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Article

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Biomass energy consumption and sustainable human development: the role of financial development in EAC member countries

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ABSTRACT

Researchers are still in conflict on how biomass energy usage affects the environment, the economy, and human development. Moreover, since its inception, climate change has become one of humanity's greatest challenges, inspiring massive efforts to lessen its effects and concentrate on sustainable development. This study examined the relationship between biomass energy consumption and sustainable human development in East African Community (EAC) member states between 1990 and 2019. This study uses econometric approaches to address the challenges of cross-sectional dependence and slope heterogeneity. We used the CIPS and CADF unit root tests together with the Westerlund cointegration test to address these issues. Additionally, Contemporaneous Correlation estimators (Feasible Generalized Least Squares – FGLS) and Panel Corrected Standard Errors – PCSE) and the Fully Modified Ordinary Least Squares (FMOLS) were employed. We also used the Dumitrescu-Hurlin panel causality test. Our analysis revealed that the East African Community (EAC) members' sustainable human development (SHD) is threatened by biomass energy consumption (BEC), which has a coefficient of -0.920. The BEC-SHD nexus is found to be reversed by the moderating impact of financial development, with an interaction coefficient of 0.329. Finally, we successfully demonstrated the existence of a bidirectional causal relationship between BEC and SHD as well as BEC and EG.

IMPACT STATEMENT

This study provides a thorough analysis of the complex connection between the use of biomass energy and the promotion of sustainable human development in the member states of the East African Community (EAC) during a span of 30 years (1990–2019). By employing sophisticated econometric techniques to tackle issues of cross-sectional dependence and slope heterogeneity, our research reveals a substantial adverse effect of biomass energy use on sustainable human development, as shown by a coefficient of -0.920. Significantly, the study demonstrates that financial development might alleviate this negative impact, indicating that measures targeted at improving financial infrastructure should encourage more sustainable utilization of biomass energy. The bidirectional causal linkages between biomass energy consumption, sustainable human development, and economic progress have been shown, highlighting the intricate nature of energy policy in the region. These insights are crucial for policymakers as they offer empirical information to inform the creation of strategies that effectively balance energy requirements with sustainable development goals. This ultimately promotes a more resilient and fair future for the East African Community (EAC).

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1. Introduction

The imperative to tackle environmental issues, alleviate the consequences of climate change, and promote sustainable development has gained significant prominence in recent times. The realisation of these goals is significantly influenced by the shift towards sustainable energy sources, especially in areas that are heavily dependent on biomass energy. A comprehensive examination is necessary to identify

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the challenges and opportunities that arise from the interplay between biomass energy consumption, financial development, and sustainable human development in the member countries of the East African Community (EAC). Thus, the study specifically considers the distinctive socio-economic and environmental features of this region, offering tailored insights and recommendations for policymakers, scholars, and practitioners at work in the EAC.

Despite a widespread energy poverty in most of the developing and less developed countries in the both Asia and Africa (Dagher et al., 2023), the steady rise in global energy demand can be attributed to industrialization, accompanied by economic pursuits and population growth. This trend was observed from 1971 to 2014, during which there was a notable surge of approximately 44% in global energy consumption. Notably, fossil fuels account for approximately 80% of the global energy supply. (Eren et al., 2019; REN21,21, 2017). The use of fossil fuels for energy production has raised concerns regarding limited energy access, energy security, and environmental degradation. (Bilgili, Koçak & Kuşkaya 2017). Thus, environmental issues are of utmost importance. Fossil fuel consumption, which is linked to soaring global temperatures and subsequent climate change, is widely acknowledged to be a major source of greenhouse gas emissions (Baek, 2016). However, the shift towards renewable energy sources is driven by the imperative to reach sustainable development objectives and keep the planet safe. This transition not only offers environmental benefits but also contributes to lowering dependence on external resources and fostering employment opportunities within nations (Alper & Oguz, 2016). The rapid growth of renewable energy sources has resulted in a significant increase in the proportion of clean energy in the total final energy consumption, increasing from 10% to 18.1% between 2008 and 2017 (REN21,21 2019). Moreover, it is projected that this percentage may reach 60% by 2050 (IRENA, 2018).

Regarding the overall energy composition, biofuel was the leading renewable energy source, with a contribution of 12.4% to the final energy consumption in 2017 (REN21,21 2019). In the East African Community, its member states heavily depend on traditional solid fuels, such as wood and charcoal, for domestic purposes, such as cooking and heating. Kenya has the lowest level of biofuel in primary energy utilization (approximately 68%), while Burundi has the highest percentage (more than 95%). On average, East Africa Community (EAC) member states rely heavily on traditional biogas, which constitutes almost 80% of their final energy consumption. However, when modern biomass was considered, this proportion increases to 86.5%. The EAC region uses 85.7% of solid biomass in its energy mix, similar to the Economic Community of West African States (ECOWAS). However, this ratio is larger than that observed in the Southern African Development Community (SADC) region, which is 61.2% (EAC Energy Status Report, 2016).

As the demand for bioenergy continues to increase, research is increasingly focusing on its implications. One group of researchers specifically investigated the potential correlation between biomass use and economic growth (Bilgili et al., 2017; Aydin, 2019; Shahbaz et al., 2016). Another group of researchers examined the impact of biomass on ecological health (Adewuyi & Awodumi, 2017; Shahbaz et al., 2019). However, currently, there is no consensus regarding the findings of these studies. Several studies have shown that biomass consumption boosts economic growth and is environmentally sustainable, while others have shown the opposite. As a result, there is still debate over the appropriateness of increasing or decreasing the use of biomass.

Against this backdrop, there is also a need to tackle the pressing issue of promoting sustainable development while ensuring access to energy and reducing ecological adverse effects. The use of biomass energy, although important for meeting energy needs, has associated environmental issues such as deforestation, indoor air pollution, and greenhouse gas emissions. By investigating the relationship between BEC and SHD, we shed light on the potential pathways for achieving sustainable development goals while minimizing negative environmental consequences. Furthermore, our research paper presents potential solutions and policy recommendations to enhance the sustainability of biomass energy consumption in the EAC. This study analyses the existing energy consumption patterns in the region and thus, explores ways to improve efficiency, promote renewable energy sources, and implement sustainable practices. This study's unique contribution lies in providing empirical evidence and insights specific to the East African context, which can inform policymakers, energy planners, and stakeholders in developing strategies that balance energy access, environmental protection, and sustainable development.

The aim of this study was to contribute new knowledge to the academic field by examining how the consumption of biomass energy impacts sustainable human development. This study builds upon the existing body of knowledge on this subject. The concept of human development, originally developed by Mahbub ul Haq in the 1970s, has become a significant measure for evaluating a nation's progress. The United Nations Development Programme (UNDP) defines human development as the expansion of opportunities and improvement of individual choices. Per capita Gross Domestic Product has traditionally been used as a primary indicator to gauge human development levels over a long period. It is important to note that traditional economic metrics such as Gross Domestic Product (GDP) may not provide a comprehensive depiction of human welfare. The Human Development Index (HDI) has become the dominant measure for evaluating human development, replacing GDP since its inception by the United Nations Development Program (UNDP) in 1990. HDI is a comprehensive metric that encompasses three key dimensions: longevity, education, and standard of living. By assessing these aspects, the HDI provides a holistic evaluation of an individual's overall QoL. Hence, countries strive to improve their HDI as they serve a significant goal for societal development.

However, with climate change and ecological disintegration, HDI's limitations are become apparent in the 21st century. HDI ignores ecology and prioritizes high income, which violates sustainability principles due to the substantial links between income and ecological effects. Countries with the highest HDI contribute the most per capita to climate change and environmental disintegration. This makes HDI's development model empirically incompatible with ecological stability and unable to universalize. The Sustainable Development Index (SDI) is an alternative index that addresses these issues. The SDI preserves the HDI basic formula but divides it into two crucial ecological indicators: CO₂ emissions and material footprint, both calculated in per capita consumption-based terms and visualized against planetary boundaries. The ecological efficiency of countries in terms of human development was measured by the SDI, indicating strong sustainability. In this study, sustainable human development as the dependent variable was proxied by Hickel's (2020) sustainable development index.

For countries to attain sustainable development, policymakers must consider the tripartite dimensions of the economy, environment, and society. [Figure 1](#) reveals the trend of financial depth in the EAC economic community, indicating the volatility of its financial sector development. Despite the notable role of financial sector development in economic growth which has been substantially covered in the recent academic literature (Beck et al., 2000; Valickova et al., 2014; Moradbeigi & Hook Law, 2017; Assefa & Varella Mollick, 2017; Sharma & Kautish, 2020; Ekanayake & Thaver, 2021); however, previous studies have mainly focused on examining the environmental and economic consequences of utilizing biomass energy, neglecting the role financial development in the nexus between biomass energy consumption and sustainable human development. Consequently, a more comprehensive understanding of the impacts of biomass energy consumption can be obtained by exploring the link between biomass energy use and sustainable human development in the presence of financial development. This would provide policymakers with valuable insights into the decision-making processes.

This study focused on the East African Community (EAC) member states, consisting of six countries: Burundi, DR Congo, Kenya, Rwanda, Tanzania, and Uganda. Apart from facing economic challenges, EAC nations have not made significant advancements in terms of achieving sustainable human development. [Figure 2](#) depicts a positive trend in the sustainable human development indicator across all six EAC countries from 1990 to 2019. However, there are variations in sustainable human development among EAC countries. Nevertheless, the results highlight Kenya's relatively greater progress towards sustainable human development in the past decade. Following Kenya, Rwanda and Uganda are the next highest-ranking countries in terms of human development within the East African Community, as shown in [Figure 2](#). The extensive exploitation of conventional biomass for cooking and heating poses considerable social and environmental difficulties within the East African Community (EAC) region. The extraction and utilization of wood-based biomass are considered unsustainable in several areas, resulting in deforestation and the emergence of pollution-related health problems. The increasing population and urbanization trends intensify the demand for cooking energy, particularly charcoal, thus exacerbating the aforementioned difficulties (United Nations Environment Programme (UNEP), 2019).

The East African Community (EAC) member nations, constituting approximately 24% of the population of sub-Saharan Africa (SSA) according to the World Bank (2021), experience one of the highest

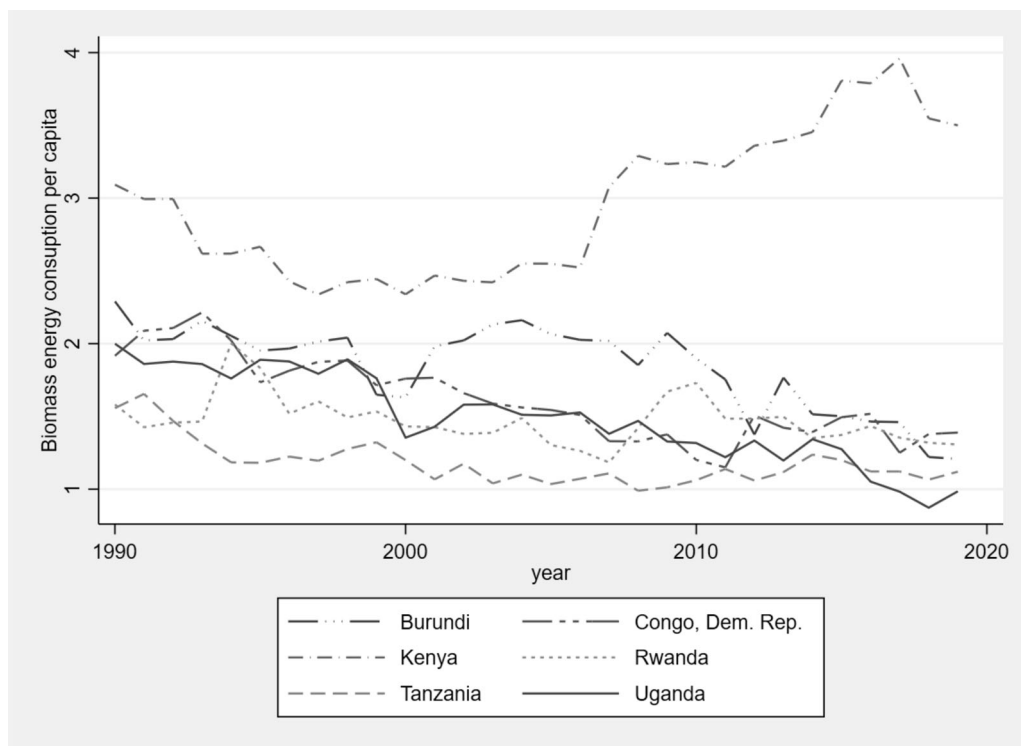


Figure 1. Trend of financial development in EAC member states from 1990 to 2019.

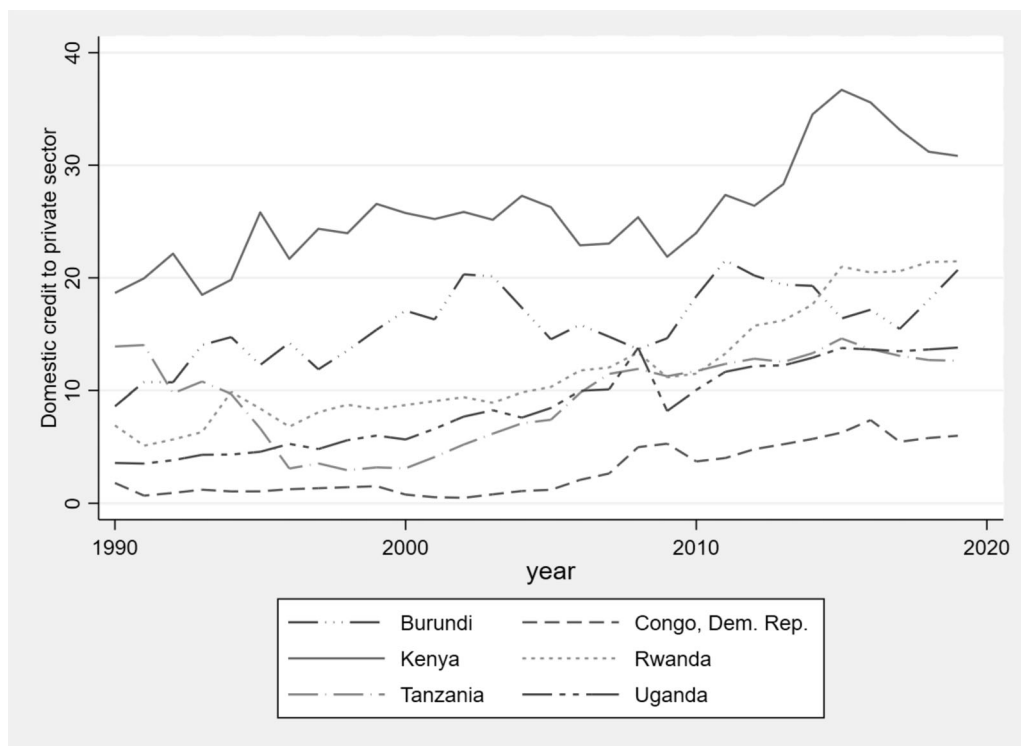


Figure 2. Trend of EAC member nations' human development index from 1990 to 2015.

population growth rates globally. These countries contribute around 15.8% of SSA's gross domestic product (GDP), which is projected to grow at an average rate of 5.9%. These relatively high rates of population growth and GDP could result in a significant increase in energy consumption. In this region, the primary source of the final energy consumption is solid biomass, including firewood, charcoal, and

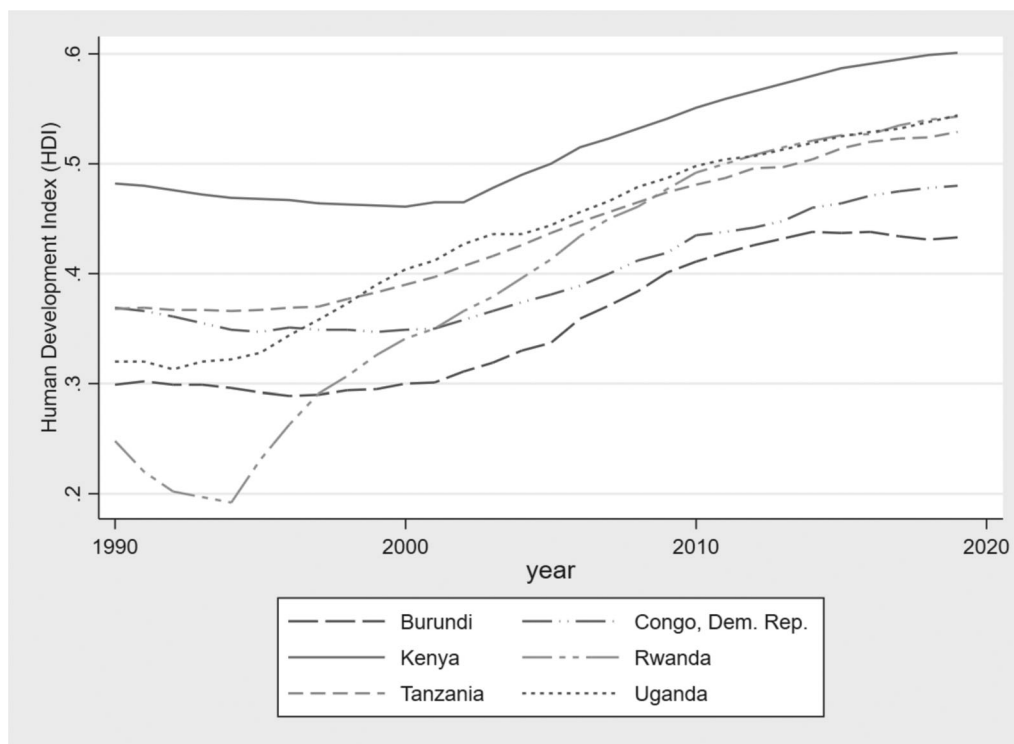


Figure 3. Trend of bioenergy consumption per capita in EAC member states from 1990 to 2019.

agricultural waste, which generally accounts for approximately 80% of the total consumption. The distribution of this energy source varies across countries, with Kenya having a proportion of 75% and Burundi exceeding 95% (EAC Report 2016). These countries have encountered notable environmental challenges in recent years. The utilization and integration of alternative, clean, and renewable energy sources is widely recognized as a feasible strategy for countries in the East African Community (EAC) to address mounting apprehensions related to environmental deterioration and energy stability. The East African Community (EAC) region has shown a discernible inclination for biomass energy in comparison to other types of renewable energy sources owing to its substantial capacity, convenient availability, and swift implementation. Figure 3 depicts the trajectory of per capita biomass energy use in the economies of the East African Community (EAC) region between 1990 and 2015. In light of this, it is imperative to analyze the effects of biomass energy use on sustainable human development in East African Community (EAC) countries.

Below are the three areas where the present study varies from prior research: (i) To the best of our knowledge, this study is the first to examine the relationship between sustainable human development (proxied by the sustainable development index) and biomass energy use. This relationship was also examined for the first time for the EAC region from 1990 to 2019; (ii) to address the problem of specification bias, trade openness, population growth, financial development, and inflation were added to the function of sustainable human development, financial development was also used to moderate the biomass energy use and sustainable human development nexus; and (iii) In this study econometric methods, which account for the issue of cross-sectional dependence and heterogeneity such as the CADF and CIPS unit root tests, Westerlund panel cointegration test, contemporaneous correlation techniques (Feasible Generalized Least Squares – FGLS) and Panel Corrected Standard Error – PCSE – estimators), and Dumitrescu-Hurlin panel causality tests were used. For a robustness check, the Fully Modified Ordinary Least Squares – FMOLS – method was employed.

Despite biomass playing a crucial role in providing energy to rural regions, the East African Community (EAC) is facing a serious energy crisis that is impacting all aspects of the economy and human life. Energy poverty is widespread in the region, and the existing energy and human development situation is in jeopardy. SDG-7 stipulates that every nation must guarantee access to renewable and reasonably priced energy for all individuals by the year 2030. Hence, our enthusiasm in investigating

the relationship between biomass energy consumption (BEC) and sustainable human development (SHD) in the East African Community (EAC) arises from our recognition of the importance of biomass energy consumption in promoting sustainable human development, as well as the prevailing energy consumption patterns in the region. Thus, this study's novel contribution is to examine, through the lens of financial development, the relationship between the use of biomass energy and sustainable human development, taking into account trade openness, economic growth, inflation, and population growth as control variables for EAC member countries.

The remainder of this paper is organized as follows. The second subsection provides an overview of the existing literature, the third section outlines the model specification and data sources employed in this study, the fourth subsection details the econometric approach employed, and the fifth subsection presents the results of the empirical analysis. The sixth subsection provides a comprehensive summary of the implications of the analysis and offers policy suggestions based on these findings.

2. Literature review

The relationship between the use of biomass energy, the development of financial systems, and the achievement of sustainable human development has received considerable attention in recent years. Understanding the intricate connections and consequences of these issues becomes essential as nations work towards achieving sustainable development goals. This literature review seeks to present a comprehensive analysis of current research and understanding about the relationship between biomass energy consumption, financial development, and sustainable human development, with a specific emphasis on the countries that are part of the East African Community (EAC). Although biomass energy continues to be a substantial energy source in the region, its long-term viability and ecological effects present difficulties. The utilisation of biomass energy intensifies deforestation rates, hence worsening environmental degradation and climate change. Furthermore, the restricted availability of financial services and the insufficiently developed financial sectors impede the potential advantages of financial development on sustainable human development outcomes.

2.1. Biomass energy consumption and human development

The pursuit of enhancing human development is a paramount objective of economic progress, prompting countries to augment their human development indexes. To attain this objective, it is imperative to address inquiries pertaining to the determinants that impact the process of human development. Scholars have recently devoted considerable attention to drivers of human development. Various explanatory factors, econometric models, and samples have been used (Tran et al., 2019). These studies have shown the impact of economic growth (Peneva & Ram, 2014; Hafner & Mayer-Foulkes, 2013; Suri et al., 2011), industrialization (Klafke et al., 2018; Qasim & Chaudhary, 2015), foreign direct investment (Fagbemi & Osinubi, 2020; Reiter & Steensma, 2010), trade openness (Mustafa et al., 2017; Sinha & Sen, 2016), population (Costa et al., & 2011), urbanization (Tripathi, 2021; Nguea, 2023), terrorism (Khan et al., 2018), education (Khodabakhshi, 2011), tourism (Rivera, 2016), natural resource rents (Sinha & Sengupta, 2019), information and communication technology (Khan et al., 2019), and carbon emissions (Shah & Services, 2016) (Costa et al., & 2011) (Bedir & Yilmaz, 2016) on human development.

Besides the above aforementioned determinants, energy consumption is regarded as a crucial aspect of human development. Increased energy consumption was commonly believed to be positively associated with increased human development. However, considering the escalating ecological issues associated with energy consumption, this viewpoint has become outdated. Increased energy consumption does not equate to increased human development (Tran et al., 2019). Numerous studies have explored the connection between energy usage and human development, with notable examples including the research conducted by Martı and Ebenhack (2008). Their study analysed a dataset comprising 120 nations, revealing a strong and significant association between energy consumption and the human development index. Between 1988 and 2008, Ouedraogo (2013) examined the correlation between energy consumption and human development in fifteen developing countries through a comprehensive study. By employing Pedroni panel cointegration, FMOLS, and DOLS estimation methods, they

successfully verified that these variables exhibited a one-way Granger causality and a negative association. In contrast to previous investigations, Tran et al. (2019) utilised the system GMM method to analyse data from 93 nations spanning the years 1990 to 2014. According to their research, energy consumption has no discernible positive effect on human development in either developed or developing countries. Using the Granger panel causality test, Niu et al. (2013) examined the relationship between energy consumption and human development in fifty countries from 1990 to 2009. Their analysis provided evidence that these variables are bidirectionally causal over the long term. A statistically insignificant relationship was found between electricity consumption and the Human Development Index (HDI) in a study conducted by Khan et al. (2018) that examined Pakistan from 1990 to 2016. The researchers employed the Auto Regressive Distributed Lag (ARDL) bound testing method to ascertain this conclusion.

The relationship between renewable energy consumption and human development has received relatively limited attention compared to the extensive research on energy consumption and human development. Two notable studies, authored by Wang et al. (2018) and Pîrlogea (2012), specifically investigated the impact of renewable energy utilization on human development. These studies yielded contrasting findings. Pîrlogea (2012) observed a positive relationship between renewable energy usage and human development based on a study spanning six European Union nations from 1997 to 2008. In contrast, Wang et al. (2018) conducted a 2SLS regression analysis focusing on Pakistan from 1990 to 2014 and found that the utilization of renewable energy was associated with a decrease in human development. These divergent findings necessitate further research to ascertain the precise connection between the utilization of renewable energy sources and human development, leaving room for additional investigation.

2.2. Financial development and sustainable human development

Profound scholarly investigation and research have been devoted to the literature concerning the correlation between financial development and sustainable development. Financial development is an umbrella term that pertains to the expansion, effectiveness, and consistency of financial systems. It comprises a multitude of components, including capital markets, regulatory frameworks, and banking institutions. Conversely, sustainable development encompasses the enduring preservation of social progress, environmental preservation, and economic advancement. A plethora of scholarly investigations have examined the complex interrelationships between sustainable development and financial development, with the aim of comprehending the ways in which financial systems may either facilitate or impede the attainment of sustainability objectives. The facilitation of sustainable development by financial institutions has been a subject of considerable scholarly inquiry. Financial institutions that finance sustainable projects and initiatives and allocate capital are indispensable. Examples of such institutions include banks and development finance institutions. The influence of sustainable finance practices, including responsible investment and green lending, on the advancement of sustainable development outcomes has been the subject of scholarly investigation.

The relationship between financial development and economic growth has been extensively studied, with varying estimates but an overall significant impact (Valickova et al., 2014; Moradbeigi & Hook Law, 2017; Guru & Yadav, 2019; Yusheng et al., 2020). Human capital and the development of the financial system are crucial factors that strongly influence economic growth. In recent literature, there has been a shift towards viewing human development as the ultimate goal of development, considering its long-term impact on well-being. The connection between financial progress and human development has been explored in contemporary research (Sehrawat & Giri, 2014; Hatemi-J & Shamsuddin, 2016).

The allocation of external finance, particularly loans invested in capital expenditure, has been found to positively impact the Human Development Index (HDI) (Chandrarin et al., 2022). Africa currently faces challenges in terms of both human and financial development, lagging behind the global average in financial growth. The lack of progress in human development in Africa poses a significant risk in the face of climate change if not addressed (Shobande & Asongu, 2021). To further illustrate the role of financial development in sustainable economic development in the very recent related literature, Wang et al. (2022) employed the Driscoll-Kraay method to estimate long-term coefficients and the Dumitrescu-

Hurlin test to establish causality. Their study explored the influence of financial development on the relationship between renewable energy usage and CO₂ emissions across 11 nations from 1990 to 2015. The findings revealed a significant reduction in CO₂ emissions resulting from the synergy between financial development and the utilization of renewable energy sources.

The adoption of sustainable energy sources is acknowledged as a vital alternative to tackle and alleviate environmental issues. Nevertheless, the introduction of renewable energy could face obstacles and grow more expensive in the absence of a proactive and crucially important financially advanced sector, which encompasses strong financial institutions and markets. Although the connection between financial development, renewable energy, and sustainable human development at this crossroads is crucial, there is a significant lack of research in investigating the precise relationship between biomass energy utilisation and sustainable human development. Furthermore, the previous literature has mainly neglected to consider the moderating impact of financial development on the relationship between biomass energy use and sustainable human development in member nations of the East African Community (EAC). Hence, our work endeavours to address this notable deficiency in the existing research literature.

3. Methodology

3.1. Theoretical framework

Prior to discussing economic modelling, it is essential to establish a theoretical basis for choosing the study variables. The phenomenon of economic expansion holds significant implications for 'unsustainable human development'. Ranis and Stewart (2005) argue that an economic boom provides opportunities for furthering human development. Income can be considered strongly connected with longevity and schooling, both of which have an impact on HDI (Shah & Services, 2016). Additionally, Rudra and Chattopadhyay (2018) contended that economic growth followed by environmental damage has an adverse effect on current and future generations' standard of living. The relationship between GDP and the HDI remains a topic of ongoing debate. Although they are interrelated, a high Gross Domestic Product (GDP) may not always indicate an elevated Human Development Index (HDI). It has been observed that certain nations can achieve a high Human Development Index (HDI) despite having a low GDP, and conversely, nations with a large GDP may have a comparatively low HDI (Ranis & Stewart, 2005).

Similar to other renewable sources of energy, biomass-generated energy can impact economic growth and, consequently, the purchasing power of individuals, income, and the standard of living (Bildirici & Özaksoy, 2018; Hermiyanti & Hamzah, 2015). Concurrently with the advancement of the economy, individuals are able to avail themselves of educational and medical services. Biomass energy in the developing world also serves to generate employment possibilities and augment income for countryside laborers, making a significant contribution to reducing poverty (Ozturk & Bilgili, 2015). Biomass energy may supply electric power, household heating, cooking, and transportation (REN21, 2017), affecting the three dimensions of human development. Biomass has gained popularity in recent years as a sustainable energy source because of its abundance and ease of production (Dogan & Inglesi-Lotz, 2017; Bilgili & Ozturk, 2015). Biomass energy also reduces energy prices, meets global energy needs, and reduces fossil fuel use (Bonechi et al., 2017). More crucially, biomass energy is 'carbon neutral' (Sikka et al., 2013) because planting trees absorbs atmospheric carbon dioxide. Thus, the energy from biomass reduces environmental pollutants and climate change, which can harm human health. Owing to changes in land use and carbon leaks, some academics contend that the utilization of biomass for energy production increases the release of carbon dioxide (Bilgili et al., 2017). According to the Institute for Advanced Sustainability Studies (IASS) (2015), compared to coal, oil, and natural gas, wood-burning biomass emits the most CO₂ per energy unit. Moreover, biomass energy generation and consumption have solved the problems of forest degradation, soil deterioration, biodiversity decline, land rivalry, food shortages, and resource scarcity.

In emerging nations, financial development is intimately linked to economic growth (Beck et al., 2000; Valickova et al., 2014; Moradbeigi & Hook Law, 2017; Assefa & Varella Mollick, 2017; Sharma & Kautish,

2020; Ekanayake & Thaver, 2021). Moreover, one of the key elements exerting an influence on sustainable human well-being is thought to be financial development. Redmond and Nasir, (2020) illustrate that financial development affects human development. Both directly and indirectly, financial progress affects human development. First, based on the estimates, the development of the finance industry has the potential to address sustainability concerns in economies with abundant oil resources by establishing the necessary economic circumstances to effectively reduce the negative impacts associated with carbon emissions (Nwani et al., 2021). Second, improving living standards and prosperity and reducing poverty are some of its benefits (Nwani et al., 2021). Moreover, financial development leads to a spike in school enrolment across all educational levels, thereby resulting in a larger pool of qualified laborers (Thierry & Emmanuel, 2023). In addition to gross domestic product (GDP), the development of financial institutions is also recognized as a possible factor in addressing environmental degradation, promoting environmental sustainability, and influencing the well-being and quality of life of individuals (Shobande & Asongu, 2021). By positively impacting biomass energy consumption, financial development is projected to moderate the relationship between biomass energy use and sustainable human development.

Financial development, trade liberalization, and population growth all contribute to economic growth in developing nations (Saidi et al., 2016). Greenhouse gas emissions can be reduced by trade liberalization through the facilitation of the widespread expansion and exchange of sustainable energy products, technologies, and services on a global scale (Yang et al., 2022). Population expansion also positively and statistically significantly affected economic growth. (Befikadu & Tafa, 2022). Increased employment prospects are triggered by both trade openness and population growth, which elevate per capita income (Duodu & Baidoo, 2020; Rehman, 2019). Thus, there is a rationale to suggest that the trade liberalization level and population growth rate influence the trajectory of human development.

3.2. Model construction

This study investigates how financial development (FD) moderates the effect of biomass energy consumption (BEC) on sustainable human development (SHD) in East African Community (EAC) countries from 1990 to 2019. Based on Wang et al., 2023; Katircioğlu and Taşpinar (2017); Chen et al. (2019) and Wang et al. (2022), we create two models: the primary impact model and the interaction model. In the primary model, denoted by Equation (1), we examined the influence of the BEC on the SHD. In the context of the moderating impact model, Equation (2) incorporates the interactions that account for the moderating influence of FD. Specifically, these variables encompass the interactions between the FD and biomass energy consumption. The aforementioned models are presented as follows.

Main effect model:

$$\ln SDI_{it} = \beta_0 + \beta_1 \ln BEC_{it} + \beta_2 \ln FD_{it} + \beta_3 \ln TO_{it} + \beta_4 \ln POPG_{it} + \beta_5 \ln GDPPC_{it} + \beta_6 \ln INFL_{it} + \varepsilon_{it} \quad (1)$$

Interactive effect model:

$$\ln SDI_{it} = \phi_0 + \phi_1 \ln BEC_{it} + \phi_2 \ln FD_{it} + \phi_3 \ln TO_{it} + \phi_4 \ln POPG_{it} + \phi_5 \ln GDPPC_{it} + \phi_6 \ln INFL_{it} + \phi_7 \ln (FD * BEC)_{it} + \varepsilon_{it} \quad (2)$$

Both models utilize the following variables: SHD, which denotes sustainable human development; BEC, which represents biomass energy consumption; FD, which signifies financial development; and TO, which represents trade openness. The term 'POPG' represents population growth. The error term is denoted by ' ε ', while ' i ' represents the cross-sectional dimension and ' t ' represents the time dimension. The positive or negative nature of constants β and ϕ remains undetermined because of their unpredictable effects on SHD.

Our approach of introducing a moderating factor into Equation (2) to analyze the indirect influence of FD on sustainable human development is crucial in this context. According to Katircioğlu and Taşpinar (2017), the presence of statistically significant interaction terms indicates the occurrence of moderating activities. All variables used logarithmic forms to minimize heteroscedasticity and variations in the data.

Table 1. Variable description and sources of data.

| Variable | Symbol | Definition | Measure | Data source |
|--|--------|--|----------------------|----------------|
| Sustainable development index | SDI | SDI consists of three factors: wellness, schooling, and living standard, CO2 emissions and material footprint. | Index | Hickel, 2020 |
| Per capita biomass energy consumption | BMPC | Utilization of energy derived from biomass. | Tones per person | Material Flows |
| Economic growth | GDPPC | The 2015 US Dollar GDP divided by the midyear population yields GDP per capita. | US Dollar per person | World bank |
| Population growth | POP_G | De facto population proportion expressed annually. | Annual % | World bank |
| Trade openness | TO | A percentage of total imports and exports to GDP. | % of GDP | World bank |
| Financial development | FDI | An index that evaluates the accessibility of financial institutions and markets. | Index | IMF |
| Domestic credit to private sector by banks | DCPS | domestic private sector credit as a percentage of GDP. | % of GDP | World bank |
| Inflation | INFL | The yearly fluctuation of the consumer price index. | Annual % | World bank |

Table 2. Results of the descriptive analysis.

| Variables | Obs | Mean | Std. Dev | Min | Max | Skew | Kurt |
|-----------|-----|---------|----------|---------|-----------|--------|---------|
| sdi | 180 | .454 | .096 | .207 | .647 | -.227 | 2.499 |
| bmcpc | 180 | 1.761 | .648 | .873 | 3.961 | 1.381 | 4.524 |
| gdppc | 180 | 651.343 | 354.341 | 190.333 | 1653.829 | 1.017 | 2.973 |
| to | 176 | 43.042 | 14.603 | 19.685 | 90.747 | .817 | 3.366 |
| pop g | 180 | 2.738 | 2.555 | -16.881 | 16.626 | -3.545 | 42.685 |
| infl | 180 | 229.014 | 2030.347 | -5.228 | 26765.857 | 12.556 | 164.015 |
| fd | 180 | .094 | .04 | 0 | .183 | -.065 | 2.901 |
| dcps | 180 | 12.31 | 8.157 | .449 | 36.648 | .699 | 2.99 |

3.3. Data description

A balanced panel dataset covering 1990 to 2019 was used in this study, covering East African Community (EAC) countries. Table 2 shows how data availability determines the sample and countries chosen. Table 1 lists the metrics used to represent these variables. The concept of Sustainable Human Development (SHD) was operationalized using a sustainable development index devised by Hickel (2020). However, GDP per capita, corrected for inflation and represented in constant 2015 US dollars, measures economic growth (GDPPC). The World Bank database provides trade openness (TO) data (comprising total imports and exports), population growth (POPG), and inflation (INFL). An IMF dataset was used as the source of the financial development index. From the Material Flows database, the Biomass Energy Consumption (BEC) was measured in tons per capita.

3.4. Estimation methods

We employ a series of econometric methodologies to achieve our research objectives. Standardizing time series and panel data is crucial in the empirical estimation of energy economics research data (Kao, 1999; Pedroni, 2004; Westerlund, 2007). To account for variations in sustainable human development and financial development among East African Community (EAC) countries, we employed the analytical approaches outlined in Figure 4. Initially, a cross-sectional independence test was performed to ascertain the potential dependency of the error terms on the cross-sections. Subsequently, the CADF and CIPS tests assess the stationary qualities of the fixed attributes, whereas the Kao, Pedroni, and Westelund tests examine the variables' long-run relationships. To address panel data heterogeneity and cross-sectional dependency, we employed Driscoll-Kraay (DK) as a baseline regression method to estimate long-term coefficients. Relevant methods like Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Errors (PCSE) were also used. Finally, the Dumitrescue-Hurlin (DH) test was used to determine causal linkages in this study. The FMOLS econometric panel approach is employed to evaluate the consistency and robustness of the study. Figure 4 illustrates the sequential processes employed in this investigation.

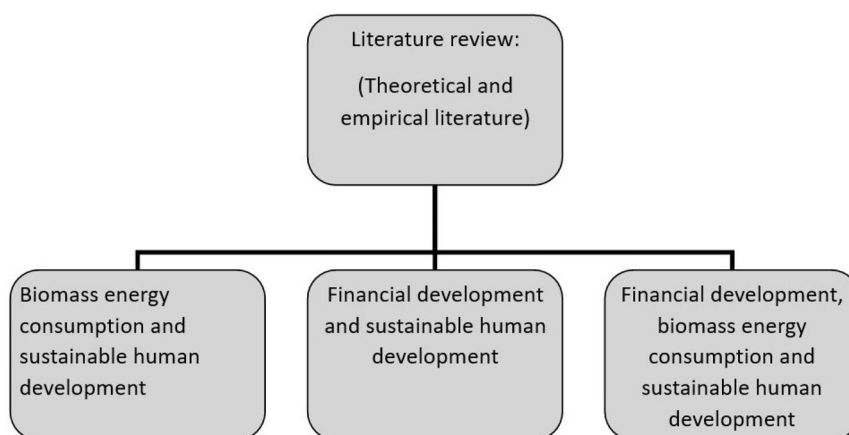


Figure 4. Literature review graphical representation in a SmartArt chart format.

3.4.1. Pre-estimation econometric approaches

Due to the complexity of macroeconomic variables across nations, this study uses panel data analysis to adjust for heterogeneity and cross-sectional dependence (CD). In panel data, stationarity and cross-sectional dependency are crucial to the economic variable analysis. Biased results can emerge from cross-sectional dependence. We examine the Lagrange multiplier (LM) and cross-sectional dependence (CD) tests to account for non-stationary economic variables (Breusch & Pagan, 1980; Pesaran, 2004). We used slope homogeneity tests (Pesaran & Yamagata, 2008) to estimate slope coefficient homogeneity after assessing cross-sectional dependence. Previous analytical techniques based on the homogeneity assumption failed to consider the unique features of each nation (Bedir & Yilmaz, 2016). Pesaran and Yamagata (2008) introduced the Δ test, a standardized dispersion test statistic, based on Swamy's (2015) model for slope homogeneity assessment.

Moreover, time series and panel data regressions might be misleading because most economic variables are nonstationary. To obtain reliable results, we checked stationarity using the Pensaran (2007) CIPS and CADF panel unit root tests. The cross-sectional averages of the lagged levels and first differences of each series are included in the ADF regressions. After running the CADF unit root test for each unit, we calculate the CIPS statistic by averaging the lagged CADF t-statistics. This study used CIPS and the CDAF unit root test to account for CD and heterogeneity and to acquire accurate results. Table 5 illustrates the CIPS and CADF outputs, where all the variables are stationary when first differenced. After the first difference, the unit root test showed stationarity in all variables; therefore, we used the Kao (1999), Pedroni (2004), and Westerlund (2007) cointegration tests. The tests indicated a long-term association between variables. The Westerlund cointegration test is also thought to yield consistent spurious-free long-term association results (Chica-Olmo et al., 2020).

3.4.2. Main panel estimation approaches

Owing to the cross-sectional dependence and heterogeneity among cross-sectional units, panel-corrected standard errors (PCSE) and feasible generalized least squares (FGLS) estimators were employed. These techniques effectively account for heteroscedasticity, serial correlations, and cross-sectional dependence. To find potential linkages between variables, panel causality test by Dumitrescu and Hurlin (2012) was performed as the Driscoll-Kraay standard error, FGLS, and PCSE methods fail to show causation between variables, which is essential for policymaking (Saud et al., 2018; Wang et al. 2023). A modified Granger non-causality test, the paired Dumitrescu-Hurlin test, accounts for the panel data heterogeneity and cross-sectional dependence. Finally, to ensure the validity of our results and evaluate their consistency, we utilized the Fully Modified Ordinary Least Squares (FMOLS) technique as well as the Augmented Mean Group (AMG) estimators to conduct robustness checking tests.

This study on financial development, biomass energy usage, and sustainable human development benefits society in the following ways. Policymakers can make better decisions and create sustainable development strategies by knowing the research variables' fundamental determinants and interactions. Access to credit, efficient capital allocation, and strong financial institutions are found to promote

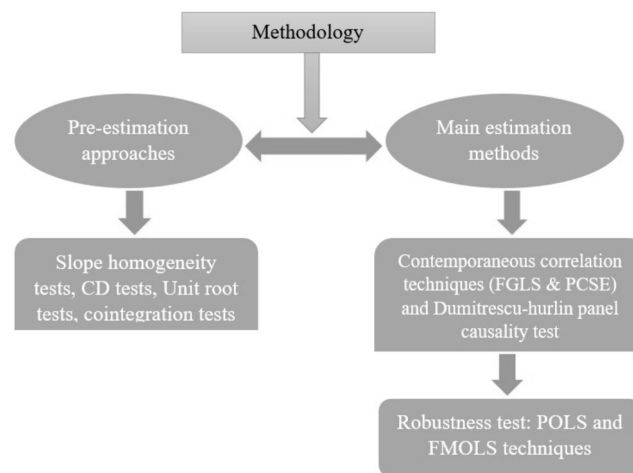


Figure 5. Graphical representation of the methods used in the study.

sustainable human development. The study informs sustainable energy planning for biomass energy consumption and human development. It highlights biomass energy's drawbacks, including deforestation, indoor air pollution, and health problems. This understanding can help policymakers and energy planners switch to cleaner, more sustainable energy sources, reducing the harmful effects of biomass energy consumption on human health and encouraging sustainable development. By addressing the constraints and trade-offs, policymakers and environmentalists may implement initiatives to limit biomass energy consumption and encourage renewable energy. This safeguards ecosystems, resources, and climate change. The research also shows how education, healthcare, and living standards promote sustainable human development. Financial development improves these variables; therefore, governments can prioritise financial inclusion, credit access, and strong financial institutions. This can improve education, healthcare, and living standards for individuals and communities (Figure 5).

4. Results and discussion

4.1. Results

Table 2 displays the range of sustainable human development, as indicated by the sustainable development index, across the countries of the East African Community (EAC), which varies from 0.207 percent to 0.647. The data presented prove a considerable difference in the sustainable development index among the aforementioned nations from 1990 to 2019. GDP per capita shows a significant disparity in economic development, ranging from 190.333 USD to 1653.829 USD. The mean GDP per capita for East African Community (EAC) countries during the specified time frame amounts to 651.343 USD. Financial development, measured by the bank's domestic credit to the private sector as a share of GDP, averages 12.31. The observed financial development indicators exhibited a notable degree of disparity.

A statistical metric, known as the correlation coefficient, can be used to quantify the strength of the correlation between two or more variables. A high correlation between two or more independent variables can lead to multicollinearity, making model interpretation difficult. According to Shrestha (2020), multicollinearity can be inferred when the absolute correlation coefficient between two or more predictors exceeds 0.8. It is clear from the results shown in Table 2 that the linear correlation coefficients among the explanatory variables examined in each regression analysis were all below 0.8. Consequently, it can be concluded that multicollinearity is absent, thereby meeting the criteria for the model's goodness of fit.

4.1.1. Pre estimations: cross-sectional dependence, panel unit root, and cointegration tests

The findings derived from the preliminary estimations are shown in Tables 3–7. The null hypothesis that there is no cross-sectional dependence is rejected at a significance level of 1% according to the findings of the Pesaran CD test and the Lagrange multiplier (LM) test (Breusch & Pagan, 1980; Pesaran, 2004).

Table 3. Matrix of correlation results.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|------------|--------|--------|--------|--------|--------|--------|--------|-------|
| (1) lshd | 1.000 | | | | | | | |
| (2) lbmcp | 0.052 | 1.000 | | | | | | |
| (3) lgdppc | 0.756 | 0.336 | 1.000 | | | | | |
| (4) lto | 0.412 | 0.099 | 0.368 | 1.000 | | | | |
| (5) lpop_g | 0.292 | −0.064 | 0.145 | −0.005 | 1.000 | | | |
| (6) lfd | 0.307 | 0.219 | 0.437 | −0.060 | −0.062 | 1.000 | | |
| (7) ldcps | 0.431 | 0.343 | 0.493 | 0.075 | −0.014 | 0.740 | 1.000 | |
| (8) linf | −0.262 | 0.092 | −0.172 | 0.054 | −0.059 | −0.363 | −0.516 | 1.000 |

Table 4. Cross-sectional dependence test output.

| Test | Statistic | d.f. | Prob. |
|-------------------|-----------|------|--------|
| Breusch-Pagan LM | 193.4637 | 15 | 0.0000 |
| Pesaran scaled LM | 32.58287 | | 0.0000 |
| Pesaran CD | 13.16767 | | 0.0000 |

Note. *** and ** indicate statistical significance at the 1% and 5% level, respectively.

Table 5. Slope homogeneity test.

| Tests | LM statistics | P values |
|----------------|---------------|----------|
| Δ | 5.730 | 0.000 |
| Δ_{adj} | 6.719 | 0.000 |

Note. *** and ** indicate statistical significance at the 1% and 5% level, respectively.

Table 6. Unit root tests results.

| Variable | CIPS test | | CADF test | |
|----------|-----------|----------------------------|-----------|----------------------------|
| | level | 1 st difference | level | 1 st difference |
| lsdi | −2.796*** | −2.906*** | −3.026*** | −2.171** |
| lbmcp | −2.238* | −5.661*** | −0.445 | −3.723*** |
| lgdppc | −1.949 | −3.702*** | −0.185 | −2.453*** |
| lto | −2.450** | −5.992*** | 0.217 | 0.217*** |
| lpop g | −1.959 | −3.170*** | −0.152 | −4.751*** |
| lfd | −2.335** | −5.558*** | −0.536 | −4.274*** |
| ldcps | −2.274* | −5.675** | −0.906 | −2.147** |
| linf | −4.203*** | −6.190*** | −1.310* | −3.492*** |

Note. At 1%, 5%, and 10% significance, the CIPS and CADF test critical values were 2.57, 2.33, and 2.21, respectively. In addition, ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

This finding suggests that shocks occurring in one nation have the potential to be transmitted to other East African community member states.

Table 5 presents the results of the slope homogeneity tests. The results also reveal slope heterogeneity in addition to the presence of cross-sectional dependence. The slope homogeneity hypothesis was rejected because the p-values for the Δ and Δ_{adj} tests were both less than 0.01. The findings derived from Tables 4 and 5 suggest that the panel dataset exhibits slope heterogeneity and cross-sectional dependence, emphasizing the need to address these issues in subsequent analyses.

The study employed the CADF and CIPS tests (second-generation unit root tests that consider the cross-sectional dependency issue) to examine whether the variables are stationary at level and 1st difference. Pesaran (2007) developed these unit root tests. Table 6 presents the outcomes of the panel unit root tests. The CIPS and CADF tests consistently indicate that inflation and sustainable human development exhibit stationarity at this level. Meanwhile, trade openness, population growth, financial development, human development, and economic growth all have unit roots at the level, but become stationary at the first difference. In the model, the variables of I(1) are integrated at this level, suggesting a cointegration relationship.

In Table 7, the panel cointegration tests of Kao, Pedroni, and Westerlund (2007) cannot disprove the null hypothesis, indicating a long-term association between the variables. Thus, the panel cointegration test results shown in Table 7 do not support the null hypothesis, suggesting a long-term relationship between the variables as evidenced by Kao, Pedroni, and Westerlund (2007).

Table 7. Results for Kao, Pedroni and Westerlund cointegration.

| Kao cointegration test | | Pedroni cointegration test | | Westerlund cointegration test | |
|------------------------|---------|----------------------------|---------|-------------------------------|---------|
| Statistic | P-value | Statistic | P-value | Statistic | P-value |
| −3.9518 | 0.000 | 3.5953 | 0.000 | 3.6451 | 0.000 |
| −3.0543 | 0.001 | 1.8755 | 0.030 | | |
| −3.5917 | 0.000 | 2.5341 | 0.005 | | |
| −2.7985 | 0.002 | | | | |
| −2.7916 | 0.002 | | | | |

Table 8. Baseline regression results.

| Variables | (Pooled OLS) | | (Fixed effects) | | (Driscoll-Kraay FE) | |
|------------------|-------------------------|-------------------------|-------------------------|-----------------------|----------------------|----------------------|
| | lsdi | lsdi | lsdi | lsdi | lsdi | lsdi |
| lbmcp | −0.127*** (0.0244) | −0.917*** (0.176) | −0.208*** (0.0612) | −0.879*** (0.231) | −0.208*** (0.043) | −0.879*** (0.177) |
| lgdpp | 0.310*** (0.0280) | 0.281*** (0.0296) | 0.441*** (0.0373) | 0.468*** (0.038) | 0.441*** (0.038) | 0.468*** (0.028) |
| lto | 0.126*** (0.0300) | 0.0989*** (0.0356) | 0.0935*** (0.0318) | 0.063* (0.034) | 0.094* (0.049) | 0.063 (0.038) |
| lpop_g | 0.139*** (0.0345) | 0.140*** (0.0331) | 0.0883*** (0.0324) | 0.089*** (0.031) | 0.088*** (0.026) | 0.089*** (0.023) |
| lfd | 0.0115 (0.0225) | −0.159*** (0.0394) | 0.0721*** (0.0262) | −0.091 (0.063) | 0.072* (0.038) | −0.091 (0.063) |
| linf | −0.0232*** (0.00607) | −0.0213*** (0.00737) | −0.0335*** (0.00938) | −0.021** (0.00995) | −0.034*** (0.009) | −0.021** (0.009) |
| lbmcp_lfd | | 0.328*** (0.0712) | | 0.294*** (0.095) | | 0.294*** (0.069) |
| Constant | 1.053*** (0.185) | 1.723*** (0.251) | 0.433 (0.275) | 0.696** (0.295) | 0.433* (0.239) | 0.696*** (0.247) |
| Observations | 180 | 177 | 180 | 177 | 180 | 177 |
| R-squared | 0.681 | 0.703 | 0.654 | 0.687 | | |
| Number of groups | | | | | 6 | 6 |
| Number of c_id | | | 6 | 6 | | |

The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The standard errors are provided in parentheses.

Table 9. Contemporaneous Correlation Models (FGLS & PCSE) Output.

| Variables | PCSE 1 | PCSE 2 | PCSE 3 | FGLS 4 | FGLS 5 | FGLS 6 |
|----------------|-----------------------|-------------------------|-------------------------|-----------------------|-----------------------|-----------------------|
| lbmcp | −0.143*** (0.0281) | −0.127*** (0.0281) | −0.920*** (0.179) | −0.143*** (0.0324) | −0.127*** (0.0324) | −0.920*** (0.217) |
| lgdpp | 0.314*** (0.0267) | 0.309*** (0.0265) | 0.281*** (0.0263) | 0.314*** (0.0255) | 0.309*** (0.0251) | 0.281*** (0.0254) |
| lto | 0.124*** (0.0310) | 0.127*** (0.0301) | 0.0993*** (0.0309) | 0.124*** (0.0337) | 0.127*** (0.0331) | 0.0993*** (0.0328) |
| lpop_g | 0.143*** (0.0533) | 0.138*** (0.0526) | 0.140** (0.0553) | 0.143*** (0.0354) | 0.138*** (0.0348) | 0.140*** (0.0335) |
| lfd | 0.0279 (0.0192) | 0.00952 (0.0193) | −0.160*** (0.0412) | 0.0279 (0.0213) | 0.00952 (0.0222) | −0.160*** (0.0507) |
| linf | | −0.0260*** (0.00842) | −0.0227*** (0.00838) | | −0.0260** (0.0103) | −0.0227** (0.0100) |
| lbmcp_lfd | | | 0.329*** (0.0730) | | | 0.329*** (0.0891) |
| Constant | 0.929*** (0.213) | 1.065*** (0.217) | 1.731*** (0.272) | 0.929*** (0.170) | 1.065*** (0.176) | 1.731*** (0.247) |
| Observations | 176 | 176 | 176 | 176 | 176 | 176 |
| R-squared | 0.668 | 0.680 | 0.703 | | | |
| Number of c_id | 6 | 6 | 6 | 6 | 6 | 6 |

Note. *** and ** indicate statistical significance at the 1% and 5% level, respectively. The standard errors are in parentheses.

4.1.2. Main estimation (Driscoll-Kraay FE, PCSE, FGLS) results

Tables 8–10 present the primary findings of this empirical study. Utilization of the Driscoll-Kraay Fixed Effects, FGLS and PCSE estimators yielded significant findings. The study employed the pooled OLS, Fixed Effects and Driscoll-Kraay estimators as a baseline regression analysis. All results of the key explanatory variables are consistent, revealing how biomass energy use harms sustainable human development, as the coefficient of biomass energy consumption is negative and statistically significant.

Table 10. Results of the Dumitrescu-Hurlin panel causality test.

| Variables | lnsdi | lnbmcp | lngdppc | lnto | lnpop_g | lnfdi | lninfl |
|-----------|----------|----------|----------|----------|----------|----------|----------|
| lnsdi | – | 7.779*** | 8.027*** | 2.852 | 10.24*** | 4.54** | 3.949* |
| lnbmcp | 4.403** | – | 4.761*** | 2.149 | 3.852* | 1.593 | 3.196 |
| lngdppc | 11.60*** | 3.238 | – | 7.759*** | 13.30*** | 2.180 | 5.876*** |
| lnto | 9.360*** | 2.151 | 7.341*** | – | 5.523*** | 7.436*** | 4.333** |
| lnpop_g | 4.668** | 1.960 | 4.676** | 4.105** | – | 4.230** | 2.457 |
| lnfdi | 2.063 | 4.201** | 2.819 | 6.455*** | 1.458 | – | 1.709 |
| lninfl | 2.681 | 1.982 | 1.237 | 2.655 | 1.394 | 6.982*** | – |

Note. *** and ** indicate statistical significance at the 1% and 5% level, respectively. The standard errors are in parentheses.

Moreover, the financial development index also reverses the adverse effects of biomass energy use when interacting with it in EAC member countries.

This study set out to investigate two key questions: first, how financial development affects the results of sustainable human development; and second, how biomass energy consumption affects sustainable human development. The results of the study on the relationship between financial development and sustainable human development showed that better results in sustainable human development were linked to greater levels of financial development. The study used empirical analysis to identify potential processes by which financial development has a favourable impact on measures of sustainable human development. Important factors that have been identified as driving this link include improved credit availability, effective capital allocation, and the existence of strong financial institutions. These results emphasise how crucial a sound financial system is to achieving sustainable development goals, such as raising living standards, improving healthcare, and advancing education.

A thorough analysis of the environmental, social, and economic effects of using biomass energy sources—wood and agricultural leftovers in particular—for energy demands was conducted in order to better understand the implications of biomass energy use for sustainable human development. The study examined the difficulties and possible trade-offs related to the use of biomass energy. It looked into the negative effects of using biomass energy, such as deforestation, indoor air pollution, poor health outcomes, and limitations on socioeconomic development. These findings emphasise the necessity of tackling the difficulties presented by the use of biomass energy in order to guarantee sustainable human development in the long run.

The analysis also evaluated the relationship among sustainable human development, biomass energy usage, and financial development. It was discovered that the use of biomass energy and financial development interact and have an impact on one another. The study found possible synergies or conflicts between activities promoting financial development and efforts towards achieving sustainable energy transitions. In doing so, it provided insight into methods that, in the context of financial development, might balance the objectives of biomass energy use and sustainable human development. These findings highlight the need of coordinating financial policies with sustainable energy initiatives to attain mutually advantageous results for both economic progress and environmental preservation.

In brief, this research offered comprehensive understandings of the connections among sustainable human development, biomass energy usage, and financial development. The findings emphasised the beneficial influence of financial development on sustainable human development outcomes, as well as the difficulties and consequences linked to biomass energy usage. In the framework of financial development, the research also shed light on how these variables interact and suggested ways to balance the objectives of biomass energy use and sustainable human development. These findings enhance our understanding of the intricate factors that affect the attainment of sustainable human growth, particularly in relation to financial and energy constraints.

After assessing the relationship between biomass energy consumption (BEC) and sustainable human development (SHD), taking into account the moderating influence of financial development, it has been shown that the use of biomass energy has a negative impact on human development. Both the PCSE and FGLS estimators reveal that a 1% increase in biomass energy use leads to a –0.143% reduction in sustainable human development, all other things being equal. The generation and utilization of biomass energy can lead to several negative consequences, including, but not limited to, food instability, declining ecosystem diversity, exhaustion of resources, and forest destruction. In addition, using traditional biomass sources, such as wood and trash, can have detrimental effects on the ecological health and

well-being of people. Biomass energy has the potential to meet humankind's energy needs for transportation, heating, cooking, and electricity production. Additionally, the biomass energy sector facilitates employment opportunities and economic growth for individuals residing in rural areas. Furthermore, it is important to note that the economic growth phenomenon can potentially contribute to the switch from traditional biomass energy sources to more contemporary alternatives such as biodiesel and green gas. However, greener and safer biofuels need to be invested in the environment, which further requires a supportive government policy to finance sustainable green projects in the EAC region. Given that energy consumption harms the environment, the shift from traditional to modern biomass energy use helps mitigate this impact. Financial development can explain the direction of the association between biomass energy use and sustainable human development in East African Community (EAC) countries. In contrast to our findings, prior studies, such as those by Shahbaz et al. (2016), Aydin (2019), and Wang et al. (2020), established that the utilization of biomass energy not only has a positive impact on economic growth and environmental preservation, but also fosters advancements in human development. Based on our findings, authorities may anticipate that biomass energy consumption can become a viable means of attaining sustainable human development in parallel with the overall development of the financial sector.

Following the estimation of the long-term coefficients, we used Dumitrescu and Hurlin (2012) model to evaluate how causal variables are linked. Based on a panel causality test of a heterogeneous nature, the results are presented in Table 10. The most noteworthy finding of this study was the bidirectional causal link between biomass energy and human development. This implies that variations in human development are a result of changes in biomass energy use and vice versa. In addition to long-run predictions, this outcome serves as a proposal for policymakers to utilize bioenergy for sustainable human development in EAC member countries.

We find that sustainable human development and economic growth are causally related in both directions. A similar result was reported by Wang et al. (2020) for the BRICS countries. Our findings, however, conflict with the conclusions drawn by Khan et al. (2018), Rivera (2016), and Khan et al. (2019). The relationship between population growth and sustainable human development was found to be causally bidirectional. Contrary to previous findings, trade openness, financial development, and sustainable human development are causally related. In addition, we discovered a unidirectional causal relationship between economic growth and biomass energy use. Although this conclusion contradicts the findings of Shahbaz et al. (2016) and Wang et al. (2020), it is in agreement with the studies by Aydin (2019) and Konuk et al. (2021).

4.2. Robustness checks

Long-run projections were analyzed using the fully modified ordinary least squares (FMOLS) approach, which was first introduced by Phillips and Hansen (1990). Table 11 displays the findings of long-run

Table 11. FMOLS long run analysis results.

| VARIABLES | (DCPS 1 | DCPS 2 | DCPS 3 | (FDI) 4 | (FDI) 5 | (FDI) 6 |
|----------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------|-----------------------|
| lbmcp | −0.229*** (0.056) | −0.2053** (0.098) | −0.475*** (0.066) | −0.308*** (0.0555) | −0.221*** (0.062) | −0.819*** (0.065) |
| lgdpp | 0.388*** (0.014) | 0.3784*** (0.076) | 0.3959*** (0.014) | 0.4991*** (0.0139) | 0.488*** (0.0140) | 0.4798*** (0.014) |
| lto | 0.058 (0.022) | −0.004 (0.061) | 0.0875*** (0.023) | 0.1055*** (0.0201) | 0.103*** (0.022) | 0.1096*** (0.023) |
| lpop_g | −0.027*** (0.0395) | 0.1424*** (0.0504) | −0.019 (0.041) | −0.065 (0.0396) | −0.053 (0.040) | 0.011 (0.040) |
| ldcps | 0.1075*** (0.0253) | 0.0999** (0.0456) | −0.009 (0.037) | | | |
| lfdi | | | | 0.0599 (0.0401) | 0.0469 (0.0454) | −0.129** (0.0504) |
| linfl | | −0.0180 (0.0254) | −0.080 (0.0705) | | −0.134* (0.076) | −0.157** (0.0761) |
| lbmcp_lfd | | | 0.2411*** (0.0542) | | | 0.2369*** (0.0310) |
| Observations | 170 | 170 | 170 | 170 | 170 | 170 |
| Adj. R-squared | | | | | | 0.6358 |
| Number of c_id | 6 | 6 | 6 | 6 | 6 | 6 |

Note. *** and ** indicate statistical significance at the 1% and 5% level, respectively. The standard errors are in parentheses.

FMOLS estimations. The results show that for EAC countries, economic growth and sustainable human development are positively and significantly correlated. The results of this study demonstrated that the use of biomass energy has a substantial and detrimental effect on sustainable human development. It has also been discovered that sustainable human development is positively affected by financial development. The positive and statistically significant coefficient of the interaction term between financial development and biomass energy use reversed the negative impacts of biomass energy consumption on sustainable human development in East African Community (EAC) countries.

The study also employed the Augmented Mean Group (AMG) econometric technique as a means of verifying the reliability of its findings. It aimed to investigate the correlation between financial development, biomass energy consumption, and sustainable human development together with other control variables. To enhance the stability and repeatability of their findings, researchers utilised the AMG technique as a robustness check, subjecting their results to extra tests and validations. The utilisation of the Augmented Mean Group (AMG) estimator offers a sophisticated analytical framework to thoroughly

Table 12. Augmented Mean Group (AMG) econometric technique results.

| VARIABLES | (All) lsdi | Burundi lsdi | DR Congo lsdi | Kenya lsdi | Rwanda lsdi | Tanzania lsdi | Uganda lsdi |
|----------------|----------------------|-------------------------|------------------------|-----------------------|-----------------------|-----------------------|---------------------|
| lbmcp | 0.198 (0.171) | −0.12566 (0.51557) | −0.131*** (0.0447) | 0.8704** (.37026) | 0.528 (.9091) | 0.1659 (0.1703) | −0.1204 (0.210) |
| lfd | 0.0854** (0.0433) | 0.02500 (0.16882) | −0.024* (.01357) | 0.2433* (0.1288) | 0.1917 (0.153) | 0.0430* (0.0259) | 0.03389 (0.0592) |
| lpop_g | −0.0345 (0.138) | −0.04764 (0.05904) | −0.0111 (.0679) | −0.6625* (0.36510) | 0.019** (0.009) | 0.175*** (0.0685) | 0.3202 (0.2835) |
| lto | −0.00696 (0.0421) | 0.09278*** (0.03145) | −0.0187** (.00777) | 0.063*** (.01657) | −0.200*** (0.0259) | 0.0053 (0.0072) | 0.0161 (0.0192) |
| lgdppc | 0.188* (0.112) | 0.5039*** (0.12639) | 0.2872*** (0.01556) | 0.339*** (.0764) | −0.159*** (.0331) | 0.3004*** (0.0255) | −0.146** (.0636) |
| linf | 0.00140 (0.00255) | 0.00315 (0.01364) | 0.00214 (0.0022) | 0.0121** (.0054) | 0.0003 (0.0056) | −0.0035 (0.0039) | −0.006* (0.0033) |
| lbmcp_lfd | −0.0773 (0.0630) | 0.0505 (0.2254) | 0.05678** (0.02335) | −0.259** (.1329) | (−0.274) (0.3917) | −0.07496 (0.0715) | 0.03696 (0.0941) |
| CDP | 1.191*** (0.365) | 1.318*** (0.13868) | 0.8324*** (.04007) | 0.368*** (0.0285) | 2.784*** (0.1035) | 0.4207*** (.0479) | 1.424*** (.1338) |
| Constant | 2.259*** (0.611) | 0.21876 (0.75567) | 2.003*** (0.21170) | 2.398* (1.2937) | 4.361*** (0.31917) | 1.158*** (.18642) | 3.413*** (1.044) |
| Observations | 168 | 30 | 30 | 30 | 30 | 30 | 30 |
| Number of c_id | 6 | 1 | 1 | 1 | 1 | 1 | 1 |

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

CDP stands for Common Dynamic Process which explains the pattern or sequence of events that occurs due to the interdependence among cross-sectional units such as countries (Figure 6).

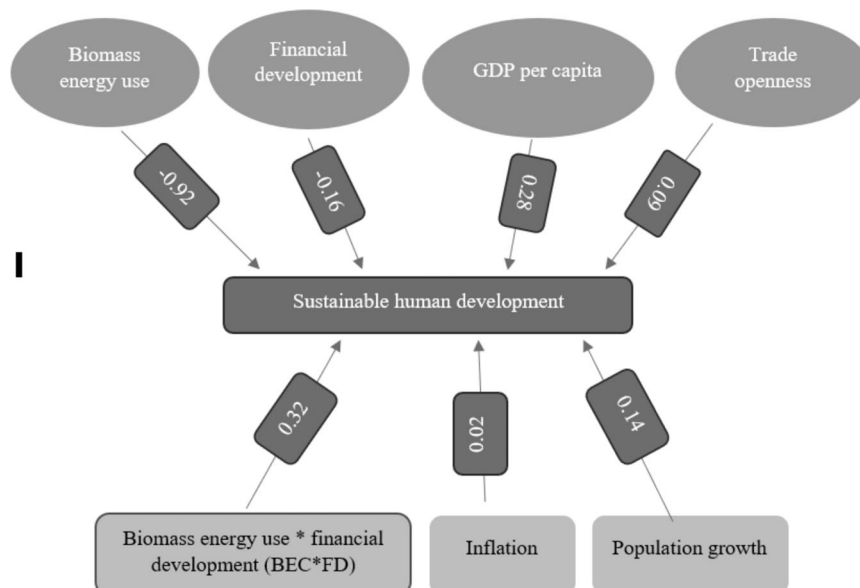


Figure 6. Graphical representation of the model results.

examine the country-specific impacts inside the cross-sectional units in a more detailed way. A deeper understanding of the underlying dynamics is provided by include the coefficients related to biomass energy use, financial development, and other control factors. The differences in coefficient values seen among different countries suggest the existence of heterogeneity in the effects, which can only be fully understood by using advanced estimators such as the AMG estimator.

The variation in the estimated coefficient values emphasises the need to consider the specific effects of each country and use advanced estimators, like the AMG estimator, to accurately capture the complexities and differences in the impacts of biomass energy consumption, financial development, and other control variables across various countries. This advanced method improves our comprehension of the complex interactions occurring and offers a more precise representation of the diverse impacts inside the individual units being studied (Table 12).

5. Conclusion

This multivariate analysis examined the relationship between sustainable human development and biomass energy use in the EAC region between 1990 and 2019. Other factors taken into account include inflation, trade openness, population growth, economic expansion, and financial development. The models employed are the FGLS and PCSE, the Dumitrescu-Hurlin panel causality test, the Westerlund panel cointegration test, and the CADF and CIPS unit root tests. These panel data analysis methods aim to mitigate the issues of slope uniformity and cross-sectional dependence. The important conclusions from the empirical analysis are as follows: there is a reciprocal relationship between the use of biomass energy and sustainable human development. Economic growth, trade openness, and population growth have contributed to sustainable human development. Additionally, financial development plays a role in influences the connection between biomass energy consumption and sustainable human development in the EAC countries.

EAC countries should consider viable policy recommendations, based on empirical studies. Traditional biomass energy use lowers the human quality of life; hence, governments should reduce its use. Modern biomass energy must be promoted in EAC countries. Additionally, fossil fuels must be limited and partially replaced by renewable energy sources. However, the low energy efficiency of biomass hinders its utilization. To increase biomass energy efficiency, governments and industries should fund R&D and innovative technologies. Researchers should also focus on lowering the biomass energy production costs and making them more competitive. Along with biomass production, socio-economic issues including food shortages, decreased biodiversity, and forest destruction must also be addressed.

Our findings indicate that economic growth, trade openness, and population growth improve human development. Therefore, governments must support the positive effects of these determinants on sustainable human development. For instance, EAC governments can increase health and education spending, reduce income disparity, safeguard ecosystems, and promote renewable energy sources and technological advances in industry. Financial development mitigates the detrimental effects of biomass energy use on sustainable human development. We believe that EAC countries should increase their financial sector development standards, notably those related to the environment, to encourage investment in greener technological projects. This can also prevent EAC countries from becoming pollution havens, which is bad for human well-being.

In light of the fact that financial development affects the relationship between the use of biomass energy and sustainable human development, it is vital that financial institutions and markets in EAC nations be prioritised and strengthened. This objective can be accomplished by implementing strategies including enhancing credit accessibility, encouraging investment in renewable energy initiatives, and cultivating a regulatory environment that is conducive to sustainable finance. The research emphasises how economic expansion positively impacts sustainable human development. Therefore, prioritisation should be given to policies and strategies that promote economic expansion. This may encompass initiatives such as fostering entrepreneurial spirit, enticing foreign direct investment, infrastructure development, and providing assistance to sectors that exhibit prospects for sustainable economic growth. The results indicate that trade liberalisation has a beneficial impact on sustainable human development. The countries in the East African Community (EAC) region should prioritise the improvement of regional and

international trade integration by means of trade agreements, the reduction of trade barriers, and the expansion of their export markets. This can facilitate the exchange of knowledge and technology, increase competitiveness, and aid in the expansion of market opportunities. It was determined that population expansion contributed to sustainable human development. In order to optimise the positive effects of population growth on development, the implementation of efficient population management strategies is critical. Potential initiatives encompass funding for family planning programmes, healthcare, education, and the advancement of gender equality and women's empowerment. The interdependent relationship between the utilisation of biomass energy and sustainable human development underscores the imperative to give precedence to sustainable methodologies in the generation and utilisation of biomass energy. Governments need to allocate resources towards the development of renewable energy technologies, advocate for energy efficiency initiatives, and institute regulatory structures that foster the utilisation of sustainable biomass energy sources while mitigating adverse environmental effects.

These areas can accommodate more research. By conducting a subregional study or evaluating the effects of biomass energy consumption on sustainable human development in advanced and emerging economies, policymakers can obtain a more thorough understanding of the implications of biomass energy use. Furthermore, rather than examining the consequences of various forms of renewable energy, this study focuses on the contribution of biomass energy consumption to sustainable human development. This is a possible avenue for future research as well as the study's limitations.

One limitation of this study is the reliance on secondary data sources, which may have limitations in terms of accuracy and availability. To overcome this limitation, future research could consider incorporating primary data collection methods, such as surveys and interviews, to gather more precise and context-specific information on biomass energy consumption, financial development, and sustainable human development in the EAC member countries. This would provide a more nuanced understanding of the challenges and opportunities within the region. Another limitation is the consideration of a relatively short time frame for analysis. This study focused on a specific period, which may not capture long-term trends and dynamics. Future research could extend the time frame to provide a more comprehensive analysis of the relationship between biomass energy consumption, financial development, and sustainable human development over an extended period. This would enable researchers to examine trends, identify patterns, and assess the long-term impacts of policies and interventions on sustainable development outcomes.

Furthermore, this study primarily focused on the EAC member countries as a collective entity, without delving into country-specific variations and disparities. Each country within the EAC has its unique socio-economic, political, and environmental context, which may influence the relationship between biomass energy consumption, financial development, and sustainable human development differently. Future research could adopt a more country-specific approach, considering the diverse characteristics of each EAC member country, to capture the nuances and specificities of the relationship.

Despite these limitations, this study has successfully achieved its objectives of examining the impact of financial development on sustainable human development outcomes and analyzing the implications of biomass energy consumption for sustainable human development in the EAC member countries. The findings have shed light on the positive influence of financial development on sustainable human development indicators and highlighted the environmental and socio-economic challenges associated with biomass energy consumption.

Moving forward, the insights gained from this study can inform policymakers and stakeholders in developing targeted interventions. By considering the remedies proposed, such as incorporating primary data collection methods, extending the time frame of analysis, and adopting a country-specific approach, future research can build upon this foundation and further advance our understanding of the intricate relationship between financial development, biomass energy consumption, and sustainable human development in the EAC member countries.

Ultimately, addressing the limitations and building upon the achievements of this study will contribute to more robust and evidence-based policymaking, fostering sustainable energy transitions, enhancing financial development, and promoting holistic and inclusive sustainable human development in the EAC member countries.

Transparency

The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Authors contributions

1. Mr. Ali Abdukadir Ali Gutale: this author played a crucial role in the conceptualization of the research project, contributed to the development of the research questions, objectives, and theoretical framework. Additionally, the author was responsible for reviewing the pertinent literature, theories and frameworks and designing the methodology of the study.

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2. Dr. Ali Yassin Sheikh Ali: this author has played a critical role in collecting data, analysed data by using Stata software package version 17. Also, the author has made the interpretation of the data, drawing connections between the findings and the research objectives.

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3. Mr. Mohamed Saney Dalmar: this author took the lead in drafting the discussion and conclusion followed by the policy implications of the study. The author also drafted the overall manuscript, ensuring clarity, coherence, and adherence to academic writing standards. Also, the author played a critical role in revising and reviewing the manuscript based on feedback from other authors, editors or peer reviewers.

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Data availability statement

Upon a reason request, the supporting data of this study can be provided by the corresponding author.

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