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Does financial development mitigate carbon emissions? Evidence from heterogeneous financial economies

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In this paper, we investigate the impact of financial market development on carbon emission intensity, taking into account the various stages of financial development among countries. Utilising the instrumental variable generalised method of moment approach and a comprehensive panel dataset of a total of 83 countries over the period 1980–2015, we show that the overall financial market development and its sub-measures such as financial market depth and efficiency reduce carbon emission intensity in the developed and emerging financial economies. However, an opposing effect is found in the frontier financial economies. For standalone financial economies, the results show that the overall financial market development and its sub-indicators have no direct impact on carbon emission intensity. Finally, the non-linear and the moderating effects of financial market development on carbon emission intensity differ across countries at different stages of financial development. The policy implications are also discussed.

1. Introduction

The role of financial development in the economic development process has received much attention among policymakers and researchers since the global financial crisis. While financial development plays a vital role in economic growth and technological progress, most scholars have argued that financial development could equally have a critical effect on the quality of environment especially on the evolution of carbon emissions (Acheampong, 2019; Abid, 2017; Tamazian et al., 2009). However, the evidence is priori uncertain. Theoretically, financial development could enhance the quality of the environment by reducing carbon emissions through technological development, research and development (R&D) (see Frankel and Romer, 1999; Tamazian et al., 2009; Zagorchev et al., 2011). In other words, financial development affords firms and governments to adopt environmentally efficient technologies that are capable of reducing carbon emissions, thereby improving the quality of the environment (Tamazian and Bhaskara Rao, 2010). Additionally, the role of financial development in fostering good corporate governance and creating reputational and financial incentives could motivate firms to adopt environmentally sustainable projects, thereby reducing carbon emissions (Claessens, 2007; Dasgupta et al., 2001).

Despite its relevance, financial development that is mostly accompanied by increased energy consumption, economic growth and technological progress could compromise environmental quality and thus contributes to carbon emissions. That is, improved financial sector enables both households and firms to have access to cheap credit that respectively allows households to patronise equipment that demands energy, and firms to expand their existing business and patronise energy-demanding machines and equipment that could contribute to the rise of carbon emissions (Acheampong, 2019; Sadorsky, 2010, 2011; Shahbaz and Lean, 2012). Similarly, through risk diversification and technological progress, financial development boosts economic growth, which in turn increases energy consumption and carbon emissions (Sadorsky, 2010, 2011). Whereas the existing theoretical argument on the impact of financial development on carbon emission is conflicting, the the empirical findings remain contradictory. For instance, one group of empirical studies report that financial development reduces carbon emissions (see Al-Mulali et al., 2015b; Tamazian and

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Bhaskara Rao, 2010; Tamazian et al., 2009) while others report that financial development increases carbon emissions (see Acheampong, 2019; Boutabba, 2014; Sehrawat et al., 2015; Shahbaz et al., 2016). In some cases, it is argue that financial development has no relationship with carbon emissions (see Dogan and Turkekul, 2016; Maji et al., 2017; Omri et al., 2015).

The above theoretical and empirical inconsistencies are attributed to two key reasons. First, the existing empirical studies have failed to account for the stages of financial development among countries when examining the impact of financial development on the environment (carbon emissions). In this paper, we argue that failure to account for different stages of financial development across countries offers a bleak analysis of the impact of financial development on carbon emissions. For instance, countries with the well-developed financial system promotes technological development and economic growth, reduced information asymmetry and provide credits to households and firms at a lower cost relative to the poorly developed financial system. Therefore, the impact of financial development on carbon emissions could not be assumed to have the same impact on carbon emissions across countries with different stages of financial development. However, it remains unclear whether the stages of financial development matters when examining the impact of financial development on carbon emissions. It is, therefore, essential for further study to carefully investigate the impact of financial development on carbon emission intensity, taking into consideration the extent of the financial development of countries.

Second, the majority of the empirical studies have utilised different individual proxies for financial development. Specifically, proxies such as domestic credit as a percentage of GDP, stock market capitalisation and stock market turnover, which are single measures for financial development, dominate the empirical literature. However, financial development is a multifaceted concept (Svirydzenka, 2016); therefore, using different individual indicators of financial development could provide conflicting results in the literature. For instance, Acheampong (2019) and Zhang (2011) demonstrated that using different proxies of financial development has a different impact on carbon emissions. In this paper, we capitalize on previous limitations and provide a rigorous comparative analysis of the role of financial development, specifically financial/stock market development, on carbon emission intensity in developed, emerging, frontier and standalone financial economies over the period 1980–2015. We define carbon emission intensity as the volume of carbon emissions due to economic activity/economic growth or carbon emissions emitted per unit of energy consumed. It is critical for this paper to consider carbon emission intensity because to tackle climate change, carbon emission intensity needs to be reduced. The study specifically focused on the financial market development since it is often viewed as a leading indicator of financial development (Sadorsky, 2010, 2011) and limited studies have utilised market-based indicators of financial development to examine their effect on carbon emission intensity.

This paper makes novel contributions to the literature on financial development and environmental quality in several ways: First, to the best of the authors' knowledge, this is the first paper to adopt a comparative approach to analyse the effect of the financial market on carbon emission intensity, taking into account the stages of the financial development among countries. Additionally, most of the previous studies have used uni-dimensional measures of financial market development even though it is a multi-dimensional process (Svirydzenka, 2016). Given this, the current paper utilises a newly constructed indicator which captures the multi-dimensional nature of the financial market. Moreover, the study disaggregates the overall financial market development into its sub-components such as financial market efficiency, depth and access, which are also multi-dimensional, to examine their respective impact on carbon emission intensity. Following Acheampong (2019), this paper further explores how financial market development moderates the effect of energy consumption and economic growth on carbon emission intensity. To achieve consistent and robust results, the paper employs an instrumental variable generalised-method of moment (IV-GMM) to control for endogeneity and omitted variable bias. The rest of the paper is organised as follows. Section 2 presents the literature review, followed by an overview of the methodology and data in Section 3. Empirical results and discussions are presented in Section 4, followed by conclusions and policy implications in Section 5.

2. Literature review

This section summarises the empirical findings on the effect of financial development on environmental pollution. The empirical literature is categorised into three main segments based on their results. The first segment reports a negative impact of financial development on carbon emissions. For instance, Tamazian et al. (2009) investigated the effect of financial development on carbon emissions in BRICS using random-effect model. Their results showed that financial development measured using stock market value, FDI, ratio of deposit money bank assets to GDP, capital account convertibility, financial liberalisation and financial openness decrease carbon emissions. Extending their previous studies, Tamazian and Bhaskara Rao (2010) further employed random effect model and dynamic GMM to examine the effect of financial development on carbon emissions in 24 transitional economies and found that financial liberalisation improves environmental quality. Similarly, Al-Mulali et al. (2015b) employed cointegration approach to examine the effect of financial development on carbon emissions in 129 countries and found that financial development (domestic credit to private sector) reduces carbon emissions. Additionally, Hao et al. (2016) employed system-GMM to examine the effect of financial development on carbon emissions in 29 China provinces and found that financial efficiency (ratio of loans to deposit) reduces carbon emissions.

In the case of Malaysia, Shahbaz et al. (2013b) found that financial development (domestic credit to private sector) contributes to the reduction in carbon emissions. In another study, Shahbaz et al. (2018) employed bootstrapping bound testing approach to examine the effect of financial development, FDI and energy innovation on carbon emissions in France to provide evidence in support of the negative role of financial development (domestic credit to private sector) on carbon emissions. Using ARDL, Abbasi and Riaz (2016) found that financial development measured using stock market turnover, stock market capitalisation, total credit and private sector credit reduce carbon emissions in Pakistan and during the financial liberalisation period (1988–2011). In the same way, Jalil and Feridun (2011) utilised ARDL to investigate the effect of financial development on carbon emissions in China, and their results revealed that financial development measured by ratio of liquid liabilities and ratio of private sector loans to the GDP reduces carbon emissions. Using ARDL, the findings from the study of Nasreen et al. (2017) revealed that financial stability improves environmental quality, and financial stability uni-directionally causes carbon emissions in Pakistan, India, Nepal, Sri Lanka and Bangladesh.

Furthermore, Xing et al. (2017) employed ARDL to examined the effect of financial development on carbon emissions in China and found that financial development reduces carbon emissions. In their study, Yuxiang and Chen (2010) applied GMM to examine the effect of financial development on carbon emissions in China, and their results revealed that financial development measured by ratio of bank loans to GDP, ratio of private loans to GDP and ratio of non-private to GDP reduces the intensity of carbon emissions. Using ARDL, Maji et al. (2017) found that financial development (domestic credit provided by banks private sector to private sector) reduces emissions from the manufacturing and construction industries in Malaysia. In the case of UAE, Charfeddine and Ben Khediri (2016) employed Gregory-Hansen Cointegration and Granger causality and found that financial development has an inverted U-shaped relationship with carbon emissions. In another study, Gokmenoglu and Sadeghieh (2019) examined the relationship between financial development and carbon emissions in

Turkey for the period 1960–2011 and found that in the short-run, financial development reduces carbon emissions.

The second segment of the empirical studies reports a positive effect of financial development on carbon emissions. Sehrawat et al. (2015) utilised ARDL and VECM to investigate the impact of financial development on carbon emissions in India and found that financial development (credit to the private sector) enhance carbon emissions. Similarly, Shahbaz et al. (2015) investigated the effect of financial development on carbon emissions in India using Bayer-Hanck cointegration test and ARDL, and their findings indicated that financial development (domestic credit to private sector) worsens carbon emissions. In another study, Shahbaz et al. (2016) used NARDL to investigate the asymmetric effect of financial development on carbon emissions in Pakistan and found that both stock market and bank-based financial development index impede environmental quality. Using ARDL and Granger causality test, Boutabba (2014) found in India that financial development (domestic credit to private sector) increases carbon emissions while uni-directional causality runs from financial development to carbon emissions. Zhang (2011) also investigated the effect of financial development in China using cointegration and causality approach and found that the indicators of the financial development drive carbon emissions. In the case of Malaysia, Maji et al. (2017) found that financial development (domestic credit provided by banks to private sector) increases carbon emissions from the transportation, oil and gas sector. Al-Mulali et al. (2015a) further utilised cointegration test and FMOLS to investigate the effect of financial development on carbon emissions in 129 countries and found that financial development measured using domestic credit to private sector increases carbon emissions.

Using system-GMM, Hao et al. (2016) found that financial depth (ratio of loans and deposits to GDP) increases carbon emissions in 29 China provinces. Their results also revealed that a U-shaped relationship exists between financial development and carbon emissions. Recently, Acheampong (2019) utilised the system-generalised method of moments to investigate the direct and indirect effect of financial development on carbon emissions for 46 sub-Saharan Africa countries over the period 2000–2015. Using several indicators of financial development, the study revealed that financial development measured using broad money, domestic credit to the private sector and domestic credit to private sector by banks increase carbon emissions while FDI, liquid liabilities and domestic credit to private sector by financial sector have negligible effects on carbon emissions. The study also indicated that FDI moderates economic growth to reduce carbon emissions but does not moderate energy consumption to affect carbon emissions. Contrarily, financial development measured using broad money, domestic credit to private sector by banks, domestic credit to private sector by the financial sector and domestic credit to private sector moderate energy consumption to increase carbon emissions while the first three indicators of financial development moderate economic growth to increase carbon emissions. Using FMOLS and DOLS, Ehigiamusoe and Lean (2019) investigated the effect of financial development on carbon emission for 122 countries over the period 1990–2014 and found that financial development worsened carbon emissions in the full sample. However, the study revealed that financial development reduced carbon emissions in high-income countries although it increased carbon emissions in low-income and middle-income countries.

The last group of the empirical studies reports an insignificant effect of financial development on carbon emissions. In their research, Omri et al. (2015) used system-GMM to examine the impact of financial development on carbon emissions in 12 MENA countries. Their results indicated that financial development (credit to the private sector) does not affect carbon emissions. Similarly, Jamel et al. (2017) employed OLS and causality analysis to investigate the effect of financial development on carbon emissions in 40 European countries and found that financial development (domestic credit provided by banks to private sectors) has no causal impact on carbon emissions. In another study, Dogan and Turkekul (2016) employed ARDL to investigate the effect of financial development on carbon emissions in USA. Their results revealed that no causal relationship exist between financial development (domestic credit to private sector) and carbon emissions. In the case of Malaysia, Maji et al. (2017) found that financial development (domestic credit provided by banks to private sector) has an insignificant impact on emissions from agriculture. Abbasi and Riaz (2016) examined the relationship between financial development and carbon emissions using ARDL and to showed that the financial development indicators- thus measured using stock market turnover, stock market capitalisation, total credit and private sector credit have no significant effect on carbon emissions in Pakistan when using the full sample period (1971–2011). In their recent study, Acheampong and Boateng (2019) found that financial development increases carbon emissions in Australia, Brazil and China while it reduced carbon emissions in India and the USA.

In regard to the inconsistency in the literature, this paper contributes to the literature by comparatively investigating the role of financial/stock market development on carbon emissions intensity in developed, emerging, frontier and standalone financial economies from 1980 to 2015.

3. Methodology and data

3.1. Empirical model

This study extends the empirical model of Acheampong (2019), Shahbaz et al. (2013a, 2013b) and Shahbaz et al. (2016), to comparatively analyse the effect of financial/stock market development on carbon emission intensity in the developed, emerging, frontier and the standalone financial economies. The general form of carbon emission intensity function follows that of Shahbaz et al. (2016), where carbon emission intensity (CO_2) is a function of financial market development (*FM*), economic growth (*RGDPG*), squared of economic growth ($RGDPG^2$) energy consumption (*TENER*) and other control variables (*X*). In this study, we adopt the reduced-form modelling approach to investigate the effect of financial market development carbon emission intensity. Therefore, the log-linear form of the empirical model specified in Eq. (1) is used for empirical estimation.

$$\begin{aligned} \ln CO_{2it} = {} & \alpha_1 + \beta_1 \ln RGDPG_{it} + \beta_2 \ln RGDPG^2{}_{it} + \beta_3 \ln TENER_{it} \\ & + \beta_4 \ln FM_{it} + \varnothing_1 X_{it} + v_i + \varepsilon_{it} \end{aligned} \tag{1}$$

Acheampong (2019) and Shahbaz et al. (2018) argue that financial development does not always have a linear relationship with carbon emissions but could also exert a non-linear effect on carbon emissions. Thus, financial development could either have an inverted U-shaped or U-shaped relationship with carbon emission intensity. As a result, this study follows Acheampong (2019) and Shahbaz et al. (2018) to augment Eq. (1) with the quadratic term of financial market development ($lnFM^2$) to probe whether the relationship between financial market development and carbon emissions intensity is an inverted U-shaped or U-shaped. The augmented carbon emission intensity function with the squared term of financial development is specified in Eq. (2) as following:

$$\begin{aligned} \ln CO_{2it} = {} & \alpha_1 + \beta_1 \ln RGDPG_{it} + \beta_2 \ln RGDPG^2{}_{it} + \beta_3 \ln TENER_{it} \\ & + \beta_4 \ln FM_{it} + \beta_5 \ \ln FM^2{}_{it} + \varnothing_1 X_{it} + v_i + \varepsilon_{it} \end{aligned} \tag{2}$$

The relationship between financial market development and carbon emission intensity could be non-monotonic. Thus, the relationship between financial development and carbon emission intensity is an inverted U-shaped if $\beta_4 > 0$ *and* $\beta_5 < 0$; otherwise the relationship between the financial market development and carbon emission intensity is U-shaped if $\beta_4 < 0$ *and* $\beta_5 > 0$. The inverted U-shaped relationship suggests that financial market development initially increases carbon emission intensity, but carbon emission intensity starts to decline after a certain threshold of financial market development. Contrarily, if the relationship between financial market development and carbon emissions intensity is U-shaped, it suggests that financial market development initially contributes to the decline in carbon emission intensity, but emission intensity starts to rise after a certain threshold of financial development.

To investigate the moderating role of financial market and economic growth, and financial market and energy consumption, on carbon emission intensity, Eq. (2) is extended to include the interaction term of financial market development and economic growth ($lnFM \times lnRGDPG$) and the interaction term of financial market development and energy consumption ($lnFM \times lnTENER$). Therefore, the empirical model given in Eq. (3) is used to investigate the moderating effect of financial market development and economic growth ($lnFM \times lnRGDPG$) on carbon emission intensity while Eq. (4) is used to examine the interaction effect of financial market development and energy consumption ($lnFM \times lnTENER$) on carbon emission intensity.

$$\begin{aligned}\mathrm{lnCO}_{2\mathrm{it}} = {} & \alpha_1 + \beta_1 \mathrm{lnRGDPG}_{\mathrm{it}} + \beta_2 \mathrm{lnRGDPG}^2{}_{\mathrm{it}} + \beta_3 \mathrm{lnTENER}_{\mathrm{it}} \\ & + \beta_4 \mathrm{lnFM}_{\mathrm{it}} + \delta_1 (\mathrm{lnFM} \times \mathrm{lnRGDPG})_{\mathrm{it}} + + \varnothing_1 \mathrm{X}_{\mathrm{it}} + \mathrm{v}_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \end{aligned} \tag{3}$$

$$\begin{aligned}\mathrm{lnCO}_{2\mathrm{it}} = {} & \alpha_1 + \beta_1 \mathrm{lnRGDPG}_{\mathrm{it}} + \beta_2 \mathrm{lnRGDPG}^2{}_{\mathrm{it}} + \beta_3 \mathrm{lnTENER}_{\mathrm{it}} \\ & + \beta_4 \mathrm{lnFM}_{\mathrm{it}} + \delta_2 (\mathrm{lnFM} \times \mathrm{lnTENER})_{\mathrm{it}} + \varnothing_1 \mathrm{X}_{\mathrm{it}} + \mathrm{v}_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \end{aligned} \tag{4}$$

where $i = 1 \ldots\ldots. N$ and $t = 1980 \ldots\ldots 2015$; α_1 is the constant parameter; $\beta_1 \ldots\ldots \beta_4$ is the coefficient to be estimated; $\delta_1 and\ \delta_2$ capture the indirect effect of financial market; v_i is the individual effect; ε_{it} is the stochastic error term; X is a set of control variables such as population size ($lnTPOP$) (see Dong et al., 2018; Zhu and Peng, 2012), trade openness ($lnOPEN$) (see Acheampong, 2018; Solarin et al., 2017) and urbanisation ($lnURPOPG$) (see Poumanyvong and Kaneko, 2010; Sadorsky, 2014), which have potential impacts on carbon emissions.

In consideration to the possible endogeneity concerns associated with the environmental quality and financial development (stock market) nexus (see Jacobs et al., 2010; Mario and Antonio, 2017; Shahbaz et al., 2013a, 2013b), estimating Eqs. (1) and (4) with conventional estimation techniques such as Ordinary Least-Squares (OLS) could produce inefficient estimates. Additionally, there are many other factors which potentially influence carbon emission intensity, hence failure to control for these variables could result in omitted variable bias, thereby producing inconsistent and misleading results. It should also be noted that the market-based financial development indicators are measured with considerable errors, which could create attenuation bias, thus causing the OLS estimates downwards. Therefore, to address the reverse causality or endogeneity problem, variable omission bias and produce consistent estimates, the instrumental variable generalised method of moment (IV-GMM)[1] technique is employed to estimate the impact of financial development on carbon emission. Additionally, the IV-GMM is robust to autocorrelation and produce consistent and efficient results in the presence of unknown heteroscedasticity through its use of orthogonality condition (Baum et al., 2002). Since this paper aims to investigate the impact of financial market development on carbon emission intensity, it is necessary to implement an instrument for the stock market indicators. While finding appropriate exogenous instrument is very difficult (Stock et al., 2002), this study used the lags[2] of the financial market indicators as the instrument for the financial market development indicators used in this study. To test the validity of the instruments, the Cragg-Donald/Kleibergen-Paap *F-statistics* and the Hansen J tests are the statistics used.

[1] The IV-GMM produced consistent and efficient estimate with relatively large *T and N (see* Stock et al., 2002).

[2] Lag 1 and 2 of the measures of the financial market development were used as the instruments.

3.2. Data

Data for the paper is over the period 1980–2015 for a total of 83 countries.[3] This study based on the Morgan Stanley Capital International (MSCI) 2018 stock market classification to classify the total sample into developed, emerging, frontier and standalone economies/markets. The paper, therefore, comprises 22 developed financial economies, 23 emerging financial economies, 29 frontier financial economies and 9 standalone financial economies. For the variables used, carbon emission intensity was proxied using CO_2 intensity (kg per kg of oil equivalent energy use). Real GDP per capita growth was used to represent economic growth. Energy consumption was represented using kg of oil equivalent per capita. Trade openness was represented using (Export +Import) as a percentage of GDP. Population size was proxied using total population while urbanisation was rendered using the total urban population. These data were obtained from the World Bank (2017) World Development Indicators.

The study uses the financial/stock market development indicator[4] developed by the International Monetary Fund (IMF).[5] The IMF financial market development indicator ranges between zero (0) and one (1). This dataset has numerous advantages over the World Bank stock market development indicators. First, it has broader coverage and provides a multi-dimensional measure for financial/stock market development using eight variables (see Svirydzenka, 2016). It further offers sub-indicators for financial market development, which includes financial market accessibility,[6] efficiency, and depth. The financial market indicators used for this study include the overall financial market development (FM) and its sub-indicators such as the financial market efficiency (FME), financial market access (FMA) and financial market depth (FMD).

Table 1 provides summary statistics of the variables. From Table 1, the mean of carbon emission intensity is highest in the emerging financial economies, followed by standalone financial economies while it is lowest in the frontier financial economies, followed by the developed financial economies. The statistics further show that the mean of the financial market development and its sub-indicators are high for the developed financial economies while it is lowest in the Standalone financial economies. Comparing the level of economic growth rate, real GDP per capita is highest in the developed financial economies followed by the emerging financial economies with the lowest level of development in the Standalone financial economies. The mean for energy consumption is high for the developed financial economies, followed by the Standalone financial economies while the Frontier financial economies have the lowest mean of energy consumption. These descriptive statistics provide a fair idea of the characteristics of the developed, emerging, and frontier and standalone financial economies.

4. Empirical results and discussions

This section presents and discusses the results for the developed financial economies, emerging financial economies, frontier financial economies and standalone financial economies. The results that emanated from the instrumental variable generalised method of moment (IV-GMM)[7] estimator are reported and discussed.

[3] See the appendix for the list of countries used for the study.

[4] See Svirydzenka (2016) for the details of the methodology used for deriving the financial market measures.

[5] http://data.imf.org/?sk¼4F8032E80-B36C-43B1-AC26-493C5B1CD33B.

[6] With the exception of the financial market efficiency, the remaining sub-indicators are multi-dimensional.

[7] Before utilising the instrumental variable generalised method of moment (IV-GMM) estimator as the main estimation technique for this study, the random effect estimator was used to estimate the baseline result for each of the financial economies. These results are not discussed because of space. Kindly check the supplementary file for the random-effect results.

Table 1
Descriptive statistics.

	Mean	Sd	Min	Max
Developed financial economies				
lnINCO2	0.821	0.290	−0.103	1.812
lnTENER	8.253	0.415	6.818	9.041
lnRGDPG	0.671	0.886	−3.128	3.194
lnOPEN	4.259	0.664	2.773	6.093
lnURPOPG	−0.243	0.932	−5.053	1.814
lnTPOP	16.557	1.247	14.697	19.587
FM	0.508	0.247	0.041	1.000
FMA	0.464	0.268	0.012	1.000
FMD	0.514	0.296	0.046	0.997
FME	0.538	0.315	0.010	1.000
Emerging financial economies				
lnINCO2	0.901	0.247	0.166	1.630
lnTENER	7.316	1.003	5.660	9.997
lnRGDPG	1.181	0.818	−2.825	3.315
lnOPEN	3.973	0.565	2.514	5.395
lnURPOPG	0.704	1.018	−4.536	2.810
lnTPOP	17.596	1.654	12.318	21.039
FM	0.320	0.187	0.000	0.892
FMA	0.312	0.207	0.000	1.000
FMD	0.247	0.216	0.000	0.884
FME	0.410	0.341	0.000	1.000
Frontier financial economies				
lnINCO2	0.572	0.618	−1.150	1.815
lnTENER	6.862	1.183	4.143	9.426
lnRGDPG	1.054	1.026	−5.504	3.576
lnOPEN	4.235	0.511	2.446	5.526
lnURPOPG	0.955	0.924	−3.834	2.383
lnTPOP	15.903	1.368	12.794	19.015
FM	0.123	0.140	0.000	0.646
FMA	0.152	0.227	0.000	1.000
FMD	0.106	0.142	0.000	0.770
FME	0.109	0.190	0.000	1.000
Standalone financial economies				
lnINCO2	0.822	0.404	−0.452	1.695
lnTENER	7.402	0.975	5.595	9.623
lnRGDPG	1.093	1.088	−3.122	4.523
lnOPEN	4.480	0.395	1.844	5.116
lnURPOPG	0.764	1.137	−7.813	2.660
lnTPOP	15.579	1.204	13.817	17.770
FM	0.097	0.128	0.000	0.714
FMA	0.062	0.095	0.000	0.533
FMD	0.119	0.131	0.000	0.631
FME	0.107	0.213	0.000	1.000

Note: lnCO_2 = Carbon emission intensity; ln*RGDPG* = Economic growth; ln*TENER* = Energy consumption; *lnTPOP* = Population size; *lnOPEN* = Trade openness; *lnURPOPG* = Urbanisation; *FM* = Overall financial market development; *FME* = Financial market efficiency, *FMA* = Financial market access; *FMD* = Financial market depth.

4.1. Developed financial economies

Table 2 presents the estimates for the developed financial market economies. It must be noted that Models 1–4 are based on Eq. (1). Also, Models 5–8 are based on Eq. (2) while Models 9–12 are based on Eq. (3). The results show that the estimated coefficient on the overall financial market development is negative and statistically significant at 1%. Thus, a percentage increase in the financial market decreases the intensity of carbon emission by 0.195%. Additionally, while financial market access exerts an insignificant effect on the intensity of carbon emissions, financial market depth and efficiency exert a significant negative impact on carbon emission intensity at 1% significance level. This result suggests that financial market depth and efficiency decrease carbon emission intensity by 0.254% and 0.185%, respectively. The significant negative effect of the overall financial market development and its sub-indicators (financial market depth and efficiency) suggest that financial market in the developed economies motivates firms to adopt environmentally friendly technologies that improve environmental quality. The result further supports the argument that financially developed market facilitate technological innovations that reduce environmental degradation (Tadesse, 2005; Zagorchev et al., 2011) and also create reputational and financial incentives for firms or industries to invest in environment-enhancing projects (Dasgupta et al., 2001).

In the models with non-linear effect, only the main terms of financial market accessibility, financial depth and their square terms, respectively exert significant positive and negative effects on carbon emission intensity. The non-monotonic effects show that the impact of financial market access and depth on carbon emissions intensity is not always linear. This evidence supports the argument of Acheampong (2019) and Shahbaz et al. (2018) that the effect of financial development on carbon emissions is not always monotonic. Thus, financial market access and depth have an inverted U-shaped relationship with carbon emission intensity in the developed financial economies. The implication is that financial market access and depth could increase carbon emission intensity, but carbon emission intensity declines after certain thresholds of these financial market sub-indicators in the developed financial economies. The interaction effect of the overall financial market development, financial market depth and efficiency do not complement economic growth to influence carbon emission intensity. This notwithstanding, the interaction term of financial market accessibility and economic growth exerts a significant positive effect on the intensity of carbon emission intensity at a 10% level. Thus, financial market access complements economic growth to increase the intensity of carbon emissions in developed financial economies.

The main term of economic growth exerts an insignificant positive impact on carbon emission intensity while its squared term exerts a significant positive effect on carbon emission intensity. This result indicates the non-existence of the EKC hypothesis and suggests that at each level of economic growth in the financially developed economies, carbon emission intensity increases. This result is also in line with previous empirical studies that found that economic growth increases carbon emissions in high-income countries (Poumanyvong and Kaneko, 2010). The non-existence of the EKC hypothesis confirms Acheampong (2019), Stern (2004) and Stern and Common (2001) argument that economic growth monotonically increases carbon emissions. The results further revealed that the estimated coefficient of energy consumption is negative and statistically significant at 1% in all the models. The energy consumption coefficient ranges from −0.257 to −0.342. The negative effect of energy consumption on carbon emission intensity stresses the increase in efficiency in energy consumption in developed countries. This finding contradicts the empirical findings of Özokcu and Özdemir (2017), and Poumanyvong and Kaneko (2010) who opined that energy consumption increases carbon emissions in developed countries.

The results further indicate that trade openness exerts a significant positive effect on carbon emission intensity at 10% or better in four of the models. This result reflects the scale effect of trade as trade openness boosts economic growth in the developed financial economies, thereby increasing the intensity of carbon emissions. Our result contradicts the findings of Abid (2017), which indicates that trade openness improves environmental quality in EU region but confirms his results in the case of MENA countries. The estimated coefficient of urbanisation is positive and statistically significant at 1% in all the models. This result implies that as urbanisation increases in the developed financial economies, consumption and lifestyle of the affluent cities are resource-intensive since there is an increase in demand transportation, urban infrastructure and increase in congestion and traffic; thereby increasing the intensity of carbon emissions (see Poumanyvong and Kaneko, 2010). This result is in line with the findings of Adams and Acheampong (2019) and Poumanyvong and Kaneko (2010), who indicate that urbanisation contributes to the rise in carbon emission intensity in the developed economies. The estimated coefficient of population size is positive and statistically significant at 1% in all the models. Thus, an increase in population coupled with unsustainable consumption, could worsen carbon emissions in the developed financial economies. The post-estimation

Table 2
Financial market development and carbon emission intensity in developed financial *economies.*

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
lnTENER	−0.286***	−0.318***	−0.263***	−0.290***	−0.292***	−0.330***	−0.273***	−0.285***	−0.291***	−0.321***	−0.266***	−0.292***
	(0.023)	(0.024)	(0.023)	(0.023)	(0.023)	(0.024)	(0.023)	(0.024)	(0.022)	(0.023)	(0.022)	(0.023)
lnRGDPG	0.011	0.014	0.012	0.009	0.011	0.014	0.013	0.011	−0.022	−0.022	−0.014	−0.005
	(0.014)	(0.015)	(0.014)	(0.014)	(0.014)	(0.015)	(0.014)	(0.014)	(0.026)	(0.026)	(0.024)	(0.022)
lnRGDPG2	0.002**	0.002**	0.002**	0.002***	0.002**	0.002**	0.002**	0.002***	0.002**	0.002**	0.002**	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
lnOPEN	0.041*	0.006	0.076***	0.025	0.039	0.000	0.067**	0.032	0.038	−0.000	0.072***	0.024
	(0.024)	(0.023)	(0.028)	(0.023)	(0.025)	(0.023)	(0.027)	(0.025)	(0.024)	(0.022)	(0.028)	(0.023)
lnURPOPG	0.048***	0.038***	0.056***	0.045***	0.047***	0.038***	0.050***	0.049***	0.049***	0.039***	0.057***	0.046***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)
lnTPOP	0.070***	0.051***	0.088***	0.074***	0.071***	0.048***	0.089***	0.076***	0.069***	0.051***	0.088***	0.074***
	(0.012)	(0.010)	(0.013)	(0.011)	(0.011)	(0.010)	(0.013)	(0.012)	(0.012)	(0.010)	(0.013)	(0.011)
FM	−0.195***				0.071				−0.231***			
	(0.051)				(0.337)				(0.058)			
FMA		0.015				0.377*				−0.036		
		(0.040)				(0.227)				(0.050)		
FMD			−0.254***				0.474*				−0.284***	
			(0.054)				(0.245)				(0.062)	
FME				−0.185***				−0.653*				−0.197***
				(0.039)				(0.384)				(0.045)
FM^2					−0.254							
					(0.311)							
FMA^2						−0.346						
						(0.211)						
FMD^2							−0.662***					
							(0.218)					
FME^2								0.409				
								(0.319)				
FM*lnRGDPG									0.066			
									(0.050)			
FMA*lnRGDPG										0.079*		
										(0.041)		
FMD*lnRGDPG											0.054	
											(0.049)	
FME*lnRGDPG												0.027
												(0.033)
Constant	1.938***	2.538***	1.328***	1.968***	1.923***	2.640***	1.290***	1.957***	2.018***	2.627***	1.398***	1.999***
	(0.336)	(0.309)	(0.387)	(0.327)	(0.330)	(0.305)	(0.370)	(0.336)	(0.328)	(0.300)	(0.381)	(0.321)
Observations	593	593	593	593	593	593	593	593	593	593	593	593
r2	0.270	0.251	0.290	0.271	0.272	0.259	0.306	0.258	0.271	0.255	0.292	0.271
F	35.580	37.109	36.677	35.477	32.724	35.804	35.721	29.957	34.354	36.735	34.312	31.774
j	0.057	0.510	0.931	1.064	0.048	0.191	2.678	0.524	0.108	0.428	0.870	1.150
jp	0.811	0.475	0.334	0.302	0.827	0.662	0.102	0.469	0.743	0.513	0.351	0.284
F-statistics	3086.599	2826.513	4087.280	642.539	72.670	57.471	125.808	39.056	1283.301	920.203	2360.739	234.438

Heteroscedasticity robust standard errors in parentheses. *J* is Hansen J-statistics; *jp* is the *p*-value of Hansen J-statistics. *F-statistics* is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the *F-statistics* also suggests the instrument are not weak.

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

statistics indicate that our estimation is reliable. Thus, the Cragg-Donald/Kleibergen-Paap *F-statistics* indicates that the instruments are not weak while the probability value for the Hansen test shows that the instruments are not over-identified.

4.2. Emerging financial economies

Table 3 presents the estimates for the emerging financial economies. Models 1–4 of Table 3 report the results from Eq. (1) while Models 5–8 are based on Eq. (2). Also, Models 9–12 of Table 3 present the results from Eq. (3). The estimated coefficient on the overall financial market development is negative and statistically significant at 1%. Thus, carbon emission intensity decreases by 0.264% when the overall financial market increases by 1%. Financial market access and depth exert significant negative effects on carbon emission intensity at 1% and 5%, respectively. This empirical result suggests that financial market access and depth decrease carbon emission intensity by 0.200% and 0.148%, respectively. Financial market efficiency exerts an insignificant negative effect on carbon emission intensity. The pollution-reducing effect of the financial markets in the emerging economies is not surprising because of the recent development in their financial market. Thus, like the developed market economies, the financial market in emerging economies improves environmental quality as it enhances good corporate governance (Claessens, 2007) and creates reputational and financial incentives for industries to invest in environment enhancing projects (Dasgupta et al., 2001).

In the non-linear models, the main coefficients of the overall financial market development, financial market access and their square terms, respectively have significant positive and negative effects on carbon emission intensity. Thus, the overall financial market and its sub-indicator (financial market access) increase carbon emission intensity, but carbon emission intensity reduces after a certain threshold of these financial development indicators. This evidence further supports the argument that financial development could have a non-monotonic effect on carbon emission intensity. Contrarily, the estimated coefficients of financial market depth and its square term, respectively exert significant negative and positive effects on emission intensity. Thus, financial market access and depth decrease carbon emission intensity, but emission intensity increases after a certain threshold of financial market depth.

Table 3
Financial market development and carbon emission intensity in emerging financial economies.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
lnTENER	0.182***	0.165***	0.163***	0.155***	0.183***	0.183***	0.161***	0.159***	0.179***	0.163***	0.165***	0.144***
	(0.017)	(0.016)	(0.015)	(0.017)	(0.018)	(0.016)	(0.015)	(0.017)	(0.017)	(0.016)	(0.015)	(0.016)
lnRGDPG	0.024	0.022	0.022	0.024	0.021	0.020	0.026	0.025	−0.024	0.042*	0.011	−0.042**
	(0.016)	(0.016)	(0.016)	(0.017)	(0.016)	(0.015)	(0.016)	(0.016)	(0.025)	(0.025)	(0.020)	(0.019)
lnRGDPG2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
lnOPEN	0.016	−0.001	0.018	−0.015	0.015	−0.005	0.019	−0.010	0.018	−0.004	0.017	−0.006
	(0.024)	(0.021)	(0.029)	(0.021)	(0.024)	(0.022)	(0.029)	(0.021)	(0.024)	(0.022)	(0.029)	(0.021)
lnURPOPG	−0.013	−0.016	−0.005	−0.010	−0.011	−0.013	−0.010	−0.014	−0.013	−0.017	−0.005	−0.014
	(0.013)	(0.013)	(0.012)	(0.012)	(0.013)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)	(0.012)	(0.012)
lnTPOP	0.029***	0.010	0.018**	0.018*	0.027***	0.011	0.019**	0.022**	0.027***	0.009	0.018**	0.010
	(0.009)	(0.007)	(0.008)	(0.009)	(0.010)	(0.007)	(0.008)	(0.010)	(0.009)	(0.007)	(0.008)	(0.009)
FM	−0.264***				0.252				−0.411***			
	(0.081)				(0.266)				(0.105)			
FMA		−0.200***				0.463***				−0.134		
		(0.061)				(0.166)				(0.089)		
FMD			−0.148**				−0.538**				−0.198**	
			(0.069)				(0.228)				(0.101)	
FME				−0.048				−0.358				−0.228***
				(0.037)				(0.251)				(0.058)
FM^2					−0.661**							
					(0.280)							
FMA^2						−0.947***						
						(0.198)						
FMD^2							0.545**					
							(0.277)					
FME^2								0.277				
								(0.210)				
FM*lnRGDPG									0.144**			
									(0.056)			
FMA*lnRGDPG										−0.061		
										(0.052)		
FMD*lnRGDPG											0.043	
											(0.050)	
FME*lnRGDPG												0.158***
												(0.034)
Constant	−0.924***	−0.427**	−0.659***	−0.495**	−0.969***	−0.616***	−0.624**	−0.553**	−0.827***	−0.402*	−0.658***	−0.231
	(0.275)	(0.208)	(0.255)	(0.247)	(0.272)	(0.202)	(0.251)	(0.254)	(0.269)	(0.207)	(0.254)	(0.230)
Observations	502	502	502	502	502	502	502	502	502	502	502	502
r2	0.277	0.279	0.266	0.267	0.303	0.342	0.262	0.280	0.283	0.282	0.264	0.305
j	2.559	0.235	0.042	2.769	2.911	1.573	0.036	2.232	2.219	0.335	0.006	3.854
jp	0.110	0.628	0.837	0.096	0.088	0.210	0.850	0.135	0.136	0.563	0.940	0.050
F-statistics	788.445	1661.216	1042.347	466.087	64.727	77.236	141.691	32.822	160.730	215.106	179.857	71.037

Heteroscedasticity robust standard errors in parentheses. *J* is Hansen J-statistics; *jp* is the p-value of Hansen J-statistics. *F-statistics* is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the *F-statistics* also suggests the instrument are not weak.

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

In the interaction effect models, the interaction term of economic growth and the overall financial market development, and economic growth and financial market efficiency have significant positive effects on carbon emission intensity at 5% and 1% respectively. Thus, the overall financial market development and financial market efficiency moderate economic growth to increase carbon emission intensity in the emerging economies. Contrarily, the interaction term of economic growth and the financial market depth and economic growth and financial access have insignificant impacts on carbon emission intensity. Thus, financial market depth does not complement economic growth to influence carbon emission intensity. The results indicate that economic growth and its squared term are mostly insignificant. It is observed that the estimated coefficient of energy consumption is positive and statistically significant at 1% level in all the models. The estimated coefficient of energy consumption ranges from 0.146% to 0.188%. Thus, unlike the developed financial economies, energy consumption in the emerging financial economies are inefficient and unsustainable, thereby worsening carbon emission intensity. Past studies have also indicated that energy consumption contributes significantly to carbon emissions in emerging economies (Sadorsky, 2014; Tan et al., 2014). Trade openness exerts an insignificant effect on carbon emission intensity. Thus, unlike the financially developed economies, trade openness does not impede the quality of the environment in the emerging countries, and this is not in line with the previous studies that found that trade openness increases carbon emissions in transitional economies (Tamazian and Bhaskara Rao, 2010). Urbanisation exerts an insignificant effect on carbon emission intensity, and this result is in line with the empirical findings of Sadorsky (2014) who noted that urbanisation has no degrading impact on the environment in the emerging economies. The estimated coefficient of population size is positive and statistically significant at 10% level or better in most of the models. Thus, the continued expansion in population size in the emerging financial economies pollutes the environment by increasing carbon emission intensity. To validate the instruments, the Cragg-Donald/Kleibergen-Paap *F-statistics* indicates that the instruments are not weak while the probability value for the Hansen test shows that the instruments are not over-identified.

4.3. Frontier financial economies

Table 4 presents the estimates for the frontier financial economies. Again Models 1–4 of Table 4 are based on Eq. (1). Models 5–8 are based on Eq. (2) while Models 9–12 are based on Eq. (3). The estimated

Table 4
Financial market development and carbon emission intensity in frontier financial economies.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
lnTENER	0.069**	0.145***	0.151***	0.112***	0.044	0.145***	0.142***	0.091***	0.069**	0.146***	0.152***	0.096***
	(0.032)	(0.027)	(0.035)	(0.024)	(0.034)	(0.027)	(0.038)	(0.025)	(0.032)	(0.027)	(0.035)	(0.025)
lnRGDPG	0.035	0.045	0.042	0.020	0.024	0.044	0.039	0.012	0.032	0.039	0.030	0.057
	(0.032)	(0.033)	(0.033)	(0.031)	(0.031)	(0.033)	(0.034)	(0.029)	(0.043)	(0.042)	(0.041)	(0.037)
lnRGDPG2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnOPEN	0.032	0.063	0.051	0.020	−0.019	0.059	0.039	−0.054	0.033	0.066	0.053	0.021
	(0.049)	(0.052)	(0.053)	(0.050)	(0.051)	(0.052)	(0.054)	(0.050)	(0.050)	(0.054)	(0.053)	(0.049)
lnURPOPG	−0.082***	−0.089***	−0.103***	−0.109***	−0.050*	−0.089***	−0.092***	−0.082***	−0.081***	−0.088***	−0.101***	−0.115***
	(0.024)	(0.025)	(0.025)	(0.024)	(0.026)	(0.025)	(0.027)	(0.025)	(0.024)	(0.025)	(0.025)	(0.025)
lnTPOP	−0.057**	−0.037	−0.034	−0.075***	−0.084***	−0.038	−0.040	−0.111***	−0.057**	−0.036	−0.034	−0.076***
	(0.026)	(0.026)	(0.026)	(0.026)	(0.027)	(0.027)	(0.027)	(0.028)	(0.026)	(0.026)	(0.026)	(0.026)
FM	1.014***				2.894***				0.992***			
	(0.208)				(0.730)				(0.258)			
FMA		0.173*				0.429				0.147		
		(0.104)				(0.268)				(0.152)		
FMD			0.170				0.815				0.115	
			(0.235)				(0.736)				(0.244)	
FME				0.842***				2.954***				1.438***
				(0.124)				(0.447)				(0.346)
FM^2					−3.552***							
					(1.139)							
FMA^2						−0.397						
						(0.295)						
FMD^2							−1.081					
							(0.970)					
FME^2								−2.713***				
								(0.494)				
FM*lnRGDPG									0.029			
									(0.133)			
FMA*lnRGDPG										0.022		
										(0.090)		
FMD*lnRGDPG											0.087	
											(0.102)	
FME*lnRGDPG												−0.440**
												(0.190)
Constant	0.717	−0.117	−0.124	0.870	1.384*	−0.096	0.043	1.770**	0.713	−0.133	−0.136	0.944
	(0.676)	(0.676)	(0.706)	(0.665)	(0.715)	(0.684)	(0.735)	(0.691)	(0.676)	(0.679)	(0.703)	(0.674)
Observations	432	432	432	432	432	432	432	432	432	432	432	432
r2	0.262	0.242	0.241	0.274	0.268	0.245	0.244	0.295	0.262	0.242	0.242	0.275
F	33.791	32.268	32.965	32.655	31.222	28.924	29.270	30.673	29.727	28.217	28.709	28.937
j	2.158	0.984	0.069	4.921	1.275	1.576	0.047	4.539	2.245	0.936	0.120	2.314
jp	0.142	0.321	0.792	0.027	0.259	0.209	0.828	0.033	0.134	0.333	0.729	0.128
F-statistics	553.070	1321.241	780.131	197.228	88.349	169.315	59.029	81.829	381.747	490.073	465.484	23.998

Heteroscedasticity robust standard errors in parentheses. *J* is Hansen J-statistics; *jp* is the p-value of Hansen J-statistics. *F-statistics* is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the *F-statistics* also suggests the instrument are not weak.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

coefficient on the overall financial market development is positive and statistically significant at 1%. Thus, carbon emission intensity increases by 1.00% when the financial market increases by 1%. For the sub-indicators of financial market development, the estimated coefficient of financial market depth, efficiency and access are positive, but only financial market accessibility and efficiency exert significant positive effects on carbon emission intensity. Thus, financial market accessibility and efficiency increase carbon emission intensity by 0.173% and 0.842%, respectively. Sadorsky (2010) found that stock market capitalisation and stock market value traded (measures of financial market depth) have no effect on energy consumption in frontier economies. The current paper also find that financial market depth has an insignificant impact on carbon emission intensity in the frontier economies. The significant effect of the overall financial market development indicator and its sub-indicator (financial market accessibility and efficiency) on increasing carbon emission intensity in the frontier markets reflect the undeveloped and inefficient nature of the financial market in the frontier economies. Contrarily to the developed financial market, the underdeveloped financial market does not promote good corporate governance, drive innovation, entice industries to adopt environmentally friendly technologies and lack proper regulations that make industries not to invest in environmental sustainability projects.

In the curvilinear models, only the main term of the overall financial market development and financial market efficiency and their squared terms, respectively exert significant positive and negative effects on carbon emission intensity in the frontier markets. Thus, the overall financial market development, as well as the financial market efficiency, increase carbon emission intensity but emission intensity reduces after a certain threshold of the financial market efficiency. In the moderation effect models, only the interaction term of financial market efficiency and economic growth exerts a significant negative effect on the intensity of carbon emission at 5% level. Thus, financial market efficiency moderates economic growth to reduce carbon emission intensity.

The results also suggest that the main term of economic growth and its squared term exerts an insignificant effect on carbon emission intensity. The estimated coefficient of energy consumption is positive and statistically significant at 5% level or better in all the models. Trade openness exerts an insignificant impact on carbon emission intensity. The estimated coefficient of urbanisation is negative and statistically significant at 10% level or better in all the models, but this contradicts the findings of Poumanyvong and Kaneko (2010) who showed that urbanisation increases carbon emissions in low-income countries. The estimated coefficient of population size is negative and statistically significant at 5% level or better in six of the models. The Cragg-Donald/Kleibergen-Paap *F-statistics* further indicates that the instruments are not weak while the probability value for the Hansen test shows that the instruments are not over-identified.

4.4. Standalone financial economies

Table 5 presents the estimates for the standalone financial economies. Models 1–4 of Table 5 report the results from Eq. (1) while Models 5–8 are based on Eq. (2). Models 9–12 of Table 3 also present the results from Eq. (3).The estimated coefficient on the overall financial market development and its sub-indicators have insignificant direct effects on carbon emission intensity. Thus, overall financial markets and its sub-indicators do not influence carbon emission intensity in the standalone economies and could be due to the infantile stage of their financial market. However, while there is no linear effect of the overall financial market development and its sub-indicators on carbon emission intensity, the non-linear models shows that the main terms of the overall financial market development, financial market access, financial market depth and their square terms, respectively exert significant positive and negative effects on carbon emission intensity in the standalone economies. This result affirms evidence of an inverted U-shaped relationship between these financial market measures and carbon emission intensity in the standalone economies. Thus, the overall financial market development, financial market access and depth increase the intensity of carbon emissions but emission intensity decreases after a certain threshold of these financial market measures. Additionally, none of the interaction terms of economic growth and the financial market measures has a significant effect on the intensity of carbon emission. The implication is that financial market development does not complement economic growth to influence environmental pollution in the standalone economies.

Table 5
Financial market development and carbon emission intensity in standalone financial economies.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
lnTENER	0.363^{***}	0.376^{***}	0.353^{***}	0.376^{***}	0.363^{***}	0.320^{***}	0.376^{***}	0.379^{***}	0.363^{***}	0.375^{***}	0.352^{***}	0.376^{***}
	(0.036)	(0.039)	(0.029)	(0.036)	(0.031)	(0.038)	(0.029)	(0.035)	(0.036)	(0.038)	(0.029)	(0.036)
lnRGDPG	−0.010	−0.010	−0.008	−0.009	0.014	−0.000	0.006	−0.002	−0.016	−0.029	−0.014	−0.010
	(0.025)	(0.025)	(0.025)	(0.025)	(0.023)	(0.021)	(0.024)	(0.024)	(0.028)	(0.030)	(0.032)	(0.024)
lnRGDPG2	0.000	0.000	0.000	0.000	−0.000	−0.000	−0.000	−0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
lnOPEN	0.376^{***}	0.382^{***}	0.355^{***}	0.382^{***}	0.316^{***}	0.345^{***}	0.310^{***}	0.387^{***}	0.376^{***}	0.380^{***}	0.353^{***}	0.383^{***}
	(0.055)	(0.056)	(0.055)	(0.053)	(0.055)	(0.056)	(0.056)	(0.051)	(0.055)	(0.057)	(0.056)	(0.054)
lnURPOPG	-0.092^{***}	-0.089^{***}	-0.093^{***}	-0.088^{***}	-0.092^{***}	-0.101^{***}	-0.087^{***}	-0.092^{***}	-0.093^{***}	-0.090^{***}	-0.094^{***}	-0.088^{***}
	(0.025)	(0.026)	(0.024)	(0.025)	(0.022)	(0.025)	(0.021)	(0.025)	(0.025)	(0.025)	(0.024)	(0.025)
lnTPOP	-0.061^{**}	-0.059^{**}	-0.067^{***}	-0.056^{**}	-0.051^{**}	-0.043^{*}	-0.062^{***}	-0.050^{**}	-0.062^{**}	-0.062^{**}	-0.068^{***}	-0.056^{**}
	(0.026)	(0.026)	(0.023)	(0.027)	(0.024)	(0.024)	(0.024)	(0.025)	(0.025)	(0.026)	(0.023)	(0.026)
FM	0.037				2.155^{***}				−0.020			
	(0.195)				(0.593)				(0.268)			
FMA		−0.091				3.075^{***}				−0.392		
		(0.293)				(0.917)				(0.403)		
FMD			0.187				1.500^{***}				0.162	
			(0.143)				(0.450)				(0.180)	
FME				−0.062				0.772				−0.082
				(0.133)				(0.722)				(0.194)
FM^2					-3.461^{***}							
					(0.892)							
FMA^2						-6.648^{***}						
						(1.762)						
FMD^2							-2.946^{***}					
							(0.944)					
FME^2								−0.890				
								(0.682)				
FM*lnRGDPG									0.058			
									(0.131)			
FMA*lnRGDPG										0.311		
										(0.233)		
FMD*lnRGDPG											0.036	
											(0.112)	
FME*lnRGDPG												0.017
												(0.091)
Constant	-2.495^{***}	-2.635^{***}	-2.260^{***}	-2.682^{***}	-2.513^{***}	-2.431^{***}	-2.371^{***}	-2.855^{***}	-2.476^{***}	-2.552^{***}	-2.225^{***}	-2.692^{***}
	(0.665)	(0.690)	(0.558)	(0.667)	(0.583)	(0.637)	(0.548)	(0.620)	(0.652)	(0.688)	(0.573)	(0.657)
Observations	141	141	141	141	141	141	141	141	141	141	141	141
r2	0.780	0.780	0.782	0.780	0.816	0.814	0.803	0.796	0.780	0.780	0.782	0.780
F	52.855	53.634	53.237	54.096	55.919	57.184	49.945	51.173	45.840	45.795	46.745	47.029
j	0.360	0.016	0.248	0.229	0.015	1.079	0.580	0.202	0.320	0.000	0.260	0.214
jp	0.548	0.898	0.618	0.632	0.902	0.299	0.446	0.653	0.571	0.987	0.610	0.643
F-statistics	196.016	441.085	224.122	102.537	18.486	14.192	15.258	11.193	43.480	144.161	79.399	29.077

Heteroscedasticity robust standard errors in parentheses. *J* is Hansen J-statistics; *jp* is the p-value of Hansen J-statistics. *F-statistics* is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the *F-statistics* also suggests the instrument are not weak.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

Table 6
Interaction effect of financial market development and energy consumption on carbon emission intensity.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16
	Developed financial economies				Emerging financial economies				Frontier financial economies				Standalone financial economies			
lnTENER	−0.242	−0.223	−0.329	1.346	0.303***	0.281***	0.128	0.225***	0.232***	0.183***	0.187***	0.222***	0.409***	0.377***	0.444***	0.416***
	(0.484)	(0.261)	(0.293)	(2.025)	(0.071)	(0.041)	(0.083)	(0.049)	(0.046)	(0.033)	(0.038)	(0.042)	(0.052)	(0.038)	(0.073)	(0.059)
lnRGDPG	0.012	0.013	0.011	0.049	0.021	0.020	0.024	0.024	0.010	0.040	0.037	0.011	0.003	−0.009	0.011	−0.001
	(0.015)	(0.015)	(0.014)	(0.053)	(0.016)	(0.014)	(0.017)	(0.017)	(0.031)	(0.033)	(0.033)	(0.030)	(0.025)	(0.023)	(0.029)	(0.024)
lnRGDPG2	0.002**	0.002***	0.002**	0.003	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	−0.000	0.000	−0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.003)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
lnOPEN	0.037	−0.008	0.083**	−0.067	−0.001	−0.020	0.028	−0.006	−0.073	0.050	0.018	−0.184**	0.329***	0.359***	0.298***	0.381***
	(0.050)	(0.043)	(0.040)	(0.114)	(0.028)	(0.023)	(0.044)	(0.022)	(0.055)	(0.052)	(0.059)	(0.089)	(0.078)	(0.060)	(0.071)	(0.051)
lnURPOPG	0.049***	0.042**	0.055***	0.076	−0.001	0.006	−0.014	−0.028*	−0.028	−0.074***	−0.088***	−0.087***	−0.085***	−0.089***	−0.076***	−0.086***
	(0.016)	(0.017)	(0.012)	(0.046)	(0.014)	(0.015)	(0.023)	(0.017)	(0.026)	(0.026)	(0.027)	(0.024)	(0.022)	(0.024)	(0.023)	(0.023)
lnTPOP	0.070***	0.050***	0.088***	0.097**	0.018	0.010	0.021*	0.013	−0.104***	−0.043	−0.047*	−0.146***	−0.048*	−0.050	−0.045	−0.047*
	(0.012)	(0.010)	(0.013)	(0.042)	(0.012)	(0.007)	(0.011)	(0.011)	(0.030)	(0.027)	(0.028)	(0.040)	(0.026)	(0.031)	(0.027)	(0.026)
FM	0.593				2.119				7.792***				5.657			
	(8.622)				(1.398)				(1.656)				(5.878)			
FM*lnTENER	−0.095				−0.323*				−0.925***				−0.672			
	(1.040)				(0.186)				(0.214)				(0.690)			
FMA		2.097				1.840***				1.480**				3.658		
		(5.739)				(0.666)				(0.688)				(5.130)		
FMA*lnTENER		−0.252				−0.276***				−0.179**				−0.432		
		(0.693)				(0.088)				(0.087)				(0.608)		
FMD			−1.361				−0.855				2.550				5.492	
			(4.815)				(1.710)				(1.963)				(4.062)	
FMD*lnTENER			0.133				0.096				−0.298				−0.685	
			(0.578)				(0.228)				(0.228)				(0.519)	
FME				27.498				1.275				7.100***				3.965
				(34.361)				(0.924)				(2.303)				(5.592)
FME*lnTENER				−3.332				−0.186				−0.870***				−0.475
				(4.139)				(0.128)				(0.312)				(0.654)
Constant	1.589	1.839	1.844	−11.542	−1.533***	−1.181***	−0.499	−0.915***	0.843	−0.222	−0.026	2.135**	−2.867***	−2.714***	−3.030***	−3.128***
	(3.866)	(1.955)	(2.331)	(16.839)	(0.399)	(0.306)	(0.401)	(0.347)	(0.728)	(0.707)	(0.727)	(0.873)	(0.639)	(0.718)	(0.753)	(0.772)
Observations	593	593	593	593	502	502	502	502	432	432	432	432	141	141	141	141
r2	0.270	0.255	0.286	−1.710	0.349	0.372	0.236	0.285	0.272	0.249	0.251	0.234	0.813	0.792	0.802	0.808
j	0.051	0.391	0.928	0.023	2.311	0.565	0.067	2.301	1.908	1.032	0.069	9.170	1.189	0.059	0.207	0.194
jp	0.821	0.532	0.335	0.880	0.128	0.452	0.795	0.129	0.167	0.310	0.793	0.002	0.276	0.808	0.649	0.660
F-statistics	3.709	3.046	10.944	0.508	14.216	15.406	11.977	8.986	23.779	38.205	15.056	3.475	4.108	2.397	1.275	1.307

Heteroscedasticity robust standard errors in parentheses. *J* is Hansen J-statistics; *jp* is the p-value of Hansen J-statistics. *F-statistics* is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the *F-statistics* also suggests the instrument are not weak.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

Economic growth and its squared term exert an insignificant effect on carbon emission intensity, and this result is consistent with the findings of Acheampong (2018) who found that economic growth does not affect carbon emissions. The estimated coefficient of energy consumption is positive and statistically significant at 1% level in all the models. Trade openness exerts a significant positive effect on carbon emission intensity at 1% level in all the models; this is consistent with the findings of Acheampong et al. (2019), which reveal that trade openness worsens the environment. The estimated coefficient of urbanisation is negative and statistically significant at 1% level in all the models. The estimated coefficient of population size is negative and statistically significant at 1% level in all the models. The Cragg-Donald/Kleibergen-Paap *F-statistics* also suggests that the instruments are not weak while the probability value for the Hansen test shows that the instruments are not overidentified.

4.5. Interaction effect of the financial market and energy consumption on carbon emission intensity

Based on Eq. (4), Table 6 presents the interaction effect results of the financial market development and energy consumption on carbon emission intensity for the developed, emerging, frontier and standalone financial economies. It is observed from Table 6 that in the developed economies (see Models 1–4), the interaction terms of energy consumption and the financial market indicators exert an insignificant effects on the carbon emission intensity. The implication is that financial market development does not complement energy consumption to influence the intensity of carbon emissions in countries with the well-developed financial market economies. In the emerging financial economies (see Models 5–8), the interaction term of energy consumption and the overall financial market development and its sub-indicator (financial market access) exert significant negative effects on the intensity of carbon emissions. This result suggests that the overall financial market development and the financial market access complement energy consumption to reduce the intensity of carbon emissions. Thus, financial market development ensures efficiency in energy consumption, which in turns reduces carbon emission intensity. In frontier financial economies (see Models 9–12), the interaction term of energy consumption and the overall financial market indicator and its sub-indicators such as financial market access and efficiency exert significant negative impacts on the intensity of carbon emissions. Thus, as identified in the emerging financial economies, financial market improvement in the frontier financial economies could introduce efficiency in energy consumption, which will subsequently reduce carbon emission intensity. Like the developed financial economies, the interaction term of energy consumption and the financial market indicators exert an insignificant effect on the intensity of carbon emissions in the standalone economies (see Models 13–16).

5. Conclusions and policy implications

The impact of financial development on environmental pollution has recently received intense debate within policy circles. While the emerging theoretical literature is conflicting, the empirical evidence is contradictory and do not consider the difference in the stages of financial development. Hence the inconsistencies within the literature. In this paper, we utilise a comprehensive panel dataset spanning the period 1980–2015 for a total of 83 countries (comprise 22 developed financial economies, 23 emerging financial economies, 29 frontier financial economies and 9 standalone financial economies) and the instrumental variable- generalised method of moment (IV-GMM) approach to estimate the impact of financial market development on environmental quality. Taking into account the stages of financial development of the selected countries, we adopt a comparative approach to investigate the effect of financial market development on the carbon emission intensity in developed, emerging, frontier and standalone financial economies while controlling for economic growth, population, energy consumption, trade openness and urbanisation. The results that emanated from this study are presented as follows:

First, the findings show that the impact of financial market on carbon emission intensity varies across the different types of financial economies. The empirical results showed that in the developed financial economies, the overall financial market development, financial market depth and financial market efficiency improve environmental quality by reducing carbon emission intensity. Additionally, in the emerging financial economies, the overall financial market indicator and its disaggregated indices such as financial market access and financial market depth reduce the intensity of carbon emissions. Contrarily, in the frontier financial economies, the overall financial market development and its sub-measures, financial market access and efficiency increase the intensity of carbon emissions while in the Standalone financial economies, the overall financial market development and its sub-measures have no direct linear effect on carbon emission intensity. These results show that in developed and emerging financial economies, the financial market facilitates technological innovations, promotes good corporate governance and creates reputational and financial incentives for industries to invest in environmental-enhancing projects, thereby reducing the intensity of carbon emissions (Acheampong, 2019; Claessens, 2007; Dasgupta et al., 2001; Tadesse, 2005; Zagorchev et al., 2011). In contrast to the developed and emerging financial economies, the under-developed and inefficient financial market of the frontier economies does not promote good corporate governance, drive innovation, entice industries to adopt environmentally friendly technologies and lack proper regulations to make industries to invest in environmental sustainability projects. Furthermore, the insignificant effect of the overall financial markets development and its sub-indicators on carbon emission intensity in the standalone financial economies could be attributed to the infantile stage of their financial market.

Second, the empirical findings also revealed that the effect of financial market development on carbon emission intensity is not always linear but non-monotonic. While the financial market measures have no linear effect on carbon emission intensity in standalone financial economies, their impacts are slightly non-linear. Thus, in the standalone financial economies, the overall financial market development, financial market access and financial market depth have an inverted U-shaped relationship with carbon emission intensity. Additionally, financial market accessibility and financial market depth have an inverted U-shaped relationship with carbon emission intensity in the developed financial economies. Financial market efficiency also has an inverted U-shaped relationship with carbon emission intensity in the frontier market. In the emerging financial economies, the overall financial market development and financial market access also have an inverted U-shaped relationship with carbon emission intensity. The evidence of an inverted U-shaped relationship between the financial market indicators and carbon emission intensity implies that these indicators increase carbon emission intensity, but emission intensity declines after a certain threshold of the financial market indicators. Contrarily, financial market depth has a U-shaped relationship with carbon emission intensity in emerging economies. Thus, the financial market depth decreases carbon emission intensity, but emission intensity increases after a certain threshold of financial market depth.

Third, the results indicated that the financial market also moderates energy consumption and economic growth to influence the intensity of carbon emissions. In the emerging financial economies, the overall financial market development and financial market access moderate energy consumption to improve environmental quality by reducing carbon emission intensity. In the same way, the overall financial market development, financial market access and financial market efficiency moderate energy consumption to reduce carbon emission intensity in frontier financial economies. In addition to the complementary effect of the financial market and energy consumption on emission intensity, the financial market indicators also moderate economic growth to influence carbon emission intensity. Financial market access also moderates economic growth to increase carbon emission intensity in the developed financial economies while the overall financial market development and financial market efficiency moderate economic growth to increase carbon emission in emerging financial economies. In the frontier financial economies, financial market efficiency complements economic growth to reduce carbon emission intensity, but none of its indicators complements economic growth to influence the carbon emission intensity in standalone financial economies. While this paper establishes that a well-developed financial market directly improves environmental quality, it indirectly degrades the quality of the environment by fuelling economic growth. Thus, developed financial economies fuel economic growth through technological innovations, which further increases emission intensity while the undeveloped financial market retards (does not promote) economic growth, which subsequently reduces (do not affect) carbon emission intensity.

In conclusions, this paper has demonstrated that the stages of financial development matters when investigating the effect of financial markets on environmental quality. In view of this, the present paper argues that the impact of financial market development on carbon emission intensity is not always linear, but could also be nonlinear/curvilinear. Finally, this paper highlights that the effect of the financial market on the intensity of carbon emission intensity is not always direct, but it also moderates economic growth and energy consumption to influence environmental quality. These findings confirm the argument and the findings of Acheampong (2019). Our paper does not only advance knowledge about the impact of the financial market on the intensity of carbon emissions but also have important policy implications, especially for policymakers in frontier economies. Policymakers from frontier financial economies should adopt public disclosure mechanisms that release the environmental performance of industries or firms to harness the potential environmental benefit of the financial market. Additionally, this paper has established that financial market directly helps to mitigate the intensity of carbon emissions in the developed and emerging financial economies because industries or firms in these economies have the incentives to invest in pollution controls as a result of stringent environmental regulations. Therefore, policymakers should use the financial markets as one of the regulatory means to achieve environmental sustainability and to a large extent, mitigate climate change. While financial market indirectly increases carbon emission intensity by fuelling economic growth in the developed and emerging economies, policymakers in these economies should urge investment in economic sectors that are environmentally sustainable. While this study solely focused on the financial market development, our next research project will extend this methodology by examining the impact of financial institutions (banking-sector) on the environment, taking into account the stages of financial development.

Credit authorship contribution statement

Alex O. Acheampong: Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Supervision, Project administration, Investigation, Resources. **Mary Amponsah:** Conceptualization, Methodology, Data curation, Validation, Software, Formal analysis, Writing - review & editing, Visualization. **Elliot Boateng:** Conceptualization, Methodology, Data curation, Validation, Software, Formal analysis, Writing - original draft, Investigation, Visualization.

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Appendix A. Appendix

Table A.1
Countries included in the study.

Developed financial economies (22)
Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Hong Kong SAR, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and the United States.
Emerging financial economies (23)
Brazil, Chile, China, Colombia, Czech Republic, Egypt, Arab Rep., Greece, Hungary, India, Indonesia, Korea, Rep., Malaysia, Mexico, Pakistan, Peru, Philippines, Poland, Qatar, Russian Federation, South Africa, Thailand, Turkey and the United Arab Emirates.
Frontier financial economies (29)
Argentina, Bahrain, Bangladesh, Benin, Burkina Faso, Cote d'Ivoire, Croatia, Estonia, Guinea-Bissau, Jordan, Kazakhstan, Kenya, Kuwait, Lebanon, Lithuania, Mali, Mauritius, Morocco, Niger, Nigeria, Oman, Romania, Senegal, Serbia, Slovenia, Sri Lanka, Togo, Tunisia and Vietnam,
Standalone financial economies (9)
Bosnia and Herzegovina, Botswana, Bulgaria, Ghana, Jamaica, Panama, Saudi Arabia, Trinidad and Tobago and Ukraine

Source: Morgan Stanley Capital International (2018).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2020.104768.

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