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Impact of Energy Use on Economic Growth: The Case of Zimbabwe (2010-2020)

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PERMANENT ADDRESS:

Dedication

I give thanks to God Almighty for providing me with health and vigor as I worked on this endeavor. Completing this study has been made possible by the guidance and assistance of numerous people. I will always be appreciative of my supervisor for his professionalism, leadership, and support. With his help, I was able to finish this dissertation in the allotted time. Finally, I appreciate the support from my family for giving me enough time to study.

Abstract

This study used time series data covering the years 2010–2020 to examine the relationship between energy use and economic growth in Zimbabwe. Data analysis has used the limits testing approach of Pesaran et al. (2001), which does not require pretesting of variables for unit root and its related error correction model. The results demonstrate the cointegration of energy consumption and economic growth, demonstrating that energy use is a Granger cause of economic expansion. It was discovered that increasing current energy use increased Zimbabwe's economic growth more than proportionally. To boost economic growth, policy actions that support energy generation and use are advised.

Contents

Acronyms and abbreviations

GHGs	Green House Gas Emissions
GOZ	Government of Zimbabwe
MoEPIP	Ministry of Economic Planning and Investment Promotion
MoMET	Ministry of Mines, Environment and Tourism
MoEPD	Ministry of Energy and Power Development
MW	Mega Watt
TFP	Total Factor Productivity
ZEPARU	Zimbabwe Economic Policy Analysis and Research Unit
ZIM ASSET	Zimbabwe Agenda for Sustainable Socio-Economic Transformation

CHAPTER 1

INTRODUCTION

1.0 Background to the Study

Every country that wants to improve the welfare of its citizens must have economic growth as one of its primary objectives. There are several factors known to influence variations in economic growth rates, including capital, labor, and the external technology factor introduced by Solow, among others. It is widely acknowledged and supported by empirical evidence that technological advancement plays a significant role in driving economic growth. In fact, technological progress is believed to contribute to over 50% of economic growth, while labor and capital account for the remaining portion (Han and Lee, 2020). However, it's important to note that some scholars argue that technological advancement alone, although crucial, is not sufficient to guarantee robust economic growth. They contend that the availability and efficient utilization of energy resources are essential for technology-driven progress to have a substantial impact on economic growth. Technology inherently requires energy for its operation (Berndt, 1990), and without energy input, even with positive inputs of technology, labor, and capital, the contribution of technology to overall output will be effectively zero. In the context of Zimbabwe, the Zimbabwe Electricity Supply Authority (ZESA) Holdings faces various challenges as it strives to provide reliable, secure, and sufficient power to meet the energy requirements of the Zimbabwean economy.

The traditional theories of economic growth do not take into account energy as a factor of production whilst ecological economic growth theory argue that energy together with capital and labour are the active factors of production and economic growth (Ahmad et al, 2020). Furthermore, there is insufficient empirical evidence to support the correlation between energy consumption and economic growth. Whilst some scholars provide evidence that energy has no long run relationship with economic growth (Hou, 2009; Okafor, 2012), others have shown that energy use have a long run relationship with economic growth (Hye & Riaz, 2008). There is differing evidence regarding the course of causation between energy usage and economic growth. Stern, (1998) found that energy use cause economic growth whilst Asafu-Adjaye (2000) and Ahmad et al (2012) established that energy use is a result of economic growth rather than a cause of growth.

Empirical literature that investigated the link between energy use and economic growth in Zimbabwe has also shown lack of consensus (Samu, Bekun, and Fahrioglu, 2019; Dabachi et al, 2020; Mhaka et al, 2020; Sunde, T., 2020). They aimed to establish the causal relationship between energy use and economic growth in order to explain the implication on growth of energy conservation policies targeted to reduce GHGs emitted by energy use (Samu, Bekun, and Fahrioglu, 2019; Dabachi et al, 2020; Sunde, T., 2020). The problem investigated to the Zimbabwean context was more general rather than customized.

Thermal (coal fired) and hydro sources of energy are the two major sources of electricity supply in Zimbabwe. The country has mainly five plants that is four thermal power stations namely Hwange Power Station, small thermals (Harare, Bulawayo and Munyati Power Stations) and one Kariba Hydro hydropower power station, (ZPC,2012). Zimbabwe relies mainly on coal fired thermal power generation which used to account for about 75% of electricity supply, (Kaseke, 2011) during the 1990s. The other 25% was generated from hydro resources of the Zambezi River (the Kariba Hydro Power Station).

Currently, electricity supply in Zimbabwe heavily relies on large hydro, coal, fuel wood and thermal power stations to meet its energy needs. The current internal energy sources together with power imports are failing to meet the country’s ever increasing demand. The pictorial picture below shows the increasing trend of electricity demand in Zimbabwe.

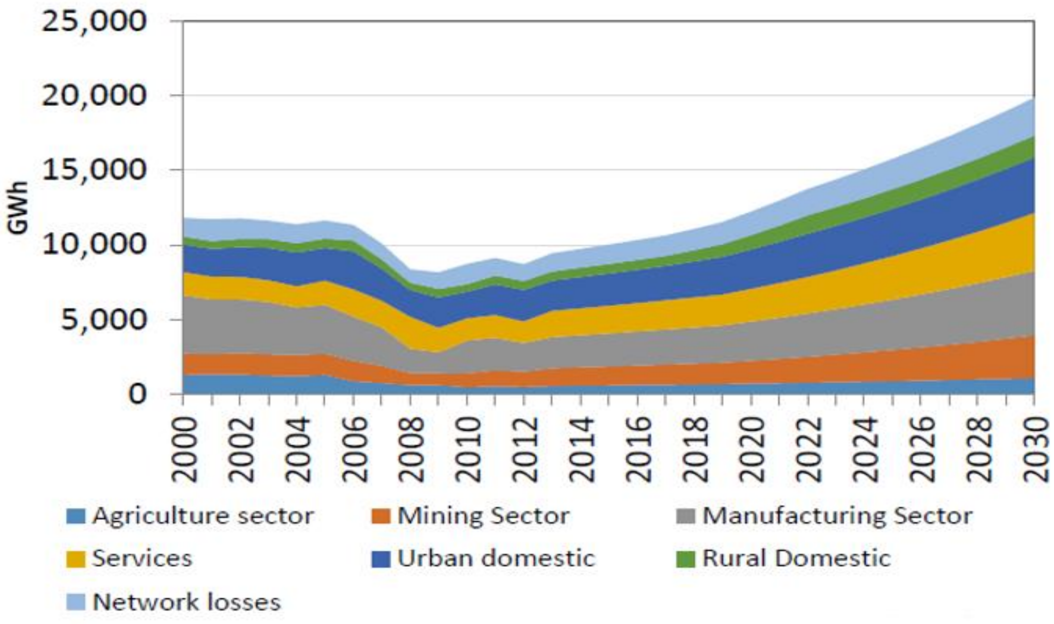


Figure 1. 3 Zimbabwe Electricity demand projections

Source: ZILF, 2014

Electricity is a critical input to any economy, as such it is a key enabler to the achievement of economic and social growth and productivity, (ZimAsset, 2013)

The government of Zimbabwe has to date installed a 1960MW capacity for generation of electricity. Available capacity as at March 2013 was 1026MW against an estimated country peak demand of 2200MW (MoEPIP, 2013). The country has been experiencing electricity supply deficits and load shedding for more than a decade (see Table. 2 below).

Table 2: Installed versus available electricity capacity 2000-2011

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
INSTALLED CAPACITY (MW)												
Hwange	920	920	920	920	920	920	920	920	920	920	920	920
Kariba	694	722	736	750	750	750	750	750	750	750	750	750
Small thermals	290	290	290	290	290	290	290	290	290	290	290	290

Total	1904	1932	1946	1960	1960	1960	1960	1960	1960	1960	1960	1960
CAPACITY AVAILABLE												
Hwange	496	716	659	498	583	579	435	421	388	287	500	727
Kariba	511	531	588	701	723	725	711	727	747	746	750	573
Small thermals	133	105	101	43	110	42	26	26	34	13	60	100
Total	1140	1352	1348	1242	1416	1346	1172	1174	1169	1046	1310	1400
% of installed capacity	59.9	70	69.3	63.4	72.2	68.7	59.8	59.9	59.6	53.4	66.8	71.4
Peak demand	1986	2013	2028	2007	2069	2066	1904	1758	1429	1403	2100	2100
Supply deficit	(846)	(661)	(680)	(765)	(653)	(720)	(732)	(584)	(260)	(357)	(790)	(700)

Table Chipumho (2011).

1.2 Problem Statement

The persistent energy crisis in Zimbabwe is considered one of the factors affecting the country's growth trajectory. For more than a decade, Zimbabwe has been experiencing energy supply deficiencies, with energy production falling short of the demand from households, industries, agriculture, and commerce. Because of these energy shortages, the amount of available usable energy in the different economic sectors is limited. There is disagreement in economic theory about how these energy restrictions affect economic growth. While ecological economics sees energy as crucial to the production process and, consequently, to economic growth, neoclassical economics downplays the importance of energy as a production-related factor. Conflicting findings from empirical studies on the impact of energy usage on economic performance further complicate understanding of this relationship.

1.3 Research Objectives

This primary objective of the research is to consider how energy use affects the economic development of Zimbabwe. To achieve this overarching objective, the study will pursue the following sub-objectives:

i. To determine whether there is a sustainable, stable connection between energy consumption and economic growth.
ii. To Establish the presence of a causal relationship concerning energy use and economic expansion.
iii. To find the impact that energy consumption has on the nation's economic expansion.

1.4 Research Questions

i. Is there a connection between energy use and economic expansion?
ii. Is rising energy consumption a cause of economic expansion or a byproduct of increased economic bustle?
iii. How much does energy usage affect economic expansion?

1.5 Research Hypotheses

The following hypotheses will be looked at in the study:

i. There is no consistent link between energy consumption and economic expansion.
ii. Energy use does not lead to economic expansion.
iii. The affiliation between energy usage and economic growth is statistically equivalent to zero.

1.6 Justification

ZESA, the Zimbabwean electricity provider, is currently grappling with a significant challenge in meeting the demand for electricity, leading to constraints on energy usage by all sectors of the economy. If energy consumption does, in fact, drive economic growth, then the nation's ongoing energy crisis is severely impeding economic growth and could lead to higher unemployment and higher rates of poverty.

As the availability of energy is a key component in the growth process, persistent energy shortages could also interfere with other macroeconomic policies intended to maintain economic growth. In order to comprehend the magnitude of lost output, increased unemployment, and increased poverty levels brought on by energy deficits, it is crucial to evaluate the degree to which energy consumption affects economic growth.

Quantifying this relationship becomes crucial if energy consumption does, in fact, promote economic growth. Policymakers would be better able to predict the amount of energy needed to keep growth at desired rates with the help of this information. It would also help with budgeting for the expenditures required to guarantee a steady energy supply capable of supporting the desired economic growth trajectory.

Furthermore, the findings of this study will be extremely useful in shaping energy policies. Reduced energy consumption would impede economic growth if a one-way causal link between energy usage and economic growth is established. Energy policies should prioritise the growth of the energy sector in such a situation to guarantee a steady supply of energy. Energy use becomes a byproduct rather than the main cause of economic growth if economic growth drives it. In this situation, more cautious energy policies could be implemented without impairing economic expansion.

Finally, the goal of this study is to provide critical evidence that can be used as a baseline or reference point in Zimbabwe for aligning macroeconomic policies with energy development policies. This research endeavour is very valuable given the significance of comprehending the part played by energy usage in economic growth as well as the limitations of earlier studies conducted in the nation that only examined the actuality of the affiliation and the direction of interconnection without estimating the long-term relationship.

1.7 Chapter Summary

The researcher has identified a critical necessity to examine the connection between energy utilization and economic expansion, recognizing various benefits and drawbacks that will be examined in the existing body of literature. The final chapter will provide recommendations based on the findings. Chapter one serves as the introduction to the study, presenting background information, articulating the statement problem, specifying the objectives, research questions, and significance, establishing the theoretical framework, stating assumptions, providing definitions, outlining the scope, and acknowledging limitations. The subsequent chapter delves into the existing literature concerning the correlation between energy consumption and economic growth.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The literature review is a pivotal component of any research endeavor, serving as a foundation upon which new insights are constructed while expanding the breadth of knowledge within a specific subject area (Bourne, 1996). This chapter investigates the influence of energy consumption on Zimbabwe's economic expansion, drawing on existing knowledge to inform and contextualise the research. Within the following pages, the gap in the literature is identified, followed by a comprehensive theoretical review and an examination of empirical studies. These elements culminate in the development of a conceptual framework that will guide the study's objectives. Importantly, this chapter seeks to address and elucidate the following contentious questions:

i. Does the cost share of energy match its productivity?

ii. Is energy serving as an intermediary factor in production?

iii. Can non-energy factors adequately substitute for the part of energy in the production process?

The review of literature begins with an examination of theoretical aspects, followed by a presentation of empirical evidence concerning the complex relationship amid energy consumption and economic growth, and concludes this chapter.

2.1 Theoretical Review

To truly comprehend the impact of energy usage on economic growth, it is necessary to first comprehend its significance in the manufacturing process. There are two opposing theoretical perspectives on energy's role in manufacturing and economic expansion.

The first is the traditional growth theory, which Solow (1956) described. The contribution of energy to production and, consequently, to generating economic growth, is minimised by this theory. This viewpoint frequently sees energy as an intermediary input that has little bearing on overall economic expansion.

According to ecological economists like Kummel et al. (2008) and Ayres et al. (2013), energy is a crucial and essential component of production. This viewpoint contends that energy use actively promotes economic expansion.

The part played by energy in production, the perspectives on economic expansion put forth by both conventional and ecological economic growth theories, and a review of how the theoretical stances impact the model used in this study will all be covered in the section that follows. In light of these theoretical viewpoints, we will also look into the impact of energy consumption on economic growth.

2.1.1 The part played by energy in the production process

Production is the process of converting raw materials into partially or fully finished goods and services. According to neoclassical economic theory, there are two different categories of factors that go into production: primary and intermediate (Sriyana, 2019). Energy, like other materials, is typically seen as an intermediate input while capital and labour are typically regarded as the primary factors. While primary factors are present at the beginning of the production period and are not depleted during that period, intermediate inputs are created and depleted during a specific production period (Sriyana, 2019).

According to Stern and Cleveland (2004), a significant portion of payments to factors of production goes to the owners of primary factors for services they directly provide or that are embedded in created intermediate inputs. In neoclassical economics, it is assumed that these factors are obtained from perfectly competitive markets, and companies must employ them until the value of the additional output produced by each factor equals its additional cost to maximize their profits. Additionally, neoclassical economics posits that there is a consistent elasticity of substitution across all production factors, suggesting that energy can be substituted with either capital or labor. Within the framework of neoclassical economic theory, energy usage is thought to have a negligible effect on production and economic growth (Kummel et al., 2010).

In ecological economics, energy is viewed as a crucial component of production along with capital and labour (Nguyen et al, 2020). Capital in this context includes devices for energy conversion and information processing, as well as the infrastructure and buildings that enable their safe and efficient use. Some of these devices' components, such as heat engines and transistors, require energy to operate. The primary function of energy is to provide the power required by machinery. Assuming that all production processes involve the use of this defined capital, it follows that with no energy input and only positive inputs of other factors, the output would be zero (Stern, 2010). While energy can be to some extent replaced by capital or labor, there are inherent limitations. Technological progress can lead to the development of energy-efficient machinery, but these devices still require energy for their operation. Likewise, labor can perform routine tasks without relying on commercial energy, but it lacks the capacity to activate industrial machinery. Consequently, considering the energy embedded within physical capital, there exists a minimum threshold of energy consumption required to prevent significant production constraints.

Within the production process, energy serves a pivotal role in activating capital, encompassing machinery and equipment. However, the management and oversight of these resources are carried out by labor, which necessitates varying levels of skill. Raw materials, in and of themselves, do not actively participate in the production process; instead, it is the combined efforts of capital, labor, and energy that drive the transformation of raw materials into valuable end products. These three factors work together to rearrange raw material particles, atoms, or molecules, transforming them into useful final products. Energy, capital, and labour are all seen as equally important in the manufacturing process in the ecological economic framework, whereas raw materials are seen as passive elements (Sriyana, 2019). Therefore, this study posits that fluctuations in energy usage are anticipated to exert a substantial influence on output variability, aligning with this perspective.

2.1.2 The Standard growth theory

The basis of conventional growth theory can be attributed to Solow's research in 1956, which is commonly referred to as neoclassical economic growth theory (Munir et al, 2020). This theory argues that persistent economic growth is the outcome of primarily two factors: technological advancement and the accumulation of capital and labor resources. This concept is represented mathematically through the neoclassical aggregate production function (Ikeshita et al, 2023):

$Y = Af(K, L)$ (1)

Y stands for the overall economic output, K for capital, L for labour, and A for technology in this equation (Ikeshita et al, 2023).

According to Solow (1956), assuming a constant level of technology, increasing the amount of capital per worker leads to higher output per worker. Labor is assumed to increase in proportion to the population growth rate, while the accumulation of capital depends on factors like savings, investments, capital wear and tear, and labor growth. To achieve economic growth, the rate at which capital accumulates must surpass the combined rates of capital depreciation and labor growth. However, this expansion merely moves the economy to a new equilibrium point along the same production function. This shift is driven by capital accumulation, but technological advancement lifts the entire production function upward. Solow's model, on the other hand, does not clarify the source or origin of technological progress and instead treats it as an external factor, typically represented as an unexplained residual above and beyond labour and capital contributions. It should be noted that this neoclassical economics-based model does not take into account how energy is used to explain economic growth, making it less appropriate for examining how energy consumption affects economic growth in Zimbabwe.

Additionally, for the Solow model to explain more than 50% of economic growth, an unknowable factor known as exogenous technology is required. This limitation highlights a substantial gap in the theory, as it depends on this unexplained component to clarify how labor and capital inputs translate into economic output (Snowdon & Vane, 2005). This shortcoming led to the emergence of endogenous growth theories, which seek to elucidate the nature of this residual.

The first group of endogenous growth theories proposes that technological advances are the result of investments in human and physical capital made by both firms and individuals. In these models, technology is regarded as something that can be actively influenced and decided upon:

$Y = f(K, L, A)$ (2)

In this equation, A represents technology, which is characterized by non-excludability. This means that firms cannot fully capture the positive externalities generated by their investments in knowledge and technology. Consequently, investments by one entity lead to positive spillover effects that contribute to the economy's overall stock of knowledge (A), ultimately shifting the production frontier of the economy.

The second group of endogenous growth theories contends that deliberate actions spurred by financial incentives are what lead to technological advancement. Here, knowledge is partly excludable due to patent laws. Because knowledge generation is non-rivalrous and incompletely excludable, it generates positive externalities that benefit the entire economy.

While these endogenous growth theories offer insights into how technology evolves, they do not explain the activation of technology to convert inputs into output. The crucial aspect missing from these explanations is the role of energy, particularly in powering the technical and industrial processes that transform raw materials into finished products and enhance productivity. By neglecting the role of energy, these models essentially assume that technology can activate and improve itself independently. Consequently, even though these theories focus on economic growth, they are not well-suited to analyze how energy use influences economic growth in Zimbabwe.

In recent times, institutional economic growth theory has emerged as another approach to explaining the factors driving technological progress. This theory emphasizes the significance of factors such as property rights, legal systems, regulatory frameworks, contract enforcement, levels of corruption, effective corporate governance, and sound economic policies in shaping both technological advancements and economic growth. However, like earlier theories, the institutional economic growth theory does not take into account the significance of energy in the context of economic growth (Sriyana, 2019).

The foundation for widely used empirical frameworks for analysing the causes of economic growth, such as the growth accounting framework, was laid by neoclassical growth theory (Sriyana, 2019). In this framework, total factor productivity (TFP) growth and the weighted average growth rates of capital and labour are combined to represent economic growth (Sriyana, 2019). Although its fundamental ideas can be extended to encompass additional elements like energy and materials, they are grounded in neoclassical economic theory and do not specifically discuss the function of energy.

$\Delta Y = \Delta A + \alpha + \beta$ (Equation 3)

$Y \qquad A \quad K \; L$

Y stands for GDP growth, A for total factor productivity growth, K for capital growth, and L for labour growth in this equation (Ikeshita et al, 2023). The variables and stand for the respective capital and labour output elasticities. The growth accounting framework, which is frequently used for empirical analysis but ignores the part played by energy in economic growth, is represented by these elements.

2.1.3 The framework for growth accounting and the part played by energy in economic growth

The growth accounting framework is founded on neoclassical theory, which assumes an idealised competitive market structure (Mahmoudi, 2021). Within this ideal market, factors of production are acquired through markets where their prices are determined by market forces, a concept famously articulated by Adam Smith. In this framework, it is assumed that all economic actors act rationally and are motivated by the pursuit of maximizing either profits or utility. The collective independent actions of these economic actors are expected to naturally guide the economy toward a state of equilibrium.

This equilibrium implies that, in their quest to maximize profits, economic actors should hire factors of production until the additional value brought by the last unit of a factor's contribution (referred to as marginal product) matches the cost of employing that factor. In simple terms, this signifies that factors like capital and labor in the growth accounting equation (Equation 3) receive compensation that precisely corresponds to the value they bring to the production process.

This alignment between factor marginal productivity value and the factor marginal cost is known as the cost share theorem, as recognized in existing literature (Kummel et al., 2010; Lindenberger & Kummel, 2011). Given this theorem, it becomes possible to estimate factor productivity using data from national income accounts.

Moreover, this equation suggests that when a particular factor of production has a higher marginal cost or represents a larger proportion of the total production cost (referred to as cost share) as indicated in national accounts, it signifies that this factor holds greater importance in terms of its productive influence.

Building upon this identity, Hoorelbeke (2011) expanded the growth accounting framework to encompass energy as a factor of production, alongside capital and labor. This expansion of the study sought to explore the drivers of growth in the construction sector across three distinct regions in Belgium (Hoorelbeke, 2011). To do so, cost allocations obtained from national accounts were employed to assess the impacts of different factor inputs on value-added decomposition.

Table.2 Factor cost shares (in % averages)

Factor		region	
	Brussels	Flanders	Wallonia
Capital	24.8	17.6	19
Labour	17.4	19	20.3
Energy	0.1	1.4	1.5
Materials	57.7	62	59.2

Table Sourced from Hoorelbeke (2011)

When the productivity equivalence of energy is examined, as shown in Table 2, it is clear that energy's contribution to value-added is minimal.

Historically, factor cost shares have remained relatively constant, with labor accounting for an average of 70%, capital for about 25%, and energy for roughly 5% (Ayres et al., 2009; Lindernberger & Kummel, 2002) of the total production cost. Energy's relatively small cost share in the context of the neoclassical cost share theorem suggests that it is excluded as a critical factor for economic growth. As a result, fluctuations in energy consumption are thought to have little impact on economic growth.

However, the neoclassical growth model faced significant criticism from ecological economists when it failed to explain economic recessions that followed events like the 1973 OPEC cartel oil crisis and the 1979 Iraq-Iran war (Kummel et al., 2002). These occurrences caused the energy supply to drop, which led to rationing. The energy supply fell by a sizable 7% during the first energy crisis. Neoclassical growth theory predicts that this 7% decline in energy supply should have led to a corresponding drop in energy consumption, which would have resulted in a negligible decline in economic growth of about 0.35 percent (5% x 7%). However, the observed decline in economic growth was ten times greater than predicted by neoclassical growth theory (Lindernberger & Kummel, 2002). Neoclassical growth theory, which weights production factors according to their respective cost shares, was unable to explain how a decline in the use of a small amount of money could cause a significant economic downturn (Hennings & Samuels, 2012).

2.1.4 Ecological growth theory

The neoclassical growth theory's inability to explain the economic downturns of the 1970s, often referred to as energy crises, has prompted criticism from a group of ecological economists, including scholars such as Hall et al. (2001), Stern and Cleveland (2004), Ayres and Warr (2009), Kummel et al. (2010), and Stern (2010). Their arguments can be summarized as follows:

1. The occurrence of economic recessions during energy crises strongly implies that energy, like capital and labour, should be treated as a primary factor of production and given equal importance within neoclassical growth theory (Sriyana, 2019).

2. During the 1970s energy crises, it became clear that the impact of energy on output exceeded its cost share in national income. This calls into question the rationale for excluding energy as a primary factor of production in neoclassical theory.

3. In manufacturing processes, there is a difference between energy and non-energy factors.

These justifications emphasise how vital energy is to both production and, consequently, economic growth. According to academics, taking these variables into account calls for a growth theory that clearly illustrates how capital, labour, energy, and raw materials interact (Sriyana, 2019).

To elaborate on these points, ecological economists assert that energy should indeed be categorized as a primary factor of production and meets the criteria outlined by neoclassical economic theory. According to Brown et al. (2011), energy cannot be created or destroyed; it can only undergo transformation and degradation. Energy enters the production system from the environment and eventually exits as waste and low-temperature heat with a low exergy. Exergy is the capacity to perform useful work. Energy's availability is therefore exogenous to the production function because it is neither produced nor used during the production phase (Dolderer et al, 2021).

Furthermore, the profit maximisation premise, which states that firms are expected to hire factors of production until the value of their marginal product equals the marginal cost of hiring them, is the foundation for the neoclassical growth theory's claim that energy plays a minor role in economic growth (Serano, 2023). However, detractors contend that this premise is incorrect because, in real-world scenarios, energy affects output more than it costs. From the calculus of unconstrained optimisation, this equality is derived. For instance, the profit function in an economy with output represented by Y(X), factor inputs in the vector X, and a vector of factor prices represented by w is written as follows (Wang et al, 2020):

$$Y(X) - wX \qquad (4)$$

By taking the equation's derivatives with respect to the factor inputs and setting these derivatives to zero, we can get the equality Y(X) = wi (Equation 5). Equation 6 is obtained by multiplying both sides of Equation 5 by Y(X)X_i: Y(X)X_i Y(X) = wi X_i. This equation demonstrates that each factor's marginal product must equal its price in order to maximise profit (Wang et al, 2020). Equation 6 also shows that each production factor's output elasticity is equal to its cost share in national income.

Neoclassical theory states that businesses can maximise profits by focusing only on the cost of hiring factor inputs (Klitgaard, 2022). It envisions businesses using inputs to create output without being restricted by physical limitations, much like a streamlined circular flow of income model. According to critics, this depiction does not accurately represent real-world production processes and ignores the physical aspects of production. The wealth distribution and the exchange of goods and services are the main topics of the neoclassical theory, which makes the assumption of perfectly competitive markets (Serrano, 2023).

In actual competitive situations, the ideal assumptions of perfect competition often do not apply. Firms encounter various constraints during their operations. Acquiring information, for example, can be costly, and there may be technological constraints, such as production facilities designed for specific energy input levels. The output will be suboptimal if energy levels fall below the designed threshold. These constraints impose additional costs on firms, which can disrupt the traditional profit maximization calculation (Ayres et al., 2013; Kummel et al., 2010).

To incorporate these constraints into profit maximization calculations, we can modify the profit function (previously represented as Equation 4) as follows:

$$Y(X) - wX - \lambda a(X) \quad (7)$$

Here, 'a' stands for constraint parameters and '' stands for the Lagrange multiplier. Equation (7) is differentiated with respect to factor inputs and the derivatives are set to zero to produce (Zungu & Greyling, 2022):

$$\partial Y(X) - wi - \lambda a \partial (X) = 0$$

Or

$\partial Y(X) = wi + \lambda a\partial(X)$ (8)

We multiply both sides of Equation (8) by 'X,' to get:

$Y(\ )X$

$X\ i\ \partial Y(X) = wi\ X\ i + \lambda\ X\ i\ \ a\partial(X)$ (9)

Equation (8) demonstrates that each factor's marginal product is greater than its price when firms consider constraints in their optimisation decisions. Equation (9) demonstrates that each production factor's output elasticity exceeds its cost share in national income when optimisation is constrained. The duality theory, a popular tool in neoclassical growth theory for estimating the output elasticity of production factors from national accounts or cost functions, is now in doubt as a result of this (Zungu & Greyling, 2022).

The question of whether non-energy factors can effectively take the place of energy in the manufacturing process is another crucial one. It is argued that there is a minimum amount of energy needed to perform work, highlighting the limited substitutability of energy and non-energy factors of production, using biophysics and the second law of thermodynamics. The output will therefore invariably be zero if the energy input is decreased to zero while the non-energy inputs remain positive. As capital stimulated by energy and non-energy inputs is unable to completely replace energy, this emphasises the idea that production processes cannot function without a positive supply of energy.

Ecological economists' three arguments refute the neoclassical growth theory's denial of the role of energy in economic expansion (Nomidis, 2019). These arguments imply that the criticisms of the neoclassical theory of the part of energy in economic growth are unfounded. An alternative growth theory is required, one that can adequately explain how various factors interact within the physical production framework of the economy.

Within the context of endogenous growth theory, Toman and Jemelkova (2003) have developed a more compelling model that clarifies the role of energy utilization in economic growth. The model is represented as follows:

$Y = F(AK\text{\^{}}K, AL\text{\^{}}L, E)$ (10)

In this model, Y stands for total economic output, and K, L, and E, respectively, stand for the use of capital, labour, and energy. The parameters AK and AL show how the use of energy increases the productivity of capital and labour, respectively. You should be aware that this model accepts that the substitutability of energy and non-energy inputs is constrained and has an elasticity of substitution of less than one. The model outlines three ways in which energy usage can impact economic growth:

1. **Direct Impact:** Energy usage directly contributes to economic growth. In any production process, energy is a vital component necessary to activate capital. Energy, working alongside capital and labor, actively participates in adding value by transforming raw materials into desired products.
2. **Enhancing Productivity:** Energy usage enhances the productivity of both capital and labor. It speeds up production processes, allowing for higher output with the same amount of capital and labor. By lowering production costs due to the increased output per unit of labour and capital, savings and new investments are made possible. Instead of just using more labour and capital, accelerated production processes result in efficiency gains that allow for economies of scale.
3. **Improving Labor Productivity:** Energy usage also improves labor productivity by extending working hours and providing opportunities for learning beyond regular working hours. Access to affordable and cleaner energy enhances healthcare systems, leading to healthier and more productive workers. Increased energy availability benefits access to clean water, better indoor air quality, food and medicine refrigeration, better sanitation, and healthcare services.

Furthermore, the use of inexpensive energy and its accessibility upsurges the cost-effectiveness of already-existing capital assets. Lowered energy costs make current capital investments more profitable, which encourages decisions to increase the existing capital base. This expansion has the potential to increase overall productivity and, as a result, economic growth. The capital stock tends to adjust gradually to changes in energy prices over time.

In addition, a consistent supply of high-quality energy promotes innovation, further contributing to economic growth. Economies transitioning from lower-quality energy sources (like wood, animal power, dung, and charcoal) to higher-quality energy forms and changes in capital structure occur in industries such as liquid fuels, gas, and electricity. This transition increases the turnover of capital assets, which drives economic growth.

Despite the fact that energy use boosts capital and labour productivity, it's important to acknowledge that technological advancements built into capital as well as knowledge gained by workers through on-the-job training or experience can also result in more efficient energy use. As a result, the ecological growth model presented in equation 10 could be improved by introducing an energy-augmenting factor, denoted as AE. In contrast to the current view that energy use benefits only capital and labour, this addition would provide a more accurate representation of how all inputs are interconnected. This transition increases the turnover of capital assets, which drives economic growth.

Although energy use increases capital and labour productivity, it is important to recognise that technological advancements embedded in capital and knowledge gained by personnel through on-the-job training exercises or experience can also lead to more efficient energy utilisation. As a result, by introducing an energy-augmenting factor, denoted as AE, the ecological growth model presented in equation 10 could be improved. This addition would provide a more accurate representation of how all inputs are interconnected, as opposed to the current viewpoint that energy use benefits only capital and labour.

Understanding the effects on economic welfare of raising productivity in particular areas versus raising productivity as a whole is crucial. An increase in total factor productivity implies that resource savings or more effective input use led to output growth. On the other hand, an increase in one factor's productivity suggests that the use of another may also increase, which could have an impact on the economy's overall input costs. Therefore, it might be more advantageous to increase all inputs' technological capabilities.

2.1.5 Discussion of the theoretical review

The relationship between energy efficiency and its share of costs in national accounts, the idea that energy input can be substituted with labour or capital inputs, and the classification of energy as a primary or intermediate factor in production are the three main areas where the two theoretical perspectives we've looked at fundamentally diverge. These disagreements raise questions about how competitive factor markets operate and how we assess the scarcity or value of factors within these markets.

In countries like Zimbabwe, energy markets are subject to heavy regulation, often controlled by government entities. Prices are typically set by authorities rather than being allowed to respond to market dynamics. This situation raises concerns about whether the equality between marginal productivity and marginal cost holds in practice. Furthermore, energy prices may be intentionally kept artificially low, even below optimal levels, to secure political support, especially during elections. Zimbabwe has experienced instances where clients of the Zimbabwe Electricity Supply Authority were granted amnesty for their outstanding bills, highlighting such practices.

In real-world situations, such as a fertilizer company facing an electricity shortage, the economic costs can go beyond the simple monetary expenses incurred due to the lack of electricity units supplied to that company (as seen in the case of Sable Chemicals). Past energy crises, particularly those of the 1970s, have offered empirical proof that energy productivity goes beyond what is reflected in national accounts in terms of cost (Li et al, 2022). The trajectory of economic growth is therefore anticipated to be more significantly and disruptively affected by variations in energy consumption than would be predicted by neoclassical growth theory. This study argues that energy consumption should be taken into account when determining how energy affects economic growth in Zimbabwe.

Energy and labor/capital inputs, according to ecological economists, are not perfect substitutes for each other. As organisations become more capital-intensive, they frequently replace labour with more capital, resulting in increased energy consumption while decreasing reliance on labour. This change is supported by empirical evidence, which shows that there is a negative elasticity of substitution between energy and non-energy inputs (Altunç, & YILDIRIM, 2020). It has been found that energy and capital work in tandem, with some studies showing that energy not only supplements skilled labour but also replaces unskilled labour.

Evidence indicates a decrease in energy consumption per unit of output, which suggests that energy can be replaced by either capital or labour. However, some studies argue that energy intensity is declining at a decreasing rate, implying that production will eventually reach a level where production would be constrained. The availability of energy remains crucial for sustaining production, and shortages beyond a certain point can hinder economic growth.

Energy productivity exceeds its cost share, and its unique role cannot be replicated by either capital or labor. The ecological economic theory's arguments regarding energy use in economic growth hold more weight, encouraging the development of a growth model that treats capital, labor, and energy as independent variables.

While the ongoing theoretical debate over the role of energy in economic growth between ecological economic theory and neoclassical growth theory remains unresolved, Stern (2010) has attempted to bridge the gap between the two. Using a nested CES production function and an energy variable, he enhanced the neoclassical growth model:

$$Y = [(1-\lambda)(AL^{\alpha}L^{\alpha}K^{(1-\alpha)})^{\phi} + \lambda(AE^{E})^{\phi}]^{\phi} \quad (11)$$

This model has a number of parameters at play, denoted by equation (11), which measure the relative effects of energy and non-energy inputs on economic growth and represent, respectively, the substitution elasticity of energy and non-energy inputs (Altunç, & YILDIRIM, 2020). Labour and energy augmentation-related parameters are AL and AE, respectively. Stern's model does not include a capital augmenting parameter, and no justification was given for this oversight. The model is constrained by the assumption that the elasticity of substitution between energy and non-energy inputs is less than one, which shows that a certain amount of energy is necessary for the production process to proceed. Model (11) demonstrates unequivocally how production is severely constrained by a lack of energy, which has an impact on economic growth. Conversely, when there is an abundance of energy supply, production constraints are alleviated. In such cases, economic growth is primarily constrained by factors such as capital and labour, in accordance with the principles of neoclassical growth theory. As a result, while neoclassical growth theory may be better suited to explaining economic growth in energy-rich economies, it may fall short in energy-scarce economies such as Zimbabwe. Additionally, improvements in energy efficiency (AE) lessen the energy needed to produce each unit of output, easing the production limitations brought on by energy scarcities. The relatively small cost share of energy in national accounts can be attributed to the fact that both increased energy efficiency and increased energy availability have the effect of lowering energy prices.

In summary:

1. Energy utilization is essential for fostering economic growth, and any inadequacy in energy supply can impede this growth.

2. The neoclassical growth theory, which assumes ample energy availability globally, can effectively account for economic growth in nations with abundant energy resources but falls short in economies like Zimbabwe where energy is scarce.

3. The low representation of energy costs in national accounts should not be interpreted as an indication that energy is insignificant in driving economic growth. Rather, it reflects the extent to which energy supply constrains production. As per the law of demand, when energy supply is abundant, it lowers energy prices, resulting in a reduced share of energy costs. Conversely, when there is an energy supply shortage, energy prices rise, leading to a higher proportion of energy costs in national accounts, assuming perfect competition in the market. In this context, the price of energy serves as an indicator of its scarcity level, not its utility. It's important to note that a low cost share due to energy efficiency should be seen as evidence of energy's high productivity, enabling increased output with the same energy input or equivalent output with fewer energy units.

The existing theoretical literature strongly supports the idea that energy is a critical factor in the manufacturing process. It asserts that energy consumption directly contributes to economic growth, and that any reduction in energy consumption is expected to result in lower economic growth. This cause-and-effect relationship is depicted as both direct and indirect, with energy improving capital and labour efficiency.

As a result, the theoretical framework for analysing how energy consumption affects economic growth in Zimbabwe is as follows:

$Y = {}_{f}(K;\ ;L\ {}_{E})$ (12)

Y here stands for overall economic output, which is typically calculated as real GDP. K, L, and E stand for the use of capital, labour, and energy, respectively. It's important to note that we have purposefully left out the capital and labour augmenting parameters, which take into account how energy use affects economic performance indirectly through capital and labour. Our research is particularly concerned with the direct effects of energy use.

The empirical questions are whether the described relationship in the theoretical framework applies to the long-term or short-term, and to what extent a decrease in energy usage would lead to a decrease in economic growth. To provide definitive answers, they require empirical analysis.

2.2 Empirical Literature Review

Particularly following the energy crises of the 1970s, the connection between energy consumption and economic growth has been a major area of empirical research. The main objective of research has been to ascertain whether an increase in energy use is a result of economic growth or if it is the cause of it (Okafor, 2012). In addressing this question, numerous studies, including those by Aqeel & Butt (2001), Okafor (2012), Hou (2009), Ifeakachukwu & Temidayo (2012), Farhani & Rejeb (2012), Hye & Riaz (2008), Asafu-Adjaye (2000), Vlahinic-Dizdarevic & Zikovic (2010), Ahmad et al. (2012), Stern (1998), Odularu & Okonkwo (2009), Warr & Ayres (2009), Ayres & Warr (2009), Stern & Enflo (2013), Tiwari (2011), Yalta & Cakar (2012), as well as Hall et al. (2001), Stresing et al. (2008), Kummel et al. (2008), and Qing & Yujie (2012), have shared the overarching goal of examining the relationship between energy consumption and economic growth, along with determining the direction of causality.

Some studies, including those by Aqeel & Butt (2001), Okafor (2012), Hou (2009), and Ifeakachukwu & Temidayo (2012), found no cointegration between energy variables and economic growth. In contrast, Farhani & Rejeb (2012) and Hye & Riaz (2008) discovered a long-term relationship between energy and economic growth variables. On the matter of causality, Asafu-Adjaye (2000), Vlahinic-Dizdarevic & Zikovic (2010), and Ahmad et al. (2012) established that economic growth leads to increased energy consumption, while Stern (1998), Odularu & Okonkwo (2009), Warr & Ayres (2009), Ayres & Warr (2009), and Stern & Enflo (2013) found that energy consumption Granger-causes economic growth. Tiwari (2011) and Yalta & Cakar (2012) concluded that energy consumption has a neutral impact on economic growth. Furthermore, Belke et al. (2010) and Akan et al. (2010) identified a bidirectional causal relationship between energy and economic growth.

It is challenging to come to a firm conclusion about whether energy consumption has a direct impact on economic growth due to the significant differences in empirical study results (Tiwari, 2011; Stern & Enflo, 2013). The next section of the literature review will investigate potential causes of inconsistent empirical results and go over how these results may change how the relationship between energy consumption and economic growth is modelled in the context of Zimbabwe.

2.2.1 Differing outcomes in empirical studies: How they affect the modeling of the influence of energy consumption on economic growth in Zimbabwe?

The inconsistent findings in empirical studies exploring the link between energy consumption and economic growth can be partially attributed to differences in research methodologies. While there is a consensus on the use of methods like cointegration and Granger causality, researchers have applied these techniques in two main ways: bivariate and multivariate approaches.

Only energy and economic expansion proxies are used as variables in bivariate models. On the other hand, multivariate models also take into account extra variables like labour and capital. Energy can have an impact on economic expansion both directly and indirectly through increasing labour and capital productivity, as has been previously discussed in the theoretical literature. Therefore, it makes sense to assume that using a multivariate or bivariate approach will produce different outcomes, with the bivariate approach omitting potential alternate causal mechanisms through which energy influences economic growth.

For instance, Hou (2009) used a bivariate approach with only energy and GDP as variables and found that energy and economic growth were not cointegrated in China, indicating a short-run feedback relationship between the two. Ahmad et al. (2012), also employing a bivariate approach, discovered that economic growth Granger-caused energy use in Pakistan. In contrast, Stern (1998), Warr and Ayres (2009), and Stern and Enflo (2013) employed multivariate approaches that included labor, capital, energy, and GDP as variables. According to their findings, there is a long-term link between energy use and economic growth, with the USA and Sweden experiencing economic growth as a result of energy use (Warr and Ayres, 2009). Using multivariate methods, Warr and Ayres (2009) found comparable results for the USA and Japan.

The empirical results of multivariate analyses are consistent with economic theory. As a result, in our research, we plan to model the influence of energy use on Zimbabwean economic growth using widely accepted incorporation and Granger causation methods within a multivariate framework. But there is disagreement in the empirical literature about which variables belong in a multivariate analysis. According to theory, factors like energy consumption, GDP, capital, and labour are taken into account in macroeconomic analyses of economic growth. The consumer price index, energy costs, household consumption spending, and various trade measures are examples of new variables that some studies have included despite their shaky theoretical underpinnings. Model misspecification may result from this practise.

Our study's empirical model will include data variables for GDP, labour, energy, and capital in order to address this problem. Theoretically, these variables are supported, and models that incorporate them have produced outcomes that are in line with the theoretical model (Equation 12).

It is also important to keep in mind that how energy variables are defined can affect how directly or indirectly energy influences economic growth. Measures of energy consumption include the oil-equivalent approach (Haque, 2021), the Divisia index, exergy, and useful work (Lin et al, 2021). Exergy, useful work, and the Divisia index are thought to account for changes in the energy mix, in contrast to the oil-equivalent approach which does not (Lin et al, 2021). Energy influences economic growth through a variety of mechanisms, one of which is improvements in energy quality.

For instance, Warr and Ayres (2009) used exergy and useful work variables for the USA and found that exergy Granger-caused economic growth in both the short run and the long run, while useful work only Granger-caused economic growth in the long run. Ayres and Warr (2009) obtained similar results using data from the USA and Japan.

The variability in research results can also be attributed to the sizes of the data samples used in these studies. Many of the reviewed studies had relatively small sample sizes, typically spanning only 30 to 40 years. For example, Shaari et al. (2012) analyzed data from 1980 to 2010 for Malaysia and found that GDP Granger-caused electricity consumption, while Ahmad et al. (2012) used data from 1973 to 2006 for Pakistan and found that GDP Granger-caused energy use. However, studies with longer data samples produced contrasting results. Stern and Enflo (2013) analyzed Swedish data from 1850 to 2000 and found that energy use Granger-caused economic growth. Ayres and Warr (2009) analyzed data for Japan and the USA spanning from 1900 to 2005 and established that energy use led to economic growth in both countries. These findings highlight the potential sensitivity of causality and cointegration techniques to variations in data samples.Researchers such as Belke et al. (2011) and Huang et al. (2008) have argued that tests like the Augmented Dickey-Fuller (ADF) unit root test and the Johansen cointegration test may not provide powerful statistical tests or may fail to detect a false hypothesis when applied to small data samples. These tests were commonly used in the studies reviewed to assess the properties of time series data. Given that this study utilizes a data sample spanning 32 years, it is essential to employ an analytical technique that offers robust performance with small sample sizes and does not rely heavily on the power of unit root tests. The bounds testing approach to cointegration developed by Pesaran et al. (2001) is a suitable alternative. This method can be used to avoid the need for unit root tests when data series are purely integrated of order one (I(1)) or integrated of order zero (I(0)).

Furthermore, causality tests conducted using the error correction model derived from the bounds testing approach have been shown to produce superior results compared to error correction models derived from the Engle–Granger and Johansen methods of cointegration (Iqbal, 2011; Iqbal & Uddin, 2013).

Another factor influencing research outcomes is the choice of time periods within a country for analysis. Economies undergo structural changes over time, altering their operational mechanisms and energy use patterns. Qing and Yujie (2012) estimated the output elasticity of energy for two periods, 1985 to 2000 and 2001 to 2009, using Chinese data. Their analysis showed that the energy output elasticity increased from 0.4864 in the initial period to 0.884 in the subsequent period, indicating that energy contributed more significantly to economic growth during the latter period (Qing et al 2012). Similar variations were observed in Germany by Stresing et al. (2008) and Kummel et al. (2008) in different time periods. Stern and Enflo (2013) also noted shifts in the causal relationship between energy use and economic growth in Sweden for different time spans. These findings suggest that the choice of time periods for analysis can significantly impact research outcomes. The study period was chosen based on the availability of data, and the analysis was carried out taking into account these potential changes in the relationship between energy use and economic growth over time.

The relationship between energy use and economic growth is not uniform across countries and regions, as observed in various studies. For instance, Hye and Riaz (2008) found that economic growth leads to increased energy consumption in Pakistan over the long term. However, Okafor (2012) discovered that total energy use drives economic growth in Nigeria, while the opposite relationship was established for South Africa. Bildirici (2012) used Granger causality tests and found that GDP Granger-causes electricity consumption for Togo, Zambia, and Zimbabwe, whereas electricity consumption Granger-causes GDP in Brunei. Chontanawat et al. (2006) conducted a study involving 30 OECD countries and 78 non-OECD developing countries, including Zimbabwe, and found that causality running from energy use to GDP is more common in developed OECD countries than in developing countries. Farhani and Rejeb (2012) used panel data for 95 countries and found that GDP and energy consumption are cointegrated. In both less developed and more developed nations, there is a causal relationship where changes in GDP precede and influence changes in energy consumption. However, in countries with intermediate income levels, it's the energy usage that precedes and influences economic growth. Kahsai et al. (2010) identified a bidirectional causality between energy use and economic growth in 40 low-income Sub-Saharan African countries. These variations can be attributed to various energy infrastructures, socioeconomic conditions, and technological stages in various nations and regions. Furthermore, an analysis of the empirical literature has shown that the outcomes are influenced by how economic or energy variables are aggregated or grouped. For example, Ifeakachukwu and Temidayo (2012) found bidirectional relationships between energy use and sectoral value added in Nigeria when analyzed at the sectoral level. In contrast, Okafor (2012) found that energy use Granger-caused economic growth in Nigeria when analyzed at the aggregate level. Moreover, results can vary depending on whether energy variables are aggregated or disaggregated. Nanthakumar and Subramaniam (2010) used aggregated energy and GDP data for Malaysia and found that the variables are cointegrated with a bidirectional relationship. However, when disaggregated energy data was used, Shaari et al. (2012) found that GDP Granger-caused electricity use, while a neutral relationship was found between GDP and other energy variables (oil and coal). This study chooses aggregated variables due to the sensitivity of research findings to the level of aggregation. Its main objective is to assess how energy use affects Zimbabwe's overall economic growth.

Moreover, it's essential to recognize that researchers sometimes inadequately match economic and energy variables when estimating causality. Variables that represent different scales of economic activities or are measured in different units should not be combined. For instance, results may be biassed if total energy consumption across the economy is combined with value added in the mining industry. Total energy consumption includes energy use in various sectors such as agriculture, households, services, and manufacturing, whereas economic growth only measures value added in one sector. Energy use in the mining sector should be matched with value added in the mining sector to ensure accurate results. Similarly, since electricity only makes up a small portion of overall energy consumption, adding GDP to the total electricity consumption for the entire economy can produce false results. In Zimbabwe, only 13% of the total energy supply was provided by electricity in 2009. Since they both represent the same level of economic activity, this study will use real GDP and total energy use as its proxy variables for economic output and energy use.

2.3 The conclusion of the literature review

The theoretical review has successfully resolved the disagreements between the neoclassical theory of growth and ecological economists regarding the significance of energy use in economic growth. Theoretical insights make it abundantly clear that energy use is essential to promoting economic growth, and Model 12 demonstrates how any reduction in energy use can seriously impede economic growth.

The results of empirical studies, however, that did not follow the Model 12 structure were in direct opposition to the widely accepted theory that energy consumption promotes economic expansion. On the other hand, studies that align their models with the framework provided in Model 12 consistently support the link between energy use and economic growth.

This study will use well-known data analysis methods like cointegration and Granger causality tests within a multivariate framework, taking the results of the literature review into consideration. The study will make use of Model 12 data variables such as GDP, labour, energy, and capital.

Furthermore, the bounds testing approach to cointegration is deemed appropriate given the study's relatively small data sample of only 32 observations. Prior unit root tests for the variables are no longer required, which improves statistical properties for small sample sizes.

Additionally, as emphasised in the literature review, this research highlights the significance of taking into account the level of aggregation for variables and making sure that the proper pairing of variables that measure the same level of economic activity is ensured.

CHAPTER 3

METHODOLOGY

3.0 Introduction

The methodology employed in this study will be discussed in this chapter, deriving conclusions from the literature reviewed in chapter two. This chapter will define the data variables used as well as specify the data sources.

3.1 Methodology

The methodology applied in this study was crafted with the primary aim of evaluating how energy consumption affects the economic growth of Zimbabwe. To be more precise, it was organized to address the three research questions that were raised.

In accordance with the theoretical model (Model 12) outlined in Chapter 2, we have formulated an estimable long-term relationship between energy usage and economic growth in log-linearized form, as expressed by Equation 13:

$$LogGDPt = \alpha0 + \alpha1LogKt + \alpha2LogLt + \alpha3LogEt + \mu t$$

In this equation, GDPt represents the total output of the economy (real GDP), Kt stands for the capital stock, Lt represents the level of employment, Et denotes energy usage, and the subscript t signifies time. Additionally, μt represents the white noise error term. It is expected, based on prior knowledge, that the coefficients $\alpha1$, $\alpha2$, and $\alpha3$ will all be greater than zero.

3.1.1 The Long run Relationship analysis: The Bounds

Testing Approach

The Pesaran and Shin (1997) and Pesaran et al. (1999, 2001) bounds testing methodology was used to determine whether there is a long-term relationship between energy use and economic growth as shown in Equation 13 (Sriyana, 2019). This methodology employs the Autoregressive Distributed Lag (ARDL) model, which is comparable to a fundamental vector autoregressive model (VAR) of order p, denoted by Zt, where Zt is a column vector containing LogGDP, LogK, LogL, and LogE. The ARDL model acknowledges that current economic variables are influenced by their past values by combining elements of distributed lag and autoregressive models (Yilanci et al, 2020). As a result, it includes past values of the dependent variable in addition to other explanatory variables.

Given that it is structured similarly to an error correction model, the bounds testing approach is also referred to as the unrestricted error correction model (Haseeb et al, 2019). However, the lagged error term in the bounds test is replaced with its equivalent in the long-term relationship specified in Equation 19.The 32 observations in the study's sample size, which is relatively small, had an impact on the decision to use the bounds testing method. The bounds testing approach provides greater statistical power in detecting false null hypotheses when working with smaller samples than some other methods for testing long-run relationships, such as the Engle and Granger (1987) or Johansen (1998) methods. This method also has a high degree of adaptability because it can be used without the need for pre-testing for unit roots whether variables are entirely stationary I(0), stationary I(1), or a combination of both. The bounds testing approach has several advantages:

1. It doesn't require pre-testing for unit roots, addressing the issue of low power in unit root tests with small samples.

2. It accommodates cases where some of the regressors are endogenous and allows for different lag lengths on each independent variable.

To ensure that the variables were not integrated above the first order (I(1)), the order of the variables' integration was first determined. We employed the Augmented Dickey-Fuller (ADF) test for unit roots for this purpose. This test looks at critical values from Fuller's table and compares them to the computed ADF statistic to see if a time series has a unit root. The unit root null hypothesis is rejected if the calculated statistic is less than the critical value. After conducting the unit root tests, our study followed the approach outlined by Pesaran and Shin (1997) and Pesaran et al. (1999, 2001) to transform Equation 13 into the ARDL (p, q1, q2, q3) bounds testing model. This transformation resulted in four distinct equations (Equations 15-18), which we estimated using ordinary least squares (OLS). We evaluated the null hypothesis of non-cointegration based on Wald or F-statistics to test whether a long-term relationship existed. Specifically:

- Null Hypothesis (H0): $b1i = b2i = b3i = b4i = 0$ for all equations.

- Alternative Hypothesis (H1): $b1i \neq b2i \neq b3i \neq b4i \neq 0$ for all equations.

In order to decide whether to accept the null hypothesis (which presumes the existence of a long-term relationship), we compare the F-statistic to an upper critical bound value. The null hypothesis is rejected if the F-statistic is greater than this bound, proving the existence of a long-term relationship (Haseeb, 2019). There is no long-term relationship if the F-statistic is less than a lower critical bound value, so the null hypothesis is accepted. To reach a conclusion when the F-statistic is between these bounds, we need more details on the variables' order of integration.

The critical bound values used in this study were obtained from Narayan (2004) rather than Pesaran et al. (2001) due to the small sample size. Narayan's critical values are tailored for smaller sample sizes, making them more appropriate for our analysis.

Furthermore, we used the Akaike information criterion (AIC) to determine the model's ideal lag length. It's important to note that the results presented in Equations 15-18 hold true when there is no serial correlation. To ensure the validity of our findings, we conducted diagnostic tests to assess the presence of serial correlation.

3.1.2 Calculating Long-Term Output Elasticities to Assess the Long-Term Relationship

In order to determine the factors' long-term output elasticities, we then estimated the long-term relationship between energy use and economic growth (Ren et al, 2020). This was accomplished by incorporating Equation 13 into an unrestricted Autoregressive Distributed Lag (ARDL) model denoted by (p, q1, q2, q3). The model took the following form:

$LogGDPt = a0 + \sum a1i\ LogGDPt\ i- + \sum a2i\ LogKt\ i- + \sum a3i\ LogLt\ i- + \sum a4i\ LogEt\ i- + \mu it$ (19). Where i=1 and i=0

Where:

- *LogGDPt* represents the logarithm of the real GDP at time t.

- *LogKt* represents the logarithm of the capital stock at time t.

- *LogLt* represents the logarithm of the employment level at time t.

- *LogEt* represents the logarithm of energy use at time t.

- The subscripts denote the time period, and *i* represents the lag order.

- μ*it* represents the error term.

In this equation, our objective was to grasp the enduring connection between economic growth and energy consumption by calculating the coefficients ((a_{1i}, a_{2i}, a_{3i}, a_{4i})) through the ARDL model (.

3.1.3 Error Correction model: Causality test.

In order to establish the causal link between energy consumption and economic growth, this study used a Granger causality test within an error correction framework. The underlying idea of the Granger causality test, according to Gujarati (2004), is that the past can be used to predict the future but not always the other way around. When two variables, X and Y, change before corresponding changes in X, we can say that X Granger causes Y. On the other hand, Y Granger causes X if prior values of Y aid in our comprehension of variations in X. This test can be set up in a bivariate context as follows:

$n \qquad n$

$Xt = \sum \alpha i \; Xt \; i - + \sum \beta j Yt - j + \mu 1t$; *where* $^{i=1 \; j=1}$ (20)

$n \qquad n$

$Yt = \sum \delta i \; Xt \; i - + \sum \lambda j Yt - j + \mu 2t$; where $^{i=1} \qquad ^{j=1}$(21)

Where μ_{1t} and μ_{2t} are uncorrelated disturbances.

Because of the cointegration of variables, the traditional causality test approach could not be used in this study. As a result, the causality test was performed with an error correction model derived from an ARDL (Yilanci et al, 2020) (p, q1, q2, q3) with the following specifications:

$p \qquad q \qquad q$

$DLogGDPt = a0 + \sum a1iDLogGDPt\ i- + \sum a2i\ DLogKt\ i- + \sum a3i\ DLogLt\ I$; $i=1$, $i=0$

q: $\sum a_{4i} DLogE_{t\ i-} + \phi_1 ECT_{t-1} + \xi_t$ where $i=0$ (22)

$p \qquad q \qquad q$

$DLogKt = a0 + \sum a1i\ DLogKt\ i- + \sum a2iDLogGDPt\ i- + \sum a3i\ DLogLt\ I$ where, $i=1$, $i=0$

q: $\sum a_{4i} DLogE_{t\ i-} + \phi_2 ECT_{t-1} + \xi_t$ where $i=0$ (23)

$p \qquad q \qquad q$

$DLogLt = a0 + \sum a1i\ DLogLt\ i- + \sum a2i\ DLogGDPt\ i- + \sum a3i\ DLogKt\ I$ where $i=1$, $i=0$

Q: $\sum a_{4i} DLogE_{t\ i-} + \phi_3 ECT_{t-1} + \xi_t$ where $i=0$ (24)

$p \qquad q \qquad q$

$DLogEt = a0 + \sum a1i\ DLogEt\ i- + \sum a2i\ DLogGDPt\ i- + \sum a3i\ DLogKt\ I$ where $i=1$, $i=0$

q: $\sum a_{4i} DLogL_{t\ i-} + \phi_4 ECT_{t-1} + \xi_t$ where $i=0$ (25)

Where^{a1i} to ^{a4i} are coefficients of short-term dynamics, and $_{ECT\,t}$ is the error correction term derived from the specified long run regression in equation (19) (Haseeb, 2019). The error correction model used in this study differs from the one created using the Engle-Granger (1987) cointegration method and performs statistically better. The ECT t used in the Engle-Granger error correction model is defined as:

$$ECT_t = \mu_t = LogGDP_t - \alpha_0 - \alpha_1 LogK_t - \alpha_2 LogL_t - \alpha_3 LogE_t \quad (26)$$

The error correction model used in this study under the ARDL model is defined as:

$p \qquad q \qquad q \qquad q$

$ECTt = \mu t = LogGDPt - a0 - \sum a1iLogGDPt\ i- - \sum a2i\ LogKt\ i- - \sum a3i\ LogLt\ i- - \sum a4i\ LogEt\ i-$ (27).

Where $i=1$, $i=0$

Iqbal (2011) and Iqbal and Uddin (2013) investigated the statistical properties' superiority of error correction models arrived at from Engle and Granger (1987), Johansen (1998) and Pesaran et al (2001) cointegration techniques. The error correction model arrived at when employing the ARDL model of Pesaran et al (2001) was found to have superior performance.

The lagged error correction term ECT (1) in equations 22 to 25 indicates how quickly the system reaches its long-term equilibrium. It is anticipated to have a negative coefficient with absolute values between zero and one. If ECT (1) is statistically significant, it means that in the long run, all of the explanatory variables have a Granger-causal relationship with the dependent variable.

Short-term Granger causality was assessed using equations 22 to 25, with a null hypothesis stating no causality as follows:

H0: $a2i = a3i = a4i = 0$, against the alternative hypothesis:

H1: $a2i \neq a3i \neq a4i \neq 0$

Long-term causality, on the other hand, was evaluated with a null hypothesis stating no causality as follows:

H0: $\phi i = 0$, against the alternative hypothesis:

H1: $\phi i \neq 0$

These tests were conducted individually using OLS estimation, and the lag length was determined based on AIC criteria.

To ensure the accuracy of the error correction model, several diagnostic tests were carried out, such as the Breusch-Godfrey Serial Correlation LM Test, White Heteroskedasticity Test, and Jarque-Bera Test for Normality (Ding et al, 2020). The study also considered the possibility that Zimbabwe's structural changes between 1980 and 2011 might have an effect on parameter stability. The Ramsey RESET Test, CUSUM, and CUSUMQ tests were applied to determine the stability of the estimated error correction model.

3.2 Data and Variable Definitions

This research made use of yearly data from 1980 to 2011 due to limitations on data availability. The total economically active population (as a proxy for labour), real GDP (representing total economic output), gross capital formation (a proxy for capital), and energy use (measured in kilo tonnes of oil equivalent) were all gathered as study variables. The Food and Agricultural Organisation (FAO) website provided information on the total economically active population, while the World Development Indicators (WDI) website provided information on GDP, gross capital formation, and energy use. To ensure comparability, all data series were standardised by multiplying each yearly value by the corresponding value from the base year, 1980.

CHAPTER 4

PRESENTATION AND INTERPRETATION OF RESULTS

4.0 Introduction

The findings of the empirical estimations are presented and interpreted in this chapter. The data series plots for the variables utilized in this study are shown first, and then the order of integration and cointegration tests are conducted. Estimates of the long-term link between energy use and economic growth will be presented later in the chapter. Lastly, an interpretation and presentation of the causality estimates' direction will be made.

4.1 Figure 1: Plots of data series

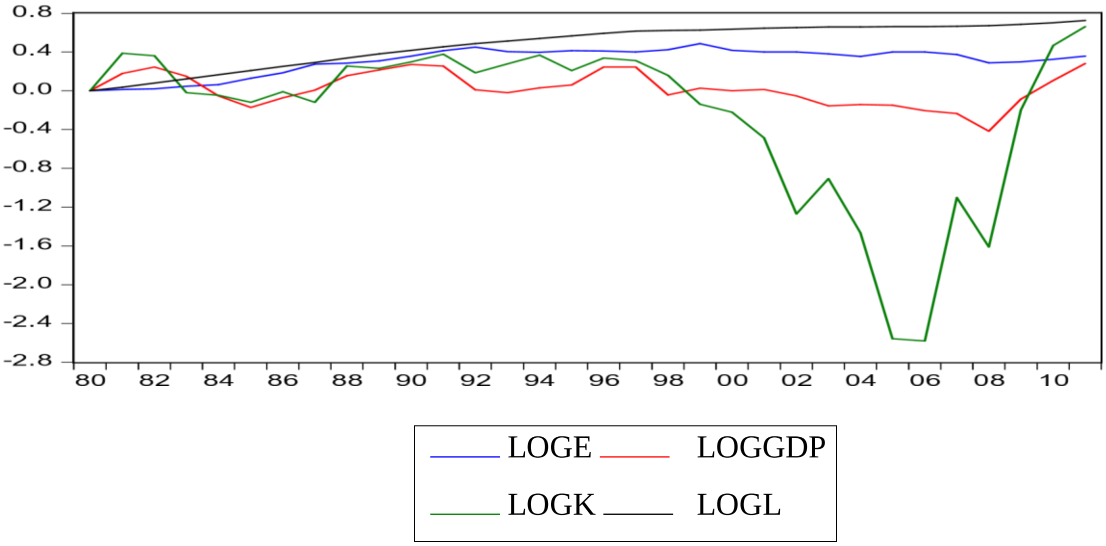


Figure 2, gives an overview of how energy use and economic growth trended over the period considered in this study. The trend show that energy use and economic growth trended together from 2010 to 2020. Thereafter, economic growth dropped to negative until 2009.

4.2 Unit root test

The outcomes of the ADF test for unit root are shown in Table 3. The data series comprise a combination of stationary and non-stationary variables, as the results demonstrate. While Log (K) and Log (E), which are non-stationary in levels, become stationary in first difference, Log (GDP) and Log (L) are stationary in levels. Although the methodology used in this study (Pesaran et al., 2001) does not require knowledge of the existence of unit roots in variables beforehand, the existence of unit roots has been evaluated to make sure that no variables are integrated of order larger than one. The critical limits values used in the F-test of cointegration are computed on the premise that variables are either integrated of order one or zero, which makes this information crucial. After determining that all variables were integrated to either zero or order one, the study moved on to examine whether energy consumption and economic growth have a long-term relationship.

Table 3: The ADF Unit root test results

Variable	levels	First Difference	Status
Log(GDP)	-3.012360**[1]	-	I(0)
Log(K)	-1.689482 [6]	-2.997981** [4]	I(1)
Log(L)	-9.325896* [0]	-	I(0)
Log(E)	-2.497761 [0]	-3.882863* [0]	I(1)

*, **, *** show the level of significant at 1%, 5% and 10% respectively. Lag length based on AIC is shown in [].

4.3 Cointegration Test

The results for cointegration test are given in table 4 below:

Table 4: The bounds test for cointegration result

DEPENDENT	F-STATISTIC	DECISION

VARIABLE		
D(LOG(GDP))	5.650738**	Co-integrated
D(LOG(K))	2.471007	No co-integration
D(LOG(L))	2.211685	No co-integration
D(LOG(E))	4.170954***	Co-integrated

NB: ***, ** and * show significance at 10%, 5% and 1% levels, respectively.

Critical values	1% level	5% level	10% level
Upper bounds	**5.928**	**4.252**	**3.566**
Lower bounds	**4.570**	**3.208**	**2.646**

When D(LOG(GDP)) is the dependent variable, a long-term association between energy use and economic growth is established at the 5% level of significance using the critical limits values taken from Narayan (2004). The long-term link between energy use and economic growth is established at the 10% significance level when the dependent variable is D(LOG(E)). We reject the null hypothesis that there is no cointegration between Zimbabwe's energy use and economic growth. When energy use is normalized, an equilibrium relationship is formed, although the link is statistically weak. The long-term link with energy was not assessed because of this and the fact that the goal of the study is to evaluate the effect that energy use has on economic growth.

Table 5: Results for serial correlation test for the ARDL Bounds tests

Variable normalised	**LM Test F-statistic**	**p-value**
D(LOG(GDP))	2.615113	0.1061
D(LOG(K))	0.108696	0.8978
D(LOG(L))	0.741790	0.4896

D(LOG(E))	2.553697	0.1056

4.4 Estimates of the long run relationship/ long run elasticities

With the establishment of an equilibrium relationship between energy use and economic growth, the study estimated this long run relationship using ARDL (2, 0, 2, 1) model. The akaike information criterion determined the lag length. Table 6: presents results of the estimated long run relationship between energy use and economic growth.

Table 6: Results of the estimated long run relationship: The dependent variable is LOG(GDP)

Independent Variables	**Coefficient**	**P-Value**
C	-0.035451	0.8636
LOG(GDP(-1))	0.705907	0.0002
LOG(GDP(-2))	-0.300795	0.1257
LOG(K)	0.087034	0.0165
LOG(L)	8.262515	0.1643
LOG(L(-1))	-16.95235	0.1265
LOG(L(-2))	8.613638	0.1410
LOG(E)	1.298481	0.0410
LOG(E(-1))	-0.966859	0.0932

The findings indicate that the elasticity of capital, as well as the elasticity of the current period and the first lag of energy, are significant, but the elasticity of labor and the first and second lags of labor are not.

At the 5% significance level, the current period coefficient of energy use has a positive relationship with economic growth. In the current period, a 1% increase in energy use will more than proportionately result in an approximate 1.3% increase in economic growth. On the other hand, the prior period's energy use coefficient is significant at the 10% level and inversely correlated with economic growth. Based on this evidence, the hypothesis that the energy use's impact on economic growth is not different from zero is rejected.

At the 5% level, the capital coefficient is significant and shows the predicted positive sign. Despite being negligible, the labor coefficient for the current era has the predicted sign. Once more, although they are all negligible, the coefficients of the first and second lags of labor are positively and negatively correlated with economic growth, respectively.

4.5 Estimates of the error correction model (Causality Test)

Lastly, table 7 displays the findings of the causality test estimated in the ARDL (1, 0, 1, 1) error correction model. It is claimed that the model estimate is parsimonious as the akaike information criterion also established the ideal lag duration. The findings demonstrate that the lagged error correction term ECT (-1) coefficient has the predicted sign, is inside the necessary range, and is highly significant at the 1% level. This indicates that, over time, labor, capital, and energy use all contribute to economic growth. Additionally, the coefficient demonstrates that a long-term relationship exists. It demonstrates that an 88.8% correction to any current period divergence from equilibrium will occur in the following period. This speed of adjustment after a shock is comparably very high.

With an adjusted R2 of 0.73, the predicted long run model shows a respectable level of goodness of fit. This suggests that variations in capital, labor, and energy consumption account for roughly 73% of GDP volatility. As demonstrated by several diagnostic tests (see appendix 1), the model is appropriately described and the calculated parameters are stable.

VARIABLE	D(LOG(GDP))		
	Coefficient	**t- statistic**	**P-value**
C	0.024548	0.746078	0.4639
D(LOG(GDP(-1)))	0.433377	2.327839	0.0300
D(LOG(K))	0.067427	1.893415	0.0722
D(LOG(L))	10.81632	2.292354	0.0323
D(LOG(L(-1)))	-11.89079	-2.596829	0.0168
D(LOG(E))	1.544674	2.861725	0.0093
D(LOG(E(-1)))	-0.934479	-1.785324	0.0887
ECT(-1)	-0.888076	-2.951493	0.0076

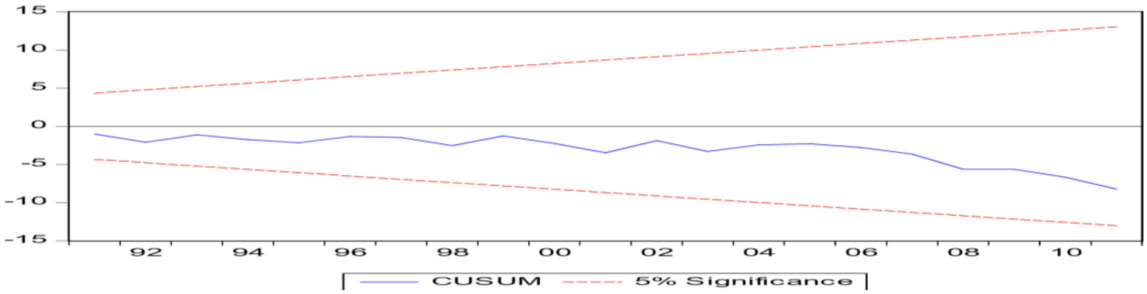
4.5.1 Diagnostic test of the error correction model:

Table 8 indicates that the error correction model passed every diagnostic test. As a result, the model is accurate and stable. The test statistics of the CUSUM and CUSUMQ, which fall under the crucial boundaries of 5% significance as indicated by figures 3 and 4, respectively, demonstrate that there is no indication of structural fractures from 2010 to 2020.

Test statistic	Critical value
LM test F-statistic	0.233256 [0.7942]
Normality test (chi-square)	1.110083[0.574048]
Reset F-Statistic	2.243965[0.1498]
Heteroskedasticity Test	0.46765 [.8874]

NB: P-values are shown in the table

Figure 2: The CUSUM Test of the ECM



4.6 Conclusion

The findings show a long-term correlation between Zimbabwe's energy consumption and economic expansion and that energy use is a short- and long-term driver of GDP growth. Growth in the economy is positively impacted by rising energy use in a more than proportionate way. The findings of this study are consistent with those of other studies (Stern, 1998; Ayres & Warr, 2009; War & Ayres, 2009; Stern & Enflo, 2013; Lean & Smyth, 2013; Sultan, 2011) that used a comparable multivariate methodology. Nevertheless, the findings of earlier research on Zimbabwe that used a bivariate approach conflict with them (Chontanawat et al., 2006; Fowowe, 2012; Farhani & Rejeb, 2012). The absence of important labor and capital factors could have affected the outcomes of these bivariate analyses.

CHAPTER 5

DISCUSSION AND POLICY RECOMMENDATIONS

5.0 Discussion of results

This study set out to evaluate how energy use affected Zimbabwe's economic expansion. An error correction model that goes along with the bounds testing approach to cointegration has been used to evaluate the relationship between energy consumption and economic growth in Zimbabwe. The study has demonstrated that, when GDP is used as the dependent variable, there is a strong long-term correlation between energy use and economic growth; however, when energy use is used as the dependent variable, there is only a weak long-term correlation. The Granger causality test has demonstrated that energy use contributes to Zimbabwe's economic growth over the short and long terms.

A rise in current period energy consumption has a greater than proportionately favorable impact on Zimbabwe's economic growth, as seen by the energy use output elasticity. The current energy use coefficient (1.298481) is higher than the capital coefficient (0.087034). The present labor coefficient (8.262515) is not very important, even though it is higher than the coefficients for energy and capital. Therefore, for the time period under consideration in this analysis, energy use had a significantly favorable impact on economic growth in Zimbabwe, to the extent allowed by the data analyzed in this study.

On the other hand, it was discovered that the lagged energy variable was negative. A theoretically proven fact that energy use influences economic growth both directly and indirectly by raising capital and labor productivity could explain the lagged energy variable's negative and weakly significant effect. The energy embodied in labor and capital during the preceding time has an indirect impact on the current economic progress. Energy has a direct and indirect impact on growth in the current era. It follows that present energy use has a higher effect on economic growth than it did in earlier eras. The effectiveness of other production elements, which depend on energy, determines how delayed period energy use affects economic growth.

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Positive coefficients for capital and current labor support the classic growth theory claim. The results of this study support the neoclassical and ecological economists' reconciliation that capital, current labor, and current energy consumption are three elements of production that are essential for economic growth, to the extent that these factors had expected coefficient indications in chapter 2.

Based on these confirmed findings, Zimbabwe's economic growth is being negatively impacted by the frequent and extended power outages that the country experiences. Energy use will continue to be constrained if the supply of energy is still insufficient to meet the levels of consumption required by all economic units, which means that the economy's growth trajectory is likely to continue falling.

5.1 Policy recommendations

The study's conclusions have significant policy ramifications. Politicians should create policies that encourage more energy use in order to boost economic growth. Any energy-saving measure will slow Zimbabwe's economic expansion. In order to increase Zimbabwe's energy consumption, policymakers must guarantee that energy is consistently available and accessible in the appropriate amounts that all economic actors require for their current needs.

5.2 Conclusion and suggestions for further research

The relationship between energy consumption and economic growth in Zimbabwe has been investigated. The information utilized spans the years 2010–2020. To determine whether there is a long-term correlation between energy use and economic growth, the limits testing technique to cointegration inside the ARDL framework was used. To verify causation, the corresponding ECM was computed. The findings demonstrated the long-term association and the short- and long-term links between energy use and economic growth. When all other factors are held constant, a 1% increase in current energy use will more than proportionately boost economic growth by 1.3%, according to calculations that have been tested for the proven long-run relationship. The findings support the initial claim stated by this research that energy use is vital for Zimbabwe’s economic growth.

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APPENDICES

Appendix 1:

Long run relationship parameter estimates

LAG ORDER SELECTION CRITERIA (AIC)

VAR Lag Order Selection Criteria Endogenous variables: LOG(GDP)

Exogenous variables: C LOG(K) LOG(L) LOG(L(-1)) LOG(L(-2)) LOG(E) LOG(E(-1))

Date: 04/11/23 Time: 16:03

Sample: 2010 2020

Included observations: 30

Lag	LogL	LR	FPE	AIC	SC	HQ
0	24.44085	NA	0.018466	-1.162724	-0.835778	-1.058131
1	32.79117	12.24712*	0.011363	-1.652744	-1.279092	-1.533210
2	34.50570	2.400342	0.010898*	-1.700380*	-1.280020*	-1.565903*

* indicates lag order selected by the criterion LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

MODEL ESTIMATED: ARDL (2, 0, 2, 1)

Dependent Variable: LOG(GDP)

Method: Least Squares

Date: 04/11/23 Time: 15:15

Sample (adjusted): 2010 2022

Included observations: 30 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.035451	0.203895	-0.173867	0.8636
LOG(GDP(-1))	0.705907	0.158309	4.459055	0.0002
LOG(GDP(-2))	-0.300795	0.188628	-1.594648	0.1257
LOG(K)	0.087034	0.033410	2.605015	0.0165
LOG(L)	8.262515	5.733707	1.441042	0.1643
LOG(L(-1))	-16.95235	10.65227	-1.591430	0.1265
LOG(L(-2))	8.613638	5.631334	1.529591	0.1410
LOG(E)	1.298481	0.596374	2.177292	0.0410
LOG(E(-1))	-0.966859	0.549770	-1.758660	0.0932

R-squared	0.801091	Mean dependent var	0.018602
Adjusted R-squared	0.725316	S.D. dependent var	0.174693
S.E. of regression	0.091557	Akaike info criterion	-1.700380
Sum squared resid	0.176037	Schwarz criterion	-1.280020
Log likelihood	34.50570	Hannan-Quinn criter.	-1.565903
F-statistic	10.57197	Durbin-Watson stat	2.227317
Prob(F-statistic)	0.000008		

TESTING MODEL ARDL (2, 0, 2, 1) FOR SERIAL CORRELATION

Breusch-Godfrey Serial Correlation LM Test:

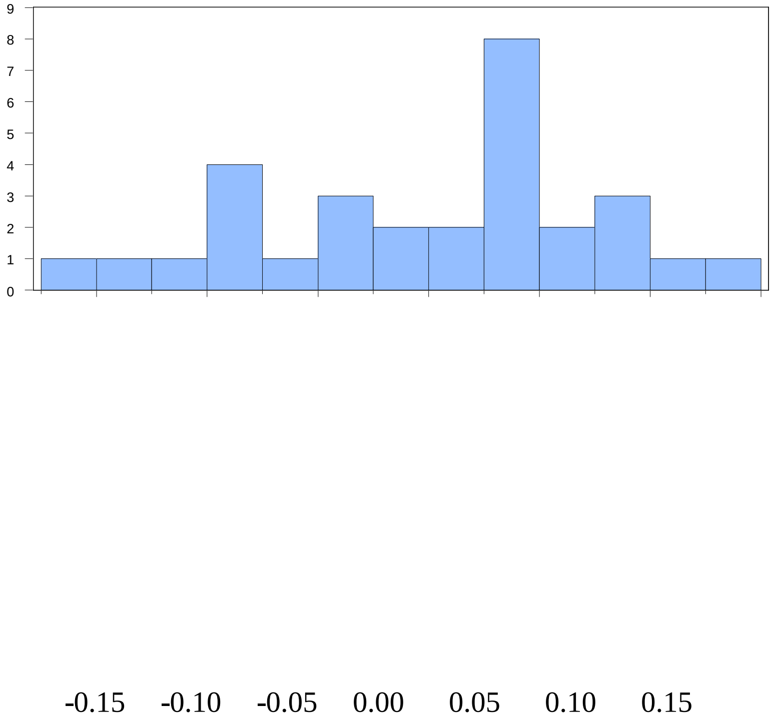
F-statistic	1.557745	Prob. F(2,19)	0.2363
Obs*R-squared	4.226209	Prob. Chi-Square(2)	0.1209

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 04/11/23 Time: 15:22
Sample: 2010 2020
Included observations: 30
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.008729	0.202546	-0.043095	0.9661
LOG(GDP(-1))	0.385527	0.275865	1.397521	0.1784
LOG(GDP(-2))	-0.025512	0.224512	-0.113631	0.9107
LOG(K)	-0.039255	0.039453	-0.994976	0.3323
LOG(L)	-1.385533	5.650100	-0.245223	0.8089
LOG(L(-1))	2.510885	10.47998	0.239589	0.8132
LOG(L(-2))	-0.950897	5.529069	-0.171981	0.8653
LOG(E)	0.001467	0.587552	0.002497	0.9980
LOG(E(-1))	-0.260327	0.557427	-0.467016	0.6458
RESID(-1)	-0.652726	0.396709	-1.645354	0.1163
RESID(-2)	-0.485609	0.352716	-1.376771	0.1846

R-squared	0.140874	Mean dependent var	6.07E-16
Adjusted R-squared	-0.311298	S.D. dependent var	0.077912
S.E. of regression	0.089218	Akaike info criterion	-1.718886
Sum squared resid	0.151238	Schwarz criterion	-1.205113
Log likelihood	36.78328	Hannan-Quinn criter.	-1.554525
F-statistic	0.311549	Durbin-Watson stat	2.158192
Prob(F-statistic)	0.968506		

TESTING MODEL ARDL (2, 0, 2, 1) FOR NORMALITY



Series: Residuals
Sample 2010 2020
Observations 30
Mean 6.07e-16
Median 0.022168
Maximum 0.143386
Minimum -0.168616
Std. Dev. 0.077912
Skewness -0.347272
Kurtosis 2.302010
Jarque-Bera 1.211977
Probability 0.545535

TESTING MODEL ARDL (2, 0, 2, 1) FOR HETEROSKEDASTICITY

Heteroskedasticity Test: Breusch-Pagan-Godfrey

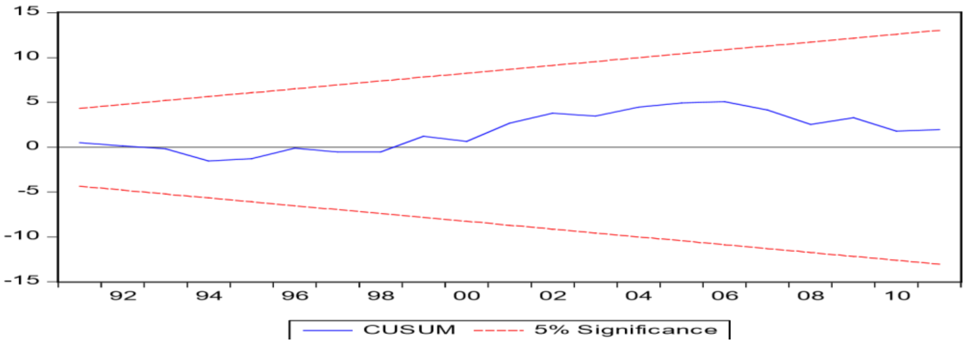
F-statistic	0.079222	Prob. F(8,21)	0.9995
Obs*R-squared	0.878867	Prob. Chi-Square(8)	0.9989
Scaled explained SS	0.280352	Prob. Chi-Square(8)	1.0000

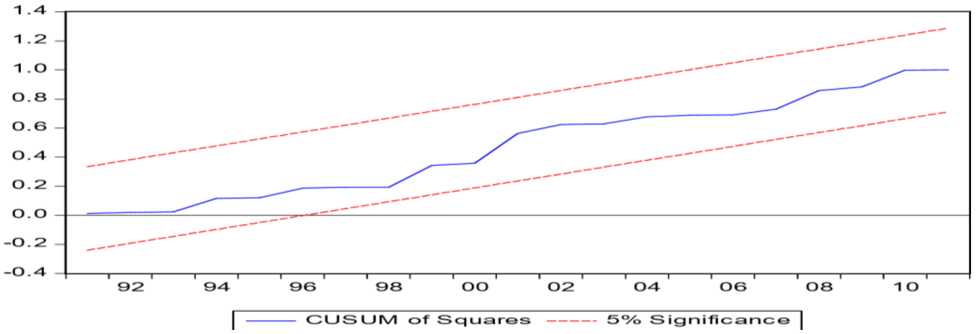
Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/11/23   Time: 21:36
Sample: 2010 2020
Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.005966	0.017559	0.339783	0.7374
LOG(GDP(-1))	-0.001426	0.013633	-0.104598	0.9177
LOG(GDP(-2))	0.001399	0.016244	0.086127	0.9322
LOG(K)	0.000895	0.002877	0.311165	0.7587
LOG(L)	-0.077479	0.493774	-0.156912	0.8768
LOG(L(-1))	0.184295	0.917349	0.200900	0.8427
LOG(L(-2))	-0.105115	0.484957	-0.216751	0.8305
LOG(E)	-0.030765	0.051358	-0.599020	0.5556
LOG(E(-1))	0.027602	0.047345	0.582999	0.5661

R-squared	0.029296	Mean dependent var	0.005868
Adjusted R-squared	-0.340497	S.D. dependent var	0.006810
S.E. of regression	0.007885	Akaike info criterion	-6.604460
Sum squared resid	0.001306	Schwarz criterion	-6.184101
Log likelihood	108.0669	Hannan-Quinn criter.	-6.469984
F-statistic	0.079222	Durbin-Watson stat	2.621794
Prob(F-statistic)	0.999500		

TESTING MODEL ARDL (2, 0, 2, 1) FOR STABILITY





Ramsey RESET Test Equation: EQ05

Specification: LOG(GDP) C LOG(GDP(-1)) LOG(GDP(-2)) LOG(K) LOG(L) LOG(L(-1)) LOG(L(-2)) LOG(E) LOG(E(-1))

Omitted Variables: Squares of fitted values

Value df

Probability

t-statistic 0.027733 20 0.9782 F-statistic 0.000769 (1, 20) 0.9782

Likelihood ratio 0.001154 1 0.9729

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	6.77E-06	1	6.77E-06
Restricted SSR	0.176037	21	0.008383
Unrestricted SSR	0.176031	20	0.008802

Unrestricted SSR	0.176031	20	0.008802

LR test summary:

	Value	df
Restricted LogL	34.50570	21
Unrestricted LogL	34.50627	20

Unrestricted Test Equation: Dependent Variable: LOG(GDP)

Method: Least Squares

Appendix 2:

Error correction model test

LAG ORDER SELECTION CRITERIA (AIC)

VAR Lag Order Selection Criteria

Endogenous variables: D(LOG(GDP))

Exogenous variables: C D(LOG(K)) D(LOG(L)) D(LOG(L(-1))) D(LOG(E)) D(LOG(E(-1))) ECT1(-1)

Date: 04/07/14 Time: 17:10

Sample: 2010 2020

Included observations: 29

Lag	LogL	LR	FPE	AIC	SC	HQ
0	28.88355	NA	0.013071	-1.509210	-1.179173	-1.405847
1	32.21209	4.820648*	0.011187*	-1.669800*	-1.292615*	-1.551670*
2	33.10957	1.237903	0.011340	-1.662729	-1.238396	-1.529833

* indicates lag order selected by the criterion LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

ERROR CORRECTION MODEL ESTIMATED:

ARDL (1, 0, 1, 1)

Dependent Variable: D(LOG(GDP))

Method: Least Squares

Date: 04/11/23   Time: 16:57

Sample (adjusted): 2010 2022

Included observations: 29 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.024548	0.032903	0.746078	0.4639
D(LOG(GDP(-1)))	0.433377	0.186171	2.327839	0.0300
D(LOG(K))	0.067427	0.035611	1.893415	0.0722
D(LOG(L))	10.81632	4.718435	2.292354	0.0323
D(LOG(L(-1)))	-11.89079	4.578965	-2.596829	0.0168
D(LOG(E))	1.544674	0.539770	2.861725	0.0093
D(LOG(E(-1)))	-0.934479	0.523422	-1.785324	0.0887
ECT1(-1)	-0.888076	0.300891	-2.951493	0.0076

R-squared	0.648140	Mean dependent var	0.001291
Adjusted R-squared	0.530853	S.D. dependent var	0.136710
S.E. of regression	0.093638	Akaike info criterion	-1.669800
Sum squared resid	0.184132	Schwarz criterion	-1.292615
Log likelihood	32.21209	Hannan-Quinn criter.	-1.551670
F-statistic	5.526112	Durbin-Watson stat	1.837371
Prob(F-statistic)	0.001034		