), an improvement in governance, quantified by a decrease in terrorism, was associated with heightened economic expansion.

Kouton (2021) undertook a distinctive evaluation involving 44 sub-Saharan African nations from 1981 to 2015, with a shift in focus from examining the relationship with economic growth to considering its effect on "inclusive" growth. This alteration in perspective acknowledged the reality that, despite significant economic growth in Africa, the continent continued to grapple with elevated poverty and inequality rates. The outcomes derived from the GMM model indicated that REC had a beneficial and statistically significant impact on inclusive growth.

4.3. Work validating the feedback hypothesis

4.3.1 Conventional energy – economic growth nexus

Using annual data for GNP and GDP, Ebohon (1996) examines the growth-energy linkage in Nigeria and Tanzania. For Nigeria, he collected data from 1960 to 1981 while for Tanzania he collected from 1960 to 1984, three years more data than that of Nigeria which was till 1981. This research illustrates that there exists a bidirectional causal connection between economic expansion and EC in developing nations. This outcome is in tandem with the findings of Erol & Yu (1987) who used the Granger test for causality technique to probe the nexus using data on Japan.

Masih & Masih (1997) took another look at the energy-growth nexus using a multivariate model. They included the Consumer Price Index (CPI) to the traditional GDP and EC variables. Their tri-variate model varies from the production sided model used in the studies of Stern (1993, 2000), which includes EC, GDP, capital, and labour. Their cointegration test revealed that for the variables in the study, cointegration was valid. They then conducted a VECM based Granger causality test which showed that for Taiwan and South Korea, a three-way causal linkage between GDP, prices and EC prevailed.

In a study that produced contrasting results to that of Masih & Masih (1996) except for that of the bidirectional causality for Pakistan in their work, Glasure & Lee (1998) used cointegration, VECM, and VAR-based standard GC tests to analyse the GDP-EC relationship. Their work focused on 1961 to 1990 annual data for the economies of Singapore and South Korea. The cointegration tests they performed showed that the two variables were cointegrated. The VAR model results indicated that there is no connection between South Korea's GDP and EC, whereas in Singapore, a one-way relationship between EC and GDP is observed. Contrarily, the VECM results showed a bidirectional causal linkage for the energy variable and GDP in both countries.

Nachane et al. (1988) tested for the presence of a long-run equilibrium relationship between EC and GDP using cointegration techniques. They collect yearly data on EC and GDP for 25 countries for the years 1950 to 1985. Out of the 25 nations studied, 16 of countries had the presence of cointegration between the two variables out of which they were 11 developing countries and 5 developed countries. For all nations except for Colombia and Venezuela, the Sims and GC tests used in the study exposed a bidirectional causal linkage between GDP and EC.

The work of Yang (2000) examined the relationship by exploring aggregate EC and income while also looking at various subcategories of energy and income. He applied Hsiao's version of the GC technique to Taiwanese data collected from 1954 to 1997. He concluded there is a bidirectional causation link between aggregate EC and GDP. He also discovered that the same relationship holds for electricity and coal consumption whereas the relationship between both natural gas and oil and GDP is a unidirectional one.

Although most studies have focused on aggregate income, Jumbe (2004) differentiated his work from others by looking at the nexus between electricity utilisation and GDP in the agricultural and non-agricultural sectors, as well as aggregate GDP for Malawi spanning 1970 to 1999. He applied the GC and error correction modelling techniques which led him discover that in the case of Malawi, electricity consumption is cointegrated with GDP as well as non-agricultural GDP. However, there was an absence of cointegration between electricity usage and agricultural GDP. Furthermore, he found that there was a looped relationship between

GDP and electricity in Malawi. Also, the GC he applied further reveals that non-agricultural GDP Granger causes electricity consumption with no feedback.

While analysing data for 57 countries from 1971 to 2005 broken down in 3 income groups namely: lower middle income, higher middle income and low income, Ozturk (2010) used the Pedroni cointegration method to establish long-run cointegration for EC and economic growth for all the income groups examined. They further used the GC method to show the direction of causality. While they found causality from income to EC in low-income countries, there was bidirectional causality between the variables for the lower middle and upper middle-income countries. They however noted that the relationship was a weak one in all the income groups examined.

In Mahadevan & Asafu-Adjaye (2007), data on twenty net energy importing and exporting countries (ten each) were compiled and analysed to investigate the energy-growth nexus. The data spanned 31 years from 1971 and was divided further into developed and developing nations in each group of net energy importing and exporting countries. Energy prices were included to make the model a tri-variate one. They then used the cointegration test proposed by Johansen and panel based VECM to analyse the data. According to their findings, a unidirectional causality relationship from GDP to EC exists for net energy exporting countries (developed and undeveloped) in the short run. Nevertheless, the relationship is a bidirectional one in the long run. The same liaison also holds for developing net energy importers. In the case of developed net energy importers, the causality link is a bidirectional one.

Sebri & Ben-Salha (2014) explored the causal link in BRICS between 1971 to 2010. They employed a multivariate framework with GDP, environmental carbon dioxide releases, trade openness and the usage of renewable energy to investigate the nature of their relationship. The ARDL bounds testing method was employed to establish cointegration between the factors, and a VECM was constructed to ascertain the path causation according to the Granger technique among them. A direct relationship which was particularly more pronounced in Brazil as compared to the rest of the countries in the bloc was found. The empirical results indicate a two-way GC relationship between the GDP and renewable EC giving further relevance to this hypothesis.

Ghali & El-Sakka (2004) applied a neoclassical production function with capital, labour and energy as inputs to explore the possibility of a nexus between income and energy use for the Canadian economy from 1961 to 1997. The Johansen cointegration technique was applied to the data to seek cointegration and it revealed cointegration between the factors. A vector error correction model was then developed to investigate the direction of causality between the variables. This search unveiled a bidirectional causality relationship between the variables of interest and shocks to energy will alter the income growth rate in Canada, refuting the neoclassical claim that energy is neutral to growth.

Foon Tang (2009) also applied the bounds testing procedure to ascertain that that electricity consumption, income, foreign direct investment, and population growth are cointegrated for the period 1970 to 2005 for Malaysia. Subsequently, he employed an ARDL estimated model to derive the coefficients for both the long-term and short-term relationships among the cointegrated variables. This revealed that FDI, population growth and GDP have a positive effect on electricity consumption in the long run. That of FDI was only significant at the 10% level. Meanwhile in the short run, the influence of income and FDI were at the 10% percent significance level. A vector error correction model is used to test for the direction of GC. It appears in this model there is a bidirectional GC link between electricity consumption and income. A one-way causality from population growth to electricity consumption was also found in contradiction to Narayan & Smyth (2005) and Kumar Narayan & Singh (2007).

For Malaysia, Nanthakumar & Subramaniam (2010) investigated this dynamic with data from 1971 to 2008 on the variables GDP and EC. Using the OLS-EG and DOLS estimations methods, the presence of cointegration in the long-term was confirmed between the factors under scrutiny. An ECM of the ARDL bounds testing approach was then used to show that the direction of causality for Malaysia both in the short term and the long term is a two-way relationship throughout the studied period.

Azam et al. (2021) conducted a comparative analysis to examine the influence of non-renewable electricity and RELC on economic prosperity from 1990 to 2015 in ten newly industrialized countries. The study aimed to test the four hypotheses related to the relationship between economic growth and EC namely the conservation, the neutrality, the feedback, and the growth hypotheses. The study utilized panel cointegration analysis, panel unit root tests, and the panel FMOLS estimation. The study's results unveiled that both RELC and non-renewable electricity use exert a favourable and statistically significant long-term influence on economic growth. The study also observed that a 1% increase in RELC had a greater effect (0.095%) compared to non-renewable electricity consumption (0.017%). Additionally, the GC tests indicated the presence of bidirectional causality between RELC and economic growth in both the short and long-run, supporting the feedback hypothesis. In conclusion, the study provided empirical evidence to confirm the feedback hypothesis regarding the growth-energy nexus in the examined countries.

In analysing the GDP-energy link, Nazlioglu et al. (2014) collected yearly data for GDP and electricity consumption in Turkey from 1967 to 2007. The Philips-Perron and Dickey Fuller unit root tests were used to test the stationarity of the data collected after natural logarithm had been taken of the values of the variables. According to the results from the stationarity tests, the measure of income and electricity usage variables were not stationary at level. Instead, they happened to be integrated at order 1. Subsequently, from the Schwartz Bayesian and the Akaike information criteria, an ARDL (1, 1) model was best suited for the model. Furthermore, cointegration bounds testing revealed income and electricity consumption were cointegrated for Turkey. The feedback hypothesis was verified using an ECM of the GC test to exist in the long-run and the short-run for Turkey in the period studied. However, after using a non-linear GC test, they found no significant causality relationship between the variables in the study.

Bildirici (2016) examined the GDP-electricity nexus in five South American countries. He collected yearly recorded figures on the real GDP and the value of electricity used between 1970 to 2010. The countries in his study are Nicaragua, Ecuador, El Salvador, the Dominican Republic, and Guatemala. The Ng-Perron and the Elliott-Rothenberg-Stock tests for stationarity were used to ascertain the presence of unit root among the variable under scrutiny. The outcome from the tests showed the series were not stationarity at level but their first differences were stationary. This result was the same for all the countries in the study. Employing a Markov-Switching VAR model, they identified the presence of three distinct business cycle regimes - recession, moderate growth, and high growth - apart from Nicaragua, where only two regimes were found to hold. The analysis revealed a reciprocal relationship between real GDP and electricity consumption, indicating bidirectional causality between these two factors. This means that changes in electricity consumption can be attributed to shifts in real GDP, and conversely, alterations in real GDP can be attributed to variations in electricity consumption, as inferred from historical data patterns.

Hwang & Yoo (2016) conducted a study on the causality linkage for the Nicaraguan economy for real GDP and electricity consumption. They used Nicaraguan economic data spanning 1971 to 2010. As is convention, the variables were expressed into natural logarithm form. For unit root testing, the researchers decided the Phillips-Perron unit root test was apposite and the discoveries from the test hinted that the data series was non-stationary. However, it became stationary after the first difference of the variables were taken making them integrated of order I (1). From the Engle-Granger test employed, cointegration between the series over the period analysed did not exist. Nevertheless, the mutual causation between income and real GDP in Nicaragua is confirmed in the series using the GC test.

In their research conducted for South Africa, Khobai & le Roux (2017) undertook an investigation to assess the influence EC exerts on economic growth in the South African economy. The researchers also included urbanisation, carbon dioxide emissions and trade openness to create a multivariate model. The authors chose to utilize yearly data that extended from 1971 to 2013. They made use of both the Johansen cointegration test and VECM GC methods to probe the presence of a relationship in the long run among the variables and causality direction. The results from the estimations indicated that the variables were cointegrated. The conclusions of the GC probe affirmed a bidirectional causal linkage between EC and income growth in South Africa. There was no short-run causality present, however.

Sultan & Alkhateeb (2019) explored the energy-economic growth relationship for India during from 1971 to 2014. Cointegration tests affirmed the reality of cointegration for EC and economic progression in the long-term. It was revealed that, energy use caused a one-way expansion in the economy of India in the short run. However, the two variables mutually caused each other in the long run.

4.3.2 Renewable energy – economic growth nexus

Focusing on a panel of twenty OECD countries, Apergis & Payne (2010) probe the interlinkage between income and REC, labour and capital from 1985 to 2005. The study proceeds to test for the order of integration of the variables using the Imp et al stationarity test after expressing the variables in logarithmic format. The unit root test showed that the variables are integrated of the same order I(1). Accordingly, the Pedroni tests for cointegration were applied on the data which showed that the factors were cointegrated. An FMOLS model was estimated from which was deduced that a percentage rise in REC in OECD countries results in 0.76% rise in income. GC tests revealed a two-way causal relationship exists between income and REC.

In another study focused on 13 Eurasian countries, Apergis & Payne (2010b) collected and analysed data from 1992 to 2007 using panel data techniques in a multivariate framework to probe the interdependence between green energy use and income with labour and capital as control variables. They first tested the data for the presence of unit root using the Imp et al test for stationarity. After confirming the variables were integrated of order I (1), the Pedroni test for the presence of cointegration is deployed which outputted that the variables were cointegrated. An FMOLS model was then estimated for the data which showed that a unit percentage rise in REC results in a 0.195% rise in income levels. The researchers then estimated a panel VECM to check the direction of GC among the factors. The GC test indicated a two-way causal relationship was present for income and REC.

Apergis & Payne (2011) worked on uncovering the relationship existing between renewable energy usage and income six countries in Central America. They made use of data for labour, capital, real GDP, and renewable electricity spanning 1980 to 2006. The factors are examined to ascertain their stationary properties using the Levin et al ADF, the Fisher-PP, the Imp et al., the Carrion-i-Silvestre et al., and the Fisher-ADF tests for stationarity. The variables turned out to be integrated of the first order. The Pedroni cointegration technique for panel data was then employed to seek the existence of an equilibrium long-run relationship between the variables. From the test, cointegration existed between the variables based on the seven test statistics of the Pedroni test. An FMOLS model was estimated to derive the elasticities of the variables in the study. From the FMOLS estimation, real GDP rises by 0.244% from every unit percentage increase in RELC. A panel VECM is estimated to apply the Engle and GC testing method. The results showed that in both the long and short term, a two-way causality relationship exists between electricity usage from alternative sources and economic growth.

In another panel model, Apergis & Payne (2012) collected data on conventional energy usage, Real GDP, green energy usage, labour and capital from 80 countries between 1990 to 2007. They then used the Levin et al ADF, the Fisher-PP, the Carrion-i-Silvestre et al., and the Fisher-ADF tests for stationarity to establish stationarity in the dataset after logarithmic transformations had been done. The variables became stationary at first difference. The long-run equilibrium test developed by Pedroni was then used to test for cointegration. It turned out that for all the countries in the panel, cointegration is positive for all variables employed in the study. According to the FMOLS model estimated, real GDP rises by 0.371% for every percentage rise in renewable energy use. The VECM specified to test for GC revealed a two-way causal relationship in the long and short run between renewable energy and income. Also, the researchers found an inverse two-way causal relationship between conventional energy use and green energy use, suggesting that both types of energy are substitutes.

Tugcu (2013) studies the impact different forms of energy usage have on total factor productivity growth for the Turkish economy. Time series data from 1970 to 2011 was collected for real GDP, labour growth and capital to obtain total factor productivity. Data on fossil energy, nuclear and alternative energy and renewable energy are also collected. Two tests of stationarity, the ADF and the KPSS, were applied to assess the presence of unit root in the data. Although the results were mixed, all the variables were stationary at first difference, so the research proceeded with ARDL bounds testing approach to ascertain the existence of a long-run equilibrium relationship. It was found that a unit percentage rise in REC's proportion of aggregate final energy results in a 0.663% rise in total factor productivity in the short-run while total factor productivity rises by 0.818% in the long-run. The remaining two aggregate measures of EC were found to have an inverse relationship with total factor productivity growth. The DL GC analysis showed that between renewable energy and total factor productivity in the Turkish economy, both variables are causal factors to themselves.

4.4. Work validating the neutrality hypothesis

4.4.1 Conventional energy – economic growth nexus

After the seminal work of Kraft & Kraft (1978), Akarca & Long (1980) in another paper considered gross EC and GNP data for the United States between 1947 to 1972, two years shorter than that of Kraft & Kraft (1978). According to them, the period of 1973 to 1974 experienced an oil embargo and sharply rising energy costs and so it was better to use a more homogenous period to obtain better result. Using the Box-Jenkins procedures for time-series as well as Granger's principle, they revealed that there is a non-existent causal relationship between GNP and gross EC. They asserted that the conclusions derived by Kraft & Kraft (1978) was misleading due to their inclusion of the years 1973 and 1974.

Yu & Hwang (1984) took another look at the data used by Akarca & Long (1980) the above-mentioned study but updated it to span the period from 1947 to 1979 in an attempt to establish the causal relationship between GNP and EC. Applying the Simms's technique to the data, they found zero causal relationship between GNP and EC However, they further attempted to seek if there exists a relationship between EC and employment. As a second finding, they uncovered a weak unidirectional causation that runs from employment to EC.

Erol & Yu (1987) investigated the energy-growth nexus for industrialised countries. They drew their conclusion from the outcome of a Sims causality test and a GC test which were conducted in the various industrialized countries they collected data on over the period from 1950 to 1982, that of Canada's was limited in 1980. Their findings indicated that in the case of Canada, France, and the UK, a neutral relationship existed between GNP and EC. Nonetheless, for Japan and Italy the growth hypothesis was confirmed to prevail. For West Germany, the causal relationship discovered ran from GNP to EC.

Employing monthly data on EC, income and employment from January 1974 to April 1990 for the USA and applying a cointegration test developed by Granger (1981) and Engle & Granger (1987), Hwang & Gum (1991) tested for a long-run equilibrium relationship between EC and income or employment. They arrived at the conclusion of a neutral liaison between income, employment, and EC over time. They further split the data down into two subperiods: one in which energy prices were rising and one in which energy prices were falling and still found that there a neutral long-run cointegration relationship between the variables of interest, further giving support to the neutrality hypothesis.

Using annual data on GNP and EC for the USA from 1947 to 1997, Cheng (1995) applied Hsiao's interpretation of the GC test and discovered additional confirmation in favour of the neutrality hypothesis, which holds that there is no relationship among the relevant variables during the observed time period. He continued by saying that the shift in the American economy from one centred on manufacturing to one based on services may mean that energy is just one of many factors that fuel economic growth.

A study by Altinay & Karagol (2004) on the GDP-energy use nexus revealed a neutral causality relationship between them as far as Turkey is concerned. The study applied unit root tests to analyse annual data in a bivariate model covering the period 1950 to 2000. Hsiao's version of the GC method was then applied to the detrended data series to arrive at this conclusion of a neutral causal linkage between income and EC.

Gross (2012) breaks down the USA economy into sectors and analyses the energy growth nexus at the sectoral level as well as the whole economy over the years 1970 to 2007. He employs a multivariate model with the variables GDP growth, EC, energy price, capital to energy ration and trade in an ARDL bounds methodology for the aggregate economy, industry, commercial and transport sectors. The GC test is also applied to ascertain the directions of causality. For the aggregate economy, the study revealed an absence of cointegration and as such the absence of a long run linkage. Nonetheless, a bi-directional nexus between growth and income is observed in the short run as well as for the industrial sector. They also found a better fit for the model when trade was included in the model for the industrial sector. This suggests that energy use in countries from where intermediate goods are imported also have an indirect effect on growth in the USA. The commercial sector was found to exhibit neutrality in the nexus probe. Finally in the case of the transport sector, for the long and short term, there existed a two-way causal relationship.

In Ciarreta & Zarraga (2010), a second objective was to examine the potential presence of a nonlinear connection using the 1971 to 2005 annual data collected for Spain on electricity usage and GDP. They employed the Hiemstra–Jones methodology to conduct a nonlinear Granger on two VAR models. First, using the data at levels, they applied GC tests on the residuals of a third order VAR. They then applied the GC tests again on a first-order VAR model. This time the data was kept in its first difference. The outcomes of both assessments suggest a nonexistence of substantial causality between electricity utilisation and economic growth for the Spanish economy.

Tamba et al. (2017) in their study on Cameroon, examined the electricity-GDP linkage from 1971 to 2013. They collected yearly observed values on the two variables and expressed them logarithmically. Dickey–Fuller unit root testing applied on the data indicated that both GDP and electricity consumption were not stationary at level. They were integrated of order I(1). It was then uncovered that there was non-existent cointegration among the two factors in the study according to the outcome of the Johansen cointegration test conducted. To address this, the authors reverted the first difference of the data back to level and estimated a VAR (1) model. The partial elasticities gotten the VAR (1) model from this model were not statistically significant. The researchers the proceeded to apply the Granger test for the presence of causality using the $\chi 2(1)$ statistic. In so doing, they verified that GDP and electricity consumption in Cameroon had no significant effect on each other.

Presenting contrasting findings for South Africa using data from 1991 to 2016, Nyoni & Phiri (2020) differed from Khobai & Le Roux (2018). In the study, both linear ARDL and nonlinear ARDL (NARDL) models were employed, and the results indicated the absence of cointegration between renewable energy and economic growth. The absence of this connection in the study was attributed to the ineffective utilization of clean energy in fostering sustainable economic development in South Africa.

4.4.2 Renewable energy – economic growth nexus

Bowden & Payne (2010) used yearly data for the United States of America between 1949 to 2006 to study the interconnection existing between real GDP and both NREC and REC for different sectors with capital and labour as control variables. All data were expressed in their natural log format. The data was then subjected to the Philips Perron and the Augmented Dickey Fuller tests for stationarity to obtain the maximum order of integration of the data series. Despite the disparities in the results from the tests for the variables in the study, they concluded that maximum order of integration is one. Using the Schwarz information criterion, an optimal lag length was determined for each factor, and this was used to specify a VAR model to test for causality in the long run using the Yamamoto test for causality. They found support for the neutrality hypothesis between the industrial and commercial sector's consumption of renewable energy and real GDP increment. Nonetheless, they found that residential use of renewable energy Granger-caused real GDP unidirectionally and positively.

In another study, Payne (2009) used data collected on the United States from 1949 to 2006 to analyse the nature of the linkage between aggregate non-renewable and REC and income growth with capital and labour employment also in included in the model. The Philips-Perron and ADF tests for stationarity were run on the data to derive the orders of integration of the variables to estimate a VAR model after the factors had been expressed in logarithmic format. The Toda and Yamamoto technique for GC was then applied to the data. this revealed the complete non-existence of a GC relationship between REC and real GDP, in favour of the neutrality hypothesis.

Table 4.1 Summary of literature for Conventional Energy – Economic Growth nexus

STUDY	PERIOD	COUNTRY	METHOD	RELATIONSHIP
Kraft & Kraft (1978)	1947-1974	USA	Sim's causality	GNP → EC
Cheng & Lai (1997)	1955-1993	Taiwan	Cointegration, Hsiao's GC	GDP → EC
Yoo & Kim (2006)	1971-2002	Indonesia	Cointegration, GC	GDP→ Electricity consumption
Zachariadis & Pashourtidou (2007)	1960-2004	Cyprus	Impulse response functions, GC	GDP → Electricity consumption Household Electricity consumption ↔ private income
Narayan & Smyth (2005)	1966-1999	Australia	Cointegration, GC	GDP & Employment → Electricity consumption
Mozumder & Marathe (2007)	1971 - 1999	Bangladesh	Cointegration, VECM GC	GDP → Electricity consumption
Yoo & Kim (2006)	1971 - 2002	Thailand, Singapore, Malaysia and Indonesia	Cointegration, GC	Indonesia and Thailand: GDP → Electricity consumption

Sekansti & Okot (2016)	1981-2013	Uganda	ARDL bounds test, GC	SR: Electricity consumption → GDP
Balcilar Et Al (2019)	1971-2014	Pakistan	Toda-Yamamoto causality	GDP → Electricity consumption
Bekun & Agboola (2019)	1971-2014	Nigeria	FMOLS, Cointegration., Maki causality	GDP → Electricity consumption
Samu Et Al (2019)	1971-2014	Zimbabwe	FMOLS, Cointegration, Maki causality	GDP → Electricity consumption
Mighri & Ragoubi (2020)	1971-2013	Tunisia	ARDL bounds test, GC	LR: GDP → Electricity consumption SR: GDP ← Electricity consumption
Stern (1993)	1947-1990	USA	GC	GDP ← Weighted mix of fuel
Stern (2000)	1947-1990	USA	Multivariate cointegration	GDP ← weighted mix of fuel
Masih & Masih (1996)	1955-1990	6 Asian countries	Cointegration, VECM	India: GNP ← EC Indonesia: GNP → EC Pakistan: GNP ↔ EC, GNP ← EC
Masih & Masih (1998)	1955-1991	Sri Lanka & Thailand	Cointegration, VECM	GNP ← EC
Soytas et al. (2001)	1960-1995	Turkey	Cointegration, VECM	GDP ← EC
Ghosh (2002)	1950-1997	India	GC	GDP ← Electricity consumption
Shiu & Lam (2004)	1971-2000	China	Cointegration, GC	GDP ← Electricity consumption
Kumar Narayan & Singh (2007)	1971-2002	Fiji	OLS, FMOLS, ARDL, GC	GDP ← Electricity consumption
Ho & Siu (2007)	1966-2002	Hong Kong	Cointegration	GDP ← Electricity consumption
Yuan Et Al (2007)	1978-2004	China	Cointegration, GC	GDP ← Electricity consumption
Lee (2005)	1975-2001	18 developing countries	Cointegration, GC	GDP ← Electricity consumption
Narayan & Smyth (2008)	1972-2002	G7 countries	Cointegration, GC	GDP ← EC

Odhiambo (2009)	1971-2006	Tanzania	ARDL bounds test, GC	GDP ← Electricity consumption
Wang Et Al (2011)	1972-2006	China	Cointegration, GC	SR: Weak GDP ↔ EC LR: GDP ← EC
Warr & Ayres (2010)	1946-2000	USA	Cointegration, GC	SR: GDP ← Exergy LR: GDP ← useful work
Soytas & Sari (2007)	1968-2007	Turkey	Cointegration, GC	LR: Manufacturing output ← Electricity consumption
Awodumi & Adewuyi (2020)	1980-2015	Top five oil producing African countries	NARDL	Nigeria: GDP←NRE Angola: GDP ← NRE
Yoo & Kwak (2010)	1975-2007	Venezuela, Peru, Ecuador, Colombia, Brazil, Argentina	Cointegration, GC	Ecuador, Chile, Brazil, Argentina: GDP ← Electricity consumption Peru: GDP ≠ Electricity consumption
Chouaiabi & Abdessalem (2011)	1971-2007	Tunisia	Cointegration, GC	GDP ← Electricity consumption
Pata & Yurtkuran (2017)	1964-2014	Five European countries	ARDL bounds testing, GC	GDP ← Electricity consumption
Hossen & Hasan (2018)	1972-2011	Bangladesh	Eigenvalue, GC	GDP ← Electricity consumption
Bekun & Agboola (2019)	1990-2016	India	GC	GDP ← Electricity consumption
Samu Et Al (2019)	1971-2014	Zimbabwe	Cointegration, Toda-Yamamoto	GDP ← Electricity consumption
Zhong Et Al (2019)	1971-2009	China	ARDL	GDP ← Electricity consumption
Ha & Ngoc (2021)	1971-2017	Vietnam	NARDL bounds testing, GC	GDP ← Electricity consumption
Nondo & Kahsai (2009)	1980-2005	COMESA	Cointegration, GC	GDP ← EC

Adams Et Al (2018)	1980-2012	30 sub-Saharan countries	Cointegration, FMOLS, DOLS	GDP←REC GDP→ NREC
Ebohon (1996)	1960-1981	Nigeria and Tanzania	GC	GDP ↔ EC
Masih & Masih (1997)	1961-1990	Taiwan and South Korea	Cointegration and VECM GC	GDP ↔ Price ↔EC
Glasure & Lee (1998)	1961-1990	Singapore and S. Korea	Cointegration, VECM GC	GDP ↔ EC
Nachane Et Al (1988)	1950-1985	25 countries	Cointegration, sims and GC	GDP ↔ EC
Yang (2000)	1954-1997	Taiwan	Hsiao's GC	GDP ↔ EC
Jumbe (2004)	1970-1999	Malawi	Cointegration, GC	GDP↔ Electricity consumption
Ozturk (2010)	1971-2005	57 countries	Cointegration, GC	GDP ↔ EC in LMI and UMI, GDP→ Energy in LI countries
Mahadevan & Asafu Adjaye (2007)	1971-2002	20 net energy importing and exporting countries	Cointegration, VECM GC	LR: GDP ↔ EC SR: GDP → EC
Sebri & Ben-Salha (2014)	1971-2010	BRICS	ARDL bounds test, VECM GC	GDP ↔ EC
Ghali & El Sakka (2004)	1961-1997	Canada	Cointegration, GC	GDP ↔ EC
Foon Tang (2009)	1970-2005	Malaysia	ARDL bounds testing, VECM GC	GDP ↔ Electricity consumption
Nanthakumar & Subramaniam (2010)	1971-2008	Malaysia	DOLS, OLS-EG, ARDL bounds testing	GDP ↔ Electricity consumption
Azam Et Al (2021)	1990-2015	10 newly industrialised countries	FMOLS, GC	GDP ↔ Electricity consumption
Nazlioglu (2014)	1967-2007	Turkey	Cointegration, GC	GDP ↔ Electricity consumption
Hwang & Yoo (2016)	1971-2010	Nicaragua	Cointegration, GC	GDP ↔ Electricity consumption
Khobai & Le Roux	2017	South Africa	Cointegration, VECM GC	LR: GDP ↔ EC SR: GDP ≠ EC

Bildirici (2016)	1970-2010	Ecuador, El Salvador, Dominican rep, Guatemala	Markov Switching VAR model	GDP ↔ Electricity consumption
Sultan & Alkhateeb (2019)	1971-2014	India	Cointegration, GC	LR: GDP ↔EC SR: GDP ← EC
Akarca & Long (1980)	1947-1972	USA	Box Jenkins and GC	GNP ≠ EC
Yu & Hwang (1984)	1947-1979	USA	Simms Causality	GNP ≠ EC
Erol & Yu (1987)	1950-1982	6 industrialised countries	GC and Sims causality	Canada, France, UK: GNP ≠ EC Japan & Italy: GNP ← EC West Germany: GNP → EC
Hwang & Gum (1991)	1961-1990	Taiwan	Hsiao's FPE	GDP ↔ EC
Hwang & Gum (1991)	Jan 1974 to April 1990	USA	Cointegration	GDP ≠ EC
Cheng (1995)	1947-1997	USA	Hsiao GC	GDP ≠ EC
Altinay & Karagol (2004)	1950-2000	Turkey	Hsiao GC	GDP ≠ EC
Ciarreta & Zarraga (2010)	1971-2005	Spain	Hiemstra-jones GC	GDP ≠ EC
Gross (2012)	1970-2007	USA	ARDL bounds test, GC	LR: GDP ≠ EC SR: GDP ↔EC
Tamba Et Al (2017)	1971-2013	Cameroon	Cointegration, GC	GDP ≠ EC
Nyoni & Phiri (2020)	1991-2006	South Africa	ARDL, NARDL	GDP ≠ EC

Table 4.2 Summary of Renewable Energy-Growth Nexus Literature

STUDY	PERIOD	COUNTRY	METHOD	RELATIONSHIP
Bowden& Payne (2010)	1949 - 2006	USA	Yamamoto GC	Income in residential sector ← REC Commercial & Manufacturing sector ≠ REC

Payne (2011)	1949 - 2007	USA	Yamamoto GC	GDP ← REC (Biomass)
Ewing et al (2007)	January 2001 to June 2005	USA	Generalised forecast error variance decomposition	GDP ← REC (Wind & Biomass)
Sari et al (2008)	January 2001 to June 2005	USA	ARDL bounds test	Labour and Industrial output → REC (Solar and Hydro)
Payne (2009)	1949 - 2006	USA	Yamamoto GC	GDP ≠ REC
Yildirim et al (2012)	1949 - 2010	USA	Bootstrap corrected Yamamoto causality test	GDP ← REC (Biomass)
Sadorsky (2009)	1994 - 2003	18 emerging economies	Panel cointegration	GDP→REC
Apergis and Payne (2010)	1985 - 2005	20 OECD countries	GC, panel cointegration, FMOLS	GDP ↔ REC
Apergis and Payne (2010)	1992-2007	13 Eurasian countries	GC, panel cointegration, FMOLS	GDP ↔ REC
Apergis and Payne (2011)	1980-2006	6 Central American Countries	GC, panel cointegration, FMOLS	GDP ↔ REC
Apergis and Payne (2012)	1990-2007	80 countries	GC, panel cointegration, FMOLS	GDP ↔ REC
Menegaki (2011)	1997-2007	27 European countries	Random effects model, GC	GDP ≠ REC
Ocal and Aslan (2013)	1990 - 2010	Turkey	ARDL, GC	GDP→REC
Leitao (2014)	1970-2010	Portugal	OLS, GMM, cointegration, GC	GDP→REC
Tugcu (2013)	1970-2011	Turkey	DL GC, ARDL bounds test	TFP↔REC
Twerefou et al (2018)	1980 - 2015	West Africa	FMOLS	GDP ← RELC GDP → Electricity Consumption
Maji et al (2019)	1995-2014	West Africa	DOLS, OLS FMOLS	GDP←REC
Banday & Aneja (2020)	1990 – 2017	BRICS	Bootstrap Dumitrescu	GDP↔REC for Brazil and China

			and Hurlin causality tests	GDP←REC for Russia GDP ≠ REC for India GDP ← NREC for Brazil, China, Russia, and India GDP ≠ NREC for South Africa
Shahbaz et al (2020)	1990-2018	38 countries	FMOLS, DOLS, heterogenous non-causality test	GDP←REC in 30 countries GDP ← NREC in 21 countries
Chen et al (2020)	1995-2015	103 countries	Threshold model	GDP ≠ REC in OECD countries, GDP←REC in developing and non-OECD countries after certain thresholds of REC
Abbasi et al (2020)	1970-2018	Pakistan	NARDL	GDP←REC
Kouton (2021)	1981-2015	44 sub-Saharan African countries	GMM	Inclusive economic growth ← REC

CHAPTER 5

5. DATA AND METHODOLOGY

5.1 Data

To achieve the goal of this study it is imperative to use panel data. A common problem encountered while working on renewable energy sources is the relatively short span of available data. This limits the ability to use time series methods as they require lengthy time series data which is usually not available. Thus, it is best to employ panel data techniques to achieve stronger results. The cross sectional component of panel data helps compensate for the relatively limited duration of time series data in the analysis (Belke, Dreger, & Dobnik, 2010).

The data employed in this study are renewable electricity consumption measured in terawatt hours (TWh) and real GDP (constant 2005 US$). Data for real GDP is taken from the World Bank's World Development Indicators database. Data for RELC is obtained from the database of Our World in Data. The data for these variables are compiled for 48 countries from 2000 to 2022. The sample has been chosen with priority given to data availability for the variables of interest over the period observed. The list of countries used for the study provided in table 5.1

Table 5.1 List of countries

HIGH-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	LOWER MIDDLE & LOW-INCOME COUNTRIES
Australia	Argentina	India
Austria	Bulgaria	Indonesia
Belgium	Costa Rica	Nicaragua
Denmark	Dominican Republic	Tajikistan
Finland	Kazakhstan	Ukraine
Germany	Malaysia	Vietnam
Iceland	Mauritius	Ethiopia
Ireland	Mexico	Madagascar
Luxembourg	Russia	Mali
Netherlands	Serbia	Mozambique
Norway	Thailand	Tanzania
Sweden	Turkey	Togo
Switzerland	China	Burkina Faso
United States	Armenia	Burundi
Japan	Brazil	Central African Republic
United Kingdom	Colombia	Democratic Republic of Congo

The World Bank categorises all its member countries into high income, upper middle income, lower middle income, and low-income countries based on their GDP per capita. High income countries include countries whose GDP per capita is greater than $13,204. Countries whose GDP per capita lies between $4,265 to $13,205 are classified as upper middle income. For countries with GDP per capita ranging from $1,086 to $4,255 are labelled as lower middle-income countries whiles those with GDP per capita falling below $1,085 are classified low-income countries. After the classifications are done, we end up with 16 high income countries, 16 upper middle-income countries, and 16 low-income and lower middle-income countries. Due to limited availability of data, low-income and lower-middle income have been lumped together to facilitate the analysis.

Table 5.2 Summary statistics of variables

Variables	GDP	REC
All Countries		
Number of Observations	1056	1056
Mean	1.03E+12	70.90528
Std. Dev.	2.79E+12	196.1608
Min	1.62E9	0.04
Max	2.05E+13	2452.53
Skewness	4.766234	6.77856
Kurtosis	26.98625	62.21966
High income countries		
Number of Observations	352	352
Mean	2.01E+12	77.09525
Std. Dev.	4.07E+12	129.1474
Min	1.19E+10	0.14
Max	2.05E+13	861.58
Skewness	3.196773	3.46049
Kurtosis	12.47327	16.72397
Upper middle-income countries		
Number of Observations	352	352
Mean	9.14E+11	115.9015
Std. Dev.	2.23E+12	303.53
Min	3.96E+09	0.28
Max	1.59E+13	2452.53
Skewness	4.511068	4.780153

Kurtosis	24.53336	29.13583
Low and Lower middle-income countries		
Number of Observations	352	352
Mean	1.79E+11	19.71906
Std. Dev.	4.55E+11	46.37446
Min	1.62E+09	0.04
Max	2.76E+12	332.2
Skewness	3.613558	4.1529
Kurtosis	16.73298	22.20545

Table 5.2 provides a comprehensive description of the study's variables as it applies to the whole sample and the subsamples as well. Considering the whole sample there are 1,506 observations in total for both real GDP and RELC and the 352 observations for each subgroup sample.

The mean GDP is about $1.3 trillion with a standard deviation of $2.78 trillion. The minimum real GDP for all countries is $1.62 billion dollars and the maximum is $20.5 trillion. GDP is rightly skewed, indicating that there are more observations of GDP above the mean GDP. The Kurtosis value of 26.99 suggests the distribution has a relatively high kurtosis which indicates that the distribution of GDP has more extreme values than a normal distribution would. The mean of RELC is 70.91 TWh but has a maximum value of 2,452.53TWh. The standard deviation in RELC for all countries in the study is 196.16TWh and the minimum observed value in the data is 0.04TWh. RELC is also skewed to the right with a measured skewness of 6.78 The recorded kurtosis is also relatively high at 62.22 indicating that there are large disparities in the consumption of renewable electricity among countries.

For the high-income subgroup, the mean GDP observed is $2.01 trillion. Its value ranges from a minimum of $11.9 billion to a maximum value of $20.6 trillion. The observed mean value is $914 billion with a standard deviation of $4.07 trillion. The data distribution has a positive skewness of 3.20 and a kurtosis of 12.47. RELC has mean of 77.095TWh and a standard deviation of 129.15TWh among high-income countries in the study. The consumption of electricity from renewable sources ranges from 0.14TWh to 861TWh among the high-income countries. The distribution of the RELC is rightly skewed at a value of 3.46 and leptokurtic at a kurtosis value of 16.72.

Upper middle-income countries have a measured mean of $914 billion with a standard deviation of $2.23 trillion. The observed minimum value stands at $3.96 billion dollars with a maximum value reaching $15.9 trillion. The distribution of GDP in the upper middle-income sample is highly positively skewed at 4.51 and a relatively high kurtosis of 24.53. RELC ranges from 0.28TWh to a maximum of 2,452.53TWh. The data for RELC among upper middle-income countries is also skewed to the right at a measured skewness value of 4.78 and a kurtosis of 29.135.

In the lower middle income and low-income countries subgroup, the mean of GDP stands at $179 billion and a standard deviation of $455 billion. GDP values recorded ranges from $1.62 billion to $2.76 trillion. The measured skewness value is 3.61 indicating a positive skew while the kurtosis value is measured at 16.73. RELC produced a mean value of 19.72TWh and a standard deviation of 46.37TWh. The consumption of renewable electricity ranges from a minimum of 0.04TWh to a maximum of 332.2TWh. Also, the distribution of RELC in this subgroup is skewed to the right with a measured skewness of 4.15TWh and leptokurtic with a kurtosis value of 22.205.

Table 5.3 Pearson Correlation Statistics

PEARSON CORRELATION STATISTICS		
ALL COUNTRIES		
	GDP	RELC
GDP	1.0000	
RELC	0.7311*** 0.0000	1.0000
HIGH INCOME		
	GDP	RELC
GDP	1.0000	
RELC	0.9202*** 0.0000	1.0000
UPPER MIDDLE INCOME		

	GDP	RELC
GDP	1.0000	
RELC	0.096* 0.0722	1.0000
LOWER MIDDLE AND LOW INCOME		
	GDP	RELC
GDP	1.0000	
RELC	0.9468*** 0.0000	1.0000

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

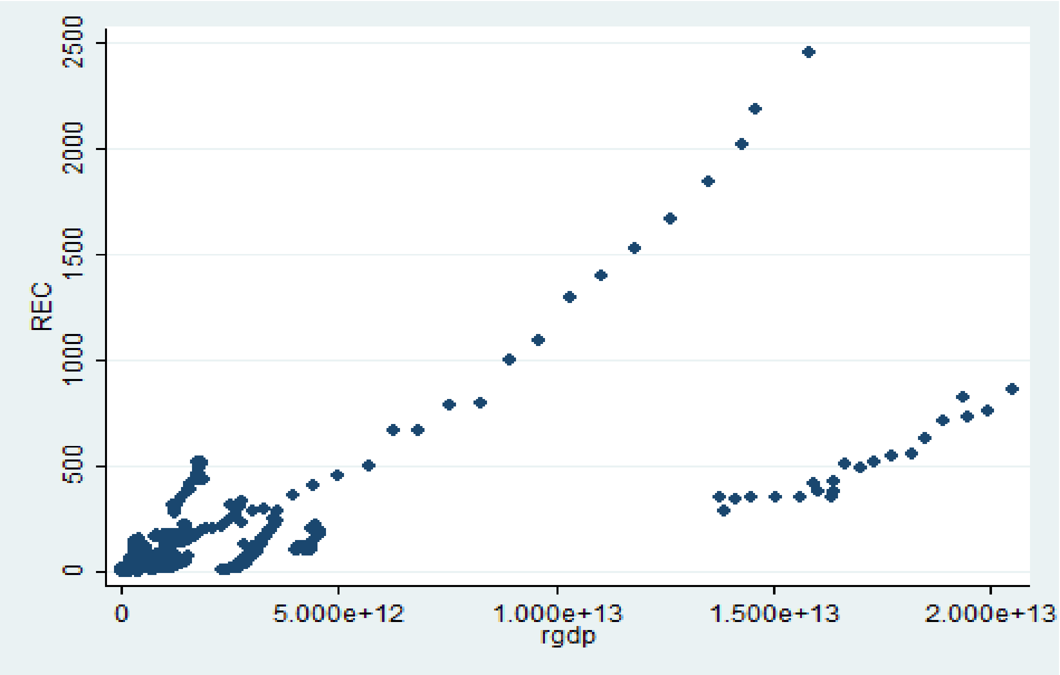

Figure 5.1 Scatter plot for all countries. Source: Author's illustration

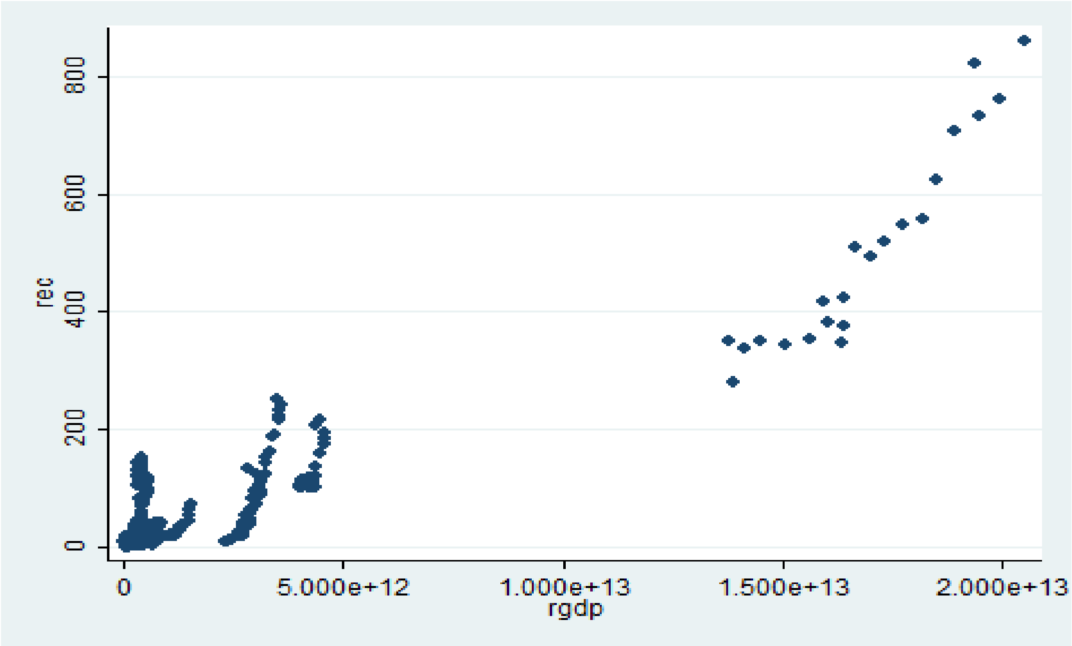

Figure 5.2 Scatter plot for high income countries. Source: Author's illustration

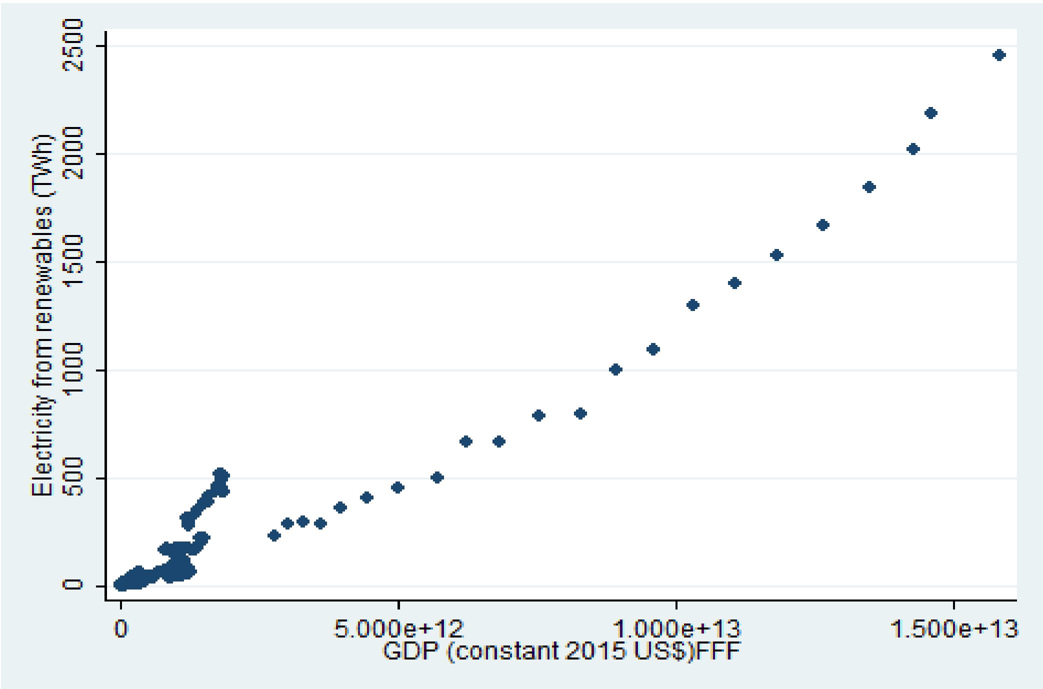

Figure 5.3 Scatter plot for upper middle-income countries. Source: Author's illustration

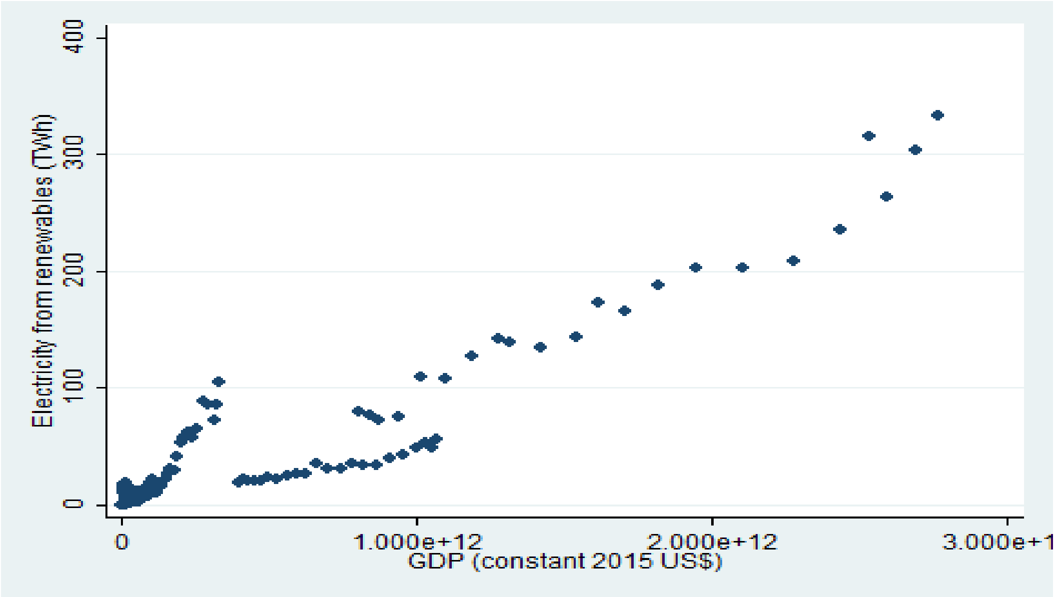

Figure 5.4 Scatter plot for lower middle-income and low-income countries. Source: Author's illustration

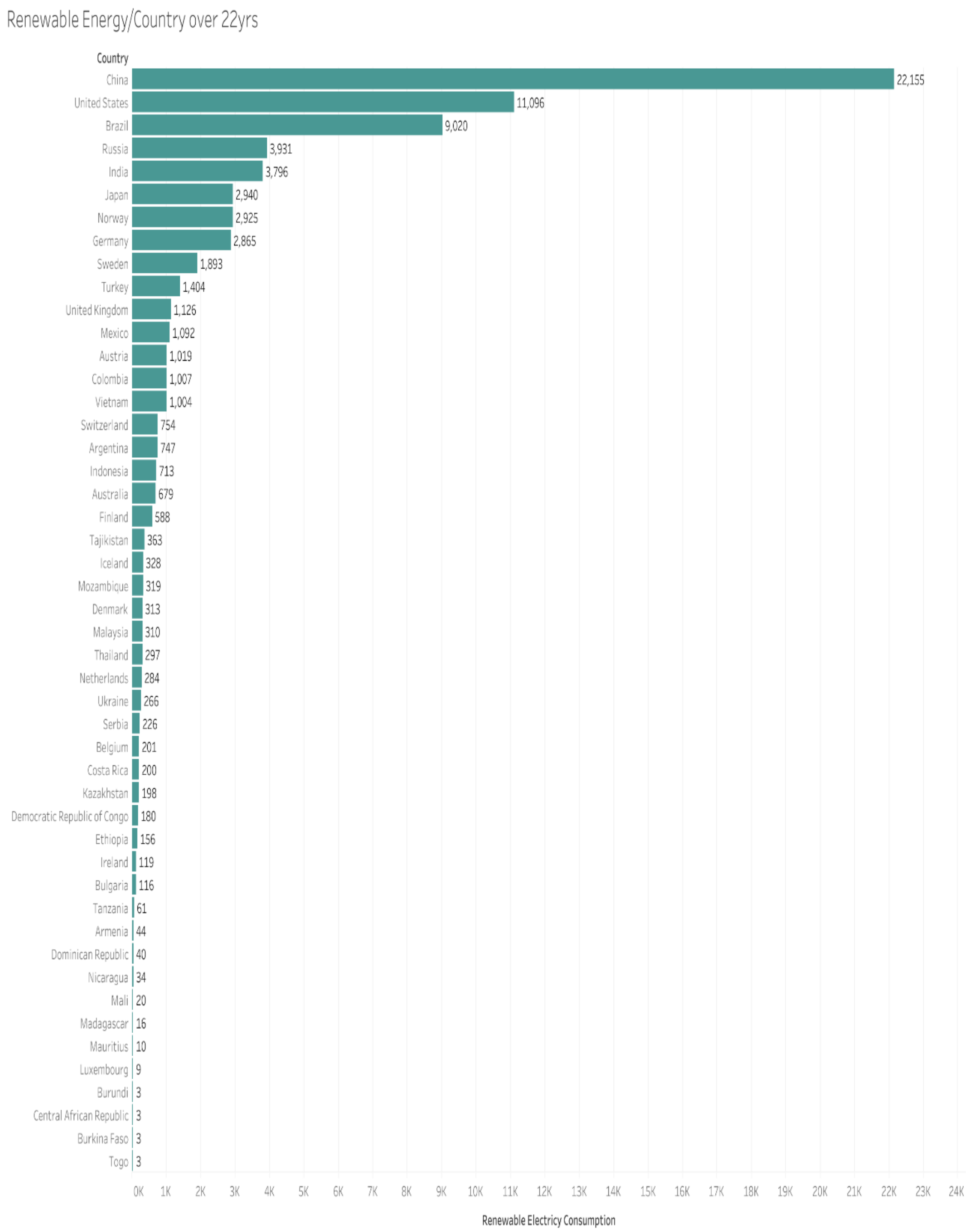

Figure 5.5 Total renewable electricity consumption by country. Source: Author's illustration

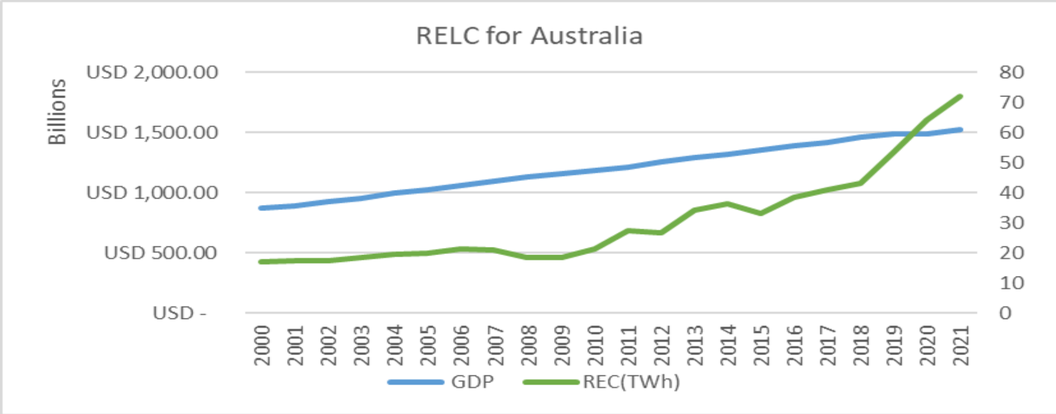

Figure 5.6 RECL and GDP for Australia. Source: Author's illustration

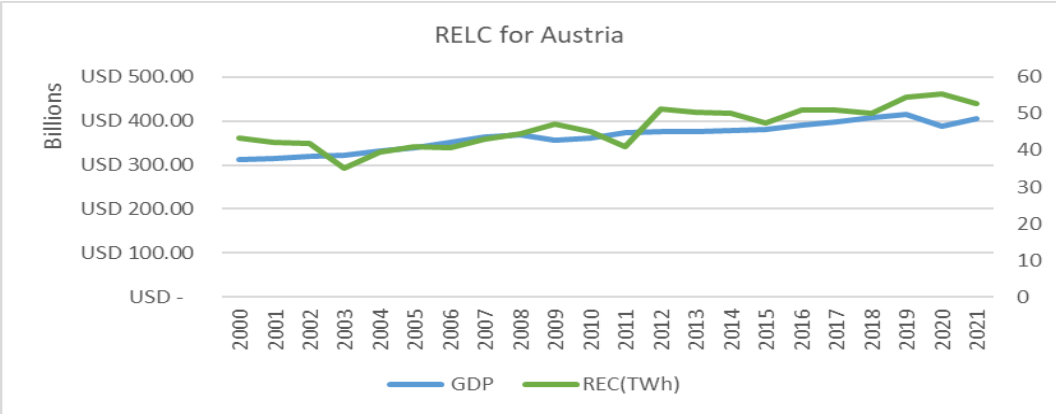

Figure 5.7 RECL and GDP for Austria. Source: Author's illustration

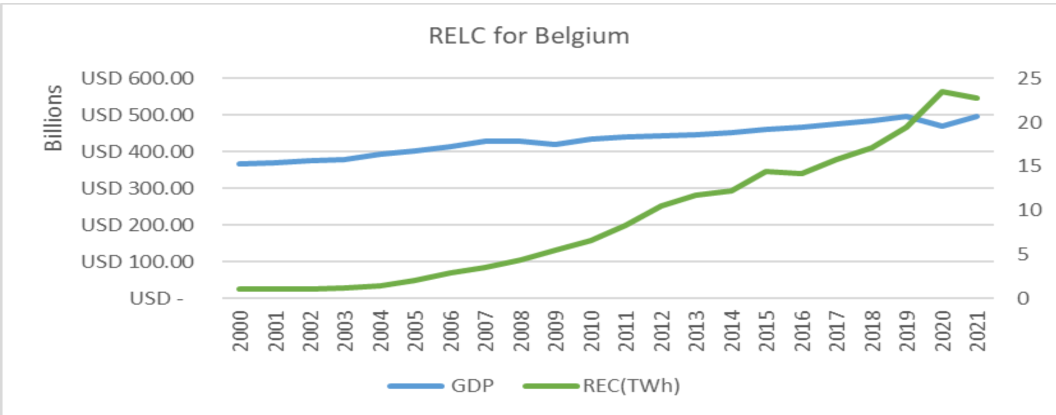

Figure 5.8 RECL and GDP for Belgium. Source: Author's illustration

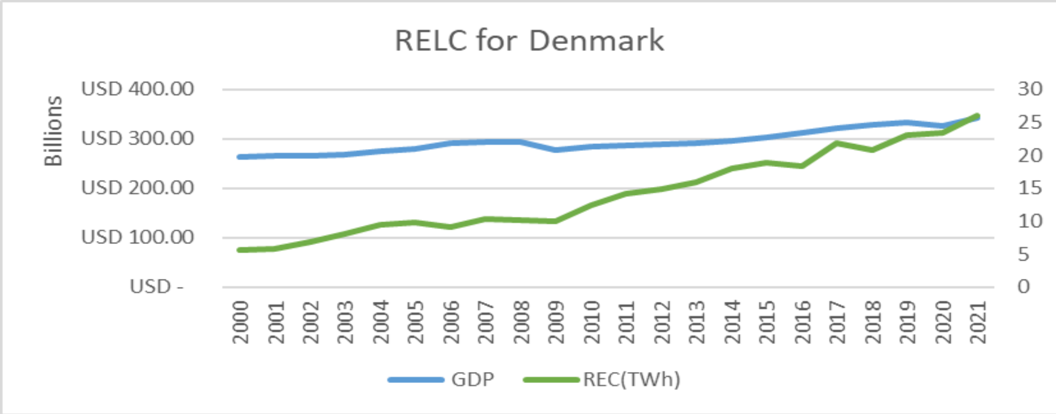

Figure 5.9 RECL and GDP for Denmark. Source: Author's illustration

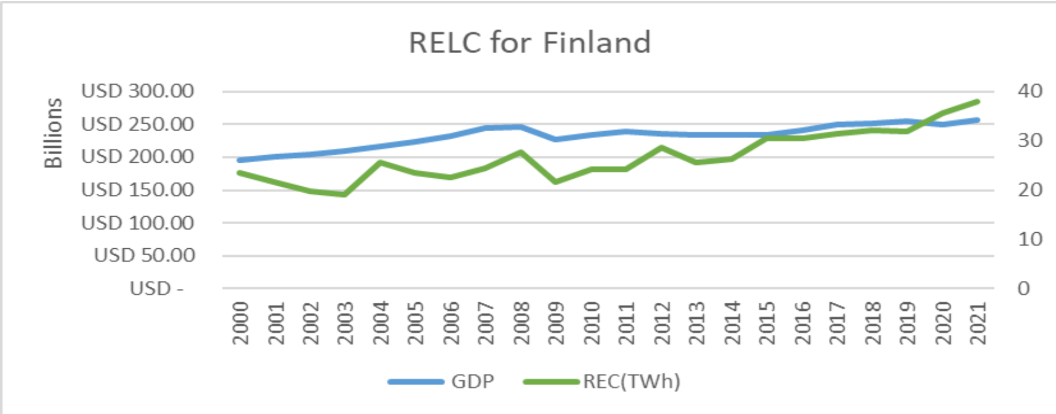

Figure 5.10 RECL and GDP for Finland. Source: Author's illustration

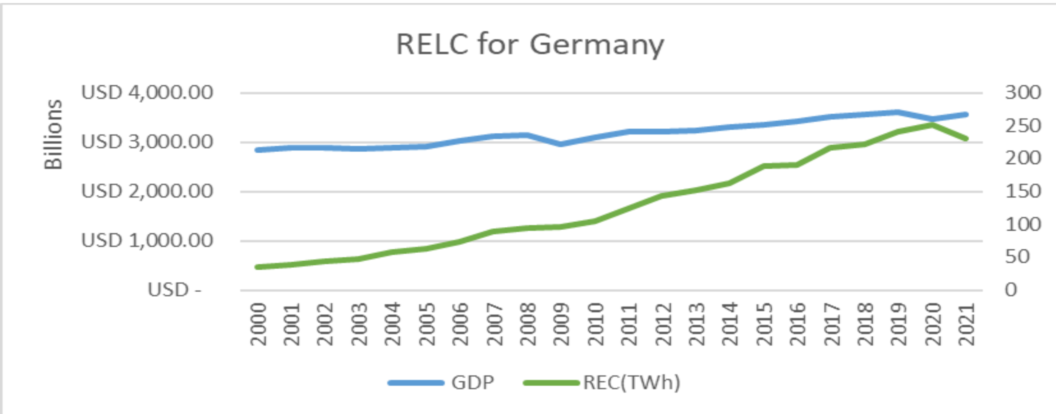

Figure 5.11 RECL and GDP for Germany. Source: Author's illustration

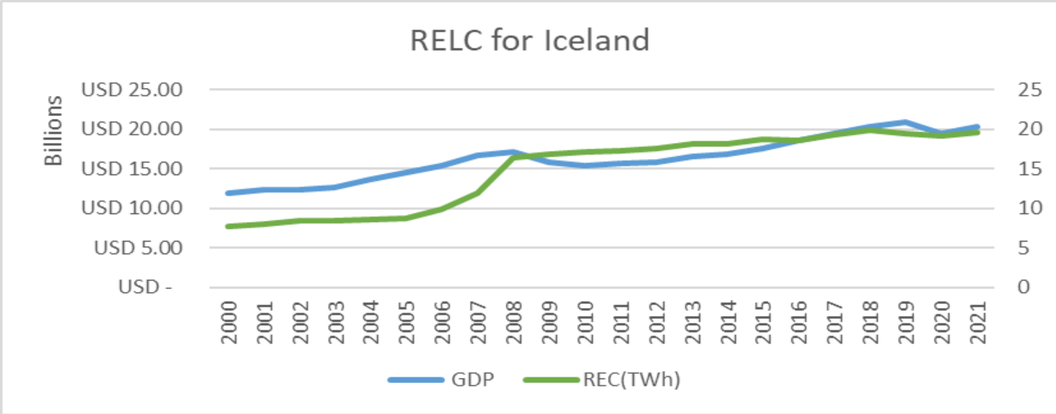

Figure 5.12 RECL and GDP for Iceland. Source: Author's illustration

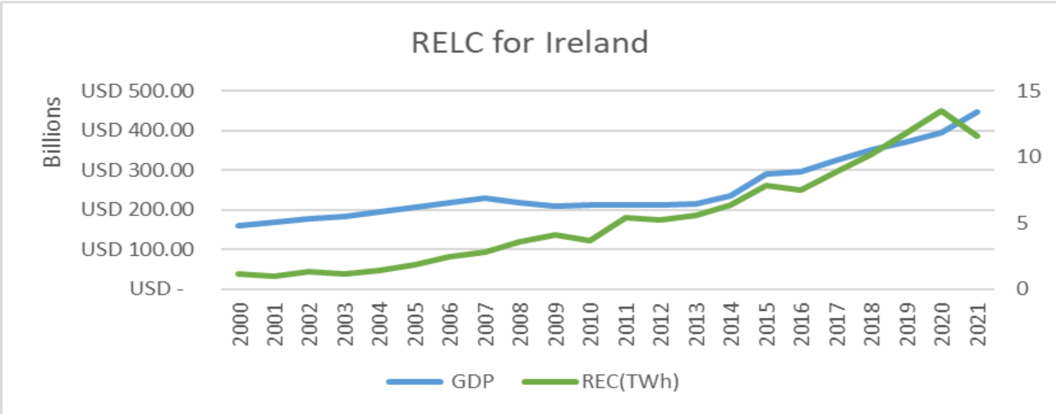

Figure 5.13 RECL and GDP for Iceland. Source: Author's illustration

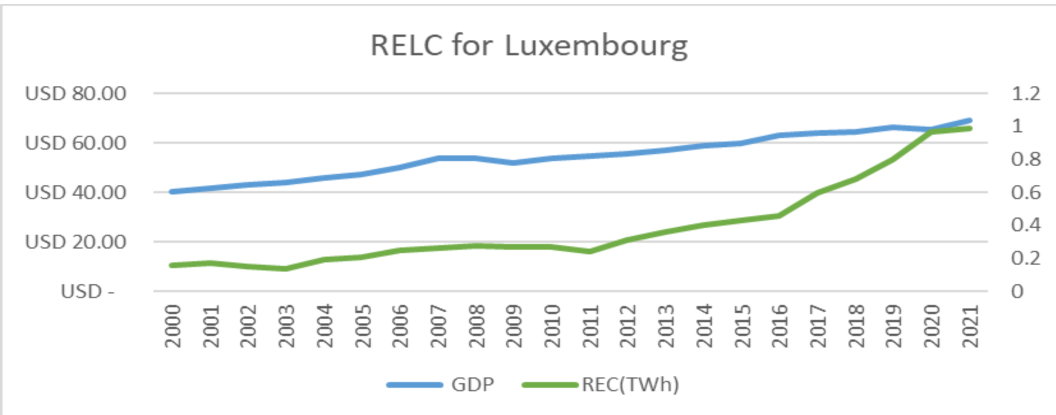

Figure 5.14 RECL and GDP for Luxembourg. Source: Author's illustration

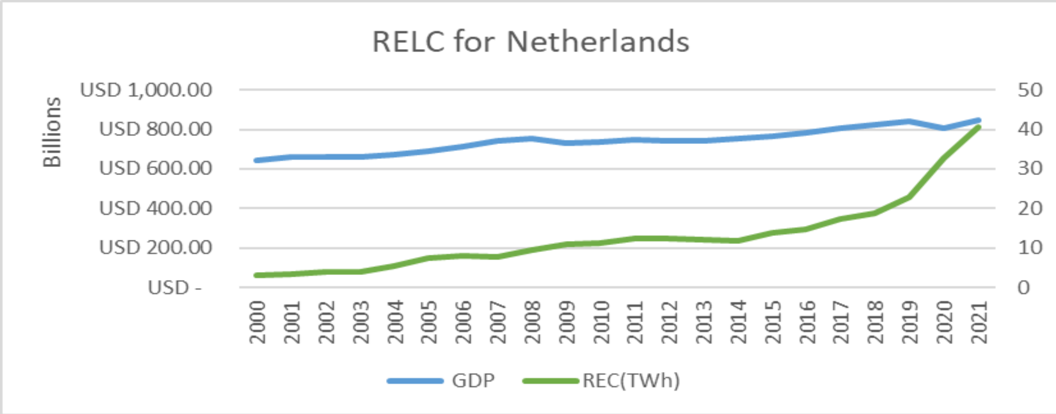

Figure 5.15 RECL and GDP for Netherlands. Source: Author's illustration

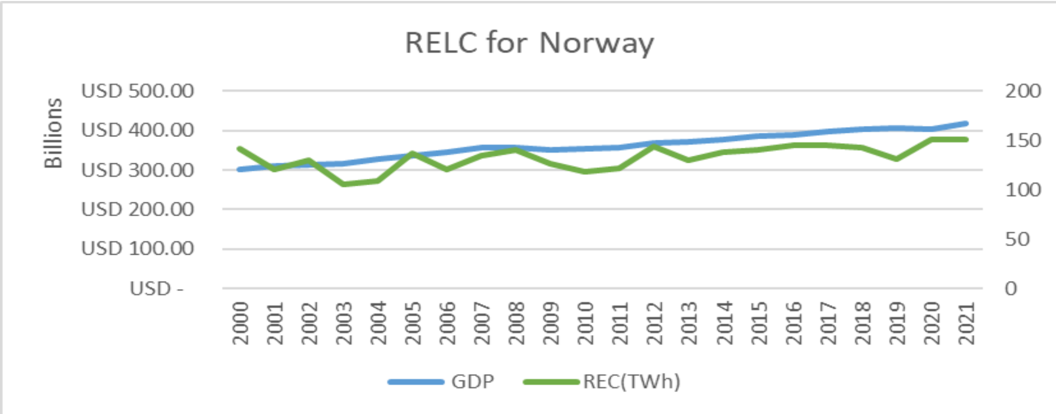

Figure: 5.16 RECL and GDP for Norway. Source: Author's illustration

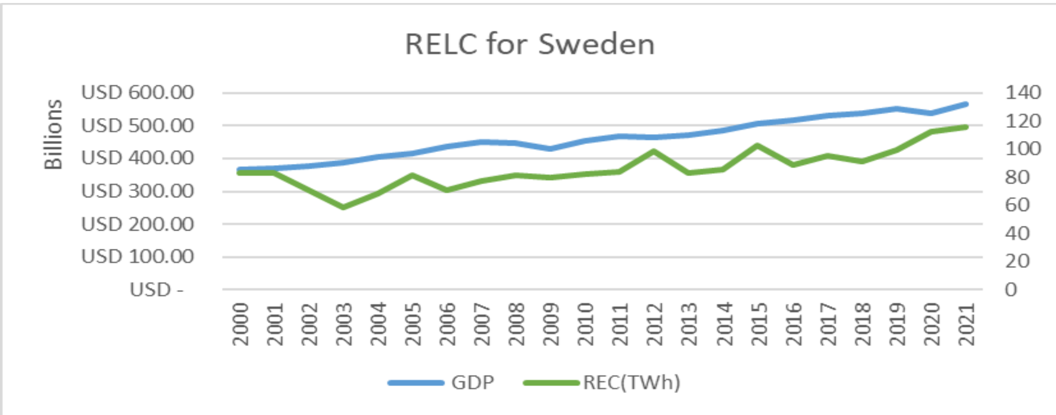

Figure 5.17 RECL and GDP for Sweden. Source: Author's illustration

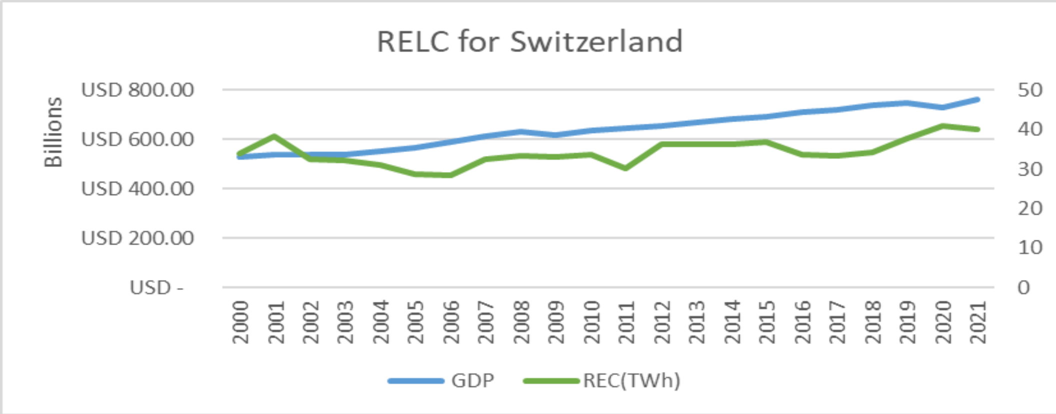

Figure 5.18 RECL and GDP for Switzerland. Source: Author's illustration

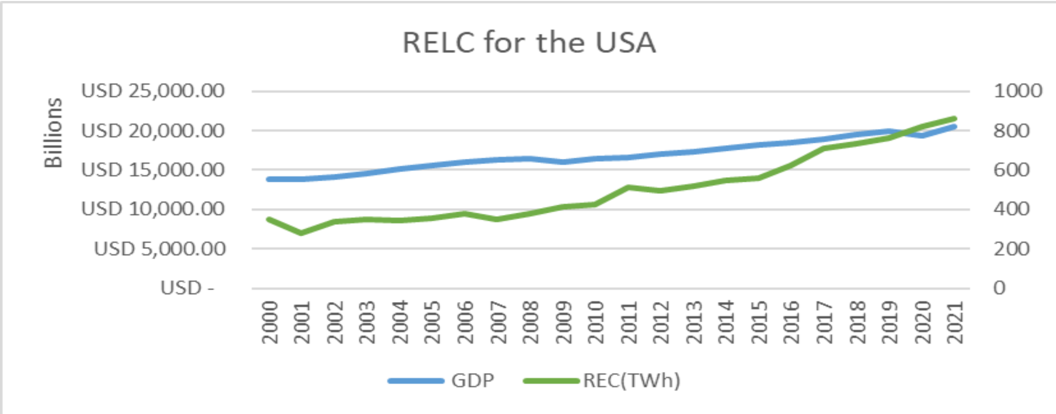

Figure 5.19 RECL and GDP for the USA. Source: Author's illustration

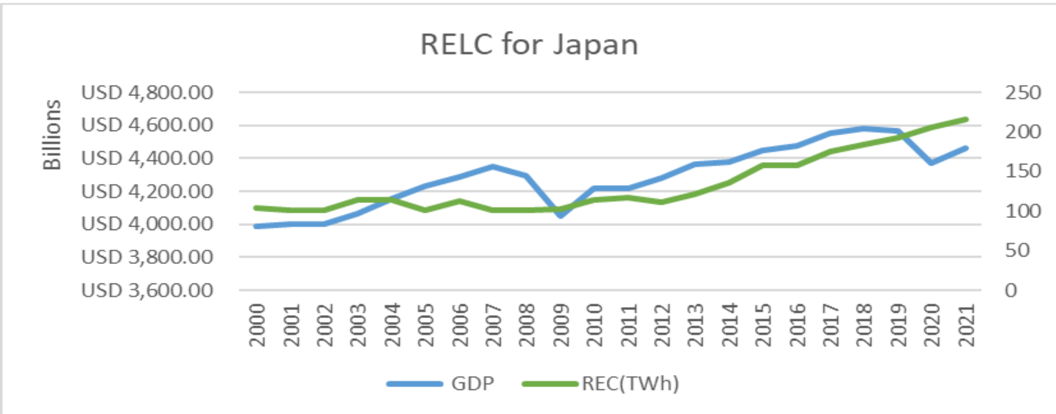

Figure 5.20 RECL and GDP for Japan. Source: Author's illustration

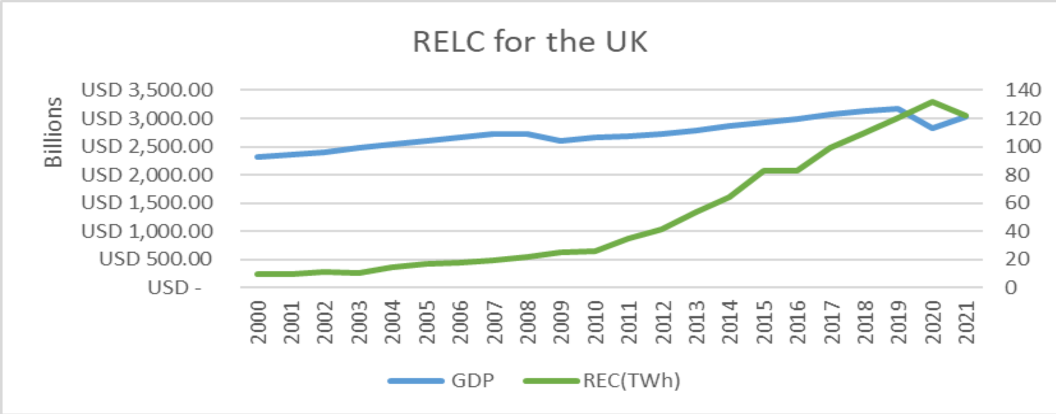

Figure 5.21 RECL and GDP for the UK. Source: Author's illustration

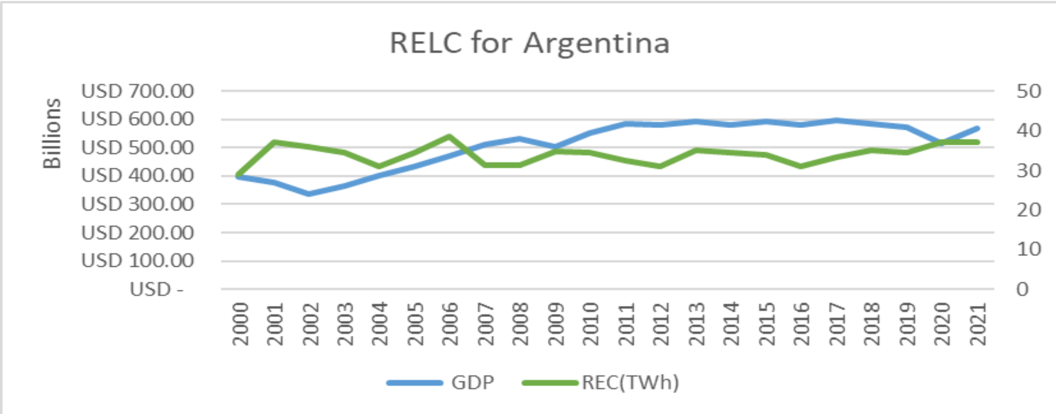

Figure 5.22 RECL and GDP for Argentina. Source: Author's illustration

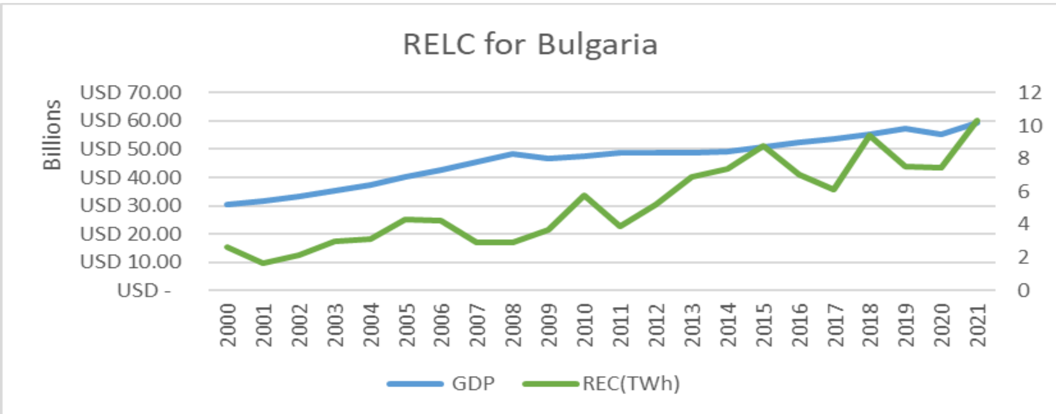

Figure 5.23 RECL and GDP for Bulgaria. Source: Author's illustration

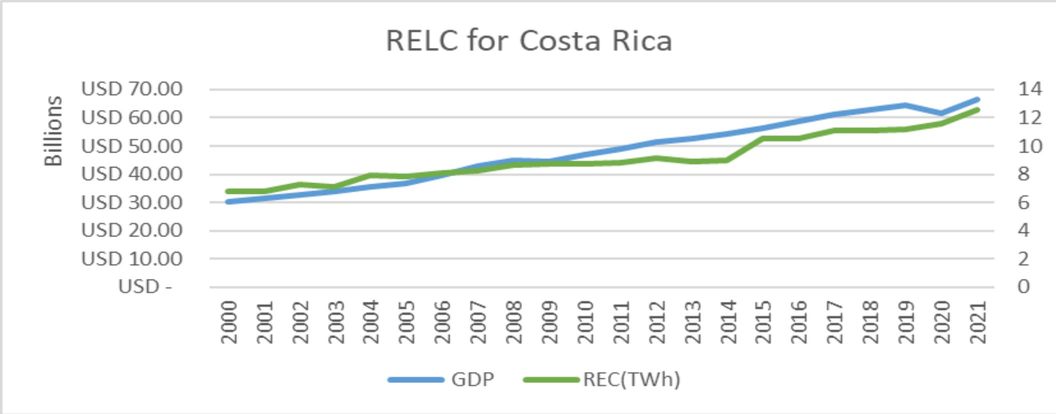

Figure 5.24 RECL and GDP for Costa Rica. Source: Author’s illustration

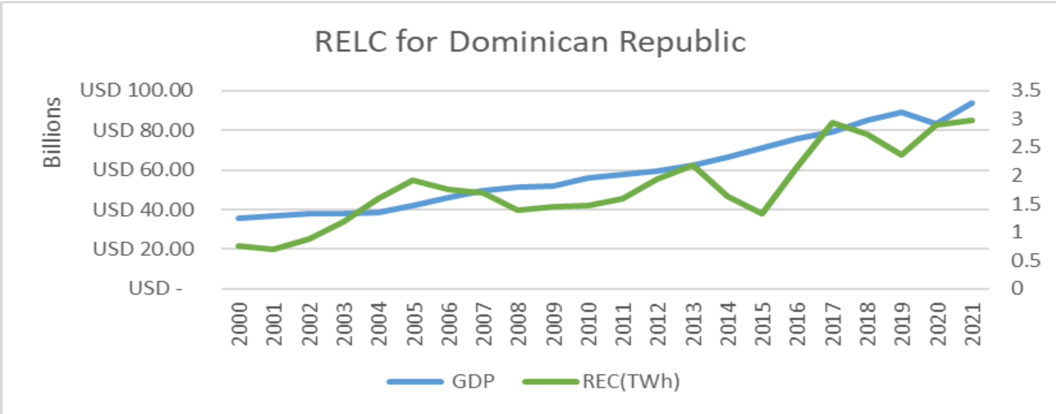

Figure 5.25 RECL and GDP for Dominican Republic. Source: Author’s illustration

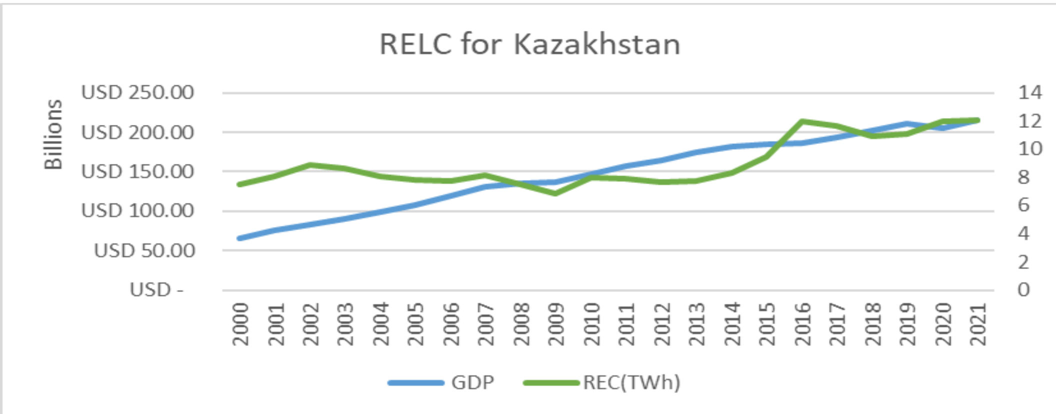

Figure 5.26 RECL and GDP for Kazakhstan. Source: Author’s illustration

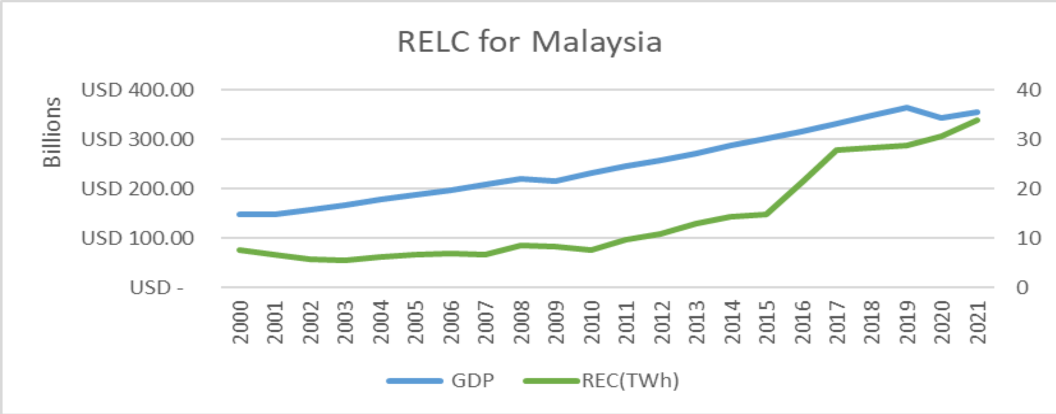

Figure 5.27 RECL and GDP for Malaysia. Source: Author's illustration

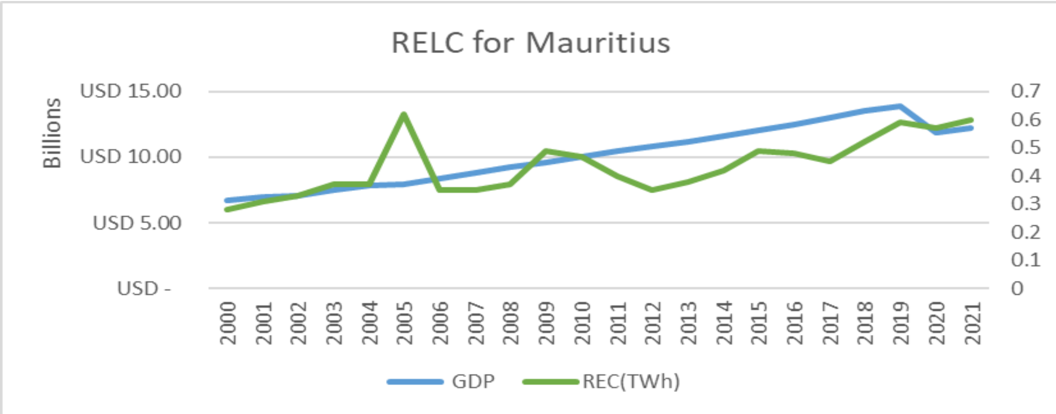

Figure 5.28 RECL and GDP for Mauritius. Source: Author's illustration

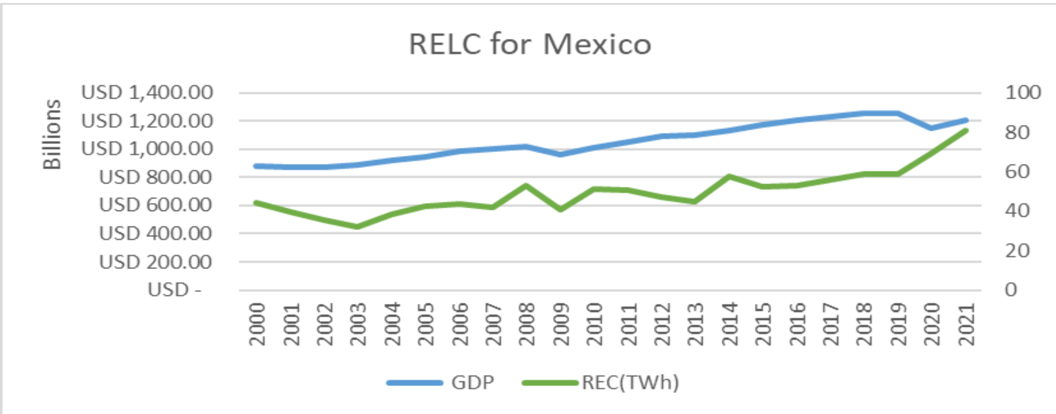

Figure 5.29 RECL and GDP for Mexico. Source: Author's illustration

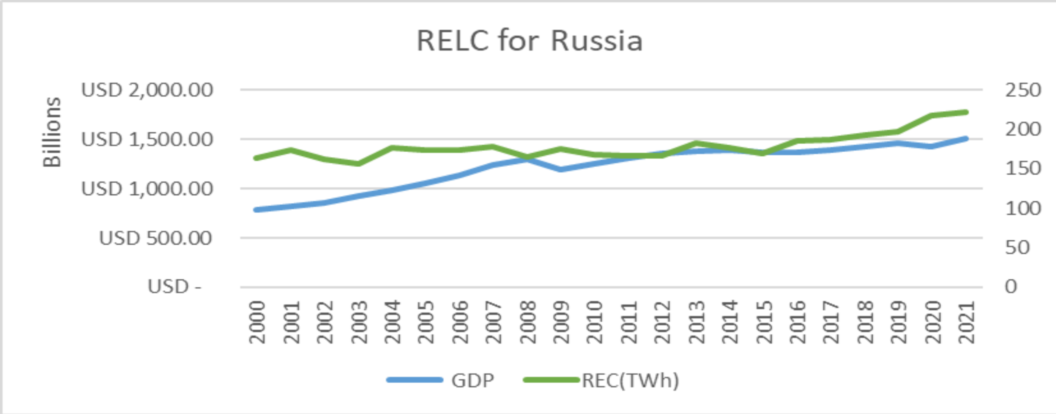

Figure 5.30 RECL and GDP for Russia. Source: Author's illustration

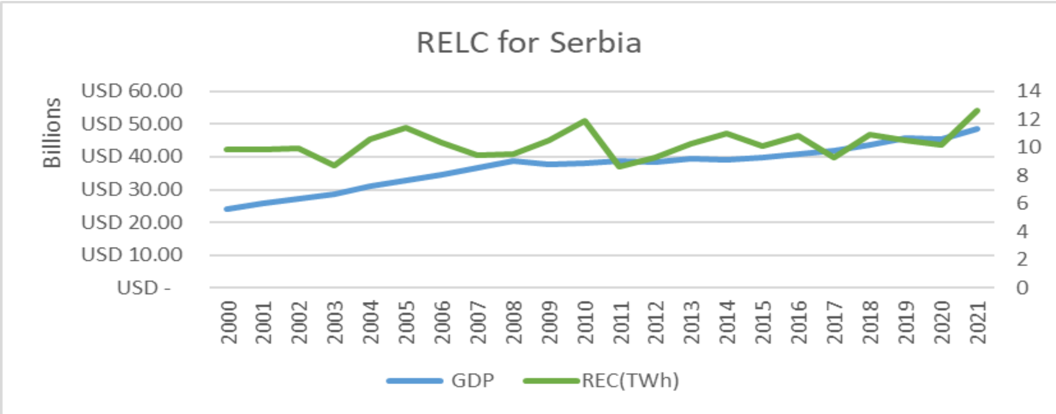

Figure 5.31 RECL and GDP for Serbia. Source: Author's illustration

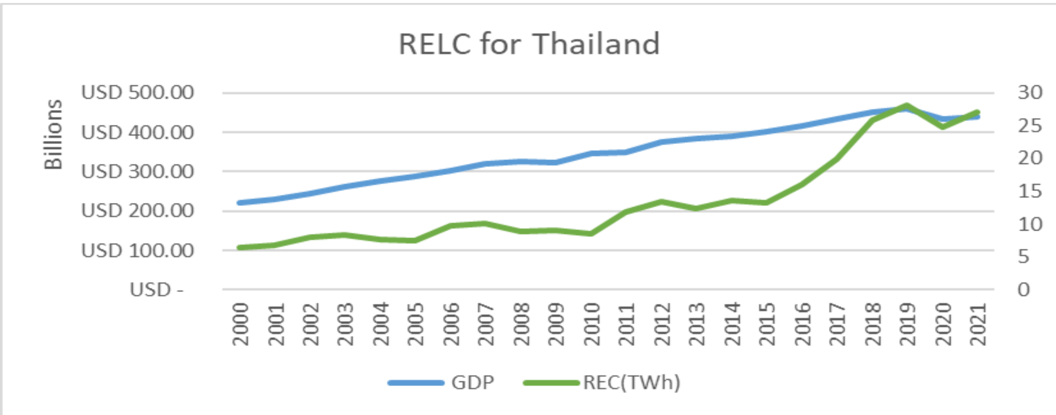

Figure 5.32 RECL and GDP for Thailand. Source: Author's illustration

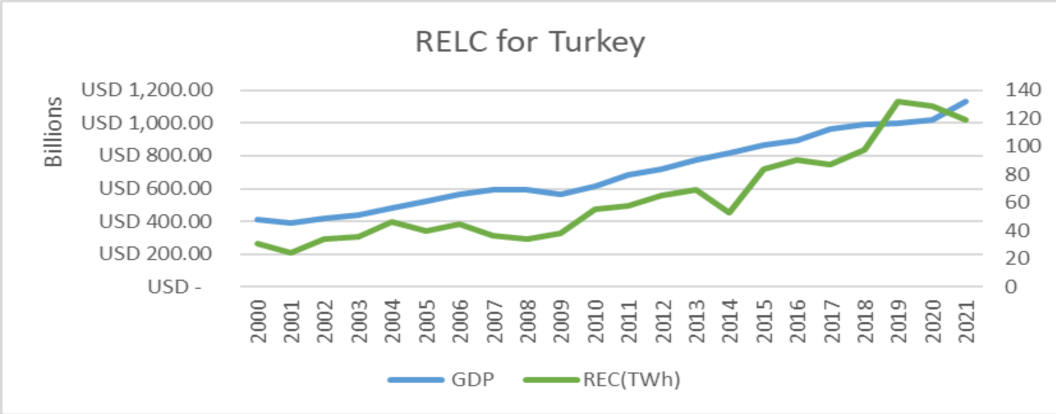

Figure 5.33 RECL and GDP for Turkey. Source: Author's illustration

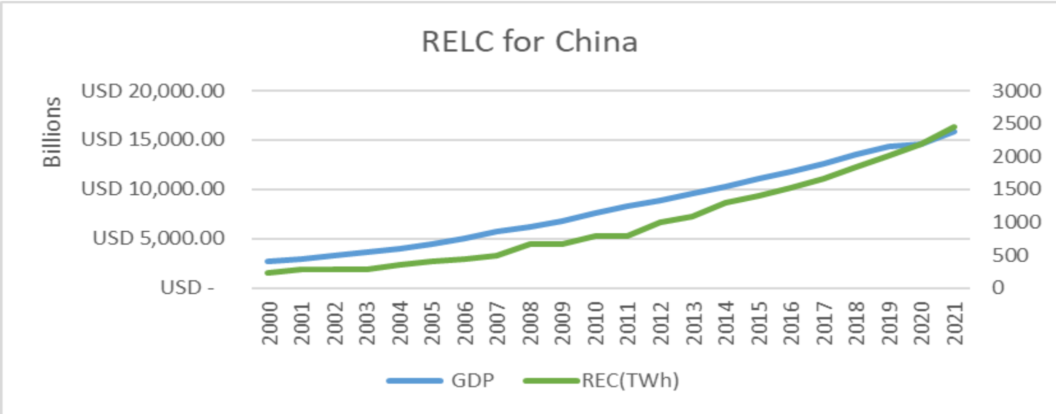

Figure 5.34 RECL and GDP for China. Source: Author's illustration

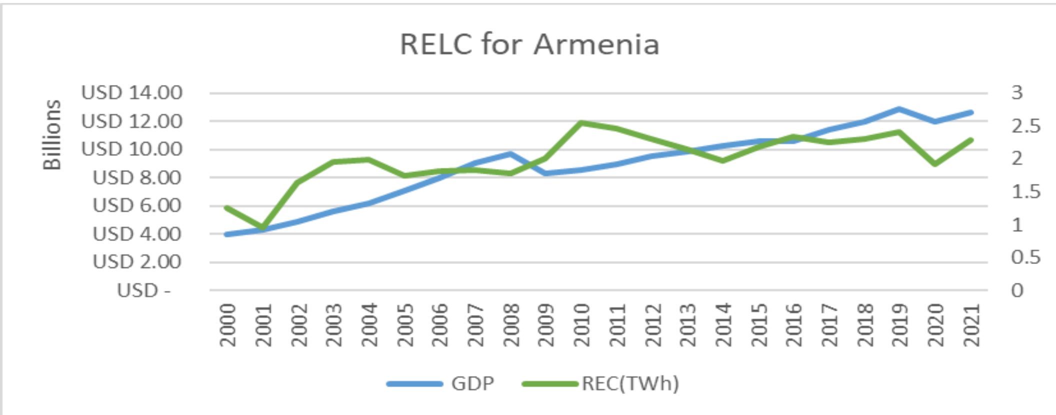

Figure 5.35 RECL and GDP for Armenia. Source: Author's illustration

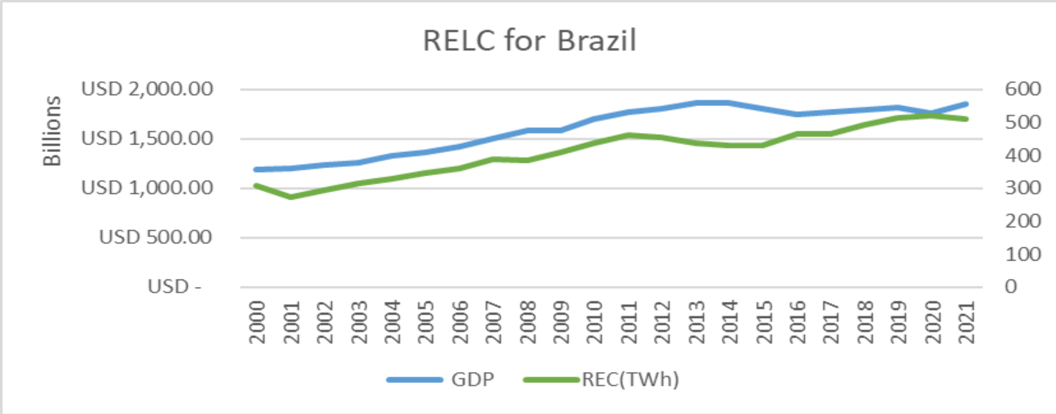

Figure 5.36 RECL and GDP for Brazil. Source: Author's illustration

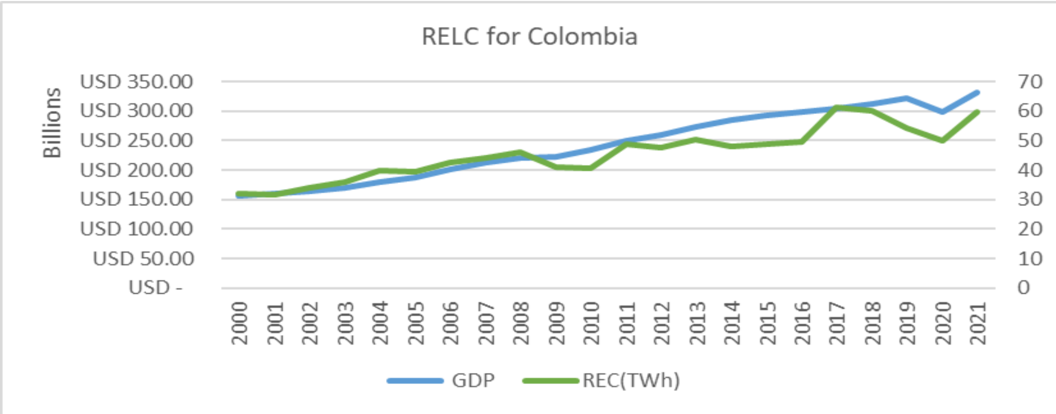

Figure 5.37 RECL and GDP for Colombia. Source: Author's illustration

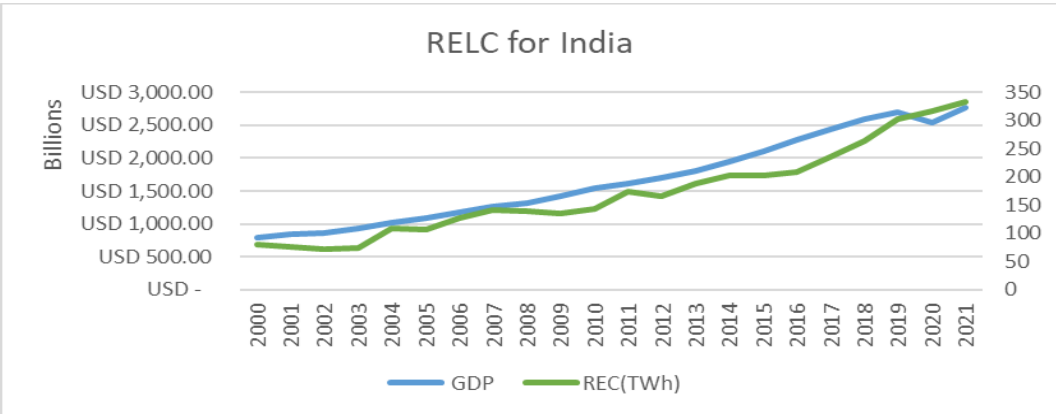

Figure 5.38 RECL and GDP for India Source: Author's illustration

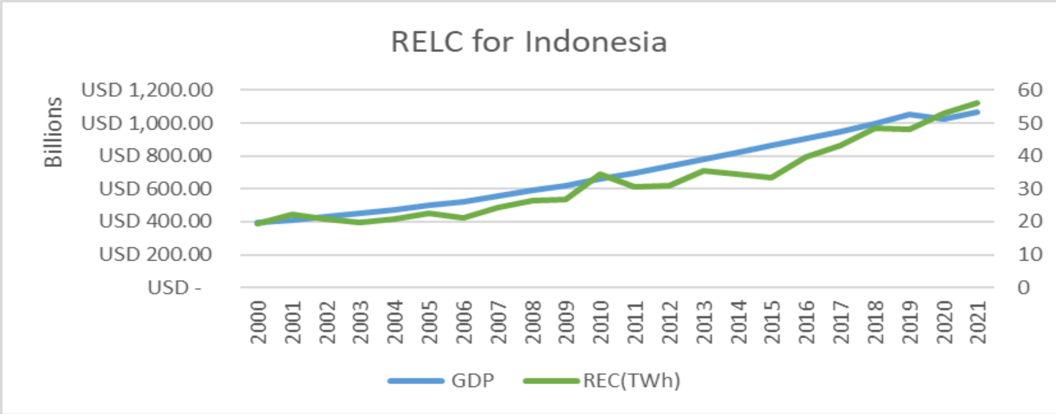

Figure 5.39 RECL and GDP for Indonesia. Source: Author's illustration

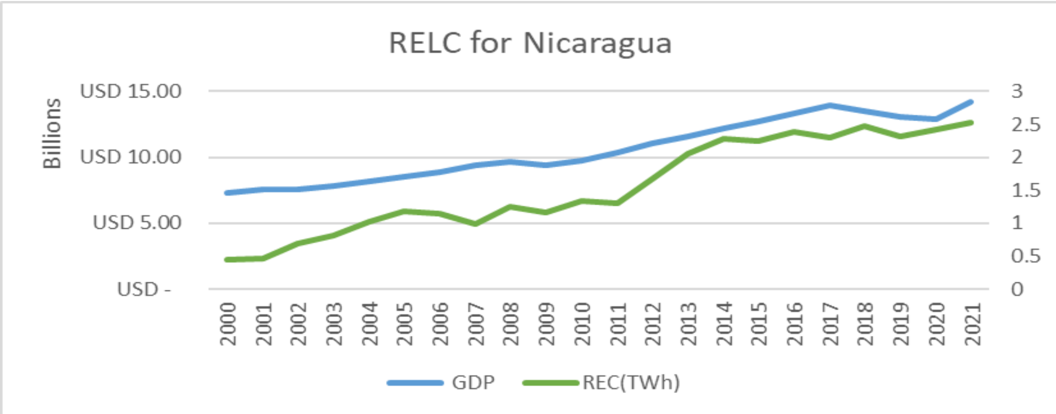

Figure 5.40 RECL and GDP for Nicaragua. Source: Author's illustration

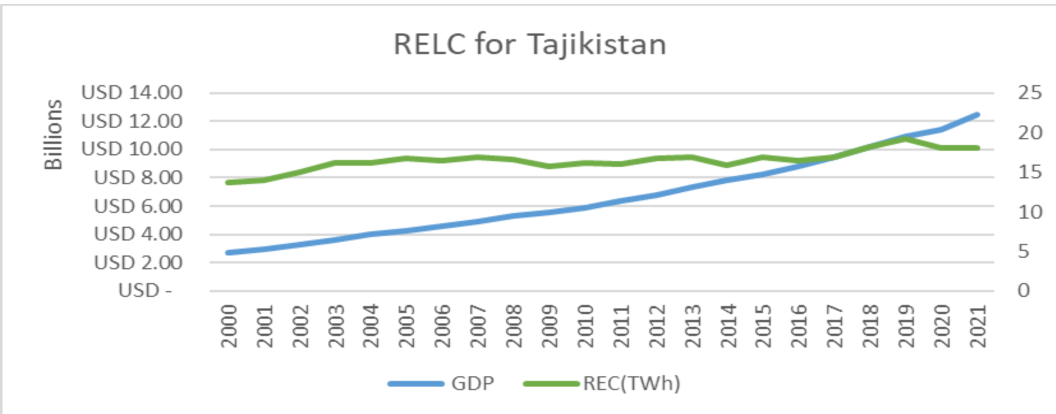

Figure 5.41 RECL and GDP for Tajikistan. Source: Author's illustration

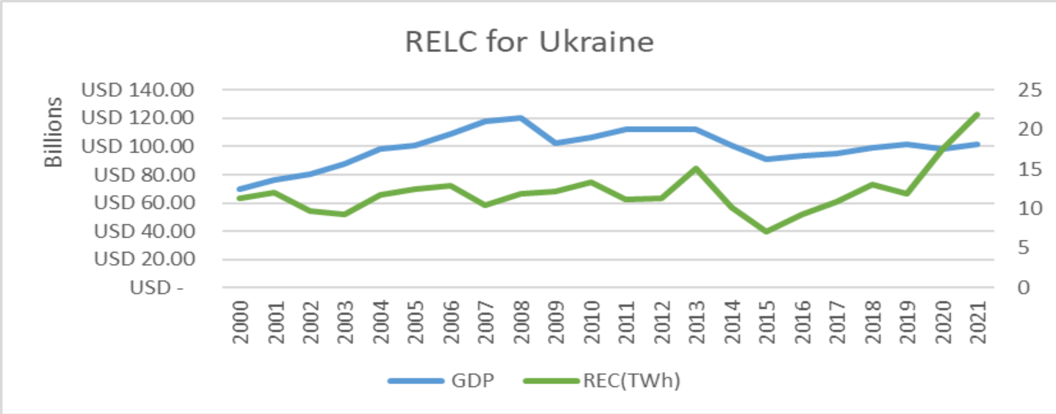

Figure 5.42 RECL and GDP for Ukraine. Source: Author's illustration

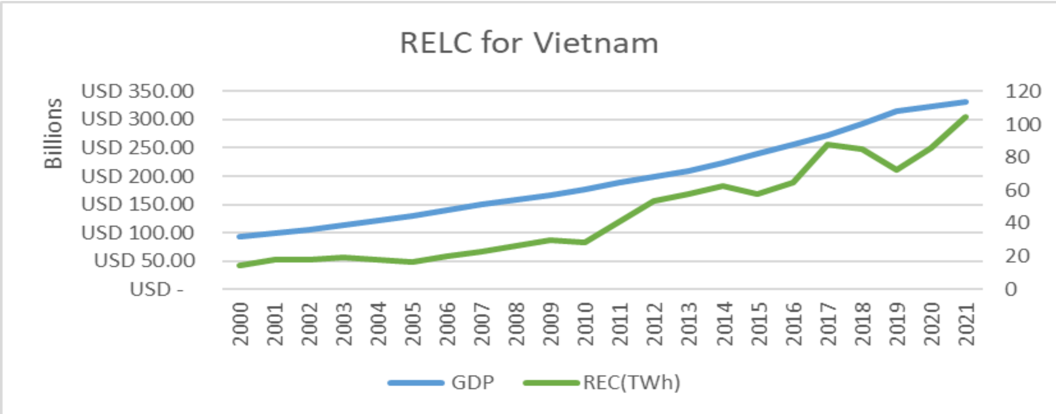

Figure 5.43 RECL and GDP for Vietnam. Source: Author's illustration

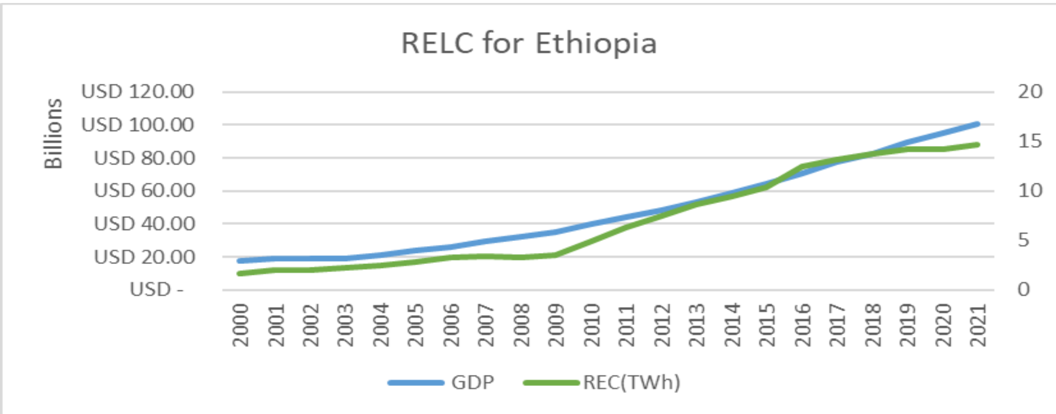

Figure 5.44 RECL and GDP for Ethiopia. Source: Author's illustration

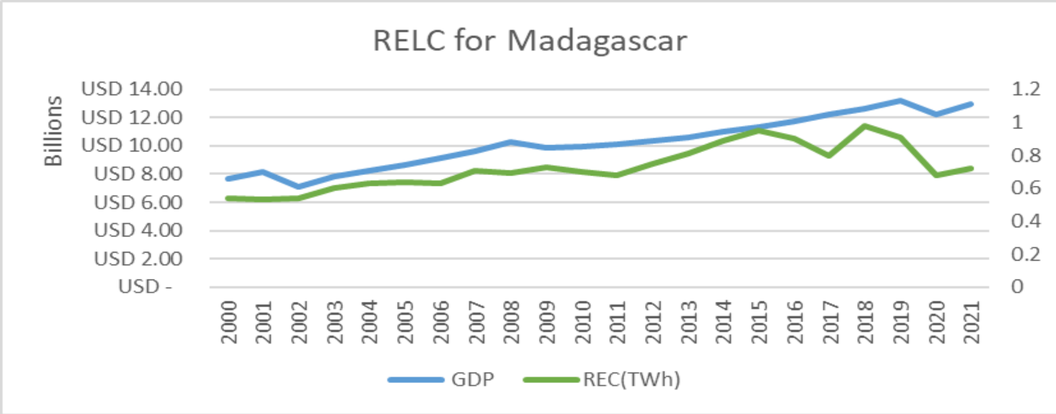

Figure 5.45 RECL and GDP for Madagascar. Source: Author's illustration

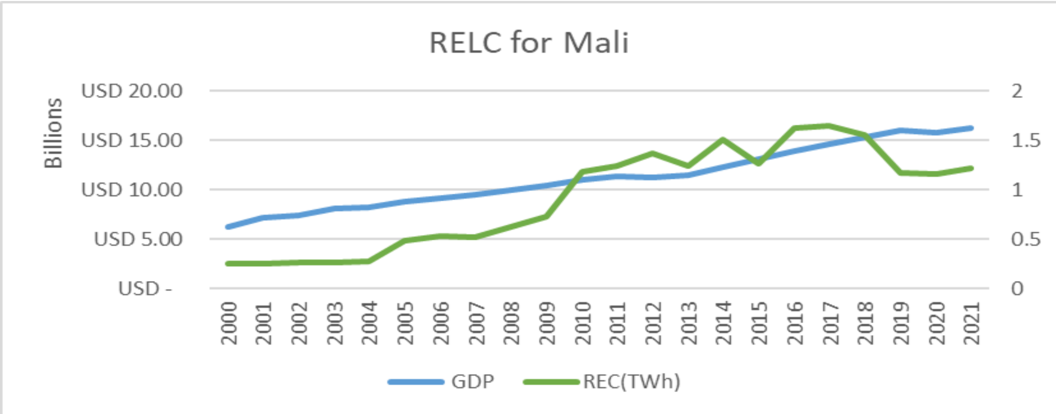

Figure 5.46 RECL and GDP for Mali. Source: Author's illustration

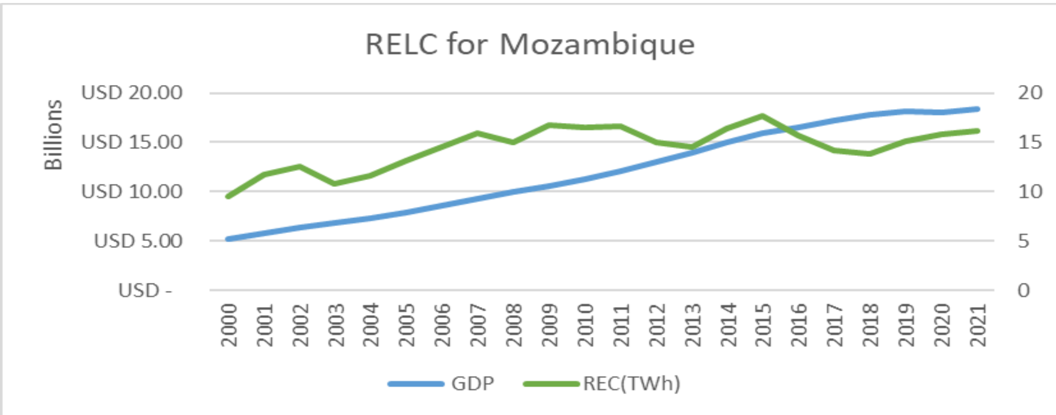

Figure 5.47 RECL and GDP for Mozambique. Source: Author's illustration

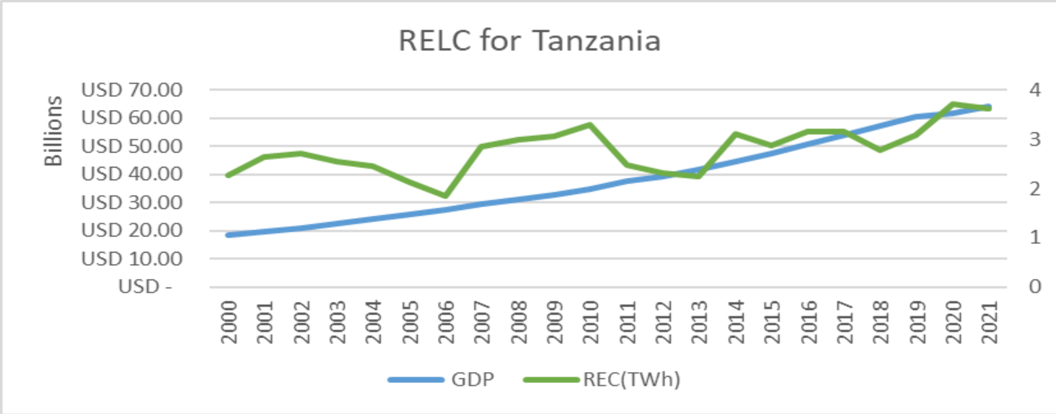

Figure 5.48 RECL and GDP for Tanzania. Source: Author's illustration

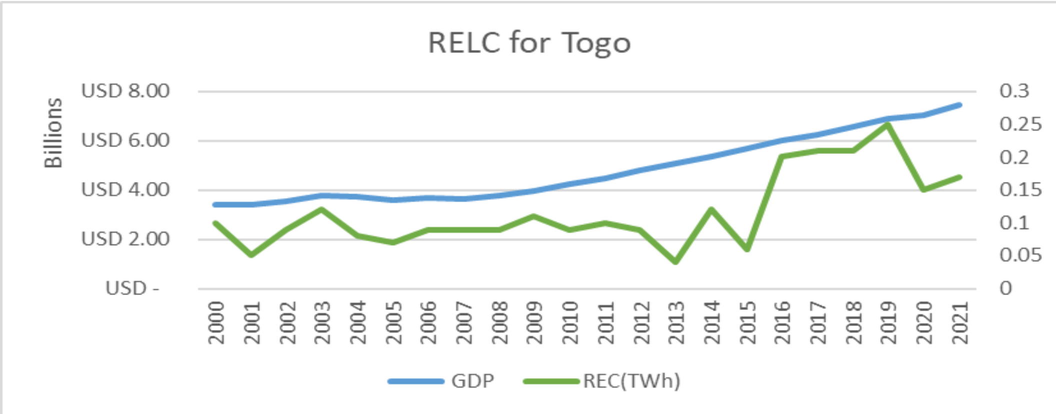

Figure 5.49 RECL and GDP for Togo. Source: Author's illustration

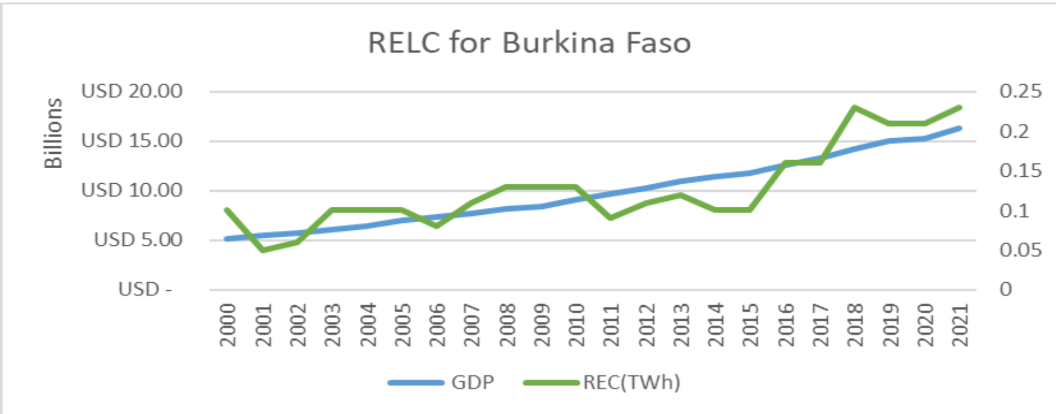

Figure 5.50 RECL and GDP for Burkina Faso. Source: Author's illustration

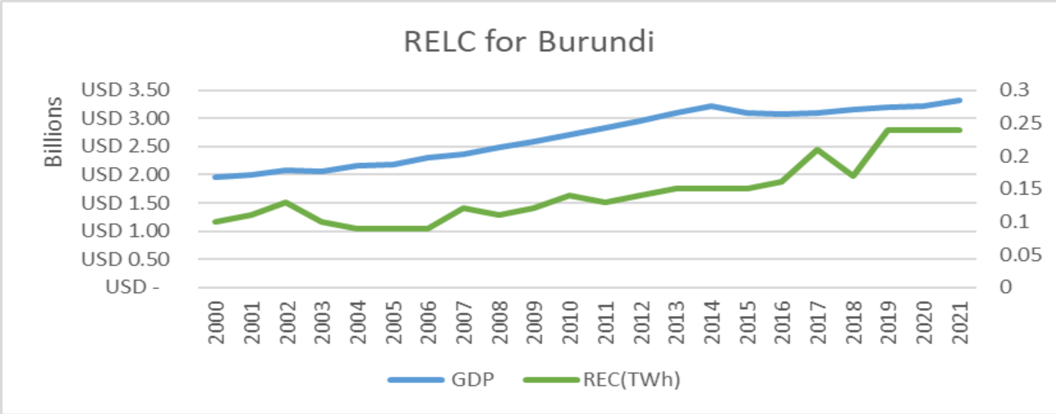

Figure 5.51 RECL and GDP for Burundi. Source: Author's illustration

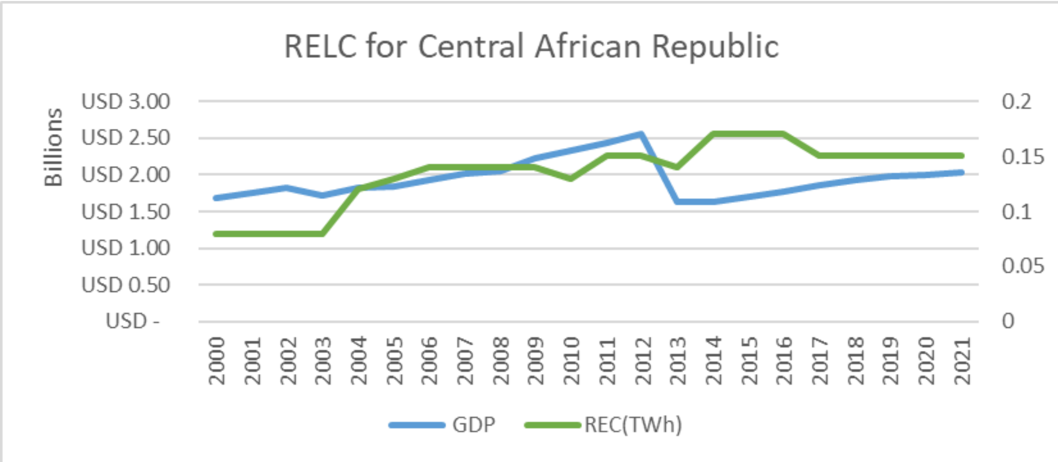

Figure 5.52 RECL and GDP for Central African Republic. Source: Author's illustration

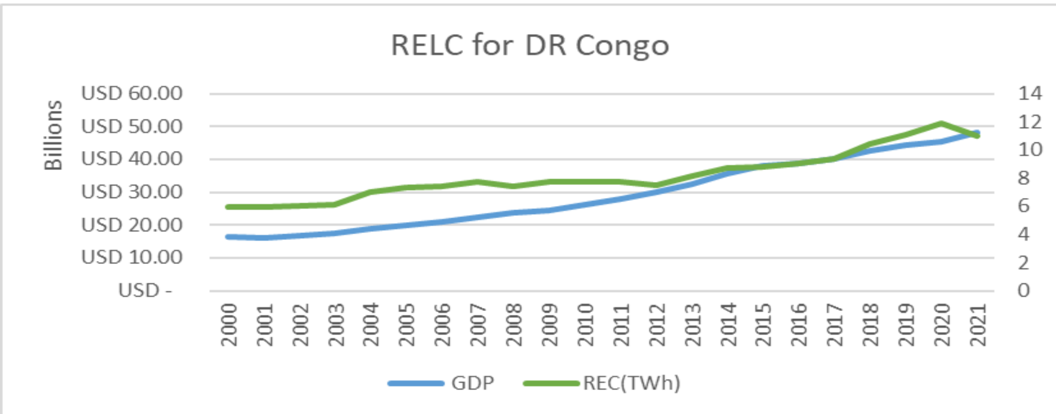

Figure 5.53 RECL and GDP for DR Congo. Source: Author's illustration

Figures 5.6 to 5.53 display the graphical representations of the trends of RELC and GDP of the countries in the study from 2000 to 2021. In Figure 5.6, Australia has had a relatively steady growth in GDP over the period. RELC for Australia grew relatively slowly from 2000 but dipped in 2008 and began rising steadily again after 2010. the rate of growth became even steeper after 2018. GDP in Austria has also trended upwards since 2000. RELC over the period has fluctuated with sharp dips in 2003 and 2011 but has kept increasing overall. RELC for Belgium crept in growth around 1 TWh from 2000 to 2004 but started to rise sharply after 2004 with a peak of 23.46TWh consumed in 2020. GDP in Denmark has also trended upwards quite at a relatively low growth rate. However, RELC in Denmark has grown at a much higher rate from 5.57TWh consumed to a high of 26.1TWh in 2021.

Additionally, much like the GDP of Denmark, the GDPs of Finland and Germany have also grown at a relatively slow pace but RELC in both countries have increased at a much higher pace, with Germany experiencing a more dramatic increase range of 195.33TWh as compared to that of Finland's increase range of 14.47TWh over the period studied. GDP for Iceland grew at a relatively flat rate between 2000 to 2003 but grew much faster after 2003 until 2008 where it shrunk and stayed relatively stagnant. It however began to grow steadily from 2013. RELC was also relatively flat in growth and rose sharply from 2006 to 2008 and began to increase at a much slower pace thenceforth. In the case of Ireland, GDP and RELC have both trended upwards at relatively similar rates over the period observed with RELC growing a higher rate than GDP between 2007 to 2021. In the case of Luxembourg, RELC and GDP have both trended upwards at relatively similar rates. However, RELC began to edge GDP in rate of growth from 2016 to 2020.

Again, like Luxembourg, Netherlands also experienced similar growth rates for RELC and GDP between 2000 to 2014. RELC began to grow faster than GDP from 2015. In the case of Norway, Sweden, Switzerland, and the USA, RELC and GDP have grown at fairly similar rates. For the USA however, RELC grew faster than GDP after 2010. For Japan, GDP has an overall upward trend despite frequent fluctuations. Nevertheless, RELC has risen quite steadily over the period especially after 2012. For the UK, GDP has risen at a relatively slow pace. In contrast, RELC in the UK has witnessed a sharp growth from 2012 to 2020 with a slight drop in 2021.

In the case of Argentina, both RELC and GDP experienced relatively little growth over the period observed. While Bulgaria has had relatively little growth in GDP, it has experienced tremendous growth in RELC despite fluctuations over the period. Costa Rica has had similar rates in terms of growth in both RELC and GDP. However, GDP has grown at a slightly higher rate than RELC over the observed period. The Dominican Republic has had a steady upward trend in GDP. However, RELC has had fluctuations in growth but has had an overall upward trend. In the case of Kazakhstan, GDP has grown at a relatively steady pace. RELC was however stagnated in overall growth between 2000 but began to take off after 2009. GDP has trended upwards together for Malaysia over the period observed. For RELC, it was relatively stagnated from 2000 to 2007 but began to grow steadily from 2008. Mauritius has witnessed a steady upward trend in GDP from 2000 till 2019. RELC has rose steadily from 2000 and experienced a sharp spike 2005 to 0.62TWh and dropped off immediately after to 0.35TWh. It then fluctuated and began to rise steadily and reached 0.6TWh of consumption in 2021.

Figures 5.28 and 5.29 for Mexico and Russia show an overall uptrend in both GDP and RECL. RECL for Mexico rose sharply between 2019 and 2021. For Russia, RELC rose sharply between 2000 to 2008 and growth slowed down thereafter. For Serbia GDP grew from 2000 to 2008, began to stagnate till 2016 and continued grow beyond that. RELC also did not experience any significant growth in Serbia, only growing by 2.82TWh over the 22-year period observed. The nation of Thailand experienced continuous economic growth from 2000 to 2019, experienced a shrinkage in 2020 and resumed its growth journey in 2021. In the same period, RELC also kept growing although it grew much faster than GDP from 2016. Thailand's RELC also fell in 2020 and resumed its growth path in 2021. In Turkey, both GDP and RELC have grown upwards since 2000. Even though RELC experienced dips between 2006 to 2009 and in 2014, it rose sharply between 2014 and 2015 as well as between 2018 and 2019.

In the case of China, Brazil, India, Vietnam, Colombia, Indonesia, Ukraine, Ethiopia, Madagascar and Burundi, the trends RELC has been fairly similar to the growth trend of GDP. Armenia experienced drawbacks in GDP growth in 2009 and 2020. For RELC, Armenia has had an overall uptrend just like their GDP but had a fall in RELC between 2005 which stayed at the same level till 2008. RELC then began to rise and hit a peak consumption of 2.54TWh and then fell to 2.29TWh in 2021. In Nicaragua, both RELC and GDP have trended upwards since 2000. Nevertheless, RELC rose much faster than GDP especially between 2012 to 2014 after which the rate of growth in RELC slowed down. GDP in Tajikistan rose since 2000 to 2021. RELC did not seen much overall growth however, only rising by 5TWh over the period. Between 2000 and 2007, Ukraine experienced GDP growth but GDP fell by USD18.7billon between 2009 and 2021. RELC over the same period started at 11TWh in 2000, rose to 15.11TWh in 2013, fell to 7.1TWh in 2015 and then rose to 21.86TWh in 2021. GDP for Mali grew from 2000 through to 2019 and has not seen much upward progress from 2019 to 2021. RELC also stagnated between 2000 to 2004 and rose thereafter to a peak of 1.65TWh in 2016 and has since fallen to 1.22TWh in 2021.

In the cases of Mozambique, Tanzania, and Burkina Faso, both GDP and RELC have risen steadily over the 22- year period observed. However, RELC experienced fluctuations in upward movements unlike GDP. For Togo, GDP was relatively stagnated between 2000 to 2007 but began to rise thereafter. RELC did not experience much upward movement and fluctuated until 2016 when it experienced a sharp rise from 0.06TWh in 2015 to 0.2TWh. GDP for the Central African Republic had an upward trend from 2000 till 2013 when it dropped sharply. Since then, it started an upward trend but still below the peak level it reached in 2012. RELC was also relatively unchanged between 2000 to 2003 and rose sharply in 2004. It then stayed relatively flat till 2010, after which it began started to rise. It again remained flat between 2014 to 2016, slumped in 2017 and stayed flat up to 2021.

5.2 Methodology

Following Ozturk et al. (2010) the model employed to test for the effect of RELC on economic growth is as follows:

$$LnGDP_{it} = \beta_0 + \beta_1 LnRELC_{it} + \varepsilon_{it} \qquad (5.1)$$

$LnGDP_{it}$ is the natural logarithm of real GDP and $LnRELC_{it}$ is the logarithm of renewable electricity consumption. ε_{it} expresses the error term. i refers to the individual countries in the cross-section component while *t* represents the time series for each unit.

5.2.1 Cross-sectional dependence

In recent decades, there has been a continuous growth in economic and financial integration among countries. This has led to significant dependencies among countries. Consequently, many studies using panel data have found that the data from the cross-sectional units are often related to each other in some way. This relationship can be due to several factors. Firstly, there might be common events or factors that affect all the entities in the dataset, leading to some similarities in their data. Secondly, there could be hidden factors that are not directly observable but influence the data for all the cross-sectional units. Additionally, there may be a form of relationship between the data points of different entities based on their locations or proximity to each other. Finally, there can be some random or unique relationships between pairs of units that don't follow any specific pattern but still contribute to the similarities in their data.

According to Phillips & Sul (2003), cross sectional dependence can lead to inefficient estimations. Unit root tests also suffer potential spurious results when cross sectional dependence is not considered during testing (O'Connell, 1998). First generation unit root tests assume cross sectional independence which makes them inappropriate for data sets where the units are correlated. Second generation unit roots were developed to handle this problem. The outcome of the cross-sectional dependence test indicates whether a first- or second-generation unit root test is appropriate for the data. For this study the Pesaran (2004) CD test and the Breusch & Pagan (1980) Lagrange Multiplier (LM) test are used to test the presence of cross-sectional dependency among the individual cross sectional elements of the data.

The Breusch Pagan LM test for cross sectional dependence employs squared pairwise correlations between estimated residuals of the units in the cross section to test for the presence of correlations between the residuals. The null hypothesis of the Breusch Pagan LM test assumes no cross-sectional dependence is present. The test statistic is calculated as follows:

$$LM_{BP} = T\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\hat{\rho}^2{}_{ij} \qquad - \qquad (5.2)$$

The Pesaran (2004) test takes the average of the correlation coefficients between pairs of cross-sectional elements excluding the correlations of entities with themselves, within the model. The null hypothesis of the Pesaran CD test assumes no cross-sectional dependence. It is calculated as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}\right) \quad - \quad (5.3)$$

The Breusch Pagan LM test is especially ideal for panel data samples where the number of cross sectional entities (N) is greater than the number of time series(T). Pesaran (2004) shows that in cases when $T < N$, the Breusch Pagan LM test can show size distortions making it unreliable under the circumstance. Pesaran then suggested the CD test that solves this problem and is thus ideal for samples with $T<N$. The Breusch Pagan LM test for this study is thus ideal for testing for the presence of cross-sectional dependence in the sub samples and complements the Pesaran CD test to provide more robust insights about the data.

5.2.2 Unit root tests

Stationarity of data is key to establishing a meaningful relationship between variables in a dataset when using panel data techniques. Thus, even before any further analysis is done on the data available, it is imperative that unit root tests must be performed on the data to establish the presence or absence of unit root before the panel data analysis begins.

Multiple unit root tests have been developed to investigate the presence of unit root in a dataset. However, when testing for unit root in panel data series, it is important to establish that the cross-sectional components of the data are independent of each other. First-generation testing methods assume cross-sectional independence of the panel units and that they are all affected equally from shocks to other panel units. With the seemingly stronger connections in the relationships of today's economies however, it is more rational to expect economies to be interdependent.

First generation unit root techniques assume cross sectional independence. As such, they tend to produce spurious results in the presence of cross-sectional dependence. Due to the challenges posed by first-generation testing methods, second generation methods were developed with an underlying assumption of a correlation between the cross-sectional variables. The CADF test for panel data, a method recommended by Pesaran (2007) is employed to test for the presence of unit root in the data.

The Pesaran (2007) CADF unit root test for panel data is an extensively used technique to test for the presence of unit root in the energy-economic growth literature. Pesaran (2007) extended the Augmented Dickey-Fuller test to consider both individual specific heterogeneity and cross-sectional dependence. The test considers a null hypothesis of non-stationarity and the model specification if given as follows (Hurlin & Mignon, 2006):

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + \nu_{i,t} \qquad (5.4)$$

The second unit root test employed in the study is the Breitung demeaned unit root test. This unit root test is a variation of the Breitung unit root test. The demeaned Breitung unit root test cross-sectionally demeans the data series to control for the impact cross sectional dependence may have on the series (Gorkey, 2023).

5.2.3. Panel autoregressive distributed lag (ARDL)

The panel ARDL technique is an extension of the traditional ARDL approach that can be used to analyse the long-run relationship between the regressand and regressors in a panel data model. Cointegration techniques allow the establishment of long-run relationships among variables. However, these methods can only be used when the variables of interest are integrated of order I (1). Thus, making them unsuitable for situations where the variables of interest have otherwise integration orders. Pesaran et al. (2001) assert that this technique does not have the restriction of the integration order of the variables as the cointegration methods. It does not matter if the variables are mutually integrated of the same order or have different orders of integration. The only caveat is for none of the variables to have an integration order I(2). As such, while it may not be necessary to perform prior unit root tests, Pesaran et al. (2001) advocated it should be done to confirm the variables are not integrated of the second order. The general model of an ARDL model in an error-correction form according to Loayza & Ranciere (2006) is given as

$$\Delta(y_i)_t = \sum_{j=1}^{p-1} \gamma_{ij} \Delta(y_i)_{t-j} + \sum_{j=0}^{q-1} \delta_{ij} \Delta(X_i)_{t-j} + \phi_i[(y_i)_{t-1} - \{\beta_{1i}(X_i)_{t-1}\}] + \epsilon_{it}$$

– (5.5)

Adapting the general form of the ARDL model to the model of the study gives us:

$$\Delta(LnGDP_i)_t = \sum_{j=1}^{p-1} \gamma_j^i \Delta(LnGDP_i)_{t-j} + \sum_{j=0}^{q-1} \delta_j^i \Delta(LnREC_i)_{t-j} + \phi^i\left[(LnGDP_i)_{t-1} - \left\{\beta_1^i (LnREC_i)_{t-1}\right\}\right] + \epsilon_{it} \qquad -(5.6)$$

where γ and δ are short-run coefficients of GDP and REC, β is the long-term coefficient, ϕ is the speed of adjustment, i is the country and t is the year.

The most common methods for the panel ARDL method are the MG, PMG, DFE estimators. The mean group estimator estimates N different regressions for all the units in the panel and takes an average of the individual estimates to obtain the group mean. This estimation method assumes the coefficients across the panel are all heterogeneous. It does not recognise that certain parameters may be the same across the panel. The DFE estimator on the other hand assumes that the slope coefficients and error variances are homogeneous across the groups. However, it allows a dynamic specification where the number of lags used can differ across the units. The PMG estimator provides a middle ground between the MG and the DFE estimators by assuming long-run homogeneity across the coefficients but allows the short-run coefficients to differ. The Hausman Test is used to choose the ideal estimator for the dataset. The selection between PMG or MG estimators depends on the outcome of null hypothesis testing. If the null hypothesis is accepted, the PMG estimator is preferred due to its higher efficiency compared to the MG estimator. Conversely, if the null hypothesis is rejected, the MG estimator is favoured over the PMG estimator. Additionally, when choosing between the PMG or DFE estimators, if the null hypothesis is accepted, the PMG estimator is considered more suitable than the DFE estimator.

5.2.4 Hausman test

The Hausman test is a statistical test used to check if there's any meaningful, consistent difference in coefficients among individual elements in a panel dataset. It can be used to identify if the variations in the coefficients are systematic. That is, if the coefficients follow a particular identifiable pattern.

In terms of the PMG, MG and DFE estimations considered in the study, the Hausman test tests the null hypothesis that long-run coefficients are homogenous against the hypothesis that they are no homogenous. If the p-value from the Hausman test is less than 0.05, it implies the long-run coefficients are not homogenous, and the

MG model is more appropriate. If the p-value> 0.05, then the PMG model is preferred. Similarly, when comparing the DFE model to the PMG model, if the p-value from the Hausman test is greater than 0.05 the PMG model is preferred. Nonetheless, if the p-value from the Hausman test is less than 0.05, the DFE model is more appropriate.

CHAPTER 6

6. EMPIRICAL ANALYSIS

Given the objectives of this study, cross sectional dependence is first tested for in the data. If cross sectional dependence is present, second-generation unit root tests are used to test the stationarity of the data. If not, first generation unit roots are used to check for stationarity. Then, the panel ARDL estimations of MG, PMG and DFE are estimated for the data. A Hausman test is then performed to indicate which model is best for the data and the results of that is further interpreted for each income group.

6.1 Cross-sectional dependence tests

To test for cross sectional dependence in the data, the Pesaran CD tests and the Breusch Pagan LM test are used. The test is applied to the whole dataset initially and then to the sub samples classified by income brackets as shown in the table below.

Table 6.1 Cross sectional dependence tests

	ALL	HIGH INCOME	UPPER MIDDLE INCOME	LOWER-MIDDLE & LOW INCOME
LnGDP				
Breusch Pagan LM test	10998.440***	1326.076***	874.254***	844.206***

Pesaran CD test	**142.172*****	**49.028*****	**49.168*****	**41.921*****
LnRELC				
Breusch Pagan LM test	7553.160***	988.126***	671.493***	715.540***
Pesaran CD test	110.183***	41.792***	33.495***	33.685***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

From the table indicating the test for cross sectional dependence, it is observed that that there is cross-sectional dependence for the variables of interest in the panel even at the 1% significance level. Consequently, the unit root testing methods that can be used in the study have to be relevant in dealing with this situation. That is, we can only adopt second generation unit testing techniques to confront the problems from cross sectional dependency.

6.2 Unit root test

The cross-sectionally augmented IPS test by Pesaran (2007) and the demeaned Breitung unit root tests are employed to test for cross sectional dependence in the data. The tests are performed on the level and first differences of each variable with the constant and constant with trend options considered for each level. Furthermore, the tests are applied to the whole data set and are also applied to the various subgroups differentiated by their income levels.

Table 6.2 Unit root tests

		Variables	**Level**		**First Difference**	
			C	C+T	C	C+T
CADF test	All	LnGDP	-1.709	-1.711	-3.230***	-3.326***
		LnRELC	-2.477***	-2.399	-4.632***	-4.781***
	High income	LnGDP	-1.349	-1.546	-3.613***	-3.946 ***
		LnRELC	-1.779	-2.394	-4.570***	-5.019***
	Upper middle income	LnGDP	-1.913	-1.700	-2.945***	-2.794**
		LnRELC	-2.881***	-3.149***	-4.990***	-5.118***

	Low & Lower-middle income	LnGDP LnRELC	-2.071 -2.144*	-2.067 -2.075	-3.590*** -4.386***	-3.553*** -4.466***
Breitung Demeaned unit root test	All countries	LnGDP LnRELC	13.4865 4.5843	5.9893 -1.3249*	-9.106*** -12.85***	-5.373*** -12.81***
	High Income countries	LnGDP LnRELC	4.948 4.3296	0.9803 1.9225	-9.18*** -8.089***	-6.133*** -6.745***
	Upper middle-income countries	LnGDP LnRELC	4.7306 1.0995	3.0500 -3.432***	-4.380*** -7.041***	-2.3998*** -7.292***
	Low & Lower-middle income	LnGDP LnRELC	6.4488 0.6339	1.7550 -1.5629*	-4.512*** -7.491***	-3.343*** -8.453***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

Per the CADF test results in the above table, in the whole sample, economic growth is not stationary at level but integrated of the order I (1) which is significant at the 1% significance level. RELC is not stationary at level with trend but stationary without trend at level. However, stationarity is observed with both constant and constant and trend options at first difference. For the high-income subgroup, both GDP and RELC do not exhibit stationarity at level, but the presence of unit root is eliminated at first difference which is also significant even at the 1% level. In the upper middle-income subgroup, LnGDP is not stationary at level for both trend and trend and constant specifications. It becomes stationary after its first difference is taken and it is significant at the 1% level as well. RELC on the other hand is stationary even at level also at the 1% significance level. The low income and lower middle-income group also exhibit non-stationarity at level for both LnGDP and LnRELC. Nonetheless, LnRELC is stationary at first difference for the constant only specification although only weakly significant. The two variables are integrated of order I (1) at the 1% significance level for both variables.

Considering the Breitung demeaned unit root test, the sample with all the countries proved to have unit root for both variables at level in both constant and constant with trend specifications except for LnRELC which was stationary but only weakly significant at the 10% level. However, at first difference both variables became stationary. For the high-income countries sample, both LnRELC and LnGDP only became stationary after their first differences were taken. For the upper middle-income countries, LnRELC was stationary at level with the constant and trend specification. The rest of the variables under both specifications had unit root present. However, both variables became stationary under both constant and constant and trend specifications at first difference. In the lower-middle income and low-income subgroup, LnGDP was not stationary at level. LnRELC was not stationary at level with the constant specification but was stationary at level with the constant and trend specification but only weakly significant. The two variables however exhibited an absence of unit root when the tests were applied to their first differences.

The two tests present relatively similar results pointing to a mixed outcome with regards to the presence of unit root in the data for both LnRELC and LnGDP. While the results are quite mixed, they still present resolute evidence to support the fact that none of the variables are integrated of order I (2) or beyond.

6.3 Panel ARDL

The long-run relationship between economic growth and electricity utilisation is examined using the ARDL approach. As Pesaran et al. (2001), indicated, this method is appropriate when either the variables are integrated of different levels or when the level is integration of the variables is not clear. However, the variables should not be stationary at second difference or beyond. Table 6.3 presents the results for three estimations: the pooled mean group (PMG), the mean group (MG), and the dynamic fixed effect (DFE) estimations for the whole sample as well as the various income groups.

Table 6.3 PMG, MG and DFE estimations

ALL	**LR**	**SR**	**EC**
PMG	0.119***	0.0196**	-0.0952***
MG	0.3581*	0.0054	-0.1394***

DFE	0.2622***	0.0112	-0.0462***
HIGH INCOME			
PMG	0.0847***	0.0152	-0.1657***
MG	0.0194839	0.0079482	-0.2302245***
DFE	0.1382857	0.0104414	-0.0354889*
UPPER MIDDLE INCOME			
PMG	0.62322***	-0.02132	-0.0850577***
MG	0.4362024	-0.020096	-0.025099***
DFE	0.4162381***	-0.0133854	-0.0867708***
LOW AND LOWER MIDDLE INCOME			
PMG	0.2236706***	0.0379336	-0.0654337***
MG	0.6185553	0.028348***	-0.085641***
DFE	0.4677116***	0.01648	-0.0386382***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

An overview of the outcome of the estimations indicate they present largely similar but slightly varied results. For the entire sample, all three estimations produced a negative and statistically significant error correction coefficient which implies that for all the countries considered, there is a long run cointegration relationship between RELC and economic growth. The long-run coefficients are also positive in all estimations, indicating that RELC has a positive impact on economic growth. However, the long-run coefficient in the MG estimation is weakly significant at the 10% level. The short-run coefficients are also positive for all estimations employed but only that of the PMG estimation was statistically significant. The other coefficients in the other estimation methods were not statistically significant.

For high income countries in this study, the error correction coefficient was also negative and statistically significant in the PMG and MG estimations but not the DFE estimation. The long-run coefficient was also positive in all estimations but only that of the PMG estimation was statistically significant. For the short-run coefficients, all three estimations produced positive values but none of them was statistically significant.

In the upper middle income sample estimations, just like the previous samples the error correction coefficient was also negative and statistically significant, implying that cointegration exists between GDP and renewable electricity usage. The long-run coefficients were also positive for all the estimation methods. The PMG and DFE long-run coefficients were statistically significant but that of the MG estimation was not statistically significant. The short-run coefficient in the PMG estimation was positive and weakly significant as well. In sharp contrast, the coefficients of the MG and DFE estimations were both negative and insignificant.

The low and lower middle-income subgroup also like the others had negative and statistically significant error correction terms. The long-run coefficients of all estimations were also positive but whiles the PMG and DFE produced statistically significant error correction terms, the coefficient in the MG estimation was not. The short-run coefficient was also positive for all estimations but only that of the MG estimation was statistically significant.

In general, it seems that cointegration is veritable between RELC and economic progression in the sampled groups in this study based on the three estimation methods examined. To a large extent as well, there is a seemingly positive impact on income growth from RELC in the long run but in varying magnitudes depending on the level of income and estimation method. The short-run influence of RELC on economic expansion appears to less pronounced, evidenced by the lesser number of statistically significant coefficients produced by all three estimation methods, with all three estimations churning negative coefficients for the upper middle-income sample in the short run.

It is evident that the three estimation methods present quite diversified outputs with different implications on understanding the dynamic interaction between electricity usage from green sources and economic growth at different income levels.

As such, it is imperative to choose a model out of the three estimations that best fits the data. To choose an appropriate model for interpretation, the Hausman test is applied to select an apt model that best fits the data. To achieve this objective, the Hausman test is applied on the MG model against the PMG model, then the DFE model is tested against the PMG model. The findings of the Hausman test are given in table 6.4.

Table 6.4 Hausman test

Sample Group	**Models**	**Chi^2**	**Prob>chi^2**	**Selected Model**
All	MG vs PMG DFE vs PMG	1.35 5.66	0.2446 0.0174	DFE
High income countries	MG vs PMG DFE vs PMG	0.03 0.40	0.8723 0.5263	PMG
Upper middle-income countries	MG vs PMG DFE vs PMG	0.48 17.58	0.4903 0.0000	DFE
Low and lower middle-income countries	MG vs PMG DFE vs PMG	1.14 3.37	0.2866 0.0665	PMG

For the whole sample, when the MG estimation is tested against the PMG estimation, we fail to reject the null hypothesis indicating the PMG estimation is better. However, when the DFE is tested against the PMG model, we reject the null hypothesis, implying that the DFE model is the best fit when considering the whole sample. In the high-income subgroup, the p-value when the MG model is tested against the PMG model implies the PMG model is better. Again, when the PMG model is tested against the DFE, the PMG model still comes out as the better option. Hence, for the high-income countries in this study the PMG model provides a better fit. For the upper middle-income countries, the PMG model is again a better fit when compared to both the MG estimation. The DFE estimation is then compared to the PMG model and the p-value indicated the rejection of the null hypothesis. Thus, the DFE estimator is the best fit for the model with only upper middle-income countries. Furthermore, for the low and lower middle-income countries, the p-value from the Hausman test indicates a weak significance for the DFE model at the 10% significance level. However, the PMG model is preferred as the best model since it is significant at the 5% level. The Hausman test gives us exactly the models to interpret as they are the best fit for the data. The Hausman test espouses that the DFE model is best when considering the whole sample as a unit as well as for upper middle-income countries. The PMG model is the best when considering the high-income sub sample and the lower middle income and low-income samples.

Table 6.5 Appropriate models

	Long-Run Coefficient	Short-Run Coefficient	Error Correction Coefficient
All Countries	0.2622***	0.0112	-0.0462***
High Income Countries	0.0847***	0.0152	-0.1657***
Upper Middle-income Countries	0.41624***	-0.0134	-0.08677***
Low And Lower Middle-income Countries	0.2237***	0.0379	-0.0654***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

From table 6.5, per the DFE model, when considering all the countries in study together, RELC is cointegrated with economic growth, and this is evidenced by the negative and significant error correction term in the model. As such, in the subsequent period, corrections are made for 4.62% of the departures from the long-term equilibrium observed in the previous period. Also, the positive and significant coefficient of the long-run variable implies that a percentage increase in RELC will result in a 0.26% rise in economic expansion. Meanwhile, in the short-run RELC does not have a significant impact on growth in the economy.

The PMG model for the high-income countries in this study reveals a long run cointegration relationship between RELC and economic growth. The coefficient of the error correction term in this model shows that 16.57% of deviations from the long-run equilibrium are corrected in the next period. Additionally, in the long run a 1% rise in RELC leads to in a 0.0847% growth in income. In the short run however, there is no impact.

Upper middle-income countries just like high income countries in this study also have a long run cointegration relationship between RELC and economic growth as shown by the DFE model. Also, 8.68% of deviations from the equilibrium in the current period are corrected in the next period. The long-run influence of RELC on economic growth is a 0.416% rise in income per percentage increase in RELC. Meanwhile in the short run, there is no effect of a change in RELC on real GDP.

Considering the low and lower middle-income sample, the existence of cointegration is confirmed by the negative and statistically significant coefficient of the error correction term. In addition, 6.5% of deviations from the equilibrium in one period are corrected in the subsequent period. Also, a unit percentage rise in RELC results in a 0.22% growth in income in the long run. The short-run influence of RELC on economic progression is not statistically significant, in congruence with that of the other samples in the model.

The selected models from the Hausman test demonstrate that upper middle-income countries gain the most from RELC, as income growth is propelled by 0.42% from every unit percentage rise in RELC. Meanwhile, high income countries benefit the least from RELC with a recorded 0.085% increase in income growth, an increase that falls below that recorded for the lower-middle and low-income countries which recorded a 0.22% increase in income growth from a percentage increase in RELC. Meanwhile, even though the short run impact coefficients were not statistically significant in any the selected models, it is worth noting that upper middle-income subgroup while having the highest of RELC in the long run, it also recorded the only negative impact in the short run from RELC. Additionally, the short-run impact observed was largest for the low and lower-middle income subgroup with high income countries recording the second highest effect of RELC in the short run.

Even though the PMG model imposes an assumption of long run homogeneity in its estimation, it allows the short run coefficients and the error correction coefficients to differ among the individual countries. The high-income and the lower-middle- and low-income samples had their PMG models selected as the best fit based on the Hausman test. As such, it benefits the analysis to delve into the estimation of these two coefficients. It also provides additional insight into the short run and error correction effect of RELC on income growth in the individual countries for which the PMG model was deemed appropriate. Table 6.6 and table 6.7 provide the short-run and error correction estimates for the high-income countries and the lower-middle and low-income countries in the study.

Table 6.6 High income countries

COUNTRY	SHORT-RUN COEFFICIENT	ERROR CORRECTION COEFFICIENT
Australia	-0.0261189	-0.0275057**
Austria	-0.016243	-0.0946149
Belgium	-0.0158237	-0.6009016**
Denmark	0.0276639	-0.0553981
Finland	0.0962752**	-0.2125289***
Germany	0.0317947	-0.2403146
Iceland	0.1130846	-0.0722779
Ireland	0.0169285	0.0747874
Luxembourg	0.0242	-0.0727964
Netherlands	-0.0232282	-0.2540703*
Norway	0.035008	-0.0419672
Sweden	0.0095529	-0.035007
Switzerland	0.0043141	-0.0149077
United States	-0.0251799	-0.0174293
Japan	0.021286	-0.325157**
United Kingdom	-0.0297243	-0.6607329***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

The error correction coefficient for the high-income countries reveals that there is a strong statistically significant cointegration relationship between RELC and income growth for Australia, Belgium, Finland, Japan and the United Kingdom as evidenced by their negative and significant error correction coefficients as illustrated in table 6.6. 2.75% of deviations from the equilibrium in one period are corrected in the next period in the case of Australia. For Belgium, 60% of deviations from the equilibrium are corrected in the next period whereas 21.25% of deviations are corrected for Finland. 32.52% and 66.1% departments from the equilibrium are corrected for Japan and the United Kingdom respectively. The error correction mechanism is thus strongest in the United Kingdom and weakest in Australia. For the

Netherlands, 25.41% of equilibrium deviations are corrected in the next period. However, the cointegration relationship is only weakly significant. The rest of the high-income countries (10 countries) demonstrate no statistically significant cointegration relationship between RELC and income growth. In the short run, all the high-income countries are not impacted by RELC with the exception of Finland. A unit percentage increase in RELC in Finland causes income growth to rise by 0.096% in the short run. Furthermore, even though cointegration was confirmed between RELC and income growth for Australia, Belgium and the United Kingdom, the corresponding short run impacts recorded were negative although not significant.

Table 6.7 Lower middle- and low-income countries

COUNTRY	SHORT-RUN COEFFICIENT	ERROR CORRECTION COEFFICIENT
India	0.049721	-0.0265795
Indonesia	-0.0034904	-0.0198043
Nicaragua	0.0014942	-0.0763435
Tajikistan	0.1648502**	-0.0169517**
Ukraine	0.0227462	-0.2859683***
Vietnam	-0.0379653**	-0.0202342**
Ethiopia	0.1305765	0.0074263
Madagascar	0.1348009	-0.047008
Mali	-0.0231472	-0.1119462**
Mozambique	0.0141735	-0.0587072***
Tanzania	-0.014958	-0.0172008***
Togo	0.0199264*	0.0542363*
Burkina Faso	0.0020233	-0.0140707
Burundi	0.019897	-0.0550644
Central African Republic	0.0883098	-0.3671199**
Democratic Republic of Congo	0.037979	0.0083963

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

In the case of the lower-middle- and low-income countries analysed, Tajikistan, Ukraine, Vietnam, Mali, Mozambique, Tanzania, Togo, and the Central African Republic experience a cointegration relationship between RELC and income growth. Nevertheless, the existing cointegration between income growth and RELC for Togo is weakly significant. India, Indonesia, Nicaragua, Ethiopia, Madagascar, Burkina Faso, Burundi and the Democratic Republic of Congo demonstrate no cointegration between income growth and RELC.

Approximately 1.7% of discrepancies from the equilibrium are corrected in the next period in Tajikistan and Tanzania, which makes them the two countries with the weakest error-correction mechanism among the lower-middle income- and the low-income sample. 28.6% of departures from the equilibrium in one period in Ukraine are amended in the subsequent period. Additionally, for Vietnam and Mali, 2.02% and 11.19% respectively of divergencies from equilibrium are resolved in the following period. Inconsistencies from balance in Mozambique are rectified at a 5.87% adjustment rate in the next period. The Central African Republic experiences a 36.71% amendment in shifts away from the equilibrium in the next period, making it the country with the strongest error correction mechanism in this particular sample. A weakly significant error correction in the subsequent period of 5.42% is experienced in the case of Togo.

Tajikistan and Vietnam showed statistically significant impacts of RELC on income growth in the short run. A one percentage rise in RELC consumption in the short run in Tajikistan stimulated economic growth by 0.164%. In contrast, the short run effect of a rise in RELC in Vietnam rather caused a shrinkage in economic growth by 0.038%. For Togo, although RELC causes income growth to rise by approximately 0.02% in the short run, it is only weakly significant.

The results of this study provide backing for the growth hypothesis, suggesting that economic growth is driven by RELC. It also makes a big case for the use and promotion of renewable energy especially electricity as it does not only drive growth, but it also draws economies closer to sustainable development. The outcome of the model for upper middle, low and lower middle income countries is in concurrence with the work of Azam, Rafiq, Shafique, & Yuan (2021) who found that renewable electricity drives economic growth in developing countries. This exact finding however contrasts that of Chen et al. (2020) who found that REC rather caused negative growth in the economies of developing countries. Furthermore Bhuiyan et al. (2022) also found that renewable energy is not a limiting factor on economic progression in developing, emerging and developed countries.

CHAPTER 7

7. CONCLUSION

With ever growing concerns on the impact of climate change and the imperative need to reverse the damage done by cutting greenhouse gas emissions, green electrification has emerged as a front runner to accelerate sustainable development and reduce the cost of current development on future generations. Considering this situation, this study has looked at the bearing of renewable electricity utilization on income growth in 48 countries. The 48 countries were further divided into three subgroups according to their levels of income as defined by the World Bank namely low-income, lower middle income, upper middle income, and high-income countries. These clearly defined groups are analysed to ascertain the influence of RELC in the short-run as well as in the long-run on the growth of their economies with a focus on how RELC distinctly affects economic prosperity in the groups.

This research contributes to the existing literature by providing a comparative insight into the green electricity use and economic growth linkage across different stages of development. That is, the nexus as it pertains to high-, middle- and low-income country statuses. Also, unlike other studies that have studied the impact on single or single-grouped countries, this study looks at the insights generated, i.e., the impacts when all countries are considered as whole and when they are analysed per income level.

Panel ARDL methods were employed in analysing the data. In particular, the PMG, MG and DFE panel ARDL methods were employed to estimate three models for each distinct income group. The Hausman test was then employed to select the best fit model for the data for each income group. This then revealed that for the entire sample as one unit the DFE model was the best fit. However, for the high income, upper middle income and the lower-middle- and low-income countries the best fit estimations were the PMG, DFE and PMG respectively. The study also further provided individual country estimates of the error correction effect and short-term coefficients as the PMG permitted for the high income and lower-middle- and low-income categories.

The findings from the study show that RELC and economic growth are cointegrated in the long-run regardless of whether it is being looked at from the whole world's perspective or from an income-level based perspective. Also, RELC has a positive impact on economic growth across the whole sample and all the sub-samples examined. However, the impact of RELC on income growth is greatest in upper middle-income countries with lower-middle- and low-income countries ranking second in benefitting from the impact. High-income countries recorded the lowest addition to income growth from RELC. As such, RELC has a larger stimulation effect on economic expansion in developing countries (middle income and low income) than in developed countries. In other words, developing countries benefit more significantly from the consumption of renewable energy than developed countries. Furthermore, RELC mostly has a weak effect or no effect on economic expansion in the immediate term. Moreover, it appears the error correction effect in stronger in developed countries than it is in developing countries. The observed corrections from deviations from equilibrium is higher when income levels are higher, and it falls as the defined income level group falls.

The insight from this study gives strong support for the adoption of green electricity production sources across all economies in the world regardless of income levels as RELC propels economic growth regardless of income levels. This finding is also important for the formulation and pursing of international policies that tackle reduction in greenhouse gas emissions. This also provides extra incentive for developing countries as policy makers in developing countries do not have to worry about negative impacts of transitioning to renewable electricity sources that could result from job losses from cutting down fossil fuel reliant electricity sources due to the adoption of green electricity production technologies.

While this research provides valuable insight on the effect of RELC on economic growth across the various income categories representing levels of development, much like every research work it also has some limitations. First, to facilitate the analysis, the lower middle income and the low-income categories had to be lumped together as one due to limited availability of data. As such, the study could not provide the impact of RELC on income growth in these income groups distinctively. Furthermore, the countries and number of countries used in the study were prioritised based on data availability. Hence the countries used may not be the most accurate representation of the world at large.

To further expand our understanding of the interaction between RELC and income growth, future research could delve into examining the impact of RELC on the output of different sectors of the economy. It would be valuable to know the dynamics of the impact of RELC on an economic sectoral basis. Also, some future research could also focus on the impact of different sources of green electricity on economic growth. Some sources of renewable electricity might be more beneficial to income growth than others potentially due to the varying resource and infrastructure availability. Thirdly, it will be valuable for future research to explore the impact of RELC on inequality. Due to the capital-intensive requirement of renewable electricity production technologies, it is plausible that investments in its production and use is mainly done by the wealthy who can afford thereby making returns and savings mostly accruing to those high up the wealth chain and further widening the gap between the rich and the poor. Results from such research could led policy on how to formulate and implement subsidies on the adoption of renewable electricity and energy sources.

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APPENDICES

APPENDIX A

Table A1 Individual country descriptive statistics

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
Australia						
GDP	1200.00 B	209.00 B	873.00 B	1520.00 B	-0.03	1.74
RELC	30.84	15.78	17.11	71.98	1.26	3.70
Austria						
GDP	365.00 B	30.80 B	311.00 B	414.00 B	-0.28	2.05
RELC	46.34	5.48	35.24	55.42	-0.09	2.02
Belgium						
GDP	434.00 B	40.40 B	366.00 B	497.00 B	-0.19	1.99
RELC	9.14	7.42	1.05	23.46	0.51	1.99
Denmark						
GDP	295.00 B	23.20 B	263.00 B	342.00 B	0.49	2.22
RELC	14.23	6.25	5.57	26.10	0.33	1.86
Finland						
GDP	232.00 B	17.60 B	196.00 B	257.00 B	-0.64	2.42
RELC	26.72	5.04	19.06	37.85	0.52	2.46
Germany						
GDP	3180.00 B	260.00 B	2840.00 B	3600.00 B	0.17	1.66
RELC	130.21	72.74	35.47	251.48	0.27	1.67
Iceland						
GDP	16.30 B	2.73 B	11.90 B	20.80 B	0.02	2.02
RELC	14.90	4.73	7.68	19.82	-0.54	1.50
Ireland						
GDP	252.00 B	79.60 B	160.00 B	448.00 B	1.06	3.02
RELC	5.40	3.87	1.03	13.46	0.63	2.22

Luxembourg						
GDP	54.70 B	8.61 B	40.40 B	69.00 B	-0.08	1.91
RELC	0.39	0.26	0.14	0.99	1.22	3.32
Netherlands						
GDP	742.00 B	60.20 B	644.00 B	847.00 B	0.07	2.09
RELC	12.89	9.32	2.97	40.47	1.56	5.18
Norway						
GDP	362.00 B	34.30 B	303.00 B	419.00 B	-0.10	1.98
RELC	132.95	12.69	106.03	151.11	-0.53	2.38
Sweden						
GDP	462.00 B	61.10 B	365.00 B	565.00 B	0.04	1.91
RELC	86.05	13.77	58.73	115.74	0.36	2.97
Switzerland						
GDP	641.00 B	75.70 B	530.00 B	760.00 B	-0.04	1.73
RELC	34.26	3.29	28.46	40.79	0.22	2.50
United States						
GDP	16900.00 B	2000.00 B	13800.00 B	20500.00 B	0.12	2.02
RELC	504.35	176.12	280.06	861.58	0.69	2.19
Japan						
GDP	4290.00 B	188.00 B	3990.00 B	4580.00 B	-0.13	1.97
RELC	133.65	38.23	100.57	216.73	0.95	2.45
United Kingdom						
GDP	2740.00 B	247.00 B	2310.00 B	3170.00 B	0.07	2.15
RELC	51.20	42.58	9.56	131.74	0.69	1.94
Argentina						
GDP	511.00 B	86.70 B	337.00 B	599.00 B	-0.73	2.05
RELC	33.96	2.49	28.89	38.67	-0.14	2.37
Bulgaria						
GDP	46.30 B	8.43 B	30.40 B	59.40 B	-0.48	2.23
RELC	5.29	2.52	1.65	10.31	0.37	1.99
Costa Rica						
GDP	48.10 B	11.70 B	30.40 B	66.40 B	-0.01	1.69
RELC	9.11	1.66	6.78	12.55	0.42	2.16
Dominican Republic						
GDP	59.40 B	18.60 B	35.70 B	93.50 B	0.36	1.86
RELC	1.80	0.68	0.70	2.98	0.29	2.27
Kazakhstan						
GDP	149.00 B	47.30 B	66.20 B	215.00 B	-0.25	1.79
RELC	9.00	1.73	6.88	12.05	0.82	2.06
Malaysia						
GDP	249.00 B	72.60 B	148.00 B	365.00 B	0.17	1.69

RELC	14.08	9.58	5.51	33.93	0.95	2.30
Mauritius						
GDP	10.10 B	2.26 B	6.73 B	13.90 B	0.00	1.72
RELC	0.43	0.10	0.28	0.62	0.42	2.04
Mexico						
GDP	1050.00 B	132.00 B	873.00 B	1260.00 B	0.07	1.66
RELC	49.65	11.28	32.11	80.65	0.92	3.90
Russia						
GDP	1220.00 B	223.00 B	780.00 B	1500.00 B	-0.75	2.23
RELC	178.69	16.45	156.43	221.62	1.29	4.16
Serbia						
GDP	37.10 B	6.59 B	24.00 B	48.60 B	-0.42	2.46
RELC	10.27	0.96	8.67	12.62	0.50	3.15
Thailand						
GDP	349.00 B	75.00 B	221.00 B	460.00 B	-0.16	1.82
RELC	13.52	7.03	6.38	28.02	1.03	2.64
Turkey						
GDP	701.00 B	227.00 B	390.00 B	1130.00 B	0.29	1.83
RELC	63.80	32.90	24.34	132.26	0.82	2.46
China						
GDP	8330.00 B	4190.00 B	2770.00 B	15900.00 B	0.27	1.77
RELC	1007.07	689.01	225.56	2452.53	0.63	2.16
Armenia						
GDP	8.91 B	2.65 B	3.96 B	12.90 B	-0.39	2.16
RELC	2.00	0.39	0.96	2.54	-1.01	3.89
Brazil						
GDP	1600.00 B	242.00 B	1190.00 B	1870.00 B	-0.55	1.73
RELC	410.01	74.89	273.71	520.01	-0.28	1.93
Colombia						
GDP	243.00 B	58.00 B	157.00 B	331.00 B	-0.06	1.60
RELC	45.77	8.62	31.69	61.39	0.13	2.31
India						
GDP	1670.00 B	656.00 B	801.00 B	2760.00 B	0.29	1.73
RELC	172.53	78.88	72.78	332.20	0.59	2.37
Indonesia						
GDP	705.00 B	227.00 B	395.00 B	1070.00 B	0.21	1.67
RELC	32.40	11.39	19.60	56.22	0.67	2.28
Nicaragua						
GDP	10.60 B	2.33 B	7.32 B	14.20 B	0.11	1.56

RELC	1.57	0.71	0.44	2.53	-0.02	1.56
Tajikistan						
GDP	6.68 B	2.91 B	2.70 B	12.50 B	0.45	2.08
RELC	16.52	1.25	13.77	19.17	-0.22	3.43
Ukraine						
GDP	99.30 B	12.80 B	69.80 B	120.00 B	-0.57	2.94
RELC	12.11	3.05	7.10	21.86	1.58	6.27
Vietnam						
GDP	196.00 B	76.70 B	93.50 B	332.00 B	0.40	1.92
RELC	45.62	28.48	14.55	104.22	0.54	1.95
Ethiopia						
GDP	48.50 B	27.40 B	17.40 B	100.00 B	0.53	1.93
RELC	7.11	4.85	1.64	14.68	0.40	1.54
Madagascar						
GDP	10.20 B	1.81 B	7.14 B	13.20 B	0.01	1.92
RELC	0.73	0.13	0.53	0.98	0.36	2.16
Mali						
GDP	11.30 B	3.08 B	6.26 B	16.30 B	0.21	1.90
RELC	0.93	0.51	0.25	1.65	-0.12	1.49
Mozambique						
GDP	12.10 B	4.53 B	5.22 B	18.40 B	0.03	1.57
RELC	14.51	2.14	9.58	17.62	-0.74	2.65
Tanzania						
GDP	38.40 B	14.70 B	18.50 B	64.20 B	0.33	1.83
RELC	2.78	0.48	1.84	3.71	0.03	2.45
Togo						
GDP	4.83 B	1.35 B	3.38 B	7.46 B	0.60	1.91
RELC	0.12	0.06	0.04	0.25	0.91	2.81
Burkina Faso						
GDP	9.87 B	3.48 B	5.11 B	16.30 B	0.34	1.90
RELC	0.13	0.05	0.05	0.23	0.79	2.66
Burundi						
GDP	2.69 B	0.48 B	1.96 B	3.32 B	-0.23	1.46
RELC	0.14	0.05	0.09	0.24	0.91	2.74
Central African Republic						
GDP	1.94 B	0.26 B	1.62 B	2.55 B	0.92	3.08
RELC	0.13	0.03	0.08	0.17	-0.98	2.84
Democratic Republic of Congo						
GDP	29.40 B	10.60 B	16.20 B	48.10 B	0.32	1.69
RELC	8.19	1.71	5.91	11.92	0.64	2.59

CURRICULUM VITAE