Investigating the Dynamic Relationships Among Disaggregate Components of Financial Development, Renewable Energy Consumption and Environmental Degradation

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Investigating the dynamic relationships among disaggregate components of financial development, renewable energy consumption and environmental degradation

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Abstract

This study investigates the relationship between disaggregate components of financial development and CO_2 emissions by considering the complicated and multidimensional nature of modern financial systems across the globe. Using panel data for 46 Sub Saharan Africa countries ranging from 1991 to 2016, we adopt the dynamic generalized-method-of moment system (sys-GMM) model to investigate the aforementioned objective of the study. The empirical results show that the development of financial market and its sub-measures such as financial market access, depth and efficiency further raise CO_2 emissions in the region. The similar impact is found for the development of financial institution and its sub-measures. However, the development of financial market has a smaller impact on CO_2 emissions compared to the development of financial institution. The results further reveal that renewable energy consumption reduces CO_2 emissions significantly. An increasing role of financial markets complement renewable energy to improve the quality of the environment. The study also reveal that the relationships among these variables and CO_2 emissions vary across countries due to different level of economic development. The policy implications are also discussed in the current study.

Keywords: financial market, financial institution, financial development, CO_2 emissions, renewable energy, Sub Saharan Africa

1. Introduction

Over the years, environmental degradation and global warming have become a major concern for nations around the world and important debatable global issues. The greenhouse gasses emissions are considered the major cause of environmental changes. Among other emissions of greenhouse gasses, carbon dioxide (CO_2) contributes 75% of total pollutants (Amin et al., 2020). The main cause of CO_2 emissions is increased use of conventional energy sources such as coal, gas and oil that negatively affects the environment and health of human beings. It is reported that polluting energy sources account for around 68% of CO_2 emissions (International Energy Agency, 2019). Thus, mitigation of CO_2 emissions has received substantial attention of researchers and policy makers because it is crucial for the policy makers to know the main driving factors of CO_2 emissions and environmental degradation.

One of the most viable solutions to mitigate the CO_2 emissions is considered the adoption of renewable energy sources while maintaining the economic growth and development of countries. In this regard, many countries have started their efforts in gradual transformation of pollute energy sources to clean energy sources (i-e. biomass, hydro, geothermal, solar and wind), as well as improving the efficiency and conservation of energy. Therefore, the share of renewable energy in total energy consumption has been increased in recent years across developed and developing economies (see, Farhani and Shahbaz, 2014; Kaung et al., 2017; Baul et al., 2018; Sinha et al., 2018; Alizadeh et al., 2020; Praveen et al., 2020). The use of renewable energy has two main advantages compared to nonrenewable energy. Firstly, renewable energy is supposed to be the potential solution to control the issue of environmental degradation as it produces low CO_2 emissions in comparison of conventional energy sources and secondly it provides high energy security to meet the increasing demand for energy (Paramati et al., 2017a). Given the importance of renewable energy consumption, it adoption can reduce carbon emissions and other pollutants significantly.

Similarly, the existing literature argues that financial development also contributes significantly in carbon emissions. Theoretically, scholars have two main opposing views on the relationship between financial development and environmental degradation. Some scholars argue that financial development deteriorate the environmental quality (Sadorsky, 2010, 2011; Tang and Tan, 2014; Kahouli, 2017; Nasir et al., 2019). A developed financial system not only increase the efficiency of a country's financial sector but also contributes to increase the economic development and growth in a country. Improved financial sector makes easier access of firms to financial capital at cheap rates which enables them to expand their existing business through building or buying more plants, buying more equipment, and hiring more workers, which increases the demand for energy. Similarly, financial development motivates customers to borrow money to purchase houses, automobiles, air conditioners and refrigerators. These heavy items consume more energy and cause to degrade the environment (Sadorsky, 2010). Furthermore, the stock and financial markets developments are particularly attractive to expansionary activities of firms as it enables them to gain access to an additional source of funding, equity financing. Thus, the growth of business activities may increase energy consumption, which may consequently degrade the environment (Sadorsky, 2011). In contrast, few scholars argue that financial development plays a significant role in reduction of CO_2 emissions by technological innovation (Tamazian et al., 2009; Zhang 2011; Shahbaz et al., 2013; Kutan et al., 2018; Acheampong, 2019). However, the findings of existing empirical studies about the effect of financial development on environmental degradation are mixed and unclear. For instance, one segment of existing literature find that financial development has a positive effect on CO_2 emissions (Zhang, 2011; Boutabba, 2014; Al-Mulali et al., 2015a; Ali et al., 2019; Kayani et al., 2020) while others find opposing influence on the environmental degradation (Tamazian et al., 2009; Al-Mulali et al., 2015b; Abbasi and Riaz, 2016; Xing et al., 2017; Gill et al., 2019).

Furthermore, a vast body of literature has used a simple and single-dimensional indicator of financial development. According to Sadorsky, (2011) and Kakar, (2016), the use of different proxies for financial development may demonstrate different relationships between financial development and energy consumption which suggest that different proxies of financial development could also have different impacts on environmental quality. Most importantly, financial systems have developed across the globe and now have become complex and multidimensional in nature with the passage of time. For instance, along with banks now other types of financial institutions also play fundamental roles in economic development such as insurance companies, investment banks, venture capital firms, pension funds and mutual funds. In the same way, financial markets have become advanced in many ways which enable businesses and people to raise their funds and diversify savings through bonds, stocks and wholesale money markets (Aizenman et al., 2015). The financial systems diversity implies that financial development needs to measure through multiple indicators across economies. Therefore, to overcome the limitation of a single indicator, this study uses a number of indicators for financial development to better understand the relationship between financial development and CO_2 emissions, which recently developed by International Monetary Fund (IMF) by using multi-dimensional approach. Secondly, some of existing studies measured financial development by combining variables of stock market and financial intermediation (Zhang, 2011; Abbasi and Riaz, 2016) while most researchers used aggregate different proxies to represent financial development (e.g. Boutabba, 2014; Shahbaz et al., 2018; Yao and Tang, 2020). However, the impacts of financial markets and financial institutions on environmental degradation might be different due to different nature of financial structures. Therefore, it is important to use separate component of financial development to assess the true effect of financial development stages on the emissions of CO_2. Given the above arguments and inconsistencies in the findings of previous studies, this study objective to examine the disaggregate effects of financial markets and financial institutions development and their sub-indices (depth, access and efficiency) on CO_2 emissions.

This study considers a panel of 46 Sub-Saharan Africa (SSA) countries to investigate the relationship between disaggregate components of financial development and CO_2 emissions.

According to the World Bank (2015), the largest proportion of people are still living below the poverty line in the Sub-Saharan Africa region compared to the other world regions. The SSA countries are already experiencing the adverse effects of climate change. Over the years, the disasters related to weather have been increased, such as floods, heat stress and droughts which have led to a reduction in food productivity and spread the diseases across Africa (Serdeczny et al. 2017). Furthermore, the financial sectors of SSA countries remain woefully underdeveloped relative to other developing regions. Allen et al. (2013) argue that the financial sector of most of the SSA countries have undergone extensive reforms in the last two decades of the same proportions as other developing countries. However, the SSA countries still have the least developed financial sectors relative to the standards of other developing and emerging countries. Therefore, it is crucial to understand the impact of disaggregate financial development and its sub-indicators on CO_2 emissions for climate change polices and sustainable economic development in SSA region.

The current paper extends the existing literature in many ways. (1) According to the best of our knowledge, there is no study which differentiates between financial markets and financial institutions to measure financial development in SSA countries. (2) We use indicators of financial markets and financial institutions development and their sub-measures of IMF that will help policymakers and researchers to better understand the impact of financial development on CO_2 emissions. (3) We add renewable energy utilization in CO_2 emissions function to investigate the nexus between it and environmental degradation. (4) This study also checks the moderating effect between each component of financial development and their sub-measures and renewable energy consumption on emissions of CO_2. (5) We segregate a panel of Sub Sahran Africa countries into two sub-panels i-e., high-income and low-income countries to add more insights in the empirical analysis. Finally, we employ a dynamic system generalized-method-of moment (sys-GMM) to estimate the empirical models which helps to control the possible issues of endogeneity.

The rest of the paper is presented as follows: Literature review is given in section 2. Section 3 describes the empirical models, methodology and data. The empirical findings and their discussions are presented in section 4. Finally, section 5 about conclusions and policy implications.

2 Literature Review

2.1 Financial development and environment degradation

Many empirical studies have used a single and different simple proxies of financial development to explore its impact on environmental quality. The findings, however are mixed across countries and regions. A group of existing literature uses a single and simple proxy for measuring financial development and reports a positive link between financial development and CO_2 emissions. For instance, Boutabba (2014) explored the relationship between carbon emissions and financial development along with other variables for Indian economy over the period 1971-2008. The author found that financial development measured by domestic credit to private sector increases environmental degradation. Al- Mulali et al. (2015a) investigated the link between CO_2 emissions and financial development (domestic credit to private sector) in Europe by using the cointegration test and fully modified ordinary least square (FMOLS) model. Their empirical findings revealed that the financial development effect worsens environmental quality. In the case of 29 China provinces, Hao et al. (2016) employed system-GMM to investigate the effect of financial development on CO_2 emissions and indicated a positive effect of financial depth measured by loans and deposits to GDP ratio on emissions of CO_2. For Malaysian economy, Maji et al. (2017) used a proxy of domestic credit to private sector by banks for financial development to examine its impact on sectoral CO_2 emissions and reported a positive relationship between financial development and CO_2 emissions in case of transportation, oil and gas sector. Using autoregressive distributed lag (ARDL) technique, Ali et al. (2018) investigated the connection between development of the financial sector and carbon dioxide emissions in Nigeria for the period of 1971 to 2010. The empirical findings found that financial development measured through domestic credit to the private sector as a share of GDP increases CO_2 emissions. More recent study by Kayani et al. (2020) found that financial development measured by domestic credit to private sector as a share of real GDP has a positive relationship with environmental degradation in case of top ten CO_2 emitter economies.

Another group of empirical studies uses individual and simple indicator of financial development and reports a negative nexus between development of the financial sector and CO_2 emissions. Tamazian and Rao (2010) checked the influence of financial development measured by financial liberalization on CO_2 emissions by using random effect and GMM model for 24 transitional economies and found that financial liberalization improves the quality of environment. For South Africa, Shahbaz et al. (2013) revealed that financial development through domestic credit to private sector ratio reduces CO_2 emissions. Similarly, Dogan and Seker (2016) employed panel econometric model to investigate the determinants of CO_2 emissions in OECD countries for the period 1975-2011. They used domestic credit to private sector to GDP ratio as an indicator of financial development. The empirical results indicated that development of financial sector reduces environmental degradation. Using Johansen cointegration technique, Paramati et al.

(2017a) examined the relationships among stock market growth, foreign direct investment, renewable energy and carbon emission across developed and developing economies of G20 over the period 1991-2012. The empirical results reported that stock market capitalization reduces environmental degradation from developed economies. For the same panel of economies, Yao and Tang (2020) examined the connection between financial structure and CO_2 emissions by employing two-way fixed effects for the period 1971 to 2014. They measured financial structure (FS) by stock market value to domestic credit and their findings demonstrated that FS has a negative correlation with per capita of CO_2 emissions in developed countries of G20. However, some studies employ the same measure and reveal insignificant relationship between CO_2 emissions and financial development (see, Ozturk and Acaravci 2013; Omri et al. 2015; Dogan and Turkekul (2016); Seetanah et al. 2018).

A couple of empirical studies employ different simple proxies of financial development to investigate its impact on environmental quality. For instance, Tamazian et al. (2009) examined the connection between environmental degradation and financial development using random effect model in BRICS countries. They used financial liberalization, financial openness, FDI, deposit money bank assets as percent of GDP and stock market value proxies for measuring financial development. They reported that development of financial sector helps to mitigate environmental degradation. Using ARDL and VECM approaches, Abbasi and Riaz (2016) studied the effect of financial and economic development on environmental quality in a small emerging economy (Pakistan) over the period 1971-2011. Their study results showed that financial development (ratio of private sector credit to GDP, stock market capitalization, and stock market turnover) improves the quality of environment during the period of financial liberalization. In case of Turkey, Katircioglu and Taspinar (2017) used different measures of financial development (liquid liabilities to GDP, broad money supply to GDP, domestic credit provided to the private sector, and domestic credit by the financial sector) and found that financial development is negatively correlated with CO_2 emissions. Recently, Shoaib et al. (2020) studied the financial development effect on the level of emissions across developed and developing countries by using panel-ARDL technique. They employed different measures of financial development (bank z-score, stock market capitalization, ratio of stock market turnover, and domestic credit to private sector as percent of GDP) and show a positive connection between development of financial sector and CO_2 emissions.

2.2 Renewable energy consumption and environment degradation

A number of studies have explored the dynamics of relationship between disaggregated energy consumption (renewable and non-renewable) and emissions of CO_2 across countries and regions around the globe. For example, Apergis et al. (2010) reported nuclear energy consumption reduces CO_2 emissions, while utilization of renewable energy increases CO_2 emissions across developed and developing economies during the 1984-2007 period. They argue that electricity generators have to rely on fossil fuel energy sources to meet high demand for energy due to lack of appropriate storage technology. By using Augmented Mean Group (AMG) approach, Shafiei and Salim (2014) explored the correlation between CO_2 emissions and disaggregated energy consumption for OECD countries and data 1980 – 2011. Their empirical results revealed that renewable energy consumption improves the environment quality whereas non-renewable energy consumption deteriorates the environment quality. Conversely, Farhani and Shahbaz (2014) suggested that the utilization of renewable energy consumption has a positive relationship with environmental degradation in MENA countries by using the panel cointegration techniques. In the case of USA, Bilgili et al. (2016) confirmed that the usage of fossil fuel energy greatly contributes to the emissions of CO_2 whereas environmental quality increases with renewable energy consumption over the period 1981-2015. A recent study by Belaid and Zrelli (2019) explored the effects of renewable and non-renewable electricity consumption on degradation of environment in a panel of nine Mediterranean countries using panel econometric methods for the period 1980 to 2014. Their results reported the consumption of non-renewable energy stimulate the level of emissions while renewable energy consumption has a negative impact on the environment.

With the growing importance of renewable energy consumption to reduce emissions of CO_2 and to meet the energy demand, some empirical studies have examined the role of renewable energy consumption in affecting the quality of environment. For instance, Salim and Rafiq (2012) employed FMOLS and DOLS approaches to analyze the determinants of renewable energy consumption for six major emerging countries (Brazil, China, India, Indonesia, Philippines, and Turkey). They reported that consumption of renewable energy has a positive relationship with pollutant emission and income. Later for the US, Jaforullah and King (2015) found that the usage of renewable energy is effective at mitigating environmental pollutants. Similarly, Rafiq et al. (2016) investigated the impact of renewable energy on energy intensity and emissions with other controlling variables for twenty two urbanized emerging economies. Their study findings showed that renewable energy consumption has a negative impact on energy intensity and emissions. Further, Paramati et al. (2017) also concluded that the consumption of renewable energy significantly improves the quality of environment in a panel of G20 economies. The findings of another study by Bhattacharya et al. (2017) also revealed that the significant growth of renewable energy consumption reduces environmental degradation in developed and developing countries across the world during 1991-2012. More recently, Khan et al. (2020) investigated the association between renewable energy uses and carbon dioxide emissions in the global panel of 192 nations and found a negative impact of renewable energy on emissions of CO_2.

3. Methodology and Data

3.1 Empirical models and research method

The main aims of this article is to explore the role of financial markets and financial institutions development and their sub-indices on emissions of CO_2 in SSA countries. This study also investigate the effect of renewable energy consumption on emissions. To achieve the aforementioned objectives, we use the following models for empirical estimation:

$$lnCO_{2,it} = \alpha_0 + \alpha_1 lnPI_{it} + \alpha_2 lnTO_{it} + \alpha_3 lnURB_{it} + \alpha_4 lnFDI_{it} + \alpha_5 lnREC_{it} + \alpha_6 FMI_{it} + \varepsilon_{it} \quad (1)$$

$$lnCO_{2,it} = \alpha_0 + \alpha_1 lnPI_{it} + \alpha_2 lnTO_{it} + \alpha_3 lnURB_{it} + \alpha_4 lnFDI_{it} + \alpha_5 lnREC_{it} + \alpha_6 FII_{it} + \varepsilon_{it} \quad (2)$$

Where i and t refer to countries and period, respectively; α denotes coefficient slope; ε represents the stochastic error term; CO_2, PI, TO, URB, FDI, REC, FMD, and FID indicate carbon emissions per capital, per capita income, trade openness, urbanization, foreign direct investment, renewable energy consumption, financial market development and financial institution development, respectively. Further, we extend the equations (1) and (2) to investigate the interaction effect between disaggregate indicators of financial development and renewable energy consumption on CO_2 emissions, which are given as:

$$lnCO_{2,it} = \alpha_0 + \alpha_1 lnPI_{it} + \alpha_2 lnTO_{it} + \alpha_3 lnURB_{it} + \alpha_4 lnFDI_{it} + \alpha_5 lnREC_{it} + \alpha_6 FMI_{it} + \alpha_7 (FMI * lnREC)_{it} + \varepsilon_{it} \quad (3)$$

$$lnCO_{2,it} = \alpha_0 + \alpha_1 lnPI_{it} + \alpha_2 lnTO_{it} + \alpha_3 lnURB_{it} + \alpha_4 lnFDI_{it} + \alpha_5 lnREC_{it} + \alpha_6 FII_{it} + \alpha_7 (FII * lnREC)_{it} + \varepsilon_{it} \quad (4)$$

We employ dynamic generalized-method-of moment system (sys-GMM) model over conventional estimation techniques such as Ordinary Least Square (OLS) to obtain consistent and efficient estimates in the present study. There are several reasons motivate us to apply the sys-GMM estimation: (a) the sys-GMM estimation is more appropriate than the difference-GMM (Arellano and Bond 1991) estimation when the time series observation is small because sys-GMM can produce more efficient estimates by reducing the finite sample bias. (b) When variables follow a random walk, the sys-GMM model is considered to more suitable because difference-GMM model has poor instruments properties in that case (Bond, 2002; Sarafidis et al., 2009). (c) Dynamic panel model permits to solve the potential issue of endogeneity which occurs when explanatory variables are correlated with the error term. (d) Omitted variable bias can be resolved easily in dynamic panel estimation than static panel estimation. (e) In multivariable dynamic panel models, the sys-GMM is known to more consistent when series are persistent, and there is a dramatic reduction in the finite sample bias due to the exploitation of additional moment conditions (Blundell et al., 2001; Roodman, 2009). Given that these reason, we have adopted the sys-GMM estimation model to deal with the potential issue of endogeneity. Moreover, to address the concerns of heteroscedasticity, and to ensure the reliability of estimates, this study estimates the above equations using the two-step sys-GMM.

3.2 Data and variables description

In this study, we use the annual data for 46 SSA countries[1] as a sample, ranging from 1991 to 2016[2]. The measurement of the considered variables in this study are as follows: CO_2 emissions in metric tons per capita; renewable energy consumption (REC) in thousands of tonnes; the GDP per capita income (PI) in constant 2010 US dollars; the sum of import and export is taken as a proxy for trade openness (TO); Urbanization (URB) is proxied as the share of Urban population; and finally, foreign direct investment (FDI) is the inflow as % of GDP. The data on CO_2 emissions, PI, TO, URB and FDI are sourced from the World Development Indicator (WDI) database[3] while data on REC is obtained from the Energy Information Administration (EIA) online database[4] for selected countries. Following previous studies (e.g. Paramati et al. 2017; Acheampong 2019), we transform all variables data into natural logarithms before commencing the empirical investigation.

Further, this study uses a separate indicators for the development of financial markets and institutions to measure financial development and their sub-measures developed by the IMF. The indicators for financial markets include financial market development (FM-D) and its sub-measures contain financial market access index (FM-AI), financial market depth index (FM-DI) and financial market efficiency index (FM-EI). Similarly, the financial institution indicators and its sub-measures include financial institution development (FI-D), financial institution access index (FI-AI), financial institution depth index (FI-DI), Financial institution efficiency index (FI-EI), respectively. These measures of financial development by the IMF range between zero and one. The data on these variables are attained from the IMF database[5].

Table 1 provides the descriptive statistics for the selected variables. The statistics show that the mean value of CO_2 emissions is 8.342; the average value of per capita income is 0.778; the average value of total urban population is 5.744; the average value of FDI net inflows is 0.613; the average value of renewable energy consumption is 4.235; the average values of overall financial market index, access, efficiency, and overall financial institution index, access, depth and efficiency are 0.304, 0.252, 0.281, 0.385, 0.377, 0.315, 0.207 and 0.584, respectively. The descriptive statistics further show that the average values of financial institution development and its sub-measures are higher than financial market development and its sub-measures except in the case of financial

[1] The sample countries included in this study are Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo (Brazzaville), Congo (Democratic Republic), Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

[2] We restrict our sample period to 2016 because the data for CO_2 emissions per capita is only available until 2016 from World Bank database at the time of analysis.

[4] https://www.eia.gov/international/data/world

institution depth sub-index in SSA countries. Concerning the standard deviations of variables, renewable energy consumption is more volatile than the other control variables. Financial institution development and its sub-measures are less volatile than the main and sub-indicators of financial market development during the study period.

Table 2 reports the correlation matrix. We note that the estimated coefficient of renewable energy consumption, FDI, urbanization are negatively correlated with CO_2 emissions per capita, which suggesting that these indicators play significant role in improving the quality of environment. Among indicators of financial development, we find that the coefficients of financial market development, financial market depth, financial market efficiency and financial institution efficiency are negatively correlated with emissions of CO_2. Further, the correlation matrix indicate that there is no strong correlation between the explanatory variables and financial development indicators. Nonetheless, we find a strong correlation between some indicators of financial development. Therefore, we estimate separate models for each indicator of financial development to produce consistent results because using all the indicators of financial development in a single equation for estimation could provide inconsistent findings due to multicollinearity.

$(Insert\ table\ 1\ about\ here)$

$(Insert\ table\ 2\ about\ here)$

4. Empirical findings and discussions

In this section, we investigate the effects of disaggregate components financial development and their sub-measures along renewable energy consumption, per capita income, FDI, urbanization and trade openness on emissions of CO_2 using sys-GMM estimator. Table 3 presents the estimated results for a panel of full sample. Models 1-4 of table 3 present the results of equation (1) while models 5-8 report the results on the basis of equation (2). It can be noted that the main interest variables of disaggregate components of financial development are positive and significant at the level of 1% in all the models except in case of financial market access sub-index. This empirical evidence suggests that an increasing role of financial markets, institutions and their sub-indicators have a considerable positive impact on the level of CO_2 emissions in these economies. Further, the results show that the estimated coefficient of financial institution development, financial institution access, depth and efficiency are higher in comparison with financial market development and its sub-measures which indicating that the financial institution development influence greatly the environmental quality than their counterparts. The possible explanation is that the listed firms in these financial markets might be more engaged in environmental green projects due to the strict environmental laws and regulations on emissions cap. This argument is similar with the findings of Paramati et al. (2018) who indicated that the financial market development less deteriorate the quality of the environment.

The results further reveal that renewable energy consumption is significantly and negatively correlated with CO_2 emissions at the 1% level in all the models. The estimated coefficient ranges from -0.541 to -0.557. This evidence shows that the quality of the environment can improve with the increase investment in renewable energy. This finding is consistent with the findings of (Paramati and Gupta 2017; Khoshnevis Yazdi and Ghorchi Beygi 2018; Khan et al. 2020), who reported that the renewable energy consumption contributes to the reduction in CO_2 emissions. In contrast, this finding contradicts with the findings of Farhani and Shahbaz (2014), who suggested that renewable energy consumption has a positive influence on CO_2 emissions. For other control variables, the growth of per capita income has a positive and significant relationship with CO_2 emissions at 1% level, which implies that the economic growth raises environmental degradation. More specifically, a 1 % raise in per capita income will reduce the quality of the environment between the ranges of 0.073 to 0.069. This evidence supports the argument that when income grows, consumers tend to purchase heavy vehicles which demand more energy and thus contribute to increase the level of emissions. The result is similar to the findings of Wang et al. (2011).

The results further show that trade openness has a significant and positive impact on CO_2 emissions at the 5% and 10% levels in seven specifications. The estimated coefficient of trade openness ranges between 0.028 and 0.029. This evidence implies that as trade openness boosts, economic growth raises in these economies and therefore degrading the environment. This empirical finding is inconsistent with the findings of Abid (2017) who indicated that the trade openness decreases CO_2 emissions but consistent with the findings of Tamazian and Rao (2010) and Acheampong et al. (2020). It is found that urbanization exerts an insignificant effect on CO_2 emissions in SSA countries. In addition, the results of this study demonstrate that FDI has a significant impact on reducing CO_2 emissions at the 1% and 5% levels in all the specifications. The estimated coefficient of FDI ranges between -0.032 to -0.055. This suggests that the quality of the environment improves with the increase in FDI inflows. This evidence is aligned with the argument that FDI inflows bring advanced technology and innovative methods for production activities in the host country which help to reduce the level of CO_2 emissions. This finding is consistent with the empirical findings of existing studies, which confirm that the impact of FDI inflows on CO_2 emissions is negative (Zhang and Zhou 2016; Solarin et al. 2017; Jiang et al. 2019).

$(Insert\ table\ 3\ about\ here)$

4.1 Additional analysis

This section conducts additional analysis to avoid the homogeneity assumption among the full sample as the dynamic relationships among disaggregated financial deepening, renewable energy, other variables and CO_2 emissions could vary across countries due to different level of economic development. According to the classification of the World Bank (2020), this study splits a panel of SSA countries into high-income and low-income countries to investigate whether the results differ across these groups.

For high-income countries, the results report in table 4 demonstrate that the development of financial market and its sub-measures such as financial market access, depth and efficiency have a negative effect on CO_2 emissions at 1% significance level. Thus, a 1% increase in overall, access, depth and efficiency of financial market development reduce CO_2 emissions by -0.536%, -0.436%, -0.424% and -0.391% respectively. This evidence implies that the development of financial markets improve the quality of the environment in high-income countries of Sub-Saharan. The significant negative effects of financial market development and its sub-indicators on CO_2 emissions suggest that financial markets in high-income economies facilitate firms with technological innovations which decrease CO_2 emissions (Zagorchev et al. 2011). On the other hand, financial institution development, depth and efficiency exert a positive and statically significant impact on the emissions of CO_2, while financial institution access has no significant link with the level of emissions. This result suggests that financial institution development and its sub-measures degrade the environment. This result align with Sehrawat et al. 2015, Shahbaz et al. (2016) and Maji et al. 2017, which show that bank-based financial development reduces the environment quality by increasing CO_2 emissions. Conversely, this finding contradicts with the findings of Shahbaz et al. 2013, Abbasi and Riaz 2016 and Shahbaz et al. 2018, which note that financial institution- based development reduces CO_2 emissions. The plausible explanation is that the financial system of Sub Saharan Africa has poor liberalization which is one of the critical factors to impede the financial institutions ability to facilitate environmental friendly projects. The results further indicate that renewable energy consumption decreases CO_2 emissions in high-income countries, and this is consistent with the findings of full sample analysis. This evidence suggests that renewable energy can help in order to address environmental degradation and energy security related issues. For FDI inflow, the results show that it reduces the environmental degradation in high-income countries of SSA, as all models estimated coefficients are negative and significant at 1%. The results further reveal that urbanization contributes to CO_2 emissions in high-income countries, this implying that urbanization in these economies helps to facilitate economies of scale for urban infrastructure that could degrade the environment quality by increasing prosperity. Additionally, per capita income and trade openness have no effect on CO_2 emissions in case of high-income countries.

Now, let us move towards low-income countries, the results report in table 5 reveal that financial market development, access and depth have a positive and significant effects on CO_2 emissions at 1% level, while financial market efficiency has a same effect at 5% level. Thus, a 1% increase in financial market development, access, depth and efficiency increase the level of emissions by 1.835%, 2.468%, 1.574% and 1.026% respectively. The implication of this finding is that the financial markets in low-income countries are inefficient and underdeveloped that do not motivate industries to adopt green technologies and also lack proper regulations that make firms not to invest in environmental friendly projects. On the other hand, the estimated coefficient on financial institution development and its sub-measures have insignificant relationship with CO_2 emissions. The similar finding is reported by Abbasi and Riaz (2016), who indicated that financial institution-based development exerts an insignificant impact on CO_2 emissions. The results further suggest that the effect of renewable energy consumption is negative and statistically significant on CO_2 emissions, and this is consistent with the findings of full sample and high-income group. The implication is that renewable energy consumption mitigate environmental degradation in low-income countries of SSA. The current study also find that FDI inflows exert a negative and significant impact on CO_2 emissions, which implying that FDI brings innovation and advanced technologies from developed countries to developing countries and further reduces environmental pollution. Further, it is found that urbanization exerts an insignificant effect on CO_2 emissions. For trade openness, the estimated coefficient is positive and significant in all the models at 1%, the finding indicates that trade openness contributes to CO_2 emissions and will worsen the environment quality in low-income countries. The results further reveal that per capita income growth has a positive and statistically significant influence on CO_2 emissions. Thus, the increase in economic growth reduces the quality of the environment in these economies.

$(Insert\ table\ 4\ and\ 5\ about\ here)$

4.2 Interactive effects

This section employs interaction between disaggregate components of financial development and renewable energy consumption to analyze whether financial market and financial institution development and their sub-measures complement renewable energy consumption to influence the level of CO_2 emissions in SSA countries. Table 6 presents the results on the basis of equations (3) and (4). The results reveal that the interaction terms of financial market development, access, depth, efficiency and renewable energy consumption have a significant negative impact on CO_2 emissions (see models 1-4). The implication is that the financial market development, financial market access, depth and efficiency moderate renewable energy to mitigate CO_2 emissions. Thus, financial markets improvement could provide finance to environmental friendly projects, which will subsequently improve the quality of the environment. On the other hand, the interactions terms of financial institution development, access, depth, efficiency and renewable energy consumption have insignificant effect on CO_2 emissions (see models 5-8). This evidence suggests that improvement in financial institutions do not complement renewable energy consumption to influence the environmental quality in the sample countries.

$(Insert\ table\ 6\ about\ here)$

5. Conclusions and policy Implications

A large body of literature has investigated the impact of financial development on CO_2 emissions by using two measures of financial development- the ratio of stock market capitalization to GDP or private credit to GDP. However, these proxies are simple in nature and do not consider the complicated stages of financial development. Secondly, the modern financial systems across countries have become multi-layered and thus it is significant to analyze the effect of disaggregate components of financial development using multiple indicators on environmental quality. Using dynamic generalized-method-of moment system (sys-GMM), this study explores the impact of financial market and financial institution development and their sub-measures on CO_2 emissions for 46 Sub Saharan Africa countries during the period 1991-2016. In this paper, we also investigate the impact of renewable energy consumption along with other factors such as per capita income, trade openness, urbanization and FDI on CO_2 emissions.

The findings of the study show that an increasing role of financial market development and its sub-measures further raise the CO_2 emissions in SSA countries. Likewise, we find out that improvement in financial institutions and its sub-measures increase CO_2 emissions. However, we observe that the impact of financial institution development is greater to deteriorate the quality of the environment than the development of financial market in SSA countries. The impact of disaggregate components of financial development on CO_2 emissions is different across income groups of Sub Saharan. For instance, we identify that financial market development and its sub-measures reduce CO_2 emissions in high-income countries while increase in low-income countries. On the other hand, financial institution development, depth and efficiency have a significant and positive relationship with CO_2 emissions in high-income countries while these indicators including financial institution access have an insignificant impact on CO_2 emissions in low income-countries. The findings further reveal that the renewable energy consumption has a significant negative effect on CO_2 emissions and consistent with the findings of sub-panels for high-income and low-income countries. This result implies that an increased use of renewable energy contribute to improves the environmental quality in the region. In addition, the estimated interactive effects between financial market development, access, depth, efficiency and renewable energy consumption reveal that improvement in financial market complement renewable energy to mitigate the level of emissions. We also find out that FDI inflows contribute to CO_2 emissions reduction in the region. However, trade openness and economic growth may boost environmental degradation.

Given the above outcomes, this study suggests important policy implications for Sub Saharan. The current paper results show that increasing role of financial markets and financial institutions impede the environmental quality. Hence, we recommend that the policy authorities should provide incentives to all listed firms/industries to invest in greener technologies and also should increase shares in pollution control projects to mitigate CO_2 emissions in Sub Saharan. Additionally, the policy authorities should implement strict regulations on emissions trading or cap such as CO_2 emissions tax to improve the quality of the environment. Financial institutions should provide cheap funds to firms or industries that are committed to investing in environmentally friendly projects and motivate them to adopt ecofriendly polices to reduce CO_2

emissions. Furthermore, the beneficial impacts of renewable energy consumption on CO_2 emissions suggests that Sub Saharan should make a substantial investment in renewable energy to strengthen the low carbon economies. Future studies can extend this study by utilizing panel data for other developing countries. A further research can also analyze the impact of financial deepening on CO_2 emissions with the role of technological innovation and institutional developments for same or different regions.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets analysed during the study are available in the website of IMF database,World Development Indicators (WDI) and International Energy Statistics (IEA).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

UMME HABIBA: Writing and statistical analysis; Cao Xinbang: Data collection and methodology.

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Table 1: Variables descriptive statistics

Variables	Mean	SD	Min.	Max.
LnCO2 emissions	8.342	3.674	4.930	10.417
LnPI	0.778	0.530	-1.964	2.130
LnTO	3.532	0.940	1.831	4.686
LnURB	5.744	2.049	2.477	6.813
LnFDI	0.613	0.657	-1.441	2.479
LnREC	4.235	4.563	0.693	5.091
FM-D	0.304	0.245	0.049	0.902
FM-AI	0.252	0.226	0.001	0.754
FM-DI	0.281	0.252	0.056	0.890
FM-EI	0.385	0.317	0.084	1.000
FI-D	0.377	0.148	0.225	0.789
FI-AI	0.315	0.216	0.110	0.754
FI-DI	0.207	0.173	0.064	0.724
FI-EI	0.584	0.145	0.175	1.000

Table 2: Correlation matrix

	$LnCO_2$	LnPI	LnTO	LnURB	LnFDI	LnREC	FM-D	FM-AI	FM-DI	FM-EI	FI-D	FI-AI	FI-DI	FI-EI
$LnCO_2$	1.000													
LnPI	0.129	1.000												
LnTO	0.009	0.057	1.000											
LnURB	-0.246	-0.041	0.273	1.000										
LnFDI	-0.157	0.248	0.315	0.362	1.000									
LnREC	-0.325	-0.033	-0.169	0.242	0.135	1.000								
FM-D	-0.348	0.113	0.483	-0.026	-0.189	0.448	1.000							
FM-AI	0.183	0.082	0.526	0.007	-0.055	0.392	0.266	1.000						
FM-DI	-0.252	-0.001	0.344	0.125	0.137	0.486	-0.438	0.733	1.000					
FM-EI	-0.317	0.345	-0.468	-0.103	-0.116	0.273	0.594	0.716	0.841	1.000				
FI-D	0.420	0.202	0.185	-0.210	0.074	-0.115	-0.337	0.539	0.376	0.775	1.000			
FI-AI	0.512	-0.059	-0.011	0.274	0.132	0.083	-0.298	-0.461	0.339	0.602	0.852	1.000		
FI-DI	0.408	0.166	0.094	0.088	-0.049	0.217	0.537	0.492	-0.253	0.558	0.814	0.624	1.000	
FI-EI	-0.563	0.614	0.211	0.192	0.207	-0.295	0.351	0.375	0.586	-0.326	0.766	0.585	0.749	1.000

Table 3: Sys-GMM estimates for full sample

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
LnPI	0.073*** (0.021)	0.070*** (0.024)	0.074*** (0.020)	0.069*** (0.021)	0.073*** (0.019)	0.085*** (0.023)	0.071*** (0.024)	0.069*** (0.022)
LnTO	0.020 (0.017)	0.028* (0.013)	0.031* (0.016)	0.033* (0.021)	0.049** (0.013)	0.046** (0.016)	0.041** (0.023)	0.029* (0.015)
LnURB	0.013 (0.027)	0.009 (0.024)	0.011 (0.030)	0.007 (0.022)	0.003 (0.027)	0.015 (0.032)	0.010 (0.025)	0.004 (0.028)
LnFDI	-0.032** (0.021)	-0.029** (0.024)	-0.029** (0.025)	-0.027** (0.019)	-0.048*** (0.036)	-0.045*** (0.039)	-0.051*** (0.036)	-0.055*** (0.033)
LnREC	-0.541*** (0.013)	-0.569*** (0.009)	-0.564*** (0.009)	-0.564*** (0.007)	-0.552*** (0.010)	-0.540*** (0.016)	-0.560*** (0.011)	-0.557*** (0.020)
FM-D	0.246*** (0.083)							
FM-AI		0.009 (0.008)						
FM-DI			0.125** (0.054)					
FM-EI				0.183*** (0.069)				
FI-D					0.395*** (0.102)			
FI-AI						0.327*** (0.115)		
FI-DI							0.206*** (0.071)	
FI-EI								0.274*** (0.096)
Constant	-1.115*** (0.163)	-0.880*** (0.125)	-0.927*** (0.179)	-0.946*** (0.210)	-0.723*** (0.219)	-1.211*** (0.175)	-0.865*** (0.188)	-0.913*** (0.180)
Hansen j-test	1.447	2.168	0.450	2.733	0.351	0.028	1.003	1.225
p-value(j-test)	0.326	0.141	0.826	0.069	0.572	0.951	0.128	0.204
AR(1)	0.005	0.002	0.000	0.007	0.005	0.001	0.001	0.002
AR(2)	0.541	0.227	0.235	0.306	0.471	519	0.420	0.392

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

Table 4: Interaction effect between renewable energy consumption and different financial development indicators on CO_2 emissions

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LnPI	0.068*** (0.013)	0.051*** (0.011)	0.077*** (0.015)	0.085** (0.049)	0.049** (0.026)	0.051** (0.027)	0.048** (0.024)	0.039* (0.024)
LnTO	0.030 (0.034)	0.037 (0.052)	0.010 (0.028)	0.051 (0.049)	0.020 (0.041)	0.069 (0.147)	0.023 (0.058)	0.155 (0.063)
LnURB	0.016 (0.020)	0.025 (0.028)	0.022 (0.027)	0.040 (0.046)	0.016 (0.012)	0.022 (0.019)	0.039 (0.041)	0.012 (0.028)
LnFDI	-0.193*** (0.031)	-0.198*** (0.036)	-0.171*** (0.025)	-0.177*** (0.025)	-0.210*** (0.038)	-0.233*** (0.041)	-0.254*** (0.039)	-0.282*** (0.044)
LnREC	-0.404*** (0.091)	-0.382*** (0.052)	-0.326*** (0.057)	-0.311*** (0.054)	-0.241*** (0.036)	-0.418*** (0.063)	-0.455*** (0.081)	-0.360*** (0.049)
FM-D	3.558*** (1.152)							
FM-D*REC	-0.651*** (0.149)							
FM-AI		2.084*** (0.866)						
FM-AI*REC		-0.328** (0.092)						
FM-DI			3.005*** (1.202)					
FM-DI*REC			-0.981*** (0.411)					
FM-EI				1.370** (0.533)				
FM-EI*REC				-0.196** (0.078)				
FI-D					0.482 (4.226)			
FI-D*REC					-0.061 (1.110)			
FI-AI						1.179 (5.937)		
FI-AI*REC						-0.336 (0.740)		
FI-DI							1.136 (3.951)	
FI-DI*REC							-0.155 (0.682)	
FI-EI								10.582 17.163
FI-EI*REC								-2.255 (5.100)
Constant	-3.117*** (0.660)	-3.049*** (0.613)	-3.185*** (0.658)	-3.190*** (0.672)	-2.768*** (0.593)	-2.615*** (0.620)	2.599*** (0.481)	-1.887*** (0.385)
Hansen j-test	0.061	1.083	0.309	0.291	0.078	0.096	0.322	0.464
p-value(j-test)	0.707	0.267	0.535	0.773	0.659	0.740	0.527	0.329
AR(1)	0.001	0.000	0.002	0.002	0.001	0.003	0.003	0.003
AR(2)	0.312	0.294	0.260	0.281	0.417	0.355	0.311	0.393

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

Table 6: Sys-GMM estimates for high-income countries

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LnPI	0.014 (0.052)	-0.029 (0.047)	-0.035 (0.048)	-0.028 (0.040)	0.011 (0.035)	0.016 (0.033)	0.020 (0.041)	0.024 (0.043)
LnTO	0.003 (0.019)	0.005 (0.023)	0.009 (0.027)	0.010 (0.019)	0.017 (0.031)	0.015 (0.036)	0.001 (0.022)	0.019 (0.029)
LnURB	0.026*** (0.007)	0.026*** (0.009)	0.017** (0.008)	0.024** (0.009)	0.031*** (0.011)	0.037*** (0.009)	0.025** (0.0011)	0.029** (0.013)
LnFDI	-0.071*** (0.032)	-0.084*** (0.026)	-0.082*** (0.026)	-0.077*** (0.031)	-0.089*** (0.027)	-0.090*** (0.031)	-0.093*** (0.032)	-0.075*** (0.024)
LnREC	-1.593*** (0.105)	-1.548*** (0.103)	-1.550*** (0.103)	-1.546*** (0.111)	-1.489*** (0.096)	-1.425*** (0.092)	-1.483*** (0.092)	-1.479*** (0.091)
FM-D	-0.536*** (0.235)							
FM-AI		-0.436*** (0.184)						
FM-DI			-0.424*** (0.209)					
FM-EI				-0.391*** (0.155)				
FI-D					0.156** (0.048)			
FI-AI						0.041 (0.032)		
FI-DI							0.093* (0.01	
FI-EI								0.188** (0.060)
Constant	-1.594***	-1.753***	-1.272***	-1.628***	-1.531***	-1.417***	-1.722***	-1.391***
Hansen j-test	0.017	0.640	1.015	0.472	0.351	0.294	0.220	0.613
p-value(j-test)	0.829	0.557	0.318	0.599	0.610	0.527	0.655	0.498
AR(1)	0.014	0.016	0.016	0.025	0.019	0.018	0.018	0.011
AR(2)	0.228	0.403	0.249	0.714	0.686	0.659	0.197	0.150

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

Table 7: Sys-GMM estimates for low-income countries

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LnPI	0.046** (0.022)	0.044*** (0.025)	0.039** (0.025)	0.041** (0.021)	0.058*** (0.038)	0.060** (0.036)	0.055*** (0.029)	0.052*** (0.025)
LnTO	1.230*** (0.030)	1.258*** (0.036)	1.204*** (0.029)	1.229*** (0.036)	1.262*** (0.035)	1.271*** (0.030)	1.273*** (0.031)	1.268*** (0.035)
LnURB	0.048 (0.081)	0.057 (0.080)	0.062 (0.080)	0.066 (0.085)	0.073 (0.066)	0.037 (0.059)	0.039 (0.059)	0.027 (0.054)
LnFDI	-0.049** (0.024)	-0.021 (0.028)	-0.035* (0.020)	-0.033* (0.021)	-0.053** (0.023)	-0.047** (0.024)	-0.047** (0.029)	-0.045** (0.025)
LnREC	-0.134*** (0.032)	-0.135*** (0.029)	-0.147*** (0.026)	-0.151*** (0.026)	-0.097*** (0.019)	-0.113*** (0.025)	-0.115*** (0.023)	-0.118*** (0.027)
FM-D	1.835*** (0.466)							
FM-AI		2.468*** (0.571)						
FM-DI			1.574*** (0.365)					
FM-EI				1.026** (0.290)				
FI-D					0.592 (0.386)			
FI-AI						0.713 (0.628)		
FI-DI							-0.219 (0.355)	
FI-EI								0.126 (0.271)
Constant	-3.161*** (0.573)	-3.179*** (0.570)	-3.145*** (0.568)	-2.910*** (0.541)	-4.397*** (0.762)	-4.162*** (0.760)	-4.402*** (0.745)	-4.274*** (0.699)
Hansen j-test	0.438	0.847	0.822	0.941	1.013	0.866	0.869	0.810
p-value(j-test)	0.645	0.342	0.329	0.420	0.391	0.320	0.438	0.440
AR(1)	0.011	0.010	0.010	0.013	0.011	0.011	0.012	0.010
AR(2)	0.108	0.596	0.572	0.105	0.102	0.103	0.115	0.118

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