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Effects of Infrastructures on Environmental Quality Contingent on Trade Openness and Governance Dynamics in Africa

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Abstract

The objective of this study is to evaluate: (i) the effects of infrastructures on CO2 emission and (ii) how trade openness and governance contribute to mitigating these effects. The results from the system GMM methodology for 36 African countries between the 2003-2019 period show that infrastructural development exacerbates CO2 emission in Africa. This result is robust across different types of infrastructural development indexes. When the indirect effect regressions are carried out by interacting governance and trade openness with the different infrastructural development variables, the following results are obtained. Firstly, infrastructural development interacts with governance producing a positive net effect, up to a governance threshold estimate of 0.532 when the positive net effect is nullified. Secondly, infrastructures interact with trade openness producing a negative net effect up to a trade openness threshold of 78.066914 (% of GDP) when the negative net effect is nullified. Positive and negative synergy effects are also apparent. Practical policy implications are discussed based on the results obtained.

Keywords: Infrastructures, CO2, trade openness, governance, Africa, System GMM

JEL Codes: N67; N77;C23 ; Q56

1. Introduction

Sustainable development is a significant policy target around the world. In fact, the reduction of greenhouse gas emission is an integral part of these goals. This has prompted international organisations and governments to seek solutions on reducing emissions around the globe. In this respect, there have been collaborations among nations on how to curb greenhouse gas emissions and address climate change. Among these collaborative policies, there is the Conference of Parties (COP21) that was held in Paris in December 2015 regrouping some 196 countries around the globe with the objective of fighting climate change and reducing greenhouse gas emissions (Umar, 2020). At the end of this conference, it was recommended that countries should develop environmental governance strategies in fighting climate change and reducing greenhouse gas emissions. Following the conference, however, greenhouse gas emissions continue to increase with fossil CO2 emission dominating in the total greenhouse gas emissions. To put this in perspective, emission of fossil CO2 in 2019 stood at 38.0 GtCO2 (range: ±1.9) which was a record before that year (UNEP, 2020). In this regards, Ngouhouo and Nchofoung (2021) posit that good environmental governance is necessary for the resilient build-up of countries. Also, there is an increasing body of literature on the economic development-environmental quality nexus. In economic literature, this relationship is summarised around the popular Environmental Kuznets Curve (EKC) hypothesis which implies that CO2 emission grows with increase in economic growth up to a certain level of growth where this relationship becomes negative.

Though Africa contributes to a very low proportion of CO2 emission, its current share today stands at more than 3%, up from 1.9% in 1973. Following the 2020 World Bank Statistics, Africa emitted 1308.5 metric tonnes of CO2 in 2019, up from 1070.2 in 2009. This is more than South and Central America whose emissions were more than that of Africa in 2009 (1096.5) and in 2019 recorded 1254.9 metric tonnes, just lagging behind Africa. At the same time, the emission in Europe rather dropped within the same period (from 4573.5 in 2009 down to 4110.8 in 2019). This indicates that despite global fights to reduce emissions, there is a high tendency for Africa to rather witness a further upsurge in CO2 emissions in the near future. Several factors can be cited to be at the origin of this panic. Firstly, in spite of the wealth of some of the continent's region in renewable energy resources, non-renewable energy fossil fuels (e.g. coal and gas) growingly constitute about two thirds of electricity generation in the continent. Moreover, even after 2030, non-hydro-renewable energy could still constitute only about 10% of the total energy (Alova et al., 2021). The authors argued that by 2030, the energy generation capacity of the continent could increase to 472 gigawatts from 236 gigawatts, with about 9.6% originating from renewable energy sources when hydropower is not included. Secondly, Africa is increasingly being integrated into the global village as a result of increased globalisation (Ngouhouo et al., 2021). This will lead to an increase in economic activities. Since most of Africa is still rural, economic activities will lead to high rates of urbanisation in the continent. In fact, the population of the continent is increasing at a geometric rate and is expected to double in size by 2050 (UNCTAD, 2018). In this respect, Adusah-Poku (2016) argued that increases in both urbanisation and population add CO2 emission in Africa. Thirdly, the continent is rich in natural resources that are yet to be exploited and its vulnerability is intensified by its high dependence on revenues from the exploitation of natural resources. Contemporary literature argues that the exploitation of natural resources exacerbates CO2 emissions (Baloch et al, 2019; Kwakwa, 2020). This is seen in the sense that the exploitation of natural resources pollutes both the soil and the water bodies around. Besides, the exploitation of the natural environment and the increasing threat of deforestation on the continent have been sources of environmental peril.

In the light of the ongoing institutional and economic reforms focused on boosting economic growth, increasing economic diversification and industrialisation, improving systems of transportation and addressing concerns related to the energy crisis in the continent, infrastructural development is increasing and is expected to witness a boom. Moreover, the modernisation, automation and digitisation of the process of production, essential in the achievement of these goals are anticipated to foster investments in infrastructures (Enache et al., 2016; Avom et al. 2020). This transformation could see the destruction of green environments for the benefit of industrial structures. Besides, the same phenomenon is witnessed with growth in urbanisation.

The transformation of the economic structures either in facilitation of trade, in creating urban centres, or in building industries requires high investments in infrastructures. Recently, Africa has witnessed an upsurge in its infrastructure endowments mostly attributed to developments in the ICT sector (Kengdo et al., 2020). Investments in infrastructures in Africa have contributed to more than half of the current economic growth and have the potential to do even more (AfDB, 2018).

In fact, the infrastructure development scores improved for 47 of the 54 African countries between 2016 and 2018 with the global index improving from 27.12 to 28.44 within this period. Given this growth trend in infrastructural development in the continent, Africa can benefit from constructing novel infrastructure that is resilient to climate change, given that owing to fast urban growth, two-thirds of the urban infrastructural investments are still projected to be realised between now and 2050 (AfDB, 2016). Studies on the determinants of CO2 emission have, however, neglected the impact of infrastructural endowment most especially in Africa. However, investment in infrastructure affects the physical environment due to its destruction for the establishment of infrastructures (Seiler, 2002). Moreover, infrastructural development enhances economic growth, and economic growth may increase industrial pollution base through the expansion of the scale of economic activities (Grossman and Krueger, 1991). Existing related studies include Pan et al. (2013) who argue that road freight and rail way transports increase CO2 emission in France. For the Asian economies, Lin and Omoju (2017) highlight the increase in CO2 emission following speedy road infrastructure development. Churchill et al. (2021) argue that transport infrastructures increase CO2 emissions in the Organisation for Economic Co-operation and Development (OECD) countries. In Africa, Engo (2019) shows that CO2 emissions increase with growth in the transport sector in Cameroon. Davis et al. (2010) had earlier argued that the ability of infrastructures to contribute to greenhouse gas emission depends on the type of infrastructures. In this light, they posit that there are infrastructures that directly participate in emissions while there are some that rather participate in producing other infrastructures that subsequently emit greenhouse gases. The objectives of this study are therefore: (i) to analyse the types of infrastructures that matter most in curbing CO2 emission in Africa and (ii) assess the transmission mechanisms through which the underlying is possible.

The contribution of this study is at least threefold. Studies on the effect of infrastructures on CO2 emissions have mostly been limited to the types of road transport infrastructures (Lin and Omoju, 2017; Engo, 2019; Churchill et al., 2021) and ICT development (Asongu et al., 2018; Avom et al., 2020). While the highlighted studies use simple measures for specific types of transports and ICT infrastructures respectively, this is the first study to the best of knowledge to use the composite infrastructural index (the African infrastructural development index) to assess its effect on CO2 emissions. Secondly, the study considers the composite indexes of transports, electricity, ICT, and water and sanitation which no study to the best of knowledge has applied, hitherto on the investigated nexus. Thirdly, literature on the matter, though partial, has mostly focused on the direct effects. This study considers the transmission mechanisms through which infrastructures affect CO2 emissions in Africa. Besides, policy thresholds are provided for the modulating variables where applicable.

2. Review of literature

This sub-section presents two strands of literature. The first strand examines the determinants of CO2 emissions and direct effects of infrastructures on CO2 emissions while in the second strand, the transmission mechanisms are presented.

2.1. Determinants of CO2 emissions

To begin with, Dogan and Seker (2016) through the EKC model for the European Union assess the effects of renewable and non-renewable energy, trade openness and real income on CO2 emissions. After taking into account cross-sectional dependence, the findings from the panel Dynamic Ordinary Least Squares (DOLS) show that trade and renewable energy mitigate CO2 emissions while non-renewable energy increases the emissions. Moreover, they show that there is unidirectional causality flowing from real income to carbon emissions, from trade openness to CO2 emissions and from CO2 emissions to non-renewable energy. Also, Baloch et al. (2019) investigate the effects of the abundance of natural resources on CO2 emissions in BRICS (Brazil, Russia, India, China and South Africa) using the Augmented Mean Group panel technique. The results also show that natural resources abundance reduces CO2 emission in Russia, while in South Africa, it contributes to pollution. Besides, using the 2SLS methodology, Muhammad et al. (2020) examine the effects of international trade and urbanization on CO2 emissions across countries in the 65 Belt and Road Initiative. The results show that export mitigates CO2 emissions in high and low income countries while import reduces CO2 emissions in high-middle and lower-middle income countries. Besides, they validated the pollution havens hypothesis on the positive link between CO2 emission and foreign direct investment.

In Africa, Shahbaz et al. (2013) through the ARDL modelling technique examine the impacts of trade openness, financial development, coal consumption and economic growth, on environmental performance using time series data in South

Africa for the period 1965–2008. The results of their analysis show that Coal consumption has significant contributions in deteriorating the South African economic environment. In addition, trade openness ameliorates environmental quality by decreasing the growth of energy pollutants and there is an existence of the EKC. Moreover, Abid (2016) investigates the impact of economic, financial and institutional developments on CO_2 emissions in SSA employing the GMM estimation technique. The results reveal that democracy, government effectiveness, political stability and control of corruption affect CO_2 emissions. On the contrary, regulatory quality and rule of law have a positive effect. On their part, Jebli and Youssef (2017) for North Africa posit that there is short and long-run bidirectional causality between agriculture and CO_2 emissions. Whereas renewable energy increases CO_2 emissions, agricultural productivity reduces emissions. In the same vein, Bokpin (2017) examines how institutions and governance could regulate how FDI affects environmental sustainability in Africa. The results show that for FDI to engender a positive influence on the sustainability of the environment, it is essential to have strong governance and institutions of quality in place to assess the conduct of businesses that are funded via FDI flows. Furthermore, Tsaurai (2019) examines the effects of financial development on carbon emission in Africa through the OLS, Fixed Effects and Random Effects regression methods. The results indicate that an increase in the domestic credits provided by the private sector leads to an increase in carbon emission. Also, Acheampong et al. (2019) scrutinise the impact of renewable energy and globalisation on CO_2 emissions in Sub-Saharan Africa. The findings show that FDI and renewable energy contribute to the decrease of carbon emissions whereas trade openness reduces environmental quality. Farther, Asongu and Odhiambo (2019) posit that enhancing population growth and economic growth leads to a U-shaped pattern while increasing inclusive human development reveals a Kuznets curve. Baloch et al. (2020) investigate the relationship between poverty, income inequality and CO_2 emissions in Sub-Saharan Africa. The findings from the Driscoll-Kraay regression estimator show that an increase in poverty and income inequality contributes in boosting CO_2 emissions. Recently, Dauda et al. (2021) have studied the non-linear relationship between innovation and CO_2 emissions in Africa using the Fixed Effects and GMM methods. The result of their analyses shows the existence of an EKC for innovation and CO_2 emission whilst renewable energy consumption and human capital reduces CO_2 emissions. Asongu and Odhiambo (2021) assess how governance affects environmental quality in SSA through the GMM method of estimation. The results rejected the hypothesis whereby an increase in economic governance is negatively related to CO2 emission and only partially validate the hypothesis whereby increased political governance is negatively related to CO2 emission.

2.2. Direct effects of infrastructure on CO2 emission

Asongu (2018) through the GMM estimation method assesses how globalisation is complemented by information and communication technology (ICT) in 44 Sub-Saharan African countries in order to influence CO2 emissions over the period 2000–2012. The empirical evidence shows that ICT can be leveraged to reduce the potentially negative impacts of globalisation on the degradation of the environment. Chakamera and Alagidede (2018) uses the Two Stage Least Squares (2SLS) assess how electricity-linked to CO2 emissions affect the growth contributions of both the ratio of electricity transmission and distribution losses (RETDL) and electricity consumption. The results indicate that electricity consumption has a positive effect on economic growth while, the RETDL influences growth negatively. Therefore, deterioration in the quality of electricity decreases economic growth. A high level of CO2 emissions that is electricity-related reduces the growth contributions of electricity consumption and increases the negative growth effect of electricity quality. Asongu et al. (2018) assess how ICT enhances environmental sustainability in SSA. The results from the GMM estimation show that increasing ICT engenders a positive net impact on CO2 emissions per capita whereas growing mobile phone penetration exclusively has a net negative impact on CO2 emissions from liquid fuel consumption.

2.3. Transmission channels through which infrastructures affect CO2 emission

There are several mechanisms through which infrastructures could affect environmental quality. Infrastructural development enhances economic growth, and economic growth may increase the industrial pollution base through the expansion of the scale of economic activities (Grossman and Krueger, 1991). Infrastructural development expands and eases commercial transactions. This will lead to the expansion of economic activities and consequently an increase in emissions. Avom et al. (2020) examine the effects and transmission channels through which ICT affects environmental quality in Sub-Saharan Africa. The results indicate a positive direct effect of ICT on CO2, a positive impact via its impact on financial development and energy consumption and an indirect negative incidence via trade openness. The overall impact was positive.

Another evident channel through which infrastructures could affect CO2 emission is via energy consumption. In this regard, several empirical studies have found that energy consumption increases CO2 emission (Dogan and Seker, 2016; Avom et al., 2020). This is most specifically true for non-renewable energy used. Besides, Dogan and Seker (2016) argue that renewable energy rather mitigates CO2 emissions. Asongu et al. (2019) posit that nations in which CO2 emissions levels are higher consistently experience a less negative impact of renewable energy relative to their counterparts with CO2 emissions levels that are lower. Non-renewable energy sources like coal are becoming exhausted with time and this is also becoming a threat to the environment. The exploitation of forest resources for the establishment of energy infrastructures (for instance electric poles widely used in Africa as wood) is leading to high rate of deforestation which engenders high emissions of greenhouse gases over the years. On the other hand, Afzaland and Gow (2016) find that energy consumption is positively correlated with ICT infrastructures in emerging economies. Dong et al. (2020) argue that despite different income level among countries, renewable energy mitigates CO2 emission and that this mitigating effect can be obscured by increased economic growth.

The next channel through which ICT can affect CO2 emission is through globalisation. Asongu and Nnanna (2021) evaluate how globalisation modulates the effects of governance on CO2 emission in SSA using the GMM regression methodology. The results indicate that there are threshold levels for both trade openness and foreign direct investments required to complement governance in mitigating CO2 emissions. An increase in the stock of infrastructures will ease trade transactions leading to the expansion of economic activities and CO2 emissions. Celbis et al. (2014) argue that infrastructures enhance trade in developing countries. Lorz (2020) argue that governments can facilitate trade by investing in transport infrastructures. At the same time, Dogan and Seker (2016) argue that trade mitigates CO2 emissions. In the same line, Muhammad et al. (2020) argue that trade mitigates CO2 emission and validates the pollution havens hypothesis whereby an increase in foreign direct investment inflows exacerbate the effects of CO2 emission. Asongu (2018) posits that ICT can be employed to dampen the potentially negative effects of globalisation on environmental degradation.

Governance is another transmission channel through which infrastructures can affect CO2 emission. The quality of governance through the setting up of laws related to environmental protection could either exacerbate or mitigate CO2 emission. Also, institutional governance is very essential for ICT adoption (Asongu and Biekpe, 2017). ICT adoption increases the stock of ICT infrastructures. This could have varying effects on governance through collective action (Breuer et al., 2012; Pierskalla and Hollenbach, 2013; Shapiro and Weidmann, 2015; Manacorda and Tesei, 2016; Asongu and Biekpe, 2017). Better ICT infrastructures will reduce corruption (Ionescu, 2013). Although a boost in ICT investment provides infrastructure in technology that can control and monitor corruption effectively, corruption can also increase with the advent of more investment avenues (Charoensukmongkol and Moqbel, 2014). However, governance quality greatly matters for CO2 emissions. In fact, empirical studies including Baloch and Wang (2019) argue that governance lowers CO2 emissions and improves the quality of the environment. Asongu and Odhiambo (2021) rejected the hypothesis whereby an increase in economic governance is negatively related to CO2 emission and only partially validates the hypothesis whereby increased political governance is negatively related to CO2 emission.

The highlighted literature has mostly focused on the determinants of CO2 emission and their transmission mechanisms. No study has actually focused on the effects of infrastructures on CO2 emission. Moreover, studies on the determinants of CO2 emission in Africa are still emerging. Also, the transmission mechanisms through which infrastructures affect CO2 emission is under-exploited. This study thus tries to fill these gaps.

3. Econometric Strategy

3.1. Empirical model specification

Inspired by the work of Asongu et al. (2018), the following empirical model is specified in Equation (1) as follows:

$$CO2_{it} = \beta_0 + \beta_1 INFRA_{it} + \beta_2 trade_{it} + \beta_3 Goovernance_{it} + \beta_j X_{it} + \upsilon_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where CO2 is carbon dioxide emission per capita, INFRA is the composite infrastructural development index, trade is trade openness (sum of exports to imports to GDP), Governance is the composite index of the Kaufmann et al. (2010)

governance indexes, X is a vector of other control variables including foreign direct investment inflows (FDI) and natural resource rents (Resource-rents).

Dependent variable

The dependent variable is carbon dioxide (CO_2) emission per capita. Several empirical studies have adopted this as a measure of environmental quality. These include Asongu et al. (2018) and Asongu and Nnanna (2021).

Independent variable of interest

The independent variable of interest is the infrastructural development index. In the first place, this study used the African Infrastructural Development Index (AIDI). Its constituent sub-indexes are further used, including Information and Communication Technology composite index (ICT), the transport composite index (Transport), the water and sanitation composite index (WSS) and the electricity composite index (Electricity). These indexes have been used in contemporary literature to capture infrastructural development including the works of Kengdo et al. (2020) and Nchofoung et al. (2021). Asongu et al. (2018) argue that increasing ICT has a positive net effect on CO_2 emissions per capita. ICT is a constituent variable of the infrastructural development variable adopted in this study. Infrastructural development is thus expected to have a positive effect on CO_2 emission in this study. From the previous arguments, the first hypothesis of the study can be stated thus: **Infrastructural development positively and significantly impacts CO_2 emission in Africa.**

Control Variables

Governance is used as an average of the six governance indicators of Kaufmann et al. (2010). This composite index is in accordance with Ngouhouo et al. (2021). Asongu and Odhiambo (2021) posit that governance is positively related to CO_2 emission. A similar result is thus expected in this study. Trade openness (trade) is used as the sum of exports and imports to GDP. Muhammad et al. (2020) posit that imports increase carbon emissions in low income countries, while decrease it in middle and high income countries. Given that Africa is made up of different income groups, a positive or negative result is thus expected in this study. Similarly, FDI was found to increase CO_2 emissions in the aforementioned study. A similar situation is expected in this study. Also, Baloch et al. (2019) argue that natural resources contribute to pollution in South Africa. A positive sign is thus expected to be associated to this variable. From the previous developments, the second hypothesis of the study is stated thus: governance and trade openness are the modulating mechanisms via which infrastructures influence CO2 emission in Africa

To include the effect of the interactive effect, Equation (1) can be specified as in Equation (2) as:

$$CO2_{it} = \beta_0 + \beta_1 INFRA_{it} + \beta_2 trade_{it} + \beta_3 Governance_{it} + \beta_j X_{it} + \pi_1(Governace_{it} \text{ x } INFRA_{it}) + \pi_2(trade_{it} \text{x } INFRA_{it}) + \mu_{it} \qquad (2)$$

Where β the direct effect coefficients and π is the indirect effect coefficient. Differentiating Equation (2) in first place with respect to infrastructures yields Equation (3) as follows:

$$\frac{\partial CO2}{\partial INFRA_{it}} = \beta_1 + \pi_1 Governace_{it} + \pi_2 trade_{it} \qquad (3)$$

Where **∂** is the partial derivative operator. Considering governance and trade as the transmission channels in this case, unit change in CO2 emission depends on the signs and coefficient of β and π. Based on the signs and significance of the direct and indirect coefficients, we can eventually have a net effect, in which case, Equation (2) is specified further as

$$CO2_{it} = \beta_0 + \beta_1 INFRA_{it} + \beta_2 trade_{it} + \beta_3 Governance_{it} + \beta_j X_{it} + \pi_1(Governace_{it} \text{ x } INFRA_{it}) + \pi_2(TRADE\text{x } INFRA_{it}) + (\beta_1 + (\Omega \times \pi)) + \mu_{it} \qquad (4)$$

The only condition for Equation (4) to hold is that β_1 and π are opposing in signs and both significant. Here Ω is the average of the modulating variable. If the above conditions are satisfied, then there exists a threshold effect for the modulating variable required for the net effect to be nullified. This is specified by equating Equation (3) to zero. In such a case,

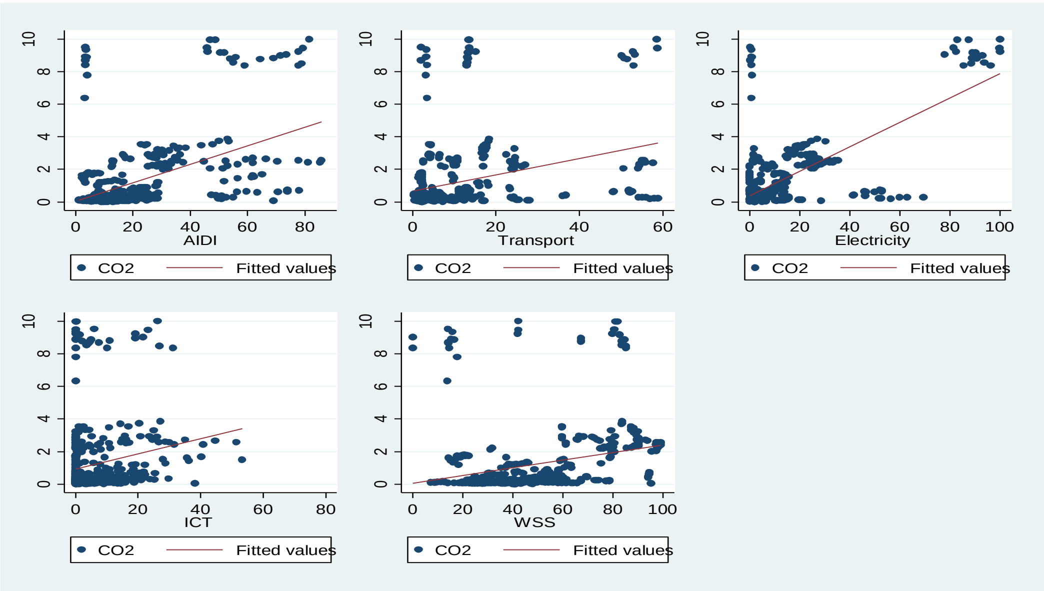
$$Threshold \xrightarrow{yields} \begin{cases} Governace = \frac{\beta_1}{\pi_1} \\ trade = \frac{\beta_1}{\pi_2} \end{cases} \qquad (5)$$

However, if the values computed in Equation (5) are not within the range of values of the modulating variables, then this threshold is not evident, and as a result, it is needless computing in such a case.

3.2. Data

The data for this study are collected for 36 African countries[1] between the 2003-2019 periods. The data for the infrastructure variables are collected from the African Development Bank, and governance variables are from the World Governance Indicators (WGI) of the World Bank. The rest of the variables are from the World Development Indicators (WDI) of the World Bank.

Figure 1. Scatter plots linking CO2 emission and different infrastructures



Source: Authors' computation

Figure 1 indicates that there is a positive link between infrastructures and CO2 emission across all the infrastructural development measures. However, there are several macroeconomic indicators that could influence this relationship. In this respect, the following section presents a suitable regression methodology in tackling this through the linear model specified in (1).

3.3. Estimation Method

[1]Algeria, Angola, Botswana, Burkina Faso, Cameroon, Congo Democratic Republic, Congo Republic, Côte d'Ivoire, Egypt, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Libya, Madagascar, Malawi, Mali,Morocco, Mozambique, Namibia, Niger, Nigeria, Senegal, Sierra Leone, South Africa, Sudan, Tanzania (United Republic of), Togo, Tunisia, Uganda, Zambia, Zimbabwe.

We use the system GMM in this study. Several factors motivated the choice of this regression algorithm. Firstly, our dependent variable (CO2) is highly correlated with it first period lag. In fact, the coefficient of correlation between the CO2 and its lag value is 0.9929. This motivated the inclusion of the lagged dependent variable as one of the explanatory variables of the model. Secondly, our time dimension (20 years) is smaller than the cross-sectional dimension (36 countries). Following Roodman (2009), the first condition for GMM to be used in any regression is that the cross-sectional dimension should be greater than the time dimension, which is the case with our data. Thirdly, the inclusion of the lagged dependent variable in the model results in it correlating with the fixed effects in the error term and such a correlation engenders a dynamic panel bias when estimated with methods like OLS (Nickell, 1981). The GMM estimation method resolves this bias and equally controls for cross-country dependence across panels (Nchofoung et al., 2021).

The main problem usually associated with the GMM estimation is the problem of too many instruments. Though there is no precise figure of the number of instruments that is considered too many, Roodman (2009) as an extension of the Arellano and Bover (1995) adopted the forward orthogonal deviation to limit instruments' proliferation and maximize sample size. This method in its computational methodology subtracts the average of all future available observations of a variable instead of subtracting previous observations from the concomitant ones. This limits the number of lags of the regressors that could remain orthogonal to the error and available as instruments in the regression. We adopt the said forward orthogonal deviation methodology in this study to limit instrument proliferations. Given that the *one-step* procedure is consistent with homoscedasticity, we used the *two-step* procedure to control for heteroscedasticity instead.

The following equations Equation (6) and Equation (7) respectively, summarize the GMM procedure in level and in difference.

$$CO2_{it} = \beta_0 + \beta_1 CO2_{i(t-\tau)} + \beta_2 INFRA_{it} + \sum_{h=1}^{k} \delta_h W_{h,i(t-\tau)} + \upsilon_t + \gamma_i + \varepsilon_{it} \qquad (6)$$

$$\begin{aligned} CO2_{it} - CO2_{i(t-\tau)} &= \beta_1\big(CO2_{i(t-\tau)} - CO2_{i(t-2\tau)}\big) + \beta_2\big(INFRA_{it} - INFRA_{i(t-\tau)}\big) + \sum_{h=1}^{k} \delta_h\big(W_{h,i(t-\tau)} \\ &- W_{h,i(t-2\tau)}\big)\,(\upsilon_t - \upsilon_{t-\tau}) + \varepsilon_{i(t-\tau)} \qquad (7) \end{aligned}$$

The variables are defined as above.

Another problem that the GMM estimation could have is the problem of identification, simultaneity and restrictions. In this regard, all our explanatory variables are suspected to be a source of endogeneity and treated as endogenous in accordance with contemporary literature (Asongu and Nwachukwu, 2016; Asongu and Leke, 2019; Nchofoung et al., 2021). Besides, period dummies are used as instruments in both the level and difference equations.

4. Results and Discussion

4.1. Direct effect

Table 1 presents the results of the direct effect regression while Tables 2 and 3 present the indirect effect regressions. The results from Table 1 show that the composite infrastructural development indicator exacerbates environmental quality in our sample. This result is replicated when the composite indicators of transport, electricity, ICT and water and sanitation infrastructures are used. This shows that infrastructural development has led to an increase in CO2 emission in Africa.

However, for the said results to be valid there should be an absence of both first and second order autocorrelation of residuals. In which case, the probability of AR1<10% and AR2>10% for first and second order autocorrelations, respectively. Also, the null hypothesis of the Sargan and Hansen over-identification restrictions tests for the validity of instruments should not be rejected (that is P-value >10%). Besides, the null hypothesis of the Fisher statistics for the overall significance of the model should be rejected (that is P-value should be<10%). Moreover, the Difference in Hansen Test (DHT) for exogeneity of instruments is employed to assess the validity of results from the Hansen test of over-identification restriction, in which case the null hypothesis of exogeneity should not be rejected. Lastly, the number of instruments is kept to be less than the number of cross-sections as recommended in Roodman (2009).

Our results actually meet these criteria highlighted above. To test the validity of our instruments, we focused on the Hansen test and the difference in Hansen test instead of the Sargan test. This is principally because Sargan is not robust and its power is not weakened by instrument proliferations.

Given the positive links established in Table 1, there is necessity to see through which mechanisms infrastructural development can instead mitigate CO2 emission, given the importance of infrastructures for economic development. Tables 2 and 3 present these results.

Table 1. Direct effect of infrastructures on CO2 emission

Variables	(1)	(2)	(3)	(4)	(5)
	Dependent Variable=CO2				
L.CO2	0.973***	0.941***	0.938***	0.969***	0.964***
	(0.00969)	(0.0126)	(0.0145)	(0.0107)	(0.0132)
Aidi	0.00139*				
	(0.000707)				
Fdi	-0.00116	0.000492	0.000800**	-0.000368	-0.000457
	(0.000422)	(0.000363)	(0.000296)	(0.000386)	(0.000386)
Trade	0.000987***	0.00158***	0.00213***	0.00143***	0.00115***
	(0.000190)	(0.000255)	(0.000230)	(0.000270)	(0.000297)
Resource rents	0.00807***	0.00812***	0.00335***	0.0109***	0.00883***
	(0.00105)	(0.00174)	(0.00105)	(0.00165)	(0.00145)
Governance	0.159***	0.296***	0.364***	0.339***	0.284***
	(0.0442)	(0.0668)	(0.0424)	(0.0693)	(0.0734)
Transport		0.00455***			
		(0.00112)			
Electricity			0.00779***		
			(0.000605)		
Ict				0.00120*	
				(0.000697)	
Wss					0.00225**
					(0.000912)
Constant	-0.0686**	0.00663	0.0259	0.0206	-0.102*
	(0.0288)	(0.0429)	(0.0393)	(0.0540)	(0.0518)
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Observations	452	452	452	452	452
Number of countries	36	36	36	36	36
Prop>AR1	0.068	0.065	0.070	0.067	0.065
Prop>AR2	0.170	0.175	0.187	0.168	0.176
Instruments	33	33	33	33	33
Prop>Sargan	0.0000	0.000156	2.17e-06	0.0833	0.0303
Prop>Hansen	0.607	0.754	0.205	0.771	0.543
Fisher	11121***	7113***	4086***	6280***	6709***
DHT for instruments					
(a) In level					
H excluding groups	0.770	0.706	0.240	0.660	0.325
Dif(null H=exogenous)	0.425	0.634	0.251	0.681	0.615
(b) iv(years, eq(d))					
H excluding groups	0.551	0.577	0.383	0.953	0.413
Dif(null H=exogenous)	0.546	0.702	0.186	0.635	0.527

NB: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; ICT is the information and communication technology index, WSS is the water and sanitation index, AIDI is the African infrastructural development composite index, and FDI is foreign direct investment inflows

Source: Authors' computation

4.2 Transmission Mechanisms

In Table 2, infrastructural development interacts with governance producing a positive direct effect and a negative indirect effect. The direct effect outweighs the indirect effect producing a positive net effect. This is up to a governance threshold of 0.532 composite index when the positive net effect is nullified. As a result, for infrastructures to have a mitigating effect on CO_2 emission in Africa, the governance level is required to go above this threshold. When alternative measures of governance are used (see appendix), their interaction with infrastructures produces negative synergy effects for control of corruption and regulatory quality; positive synergy effects for rule of law and political stability; and positive net effects for government effectiveness and, voice and accountability. These positive net effects are nullified at the thresholds of 1.141689 and 0.940746 respectively, for government effectiveness and voice and accountability. In Table 3, infrastructures interact with trade openness producing a negative direct effect and a positive indirect effect. This direct effect supersedes the indirect effect producing a negative net effect. This is up to a trade openness threshold of 78.066914 (%GDP) when the negative net effect is nullified. Looking at other sub-composite indexes, the net effect which interacts with trade are rather positive for electricity and ICT up to trade openness thresholds of 175.773 (%GDP) and 60.64 (%GDP) respectively, when these positive links are nullified.

Table 2. Indirect effect through Governance

Variables	(1)	(2)	(3)	(4)	(5)
	Dependent Variable: CO2				
L.CO2	0.00753	0.320***	0.782***	0.340***	0.978***
	(0.0182)	(0.0909)	(0.0167)	(0.0184)	(0.0230)
Aidi	0.00266***				
	(0.000331)				
Fdi	0.000607**	-3.01e-05	-7.43e-05	0.000176*	0.000463
	(0.000224)	(0.00158)	(9.40e-05)	(8.78e-05)	(0.000749)
Trade	0.000926***	-0.00127	0.00139***	0.00133***	0.000275
	(8.08e-05)	(0.000820)	(0.000195)	(0.000162)	(0.000318)
Resource rents	0.000140	-0.00284	0.00340***	0.00400***	0.00590***
	(0.000258)	(0.00205)	(0.000937)	(0.000609)	(0.00145)
Governance	0.0615***	0.296*	0.162***	0.199***	-0.799***
	(0.0139)	(0.171)	(0.0305)	(0.0328)	(0.159)
Governance×aidi	-0.00500***				
	(0.000349)				
Transport		-0.0451***			
		(0.00645)			
Governance×transport		-0.0636***			
		(0.00780)			
Electricity			0.00675***		
			(0.000351)		
Governance×electricity			0.00336***		
			(0.000788)		
Ict				-0.000474	
				(0.00117)	
Governance×ict				-0.00226*	
				(0.00130)	
Wss					0.00574***
					(0.00125)
Governance×wss					0.0114***
					(0.00223)
Net Effect	0.005955	s.e	S.e	n.a	s.e
Threshold	0.532	----	----	-----	------
Constant	0.864***	1.550***	0.129***	0.683***	-0.578***
	(0.0954)	(0.262)	(0.0352)	(0.0676)	(0.0715)
Observations	452	452	452	452	452
Number of countries	36	36	36	36	36
Prop>AR1	0.078	0.038	0.088	0.073	0.085
Prop>AR2	0.881	0.416	0.195	0.134	0.179
Instruments	31	25	25	31	25
Prop>Sargan	0.0000	0.00136	0.000212	4.74e-06	0.0135
Prop>Hansen	0.257	0.225	0.190	0.238	0.252
Fisher	754.8***	27.02***	742.9***	330.0***	2034***
DHT for instruments					
(a) In level					
H excluding groups	0.258	0.179	0.184	0.228	0.129
Dif(null H=exogenous)	0.308	0.340	0.280	0.304	0.452

(b) iv(years, eq(d))					
H excluding groups	0.163	0.424	0.415	0.258	0.653
Dif(null H=exogenous)	0.485	0.187	0.155	0.309	0.145

NB: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; ICT is the information and communication technology index, WSS is the water and sanitation index, AIDI is the African infrastructural development composite index, and FDI is foreign direct investment inflows, CO2 is environmental quality.

Source: Authors' computation

Table 3. Indirect effect through trade openness

Variables	(1) co2	(2) co2	(3) co2	(4) co2	(5) co2
L.CO2	0.582***	0.521***	0.344***	0.575***	0.562***
	(0.0550)	(0.0629)	(0.0371)	(0.0493)	(0.0314)
Aidi	-0.0420***				
	(0.0101)				
Fdi	0.00176	-0.000878	0.00123	-0.000751***	-0.000600***
	(0.00106)	(0.00116)	(0.000865)	(0.000191)	(0.000172)
Trade	-0.00801***	-0.00123	0.000175	0.000532**	0.000132
	(0.00190)	(0.00177)	(0.000456)	(0.000232)	(0.000562)
Resource rents	-0.00859***	-0.00431**	-0.00630***	0.00414***	0.00385***
	(0.00199)	(0.00203)	(0.00221)	(0.00108)	(0.00115)
Governance	0.154	0.464**	-0.264*	0.186***	0.181***
	(0.236)	(0.184)	(0.133)	(0.0372)	(0.0502)
Trade×aidi	0.000538***				
	(0.000112)				
Transport		-0.0210*			
		(0.0122)			
Trade×transport		0.000221			
		(0.000138)			
Electricity			0.0341***		
			(0.00844)		
Trade×electricity			-0.000194**		
			(7.75e-05)		
Ict				-0.00758***	
				(0.00131)	
Trade×ict				0.000125***	
				(2.62e-05)	
Wss					0.00160
					(0.000963)
Trade×wss					1.49e-05
					(1.24e-05)
Constant	2.306***	1.956***	0.836***	0.393***	0.321***
	(0.236)	(0.235)	(0.183)	(0.0913)	(0.0696)
Net Effect	-0.004414	--	0.020547	0.001115275	---
Threshold	78.066914		175.773	60.64	----
Observations	452	452	452	452	452

Number of countries	36	36	36	36	36
Prop>AR1	0.000119	0.025	0.030	0.064	0.082
Prop>AR2	0.317	0.284	0.231	0.164	0.185
Instruments	25	25	25	25	25
Prop>Sargan	0.207	0.0604	0.00929	0.00121	0.000449
Prop>Hansen	0.285	0.276	0.507	0.511	0.364
F	26.98***	27.59***	408.5***	213.5***	115.8***
DHT for instruments					
(a) In level					
H excluding groups	0.402	0.304	0.433	0.355	0.110
Dif(null H=exogenous)	0.259	0.304	0.498	0.559	0.668
(b) iv(years, eq(d))					
H excluding groups	0.822	0.354	0.370	0.813	0.811
Dif(null H=exogenous)	0.128	0.274	0.543	0.306	0.185

NB: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; ICT is the information and communication technology index, WSS is the water and sanitation index, AIDI is the African infrastructural development composite index, and FDI is foreign direct investment inflows, CO2 is environmental quality.
Source: Authors' Computation

5. Conclusion, policy implications and caveats

The objective of this study was to empirically verify the effect of infrastructures on CO2 emission in 36 African countries between the 2003 and 2019 periods. The contribution of this study is at least threefold. This is the first study to the best of knowledge to have used the composite infrastructural index (the African infrastructural development index) to verify its effects on CO2 emission. Secondly, the study considered the composite indexes of transports, electricity, ICT, and water and sanitation which no study to the best of knowledge has applied on the matter. Thirdly, this study examines the transmission mechanisms through which infrastructures affect CO2 emission in Africa. The results from the system GMM methodology reveal various tendencies. Regression on the direct effect regression shows that infrastructural development exacerbates CO2 emission in Africa; a result that was robust across different types of infrastructural development indexes.

When the regression on the indirect effect was carried out by interacting governance and trade openness with the different infrastructural development variables, the results were as follows. Firstly, infrastructural development interacts with governance producing a positive net effect. This was up to a governance threshold of 0.532 when the positive net effect was nullified. When alternative measures of governance were used, their interactions with infrastructures produced negative synergy effects for control of corruption and regulatory quality; positive synergy effects for the rule of law and political stability; and positive net effects for government effectiveness, and voice and accountability. These positive net effects were nullified at the thresholds of 1.141689 and 0.940746 respectively for government effectiveness and voice and accountability. Secondly, infrastructures interact with trade openness producing a negative net effect. This was up to a trade openness threshold of 78.066914 (%GDP) when the negative net effect was nullified. Looking at other sub-composite indexes, the net effect which interacts with trade was rather positive for electricity and ICT up to trade openness thresholds of 175.773 (% GDP) and 60.64 (% GDP) respectively, when these positive links were nullified.

This work engages policy makers in Africa on the right policy options to adopt in their durable quest for structural transformation that necessitates huge infrastructural development and the fight against greenhouse gas emission in the process. In this light, there is need for further improvements in the governance quality across the continent. Thus, the average governance quality in the continent should exceed the threshold value of 0.532 for infrastructures to have a mitigating effect on CO2 emission. To easily achieve this, the control of corruption and government effectiveness thresholds of 1.141689 and 0.940746 respectively, should be exceeded in each economy. Also, to further mitigate CO2 emission while engaging in structural transformation, trade openness should be encouraged. However, the trade openness threshold of 78.066914 (%GDP) should be avoided because it will rather nullify this mitigating effect. As regards the trade openness policies for specific infrastructural development types, trade openness thresholds of 175.773(%GDP) and 60.64 (%GDP) are needed respectively for electricity and ICT infrastructures to have a mitigating effect on CO2 emission.

Future studies on the subject could consider sub-regional and country specific studies for specific policy orientations. Moreover, other modulating policy variables could be used to assess alternative complementary policy thresholds.

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Availability of Data: the data supporting this research are openly available at:

-the World Bank at;https://databank.worldbank.org/source/world-development-indicators and https://databank.worldbank.org/source/worldwide-governance-indicators;

-The African Development Bank at:

https://infrastructureafrica.opendataforafrica.org/rscznob/africa-infrastructure-development-index-aidi

-**Code Availability**: Not applicable

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Appendix

A1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Aidi	612	21.207	18.499	1.244	87.23
Transport index	612	10.168	12.691	0	58.756
Electricity index	610	10.972	19.387	.054	100
Information and communication technology	612	7.018	10.061	0	67.391
Water and sanitation	612	50.003	22.601	0	99.014

co2	495	1.192	2.102	.021	9.998
governance	612	-.661	.528	-1.957	.88
Trade	601	69.862	31.323	16.669	311.354
resource rents	576	14.771	12.675	.49	68.79
Foreign direct investments	611	4.576	8.582	-6.37	103.337
corruption	612	-.687	.529	-1.627	1.217
government eff	612	-.727	.534	-1.922	.726
Regulatory quality	612	-.663	.556	-2.347	.804
Rule of law	612	-.675	.55	-1.852	.731
Voice and accountability	612	-.59	.629	-1.983	.736
political stability	612	-.623	.823	-2.665	1.2

NB: CO_2 is environmental quality, AIDI is the African infrastructure development index.

A2. Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) co2	1.000																
(2) L.co2	0.993	1.000															
(3) aidi	0.489	0.479	1.000														
(4) transport	0.292	0.283	0.814	1.000													
(5) electricity	0.691	0.683	0.796	0.652	1.000												
(6) ict	0.203	0.197	0.590	0.264	0.244	1.000											
(7) water and sanitation	0.253	0.245	0.752	0.564	0.474	0.304	1.000										
(8) governance	0.187	0.179	0.226	0.161	0.211	0.091	0.243	1.000									
(9) trade	0.147	0.141	0.033	0.062	0.090	-0.008	-0.034	-0.013	1.000								
(10) resource rents	0.264	0.259	0.016	0.084	0.178	-0.034	-0.175	-0.438	0.387	1.000							
(11) fdi	-0.130	-0.131	0.028	0.196	0.078	-0.077	-0.032	0.002	0.278	0.143	1.000						
(12) corruption	0.206	0.198	0.257	0.198	0.198	0.102	0.292	0.931	0.056	-0.428	0.019	1.000					
(13)	0.30	0.29	0.31	0.15	0.25	0.15	0.37	0.897	-	-	-	0.868	1.00				

governmenteffectiveness	2	4	0	6	4	8	7		0.083	0.479	0.113		0				
(14) regulatoryquality	0.129	0.122	0.216	0.141	0.170	0.101	0.261	0.907	-0.164	-0.493	-0.056	0.819	0.859	1.000			
(15) rule oflaw	0.205	0.198	0.279	0.193	0.212	0.134	0.305	0.951	-0.063	-0.444	-0.036	0.899	0.894	0.885	1.000		
(16) voice andaccountability	0.025	0.020	0.030	0.017	0.065	-0.013	0.047	0.821	-0.007	-0.439	0.082	0.746	0.646	0.728	0.723	1.000	
(17) political_stability	0.143	0.137	0.142	0.150	0.210	0.031	0.075	0.774	0.132	-0.123	0.072	0.631	0.551	0.562	0.662	0.507	1.000

NB: FDI is foreign direct investment inflows, ICT is information and communication technology, AIDI is the African infrastructures development index, CO_2 is environmental quality.

A3. Indirect effect with alternative measure of governance

	(1)	(2)	(3)	(4)	(5)	(6)
Variables			Dependent variable: CO2			
L.co2	0.0653***	0.233***	0.292***	0.123***	0.537***	0.119***
	(0.0237)	(0.0238)	(0.0402)	(0.0109)	(0.0352)	(0.00924)
AIDI	-0.00777***	0.00419**	0.0109***	0.0122***	0.00160**	0.00791***
	(0.00215)	(0.00177)	(0.00278)	(0.00216)	(0.000635)	(0.000240)
FDI	0.00171**	0.00163**	0.000732	-0.000183	-0.000478*	0.000127
	(0.000718)	(0.000718)	(0.000922)	(0.000542)	(0.000273)	(9.34e-05)
Trade	-0.00428***	-0.000758***	-0.00166***	0.000694***	0.000547	0.000807***
	(0.000714)	(0.000225)	(0.000503)	(0.000202)	(0.000391)	(7.68e-05)
Resource rents	0.00265	-0.000737	0.00564*	-0.00257***	0.00456***	0.000136
	(0.00203)	(0.00126)	(0.00302)	(0.000378)	(0.00121)	(0.000334)
Corruption (A)	-1.002***					
	(0.188)					
A×AIDI	-0.0143***					
	(0.00281)					
government_eff (B)		-0.557***				
		(0.0521)				
B×AIDI		-0.00367**				
		(0.00167)				
Regulatory quality(C)			-0.522***			
			(0.0940)			
C×AIDI			0.00305			
			(0.00298)			
Rule of law (D)				-0.0316		
				(0.0556)		
D×AIDI				0.00422*		
				(0.00222)		
voice_account (E)					0.168*	
					(0.0838)	
E×AID					-0.00169*	
					(0.000914)	
Political stability (F)						-0.0545***
						(0.00517)
F×AID						0.00418***
						(0.000108)
Constant	0.514**	0.711***	0.630***	0.891***	0.294**	0.719***
	(0.202)	(0.138)	(0.214)	(0.134)	(0.113)	(0.0676)
Net effect	s.e	0.00685809	s.e	s.e	0.002971	s.e
Threshold		1.141689			0.946746	
Observations	452	452	452	452	452	452
Number of countries	36	36	36	36	36	36
Prop>AR1	0.027	0.031	0.089	0.036	0.054	0.005
Prop>AR2	0.551	0.341	0.353	0.419	0.151	0.159
Instruments	31	31	25	31	25	31
Prop>sargan	0.0258	0.0117	0.000279	6.36e-05	0.00332	1.50e-09
Prop>Hansen	0.867	0.413	0.217	0.243	0.574	0.175
Fisher	18.08***	110.0***	115.4***	497.7***	80.80***	1573***

NB: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; ICT is the information and communication technology index, WSS is the water and sanitation index, AIDI is the African infrastructural development composite index, and FDI is foreign direct investment inflows; CO_2 is environmental quality.