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RESEARCH ARTICLE

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Does financial development lower energy intensity?

Abstract The growth-induced effects of financial development have been well-established in the empirical literature, as well as the significance of financial development to energy demand behavior. However, the empirical evidence on the relationship between financial development and energy intensity remains sparse in the literature. Given the multifaceted nature of the effects of financial development, the proposed relationship seems a complex one and warrants an empirical investigation. Using the case of Ghana, this study provides an empirical answer to the question: does financial development lower energy intensity? To provide solid grounds for either rejection or acceptance of the null hypothesis, this study performed several robustness checks. Generally, the evidence revealed that financial development lowers energy intensity. Further, the results revealed that the price of energy, trade liberalization and industry structure play significant roles. These results have important implications for the design of macro energy efficiency policies and the creation of a 'Green Bank'.

Keywords financial development, energy intensity, energy efficiency, Ghana

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1 Introduction

Energy insecurity continues to pose serious macroeconomic problems to a number of countries in Africa, particularly those in sub-Saharan Africa. This is mainly due to the poor energy supply and growth in energy demand[1)](caused by the rising middle-class population, bad energy-use practices, and urbanization) in the region. Consequently, power shortages remain a rampant phenomenon in these economies, causing employment and output losses [1,2]. The duration of power outages in sub-Saharan Africa remains the highest, which has compelled the majority of businesses in the region to depend on standby generators [3]. With the debt profile of these economies soaring[2)], the growth in capacity in the energy sector is likely to progress slowly. This signals a worrying situation for future energy security, especially given the projected future trajectories of demographic and economic growth dynamics in the region.

On this score, investment in energy-efficient technologies is crucial [4–6]. Among other things, energy efficiency increases employment, lowers production cost, lowers energy intensity and improves energy security and environmental standards [4,7]. In Ghana, for example, the appliance labeling program saved the country 120 MW of power, which saved the country US$105 million investment in additional generation and reduced emission levels by more than 110000 tonnes annually. Similarly, in 2011, South Africa Eskom's energy efficiency initiative saved the country over 3 GW of total cumulative power, which represents an electricity output of five 600 MW generators [4].

Despite its importance, commitment to energy efficiency efforts in the sub-region lags behind those in Europe, Asia, and Latin America. In Africa and sub-Saharan Africa in particular, two major factors are crucial for the slow investments in energy efficiency: the lack of political will

1) Energy demand is projected to grow in Africa by 85% between 2010 and 2040 [4].
2) Between 2010–2013, domestic and external debt as a percent of GDP in sub-Saharan stood at 17.5% and 11.5%, respectively. This increased to 20.4% and 15.4% in 2015 [8].

and financial constraints[1]. The financial constraint reason makes the development of the financial sector in Africa a critical tool to promote energy efficiency investments. However, the financial sector in the sub-region is less-developed[2] [9], which makes it difficult to secure credit. Interest rate charges in the region remain exorbitant compared to other regions in Asia and Europe, thereby imposing credit constraints for investments, such as energy-efficient technologies. Consequently, it is expected that the development of the financial sector might remove credit constraints and facilitate investments in energy-efficient technologies that will improve the technical processes in the production and consumption sectors and lower energy intensity. Despite this apparent link that exists between financial development and energy intensity, empirical studies that investigate this nexus remain sparse in the literature, particularly in sub-Saharan Africa.

Motivated by the above, this paper examines the long-run effect of financial development on energy intensity, using the case of Ghana. Ghana has serious challenges in the energy sector. The demand-supply gap keeps widening, which has contributed to the frequent outages in the country [6]. The insecurity in energy supply has affected production and consumption negatively [10]. Given that economic growth is projected to increase in the future, there is the need to pay attention to lowering energy intensity by investing in energy efficiency in Ghana. However, investments in energy efficiency remain limited in Ghana chiefly due to financial constraints, reluctance to change, and lack of strong regulation to stimulate energy efficiency. The constraint on energy efficiency investments imposed by financial constraints is further exacerbated by the acute nature of the financial sector[3], which is characterized by very high interest rate charges. Thus, in Ghana, the development of the financial sector may remove credit constraints and facilitate investments in energy-efficient technologies, which could further enhance the technical aspects of the production processes and hence lower energy intensity in Ghana. Since the financial sector and the energy sector in Ghana share common characteristics with other countries in the region, a study of this kind that uses Ghana as a case study provides useful insights into understanding the financial development-energy intensity nexus in the region.

Sadorsky [12,13] and Shahbaz and Lean [14] are among some of the earlier researchers who have examined the effect of financial development on energy consumption. Later researchers such as Chang [15], Islam et al. [16], Shahbaz et al. [17], and Mahalik et al. [18] have also hypothesized a similar relationship. However, the empirical evidences are not conclusive due to the multifaceted nature of the financial development effects. In the case of Sadorsky [12], it is argued that, through the factor productivity and factor accumulation channels, the growth-induced effects of financial development lead to higher energy consumption, all things being equal. However, others like Chang [15] and Shahbaz and Lean [14] argue in favor of a negative effect of financial development on energy consumption. According to these authors, financial development causes technical effects which lowers energy consumption. From both sides of the literature, it can be deduced that the overall effect of financial development on energy consumption is complex.

Even though the technical effect channel of financial development relates to energy efficiency improvement, empirical studies to test the direct link between an indicator of energy efficiency (i.e. energy intensity) and financial development are limited. Suppose financial development only results in output expansion and no technological change [12]. Then more energy would be required to sustain the output expansion. Since technical change in the production process is assumed away, the increase in energy consumption may outweigh the increase in total output, all things being equal. Consequently, the total energy use per unit of production will rise. On the other hand, the same output would be produced with less energy if it is assumed that financial development causes only technical changes, all things being equal. Energy intensity will fall in this case.

The above suggests that energy intensity would be lower if financial development increases investments in input efficiency. However, energy intensity will rise if the development of the financial sector leads to less or no investment in input efficiency. Moreover, the financial sector itself is highly energy-efficient in that it generates substantial value but uses little energy. This structural shift toward the services sector could result in a higher output but lower energy consumption. Depending on the share of the output contributed by the services sector, the energy intensity might decrease, increase, or remain constant. Thus, on the financial development-energy intensity nexus, the relationship seems complex and requires an empirical investigation.

Amuakwa-Mensah et al. [19] have conducted the only study that examines energy intensity and finance. Their study investigates the effect of performance indicators of commercial banks on energy intensity in sub-Saharan Africa. The study provided both short- and long-run analyses, using the system generalized method of moments (sys-GMM). The approach adopted to derive the long-run estimates is based on the partial adjustment method. Consequently, the authors are limited only to making

1) Poverty rates in Africa remain the highest, and this obstructs investments in energy-efficient technologies, which has a high initial cost and uncertain pay-back period.
2) Allen et al. [11] reveal huge development and financial gap in the sub-region.
3) The financial sector in Ghana has evolved from the period of implementation of the financial sector structural adjustment program in 1986. Though the growth of the sector has been positive, there is still much room for improvement when compared to other advanced and emerging economies.

strong statistical claims about the relationship only in the short-run and not in the long-run. Besides, their study uses the actual data in the analysis. Though the GMM approach offers the benefit of dealing with potential reverse causality problems, the use of actual data that involves short-term deviations implies that the derived long-run estimates may not be a good reflection of the true long-run parameters. Moreover, their study has provided a sub-regional perspective which hides the country-specific dynamics of the finance-energy intensity nexus.

This paper makes the following contributions to the literature. In contrast to Amuakwa-Mensah et al. [19], it provides a time-series approach which makes it possible to establish a strong statistical claim regarding the finance and energy intensity relationship in the long-run. In addition, this paper examines both potential and actual energy intensity. The latter includes the short-term deviations, which makes it vulnerable to endogeneity problems (especially reverse causality) and misrepresents the true long-run estimates. On the other hand, the former is devoid of the short-term cyclicality, and therefore, more robust in terms of capturing the true long-run effects and dealing with potential reverse causality problems. Moreover, by using the energy intensity indicator instead of total energy consumption [12–14,17,18,20–23], this paper provides important implications for the role of the financial sector in the areas of energy efficiency enhancement, low-carbon economy, and energy supply security.

2 Empirical literature

Several empirical investigations into the drivers of energy intensity have been conducted. Particularly, the important roles of market-driven tools, such as prices have been examined. Basically, the argument is that higher prices can induce investments in energy-efficient technologies and hence lower energy intensity. Cornillie and Fankhanser [24] and Fisher-Vanden et al. [25] are among some of the earlier researchers who have investigated the impact of the price of energy on energy intensity. Both of them have revealed that a higher energy price leads to a significant reduction in energy intensity. Lin and Moubarak [26] confirmed this for China, and Gamtessa [27], in a recent study, has also confirmed the energy efficiency-induced effects of the price of energy for Canada manufacturing firms. However, in a related study, Song and Zheng [28] have revealed a weak support for the claim that a higher energy price leads to a lower energy intensity in China. In the case of Africa, Adom [1,7,29] and Adom [5] have found evidence in support of the negative effect of the price of energy on energy intensity in Algeria, South Africa, Nigeria and Cameroon. In contrast, Adom and Amuakwa-Mensah [30] could not establish the important role of the price of energy in lowering energy intensity in East Africa.

The impact of other factors, such as trade openness and structural economic shifts have also been scrutinized [2,30–32]. Trade openness is found to exert scale, technical, and composition effect on energy intensity. This makes the overall effect of trade openness indeterminate a priori. Adom and Adams [2] have examined the drivers of energy intensity in Nigeria, taking into account regime changes. The result show that trade openness exerts a negative effect on energy intensity. Adom [1] has confirmed the negative effect of trade openness on energy intensity in Nigeria. Rafiq et al. [33] have investigated the drivers of energy intensity in 22 emerging economies consisting of Ghana, Angola, Namibia, Sudan, and Zambia. Their result also reveals that trade openness reduces energy intensity. In the case of Ghana, Adom and Kwakwa [34] have confirmed the negative effect of trade openness on energy intensity, with evidence of structural effect in the parameter.

Increasing the proportion of the output from the energy-intensive sector puts pressure on energy resources, and given the output, this raises the energy intensity level. Elliott et al. [31], using the provincial data from China, have revealed that a shift to the energy-intensive sector (i.e. increasing the output of the industrial sector) raises energy intensity. Ma and Yu [32] have found a similar result for China. Adom [1], in the case of Nigeria, has found that increasing the output of the industrial sector increases energy intensity. This is also confirmed by Adom and Adams [2].

Though studies have examined the effect of financial development on energy consumption [12–18,20,21], within the energy intensity literature, the study conducted by Amuakwa-Mensah et al. [19] are worthy of notice, in which the sys-GMM approach has been applied to investigate the effect of performance indicators of commercial banks on energy intensity. It is found that while an improvement in the performance of commercial banks has the tendency to improve energy efficiency (i.e. lower energy intensity), the nature of the political environment could offset this positive gain. As mentioned in the introduction, their approach to deriving the long-run relationship is based on the partial adjustment approach, which limits their statistical claim about the relationship only to the short-run. Moreover, the use of sub-regional data and actual data provides grounds for in-depth analysis of country dynamics and to capture the true long-run effect of financial development on energy intensity. The aim of this paper is to fill these important gaps in the literature.

3 Method and data

3.1 Empirical model

The empirical approach in this study follows the empirical specifications in Hübler and Keller [35], Adom [5], and

Shahbaz et al. [17] and Sadorsky et al. [36] but with a modification. Energy intensity (EI) in this study is expressed as a linear function of the prices of energy (i.e. the price of electricity (PE) and the price of oil (PO)), a vector of financial development indicators (**FD**), and a vector of other controls (***Z***). Equation (1) shows this mathematical relationship, α is the intercept, β_1, β_2, β_3, and β_4 are the long-run coefficients, referring to the time period, and ε is the stochastic term assumed to be white noise. The importance of price in this study is motivated by previous studies [1,2,5,7,24,25,27,29].

Second, the inclusion of financial development is motivated by studies that link the development of the financial sector to energy consumption [12,14–16,18,20,21], and by Amuakwa-Mensah et al. [19]. Financial development can either reduce or increase energy intensity. Since the changes in energy intensity emanate from different sources, the effects of technological spillovers from abroad and learning effects (i.e. trade openness(TOP)) and shifts in production structure (i.e. industry value-added as percent of GDP(IVA)) are also controlled. The use of both the prices of electricity and oil could create a multicollinearity problem. However, the initial checks, using the coefficient variance decomposition, show that this is not a problem in the model. For a basic model like Eq. (1), it would be important to include the effects of technological innovation on energy intensity [37]. However, for reasons due to data unavailability, appropriate measure of technological innovation, and econometric concerns, the effect of technological innovation is not considered in this paper. Technological innovation might be highly correlated with the development of the financial sector [38]. Therefore, including such a variable may create a serious multicollinearity and identification problem. Moreover, the inclusion of trade openness may also capture the flow of technological innovation from abroad to the home country.

$$\ln \mathrm{EI}_t = \alpha + \beta_1 \ln \mathrm{PE}_t + \beta_2 \ln \mathrm{PO}_t + \beta_3 \ln \mathbf{FD}_t + \beta_4 \ln \boldsymbol{Z}_t + \varepsilon_t. \tag{1}$$

3.2 Econometric strategy

The objective of this paper is to establish the long-run effect of financial development on energy intensity. The financial sector provides the funds to fund capital equipment including energy-efficient technologies. In the short term, the benefits of energy efficiency which is to reduce energy intensity may not materialize since enough time may be required ① to adopt and adapt the technology, ② for the equipment to reach its optimal operational level, and ③ to learn. The adjustment cost may be high in the short term but not in the long term due to the possibilities of information and knowledge transfer in the long term. Moreover, the standard methods, like the autoregressive distributed lag (ARDL) method, assume weak exogeneity, which is a very strong assumption. Thus, in the presence of endogeneity (i.e., the regressors in the model are not independent of the error terms) and serial correlation problems (i.e., the error terms are correlated), estimates based on the ARDL may produce biased results. For these reasons, this paper applies robust estimators that deal with endogeneity and serial correlation problems to obtain the long-run effects of financial development on energy intensity.

Equation (1) can be estimated using the ordinary least square (OLS) estimator. However, the following reasons make it impossible to do so. The first has to do with the nonstationarity of the variables (i.e., the series carries a memory of its past and is thus persistent), which could result in spurious (or nonsensical) regression if OLS is applied. Though this can be solved by differencing the series and applying OLS, it is at the cost of losing some long-run information. Therefore, in the present case, a cointegrating technique becomes the most appropriate (i.e., Cointegration exists if the series involved are trended in the long term. In other words, any shock that distorts this long-run equilibrium is only temporary and not permanent). Second, it is likely to have identification issues[1)] (i.e., second-order bias problems which result from the correlation of the nonstationary regressors and the regression residuals and the correlation among the nonstationary regressors) and serial correlation problem (i.e. noncentrality bias which results from the contemporaneous correlation of the error terms at different times) in Eq. (1). In the presence of these econometric problems, the application of the OLS will yield consistent but inefficient estimates. Phillips and Hansen [39], Park [40], and Stock and Watson [41] have provided solutions in the presence of noncentrality bias and second-order bias problems. Though these approaches provide different correction mechanisms, asymptotically their estimates seem qualitatively identical.

The fully modified OLS (FMOLS) uses the correction of both the data and the estimates to remove any existing nuisance in the parameters. However, the canonical cointegrating regression (CCR) uses only the transformation of the data and then chooses among the class of cointegrating regressions a canonical regression that is representative of the cointegrating relationship. The FMOLS and CCR estimates are derived using Eqs. (2) and (3).

$$\hat{\beta}_{\mathrm{FMOLS}} = \left(\sum_{t=1}^{T} \boldsymbol{x}_t \boldsymbol{x}_t' \right)^{-1} \left(\sum_{t=1}^{T} \boldsymbol{x}_t \mathrm{EI}_t^{+} - T \hat{j}^{+} \right), \tag{2}$$

1) This happens if the effects of the independent variable cannot be uniquely determined in the model. This could be due to reasons such as reverse causality (when the dependent variable also influences one or some of the independent variables), measurement errors, and the correlation between the independent variables and the error terms.

where $\hat{\beta}_{\mathrm{FMOLS}}$ is the FMOLS estimate, $\boldsymbol{x}$ is the vector of explanatory variables indexed from t to T, which is the time period, EI is the dependent variable, $\mathrm{EI}_t^+ = \mathrm{EI}_t - \hat{\lambda}_{ox}\hat{\lambda}_{xx}^{-1}\Delta x_i$ is the correction term for endogeneity, $\hat{j}^+ = \hat{\lambda}_{ox} - \hat{\lambda}_{ox}\hat{\lambda}_{xx}^{-1}\Delta_{xx}$ is the correction term for serial correlation, $\hat{\lambda}_{ox}$ and $\hat{\lambda}_{xx}$ are the kernel estimates of the long-run covariances, and $\hat{\Delta}_{ox}$ and $\hat{\Delta}_{xx}$ are the kernel estimates of the one-sided long-run covariances.

$$\hat{\beta}_{\mathrm{CCR}} = \left(\sum_{t=1}^{T}\boldsymbol{x}_t\boldsymbol{x}_t'\right)^{-1}\left(\sum_{t=1}^{T}\boldsymbol{x}_t\mathrm{EI}_t^*\right), \tag{3}$$

where $\hat{\beta}_{\mathrm{CCR}}$ is the CCR estimate, $\boldsymbol{x}_t^* = \boldsymbol{x}_t - \left(\hat{\Sigma}^{-1} - \hat{\Lambda}_2\right)\hat{v}_t$, $\mathrm{EI}_t^* = \mathrm{EI}_t - \left(\hat{\Sigma}^{-1}\hat{\Lambda}_2\hat{\phi} + \left[\hat{\eta}_{22}^{-1}\hat{\varpi}_{21}\right]\right)\hat{v}_t$, $\hat{\Sigma}$ is the contemporaneous covariance matrix of the residuals, $\hat{\phi}$ is the estimated cointegration equation parameters; $\hat{\Lambda}_2$ is the second column of $\hat{\Lambda}$, which is the long-run covariance; $\hat{\varpi}$ is the weighting matrix, and $\hat{v}$ is the estimated residuals from the cointegrating equation.

The dynamic OLS (DOLS) rather introduces the lead and lags of the first difference regressors into the cointegrating equation. This is to ensure that the error terms are independent of all past innovations. The DOLS version of Eq. (1) is illustrated in Eq. (4), where k is the time lag from 1 to K and the betas denote the parameter estimates. Thus, for all three estimators, the objective is to transform Eq. (1), so that it mimics a strict exogenous regressor case (i.e. the independent variables become strictly independent of the error terms).

$$\begin{aligned}\ln \mathrm{EI}_t &= \alpha + \beta_1 \ln \mathrm{PE}_t + \beta_2 \ln \mathrm{PO}_t + \beta_3 \ln \mathbf{FD}_t + \beta_4 \ln \mathbf{Z}_t \\ &+ \sum_{t=-k}^{K}\beta_{11}\Delta\ln \mathrm{PE}_{t-k} + \sum_{t=-k}^{K}\beta_{21}\Delta\ln \mathrm{PO}_{t-k} \\ &+ \sum_{t=-k}^{K}\beta_{31}\Delta\ln \mathbf{FD}_{t-k} + \sum_{t=-k}^{K}\beta_{41}\Delta\ln \mathbf{Z}_{t-k} + \varepsilon_t.\end{aligned} \tag{4}$$

3.3 Empirical strategy

The empirical approach is as follows: First, a simple model was estimated, where only the effects of the prices of energy were considered. The different indicators of financial development were subsequently introduced into the model systematically. Next, the model was expanded to include other factors, such as trade openness and industry structure. The former captured the technological spillover from abroad while the latter captured structural production shifts. Finally, the so-called potential energy intensity variable (both for aggregate energy and electrical energy) was derived which was devoid of any short-term cyclicality, using the Hodrick-Prescott filter. The actual or raw energy intensity had the short-term and long-term parts. As a result, running long-run models on the raw data, first, may create the problem of not representing the true long-run effects, and second, cause a reverse causality problem. The Hodrick-Prescott is a mathematical tool that is used to filter the cyclical component of the raw data so that a smoothed-curve representation of the original time series would be obtained, which is more responsive to the long-term than to the short-term. Thus, by using the non-cyclical component (referred to as potential energy intensity), this paper provides the advantages of possibly capturing the true long-run effects and helping to solve any possible problems of reserve causality from energy intensity improvements to any of the right-hand side variables [42]. For the general model, two indicators of energy intensity—aggregate energy intensity and electrical energy intensity were used.

3.4 Data

The annual time series data from 1970 to 2016 were used. Energy intensity was defined as total primary energy use/GDP. The price of electricity was measured as the average end-user tariff in Ghana cedis per kilowatt hours. This imposes the unusual assumption that economic decisions are made at averages and not at the margin. However, due to the nonexistence of data for marginal electricity price, the assumption imposed here become necessary. Adom [6], based on a similar argument, has also used the average end-user tariff as a measure of electricity price. This also conforms to the general practice in the energy literature.

The price of oil was measured as the real price of world oil, which was deflated using the implicit GDP deflator from the US [6]. By using the world price, the local government effects, such as taxes and subsidies, were ignored. Domestic prices are the most preferred price variable to use, but there are no data for the period considered. Nonetheless, the use of world price can be advantageous in that the absence of subsidies/taxes facilitates the capture of the true consumer behavior. Further, it is important to note that Ghana's implicit GDP deflator could not be used due to the insignificant nature of Ghana's oil demand to worldwide oil price developments. Figuratively, it would be like diving the 'elephant by the ant' [6]. Finally, four indicators of financial development which were popularly used in the literature were used. First, domestic credit to the private sector as a percent of gross domestic product (**FD**(PS)) was used as the primary measure of financial development [12,14]. As secondary measures, domestic credit to the private sector provided by the banks (**FD**(PSBK)) as a percent of gross domestic product, broad money supply (M2) as a percent of gross domestic product (**FD(**M2)), and broad money supply

(M2) as a percent of required reserve ratio (**FD**(M2_*R*)) were also used. Next, a composite measure (**FD**(INDEX)) was constructed from these indicators of financial development, using the principal component analysis. The indicators of stock market development were not included since the Ghana Stock Exchange started operation in the 1990s. Since the data period in this paper is from 1970 to 2016, it is not possible to include the indicators of stock market development. While this may be considered as a limitation of the study, the stock market in Ghana remains acute, and the development of the financial sector is mainly driven by the banking sector.

The data on the financial development indicators, trade openness (measured as total trade as a percent of GDP), industry valued-added as a percent of GDP, and energy intensity indicators were taken from the World Bank development indicator database (WDI); the data on world oil price were taken from the BP statistical review of world energy; and the data on electricity price come from the Volta River Authority (VRA), Energy Commission, Ghana, and the Electricity Company of Ghana (ECG).

3.5 Preliminary test of data

First, the unit root properties of the variables were examined since it was an important requirement for cointegrating analysis. The ADF-GLS Elliot-Rothenberg-Stock and Phillip-Perron unit root tests were used. Table 1, which contains the results, concludes that, in all, the variables are integrated of order one. Thus, there is a basis for a cointegrating analysis. Since in the presence of trend structural break, these traditional unit root approaches seem biased toward a false null, the unit root with a structural break was also tested, using the approach by Perron [43]. Table 2 shows that, except for the price of electricity where the null in levels is rejected, the null hypothesis of unit root with structural break is rejected for the rest of the variables after first-differencing. Thus, within the cointegration framework (which requires stationarity of series at first difference), a structural break problem is not envisaged. Next, the Bounds cointegrating test is applied to test the level relationship, as shown in Table 2. There is evidence of a level relationship. In all cases, the calculated *F*-statistics exceed the upper critical *F*-value at all statistical significance levels. Thus, the prices of energy, financial development, trade openness, and industry valued-added can be treated as the 'long-run forcing' variables explaining energy intensity in the country.

4 Discussion of results

4.1 Long-run estimates (baseline result)

Table 3 lists the long-run impact of price and financial

Table 1 Unit root test

Variables	ADF_GLS		Phillip-Perron		Perron unit root test with structural break		
	Constant	Constant & trend	Constant	Constant & trend	Constant	Trend	Constant & trend
lnEI	− 1.334	− 1.130	1.922	− 2.565	− 5.079^c(1999)	− 2.878(1994)	− 4.085(1999)
ΔlnEI	− 1.777^c	− 6.836^a	− 6.003^a	− 6.882^a	− 7.947^a(2000)	− 7.919^a(2003)	− 7.979^a(2003)
lnPE	0.754	− 2.846	0.585	− 4.078^b	− 8.966^a(1983)	− 4.518^c(1994)	− 9.109^a(1983)
ΔlnPE	− 8.179^a	− 4.271^a	− 12.338^a	——	——	——	——
lnPO	− 1.574	− 1.820	− 1.707	− 2.103	− 3.313(2003)	− 2.726(1996)	− 2.853(2004)
ΔlnPO	− 6.385^a	− 6.582^a	− 6.447^a	− 6.465^a	− 7.343^a(1998)	− 7.180^a(1983)	− 7.392^a(1998)
ln**FD**(PS)	− 0.770	− 1.567	− 0.720	− 2.212	− 3.524(1977)	− 3.632(1981)	− 4.290(1983)
Δln**FD**(PS)	− 4.286^a	− 5.173^a	− 6.148^a	− 6.500^a	− 8.025^a(1983)	− 7.525^a(1989)	− 7.908^a(1991)
ln**FD**(PSBK)	− 0.815	− 1.579	− 0.768	− 2.212	− 3.458(1977)	− 3.534(1981)	− 4.198(1983)
Δln**FD**(PSBK)	− 4.294^a	− 5.186^a	− 6.168^a	− 6.501^a	− 8.035^a(1983)	− 7.537^a(1989)	− 7.918^a(1991)
ln**FD**(M2)	− 1.083	− 1.744	− 1.322	− 1.884	− 3.082(1980)	− 3.544(1980)	− 3.969(1991)
Δln**FD**(M2)	− 6.826^a	− 6.863^a	− 6.760^a	− 6.714^a	− 7.761^a(1983)	− 7.317^a(1979)	− 8.534^a(1985)
ln**FD**(M2_*R*)	− 1.678	− 2.569	− 3.278^b	− 3.059	− 3.144(1981)	− 2.826(1981)	− 3.227(1981)
Δln**FD**(M2_*R*)	− 6.879^a	− 7.047^a	——	− 8.047^a	− 5.678^b(2000)	− 5.157^b(1990)	− 5.636^b(1986)
lnTOP	− 1.574	− 2.94	− 1.137	− 2.251	− 3.031(1985)	− 2.998(2003)	− 4.683(1983)
ΔlnTOP	− 4.068^a	− 4.973^a	− 4.492^a	− 4.343^a	− 6.874^a(1982)	− 4.965^a(1986)	− 7.040^a(1982)
lnIVA	0.463	− 0.156	− 0.160	− 0.873	− 3.863(1992)	− 3.474(1979)	− 4.643(1983)
ΔlnIVA	− 3.644^a	− 4.187^a	− 5.357^a	− 5.537^a	− 5.833^a(1982)	− 4.805^a(1987)	− 5.889^a(1982)

Note: *a*, *b*, and *c* denote a significance of 1%, 5%, and 10%, respectively.

Table 2 Bounds cointegrating test

Model	F-stats	1% significance		5% significance		10% significance	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
		4.13	5.00	3.10	3.87	2.63	3.35
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO})}$	9.080						
		3.65	4.66	2.79	3.67	2.37	3.20
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PS}))}$	7.792						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PSBK}))}$	7.774						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}))}$	7.230						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}\_R))}$	7.090						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\ \mathbf{FD}(\mathrm{INDEX}))}$	6.750						
		3.06	4.15	2.39	3.38	2.08	3.00
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PS}),\ \mathrm{TOP,\ IVA})}$	5.329						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PSBK}),\ \mathrm{TOP,\ IVA})}$	5.310						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}),\ \mathrm{TOP,\ IVA})}$	5.590						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}\_R),\ \mathrm{TOP,\ VIA})}$	4.568						
$F_{(\mathrm{EI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{INDEX}),\ \mathrm{TOP,\ IVA})}$	5.687						
$F_{(\mathrm{ELI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PS}),\ \mathrm{TOP,\ IVA})}$	8.216						
$F_{(\mathrm{ELI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{PSBK}),\ \mathrm{TOP,\ IVA})}$	8.227						
$F_{(\mathrm{ELI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}),\ \mathrm{TOP,\ IVA})}$	7.873						
$F_{(\mathrm{ELI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{M2}\_R),\ \mathrm{TOP,\ VIA})}$	7.913						
$F_{(\mathrm{ELI}\mid\mathrm{PE,\ PO},\mathbf{FD}(\mathrm{INDEX}),\ \mathrm{TOP,\ IVA})}$	7.431						

development on energy intensity. In model 1, the effects of financial development are excluded. The model is adjusted to include the financial development indicators in models 2 to 5. In model 2, the primary indicator of financial development is used, while the secondary measures are used in models 3 to 5. In model 1, the FMOLS and CCR indicate that the price of electricity and the real price of oil have a negative effect on energy intensity, but only the effect of the former is significant. However, when the different indicators of financial development are included in the model, the effects of both prices are negative and become statistically significant. The results suggest an elasticity range of 0.18–0.305 (in absolute terms) for electricity and 0.15 to 0.203 (in absolute terms) for oil. Thus, in the lower case, the energy intensity is expected to fall by 1.8% and 1.5% for every 10% increase in electricity price and oil price, respectively. In the upper case, the energy intensity is expected to fall by 3.05% and 2.03% for every 10% increase in electricity price and oil price, respectively.

There are two transmission mechanisms. First, a higher price of energy (oil and electricity) forces consumers of energy to embark on deliberate energy reduction behavior (i.e. energy conservation). Second, a higher price of energy (electricity and oil) causes investments in energy-efficient technologies which improve the overall energy usage. Consequently, energy efficiency is enhanced. The negative price elasticities suggest that, in the case of Ghana, the government can use tax tools to achieve reductions in energy intensity. For example, by imposing an energy efficiency tax of GH ₵ 0.5/kWh of electricity consumed, the energy intensity will be reduced by 14% and by 23%[1)] in the lower case and upper case, respectively. Besides, for an energy efficiency tax of US$5 per barrel of oil imposed, the energy intensity will fall by 2% and by 2.6% in the lower case and upper case, respectively. Thus, in both cases, the tax will lead to reasonable savings in energy (16% savings in the lower case and 25.6% savings in the upper case) in the country. The negative effect of energy price on energy intensity confirms the findings of Adom and Adams [2] for Nigeria, Adom [1] for Nigeria, Adom [7] for Algeria, Adom [29] for South Africa, Lin and Moubarak [26] for China, and Adom [5] for Cameroon.

For all different indicators of financial development, the results suggest that financial development significantly reduces energy intensity in the country, as indicated by the FMOLS and CCR. The estimates suggest lower and upper elasticity values of 0.385 and 0.54 (in absolute terms), respectively. In other words, a 10% increase in finacial development will cause energy intensity to fall by 3.85% in

1) $P_{\mathrm{ed}}\times\left(\frac{\Delta\mathrm{EP}}{\mathrm{WAEP}}\right)\times 100$, WAEP is the weighted average energy price, P_{ed} is the elasticity of energy price, and ΔEP is the change in energy price.

Table 3 Long-run estimates

Dependent variable: energy intensity

	FMOLS						Canonical cointegration						Stock-Watson DOLS					
	M1	M2	M3	M4	M5	M6	M1	M2	M3	M4	M5	M6	M1	M2	M3	M4	M5	M6
lnPE	0.294^{a}	0.184^{a}	0.185^{a}	0.236^{a}	0.305^{a}	0.206^{a}	0.293^{a}	0.185^{a}	0.186^{a}	0.233^{a}	0.303^{a}	0.206^{a}	0.300^{a}	0.206^{a}	0.207^{a}	0.276^{a}	0.295^{a}	0.225^{a}
	(0.0327)	(0.0210)	(0.0209)	(0.0299)	(0.0312)	(0.0267)	(0.0323)	(0.0188)	(0.0188)	(0.0280)	(0.0307)	(0.0238)	(0.0209)	(0.0305)	(0.0299)	(0.0349)	(0.0216)	(0.0221)
lnPO	0.099	0.196^{a}	0.200^{a}	0.156^{c}	0.098	0.183^{b}	0.098	0.199^{a}	0.203^{a}	0.151^{c}	0.117	0.185^{b}	0.166^{c}	0.153^{c}	0.158^{b}	0.212^{c}	0.067	0.110
	(0.1204)	(0.0592)	(0.0599)	(0.0869)	(0.1104)	(0.0799)	(0.1149)	(0.0590)	(0.0594)	(0.0851)	(0.1099)	(0.0779)	(0.0844)	(0.0768)	(0.0769)	(0.1089)	(0.0768)	(0.0676)
ln**FD**(PS)		0.388^{a}						0.385^{a}						0.342^{a}				
		(0.0644)						(0.0599)						(0.0938)				
ln**FD**(PSBK)			0.394^{a}						0.390^{a}						0.347^{a}			
			(0.0655)						(0.0609)						(0.0943)			
ln**FD**(M2)				0.521^{b}						0.535^{b}						0.166		
				(0.1993)						(0.2033)						(0.2651)		
ln**FD**(M2_*R*)					0.310^{b}						0.256^{b}						0.204^{c}	
					(0.1387)						(0.1010)						(0.1198)	
FD(INDEX)						0.140^{a}						0.140^{a}						0.109^{a}
						(0.0340)						(0.0317)						(0.0294)
Con	18.52^{a}	16.878^{a}	16.861^{a}	16.406^{c}	18.284^{a}	17.787^{a}	18.522^{a}	16.873^{a}	16.858^{a}	16.376^{a}	18.241^{a}	17.780^{a}	18.276^{a}	17.302^{a}	17.279^{a}	17.448^{a}	18.513^{a}	18.222^{c}
	(0.4967)	(0.3432)	(0.3469)	(0.7599)	(0.4660)	(0.3462)	(0.4703)	(0.3558)	(0.3591)	(0.7692)		(0.0354)	(0.3304)	(0.5036)	(0.5032)	(0.8844)	(0.3306)	(0.3028)
Adj *R*-square	0.872	0.957	0.956	0.899	0.875	0.933	0.873	0.957	0.956	0.899	0.882	0.933	0.965	0.977	0.977	0.946	0.926	0.956
SER	0.216	0.125	0.127	0.192	0.214	0.156	0.216	0.125	0.127	0.192	0.207	0.156	0.104	0.092	0.092	0.137	0.165	0.126
SSR	2.013	0.660	0.675	1.551	1.923	1.025	2.002	0.658	0.673	1.548	1.807	1.026	0.250	0.261	0.262	0.580	0.955	0.574
LRV	0.211	0.048	0.049	0.110	0.177	0.091	0.211	0.048	0.049	0.110	0.177	0.091	0.042	0.037	0.036	0.075	0.072	0.043

Note: *a*, *b*, and *c* denote 1%, 5%, and 10% significance. The figures in () denotes standard errors. Long-run covariance estimate (Bartlett Kernel, Newey-West fixed Bandwidth, optimal prewhitening lag selected based on the Akaike Information Criterion (AIC)). For the DOLS, the optimal lead-lag was selected based on AIC.

the lower case and by 5.4% in the upper case. The development of the financial sector removes the problem of credit constraints, all else equal. Consequently, the investments in technologies (including energy-efficient technologies) are enhanced. Thus, the investments in technologies fuelled by the financial sector improve the economic-wide appliance and equipment efficiency in the country. The dividend is that energy is used efficiently without production losses.

There are two other important things that are worth stating here. First, energy intensity is the ratio of energy usage to output. As stated earlier in this paper, the development of the financial sector will lead to both scale and technical effects. Second, the negative effect of financial development on energy intensity suggests that, in the case of Ghana, the technical effects dominate the scale effects leading to an overall improvement in cost efficiency (in terms of energy) and economies of scale. Thus, the development of the financial sector will cause economies of scale and lead to a significant reduction in energy intensity. The findings of the current paper directly support the findings of Amuakwa-Mensah et al. [19] and indirectly support the indirect claims by studies that argue that financial development causes more technical effect [14,18,20,23] but contradict the findings of studies that claim that financial development will cause more scale effects [12,13,15,21]. The energy efficiency-induced effects of financial development suggest that, in principle, government policies targeted at developing the financial sector can complement government energy efficiency policies to bring significant reduction in energy intensity.

Next, some robustness checks were performed on the baseline results. First, in Table 3, a composite index was derived for financial development (called **FD**(INDEX)) from the four different indicators, using the principal components analysis. Of the four principal components derived, it is only the first component that is positively associated with the different indicators of financial development, an indication that this component relates generally to the economy. The rest are not consistent in their signs which rule them out as an appropriate candidate for an economic-wide measure of financial development. The results of this estimation are shown in model 6 in Table 3. Consistent, in Table 3, is the result that financial development has a significant negative effect on energy intensity, according to the two estimators. The estimates suggest a long-run elasticity of 0.140 (in absolute terms), which implies that, for every 10% increase in financial development, energy intensity will decrease by 1.4%. The negative effect of financial development on energy intensity is consistent with the earlier findings in this paper. Second, the results in model 6 in Table 3 further show a consistently negative effect of electricity price on energy intensity. The long-run price elasticity is 0.206 (in absolute terms). Thus, for a tax policy of GH ₵ 0.5/kWh of electricity consumed, the country is expected to save 15.8% of energy. In addition, consistent in Table 3 is the result that the price of oil has a significant negative effect on energy intensity. The long-run price elasticity ranges between 0.183 and 0.185 (in absolute terms). Thus, for a tax of GH ₵ 5 per barrel of oil, the energy intensity will decline by 2.3%.

Next, the DOLS estimator was applied since Monte Carlo studies showed that it performed better in a finite sample than CCR and FMOLS [6]. The result is shown in the last part of Table 3. Model 1 shows that a higher price of electricity and oil price significantly reduces energy intensity levels in the country. The estimates suggest a 3% and 1.7% fall in energy intensity for a 10% rise in electricity price and oil price. When different indicators of financial development were adjusted from models 2 to 6, the effects of the price of electricity and oil remained significantly negative. The values suggest an elasticity range of 0.206 to 0.295 (in absolute terms) for electricity and 0.110 to 0.212 (in absolute terms) for oil. These values compare favorably well with the estimates obtained based on the FMOLS and CCR. The elasticity values suggest a 16%–23% and 1.4%–2.7% fall in energy intensity for a tax increase of GH ₵ 0.5/kWh of electricity consumed and US $5 per barrel of oil consumed, respectively.

The effects of different indicators of financial development on energy intensity are also negative. The values suggest an elasticity range of 0.109 to 0.347 (in absolute terms). The estimates also compare favorably well with that obtained based on the FMOLS and CCR. Based on the elasticities, the energy intensity will decline by 1.09% in the lower case and by 3.5% in the higher case if financial development increases by 10%. This confirms the earlier result that the development of the financial sector significantly lowers energy intensity.

4.2 Long-run estimates (extended model)

The models estimated so far seem very simplistic since they omit some other important factors. This possible omission, if not accounted for, could amount to omitted variable bias, which can affect the results obtained. To deal with this, the effects of industry structure and trade openness were controlled in this paper. The former indicates a structural production shift, and the latter, technology spillover and learning effects. As shown in Table 4, financial development (measured by the individual indicators and the composite indicator) has a consistently negative effect on energy intensity. For the composite measure, the elasticity suggests a decline in energy intensity of between 0.98 and 1.30% following a rise in financial development by 10%, which confirms the previous findings that financial development lowers energy intensity.

Besides, for the prices of energy (i.e. electricity and oil), the evidence of a negative effect is stronger. The long-run elasticities for electricity price range from 0.206 to 0.295

Table 4 Long-run estimates (with controls)

Dependent variable: energy intensity

	FMOLS					Canonical Cointegration					Stock-Watson DOLS				
	M1	M2	M3	M4	M5	M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
lnPE	−0.171^{a}	−0.173^{a}	−0.175^{a}	−0.206^{a}	−0.174^{a}	−0.176^{a}	−0.179^{a}	−0.172^{a}	−0.201^{a}	−0.175^{a}	−0.153^{a}	−0.185^{a}	−0.169^{a}	−0.186^{a}	−0.175^{a}
	(0.0193)	(0.0192)	(0.0336)	(0.0320)	(0.0252)	(0.0189)	(0.0190)	(0.0351)	(0.0360)	(0.0257)	(0.0271)	(0.0219)	(0.0395)	(0.0381)	(0.0286)
lnPO	−0.189^{a}	−0.192^{a}	−0.401^{a}	−0.409^{a}	−0.232^{a}	−0.180^{a}	−0.181^{a}	−0.423^{a}	−0.415^{a}	−0.253^{a}	−0.233^{c}	−0.172^{c}	−0.362^{a}	−0.383^{a}	−0.247^{b}
	(0.0573)	(0.0573)	(0.1039)	(0.0916)	(0.0794)	(0.0650)	(0.0649)	(0.1157)	(0.0944)	(0.0877)	(0.1326)	(0.0854)	(0.1158)	(0.0927)	(0.1101)
ln**FD**(PS)	−0.413^{a}					−0.391^{a}					−0.338^{c}				
	(0.0752)					(0.0754)					(0.1817)				
ln**FD**(PSBK)		−0.417^{a}					−0.395^{a}					−0.381^{a}			
		(0.0760)					(0.0763)					(0.1087)			
ln**FD**(M2)			−0.191					−0.118					−0.145		
			(0.2399)					(0.2839)					(0.2666)		
ln**FD**(M2_*R*)				−0.074					−0.045					−0.052	
				(0.0992)					(0.0922)					(0.1060)	
FD(INDEX)					−0.130^{a}					−0.109^{a}					−0.098^{c}
					(0.0382)					(0.0364)					(0.2729)
lnTOP	−0.159	−0.149	−0.569^{b}	−0.497^{a}	−0.394^{b}	−0.133	−0.118	−0.615^{b}	−0.519^{c}	−0.429^{c}	−0.562	−0.157	−0.717^{b}	−0.684^{b}	−0.496^{c}
	(0.1408)	(0.1417)	(0.2297)	(0.2240)	(0.1831)	(0.1834)	(0.1854)	(0.2711)	(0.2818)	(0.2364)	(0.3678)	(0.2433)	(0.2814)	(0.2555)	(0.2838)
lnIVA	0.301	0.285	0.203	0.064	0.431	0.242	0.219	0.223	0.084	0.399	0.727^{b}	0.291	0.450	0.339	0.490^{a}
	(0.1998)	(0.2000)	(0.3729)	(0.3246)	(0.2772)	(0.2244)	(0.2254)	(0.4270)	(0.3811)	(0.2991)	(0.2575)	(0.2204)	(0.3906)	(0.3101)	(0.2838)
Con	−17.070^{a}	−17.061^{a}	−14.515^{a}	−15.002^{a}	−17.192^{a}	−17.094^{a}	−17.092^{a}	−14.516^{a}	−14.952^{a}	−16.876^{a}	− 16.724^{a}	−17.284^{a}	−15.012^{a}	−15.181^{a}	−16.951^{a}
	(0.5051)	(0.5064)	(0.7857)	(0.7999)	(0.8064)	(0.6206)	(0.6216)	(0.7651)	(0.7554)	(0.8222)	(1.3600)	(0.8577)	(0.9422)	(0.9554)	(1.3278)
Adj *R*-square	0.955	0.954	0.905	0.908	0.931	0.957	0.956	0.903	0.909	0.934	0.984	0.981	0.956	0.960	0.960
SER	0.129	0.130	0.186	0.183	0.159	0.126	0.127	0.188	0.182	0.156	0.075	0.085	0.127	0.121	0.105
SSR	0.664	0.677	1.384	1.344	1.011	0.634	0.645	1.414	1.330	0.971	0.095	0.208	0.469	0.425	0.322
LRV	0.027	0.027	0.077	0.073	0.048	0.027	0.027	0.077	0.073	0.046	0.009	0.014	0.032	0.028	0.023

Note: *a*, *b*, and *c* denote 1%, 5%, 10% significance. The figures in ( ) denote standard errors. Long-run covariance estimate (Bartlett Kernel, Newey-West fixed Bandwidth, optimal prewhitening lag selected based on AIC). For the DOLS, the optimal lead-lag was selected based on AIC.

(in absolute terms), which suggest that, for a tax policy of GH ₵ 0.5/kWh on electricity consumed, the energy intensity will fall by 15.8% (in the lower case) and 22.7% (in the upper case). The long-run elasticities for oil price range from 0.172 to 0.415 (in absolute terms). Thus, for a tax policy of GH ₵ 5 per barrel of oil consumed, the energy intensity will fall by 2.2% (in the lower case) and 5.2% (in the upper case). For the controls, trade openness has a consistently negative effect on energy intensity, which supports the claim that technological spillovers from abroad help improve energy efficiency and hence lower energy intensity. On the other hand, increased industrialization has a consistently positive effect on energy intensity, which also supports the claim that shifts in production structure toward the more energy-intensive sectors increase energy intensity. In all, it can be concluded that the results are robust.

Next, as a further robustness check, the aggregate energy intensity indicator was replaced with electrical energy intensity. This result is shown in Table 5. Consistently, the price of electricity has a negative effect on electrical energy intensity. The long-run elasticity ranges from 0.057 to 0.195, which suggests that, with a similar tax proposed above, the electrical energy intensity will fall by 4.38% (in the lower case) and 14.8% (in the upper case). The average electricity use in the country, for the period between 1970 and 2016, stands at 3.2×10^8 kWh per annum. By implication, the tax policy will save the country an average electrical energy of between 1.4016×10^7 kWh and 47188940 kWh annually. This represents savings on an additional capacity with a power capacity of between 14 and 47 GW, which can provide electricity to more new homes. Using the International Energy Agency (IEA) composite electricity/heat factor of 0.2143357 kg CO_2/kWh for Ghana [44], the tax represents an equivalent CO_2 emission reductions from electricity sources of 3004119.366 kg CO_2 (in the lower case) and 10114241.4556 kg CO_2 (in the upper case).

In addition, in Table 5, the effect of the price of oil is consistently negative, with the long-run elasticities ranging from 0.110 to 0.485 (in absolute terms). This suggests that the electrical energy intensity will fall by 1.38% (in the lower case) and 6.6% (in the upper case) for a similar tax policy assumed above. Next, there is a claim of a negative effect of financial development on energy intensity, but the evidence is not statistically stronger in this case as compared to the previous one. Moreover, trade openness has a negative effect while industry structure has a positive effect on electrical energy intensity.

4.3 Long-run estimates (potential energy intensity)

So far, the actual energy intensity indicator which is not devoid of the short-term cyclicality has been examined. This could pose two potential problems. The first one is a reverse causality from energy intensity improvements to energy price, due to a possible rebound effect. The second one is that the estimates are not likely to depict the true long-run effects. To deal with this, the potential/trend energy intensity is used as the dependent variable which is derived using the Hodrick-Prescott filter. The potential energy intensity variable is devoid of any short-term cyclicality and hence useful in dealing with potential reverse causality problems and capturing the true long-run effects. The results for this further robustness check are shown in Electronic Supplementary Material. When comparing Table 4 and Table S1 (in Electronic Supplementary Material), it is obviously seen that the standard errors of the estimated coefficients in Table S1 are lower in all cases, suggesting that there is a gain in terms of model efficiency by using the potential energy intensity variable. The lower standard errors of the coefficients are, therefore, suggestive of the fact that the estimates in Table S1 are much closer to the true population parameter than those obtained using the actual energy intensity variable. A similar observation can be made when comparing the results in Table 5 and Table S2 (in Electronic Supplementary Material). The standard errors of the coefficients in Table S2 are smaller, suggesting model efficiency improvements.

Consistent, in Table S1, is the result that financial development has a negative effect on energy intensity, which confirms the earlier claim. Similarly, the prices of energy (electricity and oil) exert negative effects on energy intensity. The long-run price elasticities for electricity and oil are between 0.100 and 0.212 (in absolute terms) and between 0.062 and 0.451 (in absolute terms), respectively. For a tax of GH ₵ 0.5/kWh of electricity consumed, the energy intensity will fall by 7.7% (in the lower case) and 16.3% (in the upper case). Similarly, for a tax of GH ₵ 5 per barrel of oil, the energy intensity will fall by 0.78% (in the lower case) and 5.7% (in the upper case). Further results in Table S1 show that while trade openness exerts negative effects, the effect of industry structure is positive. Thus, while technological spillovers from abroad lower energy intensity, the shifts in economic structure toward the more energy-intensive sector increase it.

In Table S2, there is a claim of a negative effect of financial development on electrical energy intensity, but the evidence is not very strong. Moreover, consistent, in Table S2, is the result that the prices of energy (electricity and oil) have a consistently negative effect on electrical energy intensity. The long-run elasticities for the price of electricity and the price of oil are estimated at 0.161–0.212 and 0.113–0.369, respectively. This means that, for a government tax policy of GH ₵ 0.5/kWh of electricity consumed, the electrical energy intensity will fall by 12.4% (in the lower case) and 16.3% (in the upper case). This will translate to an average annual electrical energy savings of 3.968×10^7 kWh (in the lower case) and 5.216×10^7 (in the

Table 5 Long-run estimates

Dependent variable: electrical energy intensity

	FMOLS					Canonical cointegration					Stock-Watson DOLS				
	M1	M2	M3	M4	M5	M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
lnPE	–0.160^{a}	–0.163^{a}	–0.192^{a}	–0.150^{a}	–0.194^{a}	–0.165^{a}	–0.168^{a}	–0.195^{a}	–0.149^{a}	–0.166^{a}	–0.152^{a}	–0.155^{a}	–0.057	–0.087^{b}	–0.116^{b}
	(0.0300)	(0.0297)	(0.0419)	(0.0365)	(0.0317)	(0.0302)	(0.0302)	(0.0443)	(0.0409)	(0.0377)	(0.0466)	(0.0469)	(0.0461)	(0.0389)	(0.0440)
lnPO	–0.122	–0.124	–0.441^{a}	–0.358^{a}	–0.191^{c}	–0.110	–0.111	–0.466^{a}	–0.366^{a}	–0.294^{b}	–0.332	–0.317	–0.425^{a}	–0.555^{a}	–0.485^{a}
	(0.0890)	(0.0886)	(0.1296)	(0.1043)	(0.997)	(0.1022)	(0.1017)	(0.1461)	(0.1096)	(0.1286)	(0.1956)	(0.1932)	(0.1136)	(0.0851)	(0.1613)
ln**FD**(PS)	–0.414^{a}					–0.410^{a}					–0.196				
	(0.1168)					(0.1214)					(0.2635)				
ln**FD**(PSBK)		–0.414^{a}					–0.411^{a}					–0.232			
		(0.1175)					(0.1226)					(0.2683)			
ln**FD**(M2)			0.433					0.527					– 0.301		
			(0.2993)					(0.3587)					(0.2846)		
ln**FD**(M2_*R*)				0.251^{b}					0.252^{b}					0.342^{a}	
				(0.1131)					(0.1233)					(0.1163)	
FD(INDEX)					–0.056					–0.021					0.024
					(0.0480)					(0.0606)					(0.0808)
lnTOP	–0.384^{c}	–0.376^{c}	–0.649^{b}	–0.658^{b}	–0.537^{b}	–0.354	–0.340	–0.692^{c}	–0.693^{b}	–0.728^{b}	–0.685	–0.614	–1.459^{a}	–1.191^{a}	–1.321^{a}
	(0.2188)	(0.2192)	(0.2865)	(0.2552)	(0.2299)	(0.2929)	(0.2944)	(0.3518)	(0.3237)	(0.3563)	(0.5618)	(0.5997)	(0.2994)	(0.2514)	(0.4177)
lnIVA	0.894^{a}	0.877^{a}	0.126	0.316	0.694^{c}	0.872^{b}	0.847^{b}	0.156	0.381	0.678	0.866^{c}	0.839^{c}	1.401^{a}	0.765^{b}	1.067^{a}
	(0.3105)	(0.3095)	(0.4650)	(0.3699)	(0.3481	(0.3727)	(0.3722)	(0.5400)	(0.4468)	(0.4743)	(0.4364)	(0.4383)	(0.4014)	(0.2942)	(0.3772)
Con	–18.338^{a}	–18.323^{a}	–15.954^{a}	–15.560^{a}	–17.810^{a}	–18.464^{a}	–18.457^{a}	–16.076^{a}	–15.579^{a}	–16.486^{a}	–16.652^{a}	–16.846^{a}	–13.901^{a}	–13.866^{a}	–14.391^{a}
	(0.7847)	(0.7833)	(0.9999)	(0.9114)	(1.0126)	(0.9631)	(0.9612)	(0.9240)	(0.8799)	(1.2627)	(2.0013)	(1.9932)	(1.0262)	(0.9483)	(2.1081)
Adj *R*-square	0.731	0.730	0.716	0.741	0.716	0.733	0.732	0.715	0.740	0.707	0.922	0.923	0.939	0.950	0.928
SER	0.311	0.312	0.317	0.306	0.320	0.310	0.311	0.317	0.307	0.325	0.165	0.164	0.146	0.132	0.158
SSR	3.879	3.891	4.027	3.745	4.095	3.854	3.864	4.114	3.758	4.225	0.625	0.017	0.490	0.404	0.575
LRV	0.065	0.064	0.070	0.095	0.076	0.065	0.064	0.119	0.095	0.107	0.039	0.039	0.021	0.017	0.027

Note: *a*, *b*, and *c* denote 1%, 5%, 10% significance. The figures in ( ) denote standard errors. Long-run covariance estimate (Bartlett Kernel, Newey-West fixed Bandwidth, optimal prewhitening lag selected based on AIC). For the DOLS, the optimal lead-lag was selected based on AIC.

upper case), which represents savings on an additional capacity with power capacity of between 40 and 52 GW[1)] and emission reductions of between 8504812.8–11179713.6 kg CO_2. On the other hand, for a tax policy of GH ₵ 5 per barrel of oil consumed, the electrical energy intensity will fall by 1.4% (in the lower case) and 4.6% (in the upper case). Further, while the effect of trade openness is negative, that of industry structure is positive. Thus, in all, the result that financial development lowers energy intensity is robust.

4.4 Graphical display of financial development impact across models

The estimated impact of financial development indicators on energy intensity across the various models were summarized in Fig. 1. In Fig. 1, the bars show the size of the estimated elasticity of the different indicators of financial development on energy intensity across the three model estimators. The vertical axis shows the estimated elasticities of financial development while the horizontal axis shows the model estimators for different model specifications. For example, the first bar starting from the left shows the different estimated elasticities of the five financial development indicators using the FMOLS estimator, while the next two bars show a similar information when CCR and DOLS estimators are used. Estimators with the subscript 'B' refer to the baseline model (i.e. without trade openness and industry structure effects) when actual aggregate energy intensity is used as dependent variable. Estimators with the subscripts GE refer to the general model (i.e. with the effects of trade openness and industry structure effects) when the actual aggregate energy intensity is used as the dependent variable. Those with subscripts GEL refer to the general model when actual electrical energy intensity is used as the dependent variable. Lastly, those with the subscripts PE and PEL refer to the general models when potential aggregate energy intensity and potential electrical energy intensity are used as the dependent variables, respectively. Except for **FD**(M2) and **FD**(M2_*R*), the size of the impact of the other indicators of financial development on energy intensity does not change significantly between the baseline model and the general model. Considering the two indicators of energy intensity (i.e. overall energy intensity and electrical energy intensity), the estimated impact of financial development on these indicators are generally consistent.

In the case of **FD**(INDEX), the impact on overall energy intensity is greater than that on electrical energy intensity. Hydro and thermal plants are the major generating sources in the electricity sector. Although the latter has become increasingly important, the electrical system depends hugely on the former for reasons, such as the cheaper cost of production and difficulty in purchasing fuels to power thermal plants. The solar generation source started in 2013 but the share in total generation remains very insignificant. Generally, the electric generation assets in Ghana are relatively fixed over the short- to medium-term, therefore, substitution possibilities given broader access to financing are weaker than in other energy sectors. However, with the growth in the middle-class population and urbanization, the demand for both commercial and private vehicles, as well as demand for cleaner cooking

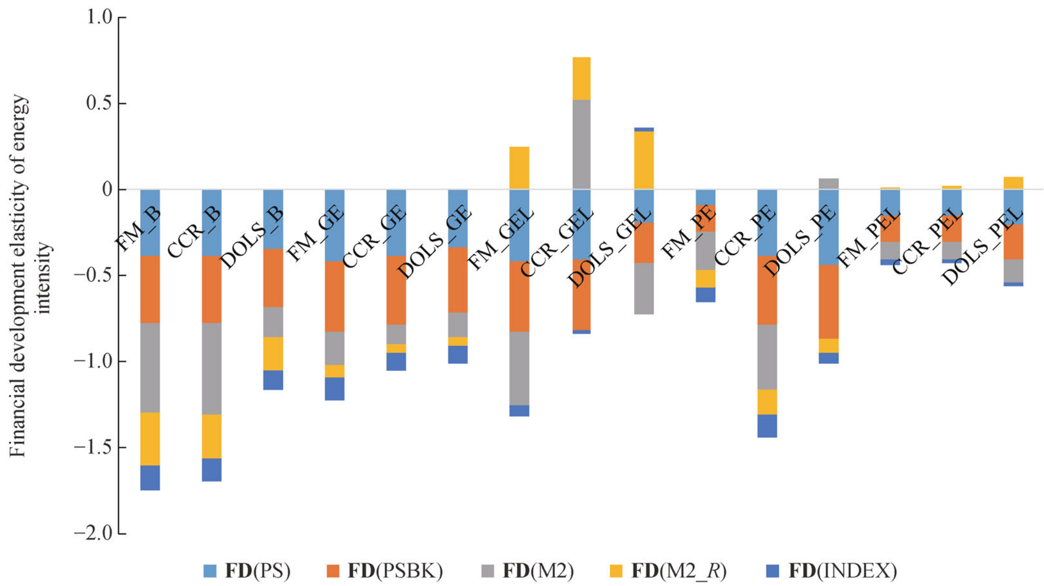

Fig. 1 Plot of estimated impact of financial development on energy intensity

1) This can provide electricity to more than 10 million new homes.

sources, such as liquefied petroleum gas (LPG) and electric cooking stoves (but the former dominates) have increased. Consequently, the automobile sector (which relies solely on fossil fuel) and households (that depends relatively more on LPG) become much responsive to developments in the financial sector. Since the combined shares of fossil fuel and gas dominate the electricity in total energy use, the total energy system becomes much responsive to financial development. Finally, between the actual and potential energy intensity, the estimated impact of the indicators of financial development is smaller in the latter case, which confirms the claim that using potential instead of actual data improves model efficiency [42].

5 Conclusions and policy recommendations

This paper examined whether financial development significantly lowers energy intensity, using the case of Ghana, where the financial and energy sectors not only exhibit an interesting trajectory but also provide a significant contribution to regional integration and regional energy security. To check the robustness of the estimates, several robustness checks were conducted, which included using different indicators of financial development, different indicators of energy intensity, and different estimators.

The following results emerged from the study. First, financial development leads to a significant reduction in energy intensity. By implication, government policies to stimulate the growth of the financial sector can effectively complement existing government energy efficiency policies to lower energy intensity in the country. Consequently, government policies should be integrated in nature. To reap the benefits of this complementarity, the government should remove all market barriers that impede the growth of the sector, as well as create the favorable political and business environment for financial intermediation. More ambitiously, the government should consider establishing a 'Green Bank' that will primarily fund green investments in the economy. This could be achieved via effective public-private partnership.

However, this alone may not be sufficient enough to achieve the energy savings targets required in the country. Other market-driven tools may also be important. As indicated in this paper, the prices of electricity and oil have a significant negative effect on the energy intensity in the country, which opposes the idea of subsidizing energy prices, all things being equal. Thus, the government can use taxes to achieve significant reductions in energy intensity. However, such a tax initiative should aim at promoting energy intensity reductions through energy efficiency enhancement. At the economic-wide level, this could help save a significant amount of energy, reduce the related carbon emissions, and prevent investments in additional generation capacity. While such an initiative could prove costly for end-users and hence lower their consumption of energy services in the short term, in the long term, the positive effects of energy efficiency enhancements may outweigh these losses, but this is a welfare issue that is beyond the scope of this paper. Further, trade liberalization will help improve energy efficiency and lower energy intensity in the country.

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