Greenhouse Gas Emission Widens Income Inequality in Africa

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Greenhouse Gas Emission Widens Income Inequality in Africa

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Abstract

Over the past couple of decades, we have witnessed a rise in greenhouse gas emissions and widening income inequality that threaten human well-being. Addressing these challenges and ensuring sustainable economic growth becomes a pressing issue for the development policy agendas across Africa. This paper offers an answer for the impact of greenhouse gas emissions on income inequality by taking the most vulnerable region. In doing so, a panel data set from 1981-2015 across 49 countries are used and applied a panel data fixed effect regression and instrumental variable method (IV). We establish s causal relationship and show that greenhouse gas emission widens income inequality. We further cemented our baseline finding using alternative emission indicators typical to the Agrarian society. Our findings shed light on alternative development policy choices to the African continent where the traditional policy prescription does not fit the current dynamics in demography, urbanization, and agricultural practices. Hence, we emphasize the Agriculture Development Lead Industrialization (ADLI) policy that places high importance on transforming the livelihood of the people engaged in agriculture. The approach has proven to unlock the trinity challenge posed by environmental degradation, income inequality, and stagnant economic growth. Indeed, industrialization can be realized through transforming agriculture first. Adding value to agriculture reduces emission, redistributes income, and eventually maintains steady per capita income growth in Africa.

Key Words: Africa, Carbon, Emission, Fossil Fuel, Greenhouse, Income-Inequality, Methane

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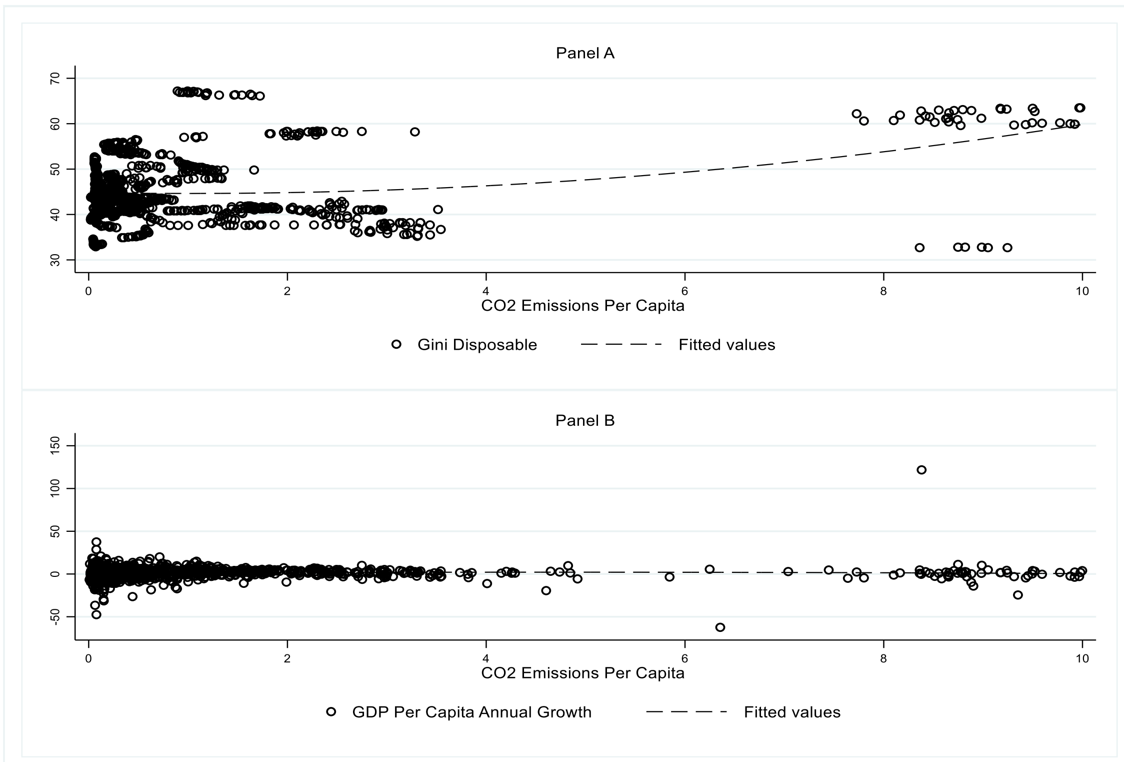
Declaration

- Ethics approval and consent to participate "Not Applicable."
- Consent for publication "Not applicable."
- The datasets generated and analyzed during the current study are available from (Solt, 2020). The database provides a set of Gini index equalized (square root scale) household disposable income, using Luxembourg Income Study data as the standard. We have also used the (WDI, 2021) for other indicators.
- The authors declare that there is no competing interest.
- There is no funding body for this study.
- Authors' contributions: the corresponding author design the study, perform the analysis, wrote the paper, and was the sole owner of the article.

1. Introduction

Two of the leading global challenges facing the world citizens are the unprecedented climate change and widening income inequality that resulted in disproportionate burdens on the world's poor. Thus, combating them must involve reducing the vulnerabilities of the poor (Rao & Min, 2018). When speaking about the so-called "the poor," the African continent caught the development policy discussion. In this paper, our objective is to empirically examine the impact of greenhouse emissions on income inequality in Africa.

Figure 1. Relationship between Carbon Emissions, Income Inequality & GDP. Growth



Note: The scatter plot shows the relationship between Gini Disposable against carbon emissions per capita (CO2) (Panel A) and Gross Domestic Product (GDP) Per Capita Growth against CO2 (Panel B). The data covers from 1981-2015 across 49 countries.

A shred of empirical works in the environmental economics literature is motivated to test the inverted U-shaped hypothesis Kuznets (1955) using a range of datasets (Sohag et al., 2019). When the state of human well-being improved, the need for energy consumption also increases. Given two-thirds of the population lives in rural areas, under subsistence farming, uses coal, combust, and other gaseous fuels for energy consumption (Henderson et al., 2017). Hence, the desire to emit fewer greenhouse gases to the environment is not the issue that comes to the mind of a typical farmer. Because what is essential to the farmer in Africa and the elites in the environment, growth and inequality disciplines are not compatible.

Existing knowledge about greenhouse emissions and income inequality in Africa is scarce. Thus, finding a prudent policy in pursuit of rapid economic development, maintaining a balance with environmental quality, and reducing income inequality between the poor and rich has been a fancy choice for a long period among policymakers.[2]

We formulate our research question from (Figure 1). A rise in carbon emission (CO2) leads to a substantial increase in the Gini index measured by Gini disposable. To get a sense of the relationship, countries with higher CO2 emissions recorded a higher income inequality and vice versa. Second, the impact of CO2 emission is pronounced in increasing income inequality than GDP Per Capita growth, even though a positive relationship has been depicted. Therefore, in this paper, we answered the intertwined question of how to warrant sustainable economic growth by narrowing income inequality and containing greenhouse emissions to the lowest level for the economies under transition? More specifically, how do African countries compromise the impact of environmental degradation with the need to develop the economy and ensure equitable income distribution amongst citizens? We offer an answer to these questions following different identification assumptions.

Consequently, three contributions were pinpointed. First, most countries need economic development and pull their people out of poverty, yet the question that remains unanswered is how these nations achieve the objective by maintaining environmental quality? We offer an agricultural value addition approach to this quest that deviates from the traditional "Agrarian-to-modern society approach." Second, the continent also needs to ensure evenly distributed income amongst its citizens. A tradeoff between CO2 emission, Gini disposable, and GDP per capita growth is a thorough empirical investigation that shows the opportunities that have not been utilized effectively yet play an essential role for sustainable economic transformation through benefiting all citizens in the continent is identified. Third, environmental degradation is not under the mere control of domestic policies due to its global dimension. If Africa needs to feed its population mitigating the impact of climate change should give paramount importance.[3]

To answer the underlying question, we used a panel data set from 1981-2015 from World Development Indicators (WDI, 2021) and the Standardized World Income Inequality Database (SWIID) Solt (2020) for a panel of 49 African countries. We cannot cover the most recent years due to data limitations in the income inequality dataset. Moreover, we employed a panel data fixed effect estimation and instrumental variable method (IV) to establish causality. After that, we confirm that our estimators display a causal relationship using a series of robustness tests.

Our finding shows that greenhouse emission in CO2, agricultural methane gas, and fossil fuel energy consumption widens income inequality. A series of econometric tests justify that our estimators are robust. Given this relationship, we propose a feasible strategy to grow the African continent and indicate an alternative development strategy that drifts from the orthodox view that "industrial development is an engine of growth."

From the intertwined problem point of view, Africa has comparative advantages in agricultural value addition. The vein of our proposal is Agriculture Development led Industrialization policy (ADLI), which gives due attention to transforming smallholder agricultural practices. We claim this approach based on the comparative advantages of the sector in creating employment, the immense potential to access arable land, the water resource available to use for agriculture, and demographic advantages (i.e., the continent endowed with young age citizens). Our proposal has an empirical foundation that promoting agriculture reduces greenhouse emissions, creates job opportunities to distribute income, and eventually conserves environmental quality.

The subsequent section is organized as follows. In section 2, we present our material and method, section 3 presents the main empirical results using ordinary least squared (OLS) and two-stage least squared (2sls)

[2] *We should know that specific country cases can be provided, such as Ethiopia. The nation that have a long term plan to recover the environmental depletion by a massive afforestation program are in place. rd of 4-5 billon seedlings during the rainy season and maintained a positive growth for over the past couple of years.*
[3] *Note that the agricultural practices of small farm household is exposed to environmental tsunami like draught, rain, flood, and rising temperature.*

methods. In section 4, we discuss why agriculture is still important to answer the intertwined effect of climate change, income inequality, and sustainable economic growth. Finally, in section 5, we conclude and forward future policy insights.

2. Material and Method

In this paper, we used two datasets-the Standardized World Income Inequality Database (SWIID) from (Solt, 2020). The database provides a set of Gini index equalized (square root scale) household disposable income, using Luxembourg Income Study data as the standard. We have also used the (WDI, 2021) to proxy greenhouse emission and other control variables (see Online Appendix 1a) for variable definition. Due to data limitation in SWIID we limit our time to 2015 to obtain a broad range of countries. Accordingly, we used the indicators that give the highest data point from our dataset's potential 45 candidates representing greenhouse emission. (Table 1) presents summary statistics of selected variables for 49 countries[4] over the period 1981-2015.

Table 1. Summary Statistics

Variable	Gini	CO2 Emission	Oil Rent	Forest Area	Population Growth	GDP Per Capita Growth	Urban Population Growth	School Enrollment
Obs	1,085	1,697	1,640	1,253	1,715	1,605	1,715	1,001
Mean	45.290	1.045	3.979	30.049	2.496	1.173	4.031	0.846
Std. Dev.	6.871	1.963	9.958	24.939	1.053	6.257	1.958	0.168
Min	32.7	0.008	0	0.044	-6.766	-62.378	-7.182	0.347
Max	67.2	9.997	66.712	92.217	8.117	121.78	17.499	1.374
Gini	1							
CO2 Emission	0.257*	1						
	(0.000)							
Oil Rent	-0.162*	0.347*	1					
	(0.000)	(0.000)						
Forest Area	0.001	-0.087*	0.133*	1				
	(0.965)	(0.002)	(0.000)					
Population Growth	-0.041	-0.246*	0.027	0.146*	1			
	(0.167)	(0.000)	(0.276)	(0.000)				
GDP Per Capita Growth	-0.049	0.027	0.053*	-0.078*	-0.054*	1		
	(0.101)	(0.277)	(0.034)	(0.006)	(0.031)			
Urban Population Growth	0.055	-0.271*	-0.071*	0.036	0.535*	-0.001	1	
	(0.065)	(0.000)	(0.004)	(0.198)	(0.000)	(0.955)		
School Enrollment	0.312*	0.380*	0.033	0.031	-0.343*	0.158*	-0.204*	1
	(0.000)	(0.000)	(0.301)	(0.409)	(0.000)	(0.000)	(0.000)	

Note: only selected indicators to save space. The summary statistics provide one identification strategy to select a good IV. Panel data unit root test is in (Online Appendix 1b).

The first empirical underpinning from (Table 1) is that the average Gini Disposable, CO2 emissions, Forest Area, and GDP Per Capita growth stood at 45, 1.09, 30, and 1.17 percent, respectively. Looking closer at the CO2 emission and typical policy mitigation mechanisms such as forest area coverage, while the continent

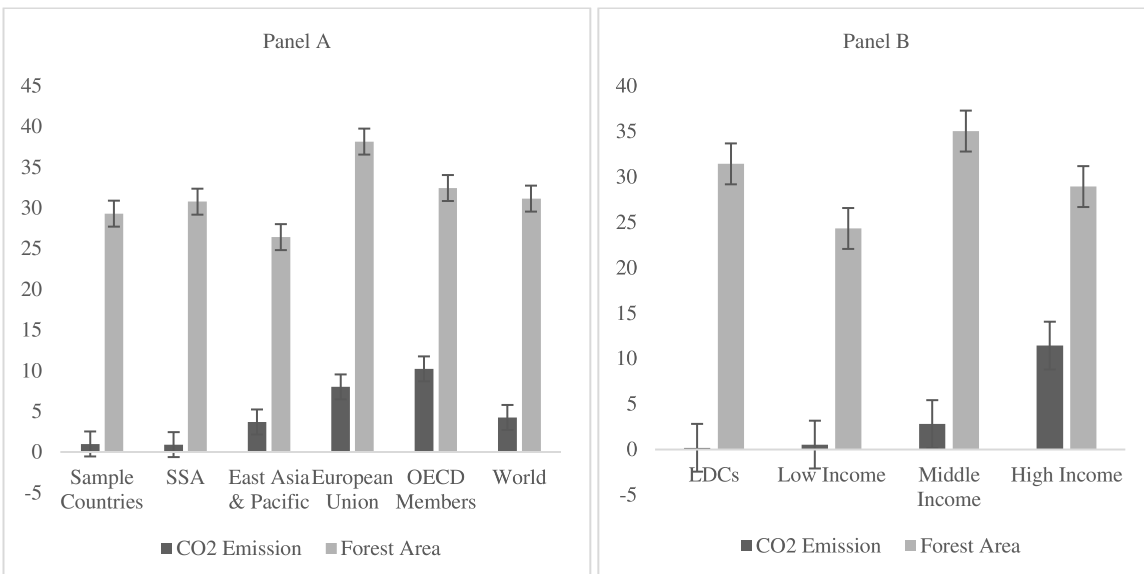
[4] *Sample countries include Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo Dem Rep, Congo Rep, Côte d'Ivoire, Djibouti, Egypt, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.*

emission contribution is by far lower than the world average (Figure 2), the forest area coverage is relatively higher. From these, we obtained the second identification assumption for exploiting why Africa lags with economic development, amidst the potential to build an environment resilient economy, is at hand?

The second empirical implication shows a positive correlation between the Gini index with CO2 emission and school enrollment while negatively correlating with oil rent. The correlation between CO2 emission, oil rent, forest area coverage, population growth, and urban population growth has varying signs and magnitude. The implication is that the continent must place high importance on forest area coverage in mitigating CO2 emission, provided that the continent barely affords other emission reduction technologies (Figure 2).

In our instrumental variable method (IV), we exploited the fact presented in (Figure 2) to derive a mitigation mechanism that helps economic growth and reduces greenhouse emissions. Unlike developed countries where CO2 emission is related to industrial development, the African experience is too little. Using sample countries, we propose an alternative mechanism that deviates from the conventional economic growth theories of transforming society from agrarian to industrialist, at least in the short run.

Figure 2. CO2 & Forest Area Coverage



Note: Panel A shows CO2 & Forest Area coverage by geographical location, and Panel B uses the United Nations (UN) income classification by income categories.

To assess the impact of greenhouse emissions on income inequality, we estimate two regression models. Our baseline equation fits the data with the traditional panel data fixed effect regression model using CO2 as the primary predictor.

$$Gini_{it} = \alpha + \beta_1 CO2_{it} + \beta_2 CV_{it} + \gamma_i + \delta_t + \varepsilon_{it} ------------------------ (1)$$

Where;

$\mathrm{Gini}_{\mathrm{it}}$ is the vector of outcome variables represented by Gini disposable (post-tax, post-transfer) and Gini Market (pre-tax, pre-transfer), $\mathrm{CO2}_{\mathrm{it}}$ is our variable of interest it measures CO2 emissions (metric tons per capita), $\mathrm{CV}_{\mathrm{it}}$ is the vector of control variables such as GDP per capita growth, urban population growth, and school enrollment (average primary and secondary school enrollment), γ_{i},

δ_t, ε_{it} captures country fixed effect, time fixed effect, and the random error term, respectively. β_1 captures the impact of emission on income inequality.

The second regression model uses key instruments and is estimated using the two-stage least squared estimation (2sls) method. We believe emission might not directly affect income inequality, given that CO2 is endogenous in eq.1, using key instruments becomes empirically appealing. Hence, we use exogenous variations such as forest area coverage proxied by agriculture value addition from forest and fishery, population growth, arable land, and fertilizer usage. Besides, we cement our analysis by using alternative emission indicators that contribute a significant share of greenhouse emissions in Africa, such as agricultural methane emissions and fossil fuel energy consumption.

Equations 2a and 2b are up on our baseline equation presented in equation 1. At the same time, the second batch of 2sls estimation presented in equation 2c and equation 2d is part of the robustness test for our causal inference;

$$Gini_{it} = \omega + \varphi_1 CO2_{it} + \varphi_2 CV_{it} + \varepsilon_{it} \text{------------------------} (2a)$$

$$CO2_{it} = \theta + \pi_1 IV_{it} + \pi_2 CV_{it} + \mu_{it} \text{------------------------} (2b)$$

$$Gini_{it} = \omega + \varphi_1 Other\ Emissions_{it} + \varphi_2 CV_{it} + \varepsilon_{it} \text{------------------------} (2c)$$

$$Other\ Emissions_{it} = \theta + \pi_1 IV_{it} + \pi_2 CV_{it} + \mu_{it} \text{------------------------} (2d)$$

Where;

From equation 2a & 2b Gini_{it} is our outcome variables represented by Gini disposable and Gini Market, $\mathrm{CO2}_{it}$ is endogenous in our model and measures carbon emissions (metric tons per capita). IV_{it} is a set of instrumental variables represented by ForAr_{it}-forest area (percentage of land area), $\mathrm{PopGrowth}_{it}$ - population growth rate, $\mathrm{AgriValueAdd}_{it}$ -agricultural value-added from forestry and fishery. CV_{it} is the vector of other control variables such as GDP per capita growth, urban population growth, and school enrollment (average primary and secondary school enrollment), and ε_{it} & μ_{it} represents error terms. Estimation results are presented in Table 3 & Table 4.

From equation 2c & 2d Gini_{it} is the vector of outcome variables represented by Gini disposable and Gini Market, $\mathrm{Other\ Emissions}_{it}$ is represented by agriculture methane gas emission and fossil fuel energy consumption. IV_{it} in the set of instrumental variables, represented by $\mathrm{ArableLand}_{it}$ share of total land suitable for agricultural practices, $\mathrm{Fertilizers}_{it}$ the KG amount of fertilizers applied in squared are of land. CV_{it} is the vector of other control variables such as GDP per capita growth, urban population growth, and school enrollment (average primary and secondary school enrollment), and ε_{it} & μ_{it} represents error terms. Estimation results are presented in Table 5 & Table 6.

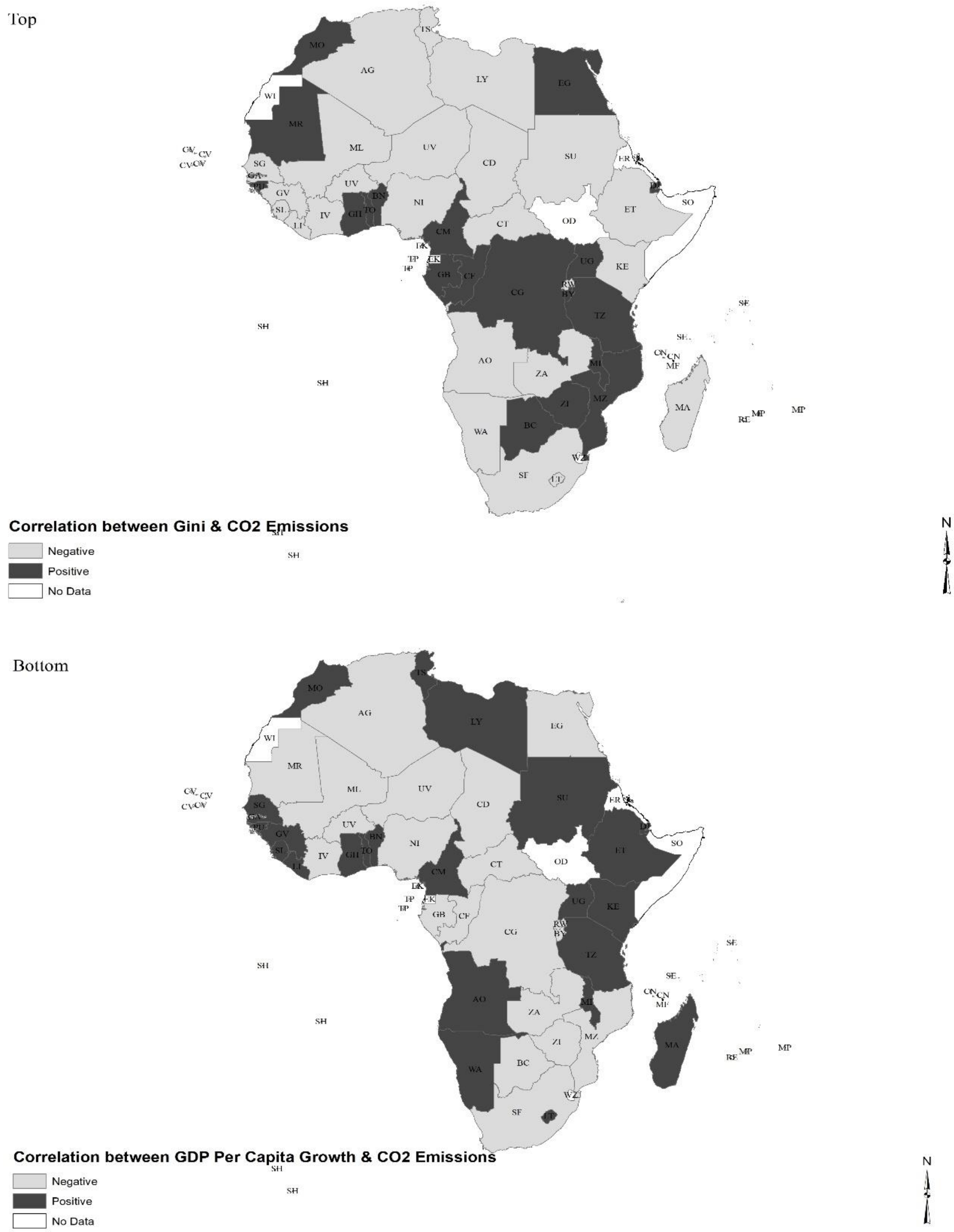
3. Results

3.1. Fixed Effect Regression Results

From the first empirical exercise, we find a positive impact of CO2 emission on both Gini indicators after controlling school enrollment and other covariates. A unit increase in CO2 emission widens income inequality by 0.39-0.55 units. While oil rent to GDP reduces inequality on average from 0.03 to 0.07 units. The role of urban population growth and school enrollment has underscored in narrowing income inequality from our result.

However, the country-specific relationship shows a different degree of correlation. Countries ranked on top with their level of wealth and economic growth performs differently. For instance, in the majority of the wealthiest countries, CO_2 emission is negatively correlated to Gini Disposable except for Egypt and Botswana (Figure 3, Top).

Figure 3: Spatial Distribution of Correlation Coefficients-Gini, GDP & CO_2



Note: Figure 3 shows the pairwise correlation coefficient labeled as negative & positive between Gini & CO_2 emission per capita (Top) and GDP Per Capita Growth & CO_2 emissions (Bottom) from 1981-2015.

On the other hand, pertinent to GDP per capita growth amongst the fastest growing economies, we find a positive correlation with CO2 emission in Morocco, Kenya, Ethiopia, Ghana, and Tanzania. Our finding provides little evidence that rapid economic growth is attributed to industrialization since we failed to establish CO2 emission attributed to economic growth in economic powerhouses such as Nigeria, South Africa, and Egypt. We have shown in these economic powerhouses; the correlation coefficient is negative.

As a result of economic transformation, income inequality remained the hot spot in establishing theoretical and empirical research in the economics of inequality and the environment. The study conducted by Brückner, (2012), across a panel of 41 African countries during the period 1960-2007, shows that a decline in the share of the agricultural value-added lead to a significant increase in the urbanization rate, which ultimately affects GDP per capita growth negatively. The finding partly explains why the impact of CO2 emission is pronounced in widening income inequality than economic growth (Figure 1).

Table 2. Fixed Effect Regression for Gini

Dependent Variable	Gini Disposable		Gini Market	
	I.	II.	III.	IV.
CO2 Emission Per Capita	0.113	0.393***	0.201	0.551***
	(0.084)	(0.095)	(0.104)	(0.120)
Oil Rent to GDP	-0.029**	-0.061***	-0.032**	-0.070***
	(0.008)	(0.013)	(0.011)	(0.016)
Urban Pop Growth	-0.046*	-0.046	-0.081**	-0.081*
	(0.020)	(0.028)	(0.025)	(0.035)
GDP Per Capita Growth	0.007	0.015	0.010	0.019
	(0.006)	(0.009)	(0.007)	(0.012)
School Enrollment		-3.538***		-4.284***
		(0.473)		(0.592)
Country FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observation	1083	642	1083	642
adR-sq	0.017	0.136	0.023	0.135

*Note: Table 2 presents panel data fixed effect regression estimators for Gini Disposable in column (I-II) and Gini Market in column (III-IV). Our result shows a positive and statistically significant impact of CO2 emission after controlling for school enrollment, whereas a negative relationship with oil rent, urban population growth, and school enrollment. * shows the level of significance at 0.05, ** at 0.01, and *** at 0.001 respectively*

Padilla & Serrano (2006), in the distributive issues of climate change, studies the relationship between CO2 emissions and GDP and shows that an important inequality follows income inequality across countries in the distribution of emissions. On the other front, Liu et al. (2019) studied how income inequality facilitated the reduction in carbon emission in the US and documented that higher income inequality increases CO2 emissions in the short term. In contrast, it promotes carbon reduction in the long term.

However, there are several important reasons for not interpreting the relationship as causal. First, the policy perused across countries in mitigating the emission impact might negatively correlate (see Figure 2, Top). In this case, the inequality widening hypothesis may either vanish or be inflated in our baseline estimator. Second, we might encounter omitted variable bias as we naturally have other predictors that determine the level of CO2 emission that varies across countries. From (Table 1), some variables correlated to CO2 but not with Gini, hitherto not included in our baseline model. Finally, we also expect measurement error in our vectors, which leads our estimator to be biased upward or downward. Solt, (2020) computes the standard error in computing Gini Indexes.

All of these problems could be solved if we had an instrument for CO2. We adopt Acemoglu et al. (2012) approach in finding a good instrument to capture the context of the African economy. Accordingly, we have identified instruments correlated to CO2 and provided the mechanism for the importance of agriculture transformation using key instruments.

3.2. Two-Stage Least Squared Estimation (2sls) Estimates

Due to the endogeneity problem, the relationship presented in (Table 2) might not be interpreted as a causal relationship. Therefore, we identified three mechanisms vis-a-vis the agriculture sector practices, demographic change, and alternative emission indicators for the agrarian economy to establish causal relationships.

3.2.1. The Implication of Forest Area Coverage

Table 3. IV Regression for Gini with CO2 Emission

Panel A: Two-Stage Least Squares				
Dependent Variable	Gini Disposable		Gini Market	
	I.	II.	III.	IV.
CO2 Emission Per Capita	3.110***	2.582***	3.748***	3.418***
	(0.251)	(0.368)	(0.278)	(0.428)
Panel B: First Stage for CO2 Emission Against Agriculture Forest Value Added				
AGRI Forest & Fish Value Added	-0.062***	-0.063***	-0.062***	-0.063***
	(0.003)	(0.004)	(0.003)	(0.004)
Urban Pop Growth	-0.126***	-0.128***	-0.126***	-0.128***
	(0.021)	(0.027)	(0.021)	(0.027)
GDP Per Capita Growth	Y	Y	Y	Y
School Enrollment		Y		Y
adR-sq	0.309	0.348	0.309	0.348
IV First Stage F Statistics	220.12	118.59	220.12	118.59
Observation	1480	895	1480	895
Panel C: Fixed Effect Estimate				
CO2 Emission Per Capita	0.113	0.393***	0.201	0.551***
	(0.084)	(0.095)	(0.104)	(0.120)

*Note: Table 3 reports 2sls estimator in panel A and the corresponding first stage estimate in panel B. Compared with the fixed effect estimator in Panel C, our 2sls shows a pronounced effect of CO2 emission with virtually the same sign with the baseline model. We show the validity of our instrument by the first stage F-statistics in (Panel B). Urban population growth is not an instrument. It shows that the pull factor for rural to urban migration is not the proliferation of manufacturing industries but rather seeking employment in the construction sector as a daily laborer. These dynamics resulted in less CO2 emission. * shows the level of significance at 0.05, ** at 0.01, and *** at 0.001 respectively*

In developing countries, evidence is rampant that greenhouse emission is associated with forest degradation (Pearson et al., 2017). However, the impact of forest area coverage on greenhouse gas emission is known less as more empirical research is leaning to assess deforestation's impact. Given the infant industrial development, low capacity for affording emission reduction technologies, and capacity constraint on building a resilient economy, the impact of greenhouse emission is inevitable. Planting trees and increasing forest area coverage appear to be a vital toolkit in this regard (Popkin, 2019). If a value added, it serves the dual purpose of reducing emissions and raising GDP per capita income.

To support our argument, we used the agricultural value added from forestry and fishery as an instrument for CO2 emission. Our finding shows that the effect of CO2 emission under IV estimation is higher in affecting income inequality. Furthermore, the growth of the urban population reduces carbon emission, which in the African context shows the shift from wood, fossil, combust, coal, and other agricultural emittance to urban renewable energy consumption like electricity plays a substantial role in emission reduction. Nevertheless, the impact of CO2 emission in widening income inequality remained robust.

3.2.2. The Role of Demographic Change

Pimentel, 1991 shows that the rapidly growing population puts pressure on the global environment and threatening its ability to supply a quality environment. Similarly, Alam et al. (2016) show that the relationship between CO2 emissions and population growth is statistically significant for India and Brazil, yet not for China and Indonesia in both the short and long run. The percentage of people living in the urban area explained part of the story.

In understanding the drivers of urbanization in Africa, Henderson et al., (2017) show urban migration provides an "escape" from adverse agricultural moisture shocks, which leads to reduced farm incomes. This finding partly explained that the impact of CO2 emission in elucidation the growth of GDP per capita is not as high as the growth in Gini Disposable (Figure 1). Here, urbanization can be a means to sustaining life by shifting from agricultural labor to urban labor.

Figure 4: Spatial Distribution of Correlation Coefficients-Urbanization

Note: Figure 4 shows the pairwise correlation between CO2 emission and urban population growth. We use urban population growth to approximate population growth because it is the former that is related to CO2 emission using data from 1981-2015.

Our data shows that population growth in Africa over the past three decades mounted at 2.6 percent. A significant part of the development was attributed to the growth of the population living in urban centers. Urban dwellers reached 37 percent of the total population, where in some countries, the share roses to 88 percent.

However, the urbanization dynamics are not associated with the growth in CO2 emitting industries. We provide empirical evidence in our first stage regression (Table 4) that shows population growth and urban population significantly reduce CO2 emission on average by 13-38 units. Moreover, even if evidence varies across countries, the growing importance of literacy captured by school enrollment becomes essential in creating public awareness to shift to less CO2 emission products such as renewable energy sources for daily energy uses.

Table 4. IV Regression for Gini with Population & Urban Population Growth

Panel A: Two-Stage Least Squares				
Dependent Variable	Gini Disposable		Gini Market	
	I.	II.	III.	IV.
CO2 Emission Per Capita	2.097**	3.400*	2.949***	5.044**
	(0.683)	(1.513)	(0.773)	(1.915)
Panel B: First Stage for CO2 Emission Against Population Growth				
Population Growth	-0.386***	-0.315***	-0.386***	-0.315***
	(0.052)	(0.069)	(0.052)	(0.069)
Urban Pop Growth	-0.179***	-0.132***	-0.179***	-0.132***
	(0.027)	(0.034)	(0.027)	(0.034)
GDP Per Capita Growth	Y	Y	Y	Y
School Enrollment		Y		Y
R-sq	0.118	0.223	0.118	0.223
IV First Stage F-Statistics	70.40	67.41	70.40	67.41
Observation	1587	944	1587	944
Panel C: Fixed Effect Estimate				
CO2 Emission Per Capita	0.113	0.393***	0.201	0.551***
	(0.084)	(0.095)	(0.104)	(0.120)

*Note: Table 4 reports 2sls estimator in panel A and the corresponding first stage estimate in panel B. Compared with the fixed effect estimator in Panel C, our 2sls shows a pronounced effect of CO2 emission with virtually the same sign to the baseline model. We show the validity of our instrument by the first stage F-statistics in (Panel B). Urban population growth is not an instrument. It shows that the pull factor for rural to urban migration is not the proliferation of manufacturing industries but instead seeking employment in the construction sector as a daily laborer. These dynamics resulted in less CO2 emission. . * shows the significance level at 0.05, ** at 0.01, and *** at 0.001, respectively.*

Looking closer to our IV estimator, even if our instrument reduces CO2 emissions, the story remained the same in widening income inequality. Apart from this, our IV estimator is robust, implying a growing tendency of emission reduction due to population growth, yet in shaping social welfare through widening income inequality, population policies need to be checked.

3.2.3. Alternative Emission Indicator

We extend our empirical exercise for the income inequality widening hypothesis using alternative emission indicators. Methane is the second most important greenhouse gas contributor to climate change, following CO2. Bhatia et al., (2004) show agricultural soils contribute to methane and nitrous oxide emission places as important greenhouse gases causing global warming. Moreover, from the experimental study by Biernat et al., (2020), arable organic farming showed the ability to produce agricultural commodities with low nitrous oxide emissions per unit area.

Koga et al., (2004) also show that the rates of methane uptake by arable soils were less sensitive to crop type, field management practices, and fertilizer application rates. However, the rates are strongly influenced by long-term tillage management. In this manner, we associate this emission from agricultural practices with our main question; does agricultural emission widens income inequality?

Given diverse soil characteristics, land-use types, and climatic conditions, we show emission contributions from methane gas and fossil fuel energy take a significant share of greenhouse emission (Online Appendix 1c). These emission indicators are the characteristics of the developing world. Thus, we cement our finding by incorporating two alternative emissions because most people's livelihood relies on agriculture in Africa.

Table 5. IV Regression for Gini with Agricultural Methane Emission

Panel A: Two-Stage Least Squares				
Dependent Variable	Gini Disposable		Gini Market	
	I.	II.	III.	IV.
AGRI Methane Emission	0.255***	0.204***	0.260***	0.233***
	(0.041)	(0.044)	(0.045)	(0.052)
Panel B: First Stage for Methane Emission Against Arable Land & Fertilizer Consumption				
Arable Land	-0.329***	-0.376***	-0.329***	-0.376***
	(0.054)	(0.062)	(0.054)	(0.062)
Fertilizer Consumption	-0.029***	-0.015	-0.029***	-0.015
	(0.008)	(0.009)	(0.008)	(0.009)
Urban Pop Growth	Y	Y	Y	Y
GDP Per Capita Growth	Y	Y	Y	Y
School Enrollment		Y		Y
adR-sq	0.121	0.214	0.121	0.214
IV First Stage F-Statistics	33.41	32.67	33.41	32.67
Observation	978	607	978	607
Panel C: Fixed Effect Estimate				
CO2 Emission Per Capita	0.113	0.393***	0.201	0.551***
	(0.084)	(0.095)	(0.104)	(0.120)

*Note: Table 4 reports 2sls estimator in panel A and the corresponding first stage estimate in panel B. Compared with the fixed effect estimator in Panel C, our 2sls shows a pronounced effect of CO2 emission with virtually the same sign to the baseline model. We show the validity of our instrument by the first stage F-statistics in (Panel B) and Sargan test of identification restrictions(p = 0.7575) also met over-identification assumptions. Our instruments reduce methane emissions. * shows the significance level at 0.05, ** at 0.01, and *** at 0.001 respectively.*

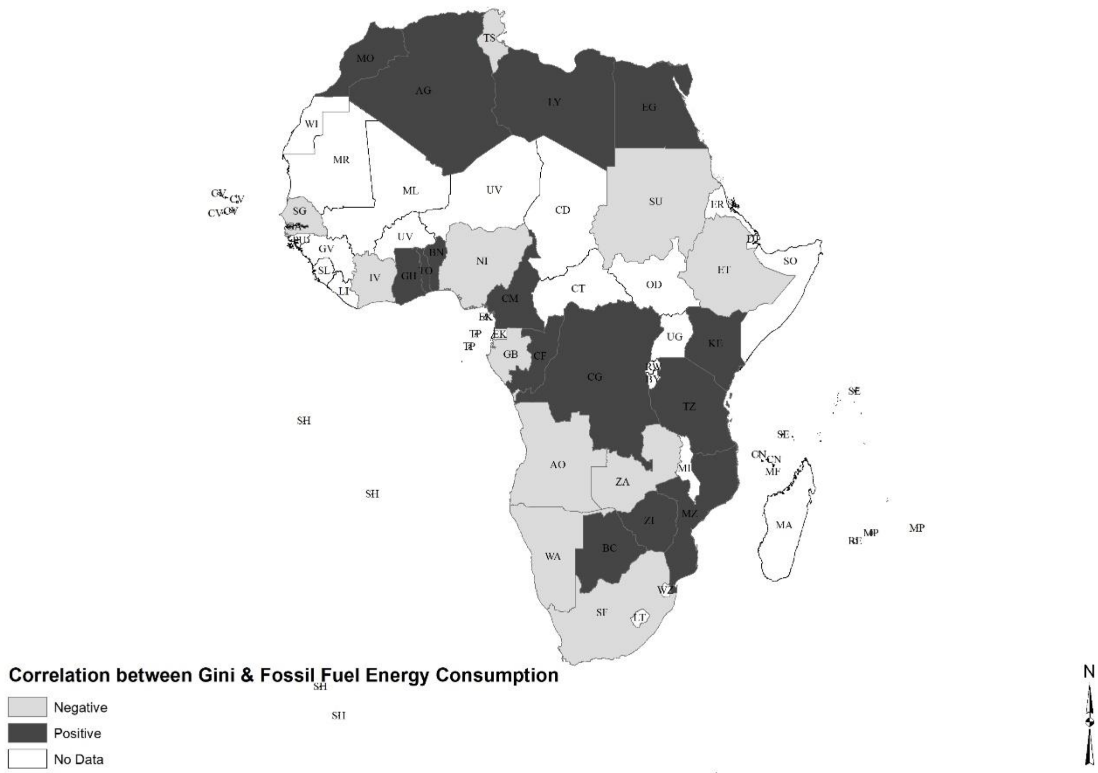
We show that both arable land coverage and fertilizer usage per square meter of land for agriculture reduce agriculture methane emission on average between 1.5-38 units. Organic agricultural practice, amongst others, might explain the emission reduction effect from agricultural practices, but also it shows the entry point to address the trinity puzzle.

The relationship brings enormous benefits to the agriculture sector in Africa. It is the dominant means of livelihood for most rural households. We have shown the expansion of agriculture practices reduce emission. But, this is not the sole benefit it brought to the continent, given it is a means for two-thirds of the people and absorbs 60 percent of the labor force. Hence, some nations can design a sustainable development strategy that answers rapid economic growth without affecting environmental quality and ensuring a balanced income distribution. We provide empirical justifications on how to do this in the discussion section.

Nevertheless, the impact of agriculture methane gas emission on income inequality remained the same with previous results.

Apart from agriculture methane gas emission, we used fossil fuel energy consumption as an alternative emission indicator. Globally, fossil-fuel-related emissions account for about 65 percent of the excess mortality and 70 percent of the climate cooling by anthropogenic aerosols (Lelieveld et al., 2019). Given its health effect, we believe it also affects income inequality. Analyzing its impact makes sense because since 1751 approximately 337 billion metric tons of carbon have been released into the atmosphere from the consumption of fossil fuels and cement production (Boden, T.A., et al, 2013).

Figure 5: Spatial Distribution of Correlation Coefficients



Note: Figure 5 shows the pairwise correlation between Gini disposable and fossil fuel energy consumption using data from 1981-2015.

Besides, fossil fuel rank, the second-highest emission factor in our greenhouse emission indicators (see Online Appendix 1c). We show a positive correlation between Gini disposable and fossil fuel consumption in most Northern, few Central, and South-Eastern African countries.

Fossil fuels (coal, oil, gas) have, and continue to, play a dominant role in global energy systems. However, they also come with several negative impacts. When burned, they produce CO2 and are the most significant driver of global climate change. They are also a significant contributor to local air pollution, which is estimated linked to millions of premature deaths, agricultural production shocks, rural-urban migration, and indeed widens income inequality.

We also find similar results in reducing fossil fuel emission due to a rise in arable land. Unlike other places in Africa, the relationship is associated with agricultural dwellers, where most energy sources are not from fossil fuel energy consumption. The renewable energy source is critical in unlocking the energy demands in the continent. In most rural parts, solar energy is typical in recent years. Besides, the emission contribution from fossil fuel attributed to the dead plants traditionally used as a means for natural combustion that helps increase the productivity of agriculture and a means for alternative energy sources.

Likewise, fossil fuel energy consumption is the dominant energy source for a few industries and transportation. So, compared with the emission coming from the agriculture sector, the industrial practice is found to have minimal effect.

Table 6. IV Regression for Gini with Fossil Fuel Energy Consumption

Panel A: Two-Stage Least Squares				
Dependent Variable	Gini Disposable		Gini Market	
	I.	II.	III.	IV.
Fossil Fuel Energy Cons	0.637**	0.433*	0.732**	0.538*
	(0.207)	(0.176)	(0.231)	(0.211)
Panel B: First Stage for Fossil Fuel Against Arable Land				
Arable Land	-0.392***	-0.339**	-0.392***	-0.339**
	(0.082)	(0.106)	(0.082)	(0.106)
Urban Pop Growth	Y	Y	Y	Y
GDP Per Capita Growth	Y	Y	Y	Y
School Enrollment		Y		Y
adjR-sq	0.181	0.242	0.181	0.242
IV First Stage F-Statistics	65.39	43.13	65.39	43.13
Observation	892	544	892	544
Panel C: Fixed Effect Estimate				
CO2 Emission Per Capita	0.113	0.393***	0.201	0.551***
	(0.084)	(0.095)	(0.104)	(0.120)

*Note: Table 6 reports 2sls estimator in panel A and the corresponding first stage estimate in panel B. Compared with the fixed effect estimator in Panel C, our 2sls shows a pronounced effect of CO2 emission with virtually the same sign to the baseline model. We show the validity of our instrument by the first stage F-statistics in (Panel B. * shows the level of significance at 0.05, ** at 0.01, and *** at 0.001, respectively*

Finally, climate change is not merely under the control of domicile socio-economic phenomena. Hence examining the cumulative effect from the previous years gives our estimator a reliable implication. Our final empirical exercise tested the impact of CO2 emission in a lag form on income inequality. We obtained the same result after taking two years of lagged CO2 emission (see Online Appendix 1d).

4. Discussion

Broadly speaking, two insights regarding the nexus between environmental quality and income inequality can be hypothesized. The first school of thought shows that inequality leads to the consumption of carbon-intensive products (Golley & Meng, 2012; Baek & Gweisah, 2013). The other side of the literature claims income inequality could improve environmental quality. When the income distribution is more balanced, the poor enter the middle class and consume more carbon-intensive products (e.g.,Heerink et al., 2001). This paper establishes a mechanism to understand the relationship and provide alternative mechanisms to handle the problem.

For our discussion, Barrios et al., (2006) show for a sample of sub-Saharan African countries, climatic change, peroxide by rainfall, has acted to change urbanization in sub-Saharan Africa. We underscore the mechanism is highly attributed to the agricultural sector characterized by poor agricultural practices and vulnerability to climate change and other natural disasters.

In support of our baseline estimation results, our IV approach shows population growth, arable land expansion, fertilizer usage, and urbanization significantly reduces greenhouse gas emission. However, it didn't veto a widening income inequality. We take this evidence as a springboard to find alternative development strategies. The finding amplifies the role of Agriculture in Africa is substantial in many ways. Especially when it comes to balancing the environment-inequality-growth nexus, countries need to focus on their agriculture practices or generally their comparative advantages.

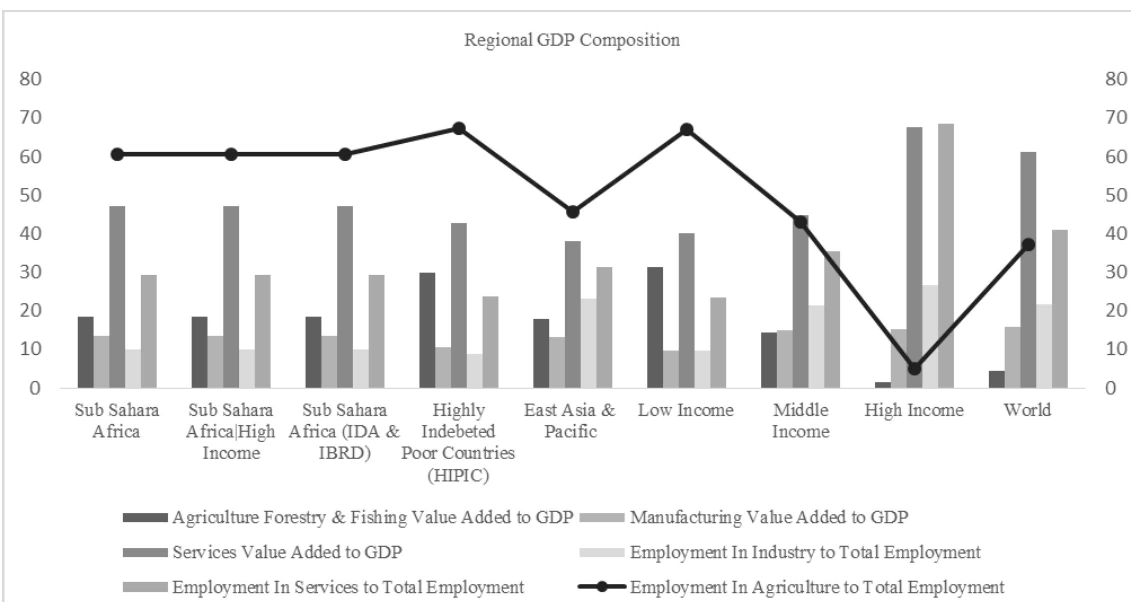
We argue agriculture has become the key for unlocking the intertwined problems, and the sector's potential can be examined from the employment creation potential of the sector for the youth population vis a vis other sectors such as industry and services. Under this vein, we decompose the share of GDP and associate it with the employment creation potential of each sector.

The agriculture sector employs more than 60 percent of the total labor force, followed by service and manufacturing (Figure 6). Comparing the figure with the rest of the world, investing in agriculture value addition can boost per capita income growth, reduce greenhouse emissions (i.e., based on previous estimation results), and redistribute income among the labor force. We believe these intertwined objectives are realized by transforming the productivity of the agriculture sector.

However, the sector's productivity was hampered by various factors such as climate condition, soil type, the effect of the slave trade, and the prevalence of the disease for an extended period. Due to these factors, the sector has underperformed for a long period (Bjornlund et al., 2020). Our argument lends from Senbet & Simbanegavi, (2017), in reducing poverty and foster broader structural transformation transforming the agricultural practice of smallholder farmers that accounts for 80 percent of Sub Sahara Africa (SSA) population is vital.

One way to transform the sector is to detach its dependence on rainfall and use the water potential through irrigation so that producing all season supports the subsistence of rural farms and produces a surplus that improves the GDP per capita of the smallholder farmer. It is documented that crop intensification causes little water stress in Africa (Pfister et al., 2011), so ensuring food security through arable land expansion is feasible. In this regard, emphasis on agricultural products value addition should get paramount importance. Our finding has further cemented by Gassner et al., (2019), echoing that agriculture serves the dual objective of food security and poverty reduction.

Figure 6: Comparing Sectoral Contribution



Note: Figure 6 shows the mean score of regional GDP composition using data from 1981-2015. The right axis measures employment in the agriculture sector. Read the color code horizontally from left to right for identification.

Furthermore, we argue that the industrialization narrative for sustainable economic development may fail to work for different reasons. Most importantly, timing matters in policy implementation across countries. Our data shows the growth in school enrollment is growing steadily that may not respond to the need of semiskilled or highly skilled human resource needs in the industrial sector. Besides, the growth of the urban population has also been growing at a decreasing rate in recent years, showing the pull factors are not readily available in urban centers (see Online Appendix 1b). These pieces of evidence suggest that the ingredient and the pull factor are not growing in tandem with population growth.

Therefore, our proposal to answer the intertwined question is the Agriculture Development Lead Industrialization (ADLI) policy. The vein of our policy is agriculture sector transformation should come first and pave the way for industrial development.

Hence, enhancing the productivity of rural farmers through agriculture transformation is the first task for African countries. Production and productivity can be enhanced through producing all-season, using irrigation, fertilizers usage, and accelerating the value chain in the sector. Moreover, it should be accompanied by access to finance for rural entrepreneurs to produce highly demanded crops and animals, to incline to export-oriented products. Most importantly, value addition on agricultural products will benefit the mass rural population and balances income distribution.

Furthermore, we believe transforming the economic composition is central to sustainable development in the long run. However, based on the comparative advantage, countries must utilize their advantages given the current global environmental degradation and its unprecedented effects on the rural poor. This is why the need to balance income inequality, improving environmental quality, and achieving rapid economic growth requires a shift in looking for alternative means to prosper the African continent.

5. Conclusion

In this paper, we unlock the question surrounding the sustainable development ambition of African states by addressing the bottlenecks of income inequality and environmental degradation. We used several proxies for greenhouse emission and establishes a causal relationship with income inequality by employing sound econometric methods. The key takeaway from our finding is that transforming the agriculture practices of smallholder farmers is a good candidate for realizing development ambitions.

The baseline model provides support for income inequality widening evidence for a rise in greenhouse emissions. To galvanize the causal mechanism, we used key instruments representing the characteristics of the agrarian economy. The alternative estimation method confirms that greenhouse emission widens income inequality, and paying due attention to transforming agricultural practices is the best way to tackle the problems.

We obtain three implications. First, the continent needs to go a long way in transforming the poor farmer-based economy into an industrial society. Given the existing capacity for literacy, infrastructure development, technology, and institutional capability, industrialization should focus on agriculture value addition. At least in the short run, if countries pursue to promote industrialization, it necessitates shifting the scarce resources available in the domestic economy and making sure greenhouse emission management is in place, which is not feasible unless the path of planting trees across countries becomes a common practice. It is why capitalizing on agricultural value addition from forestry and fishery remained a heavenly approach. Doing so addresses GDP per capita growth, less greenhouse emission, and creating job opportunities narrow income inequality.

Second, population growth, especially a rise in urban population, reduces emissions. The shift to renewable energy sources in cities is vital in this regard. If accompanied by a growth in school enrollment, citizens' attitude towards the environment will improve, eventually shaping individuals' attitudes to build the habit of using emission-reducing products in daily life can be realized.

Third, from the alternative emission indicators such as agricultural methane gas emission and fossil fuel consumption, it is prevalent in many countries in reducing methane and fossil fuel emission. Besides, using either organic combustible or inorganic fertilizer is proven to reduce emissions from the agriculture sector. Again, given the massive potential for agricultural production, our result suggests an alternative means to prosper the African farmer. Hence, the whole process of value addition in agricultural products and other primary economic activities is a good candidate in transforming the livelihood of poor farmers.

In a nutshell, our result is robust for alternative estimation methods, emission indicators, and spatiotemporal evidence has also been provided. In all cases, emission widens income inequality, and the means to mitigate its impact is investing more in transforming the agriculture sector of Africa.

There are plenty of ways to extend the paper. Using household-level data, a comparative analysis with the developed nations, and other feasible indicators in explaining the African state of economic structure and dynamics can be considered to enrich the main findings presented in this paper.

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