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Technical fossil fuel energy efficiency (TFFEE) and debt-finance government expenditure nexus in Africa

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ABSTRACT

Achieving the SDG7 goal, among other things, requires doubling efforts in energy efficiency improvements. However, in Africa, the progress has been slow, proving difficult for the continent to achieve the target set for 2030. The purpose of this study was to examine the effect of government expenditure (conditioned on external debt finance) on fossil fuel energy efficiency in 28 African countries, using data from 1988 to 2016. We employed the stochastic frontier method to estimate energy efficiency and Tobit regression to examine the relationship between energy efficiency and the conditional effect of government expenditure. The results showed that increasing government expenditure reduces TFFEE, but when conditioned on external debt finance, the effect is positive and partial in nature. This rather suggests an optimal mix of tax and debt finance instead of the total reliance on the latter to promote energy efficiency. While increasing debt finance for energy efficiency purposes can trigger a *generational paradox in energy efficiency*, responsible savings by current generation of energy efficiency gains and altruistic behaviour of the current generation could help deal with this generational paradox in energy efficiency.

1. Introduction

The United Nations Sustainable Development Goals (SDGs) highlight the importance of doubling efforts in energy efficiency to achieve the SDG 7 goal, which is to ensure a universal access to affordable, reliable, sustainable, and modern energy for all. Even though most economies have concerted to the energy efficiency efforts, globally, we are still far from achieving the target improvement of 2.7 percent in energy intensity by 2030 (United Nations, 2018). In sub-Saharan Africa, the average energy intensity stands at 8.2 MJ/USD compared to the world average of 5.2 MJ/USD (UNIDO, 2016). Clearly, improving upon energy efficiency in Africa is, first and foremost, very critical to achieving the SDG 7 goal. Moreover, improvement in energy efficiency is carbon free and hence very good for the environment (Hanley et al., 2009). From ecological perspective, the majority of the earth's ecosystem depends on energy for survival (Beman, 2010). This means that saving energy via improvement in technical efficiency would make available more energy to be used by the earth's ecosystem. In a recent study, Carranza and Meeks (2020) found that saturation of energy efficiency project improve reliability, reduce energy consumption, provide technological externalities that benefit households, and minimise outages in electrical system. Energy efficiency improvement can reduce the investment in energy infrastructure (OECD/IEA, 2011; Bertrand et al., 2015) as well as contribute positively to economic growth (Go et al., 2019; Rajbhandari and Zhang, 2018; Koskimaki, 2012). In developing and emerging economies, improving energy efficiency can potentially reduce the tensions between economic growth and the commitment to sustainable development (Fowler and Meeks, 2020). Cantore et al. (2016) found that lowering energy intensity (i.e. improving energy efficiency) are associated with higher total factor productivity and economic growth. Other studies, such as Smulders and de Nooij (2003), Go et al. (2019) and Rajbhandari and Zhang (2018) have found a causal relationship from energy efficiency improvements to economic growth. In fact, Ayres and Warr (2009) note that, since the industrial revolution, improving energy efficiency perhaps has been the major driver of economic growth.

Africa is one of the least-developed continents in the world, with innumerable developmental challenges, such as poor infrastructure, high poverty incidence, energy poverty, and wider income inequality gap among others. Addressing some of these developmental challenges, which would suggest raising government expenditures, albeit eminent, could pose a difficulty for

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achieving the goal of improving energy efficiency, particularly when we consider the financing option.[1] In Africa, taxes remain the major reliable revenue source for government business in most economies. The average tax-to-GDP ratio in Africa has increased from 13.1% in 2000 to 18.2% in 2016, according to the Revenue Statistics in Africa (2018). Africa now collects about $500 billion in tax revenue every year (Africa Development Bank, 2018). It is, therefore, natural to expect that, in Africa, increasing government expenditures would normally connote higher tax burden on the citizenry, all things being equal.

Given that, in Africa, lack of finance, among other factors, contributes significantly to the lack of improvement in energy efficiency (Lyakurwa and Mkuna, 2018; Katrina, 2015), taxing people more to provide government goods can disincentivise investment in energy efficiency projects. Tax financing of government business imposes tax liabilities on the present generation, and this could crowd-out private and household investment in innovation that enhances energy efficiency. Cashin (1995) and Anderson et al. (1986) assert that bigger government size connotes higher taxes,[2] which distorts the innovative processes of firms and households' investment drive in technology. Ferriere and Navarro [2018] and Ahmed and Miller (2000) found that tax-financed government spending crowds out private investment. From the above, one can theorize that tax-financed government expenditure can reduce investments in green environmental goods, such as energy efficiency improvements, which have a positive implication on environmental quality (Wilkinson et al., 2017; Herring, 2006).

In order to promote energy efficiency, the alternative financing source for government activities should be able to postpone current tax liabilities into the future and free resources for both private firms and individual households to invest in energy-efficient technologies. In recent times, there have been greater appetite for debt to finance infrastructure and social sectors in Africa (Africa Development Bank, 2018). Although, on one hand, this has implications of debt overhang on African economies, debt-financed government expenditure can promote green environmental goods, such as energy efficiency. Debt financing postpones current tax liabilities into the future, and this frees resources for investment in innovation, all things being equal. Thus, debt financing provides a setting where the future taxes implicit in the public debt can be capitalized by current generation (Anderson et al., 1986). While this makes government spending services relatively cheaper compared with private services and thereby triggering substitution effects that facilitate the growth of government and the economy, the current generation are further incentivised to invest in technological innovation with the savings made, all else equal. Ahmed and Miller (2000) found that tax-financed government expenditure crowds out private investment more than debt-finance government expenditure. In addition, Shen et al. (2018) found that external financing increases the resource envelope of the economy and thereby mitigate the crowding out effects (Shen et al., 2018). The hypothesis that *financing government activities via debt-finance induce investment in energy efficiency* is based on the assumption that the citizenry do not anticipate future tax obligations and that there is a close connection between the current generation and future generation, which makes the former selfless. Several empirical studies have demonstrated that many people are not purely selfish (Rand et al., 2012; Wade-Benzoni and Tost, 2009). However, if citizens are rationale and anticipate future tax obligations, debt-finance can reduce investment in technological innovation (including energy efficiency) now but raise current savings to pay future tax obligations. The contrasting transmission mechanisms suggest that, a priori, the effect of debt-finance government expenditure on energy efficiency is indeterminate. This requires an empirical investigation.

The aim of this article is to test the TFFEE and external (debt) - finance government expenditure nexus. Fossil fuel energy consumption is a major contributor to atmospheric greenhouse gas emissions in the world and Africa (International Energy Agency [IEA], 2019; Boluk and Mert, 2014). In Africa, dependence on fossil fuels, especially in electricity generation, is on the ascendency as economies expand generation to improve energy access rate in these economies. A recent study by Marais et al. (2019) has revealed that exposure to fossil fuel use would increase the disease burden among Africans. Specifically, the authors simulate that pollution from these power plants complemented with the rise in transport fossil fuel use could cause an avoidable 48,000 early deaths per year by 2030 in Africa. With the potential of many African countries to become exporters of fossil fuel in the future, fossil fuel energy systems would continue to dominate in Africa's energy mix. Therefore, improving the efficient use of fossil fuel is critical in Africa, especially for lowering the emission of atmospheric greenhouse gas emissions from fossil fuel sources (Lanzi et al., 2011; Rashid et al., 2019).

Several studies have investigated the drivers of energy efficiency in developing economies. These studies generally differ in terms of how energy efficiency is measured and the data type used as well as the method of estimation. Many of these studies used energy intensity as an indicator of energy efficiency (see Amuakwa-Mensah et al., 2018; Atalla and Bean, 2017, inter alia). However, the use of energy intensity as an indicator of energy efficiency has been criticised, especially at the national level. This is because several factors, such as climatic factors, the price of energy, population density, and structural changes in the economy, affect energy intensity. Therefore, changes in energy intensity may depict something more than efficiency change (Zhang and Adom, 2018; Filippini and Zhang, 2016). In the case of Africa, Adom et al. (2018) found that there is a weak correlation between energy efficiency and energy intensity. Second, these studies did not consider the effects of fiscal policy change on energy efficiency, albeit, as argued above, this could be an important driver of energy efficiency.

There are studies that have addressed the concerns of measuring energy efficiency, using either parametric (Adom, 2019; Adom et al., 2018; Stern, 2012, inter alia) and non-parametric methods (Huo et al., 2020a,b; Sheng et al., 2017; Jebali et al., 2017). However, these papers did not examine the nexus between energy efficiency and fiscal policy variables. Moreover, the above studies estimated total energy consumption efficiency and not fossil fuel energy consumption efficiency. The current study is novel since it provides the first empirical attempt to test the nexus between TFFEE and fiscal policy variable, especially in Africa. This paper argues that by financing government activities with external financing, energy efficiency can be enhanced. Though a study by Yuxiang and Chen (2010) tested the nexus between energy efficiency and government expenditure in China, this study has two limitations. First, it did not measure energy efficiency but rather used energy intensity as an indicator, which is problematic. Second, the study did test the energy efficiency − government expenditure nexus and not the energy efficiency − debt-finance government expenditure nexus tested in this study. Thus, the current study estimates both the direct and indirect effects (via debt-finance) of

[1] From a developing economy perspective, there are supporting empirical findings that suggest bigger government size promotes economic growth and development (Asimakopoulos and Karavias, 2016; Kim et al., 2018; Di Liddo et al., 2018). In Africa, Mazorode (2018) found the effect of expanding government size to be positive on economic growth, which confirms the Wagner's law.

[2] Robert Barro in contrast to the views of Friedman argues that higher government spending forces up taxes (Anderson et al., 1986).

expanding the size of government on fossil fuel energy efficiency consumption. There is also an issue of context heterogeneity given that the current study focuses on Africa.

The rest of this article is structured as follows: Section 2 describes the method and data used. Section 3 analyses and discusses the data. Section 4 concludes the work with some implications for policy.

2. Method and data

This section describes the method and data used in this paper. It has six sub-divisions: theoretical measurement of energy efficiency, theoretical link between energy efficiency and the size of government, empirical model, econometric strategy, identification issues, robustness check, and data type and sources.

2.1. Theoretical foundations for measuring technical energy efficiency

Efficiency is the ability to extract maximum effort from an activity. Thus, it provides the objective yardstick to measure the effectiveness of an activity (Malghan, 2019). Technical efficiency is defined as the effectiveness with which producers of an output uses an input. A technically efficient producer is the one that uses minimal input requirement to generate a maximum output. Energy is a derived demand, which means that the end-user uses energy as an input to satisfy energy services, such as lighting, heating, cooking, and production of goods etc. For the end-user of energy, the objective is to maximize the energy services. We can think about this as a typical production process, where energy and the energy-using appliance serve as the input needed to produce the energy services. Measuring efficiency (in this case technical energy efficiency in consumption) involves three stages: (1) defining a normative benchmark for a phenomenon, (2) observing the actual state of the world, and (3) reporting the extent of deviation of the observed state of the world from the normative benchmark (Malghan, 2019).

Fig. 1 shows the production curve IQ and cost curve IC. The point of tangency between the production and cost curve shows the optimal inputs location point, where the production of energy services is maximized. At this point, the production of energy services is both technically and allocatively efficient (i.e. economically efficient). However, assume that instead of Q* (i.e. the normative benchmark), Q1 (i.e. the actual state of the world) of energy services is produced. This point is outside of the production and cost curves. Therefore, allocation of inputs levels e1 (i.e. energy) and k (i.e. capital) are allocatively and technically inefficient (i.e. economically inefficient).

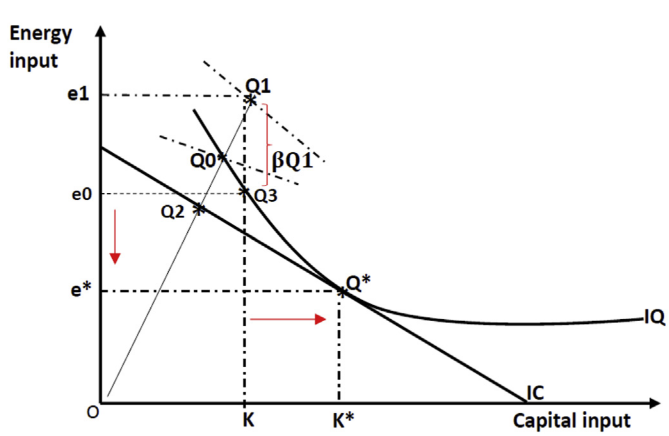

Fig. 1. Diagrammatic illustration of technical efficiency in energy consumption.

Since this paper is interested in technical efficiency, we limit the theoretical explanation to technical efficiency. Assume point Q3 (i.e. normative benchmark) on the isoquant. At this point, the producer of energy services is technically efficient but allocatively inefficient. Now suppose, Q1 is actually observed. At Q1, the producer of energy services is not technically efficient. Using the classical input-oriented radial measure by Farrel (1957), the extent of technical inefficiency at Q1 is estimated as the ratio of the distance from the origin to the point Q0 to the distance from the origin to the point Q1. However, the radial measure treats each input equi-proportionally in terms of their contribution to technical efficiency. Since, we are interested in an input specific technical efficiency; this study adopted the non-radial approach by Kopp (1981). This approach estimates technical efficiency as the ratio of KQ3 (the minimum feasible energy use) to KQI (observed energy use). From the figure, the movement from Q1 to Q3 requires that, given the production technology, output and the levels of input, we reduce the energy input from e1 to e0. This is the same as, for example, improving the insulations in buildings, and replacing outdated equipment and appliances (Adom, 2019; Filippini and Hunt, 2011).

2.2. Econometric estimation of energy efficiency

Using the non-radial approach by Kopp, Filippini and Hunt (2011) has developed a technical efficiency measure for energy consumption by estimating a stochastic energy demand frontier. Following Filippini and Hunt (2011), we estimated a single stochastic conditional energy input demand frontier, which shows the optimal energy use (denoted as KQ3 in Fig. 1) and the extent of deviation from the optimal (denoted by KQ1 in Fig. 1). Let the optimal energy use be denoted as $f(x_{it};\beta)e^{v_{it}}$ and the deviation from the optimal be denoted as $e^{-u_{it}}$. The stochastic conditional energy input demand frontier can be specified as Equation (1), where ED_{it} denotes fossil fuel energy demand in country 'i' at time t, 'x' is a vector of the drivers of energy demand, β is the frontier parameter, v_{it} represents the noise term, and $-u_{it}$ represents the inefficient term, which is the deviation from the optimal energy use point.

$$ED_{it} = f(x_{it};\beta)e^{v_{it}} * e^{-u_{it}} \tag{1}$$

Assume $f(x_{it};\beta)$ approximates a Cobb-Douglas production function (specified as Equation (2)), and the composed error term (ε_{it}) is the sum of the noise and inefficiency term (i.e. $\varepsilon_{it} = v_{it} - u_{it}$). A logarithmic transformation of Equation (1) can be reformulated as Equation (3), where $lnA = \alpha$. The random term is white noise (i.e. normally distributed) while the inefficiency term is one-sided non-negative with a half-normal distribution.

$$f(x_{it};\beta) = Ax_{it}^{\beta} \tag{2}$$

$$lnED_{it} = \alpha + \beta lnx_{it} + v_{it} - u_{it} \tag{3}$$

The inefficiency term, following Adom and Adams (2020), Kumbhakar et al. (2014), Alberini and Filippini (2018) and Zhang and Adom (2018), can further be decomposed into a time-varying component (i.e. short-term or transient inefficiency [σ_{it}]) and a time-invariant component (i.e. long-term or persistent inefficiency [τ_i]). This distinction is very important since it affords the policy maker the opportunity to know (1) the sources of inefficiency and (2) the policy weights to attach to short-term and long-term inefficiency (Adom et al., 2018; Kumbhakar et al., 2014). Taken into account the decomposition of the inefficiency term, Equation (3), where $u_{it} = \sigma_{it} + \tau_i$, can be rewritten as 4.

$$lnED_{it} = \alpha + \beta lnx_{it} + v_{it} - \sigma_{it} - \tau_i \quad (4)$$

The vector 'x' includes the price of energy (P_e), real income per capita (Y), share of service value-added as a percent of GDP (SSH), industry value-added as a share of GDP (ISH), population density (POPD), and urbanization (UR). We also included the time trend and its square to capture the underlying energy demand trend, which shows the effect of technical and social innovation on energy consumption. We used the approach by Jondrow et al. (1982) to compute TFFEE (see Equation (5a)), where $TFFEE_{pe}$ is persistent TFFEE and $TFFEE_{te}$ is transient TFFEE. TFFEE is bounded between 0 and 1, where 0 implies inefficiency and 1 implies full efficiency.

$$TFFEE_{it} = \exp(-u_{it}) = TFFEE_{pe}*TFFEE_{te} \quad (5a)$$

In order to estimate the different aspects of TFFEE, this paper adopted a two-stage approach (see Zhang and Adom, 2018; Filippini and Zhang, 2016; Adom et al., 2018). First, this paper applied the fixed effect model (FEM) by Schmidt and Sickles (1984) to estimate the time-invariant efficiency. The fixed effect approach is distribution free and assumes country-specific effect as inefficiency. This creates a problem of biased estimate of the efficiency term since the inefficiency term captures unobserved country-specific heterogeneity as inefficiency. Moreover, it ignores time-varying technical efficiency. This is solved in the second stage by using the true fixed effect model [TFEM] (Greene, 2005a, 2005b), which is able to separate unobserved country-specific heterogeneity from inefficiency but ignores persistent energy efficiency. There have been other proposals in the literature that simultaneously estimate transient and persistent technical energy efficiency, but these methods are either very complex to apply (Kumbhakar et al., 2014; Colombi et al., 2014) or yet to be proven to work very efficiently (Filippini and Hunt, 2016). Another problem with these simultaneous techniques is that misspecification at one stage affects the other stage and consequently, the final estimation of energy efficiency. Thus, where there exist bias in one stage, it may compound the problem in the other stage.

The attainment of Sustainable Energy for All by 2030 requires that we achieve regional and sub-regional targets in greenhouse gas emission and energy security. In this regard, the question of whether countries are converging in TFFEE is critical. To ascertain this, this paper determined the conditional beta convergence by estimating Equation (5b). 'η_i' is the fixed effect term and $\beta < 0$ denotes the presence of beta convergence.

$$\ln\left(\frac{TFFEE_{it}}{TFFEE_{i,t-1}}\right) = \alpha + \beta lnTFFEE_{it} + \eta_i + \varepsilon_{it} \quad (5b)$$

2.3. Theoretical framework to link energy efficiency and the size of government

We followed the theoretical approach of the drivers of energy efficiency proposed in Amuakwa-Mensah et al. (2018). The representative economic agent is assumed to maximize profit or utility. Given the constraint as a production quota, the representative economic agent's problem is to select the optimal input required for the attainment of profit.[3] Equations (6)–(8) set-up the representative agent's problem, where (6) is the profit function (π), (7) is the production quota (Y), and (8) is the Lagrange equation (L). The variables, P, P_e, $TFFE$, Z, and A denote the price of output, the price of fossil fuel energy, total fossil fuel energy consumption, composite input, and total factor productivity, respectively. The price of the composite input has been normalised to one.

$$max: \ \pi = PY - P_e(TFFE) - Z \quad (6)$$

$$subject\ to: Y = A(TFFE)^{\alpha} Z^{\beta} \quad (7)$$

$$L = PY - P_e(TFFE) - Z + \lambda(Y - A(TFFE)^{\alpha} Z^{\beta}) \quad (8)$$

Performing the first-order condition for maximisation produces equation (9a) − 9c. Solving 9a − 9c simultaneously, we derive the optimal energy input demand as Equation (9d). Assuming a competitive market situation, the representative energy demand can be generalised to the national level. Further, we specify total factor productivity (see equation (10)) as an exponential function of foreign direct inflows *[FDI]* (see Ashraf et al., 2016; Griffith and Simpson, 2003; Xu and Yu, 2012), government size [*SGovt*] (see Ram, 1986; Gong, 2018), demography *[Dem]* (see Ciccone, 2002; Krugman, 1991; Xu and Yu, 2012), and external debt (Shen et al., 2018).

$$\frac{\partial L}{\partial TFFE} = -P_e - \alpha\lambda A(TFFE)^{\alpha-1} Z^{\beta} = 0 \quad (9a)$$

$$\frac{\partial L}{\partial Z} = -1 - \beta\lambda A(TFFE)^{\alpha} Z^{\beta-1} = 0 \quad (9b)$$

$$\frac{\partial L}{\partial \lambda} = Y - A(TFFE)^{\alpha} Z^{\beta} = 0 \quad (9c)$$

$$TFFE = \left(\frac{\alpha}{\beta}\right)^{\frac{\alpha\beta}{\alpha\beta+1}} \left(\frac{1}{P_e}\right)^{\frac{\alpha\beta}{\alpha\beta+1}} \left(\frac{1}{A}\right)^{\frac{\alpha}{\alpha\beta+1}} Y^{\frac{\alpha}{\alpha\beta+1}} \quad (9d)$$

$$A = e^{\beta_2 FDI - \beta_3 SGovt + \beta_4 Dem - \beta_5 lnextdebt} \quad (10)$$

Next, we substituted 10 into 9d, divided through by Y to obtain energy intensity (an indicator of energy efficiency), and performed a log transformation. The resultant equation is Equation (11), where $\alpha - (\alpha\beta + 1) < 0$. Earlier in this paper, we argued that the use of energy intensity as a surrogate for energy efficiency has some limitations for which reason we apply a stochastic frontier approach to compute TFFEE. Since energy intensity is inversely correlated with energy efficiency (Filippini and Zhang, 2016; Adom et al., 2018), replacing the dependent variable in Equation (11) with TFFEE changes Equation (11) slightly in terms of the direction of the effect of the variables. Equation (12) is the resultant equation.

$$lnTFFEI = \underbrace{\frac{\alpha\beta}{\alpha\beta+1} ln\left(\frac{\alpha}{\beta}\right)}_{\gamma_0} - \underbrace{\frac{\alpha\beta}{\alpha\beta+1}}_{\gamma_{pe}} lnP_e - \underbrace{\frac{\alpha\beta_2}{\alpha\beta+1}}_{\gamma_{fdi}} FDI + \underbrace{\frac{\alpha\beta_3}{\alpha\beta+1}}_{\gamma_{SGovt}} SGovt - \underbrace{\frac{\alpha\beta_4}{\alpha\beta+1}}_{\gamma_{Dem}} Dem + \underbrace{\frac{\alpha\beta_5}{\alpha\beta+1}}_{\gamma_{ext}} lnextdebt - \underbrace{\frac{\alpha-(\alpha\beta+1)}{\alpha\beta+1}}_{\gamma_{ypc}} lnY \quad (11)$$

$$lnTFFEE = \gamma_0 + \gamma_{pe} lnP_e + \gamma_{fdi} FDI - \gamma_{SGovt} SGovt + \gamma_{Dem} Dem + \gamma_{ext} lnextdebt + \gamma_{ypc} lnY \quad (12)$$

[3] A similar optimisation problem can be derived using a utility maximising as the objective function. The results are similar.

2.4. Empirical model

Based on Equation (12), the empirical model of this paper is specified as 13, where the error term (ε) captures unobserved factors that affect energy efficiency, 'i', denotes country id, 't' is the time period, η_i denotes country-specific effects that is time-invariant, and κ_t is time-varying country-specific effects. We used two indicators to measure demographic effects: degree of urbanization (*UR*) and population density (*POPD*). While urbanization puts pressure on energy resources, the concentration of people at a place can improve the provision of energy services. Krugman (1991) notes that there are externalities via agglomeration, and these include forward and backward linkages and knowledge spillovers. Population density reduces travel time and consequently induce the use of less energy-intensive or non-energy-using transport services, such as trekking and biking. However, densely populated areas can affect positively the energy intensity of transport, manufacturing and residential sectors (Adom et al., 2018). These suggest that the overall effect of urbanization and population density on energy efficiency is indeterminate a priori.

$$
\begin{aligned}
lnTFFEE_{it} = {} & \gamma_0 + \gamma_{pe} lnP_{e,it} + \gamma_{fdi} FDI_{it} + \gamma_{SGovt} SGovt_{it} \\
& + \gamma_{Dem} Dem_{it} + \gamma_{ext} lnextdebt + \gamma_{ypc} lnY_{it} + \eta_i + \kappa_t + \varepsilon_{it}
\end{aligned} \tag{13}
$$

Since external financing (1) increases the resource envelop to mitigate crowding out effect and (2) postpones current tax liabilities into the future thereby freeing resources for present generation, government spending financed by external financing might provide further impetus for energy efficiency enhancement. This is because, in the short- to medium-term, the external debt-financed government expenditure would reduce the domestic tax burden of government expenditure on the citizenry. However, it is uncertain, whether in the short- to medium-term, external debt-finance of government expenditure would promote investment in technological innovation. If citizens do not anticipate higher taxes in the future, then debt-finance would stimulate investment in technological innovation or energy-efficient technologies, all things being equal. On the other hand, if citizens are rational and anticipate higher future tax burden due to debt accumulation, in the short- to medium-term, debt-finance government expenditure would stimulate savings to pay future tax liabilities and rather displace investment in technological innovation. Determining which transmission mechanism is more likely requires an empirical test.

As a result, we have included the interaction of the size of government and external debt as an additional model in Equation (14).[4] The total effect of the size of government on energy efficiency is derived as Equation (14b), where γ_{SGovt} measures the direct effect of government expenditure and γ_{ext_sgovt} captures the indirect effect of government expenditure. Since, the total external debt data has non-zeros, it would be wrong to interpret the direct effect of government expenditure as when total external debt data is zero. For this reason, we transformed the variables by demeaning the data. By such transformation, the interpretation of the direct effect of government expenditure on TFFEE is evaluated at the mean of total external debt.

[4] The following variables FDI, SGovt, and UR are not in their logs since these are measured as a proportion or percentage. Taking further log of these variables may make the values very small. In the case of FDI, there are possible cases of negative values as this is a net measure.

$$
\begin{aligned}
lnEE_{it} = {} & \gamma_0 + \gamma_{pe} lnP_{e,it} + \gamma_{fdi} FDI_{it} + \gamma_{SGovt} SGovt_{it} \\
& + \gamma_{extdebt} Extdebt_{it} + \gamma_{ext\_sgovt} SGovt_{it}{*}Extdebt_{it} + \gamma_{ur} UR_{it} \\
& + \gamma_{popd} lnPOPD_{it} + \gamma_{ypc} lnY_{it} + \eta_i + \kappa_t + \varepsilon_{it}
\end{aligned} \tag{14a}
$$

$$
\frac{\partial lnEE_{it}}{\partial SGovt_{it}} = \gamma_{SGovt} + \gamma_{ext\_sgovt} Extdebt_{it} \tag{14b}
$$

2.5. Estimation strategy

This paper adopted a multi-step approach in arriving at the results. First, the study applied the stochastic frontier technique to obtain both the drivers of the demand frontier and the estimate of TFFEE. The next stage used the computed TFFEE data as the dependent variable, and then examined the effect of government expenditure and other driving factors on TFFEE. This two-step approach has been criticised by Wang and Schmidt (2002) as leading to biased results. However, in the present case where the efficiency component is decomposed into transient and persistent components, we are not aware of any methodological procedure that estimates simultaneously transient and persistent energy efficiency while at the same time modelling them as functions of other variables. Our two-step approach is similar to Zhang and Adom (2018) and Adom et al. (2018).

The data of the estimated TFFEE is censored. Therefore, this study applied the Tobit regression estimator to estimate Equation (14). In estimating Equation (14), the study proceeded as follows. First, we modelled TFFEE as a function of the price of fossil fuel energy, income, and government expenditure. We then tested the stability and consistency of the results by controlling for omitted variable bias by including external debt and its interaction with the size of government, FDI, population density, and the degree of urbanization as additional variables. The introduction of these variables are done in stepwise manner and captured as Models I to V.

2.6. Identification issues

Correct inference made based on the effect of government size on TFFEE depends critically on the unique identification of the effect. Several factors can undermine the unique identification of the effect of government size. In this paper, we pay particular attention to two of these factors: omitted variable bias and reverse causality. The size of government may be correlated with unobserved country-specific effects, both time-varying and time-invariant. The inclusion of the time-varying country-specific effects and time-invariant country-specific effects therefore conditions out their effects to enhance the identification of the size of government. In addition, foreign direct inflows fills the domestic investment gap. This means that an increase in FDIs could reduce government investment and hence the size of government. Including the effects of FDIs help condition out these effects and thereby help improve the identification of government expenditure. Moreover, both urbanization and population density affect fuel use efficiency, and the link between urbanization and population density and energy consumption suggests that these variables may be correlated with economic growth, the size of government, and the price of energy. Therefore, the omission of these variables from the model would amount to omitted variable bias and hence make the parameters unidentified. By including urbanization and population density in the model, we condition out their effects and make the effect of government size uniquely identified.

Lastly, there is a potential reverse causality issue with Equation (14). According to the *Jevons' Paradox*, economical use of resource due to technological progress causes an increase in the demand for the resource, which is called the rebound effect (Sorell et al., 2009; Gillingham et al., 2016). First, improvements in TFFEE can reduce fossil fuel demand, and given supply, the corresponding price of energy could fall, all things being equal. The fall in price could drive consumption of fossil fuel upwards, and this could neutralise partially or fully the positive savings in consumption achieved through energy efficiency improvements. The overall effect on energy consumption would depend on the size of the rebound effect. The Jevon's Paradox is the case where the rebound effect is 100 percent or more. The possible existence of rebound effect implies efficiency improvement can cause energy price, economic growth and hence government expenditure.

Since the price of energy is the main transmission mechanism by which the rebound effect can occur, this paper included the lag of the price of energy to break the causality from TFFEE improvements to the price of energy. The lag price variable makes the reverse causality from TFFEE to price meaningless since energy efficiency improvements in this year can only have implications for present and future prices and not past prices. However, the causality from last year's price to this year's TFFEE makes sense. Lower prices in the past can work in two ways by either inducing savings that will propel future investment in innovation or irresponsible increase in energy usage. Both could have different effects on TFFEE improvements.

2.7. Robustness check

This study performed two robustness checks of the results. First, TFEM suffers from the incidental parameter problem (despite been able to separate unobserved country-specific heterogeneity from time-varying efficiency). Consequently, the variance parameters as well as the efficiency value are inconsistently estimated. This paper applied the consistent true fixed effect (CTFEM) estimator by Chen et al. (2014) to deal with the incidental parameter problem. Lastly, this paper used energy intensity (a measure of energy efficiency) as the dependent variable and applied the simultaneous system generalised method of moments, two-stage least square and the fixed effect models as the estimators. Energy intensity and energy efficiency are negatively correlated. If so, the conditional effect of government expenditure should be invariant whether we use intensity as a measure of efficiency (albeit it is less preferred in this case) or the estimated TFFEE.

2.8. Data type and source

This paper used unbalanced panel data that consisted of twenty-eight (28) African[5] countries spanning from 1988 to 2016. Each sub-region in the continent is represented, and this makes the sample representative. Thus, generalisation of the results is possible.

Foreign direct inflows measure foreign investment. It is defined as the net foreign direct inflows as a percent of gross domestic product. FDIs embody the latest technology in production, management, and acts as a source of technological diffusion (Griffith and Simpson, 2003). Total government expenditure as a percent of GDP measures the size of government. Total external debt captures external financing. In contrast to total domestic debt, external financing widens the resource envelope and thereby mitigate against possible crowding out effect (Shen et al., 2018).

Real gross domestic product per capita captures the potential income effect. The Brent crude oil price in US dollars captures the price of fossil fuel energy effect. Urbanization is the total urban population as a percent of total population. Population density is the total population per sq. km2 of land area. Except for data on the price of crude oil that were obtained from the BP Statistical Review of World Energy, the rest of the data were obtained from the World Bank Development Indicator database. Table 1 shows the descriptive statistics of the data.

3. Empirical results and discussion

This section presents and discusses the results of the study. Specifically, the section is organised as follows: determinants of fossil fuel energy demand frontier; estimate of TFFEE; convergence in TFFEE; correlation between TFFEE and fossil energy intensity, TFFEE and the size of government, and robustness check.

3.1. Determinants of fossil fuel energy demand frontier

Table 2 shows the determinants of fossil fuel energy demand. The price of fossil fuel energy is negative but statistically weak based on the fixed and true fixed effect estimates. The negative insignificant price elasticity is an indication that pricing tool may prove ineffective in reducing fossil fuel energy consumption. This could stem from (1) the inelastic nature of demand and (2) lack of substitutes. Kwakwa et al. (2018) and Zhang and Adom (2018) recorded negative price effect on fossil fuel energy consumption. The income elasticity is significant and positive. The coefficient suggests that raising the income levels by 10% will cause the consumption of fossil fuel energy to increase by 6.61%–8.13%. This implies that economic growth that translates into higher income can trigger more fossil fuel energy consumption. This is consistent with the findings of Adom et al. (2019), Kwakwa et al. (2018) and Keho (2016).

The effect of population density is significantly positive and elastic in nature. In other words, an increase in population density will cause more than a proportionate increase in fossil fuel energy consumption. In contrast, Adom et al. (2018) found that population density has a negative effect on total energy consumption. The effect of urbanization is positive but statistically not significant. This is consistent with the findings of Kwakwa et al. (2018) and Huo et al. (2020a,b) for building sector. An increase in the share of industry value added raises fossil fuel energy consumption but an increase in the share of service valued added lowers fossil fuel energy consumption. This is because the industrial sector is more energy-intensive than the service sector. Filippini and Zhang (2016), Adom et al. (2018), and Keho (2016) found similar results, albeit their study examined total energy consumption.

Table 1
Descriptive statistics.

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
$\boldsymbol{log(ED)}$	764	3.331	0.975	0.495	4.605
$\boldsymbol{log(YPC)}$	761	7.257	1.031	5.087	9.403
$\boldsymbol{log(P_e)}$	783	4.040	0.430	3.179	4.756
$\boldsymbol{log(POPD)}$	775	3.341	1.241	0.4589	6.432
$\boldsymbol{log(Extdebt)}$	716	22.527	1.211	17.185	25.700
SSH)	683	47.2593	11.577	18.909	73.985
ISH	685	30.948	14.275	3.163	78.518
FDI	766	2.860	4.750	−8.589	41.810
UR	780	41.435	16.605	12.143	86.92

Source: Author's own computation

[5] Algeria, Benin, Botswana, Cameroon, Cong DR, Congo REP, Egypt, Ethiopia, Ghana, Kenya, Mauritius, Morocco, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Zambia, Angola, Coted'Ivoire, Eritrea, Gabon, Libya, Namibia, and Niger.

Table 2
Determinants of fossil energy demand frontier.
Dependent variable: log (fossil energy consumption).

Frontier	FEM	TFEM	CTFEM
$\log(P_e)$	−0.0306 (0.0413)	−0.0203 (0.0240)	0.0156 (0.0318)
$\log(Y)$	0.813*** (0.0609)	0.661*** (0.0475)	0.7446*** (0.0552)
$\log(POPD)$	1.3130*** (0.1822)	1.133*** (0.1344)	1.233*** (0.1751)
UR	0.005 (0.0046)	0.0005 (0.0032)	0.0066 (0.0043)
ISH	0.0049** (0.0024)	0.0077*** (0.0022)	0.0030 (0.0018)
SSH	−0.0075*** (0.0024)	−0.002 (0.0020)	−0.003 (0.0019)
t	−0.043*** (0.0073)	−0.0297*** (0.0050)	−0.0515*** (0.0065)
t^2	0.0004* (0.0002)	0.0000 (0.0001)	0.0006*** (0.0002)
usigma_cons		−2.616*** (0.1080)	
vSigma_cons		−6.016*** (0.3869)	
lambda		5.473*** (0.0218)	7.889*** (2.6217)
constant	−6.649*** (0.7728)		
Sigma_u		0.2704*** (0.0146)	
Sigma_v		0.0494*** (0.0096)	
$Sigma^2$			0.1522*** (0.0111)
Observation	679	679	679

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' own construction

The time trend has a non-concave effect on fossil fuel energy consumption. This contrasts the findings of Adom et al. (2018). Technological and social innovation may lower consumption of fossil fuel energy initially, but consumption might reverse later due to depreciation. A very important variable in this table is lambda. This shows the extent of inefficiency in fossil fuel energy consumption. The coefficient is positive and statistically significant. This means that there is significant technical inefficiency in fossil fuel energy consumption in Africa. Based on Table 2, we provide the estimate of TFFEE in the next section.

3.2. Estimate of TFFEE

Table 3A shows the summary statistics of the estimated TFFEE. Overall, TFFEE is lower, with a mean value of 0.0585, which suggests that, in Africa, there is a large scope for fossil fuel energy consumption efficiency. Stern (2012) and Adom et al. (2018) found energy efficiency to be low in Africa but these studies estimated total energy consumption efficiency.

The decomposition of TFFEE shows that the inefficiency in fossil fuel energy consumption is structural in nature. The mean $TFFEE_{pe}$ is estimated as 0.0728 compared to $TFFEE_{te}$ score of 0.797. The relatively low $TFFEE_{pe}$ implies that fossil fuel energy consumption inefficiency in Africa will persist if there is no change in government policy.

Authors' computation

Table 3B shows the sub-regional classification. The mean TFFEE is small for all sub-regions, an indication that there exists large energy efficiency potentials in these regions. For all the sub-regions, $TFFEE_{te}$ is higher than $TFFEE_{pe}$, which implies that the problem of technical inefficiency in fossil fuel energy consumption is long-term oriented. Comparatively, East Africa emerged as the region with the highest efficiency score in fossil fuel consumption. Thus to improve TFFEE, government policies should aim at targeting changing long-run behaviours, such as energy efficiency regulation; the habitual nature of how energy is used, a ban on overage cars, and incentives to acquire fuel-efficient equipment and machinery.

Table 3B
Summary Statistics of efficiency estimate for sub-regions.

Region	Observation	Overall	Persistent	Transient
Eastern Africa	135	0.1730	0.2317	0.7552
West Africa	162	0.0546	0.0727	0.7448
Central Africa	135	0.0134	0.0187	0.7164
North Africa	162	0.0115	0.0155	0.7414
Southern Africa	162	0.0085	0.0114	0.7420
Sub-Saharan Africa	593	0.0596	0.0800	0.7400

Source: Authors' computation

3.3. Convergence in fossil fuel energy efficiency

This section tested for beta-convergence in TFFEE, taking into account unobserved country-specific heterogeneity. In other

Table 4
Convergence in fossil energy efficiency.

Variable	Conditional convergence
$\beta -$ ***convergence***	−0.459*** (0.0341)
Constant	−0.256*** (0.0190)
Observation	651

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' computation

Table 3A
Summary statistics for full sample.

		FE & TFE			FE & CTFE		
	Obs	Mean	Min	Max	Mean	Min	Max
Overall	679	0.0585 (0.1645)	0.0005	0.9702	0.0539 (0.1469)	0.0004	0.964
Persistent	679	0.0728 (0.1952)	0.0006	1	–	–	–
Transient	679	0.7974 (0.1843)	0.1252	0.9895	0.738 (0.1266)	0.3591	0.998

Figures in parenthesis are the standard deviation.

words, the authors determined whether poor performing countries in TFFEE are catching up to better performing economies in the region. Table 4 shows the results. The coefficient of beta is significantly negative, and this confirms the existence of beta-convergence in the region. Thus, countries in Africa have the potential to achieve common targets in TFFEE, which could help reduce greenhouse gas emissions and improve energy security.

3.4. Correlation between TFFEE and Total Fossil Fuel Energy Intensity (TFFEI)

Table 5 shows the correlation matrix between TFFEE and TFFEI. Two important conclusions can be drawn from this table. First, the TFFEE score is negatively correlated with TFFEI, an indication that lowering TFFEI connotes TFFEE improvement. However, the correlation is very weak, which confirms the argument that the intensity-based criteria is not a good measure of efficiency especially at the national level (Adom et al., 2018). Second, there is a weak correlation between $TFFEE_{pe}$ and $TFFEE_{te}$. This indicates that transient consumption efficiency differs from persistent consumption efficiency.

3.5. TFFEE and the size of government

Table 6A contains the results on the direct and indirect effects of government expenditure on TFFEE (computed as the product of efficiency from FEM and efficiency from TFEM). Model I shows the baseline result, where the estimated TFFEE is a function of the price of fossil energy, income, and the government expenditure. Government expenditure has a significant negative effect on the estimated TFFEE, which confirms the results of Yuxiang and Chen (2010). The inefficiency-induced effect of higher government expenditure, first, is a confirmation of the fact that inefficiency shrouds public investment or provision of public goods and services especially in developing economies. Second, since bigger government size connotes higher taxes, higher government expenditure displaces private investment in innovation and technology, which causes TFFEE to fall. The fall in TFFEE means that in Africa, the continuous expansion of tax-financed government expenditure might compromise the goal of energy efficiency.

Model II estimates the direct and indirect effects (through external financing) of government expenditure on the estimated TFFEE. Given the mean total external debt, the direct effect of the government expenditure on estimated TFFEE is −0.1353, but this is statistically not significant. However, the indirect effect is positive, albeit statistically it is not significant. The positive indirect effect reduces the total effect of government size to −0.0524, and this is statistically different from zero. This implies that conditioning the effect of government expenditure on external debt-finance minimises the negative effect of the size of government on TFFEE. Models III to V in the table deals with potential omitted variable problems, which could bias the results and hence the consistency of the results. Models III to V include FDI, population density and urbanization rate, respectively. The result shows consistently a negative direct effect of government expenditure on TFFEE. However, the effect of government expenditure conditioned on external debt finance (i.e. the indirect effect) is consistently positive. The total effect of government expenditure is less negative than the direct effect of government expenditure, which suggests that debt-finance government expenditure minimises the energy inefficiency associated with higher government expenditure. In the most preferred model, which is model V, the estimated direct, indirect and total effects of government expenditure are statistically significant and given as −0.1076, 0.0039 and −0.0206, respectively.

Table 5
Correlation of TFFEE and TFFEI.

	TFFEI	***TFFEE***	$\boldsymbol{TFFEE_{te}}$	$\boldsymbol{TFFEE_{pe}}$
TFFEI	1			
TFFEE	−0.1876	1		
$\boldsymbol{TFFEE_{te}}$	−0.1345	0.0606	1	
$\boldsymbol{TFFEE_{pe}}$	−0.1841	0.9919	**0.0125**	1

Source: Authors' computation

The above results suggest that financing government activities via external financing can partially compensate the inefficiency-induced effect associated with higher government size. Apart from expanding the resource envelop, which helps reduce the crowding out effect, external (debt)-finance for government expenditure postpones the tax obligations of the current generation into the future. This could free resources in the short-term, which could be spent on technological innovation, all things being equal.

Even though the findings recommend financing government activities through debt-finance, such a financing option might not be sufficient to achieve completely the goal of energy efficiency improvements in fossil fuel let alone the overall goal of doubling energy efficiency improvements. As shown in this study, debt (external) financing of government expenditures can only provide a partial compensation for the improvement in TFFEE in Africa. While debt-finance option may be crucial to mitigate the income barrier factor to achieving energy efficiency, political restrictions, low-level knowledge on energy efficiency, lack of local skill capacity in energy efficiency, behavioural restrictions, and lack of awareness remain important barriers to improving energy efficiency in Africa. At best, debt-finance for government business can advance transient technical efficiency but less so for persistent technical efficiency in fossil fuel energy consumption. By a logical deduction, a network of other complementary programmes, such as the creation of awareness about energy efficiency, design and implementation of energy efficiency policies and policies targeted at changing long-term behaviours, might be crucial to achieve the goal of doubling energy efficiency in Africa, as captured in SDG 7 goal.

On the controlled variables, income has a positive and significant effect on TFFEE. This implies that economic recession or lower economic growth can be an important limiting factor for TFFEE improvement as cited in the literature. The positive correlation between energy efficiency and income is consistent with the findings of Adom et al. (2018) for Africa but contrasts the findings of Zhang and Adom (2018) for China. The price effect is consistently negative, and this is consistent with the findings of Sineviciene et al. (2017) and Du et al. (2016). Reasons such as postponing the purchase of fossil-efficient machinery due to higher energy bill, higher machinery investment cost visa-vis cost imposed by energy, limited fuel substitutability options, and rebound effect have been cited (Adom et al., 2018) as the potentials reasons for the negative effect of price.

The effect of FDI is significantly positive, and this is consistent with the findings of Zhang and Adom (2018) and Du et al. (2016) but contrasts the findings of Adom et al. (2018), Stern (2012), and Lv et al. (2017). Population density positively affects TFFEE, and this confirms the findings of Adom et al. (2018). Urbanization decreases TFFEE. The negative effect of urbanization contradicts the findings of Zhang and Adom (2018) and Adom et al. (2018).

The comparison of this study's findings with other studies should be interpreted with caution, especially where we draw consensus with other studies, for two reasons. First, the context study might be different. Even with studies that investigated similar context, the sample period is different as well as the measure of energy efficiency. All those studies examined total energy

Table 6A
Estimation results_ *TFFEE = FEM & TFE.*
Dependent variable: TFFEE.
Estimation technique: Tobit.

Variable	Model I	Model II	Model III	Model IV	Model V
$\log(P_e)$	−0.3098** (0.1321)	−0.3392*** (0.1249)	−0.3259** (0.1267)	−0.5029*** (0.0621)	−0.4824*** (0.0611)
$\log(Y)$	0.0215 (0.0701)	0.1881** (0.0836)	0.1843** (0.0834)	0.2508*** (0.0317)	0.387*** (0.0427)
SGovt	−0.0670*** (0.0090)	−0.1353 (0.1069)	−0.1748 (0.1305)	−0.0801** (0.0386)	−0.1076*** (0.0403)
$\log(Extdebt)$		−0.0200 (0.1192)	−0.0443 (0.1295)	−0.0322 (0.0441)	−0.046 (0.0440)
SGovt * $\log(Extdebt)$		0.0037 (0.0047)	0.0055 (0.0058)	0.0029 (0.0018)	0.0039** (0.0019)
TE_SGovt		−0.0524*** (0.0080)	−0.0513*** (0.0081)	−0.0159*** (0.0046)	−0.0206*** (0.0042)
FDI			−0.0049 (0.0092)	0.0098** (0.0040)	0.0120*** (0.0040)
$\log(POPD)$				1.0520*** (0.0248)	1.021*** (0.0240)
UR					−0.0117*** (0.0031)
Constant	−2.0078	−2.7289 (2.6381)	−2.2081 (2.887)	−6.660*** (1.0221)	−6.745*** (1.0374)
F_Prob	0.0000	0.000	0.000	0.000	0.000
Psuedo R^2	0.034	0.0356	0.036	0.462	0.470
observation	622	583	581	581	581

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' computation

consumption efficiency while this present study investigated fossil energy consumption efficiency.

3.6. Robustness check

3.6.1. Robust estimate of fossil energy efficiency

We replicated the results in Table 6A, with the TFFEE computed as the product of persistent efficiency from FEM and transient efficiency from CTFEM. As mentioned earlier, the CTFEM deals with the incidental parameter problem. Table 6B shows the results. For brevity, we discuss the preferred model, which is V.

The statistical power of the model has improved significantly, and the results look very robust. The direct effect of government size maintains its robust significant negative sign, while the indirect effect maintains its robust significant positive sign. However, the indirect effect only partially compensates the negative direct effect of government size. Consequently, the total effect of government size on TFFEE maintains its robust significant negative effect, but it is less negative when compared with the direct effect. This confirms the earlier result that debt (external) financing government expenditure promote TFFEE but partially. Thus, changing the financing source of government business in favour of debt-finance can help contribute positively to improving TFFEE.

The results also remain robust for the controls. The price of energy and degree of urbanization exert significant negative effect on estimated fossil energy consumption efficiency. Income, FDIs, and population density, in contrast, exert significant positive effect on fossil energy consumption efficiency.

3.6.2. Reverse causality

Table 6C shows the results when we included the lag of price to deal with the reverse causality problem. The results remain very consistent. External (debt) financing of government expenditure partially improves TFFEE. As shown in Table 6C, the indirect effect of government expenditure (via external debt finance) is significantly positive but lesser than the direct of government expenditure. The partial compensation implies that external (debt) financing of government expenditure is not sufficient to achieve the goal of full TFFEE. In addition, the results remain robust for the controls. The price of energy and urbanization exert negative effect while income, FDI and population density affect fossil energy efficiency positively.

Table 6B
Estimation results_ (TFFEE = FEM & CTFEM).
Dependent variable: TFFEE.
Estimation technique: Tobit.

Variable	Model I	Model II	Model III	Model IV	Model V
$\log(P_e)$	−0.214 (0.1323)	−0.2586** (0.1250)	−0.2515** (0.1268)	−0.429*** (0.0604)	−0.4186*** (0.0607)
$\log(Y)$	−0.057 (0.0707)	0.1222 (0.0835)	0.1198 (0.0831)	0.186*** (0.0333)	0.253*** (0.0407)
SGovt	−0.0723*** (0.0093)	−0.2019* (0.1164)	−0.240* (0.1421)	−0.1456*** (0.0462)	−0.1590*** (0.0489)
$\log(Extdebt)$		−0.1216 (0.1237)	−0.1458 (0.1354)	−0.134*** (0.0458)	−0.1404*** (0.0467)
SGovt * $\log(Extdebt)$		0.0063 (0.0052)	0.008 (0.0063)	0.0053** (0.0022)	0.0059*** (0.0023)
TE_SGovt		−0.0589*** (0.0084)	−0.0582*** (0.0085)	−0.0228*** (0.0053)	−0.0251*** (0.0050)
FDI			−0.0028 (0.0091)	0.0118*** (0.0041)	0.0129*** (0.0042)
$\log(POPD)$				1.0522*** (0.0257)	1.0369*** (0.0249)
UR					−0.0057* (0.0032)
Constant	−1.788*** (0.6548)	−0.224 (2.7489)	0.309 (3.0274)	−4.142*** (1.0629)	−4.184*** (1.0826)
F_Prob	0.0000	0.000	0.000	0.000	0.000
Psuedo R^2	0.040	0.0384	0.0384	0.459	0.461
observation	622	583	581	581	581

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' computation

Table 6C
Estimation results (TFFEE = _FEM * CTFEM).
Dependent variable: TFFEE.
Estimation technique: Tobit.

Variable	Model I	Model II	Model III	Model IV	Model V
log(P_e)_-1	−0.172 (0.1367)	−0.236* (0.1286)	−0.227* (0.1309)	−0.398*** (0.0629)	−0.390*** (0.0632)
log(Y)	−0.0666 (0.0715)	0.115 (0.0842)	0.112 (0.0837)	0.181*** (0.0342)	0.2406*** (0.0418)
SGovt	−0.0728*** (0.0095)	−0.1919* (0.1124)	−0.2302* (0.1374)	−0.145*** (0.0438)	−0.157*** (0.0459)
log(Extdebt)		−0.1052 (0.12295)	−0.1293 (0.1340)	−0.126*** (0.0450)	−0.1315*** (0.0457)
SGovt* log(Extdebt)		0.006 (0.0050)	0.0077 (0.0061)	0.0053*** (0.0021)	0.0059*** (0.0022)
TE_SGovt		−0.0568*** (0.0082)	−0.0558*** (0.0083)	−0.0209*** (0.0053)	−0.023*** (0.0050)
FDI			−0.0043 (0.0091)	0.0113*** (0.0041)	0.0122*** (0.0042)
log(POPD)				1.050*** (0.0266)	1.036*** (0.0257)
UR					−0.005 (0.0033)
Constant	−1.890*** (0.6667)	−0.676 (2.7249)	0.146 (2.9885)	−4.452*** (1.0451)	−4.485*** (1.0586)
F_Prob	0.0000	0.000	0.000	0.000	0.000
Psuedo R^2	0.040	0.037	0.037	0.453	0.454
observation	602	565	563	563	563

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' computation

Table 6D
Estimation results.
Dependent variable: log (fossil energy intensity).

Variable	POLS	FE	2SLS	Sy_GMM
log(fossil energy intensity)_-1	–	–	–	0.7369*** (0.1158)
log(P_e)	0.059 (0.0542)	−0.053 (0.0324)	−0.0908* (0.0432)	0.0145 (0.0156)
log(Y)	−0.395*** (0.0395)	−0.275*** (0.0600)	−0.271*** (0.0640)	−0.2215** (0.0964)
SGovt	**0.107** (0.0417)**	**0.0165 (0.0296)**	**0.01295 (0.0296)**	**0.1429** (0.0600)**
log(Extdebt)	0.120*** (0.0391)	−0.0203 (0.0362)	−0.0246 (0.0362)	−0.0946** (0.0419)
SGovt*log(Extdebt)	**−0.004* (0.0019)**	**−0.006 (0.0003)**	**−0.0005 (0.0013)**	**−0.006** (0.0027)**
TE_SGovt	**0.024*** (0.0039)**	**0.0021 (0.0026)**	**0.0017 (0.0026)**	**−0.001 (0.0007)**
FDI	−0.014*** (0.0048)	−0.0047* (0.0024)	−0.0047* (0.0024)	0.014** (0.0006)
log(POPD)	0.204*** (0.0221)	0.800*** (0.1214)	0.915*** (0.1327)	0.6546 (0.5266)
UR	0.006** (0.0026)	−0.026*** (0.0052)	−0.0276*** (0.0055)	−0.0284 (0.0253)
Constant	−5.292*** (0.9331)	−2.994*** (0.8288)	–	−2.728** (1.3848)
F_Prob	0.0000	0.000	0.000	0.000
observation	642	642	621	563
1***st order serial correlation***	–	–	–	−2.695***
2***nd order serial correlation***	–	–	–	.2318
Sargan test	–	–	–	10.965
Cragg − Donald	–	–	16.38	–

Figures in parenthesis denote standard errors. ***, ** and * denote 1%, 5% and 10% statistical significance level, respectively.
Source: Authors' computation

3.6.3. *Using TFFEI as a measure of energy efficiency*

In order to ensure that the causality identified above is not accidental, we used the intensity-based measure of fossil fuel energy efficiency as the dependent variable. Given that we found a negative correlation between TFFEE and TFFEI, it should not matter for our results whether we use TFFEE or TFFEI as the dependent variable. Thus, the signs should be robust. However, in this case, we expect the variables to reverse in sign due to the negative correlation that exist between TFFEE and TFFEI. The TFFEI data unlike the TFFEE is not censored. Therefore, we applied the pooled ordinary least squares (POLS), fixed effect (FE) model, two-stage instrumental variable (2SLS) model, and the system-generalised method of moments (sys_GMM), which have different underlying assumptions regarding endogeneity. However, in this section, for brevity, we only reported the results of the most preferred model. Table 6D shows the results.

POLS estimate shows that the direct effect of government expenditure on TFFEI is significantly positive. However, the indirect effect of the size of government is significantly negative but lower than the direct effect. Consequently, the total effect of government size on TFFEI is significantly positive. However, the POLS assume strict exogeneity of the independent variables. Moreover, POLS does not control for country-specific effect. The FE introduces a country-specific effect but imposes the assumption that the independent variables are independent of the random term while the country-specific effect is allowed to be endogenous. Thus, FE assumes a weak exogeneity case. The results remain robust when we control for unobserved country-specific heterogeneities. However, the statistical power is weak. Both strict exogeneity and weak exogeneity are strong assumptions to make. The author included the lag of the size of government expenditure (assumed to be endogenous) as the instrument. The Cragg-Donald F-value exceeds the threshold value of 10, an indication that the instrument is valid. The result based on the 2SLS remains robust, albeit statistically it is weak.

The above models are static in nature. Possible inertia in the dependent variable and first-order serial correlation could be a potential source of endogeneity. This study applied the simultaneous system GMM to account for dynamism and serial correlation. In order to ensure that there is no instrument proliferation, we restricted the maximum instruments lag to one. Generally, we found the number of instruments is lesser than the number of cross sections, which suggests we did not encounter instrument proliferation. The errors exhibit first-order serial correlation but no second-order serial correlation. The Sargan test failed to reject the null hypothesis of instrument validity.[6] The results remain robust. The direct effect of government size on TFFEI is positive, but the indirect effect is less negative and thereby provide only a partial compensation. Both are statistically significant.

4. Conclusion and policy recommendations

Africa's dependence on fossil fuel energy is growing and with the potential of many countries in Africa to be exporters of fossil fuel energy, fossil fuel energy system would continue to be important in the energy mix. With the energy-related emissions expected to grow causing possible negative consequences on the environment and human existence, the time has come in Africa to improve fossil fuel energy consumption efficiency. To this end, this article analysed the role of government expenditure conditioned on external (debt) finance on fossil fuel energy consumption efficiency. This paper applied the stochastic frontier technique to estimate fossil fuel energy consumption efficiency and then the Tobit model to examine both the direct and indirect effects of government size. We performed several robustness checks. This paper used unbalanced panel data that consisted of twenty-eight (28) Africa countries spanning from 1988 to 2016.

The results showed that bigger government size compromises fossil fuel energy consumption efficiency; this can be interpreted to mean higher tax burden, which disincentivise investment in energy efficiency. However, conditioning the effects of government size on external (debt) finance is positive and provides a partial compensatory effect on fossil fuel energy consumption efficiency. Thus, increasing the share of external (debt) finance in total public finance can help contribute towards achieving the goal of doubling energy efficiency improvements in Africa. The critical role played by external financing in promoting energy efficiency raises concerns about the terms of negotiations for externally sourced funds. Since climate change is a global concern with no boundaries, on equity grounds, the terms of negotiations for these funds should be flexible.

The above results raise three key issues. First, should the government completely forgo tax financing in favour of external debt financing? The answer is a no. The complete reliance on either financing option can be disastrous for any economy. Totally depending on taxes can discourage investment in innovation and technology, and this can be problematic especially in developing economies where there is an investment gap in innovation and technology. On the other hand, depending totally on external financing can be disastrous for the economic security and sovereignty of the country. Moreover, financing government business completely from external financing could intensify external dependency and make the domestic economy very vulnerable to external developments. In reality, these extremes are not strongly recommended. Therefore, finding an optimal mix of tax and external debt financing is strongly recommended. Determining the optimal mix of tax and external financing is, however, beyond the scope of this paper. Future studies can investigate into the optimal mix of public financing that is consistent with the goal of energy efficiency.

Second, one underlying assumption of the result of this paper is that taxpayers do not care about future taxes. What happens, if the Ricardian Equivalence holds? Promoting energy efficiency for the current generation via external financing could impose higher future tax liability on taxpayers. This creates a *generational paradox*- i.e. *energy efficiency improvement for current generation against higher future tax liability on future generation, which could compromise energy efficiency for future generation*. However, the *generational paradox* may not be a problem if responsible savings and investment decision of incomes generated from energy efficiency improvements by the current generation pass over successfully as a bequest to the future generation to cater for the higher tax liability. If that happens, the Ricardian Equivalence might not hold for energy efficiency improvements. Thus, in terms of promoting energy efficiency, the financing type used for government activities would matter.

Lastly, an underlying assumption of this study is that savings made by the current generation due to the postponement of future taxes by externally funded government projects will translate into investment in innovation and technology that will promote energy efficiency. What happens when these investments do not occur? The efficiency benefits associated with externally funded government projects would not be realised. There is the tendency for people to spend higher incomes according to their preferences, especially when not guarded or earmarked for target spending. Therefore, demonstration by political leaders and policy makers to nationally commit, through the institution and implementation of a national plan and regulation to achieve energy efficiency can drive individuals' investment in innovation and technology in that direction.

In conclusion, just increasing the share of external debt finance in public finance might not be sufficient to drive the goal of doubling energy efficiency improvements. Other complementary actions are necessary, such as responsible savings of the gains achieved from energy efficiency on the part of the citizens, altruistic behaviour of current generation to future generation, and deliberate national commitment by instituting a national plan, energy efficiency regulation and setting benchmarks for energy efficiency. Creating awareness and building local capacity in energy efficiency projects are also critical.

CRediT authorship contribution statement

Philip Kofi Adom: Conceptualization, Data curation, Formal analysis, Investigation, Software, Methodology, Visualization, Writing - original draft, Writing - review & editing, Validation. **Samuel Adams:** Validation, Writing - review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[6] The Hansen test is not reported here because it is not a post-estimation command for xtdpdsys in STATA.

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