Getting into the details: structural effects of economic growth on environmental pollution in Ethiopia

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ABSTRACT

Reduced-form approaches are like a ‘black-box’ which do not explicitly display the possible channels (exact forces) through which growth may influence the environment. Accordingly, this study aims to provide some empirical evidence regarding the underlying structural effects of growth on emissions of carbon dioxide (CO2), Methane (CH4), and Nitrous oxide (N2O) in Ethiopia over 1975–2017. Autoregressive Distributed Lag (ARDL) model is employed and the results confirm that the scale effect of growth increases all types of emissions in both the short run and long run. And, the composition effect has a long-run monotonically increasing relationship with CO2 emissions and a non-increasing pattern with CH4 and N2O emissions. On the other hand, a generally decreasing (for CO2 emissions) and an Inverted-U shaped (for CH4 and N2O emissions) technique effects of growth are obtained. This indicates that while growth through its technique effect reduces CO2 even at a lower level of income, the country needs to achieve a higher income level for the technique effect to be effective in reducing CH4 and N2O emissions. Fossil fuel energy appears to be the main driver of environmental pollution. Furthermore, the Toda-Yamamoto Granger causality test indicates a unidirectional causality from the three structural components of growth to all emissions. The findings, generally, suggest that a self-correcting mechanism in the growth process may not automatically reduce environmental pollution. Quite simply, to achieve environmentally sustainable economic growth, the technique effect should be sufficiently strong to offset the scale effect.

1. Introduction

Sustainable economic growth with little or no environmental degradation is the main goal of many developing countries. Nevertheless, the quest for economic growth has been linked with different environmental problems such as Greenhouse gas (GHG) emissions, deforestation, land degradation, and drought. Despite its remarkable growth over the last couple of decades, Ethiopia is no exception to this issue. For instance, the country lost an average of 74,031 ha or 0.64% of its net forest cover per year between 2000 and 2015. Quite simply, about 8.8% of total forest cover was disappeared in Ethiopia during the same period although a modest increase in forest land was observed in the late few years (FAO, 2020). Further, according to the Carbon Dioxide Information Analysis Center, the total anthropogenic Greenhouse gas emissions in Ethiopia by the year 2014 amount to 129 metric tons, expressed as CO2 equivalents, indicating a 96% increase from 1990. The leading GHG emissions in the country are Methane (54% in 2014), Nitrous oxide (37%), and Carbon dioxide (9%).

In both theoretical and empirical literature, the effects of economic growth on the environment have been much more extensively investigated under the Environmental Kuznets Curve (EKC) framework using reduced-form approaches (in either quadratic or cubic form) over the last two and three decades. Indeed, the reduced-form methods to the EKC relationship provide a better insight on the net environmental effect of growth although evidence is typically mixed and remains inconclusive. On top of this, as Panayotou (1997) described, EKC is a ‘black box structure’ in which demand and supply, the scale and composition factors are lumped together. That is to say, it hides more than it reveals and does not explain why the observed relationship exists. It also ignores the importance of structural effects in the growth process which lends itself to misleading policy implications (Panayotou, 1997; Tsurumi and Managi, 2010). On the other hand, environmental pollution is the outcome of the interplay of two sets of forces—forces generating emissions and forces working for pollution control and abatement (Islam et al., 1998). Modeling such opposing forces and their interaction through reduced form approaches is quite difficult. Put differently, since growth acts as a
surrogate of various underlying attributes, the reduced form of EKC relationship could not explicitly describe the specific environmental role of the scale and structure of the economy and the technological change in the growth process. Hence, estimating a reduced-form EKC should only be taken as a first step, not the end, in our attempt to understand the environment-growth linkage.

Accordingly, looking inside the black box and disaggregating the possible channels (structural factors) through which growth may influence the environment is reasonably important to address the aforesaid problems observed in the conventional reduced-form of the EKC models. In fact, the net effect of growth on the environment which produces the EKC relationship is determined by the relative importance of scale of economic activities (scale effect), the structural change of the economy (composition effect), and the change in production techniques (technique effects).

Empirically, the disaggregated environmental effects of growth are not well investigated compared to the EKC reduced-form approaches. Few country-specific (such as Mohapatra et al., 2016; Jena, 2018; Shabbaz et al., 2019) and panel data studies (like Bakehe, 2018; Nikengfack et al., 2019; Ansari and Khan, 2021, among others) were conducted and they even came up with mixed evidence particularly regarding the composition and technique effects of growth. Second, these studies used a linear specification to decompose the three effects of growth which is quite restrictive and less flexible to detect the true relationship as these effects may not have a uniform relationship along the different paths of development. For instance, countries may not need to attain a higher level of development to concern about environmental quality, which cannot be captured in a linear functional form. Finally, to the best of our knowledge, no prior study has been conducted on the decomposed relationship between growth and environment in the Ethiopian context. This study, therefore, fills these gaps and provides some empirical evidence on the role of scale, composition, and technique effects of growth on the environmental pollution in Ethiopia over the period between 1975 and 2017. It also examines the direction of Granger causality between the scale, composition, and techniques effects and GHG emissions.

The rest of the paper is structured as follows: Section 2 provides a brief review of the related literature. Section 3 discusses data issues and methodology. Section 4 presents the empirical results and discussion and finally, section 5 gives a conclusion with some relevant policy implications.

2. Brief review of literature

There have been long-standing and continuing theoretical debates and wide-ranging empirical literature on the environment-economy relationship since the early 1970s, when the famous book-Club of Rome’s Limits to Growth (Meadows et al., 1972) urged a zero economic growth to avoid dramatic environmental scenarios in the future (Dinda, 2004; Gulati, 2007). In the meantime, the EKC hypothesis in its reduced form was introduced in the early 1990s and has become a standard framework in describing an Inverted-U shaped environment-growth relationship. It postulates that environmental quality gets worse at low levels of economic growth and starts to improve with further increasing levels of growth. The existence of the EKC hypothesis is consistent with the optimistic view that growth is a possible panacea for environmental degradation. In this regard, the famous quotation from Beckerman (1992) remarked that “the strong correlation between incomes, and the extent to which environmental protection measures are adopted, demonstrates that in the longer run, the surest way to improve your environment is to become rich.”

Accordingly, since the mid-1990s, a vast literature on the relationship between environment and economic growth has been undertaken across different countries and regions of the world under the EKC framework. For instance, Endeg (2015); Lin et al. (2016); Twerefou et al. (2016); Adu and Denkyirah (2019); Mahrous (2017); Effiong and Iriabije (2018); Adedoyin et al. (2020); Bah et al. (2020); Halliru et al. (2020); Sisay and Kotosz (2020); Teame and Habte (2020); Tenaw and Beyene (2021) are some of the EKC studies recently conducted in the African context. Nevertheless, there has been no consensus regarding the findings on the EKC relationship at both country and cross-country levels.

More essentially, Panayotou (1997) noted that EKC is a black-box formulation that lumps demand and supply, scale, and composition factors together; provides only the net effect of growth on the environment, and thus yields inadequate policy implications. Accordingly, the net environmental impact of growth can be disaggregated into different structural components which unravel the channels through which growth may affect the environment. And, it is crucial to carefully consider these components of growth to understand the true environment-growth relationship (Mohapatra et al., 2016). First, increasing the scale of production activities in the economy will cause more environmental damage since it requires more natural resources as inputs and generates more wastes and emissions as by-products (Dinda, 2004; Arouri et al., 2012). This effect is termed as the scale effect of growth. Second, the composition effect of growth (the change in the structure of the economy) indicates the change in the effect of the sectoral composition of economic activities. The pollution control and abatement effort in the growth process which reduces the environmental degradation is, on the other hand, explained by the technique effects of growth.

Few empirical studies have been carried out on the decomposed environmental effects of growth across different parts of the world. For example, Panayotou (1997) made one of the earlier studies to explore these structural effects of growth in the income-environment relationship using fixed-effects regression model in 30 developed and developing countries over 1982–1994. The estimation results indicate the scale effect of growth increases ambient SO2 concentrations with a diminishing rate and a non-decreasing relationship is observed in the composition effect. While the abatement effect reduces ambient SO2 levels up to the threshold level. Another study by Bouvier (2004) disaggregates the relationship between per capita income and emissions of CO, CO2, SO2, and volatile organic compounds into scale, composition, and technology effects in 35 European and North American countries over the period 1980–1986. Results indicate that the scale effect outweighs the composition and technology effects in the cases of CO2 and volatile organic compounds, while the opposite is true in the cases of CO and SO2.

Tsurumi and Managi (2010) also investigated the scale, composition, and technique effects of growth on CO2 emissions, SO2 emissions, and energy use in 112 countries over 1963–2000 using a generalized additive effects model. The study found a positive slope for scale effects and non-linear relationships for composition effects, while the technique effect was sufficient to reduce only SO2 emissions. Further, Ling et al. (2015) employed the ARDL approach and reported a positive impact of scale effect and negative impact of technique effect on CO2 emissions in the case of Malaysia over 1970Q1-2011Q4. Mohapatra et al. (2016) analyzed the dynamic scale and technique effect of growth on GHG emissions in Canada over 1990–2010 with the help of a panel VAR model. The findings revealed that the scale effects of growth dominate over the technique effects, making the net effect of growth unfavorable for the environment.

Bakehe (2018) undertook another study in 10 Congo basin African countries over 1990–2010 using non-parametric regression analysis. He confirmed that the existence of scale and composition effects on deforestation, but not the technique effect. Liobikiene and Butkus (2018) examined the relationship between GHG emissions and economic growth in 147 countries over 1990–2012 and their estimation results indicated the existence of scale and technique effect, but no evidence of composition effect of growth. Further, Jena (2018) assessed the impact of the three effects on different air pollutants in India over 1991–2013 and he concluded that the positive scale effect is dominated by the negative
technique effect for sulfur dioxide (SO2) and the scale effect outweighs for nitrogen oxide (NO2) and suspended particulate matter (SPM).

More recently, Nkengfack et al. (2019) decomposed the effects of growth on CO2 emissions in 23 SSA countries over 1996–2014 using static and dynamic panel regressions and the results revealed that scale and composition effects increase carbon emissions while technique effects have a reducing effect on emissions. However, the weights of the scale, composition, and technique effects are found heterogeneously distributed across the CO2 emissions levels. Shahbaz et al. (2019) also studied the decomposed role of growth on CO2 emissions in the USA over 1965–2016 and they found out that the scale effect increases emissions, while the composition and techniques effects reduce it. Further, Ansari and Khan (2021) suggested that the scale effect increases environmental degradation while the composition and technique effects decrease it in different income groups of Asian countries over 1991–2016. This study also indicated that the scale and composition effects granger cause ecological footprint.

To conclude, the disaggregated environmental effects of growth are not widely investigated compared to the reduced-form models to EKC relationship. Second, the existing empirical works found out mixed results particularly in composition and technique effects of growth. Different proxies used for each structural component, more restrictive functional forms (linear specification), and methodological problems are also observed in the reviewed empirical works. Further, as far as we are concerned, there is no such prior work in the study area. It is, thus, quite worthwhile to further examine the scale, composition, and technique effects of growth on the environment in the Ethiopian context using recent data.

3. Data and methodology

3.1. Data type and sources

Annual secondary data was used to conduct this study, which were collected from different sources. For instance, CO2, CH4, and N2O emissions were obtained from the World Bank and World-Resources Institute CAIT Climate Data Explorer. Data for fossil Fuel energy consumption was taken from World Bank, and all other variables were extracted from annual reports of the National Bank of Ethiopia (NBE) and the Ministry of Finance and Economic Development of Ethiopia. Table 1 presents the description and summary statistics of variables used in the study.

3.2. Disaggregating the growth-environment relationship: decomposition analysis

As noted earlier, the conventional reduced-form of EKC equations do not explain the specific structural factors (exact forces for which growth acts as a proxy) through which economic growth may influence the environment. As a result, introducing alternative methods like decomposition analysis would be useful to reveal the underlying structural relationships between growth and environment—to break down the environmental role of growth into the scale (level), composition, and technique effects and to empirically assess their relative contribution. Accordingly, this study makes a modest attempt to investigate the dynamics inside the black box formulation.

Following the empirical works of Grossman (1993) and Brock and Taylor (2005), the total emission (E) generated in the economy at a given period, t is given, by definition, as:

\[ E_t = Y_t \left( \sum_{i=1}^{n} \frac{Y_{it}}{X_{it}} \right) \left( \frac{E_{it}}{Y_{it}} \right) = Y_t \sum_{i=1}^{n} L_i K_{it} \]

where \( Y_t \) is the national output representing the scale of economic activities, \( L_i \) is the amount of emissions per unit of production in each sector of the economy and \( K_{it} \) represents the share of each sectors’ output in the economy and \( \sum_{i=1}^{n} K_{it} = 1 \). According to Eq. (1) \(^1\), the total amount of emissions in the economy is the product of total output and emission intensity of production by sector weighted by the share of the output of each sector in the economy. Then, differentiating both sides with respect to time and we obtain:

\[ \dot{E} = \dot{Y} + \sum_{i=1}^{n} \pi_i \dot{K} + \sum_{i=1}^{n} \lambda_i \dot{I}, \]

where \( \pi_i \) and \( \lambda_i \) represent the shares of composition and technique effects in aggregate emissions.

Eq. (2) indicates how changes in aggregate emissions generated in the economy can be decomposed into the three structural effects of growth. \( \dot{Y} \) represents the scale (level) effect and captures the environmental effect of an increase in economic activity per unit of area assuming the composition of output and the state of technology in the economy remain unchanged. The scale effect is commonly measured by GDP per unit of area (Panayotou, 1997; Nkengfack et al., 2019) and real GDP (e.g. Tsunumi and Managi, 2010; Shahbaz et al., 2019).

The second term on the right-hand side (RHS) of Eq. (2) indicates the composition effect which captures the environmental effect of a change in the sectoral composition of economic activities that reflects the underlying process of industrialization (Islam et al., 1998). Capital-labor ratio (see Nkengfack et al., 2019; Shahbaz et al., 2019) and industry share of GDP (Panayotou, 1997) are widely used proxies for composition effect. Finally, the change in environmental pollution arising from the technique (abatement) effect of growth is represented by the last term on the RHS of Eq. (2). The technique effect is measured by per capita GDP (Tsurumi and Managi, 2010; Shahbaz et al., 2019).

\(^1\) A’ over X indicates \( \frac{\partial X}{\partial X} \).
3.2.1. Model specification of the three effects

The scale effect, that will happen in the initial stage of growth, is expected to worsen environmental problems as an increase in the scale of production activities requires the use of more energy and resources, and hence generates more environmental pollution (wastes and emissions) in a given area. As a result, the scale effect is likely to increase environmental pollution (captured by linear specification in equation 3).

**Hypothesis 1.** The scale effect of growth on environmental pollution appears to be positive.

Second, economic growth exhibits a composition effect leading to environmental improvement assuming the share of a more pollution-intensive industrial sector is gradually declined and an economy moves towards producing a set of cleaner goods and services on average than the set produced before (Dinda, 2004; Brock and Taylor, 2005).

**Hypothesis 2.** The composition effect of growth, in the quadratic specification, will have an Inverted-U-shaped pattern with environmental pollution. That is, growth through its composition effect may initially trigger higher emissions, but its detrimental impact tends to diminish as the share of the industrial sector increases further.

Third, the technique effect of growth is expected to reduce environmental degradation keeping the scale and composition of output unchanged as cleaner and environmentally friendly technologies in the production process are likely to become more applicable at higher levels of income. As noted in Islam et al. (1998), however, both the demand for better environmental quality and supply side of abatement effects (like expenditures on pollution control and R&D activities) may not be delayed till the attainment of a higher level of income. This implies that the technique effect may lead to a reduction in environmental degradation even at a lower level of income.

**Hypothesis 3.** The technique effect of growth is likely to have a generally decreasing relationship with environmental pollution.

Finally, given the decomposed equation stated in Eq. (1) and having the above theoretical justifications (hypotheses), the scale (Y), composition (K) and technique (I) effects of growth on the environment can be specified as:

\[
\ln \text{Et} = \beta_0 + \beta_1 \ln \text{Yt} + \beta_2 \ln \text{Kt} + \beta_3 (\ln \text{Kt})^2 + \beta_4 \ln \text{It} + \beta_5 (\ln \text{It})^2 + \beta_6 \ln \text{FECt} + \epsilon_t
\]

(3)

Fossil fuel energy consumption is included in this study given that it is one of the main drivers of environmental pollution. In this study, the scale effect is represented by GDP per km² as it indicates the scale of economic activities in a given surface area of the country. And, we use the share of value-added in the industrial sector relative to the share of other sectors as a proxy for the composition effect of growth (it indicates how the sectoral composition of output in pollution-intensive sectors relative to less-pollution intensive and cleaner sectors). Here, the use of a relative measure of industrial GDP to other sectors is preferred as the share of one sector value-added may not contain the entire information regarding the composition of output. Income per capita (GNDI per capita) is taken to measure the technique effect of growth. The use of income per capita as a proxy for technique effect is to capture income-induced environmental regulations and public expenditures on pollution controls and abatement (see Panayotou, 1997; Islam et al., 1998).

3.3. Econometric methods

3.3.1. Autoregressive distributed lag (ARDL) regression model

ARDL regression model is mainly employed to empirically investigate the impacts of scale, composition, and technique effects of growth on GHG emissions in Ethiopia over the last four decades. ARDL model is the most popular Ordinary Least Square (OLS) based dynamic regression model employed to estimate the relationship between variables in a single-equation time series setup. It can be applicable for non-stationary time series and for time series with mixed order of integration. It also provides short-run and long-run estimates and can be used for a combination of endogenous and exogenous variables (Nkoro and Uko, 2016; Shrestha and Bhatta, 2018).

Based on Eq. (3), the generalized ARDL (p, q) model can be specified as:

\[
\ln \text{Et} = \theta_0 + \sum_{i=1}^{p} \delta_i \Delta \text{Et}_{-i} + \sum_{i=0}^{q} \theta_i \ln \text{Yt}_{-i} + \theta_2 \ln \text{Kt}_{-i} + \theta_3 (\ln \text{Kt}_{-i})^2 + \theta_4 \ln \text{It}_{-i} + \theta_6 \ln \text{FEC}_{-i} + \epsilon_t
\]

(4)

where \(Y_t\) and \(X_t\) are dependent and a set of independent variables respectively, \(p\) and \(q\) are lag of dependent and independent variables and \(\theta\)s are coefficients of independent variables. Further, The ARDL model specified in Eq. (4) can be re-parameterized in Vector Error Correction form to integrate the short-run adjustments along with the long-run relationship in a single equation without losing long-run information (Nkoro and Uko, 2016; Shrestha and Bhatta, 2018). Hence, the error-correction based ARDL model can be finally stated as:

\[
\Delta \ln \text{Et} = \theta_0 - \phi (\ln \text{Et}_{-1} - (\beta_1 \ln \text{Yt}_{-1} + \beta_2 \ln \text{Kt}_{-1} + \beta_3 (\ln \text{Kt}_{-1})^2 + \beta_4 \ln \text{It}_{-1} + \beta_6 \ln \text{FEC}_{-1})) + \sum_{i=1}^{p} \delta_i \Delta \ln \text{Et}_{-i} + \sum_{i=0}^{q} \theta_i \ln \text{Yt}_{-i} + \theta_2 \ln \text{Kt}_{-i} + \theta_3 (\ln \text{Kt}_{-i})^2 + \theta_4 \ln \text{It}_{-i} + \theta_6 \ln \text{FEC}_{-i} + \epsilon_t
\]

(5)

where \(\Delta Y_t = Y_t - Y_{t-1}\), the speed of adjustment coefficient, \(\phi = 1 - \sum_{i=1}^{p} \delta_i\) and the long run coefficients, \(\beta_i = \sum_0^\infty \delta_i\) and \(\theta_i\) represent the short-run coefficients of lagged dependent and independent variables respectively. Note that the speed of adjustment (error correction term) shows how quickly variables converge/diverge to equilibrium. The highly significant error correction term with a negative sign confirms the existence of a stable long-run relationship.

3.3.2. Toda-Yamamoto Granger causality test

The direction of causality between the variables is not detected using either the cointegration tests or the ARDL models. As a result, The Toda and Yamamoto (1995) granger causality approach was employed to assess the direction of causal linkages between the three structural components of growth and environmental pollution. The Toda-Yamamoto causality test is the modified version of granger causality test and does not require precise knowledge about the order of integration and cointegration of variables. That is, it appears robust to the integration and cointegration properties (Alimi and Ofeneylu, 2013) and eliminates unit-roots pre-testing biases.
The Toda-Yamamoto causality test is employed based on the adjusted Vector Auto-regression (VAR) model of order \((k + d_{\text{max}})\), which allows a modified Wald (MWALD) test.

\[
y_t = \alpha_0 + \mathbf{X}_t^{k+d_{\text{max}}} \delta_1 + \epsilon_t
\]

\[
x_t = \beta_0 + \mathbf{X}_t^{k+d_{\text{max}}} \theta_1 + \epsilon_t
\]

where \(k\) is the optimal lag length and \(d_{\text{max}}\) is the maximum order of integration of the variables. The Toda-Yamamoto Granger causality test assumes the null hypothesis of no Granger causality (\(\delta_1 = 0\) for Eq. (6) and \(\theta_1 = 0\) for Eq. (7)). For example, a bi-direction causality is detected if both \(\delta_1\) and \(\theta_1\) are statistically significant.

4. Empirical results and discussion

Before the main econometric analysis, the two preliminary tests (unit-root and cointegration tests) are checked to avoid the possibility of spurious regressions.

4.1. Unit root test results

The augmented Dickey-Fuller (ADF) test is the most widely used unit-root test although it has poor size and power properties and may not be reliable for a small sample size. As a result, to address these limitations of the standard ADF test, Dicky-Fuller generalized least square (DF-GLS) detrending test, a modified Dickey-Fuller unit root test proposed by Elliott et al. (1996), was conducted to find out the existence of unit root in each of the time series (see Table 2). Nevertheless, the DF-GLS unit root test does not take into account the possibility of structural breaks and may yield misleading results if there is a structural break in the data. As a result, the Zivot and Andrews (1992) unit root test, which allows for one structural break, is applied in this study.

As can be observed in Table 2, the DF-GLS unit-root test indicates that all variables are integrated of order one (variables become stationary after first differences). In the Zivot-Andrews test, on the other hand, all variables (except CH4) are found non-stationary at levels. Hence, similar results are obtained in the two unit-root tests with the expectation of CH4.

4.2. Cointegration test

Once checking for the stationarity of all variables in the model and a unit root is detected in at least one of the variables, we proceed to the next step which involves the test of cointegration. In doing so, we employed the Pesaran et al. (2001) ARDL bounds test to check the existence of a long-run cointegrating relationship among variables. This cointegration test is preferred over other cointegration tests in that it can be applicable for entirely I(1) variables or for mutually integrated variables. It also gives better results for a small sample size.

As can be observed in Table 2, the DF-GLS unit-root test indicates that all variables are integrated of order one (variables become stationary after first differences). In the Zivot-Andrews test, on the other hand, all variables (except CH4) are found non-stationary at levels. Hence, similar results are obtained in the two unit-root tests with the expectation of CH4.

### Table 2. Unit-root test results.

| Variables | DF-GLS unit-root test | Zivot-Andrews unit-root test | Order of Integration |
|-----------|-----------------------|-----------------------------|---------------------|
|           | Intercept             | Intercept + trend           |                     |
| ln CO2    | \(I(0)\)              | -2.232                      | -3.172              | \(I(1)\)             |
|           | \(I(1)\)              | -6.338*                     | -6.537*             |                       |
| ln CH4    | \(I(0)\)              | -1.117                      | -4.631**            | \(I(1)\)             |
|           | \(I(1)\)              | -6.541*                     | -6.559*             |                       |
| ln N2O    | \(I(0)\)              | -1.826                      | -4.316**            | \(I(1)\)             |
|           | \(I(1)\)              | -7.498*                     | -7.949*             |                       |
| ln RGDP   | \(I(0)\)              | 0.17                        | -0.956              | \(I(1)\)             |
|           | \(I(1)\)              | -8.354*                     | -8.621*             |                       |
| ln Ind-ratio | \(I(0)\)        | -1.741                      | -1.770              | \(I(1)\)             |
|           | \(I(1)\)              | -4.132*                     | -7.782*             |                       |
| (ln Ind-ratio)² | \(I(0)\)    | -2.00                       | -3.040*             | \(I(1)\)             |
|           | \(I(1)\)              | -4.256*                     | -5.429*             |                       |
| ln GNDI   | \(I(0)\)              | 0.083                       | -1.737              | \(I(1)\)             |
|           | \(I(1)\)              | -7.052*                     | -7.974*             |                       |
| (ln GNDI)² | \(I(0)\)        | 0.128                       | -1.728              | \(I(1)\)             |
|           | \(I(1)\)              | -8.233*                     | -8.765*             |                       |
| ln FIC    | \(I(0)\)              | -2.498                      | -3.614              | \(I(1)\)             |
|           | \(I(1)\)              | -5.215*                     | -6.266*             |                       |

Note: * denote statistical significance at 1 % level. \(I(0)\) and \(I(1)\) represent at levels and first differences respectively. ** indicates that the I(0) variables in the Zivot-Andrews test results.

### Table 3. ARDL Bounds test for cointegration.

|                      | F-bounds test | Upper critical values | t-bounds test | Upper critical values |
|----------------------|---------------|-----------------------|---------------|----------------------|
|                      | 1%            | 5%                    | 1%            | 5%                   |
| Model with CO₂       | 14.97         | 5.332                 | -6.771        | 4.967                |
| Model with CH₄       | 6.664         | 5.169                 | -3.703        | 4.954                |
| Model with N₂O       | 6.303         | 5.211                 | -4.529        | 4.963                |

Source: EViews 10 output.
critical value for upper bound, I(1), or if the corresponding p-values are less than 5%. Accordingly, in all three models, both the F-bounds test and t-bounds test results confirm the existence of a stable long-run relationship at a 1% level (see Table 3).

4.3. ARDL regression model results

As stated in section 3.3, the ARDL regression model is applied to empirically examine the decomposed effects of economic growth on environmental pollution in the short run and long run. CO$_2$, CH$_4$, and N$_2$O emissions are used as environmental pollution indicators.

4.3.1. The scale effect

Table 4 presents that the scale effect of economic growth is positive and statistically significant at a 1% level in both the short run and long run for all types of emissions. This indicates that the expansion of economic activities in Ethiopia increases environmental pollution during the study period. Our results are quite consistent with Hypothesis 1 and with the earlier empirical findings\textsuperscript{5}. However, the scale effect is found stronger in the case of CO$_2$ emissions. A one percent rise in the scale effect of growth induces a 1.25 percent increase in CO$_2$ emissions in the long run while CH$_4$ and N$_2$O emissions would be grown by 0.42 and 0.54 percent, respectively.

4.3.2. The composition effect

Economic growth through its composition effect represented by the share of industrial GDP relative to the share of other sectors is found to have a monotonically increasing relationship with CO$_2$ emissions in the long run. This indicates that a rise in the share of industrial activities in the economy is associated with higher carbon emissions. Put differently, the current industrialization process in Ethiopia has not reached a sufficient level to reduce carbon emissions. On the contrary, the composition effect appears to have a non-increasing pattern with CO$_2$ emissions which might be because they are more linked with agricultural activities.

4.3.3. The technique effect

A lagged GNDI per capita which captures the technique effect of growth confirms a monotonically decreasing pattern with CO$_2$ emissions, reflecting that an increase in income leads to a reduction of carbon emissions even at lower levels. Comparable results were reported in Islam et al. (1998) in this regard. Such a relationship might happen in low-income countries like Ethiopia with increased public awareness of CO$_2$ emissions and the use of environmentally friendly technologies (like re-afforestation and renewable energy). In contrast, an Inverted-U-shaped technique effect of growth is observed in the case of CH$_4$ and N$_2$O emissions which might be because they are more linked with agricultural activities.

\textsuperscript{5} Such as, Tsurumi and Managi (2010); Mohapatra et al. (2016) Liobikiene and Butkus (2018); Nkengfi et al. (2019); Shahbaz et al. (2019).

\textsuperscript{6} Note that a one period lagged GNDI per capita is used in the regression just to allow some time lag (lagged responses) between the rise in income and its effect to be transmitted to emissions.
Figure 1. CUSUM and CUSUM of squares stability tests.
in reducing these types of emissions. One point that has to be noted here in the findings of technique effect is that there could be good environmental awareness and greater public exposure to CO2 emissions than other GHG emissions in Ethiopia, resulting in a generally decreasing relationship of CO2 emissions with income (Hypothesis 3 is supported for CO2).

Moreover, the ARDL results reveal that fossil fuel energy (non-renewable energy) consumption has a significant positive effect on all types of GHG emissions in the long run. The effect appears to be more pronounced for CO2 emissions, indicating fossil fuel energy is highly correlated with carbon emissions. In the long run, for a one percent rise in fossil fuel energy, CO2 emissions would increase by about 1.4 percent, CH4 emissions by 0.26 percent, and N2O emissions by 0.24 percent. This environmental damaging impact of fossil fuel energy underscores the importance of energy transition to eco-friendly energy sources.

The coefficients of error correction term are highly significant and with the expected right sign. The coefficients indicate that 77 percent of shocks in CO2 emissions are removed every year while 47 percent and 69 percent of shocks are corrected in CH4 and N2O emissions, respectively. Regarding the model diagnostic tests, as shown in the lower panel of Table 4, the Breusch-Godfrey test of serial correlation, the Breusch-Pagan-Godfrey test of heteroscedasticity, the Ramsey-RESET test of model specification, and the Jarque-Bera test of normality confirm that the ARDL models with the three emissions satisfy all model assumptions (all tests fail to reject their respective null hypotheses). That is, the models are free from auto-correlation, heteroscedasticity, non-normality, and model misspecification problems.

Further, the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUM square) stability tests depict that the parameters in both short run and long run are stable over the specified period as plots move within the lower and upper boundaries at 5% level (see Figure 1).

4.4. Toda-Yamamoto Granger causality test results

As presented in Table 5, the causality test results indicate that the scale, composition and techniques effects of growth Granger cause CO2, CH4 and N2O emissions. The results do not support causality from the three types of emissions to growth components, however. Hence, the findings from the Toda-Yamamoto causality test confirm evidence of a unidirectional (one-way) Granger causality from economic growth to environmental pollution. This may imply that policies adopted to achieve higher economic growth will significantly affect GHG emissions in Ethiopia. In contrast, policy measures taken to mitigate environmental pollution may not affect the growth process in the country.

5. Concluding remarks

This study makes a modest attempt to provide some empirical evidence on the disaggregated role of economic growth on environmental pollution in Ethiopia over 1975–2017 using the ARDL regression model. The results confirmed that the scale effect of growth is found to have an emission-increasing impact in all types of GHG emissions used in the study (CO2, CH4, and N2O). Further, the composition effect of growth shows a monotonically increasing pattern in the case of CO2 emissions and appears to have a non-increasing relationship with other types of emissions. On the other hand, a generally decreasing (for CO2 emissions) and an Inverted-U shaped (in the case of CH4 and N2O emissions) technique effects of growth are observed in Ethiopia over the study period. In general, the decomposition analysis in the growth-environment relationship is proven useful to better understand the exact forces (sources of emissions and abatement effects) of environmental pollution, which in turn leads to a more appropriate and desirable policy interpretation.

In the context of policy implications, a self-correcting mechanism in the growth process may not automatically reduce environmental pollution. In other words, better environmental quality is more likely to be achieved only if the technique effect is sufficiently strong to offset the scale effect of growth on the environment. As a result, the currently developing countries including Ethiopia should follow a clean-growth trajectory in their quest for enjoying higher economic growth, should take lessons from history, and avoid mistakes of earlier growth experiences in developed countries. Further, a lot of efforts need to be made to raise public awareness and exposure to GHG emissions to reduce the extent of emissions even at a lower level of income (at the early stage of development).

Fossil fuel energy consumption is found to be a significant driver of environmental pollution in Ethiopia, suggesting the need to promote clean energy transformation in the country’s growth process. On the other hand, the Toda-Yamamoto Granger causality test indicates a

### Table 5. Toda-Yamamoto Granger causality test.

| Hypothesis | Chi-Square test | p-value |
|------------|----------------|---------|
| scale effect does not Granger cause lnCO2 | 62.85* | 0.000 |
| lnCO2 does not Granger cause the scale effect | 0.781 | 0.377 |
| Composition effect does not Granger cause lnCO2 | 6.474** | 0.011 |
| lnCO2 does not Granger cause the composition effect | 0.098 | 0.754 |
| Technique effect does not Granger cause lnCO2 | 6.108** | 0.013 |
| lnCO2 does not Granger cause the technique effect | 0.585 | 0.445 |
| scale effect does not Granger cause lnCH4 | 44.99* | 0.000 |
| lnCH4 does not Granger cause the scale effect | 0.225 | 0.635 |
| Composition effect does not Granger cause lnCH4 | 6.151** | 0.013 |
| lnCH4 does not Granger cause the composition effect | 1.129 | 0.288 |
| Technique effect does not Granger cause lnCH4 | 32.39** | 0.000 |
| lnCH4 does not Granger cause the technique effect | 0.504 | 0.478 |
| scale effect does not Granger cause lnN2O | 27.55* | 0.000 |
| lnN2O does not Granger cause the scale effect | 1.901 | 0.168 |
| Composition effect does not Granger cause lnN2O | 2.711*** | 0.100 |
| lnN2O does not Granger cause the composition effect | 0.054 | 0.816 |
| Technique effect does not Granger cause lnN2O | 9.56* | 0.002 |
| lnN2O does not Granger cause the technique effect | 1.915 | 0.166 |

**Note**: *, ** and *** denote significance at 1 %, 5 % and 10 % levels, respectively.
unalidirectional Granger causality from the structural components of growth to the GHG emissions. This implies that growth-oriented policies in Ethiopia will adversely affect the environment and that any policy interventions taken to mitigate emissions may not affect economic growth. Hence, the adoption of environmental-friendly technologies and pollution abatement measures need to be encouraged to maintain environmental sustainability.

Finally, we suggest the future studies to extend this area using other environmental sustainability indicators and incorporate country-specific characteristics such as the quality of institutions, the use of renewable energy technologies and the stringency of environmental regulations.

Declarations

Author contribution statement

Dagmawe Tenaw: Analyzed and interpreted the data; Wrote the paper.

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Data will be made available on request.

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Additional information

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