Is climate change a monetary phenomenon? Evidence from time series analysis

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ABSTRACT
This study examined the role of monetary policy in addressing climate change in the East African Community using a time series approach. The empirical evidence shows that monetary policy through the credit and interest rate channel can help smooth the transition to low-carbon economies, but at the cost of financial uncertainty.

1. Introduction

According to the scientific consensus, climate change is non-negotiable (Nordhaus 2007; Dell et al. 2012; Campiglio et al. 2018). However, swift action is required to avoid its negative effects, mitigate its economic impact, and avert catastrophe. This study examined the role of monetary policy in addressing climate change in the East African Community (EAC) to provide information to help central banks (CBs) manage macroeconomic fluctuations, while promoting environmental sustainability.

This inquiry into the role of monetary policy in addressing climate change in the EAC is motivated by several factors. First, the EAC’s main source of income is agriculture, which has the potential to increase carbon emissions (IPCC 2014; Omambia et al. 2017). Most farmers still heavily rely on traditional farming methods, which may explain the increasing rate of carbon emissions reported in the region. Thus, monetary policy can help to provide access to credit, allowing farmers to acquire smart agricultural technology, which can mitigate the impact of anthropogenic carbon emissions (Nordhaus 2008, 2010; Georgopoulou et al. 2017; Singh and Dhadse 2021). Second, the financial inclusion in East Africa is relatively low. The increase in the unbanked population has been attributed to poor interest rates. Many businesses have collapsed or delayed investment due to a monetary policy motivated by mechanisation, which has been adopted by most CBs in the region (McKibbin et al. 2020; Nguyen et al. 2021; Shobande and Shodipe 2021). Third, East Africa is not only facing extreme climate-related events, but many nations also suffer from hyperinflation, which affects living standards. This casts doubt on the possibility of including climate mandates and the objective of inclusive growth as an additional mandate of CBs when banks are already hindered by the strait.

Nations has continued to advocate for financial inclusion in East Africa to promote deposits and savings, which will improve the overall well-being of society. In contrast, deposit money banks are not motivated to do so, as it is difficult for the population to meet the essential documentation requirements of formal bank accounts due to poor financial literacy in the region (Shobande and Enemona 2021; Schoenmaker 2021). Fifth, the global economy is experiencing a transition to a low-carbon economy. CBs have been required to add climate change policy mandates to help finance and manage this transition. However, the CBs in the EAC need to understand whether the implication of a low-carbon transition will impact their present monetary policies. Similarly, information on the medium through which monetary policy can help address climate change without compromising the stability role of CBs makes this inquiry a timely one.

On a global scale, climate change is one of the most daunting issues. This is because climate events could pose a risk to human survival and future productivity (Birthal et al. 2014; Banerjee et al. 2020; Chan and Wichman 2020; Cui 2020; Dundas and Von Haefen 2020; Ortiz-Bobea, 2020). One controversial proposal for delaying the impact of climate change is the use of monetary policy, based on the premise that financial policies can help to implement low-carbon emission transitions in a variety of ways. First, financial policy tools and regulatory prudential structures can help to address potential underpricing and the lack of transparency of climate risks in financial markets (Dell et al. 2009, 2014; IPCC 2012; Burke et al. 2015; Serdeczny et al. 2017). Second, financial resources are reallocated...
from a surplus to a deficit unit through the credit channel of monetary transmission (Burke and Emerick 2016; Serdeczny et al. 2017). The third argument is that policy rates can be used to affect investment in ways that benefit the environment and save lives. The fourth is a new initiative that encourages climate finance.

Despite efforts to use monetary policy to address climate change, the financial risks associated with climate change remain. Currently, three main financial threats are often discussed in association with climate risks: (a) physical, (b) transition, and (c) liquidity threats. In terms of physical risk, there is growing concern that climate events will disrupt the valuation of investments and production potential, which will have implications for financial regulation and bank supervision (Acemoglu et al., 2012; Batten et al., 2016; Auffhammer 2018). Thus, the extent to which financial interconnectedness can have major spillover effects on investors as a result of market uncertainty and volatility brought on by slow productivity and the search for new energy sources (Admati 2017; Auffhammer 2018; Battiston and Monasterolo 2019). For liquidity risks, an unforeseen disaster can disrupt credit channels and make it difficult to pursue legal proceedings against businesses and other economic actors, resulting in financial instability (Carney 2015; Campiglio et al. 2018).

The existing literature has identified several channels through which climate change can affect monetary policy. The first is slow productivity, which tends to trigger inflationary pressure and results in uncertainty, making it difficult to ensure financial stability (Murphy and Hines 2010; Rozenberg et al. 2013; Assenza et al. 2015; Batten et al. 2016). The second arises from the physical risk of potential damage caused by extreme climate-related events, which creates an unexpected spike in asset pricing through a business risk model (Rozenberg et al. 2013; Barkawi & Monnin, 2015; Anderson 2015; Campiglio, 2016; Matikainen et al. 2017; Campigilo et al., 2018). The third can arise from mortgage lenders’ inability to recoup loanable funds due to climate damage, which can trigger unexpected financial crises (Scott et al. 2017; Popyan et al., 2017; Monasterolo & Roberto, 2018). The fourth is attributed to the direct and indirect impacts of sustainable financing. This suggests that CBs should use the credit channel of the monetary transmission mechanism to promote sustainable finance technology needed for low-carbon transition, which will, in turn, mitigate carbon emissions and enhance environmental sustainability (Keen and Pakko 2007; Johnson 2012; Brede 2013; Shahbaz et al. 2013a, 2013b; Klomp 2014; Aglietta and Espagne 2016; Stolbova et al. 2018). The fifth is the use of the interest channel of the aforementioned mechanism to ensure business compliance with climate-related regulations (Batten et al. 2016; Assenza et al. 2015; Murphy and Hines 2010; Cosmas et al. 2019; Mahony 2013; Chan 2020, Dafermos et al., 2018). While monetary policy must contribute to mitigating climate chaos, there is increasing concern that CBs should not be held accountable for environmental mandates.

This study contributes to the emerging empirical literature on the link between monetary policy and climate change in three ways: (1) it investigates the impact of monetary policy on climate change indicators after controlling for other confounders; (2) it uses the four advanced time-series approaches to make some inferences with respect to the causation in this link; and (3) using panel Granger causality, we reveal the dynamic interaction between the monetary transmission mechanism and climate indicators. The empirical finding highlights the importance of monetary policy in reducing carbon emissions, with a trade-off for financial instability. The mechanisms through which monetary policy can affect climate change have been identified as trade and agriculture.

The remainder of this paper is organised as follows. Section 2 presents a concise literature review and research question. Section 3 describes the data and research methods. Section 4 presents the results and discusses the findings, while Section 5 concludes the paper with future research.

2. Literature review

2.1 Related studies

There is a rapidly accumulating body of empirical research assessing the implications of including climate change as part of monetary policy mandates. In contrast, opinion has not helped in formation of consensus regarding transition to low-carbon societies and economies, which is urgently needed to save humanity, avert business risk, and promote productivity growth.

There are currently two major strands of empirical studies attempting to justify the appropriateness of using monetary policy to combat carbon abatement and enhance environmental sustainability. The first is studies that utilise Granger causality to analyse the link between monetary policy, financial stability, and carbon shock. For example, in a series of empirical studies, Shahbaz (2013) using autoregressive distributed lag (ARDL) to examine the impact of financial instability on Pakistan’s environmental degradation for the period 1971 to 2009. They reported that financial instability increases environmental degradation. They also replicated the approach for Malaysia (2013a), South Africa (2013b), (2013 c) and China (2013d), and reported mixed evidence. Odhiambo (2020) investigated the impact of financial development on carbon emissions for sub-Saharan Africa and reported that access to credit could reduce CO2 emissions and improve environmental sustainability. Tamazian et al. (2009) examined the impact of financial development
on environmental degradation from 1992 to 2004 for Brazil, Russia, India, and China (BRICs). They revealed that financial development could play a key role in environmental disclosure. In contrast, Tamazian and Rao (2010) investigated the impact of financial development on environmental degradation for a panel of 24 transition countries using the generalised method of moments (GMM) for 1993 and 2004. They reported that financial development may be harmful to environmental quality. Using the autoregressive distributed lag (ARDL) model, Cosmas et al. (2019) estimated an econometric macroeconomic determinant of carbon emissions (CO2) in Nigeria for the period 1981 to 2018 and reported the strong impact of these emissions on economic growth. Their results further indicated that a bidirectional relationship exists between energy consumption, carbon emissions, and economic growth.

The second strand focuses on building a monetary model based on the dynamic stochastic general equilibrium model to explain the role of monetary policy in carbon abatement. For example, Ishiwata and Yokomatsu (2018) formulated a dynamic stochastic macroeconomic model to optimise the negative impacts associated with human capital, productive growth, and household assets in Pakistan. Using the Monte Carlo method to quantitatively evaluate the expected volatility of growth combined with investment, Ishiwata and Yokomatsu (2018) revealed that, in Pakistan, the impact of natural disasters on investment is negligible. Using a dynamic stochastic general equilibrium (DSGE) model, Shobande and Shodipe (2019) investigated the impact of energy policy in curbing the effect of carbon emissions disclosure in the United States, China, and Nigeria, and reported that monetary policy could promote measure to address climate change through the interest rate channel of the monetary transmission mechanism. Mahony (2013) used Kaya identity to decompose the change in carbon emissions in Ireland between 1990 and 2010 and reported that the renewable energy transition impacted economic policy changes.

Using a DSGE model, Keen and Pakko (2007) investigated the appropriateness of using monetary responses to a natural disaster. The authors reported that the standard Taylor rule increases the nominal interest rate during a natural disaster, which can help to minimise the impact of inflation and distortion in the output. Brede (2013) developed a simple New Keynesian model for a small economy that can unveil potential distortion in the system during a natural disaster and reported that such disasters often lead to a recessed economy due to poor savings. Using a DSGE model, Chan (2020) examined macroeconomic policies for combating air pollution and demonstrated that changes in monetary and fiscal policies can help promote environmental sustainability. Using a stock-flow fund ecological macroeconomic model, Dafermos et al. (2018) developed, calibrated, and simulated a model for investigating the effect of climate change on financial stability and its implications regarding green quantitative easing programmes for the period 2016 to 2120. The authors reported that climate change has consequences regarding portfolio reallocation and may induce financial instability, which in turn can have adverse effects on credit expansion.

A cursory look at the literature reveals the divergence of opinion on the potential of using monetary policy to promote environmental sustainability. Evidence from the two strands of empirical studies provides a critical reflection on this divergence. Shahbaz (2013) and Shahbaz et al. (2013a), (2013b), (2013c), (2013d) investigated the possibility of promoting financial stability in, Pakistan, Malaysia South Africa and China and reported mixed evidence. After thousands of simulations for the United States, China, and Nigeria, Shobande and Shodipe (2019) suggested that monetary policy complements sound fiscal policy in promoting the environment. Similarly, after a series of simulations, Dafermos et al. (2018) revealed that the use of monetary policy to promote climate change can result in financial instability through the credit channel. Several studies have warned that monetary policy to combat climate change can result in carbon bubbles (Murphy and Hines 2010; Assenza et al. 2015; Batten et al. 2016). Given the intensifying arguments for and against the use of environment-related monetary policy, this study seeks to establish whether similar experiences hold for the EAC, especially when there is a growing concern that the region is among the vulnerable candidates for climate change.

2.2 Research question

Based on the above review, this study seeks to answer the following research questions:

Question 1 Is there an impact of monetary policy on climate change?

Question 2 Are there short- and long-run impacts of monetary policy on climate change?

The answer is important for the EAC in three aspects. The first research question will help to isolate the mechanism that links monetary policy and climate indicators, which will aid in making informed policy in the region. The second research question is intended to determine whether there is a cumulative impact of the monetary transmission mechanism (interest rate and credit channel) on climate indicators. Third, the answer will help create a sound monetary policy for the region in the context of a low-carbon transition policy and efficient management of its stability roles.
3. Data and methodology

3.1 Data

This study investigated whether monetary policy could promote environmental sustainability in a panel of six EACs (Kenya, Uganda, Tanzania, Burundi, Rwanda, and South Sudan) with data from the World Bank for the period 1990–2019. The EAC was chosen for this study because of the availability of data and vulnerability to climate change emphasised by different reports (IPCC 2002, 2014). The dependent variable is carbon (CO₂) emissions per capita, which captures climate policy (Shobande and Enemona 2021; Shobande and Ogbiefun 2021). Monetary policy is indicated by two proxy variables based on the monetary transmission mechanism: interest rate channel and credit channel (Asongu et al. 2019; Adrian and Shin 2009; Cloyne et al. 2020; Gertler and Karadi 2015; Acharya et al. 2020; Auclert et al. 2020; Kaplan et al. 2018; Nordhaus 2006; Abraham and Mackie 2006; Bernanke, 2019; Asongu et al. 2020; Shobande 2020). The real interest rate is used for the monetary channel to promote environmentally friendly investments. The second is the credit channel, for which credit to the private sector by deposit money banks is a proxy for financial development (FD) (Shobande and Enemona 2021). Intuitively, it is expected that a strong financial sector will help in climate financing. Real gross domestic product per capita (USD) is a proxy for economic growth. Intuitively, the quest for economic growth is expected to increase in carbon (CO₂), which may have consequences for climate change. This study controls for trade openness and foreign direct investment (FDI) based on the pollution haven hypothesis (Pethig 1976; Baumol and Oates 1988; Marrifield, 1988; Knetisch 1990; Copeland and Taylor 1994; Hahn 2000; Jaffe et al. 2002; Elte and Fredriksson 2002; Sigman 2002; Bento 2013). The influx of FDI through technology financing will help reduce carbon emissions (Sarkodie and Strezov 2019; Sarkodie et al. 2020). Per capita agricultural value added is used to capture the level of economic activities, which is supported by empirical literature (Reilly and Hohmann 1993; Cline 1996; Gollin et al. 2002; Kurukulasuriya et al. 2006; Deschenes and Greenstone 2007; Deschenes & Greenstone, 2007; Shilomboleni 2020). The level of economic activities is captured with energy consumption and agricultural value added and this inconsistent with existing literature (Reilly and Hohmann 1993; Cline 1996; Gollin et al. 2002; Kurukulasuriya et al. 2006; Deschenes and Greenstone 2007; Shilomboleni 2020). Many studies have consistently recognised that the expansion of agriculture is a major driver of biodiversity loss, as highlighted in climate change reports (IPCC 2014). In EAC, agriculture has been the main driver of the economy, and the inclusion of such variables can provide information about the link between improved agricultural productivity and the environment. Similarly, Shahbaz (2013) have used energy consumption as proxy for level of economic activity. The energy consumption is necessary for economic growth and it is leading causes of air pollution which is critical for climate policy.

3.2 Methodology

3.2.1 Motivation

This study is framed in panel VAR/VEC Granger causality developed by Granger (1969). The approach as gain superiority in multidisciplinary studies, particularly in the field of monetary, energy and environmental sciences (Granger 1969; Bressier & Seth, 2011; Dumitrescu and Hurlin 2012; Kuruppuarachchi and Premachandra 2016). Two reasons justify the use of this approach. First, it provides an avenue to determine the short and long dynamics of the variables. This is important since monetary policy does follow a contemporaneous effect, and accumulated effects can impact on the environment. Second, it revealed the vector error correction term (VEC), which determines the variable’s convergence speed to their equilibrium position.

3.2.2 Empirical model

The baseline model for this study is stated as follows:

\[
\text{co}_{2,t} = f(mp_{t-1}, credit_{t-1}, gdpt, fdi_{t}, trade_{t}, agric_{t}, energy_{t})
\]

(1)

where, \(i\) is an index of country, \(t\) is time, climate policy indicator is taken as \(co_2\) is measure as carbon emissions per capita. Monetary policy is proxy with two variables, namely: real interest rate (%) (\(mp\)) and credit channel (\(credit\)) measure as domestic credit to private sector (% of GDP). Other control confounders, namely: economic growth (\(gdp\)), Foreign Direct Investment (\(fdi\)), and Trade openness (\(trade\)). The level of economic activities is captured with agricultural value added per capita (\(agric\)) and energy consumption per capita (\(energy\)). Next, we introduce logarithm because all the variables exhibit a natural logarithm, and equation 1 is respecified econometrically as

\[
\ln co_{2,t} = \phi_0 + \phi_1 mp_{t-1} + \phi_2 \ln credit_{t-1} + \phi_3 \ln fdi_{t} + \phi_4 \ln gdpt + \phi_5 \ln trade_{t} + \phi_6 \ln agric_{t} + \phi_7 \ln energy_{t} + \epsilon_{t}
\]

(2)

where \(\epsilon_0\) is an intercept, while the coefficient \(\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7\) are the elasticity of \(co_2\). Since the study is framed in Granger causality, it important to note that the variables are treated endogenously.

3.3. Short and long run dynamics model

In the preceding section, the model in equation 2 is respecified to capture the dynamics of the long run and
short run as well as the speed of adjustment using the vector autoregressive (VEC)/vector error correction (VECM). Thus, the baseline model in equation (3–9) is re-stated:

\[
\ln \Delta \text{co}_{2i,t} = \phi_{10} + \sum_{p=1}^{k} \phi_{11p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{12p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{13p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{14p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{15p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{16p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{17p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{1} \text{ECT}_{t-1} + \epsilon_{1i,t}
\]  

(3)

\[
\ln \Delta \text{mp}_{i,t} = \phi_{20} + \sum_{p=1}^{k} \phi_{21p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{22p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{23p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{24p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{25p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{26p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{27p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{2} \text{ECT}_{t-1} + \epsilon_{2i,t}
\]  

(4)

\[
\ln \Delta \text{credit}_{i,t} = \phi_{30} + \sum_{p=1}^{k} \phi_{31p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{32p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{33p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{34p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{35p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{36p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{37p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{3} \text{ECT}_{t-1} + \epsilon_{3i,t}
\]  

(5)

\[
\ln \Delta \text{fdi}_{i,t} = \phi_{40} + \sum_{p=1}^{k} \phi_{41p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{42p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{43p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{44p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{45p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{46p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{47p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{4} \text{ECT}_{t-1} + \epsilon_{4i,t}
\]  

(6)

\[
\ln \Delta \text{gdp}_{i,t} = \phi_{50} + \sum_{p=1}^{k} \phi_{51p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{52p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{53p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{54p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{55p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{56p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{57p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{5} \text{ECT}_{t-1} + \epsilon_{5i,t}
\]  

(7)

\[
\ln \Delta \text{trade}_{i,t} = \phi_{60} + \sum_{p=1}^{k} \phi_{61p} \ln \Delta \text{trade}_{i,t-p} + \sum_{p=1}^{k} \phi_{62p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{63p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{64p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{65p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{66p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{67p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{68p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{6} \text{ECT}_{t-1} + \epsilon_{6i,t}
\]  

(8)

\[
\ln \Delta \text{agric}_{i,t} = \phi_{70} + \sum_{p=1}^{k} \phi_{71p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{72p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{73p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{74p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{75p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{76p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{77p} \ln \Delta \text{energy}_{i,t-p} + \alpha_{7} \text{ECT}_{t-1} + \epsilon_{7i,t}
\]  

(9)

\[
\ln \Delta \text{energy}_{i,t} = \phi_{80} + \sum_{p=1}^{k} \phi_{81p} \ln \Delta \text{energy}_{i,t-p} + \sum_{p=1}^{k} \phi_{82p} \ln \Delta \text{mp}_{i,t-p} + \sum_{p=1}^{k} \phi_{83p} \ln \Delta \text{credit}_{i,t-p} + \sum_{p=1}^{k} \phi_{84p} \ln \Delta \text{fdi}_{i,t-p} + \sum_{p=1}^{k} \phi_{85p} \ln \Delta \text{gdp}_{i,t-p} + \sum_{p=1}^{k} \phi_{86p} \ln \Delta \text{co}_{2i,t-p} + \sum_{p=1}^{k} \phi_{87p} \ln \Delta \text{agric}_{i,t-p} + \sum_{p=1}^{k} \phi_{88p} \ln \Delta \text{agric}_{i,t-p} + \alpha_{8} \text{ECT}_{t-1} + \epsilon_{8i,t}
\]  

(10)

In equation 3–9, $\phi_{10}$, $\phi_{20}$, $\phi_{30}$, $\phi_{40}$, $\phi_{50}$, $\phi_{60}$, $\phi_{70}$, $\phi_{80}$ are taken as intercept associated with an individual model for each variable; $\phi_{11}$–$\phi_{78}$, $\phi_{31}$–$\phi_{58}$, $\phi_{41}$–$\phi_{68}$, $\phi_{51}$–$\phi_{78}$, $\phi_{61}$–$\phi_{88}$ are not only parameters and elasticity for each model associated with endogenous factors; $p$ is the lag length, and it is selected using the AIC, SC and HQ criteria; $\epsilon_{1i,t}$, $\epsilon_{2i,t}$, $\epsilon_{3i,t}$, $\epsilon_{4i,t}$, $\epsilon_{5i,t}$, $\epsilon_{6i,t}$, $\epsilon_{7i,t}$, $\epsilon_{8i,t}$ is the shocks arising from each variable transmitted to
climate change from each endogenous models; \( \Delta \) is the differences operators. \( \Delta \) is the difference operator, \( a \) is the short-run dynamic coefficients to be estimated and is the serially uncorrelated error term \( \varepsilon_{it} \); \( k \) which is the optimal lag length reduced by 1, \( a \) is the speed of adjustment parameter with a negative sign, and ECT,\(_{t-1}\) is the error correction term, which is the lagged value of the residuals obtained from the cointegration regressions of the dependent variable on the regressors. Thus, the past disequilibrium term (i.e., ECT) determines if the long-run causality holds.

4. Empirical results

This section presents the empirical results on the connectivity of monetary policy and environmental sustainability. It begins with the preliminary checks and ends with the main findings.

Preliminary checks

This section focusses on the initial analysis of the summary statistics, cross sectional dependency and stationarity of properties of the series. The central aim is to understand the behaviour of the series before undertaken further analysis. Table 1 reports the summary statistics.

The average value and standard deviation of CO\(_2\) is 0.47(0.68), interest rate, is 0.04 (0.024), credit is 0.66 (0.07), foreign direct investment, 0.31 (0.2), economic growth 0.11 (0.05), trade openness 0.83 (0.15), agricultural value added, 0.41 (0.006), and energy 0.32 (0.51),

4.1. Testing for cross-sectional dependency

This study applied three main statistical procedure for CD checks. We start with Breusch and Pagan (1979) Lagrange multiplier statistics, specified as:

\[
\text{CD}_{LM} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2
\]

In the formula above, \( \hat{\rho}_{ij} \) is taken as the correlated coefficient with there residuals estimated from the regression. The is based on the null hypothesis that no CD with \( N \) and \( T \) taken as fixed. The CD test is assumed to be asymptotically distributed with a chi-square (\( \chi^2 \)) with a degree of freedom \( N(N-1)/2 \).

Unfortunately, the Breusch and Pagan (1979) LM is not without problem, research has shown that when \( N \) is becoming larger, the Breusch and Pagan (1979) LM is unlikely to be efficient (Pesaran et al. 2004; Pesaran et al. 2014; Su & Chen, 2013; Pesaran and Yamagata 2008; Dijkgraaf and Vollebergh 2005). To circumvent the problem, can use the LM statistics proposed by Pesaran (2004).

\[
\text{CD}_{LM} = \frac{1}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T \hat{\rho}_{ij}^2 - 1)
\]

It turns out that the Pesaran CD treated the null hypothesis of no cross-sectional dependence in case of \( N \to \infty \) and \( T \to \infty \), and the Pesaran (2006) LM is asymptotically robust to normal distribution. However, the test is not without shortcomings as it is unlikely to reveal distortions if \( N \) is relatively larger to \( T \). To address this problem, Pesaran (2004) developed a cross-sectional dependency test which is specified as:

\[
\text{CD}_{P} = \frac{1}{(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}
\]

where \( \hat{\rho} \) denote the coefficient of correlation that explains the association’s nature among the panel candidate estimated, the null hypothesis is the CD. Other contexts consider in Pesaran (2004) could be stated as:

\[
\text{CD}_{P} = \sqrt{T/(2N-p-1)} \left( \sum_{i=1}^{p} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \Rightarrow N(0,1),
\]

where \( p = 1, 2, 3 \); the CD test follows the order of \( p \); thus \( CD(N-1) \) reduce to the CD statistic. Then, the dependency can be inferred as the value of \( p < N-1 \). Table 2 presents the CD test results.

The analysis of the confirmed the existence of cross-sectional dependency among the variables. This implies that shows a shock on these macroeconomic indicators is likely to reflect in the counterpart countries. For example, these East Africa have similar geographical peculiarities and possible level of economic activities.

4.2. Testing for panel unit roots

In panel data, it essential to have information about the stationarity properties of the series before undertaking any analysis. Two major reason makes the stationarity testing more crucial in time series analysis. First, stationary testing may help avoid the use of spurious data that can yield invalid results. Second, in order to prevent misleading outcomes, stationary tests help to assess the past
behaviour of the series and help to ensure treatment before use (Chiang & Kao, 2002; Pesaran and Shin 2002). For example, a random walk, log regular, and long-cycle random walk, have different diagnostic procedures before it can be used. The results of the Levin, Lin, Chu (2002) (LLC) test and Im et al. (2003) (IPS) tests applied are in Table 3.

Both the LLC and IPS panel unit root test admitted that the variables are not stationary at level. We transformed the variables by taking their first differences to and they become stationary.

Since this series is only stationary after differentiation, it is important to verify the long-term potential of the series, but before long-term convergence can be checked, lag selection criteria are important. Table 4 reports the la order selection using the AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion.

Nearly all the lag selection criteria agreed that lag 3 is the optimal lag length and this provide the avenue to conduct the panel cointegration test.

4.3. Panel cointegration test

The particular panel cointegration tests implemented follows Kao (1999) and Pedroni (2004). The Pedroni (1999, 2004) is based on seven statistical criteria which are described as follows.

(a) Panel $v$ - statistic

$$Panelv : T^2N^{-3/2} \left( \sum_{i=1}^{N} \sum_{t=1}^{T} \Delta X_{it} \right)^{-1}$$

(a) Panel $\rho$ - Statistical

$$\sigma N, T^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \Delta X_{it} \sim \chi^2(1)$$

(a) Panel $t$ - Statistics(nonparametric)

$$sN, T^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \Delta X_{it} \sim \chi^2(1)$$

(a) Group $\rho$ - Statistical

Table 2. Cross-sectional dependency tests.

| Test          | $C_{01}$ | $mp$    | credit | fdi   | gdp  | trade | agric | energy |
|---------------|----------|---------|--------|-------|------|-------|-------|--------|
| Brush-Pagan LM| 387.7**  | 281.6** | 382.3* | 281.5**| 297.85**| 285.7**| 329.2**| 451.0**|
| (0.00)        | (0.00)   | (0.00)  | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Pesaran CD    | 36.1**   | 24.94** | 30.64**| 24.94**| 26.7**| 25.3**| 39.2**| 29.6**|
| (0.00)        | (0.00)   | (0.00)  | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Pesaran CD    | 12.06**  | 8.68**  | 11.87**| 9.15**| 8.16**| 7.74**| 16.6**| 10.8**|
| (0.00)        | (0.00)   | (0.00)  | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |

Carbon emissions ($CO_2$) per capita, interest rate channel (mp), credit channel (credit), economic growth (gdp), foreign direct investment (fdi), trade openness (trade), agricultural value added (agric), energy consumption (energy), and $i$ is the standard error. *** (***) denotes the rejection of null hypothesis at 1% (5%) significant level.

Table 3. Panel unit roots tests.

| Variables | At level | At first differences |
|-----------|----------|----------------------|
| $C_{02}$  | $-1.55$ | $-4.59**$ |
| $mp$      | $-1.92$ | $-6.56**$ |
| Credit    | $-1.85$ | $-6.42**$ |
| Fdi       | $-0.71$ | $-6.20**$ |
| Gdp       | $-1.37$ | $-2.95**$ |
| Trade     | $-2.11$ | $-3.88**$ |
| Agric     | $-1.25$ | $-7.01**$ |
| Energy    | $-1.40$ | $-5.48**$ |
| IPS tests | $2.16$  | $5.43**$ |
| $C_{02}$  | $1.03$  | $-4.01**$ |
| $mp$      | $1.20$  | $-5.75**$ |
| Credit    | $1.55$  | $-6.71**$ |
| Fdi       | $-0.53$ | $-2.42**$ |
| Gdp       | $-1.36$ | $-4.13**$ |
| Trade     | $-0.59$ | $-6.14**$ |
| Agric     | $-1.67$ | $-4.29**$ |
| Energy    | $-0.67$ | $-7.93**$ |

Carbon emissions ($CO_2$) per capita, interest rate channel (mp), credit channel (credit), economic growth (gdp), foreign direct investment (fdi), trade openness (trade), agricultural value added (agric), energy consumption (energy), and $i$ is the standard error. *** (***) denotes the rejection of null hypothesis at 1% (5%) significant level.
Table 4. VAR lag order selection criteria.

| Lag | Lolo | LR  | FPE  | AIC  | SC   | HQ   |
|-----|------|-----|------|------|------|------|
| 0   | -6103.603 | NA  | 1.07e+11 | 45.26373 | 45.35702 | 45.30119 |
| 1   | -1333.090   | 9298.330 | 6.94e-05 | 10.29956 | 11.03699 | 10.58925 |
| 2   | -714.2301 | 1168.957 | 1.02e-06 | 6.068371 | 7.467757 | 6.630304 |
| 3   | -428.6256 | 524.6660* | 1.77e-07* | 4.315745* | 6.368178* | 5.139913* |

* indicate the lag length selection based on AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion, LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error.

\[
T/1 \sqrt{N} - \sum_{t=1}^{T} (i = 1) N_i T \sum_{t=1}^{T} \left( \sum_{i=1}^{T} (i - 1) - 1 \Delta e_i, t - 1 \right)
\]

(a) Group t – Statistic (nonparametric)

\[
1/\sqrt{N} \left( \sum_{t=1}^{T} (i = 1) N_i (\sum_{t=1}^{T} (i - 1) - 1 \Delta e_i, t - 1) \right)
\]

The panel t and Panel p are called with dimension residual-based cointegrated tests, while the group panel dimension, which is the group tand group p is the null of no cointegration statistics, and other respectively.

The null hypothesis of no panel cointegration in each statistic is expressed as:

\[
H_0 : \theta_i = 1 \text{ for all } i = 1 \ldots N,
\]

The alternative hypothesis of the between dimension based on the statistics procedure is stated as:

\[
H_1 : \theta_i < 1 \text{ for all } i = 1 \ldots N,
\]

where a similar value of \(\theta_i = \theta\) is not essential, Tables 5 and 6 present the results of the panel cointegration tests.

Interestingly, nearly all the Pedroni seven criteria admitted that panel cointegration exists among the variables and similar results was confirmed by the Kao (1999) panel cointegration approach.

To further confirm the panel cointegration results of the first-generation method, the Westerlund (2008) panel cointegration tests was further implemented in Table 7, and the findings were consistent with formal results.

4.4. VAR/VEC Granger causality tests

As previously indicated, this research is framed by panel Granger causality tests developed by Granger (1969). The strategy has become the cornerstone of empirical research, as it has been found appealing in most empirical research by multidisciplinary studies. The Granger causality strategy was motivated by two primary reasons. (a) the Granger causality will help untangle the dynamics of the short and long run between the variables; (b) the Granger approach can help determine the speed at which the variables converge to the long-term mean; (c) The Granger method can help to decide the direction of causality, which in turn provides the necessary information for policymaking. Table 8 reports the summary of the results of the VAR/VEC Granger causality tests.

The findings are summarised as follows. First of all, the analysis proves that long and short run relationship exist among the variable. second, the speed of convergence of

| Table 5. Pedroni panel cointegration tests. |
|---------------------------------------------|
| Criteria | CO2 | mp | credit | fdi | gdp | trade | agric | energy |
| Panel – stat | -5.04** | -3.7** | -4.76** | -1.78** | -4.87** | -2.55** | -1.97** | -2.67** |
| Panel σ – stat | 3.13** | 2.23** | 2.28** | 0.95 | 3.48** | 1.71** | 2.60** | 2.81** |
| Panelgp – stat | 1.63** | -3.5** | -1.67** | -2.32** | 3.36** | -2.33** | -3.60** | 1.96** |
| Panelad – stat | 1.92** | -0.47 | -1.62** | -1.88** | 3.74** | -2.31** | -0.65** | -2.14** |
| Group σ – stat | 4.30** | 3.98** | 2.43** | 2.18* | 3.88** | 2.97* | 3.76** | 4.82** |
| Groupgp – stat | 3.25** | -1.9** | -3.30* | -1.92** | 2.25** | -2.57** | -1.41* | -1.76* |
| Groupad – stat | 3.85 | -1.6** | -1.56* | -1.18 | 2.94** | -2.15** | 0.97 | -2.65** |

Carbon emissions (CO2) per capita, interest rate channel (mp), credit channel (credit), economic growth (gdp), foreign direct investment (fdi), trade openness (trade), agricultural value added (agric), energy consumption (energy), and (p) is the standard error. **(*) denotes the rejection of null hypothesis at 1% (5%) significant level.
4.5. Implications of the study

This study has the following implications. First, the model suggests a long-lasting link between monetary policy and the environment, which implies that compromising financial stability for carbon reduction will have persistent implications for the stability role of CBs. As already indicated, agricultural yield and energy consumption are potential mechanisms through which monetary policy can affect the environment. Second, the failure to finance the environment can increase carbon (CO₂) emissions and lead to biodiversity loss. The aftermath is climate change, which tends to reduce economic performance beyond this limit. Third, trade and FDI are channels through which monetary policy may affect the environment. The EAC has the largest agricultural trade network on the African continent, which can be explained by regional proximity and agricultural productivity. Therefore, it is important to reconsider FDI and trade channels before choosing a monetary channel for low-carbon transition. Third, climate can have an impact on the financial sector through credit channels. The model shows some sensitivity when using interest rate transmission mechanisms and credit channels for low carbon transition at a cost.

5. Conclusion and policy implications

The threat of climate change continues to receive attention in both academia and generally in the world. Prolonged exposure to climate-change-related risks may render the portfolios of many banks useless. Disruption may create carbon bubbles. Mortgage and insurance companies may be at risk. This study examines the role of monetary policy in addressing climate change in EAC using a time series approach. The empirical evidence shows that monetary policy (credit and interest rate channels) can help smooth transitions to low-carbon economies, but not without financial disruption. This raises concerns about the extent to which monetary policy can be used to combat climate risks, which is determined by both short- and long-term consequences. Although there is evidence that the short-term impact would be smaller than the long-term impact, another problem is that climate change

Table 6. Kao panel cointegration tests.

| Cointegration Test | Statistic | p-value |
|--------------------|-----------|---------|
| Modified DF        | −2.0620** | 0.0089  |
| DF                 | −1.6967** | 0.0058  |
| ADF                | −1.5771** | 0.0017  |
| Unadjusted Modified DF | −2.2170** | 0.0013  |
| Unadjusted DF      | −1.6182** | 0.0046  |

** denotes the rejection of null hypothesis at 5% significant level.

Table 7. Westerlund panel cointegration tests results.

| Cointegration Test | Statistic | p-value |
|--------------------|-----------|---------|
| Variance ratio     | 3.8340**  | 0.0015  |

** denotes the rejection of null hypothesis at 5% significant level.

the variables to their long-term mean was negative and statistically significant for nearly all the coefficients but was very slow and it is consistent with previous findings (Tamazian and Rao 2010; Shahbaz 2013). Third, credit transmission channel (credit) and economic growth (gdp) unidirectionally Granger cause carbon emissions (co₂) and the results are consistent with previous study (Shahbaz 2013; Shobande and Enmona 2021). However, interest monetary channel (mp), trade openness (trade), agricultural value added (agric), and energy consumption (energy) bidirectionally Granger cause carbon emissions (co₂). Fourth, credit transmission channel bidirectionally Granger causes interest rate channel. Fifth, the mechanism through which monetary policy influence carbon emissions (co₂) was identified as trade, agriculture and energy consumption.

Table 8. Panel VAR/VEC Granger causality tests.

| Independent Variable | ΔCo₂t-Δ, Δp, Δcredit, Δδt, Δgdp, Δtrade, Δagric, Δenergy, VEC, | Long run |
|----------------------|--------------------------------------------------------|----------|
| ΔCo₂t-Δ             | 3.96**                                                 | 0.000    |
| Δp                   | 0.00                                                   | 0.00     |
| Δcredit             | 2.00                                                   | 0.00     |
| Δδt                  | 3.00                                                   | 0.00     |
| Δgdp                 | 4.00                                                   | 0.00     |
| Δtrade              | 5.00                                                   | 0.00     |
| Δagric              | 6.00                                                   | 0.00     |
| Δenergy             | 7.00                                                   | 0.00     |

Carbon emissions (CO₂) per capita, interest rate channel (mp), credit channel (credit), economic growth (gdp), foreign direct investment (fdi), trade openness (trade), agricultural value added (agric), energy consumption (energy), and (l) is the standard error and (l) represent p-value. ** (*) denotes the rejection of null hypothesis at 1% (5%)10% significant level.
could increase the frequency and severity of supply shocks, making it more difficult for monetary authorities to forecast demand gaps and rendering monetary policy counterproductive.

For policy purpose, climate change is expected to have three major impacts on monetary policy. (a) disruption of economic activity such as slow economic growth; (b) distribution shocks and irreversible consequences for the economy. For example, providing loans for mortgages and buildings’ collapse means that credit cannot be recovered. (c) Risk of financial instability. Overall, the relationship between monetary and climate policy suggests that central banks could face a policy challenge in deciding whether to respond to potential climate disruptions at the risk of financial instability. Future research can examine the likelihood of climate financing and stock market volatility, which may add more value to the present findings.

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Appendix A. Variable Descriptions

| Variables                      | Signs | Definition                                           | Sources            |
|--------------------------------|-------|-----------------------------------------------------|--------------------|
| Climate Policy                 | Co₂   | Carbon emissions by metric tons per capita          | World Bank         |
| Interest Rate Channel          | mp    | Real interest rate (%)                               | World Bank         |
| Credit Channel                 | credit| Domestic credit to the private sector (% of GDP)     | World Bank         |
| Economic Growth                | gep   | Real GDP per capita (US$)                            | World Bank         |
| Foreign Direct Investment      | fdi   | Foreign direct investment, net inflows (% of GDP)    | World Bank         |
| Trade Openness                 | trade | Real trade (import + export) (% of GDP) per capita    | World Bank         |
| Agriculture                    | agirc | Agriculture, forestry, and fishing, value added (% of GDP) per capita | World Bank         |
| Energy Consumption             | energy| Energy use (kg of oil equivalent per capita)         | World Bank         |