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Special Issue

Environmental Effects of the African Continental Free Trade Agreement: A Computable General Equilibrium Model Approach

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ABSTRACT

Growth and development in middle- and low-income countries often come at an environmental cost, but is that trade-off always necessary? This study uses a computable general equilibrium model to estimate the macroeconomic and environmental impact of the world's most significant plurilateral trade agreement, the African Continental Free Trade Agreement (AfCFTA). We build a novel dataset using the Global Trade Analysis Project data, which allows us to estimate the effect on emissions of carbon dioxide (CO_2), non-CO_2, and other pollutants. In terms of macroeconomic impact, African nations benefit from gross domestic product growth by 1.2% and employment by 2.1%, with less developed economies, such as Togo and Benin, obtaining the largest macroeconomic gains from trade liberalization. On aggregate, we estimate that the agreement will lead to a marginal, 0.3% increase in CO_2 emissions, a 19.6% increase in non-CO_2 greenhouse gas emissions, and a 21.5% decline in air pollutants. We find considerable heterogeneity across countries. For Nigeria, the rest of Central Africa, and South-Central Africa, the AfCFTA is expected to reduce emissions, while in Ethiopia, Cameroon, and Burkina Faso, estimations show an increase. Transit countries connected to large ports, such as Togo and Benin, are most negatively impacted. We conclude that while the AfCFTA implementation is expected to lead to notable improvements in air quality by reducing air pollutants, the resulting increase in climate-related emissions may require member countries to make concerted efforts to deal with the adverse effects.

1. INTRODUCTION

Africa is currently on the road to operationalizing its continental free trade area. The African Continental Free Trade Agreement (AfCFTA), which entered into force in May 2019, is the world's largest free trade area regarding the number of participating countries since the formation of the World Trade Organization.[1] The AfCFTA brings together 1.3 billion people with a combined Gross Domestic Product (GDP) valued at 2.5 trillion US dollars. The successful implementation of the AfCFTA is a concern for the African Union and the rest of the world, given the current political environment, which is gripped by trade tensions.[2]

The agreement is set up to remove tariffs for 97% of all tariff lines and not less than 90% of all trade, aiming to allow free access for commodities, goods, and services across the continent.[3] The main objectives of the agreement are to create a single market, deepen the economic integration of the continent, achieve market liberalization, allow the movement of capital and people, and foster investment. In sum, the implementation of the agreement aims to achieve sustainable and inclusive socio-economic development.

Environmental protection is currently one of the main objectives for trade policymakers to ensure the sustainability of countries' economic growth. The connection between trade and the environment has been widely recognized in the international community and is now also

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Data availability statement: The data that support the findings of this study are available from the corresponding author [BN], upon reasonable request.
[1]For a list of countries that have ratified the AfCFTA agreement and updates, check https://www.africancfta.org/.
[2]The AfCFTA is set to be implemented in phases, some of which are still under negotiation. Both the implementation and negotiation schedules for the agreement have been delayed due to the COVID-19 pandemic.
[3]Countries can implement tariff reductions over a longer period for 7% of tariff lines. They can maintain existing tariffs for the remaining 3% of tariff lines if the value of trade under the remaining 3% does not exceed 10% of the total trade within Africa.

earning a seat at the table in trade negotiations. Since trade is known to facilitate the industrial transition, policymakers are finding it increasingly necessary to study whether trade can also be used as a tool to tackle environmental concerns. The improvement of the environmental quality in the context of Africa should be a top priority in setting the rules for trade. While Africa's carbon emissions are among the lowest in the world, African Greenhouse Gas (GHG) emissions, mainly stemming from agricultural activities, are among the fastest-growing emissions globally (Tongwane and Moeletsi, 2018). Additionally, a high concentration of air pollutants is directly linked to negative health outcomes, increase in poverty rates and delay development. Due to less advanced technologies and excessive reliance on coal and biomass, less developed economies are more prone to have higher air pollutants than GHG emissions.

Despite the environmental impact being one of the most relevant socio-economic issues worldwide, little focus has been put on the potential environmental effects of the implementation of AfCFTA. This paper aims to bridge this gap. In particular, we set out to answer the question: can AfCFTA help reduce pollution? The purpose of the study is to estimate the impact of trade liberalization on the African continent, focusing on carbon dioxide (CO_2), non-CO_2 emissions (GHGs), and other air pollutants. We argue that this question is crucial since the main objective of a free trade area is to boost trade and prevent trade from having a negative effect on the environmental quality of both the signatory countries and their trading partners.

We construct a novel dataset for the 55 countries involved in the AfCFTA agreement to answer this question. We use a Computable General Equilibrium (CGE) model to measure the impact of the free trade area on the environment. In the study, we use the Global Trade Analysis Project (GTAP) database version 10. A (which includes data for four benchmark years 2004, 2007, 2011, and 2014) and the standard GTAP model (Hertel, 1997). Using these data allows us to split the composite African regions into individual countries that are members of AfCFTA to gain access to macroeconomic, trade, and sectoral data from these countries. Furthermore, we collect and merge the CO_2 and non-CO_2 emissions (GHG) databases originating from different sources into the GTAP database. The CGE model allows us to capture linkages between all sectors and agents of the economy and compute trade flows across AfCFTA members and the rest of the world.

The closure of our model is set to allow for the national level of labor employment to change to better reflect the underlying African labor market dynamics without keeping the real wages fixed. We assume an aggregate labor supply curve with an elasticity of 1. While this is a feature that most of the previous CGE studies on the impact of the AfCFTA do not include, it is nevertheless an approach to modeling the labor market, which is both well-documented and implemented in other studies (see Peterson, 2019). Moreover, the focus of previous studies is to estimate the economic and welfare effects of the implementation of the agreement. While our analysis also does render the macroeconomic and welfare impacts of the agreement, our primary focus lies on estimating the impact on the environment. Compared to previous studies on trade and environment that focus solely on carbon emissions, we contribute to this strand of the literature by expanding the focus beyond CO_2 emissions and including the effects on two additional environmental outcomes, namely non-CO_2 emissions and air pollutants.

There is a shortage of studies that focus on the environmental assessment of FTAs in general and the AfCFTA in particular. As far as we know, no other studies are focusing on the impact of AfCFTA on CO_2, GHGs, and air pollutants. The results of our analysis suggest a positive and significant macroeconomic impact, with an increase in trade and GDP across Africa, with the less-developed nations expected to benefit the most from trade liberalization economically. Our estimates suggest the negative environmental impact of the liberalization of trade within Africa on $CO_{2,}$ and GHGs, both increasing. Meanwhile, our results predict the AfCFTA to lead to the reduction of African emissions of other air pollutants by almost 25%.

Our paper shows that Africa's growth and development can be fostered through intra-regional trade but we need to assess the effect on the environment for governments to design policies and regulations to cope with potential negative externalities. The rest of the paper is organized as follows: Section 2 presents the review of the previous literature; Section 3 describes the model, data, and assumptions; Section 4, presents the results; and Section 5 contains conclusions and policy recommendations.

2. LITERATURE REVIEW

Several previous studies use the CGE model incorporating GTAP data to estimate the economic impacts of the AfCFTA. The studies have used different setups, both regarding underlying assumptions for the baseline model and the expected outcome of the agreement. None of the previous studies, however, assess the estimated impact on emissions. This section provides an overview of previous studies to provide a backdrop for our paper.[4] Hence, we summarize the findings of previous studies modeling the elimination of Intra-African tariffs. However, with the exception of the dynamic closure in Saygili et al. (2018) and Sandrey and Jensen (2015)'s model – which do allow for labor mobility – it is important to note that previous studies differ from ours. These studies assume that the supply of production factors, that is, labor and capital, is constant. In our baseline model, the increase in demand for labor can be captured even at the aggregate level.[5]

The previous studies estimate the welfare and GDP gains to be between 0.1% and 0.5%, and the estimated economic impact differs significantly across the continent. This results from the heterogeneity in country characteristics such as geographical location, production, and trade patterns. The most recent AfCFTA CGE modeling exercise is the World Bank (2020) study, which uses GTAP 2014 data and the

[4]For an overview of overall set ups and outcome of the AfCFTA CGE modelling simulations, see Abrego et al. (2019).

[5]In the static set up, changes in demand will lead to changes in prices, that is, wages and return to investments, which in turn causes production factors to move between sectors within the economy – from less to more profitable – stemming from policy induced changes.

World Bank's ENVISAGE CGE model. Table 1 summarizes the main characteristics and results of previous studies that focus on welfare and macroeconomic effects.[6]

Concerning the literature that focuses on the environmental effects of FTAs, Glomsrød et al. (1992) is one of the first studies that use a CGE model to analyze the economic impact of introducing CO_2 stabilizing policy instruments on Norwegian economic growth. Their analysis, which includes CO_2 and other emissions, indicates that a cap on CO_2 emissions could be introduced without dramatically reducing economic growth. That policy implementation could simultaneously reduce emissions to air other than CO_2, yielding considerable gains in noneconomic welfare. Baghdadi et al. (2013) investigate whether Regional Trade Agreements (RTAs) with environmental provisions affect absolute and relative pollution levels. The study focuses on the determinants of CO_2 emissions for a cross-section of 182 countries over the period 1980–2008. A propensity score matching approach is combined with difference-in-differences techniques to effectively isolate the effect of the RTA variable. The main results indicate that the CO_2 emissions of the pairs of countries that belong to an RTA with environmental provisions tend to converge and are lower in absolute terms. Furthermore, they find that emissions converge more rapidly for North American Free Trade Agreement (NAFTA) than for EU-27 and Euro-Med countries. Cherniwchan (2017) estimates the effects of NAFTA on the emissions of particulate matter (PM10) and sulfur dioxide (SO_2) from manufacturing plants in the United States. The findings suggest that trade liberalization led to significant reductions of these pollutants at affected plants. On average, the estimates account for nearly two-thirds of the reductions in PM10 and SO_2 emissions from the US manufacturing sector between 1994 and 1998. Those reductions can be attributed to trade liberalization following NAFTA. Zhou et al. (2017) use panel data methods for 136 countries from 2001 to 2010 to estimate the effect of trade liberalization with and without environmental provisions on the resulting levels of PM 2.5 air pollution.[7] Their main results show support for including environmental provisions in RTAs since those RTAs are likely to be associated with a lower level of PM2.5 concentrations, and those without lead to worse air.

Less attention has been directed to the effects of trade and trade policies on local air pollution in developing countries. Xu and Masui (2009) assess the impacts on local air pollutant emission reduction and ancillary CO_2 emission reduction of SO_2 by introducing a sulfur tax in China.[8] Their results show that, while an emission cap could help control SO_2 emissions, it would also likely result in a large GDP loss. Oh et al. (2019) use a static CGE model to analyze the economic impact of policies for reducing air pollutants and the interactions between those policies in Korea. The results indicate that the economic impacts of policies aiming to reduce air pollutants and GHGs were significant, ranging from 0.3% to 1.8% of GDP.

Gumilang et al. (2011) use a CGE model for Indonesia to compute the environmental impact of its trade agreements with Japan (IJEPA; Indonesia-Japan Economic Partnership Agreement) and ASEAN (AFTA; ASEAN Free Trade Area). Overall, tariff reform is shown to induce air pollution and reduce water pollution. Results indicate that Indonesia's participation in the IJEPA and AFTA agreements is not likely to bring drastic changes to the economic and environmental performance. Yao et al. (2019) use a gravity framework to study the impact of FTAs on carbon emissions. They find a significant impact of FTA agreements on reductions of CO_2 pollution by pair of countries. However, the evidence is mixed: for high-income countries, FTAs are beneficial, but for lower-middle-income countries, the environmental

Table 1 | Estimates of the welfare effects of the impact of the African Continental Free Trade Agreement

Authors	Model	Data and liberalization	Results
Mevel and Karingi (2012)	Mirage model	2004, total liberalization by 2017	0.6% increase in GDP
Sandrey and Jensen (2015)	GTAP model and data	2011	Increase in African welfare by $17 billion
Chauvin et al. (2016)	Mirage model and GTAP data	2007	Increase of 1.3% in GDP
Vanzetti et al. (2018)	Mirage model and GTAP data	2014	Overall welfare gain of about US$ 3.6 billion in the long run, which is approximately 0.1% of GDP
Saygili et al. (2018)	CGE dynamic model	2014, liberalization takes place over 5 and 8 years, respectively	GDP growth estimated by 1% and total employment to increase by 1.2%. Intra-African trade is estimated to expand by 33%
African Development Bank (2019)	CGE	2014	0.1% increase in net real income for the African continent, corresponding to an increase of $2.8 billion. Assumes NTB reductions in addition to tariff reductions as a result of the agreement
Abrego et al. (2019)	CGE with GTAP data	2014	Increase in the welfare of 0.05% for the continent GDP
World Bank (2020)	World Bank's ENVISAGE CGE model GTAP data	2014	Continental real income to increase by 0.2%. Major gains from the introduction of trade facilitation measures and the reduction of non-tariff barriers*

Notes: Own elaboration. *This study models tariff reductions in a less stylized way, incorporating more progressively reductions to mimic the actual outcome of the negotiations closer. Tariff lines on 90% of tariff lines are eliminated over a 5-year period (10-year period for the least developed countries, or LDCs). Starting in 2025, tariffs on an additional 7% of tariff lines are assumed that will be eliminated over a 5-year period (8-year period for LDCs). NTB, Non-Tariff Barriers.

[6]Our estimation results are in line to those obtained by Chauvin et al. (2016) and Saygili et al. (2018). However, in our study neither the underlying data nor the underlying assumptions or model structures are identical to previous analysis, which helps to explain the nuance in results.

[7]Fine PM ≤2.5 μm in diameter.

[8]This study is based on the Asia-Pacific Integrated Model/CGE country model, simulating the period between 1997 and 2020.

quality declines. They claim that low-income countries have a more significant pollution effect even after implementing an FTA due to lenient environmental standards.

In the specific context of Africa, studies that relate trade, development, and environmental impact are quite scarce. Our work breaks new ground in quantifying the impact of an increase in trade and economic activity due to implementing the AfCFTA on environmental outcomes.

Frankel and Rose (2005) set out to determine the causality behind the observed correlation between trade openness and environment, that is, analyzing the effect of trade on a country's environment for a given level of GDP. Their results support trade as a measure to reduce air pollution, such as SO_2 and NO_2. They interpret their findings as refute to the race-to-the-bottom theory, which states that increased openness to trade has a generally detrimental effect on the environment. Moreover, they conclude that their analysis lends general support for the Environmental Kuznets Curve (EKC). EKC is the notion that openness to trade accelerates the growth process at higher income levels and has positive effects on the environment.[9]

Other studies, such as Osabuohien et al. (2015), extend the EKC model by including indicators of the presence of multinational corporations, trade, and energy to analyze their impact on measures of environmental pollution (CO_2). This model was tested on a sample of 27 African countries for the period 1996–2010. Their findings suggest that trade may not have much contemporaneous impact on the environment. However, their lagged values have an adverse and significant influence on the current values of environmental challenges. They suggest that institutional development helps to suppress the negative excesses (like pollution) from the activities of trade and consequently reduce environmental pollution.

Beyene and Kotosz (2020) focus on testing the EKC hypothesis for East African countries from 1990 to 2013. The results show that the economic activities in East African countries do not lead to a significant increase in CO_2 emissions. They find that the relationship between per capita income and CO_2 emissions follows an inverted U-shaped relationship. For low-middle-income countries, higher development will lead to higher levels of emissions until those countries reach a more advanced level of development; economic growth (hence higher income) will reduce emissions.

3. METHODOLOGY AND DATA

In this study, we use the GTAP database version 10a and our customized extension of the standard GTAP model (Hertel, 1997) to analyze the macroeconomic and environmental impact of the AfCFTA. We use the GTAP CGE modeling framework to explore the impact of trade liberalization under the AfCFTA on emissions in the African Subcontinent. The GTAP Model is a multi-region, multisector, CGE model with perfect competition, which runs simulations interactively using the GTAP general equilibrium model.

To complement the standard GTAP model, we include emissions as a function of output and inputs. Here, CO_2 emissions are available for different uses of commodities: government consumption, private consumption, and intermediate inputs – both domestic and imported. The equations in the model depict the change (in %) of each type of emissions as the change (in %) in the corresponding economic variable. For example, a change in imported private consumption $qpm_{i,s}$ also induces a change in emissions from the imported private consumption. The aggregate CO_2 emission is the sum of all these types of emissions as shown in Equation (1), for a commodity *i* in region *s*; industrial emissions are summed across industry uses *j*:

$$CO_{2i,s} = \Sigma_j CO_2Firms_{i,j,s} + CO_2Households_{i,s} + CO_2Government_{i,s} \quad (1)$$

The GTAP-E model captures the changes such as the ones above. However, the purpose of this paper is not to analyze emissions trading and carbon taxes, but instead, we use this extension for emissions accounting to examine the impact of trade policy on emissions. Furthermore, we include other types of emissions and pollutants, which is a novel contribution of our model extension within the GTAP framework. It is important to note that there are trade-offs and tensions between reducing different types of emissions, which we set out to capture in our analysis. We have output-linked emissions for air pollutants and non-CO_2 GHG emissions, whose percent change is the same as the percent change in output, input-linked emissions, and consumption-linked emissions. In addition, we have emissions linked with intermediate inputs and endowment use by firms, separately identified in the model. Equation (2) shows the accounting equation for Air Pollutants (AP) and non-CO_2 GHG emissions, denoted collectively by $APNonCO_2$, for a given sector *i* and region *s*, while the emissions associated with the inputs are summed up across industries *j*.

We follow Chepeliev (2020a and b) methodology in which the input-based emissions (both primary and intermediate inputs), output-based emissions, and consumption-based emissions are mutually exclusive. Input-based emissions come from the use of specific primary inputs consumed by industries. Output-based emissions are those that are only generated during the process of production. Those sum up to the total emissions for both non-CO_2 emissions and air pollutants.

$$APNonCO_{2i,s} = \Sigma_j APNonCO_2inputs_{j,i,s} + APNonCO_2Households_{i,s} + APNonCO_2Output_{i,s} \quad (2)$$

[9]The EKC depicts a hypothesized relationship between various indicators of environmental degradation and income per capita, based on the hypothesis that economic development first leads to a deterioration of the environment and subsequently to an improvement.

Each variable in Equations (1) and (2) is derived from a corresponding variable in the economic part of the model as described above. Equations (3)–(6) show these linkages for inputs, households, output, and government, respectively, in a simplified way and expressed in percent differences. We have more complex linkages in the actual model code, such as those between domestic and imported consumption by firms, government, and households, for CO_2 emissions and not for non-CO_2 or air pollutant emissions. We linearized the equations that capture emission intensities. In so doing, we assume that the emissions intensity with respect to a specific type of category of emissions remains the same before and after our simulation. For instance, if an industry emits X units of emissions when one unit of output is produced, then if the output doubles, it is assumed that the emissions also double. In other words, these equations do not capture any behavioral relationship between different variables and emissions, but instead, they are simply accounting linkages between them.

$$\%\text{ change in APNonCO}_2\text{inputs}_{i,j,s} = \%\text{ change in CO}_2\text{firms}_{i,j,s} = \%\text{ change in firms' inputs } qf_{i,j,s} \tag{3}$$

$$\%\text{ change in APNonCO}_2\text{Households}_{i,s} = \%\text{ change in CO}_2\text{Households}_{i,s} = \%\text{ change in household consumption } qp_{i,s} \tag{4}$$

$$\%\text{ change in APNonCO}_2\text{output}_{i,s} = \%\text{ change in output } qo_{i,s} \tag{5}$$

$$\%\text{ change in CO}_2\text{Government}_{i,s} = \%\text{ change in Government } qg_{i,s} \tag{6}$$

Another departure we make from the standard GTAP model is to assume that both aggregate employment and real wages can change and assuming an upward-sloping labor supply curve, with a unit-elastic response of labor supply to real wages at an aggregate level. This is a standard assumption in the literature, particularly dealing with CGE modeling for labor markets comprehensively (Peterson, 2019). This is shown in Equation (7):

$$\%\text{ change in employment}_{i,s} = \%\text{ change in real wages}_{i,s} + \text{ slack} - \text{variable}_{i,s} \tag{7}$$

It is possible to use the slack variable to allow for exogenous changes in labor supply or even endogenize it. In other words, our assumption is flexible, with possibilities to fix or flex different types of labor using the slack variable. Therefore, we do not require to keep all types of labor as fully employed or otherwise. We can assume one type of labor as fully employed and another type under-employed, if needed. This flexibility in assumption is important to capture the reality that trade liberalization can simultaneously affect employment and real wages. For our simulation, we assume full employment in skilled labor and unemployment in unskilled labor.

For our study, we use the GTAP 10A database with the benchmark year of 2014. The CO_2 and non-CO_2 emissions (GHG) databases are integrated into the GTAP database. We use the database FAOSTAT 2019 (Food and Agriculture Organization of the United Nations) to source agricultural non-CO_2 GHG emissions, and EDGAR version 5.0 and version 4.2 databases are used to source non-agricultural emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, input use by industries, and consumption by households (see Chepeliev, 2020a and b). FAOSTAT reports 10 emission categories under agricultural emissions. Those represent activities that produced such emissions. FAOSTAT does not report agricultural emissions of Fluorinated Gases (FAGS), but only nitrous oxide (N_2O) and methane (CH_4) emissions. Three out of 10 emission categories have both GHGs; these include burning crop residues, burning savanna, and manure management, while seven remaining categories produce either N_2O or CH_4.

The following emissions are included in our analysis:

(i) CO_2 emissions presents CO_2 emissions data from energy commodities consumption. Energy commodities include coal extraction (coa), crude oil (oil), natural gas extraction (gas), petroleum products (p_c), electricity (ely), and gas manufacture and distribution (gdt). CO_2 emissions for electricity are equal to zero, as well as for all other non-energy commodities. The CO_2 emissions are measured in Giga gram or Gg.

(ii) Non-CO_2 GHGs emissions: The GTAP non-CO_2 database complements the GTAP-E database and provides information on other GHG emissions: CH_4, N_2O, and FAGS.

(iii) The air pollution database provides information on the emissions of 10 air pollutants: black carbon (BC), carbon monoxide (CO), ammonia, non-CH_4 volatile organic compounds (short cycle carbon) (NMVB), non-CH_4 volatile organic compounds (long cycle carbon) (NMVF), nitrogen oxides, organic carbon, PM10, PM2.5, and SO_2.

Hence, we arrive at a total of 14 types of emissions and air pollutants. The AfCFTA will create an expanded single continental market; African countries have agreed to eliminate 97% of tariff lines on intra-Africa trade in goods. Hence in simulating the experiment, we shock by eliminating 97% (Chidede, 2020; IMF, 2020a and b) of import tariffs of all tradable commodities in all the AfCFTA regions and countries. The import tariff elimination will lead to the proliferation of imports, and with that, the domestic industry will boost employment opportunities and production output.

In the Appendix, Table A1 shows the corresponding codes for the endowments, Table A2 shows the 65 sectors that have been used for the analysis, and Table A3 summarizes the regions and areas object of study.

4. RESULTS

First, we focus, succinctly, on the macroeconomic and welfare results based on 97% intra-African tariff elimination. Figure 1 summarizes the estimated change in trade in the African subcontinent. As can be seen from Figure 1, the vast majority of countries are estimated to experience increases in trade (exports and imports), with the largest increases in Togo (39%), Senegal (24.7%), Kenya (22.1%), and Ethiopia (21.3%). The exception, with a substantial drop in exports, is Burkina Faso.[10] Imports in the coastal countries of Benin, Ghana, Cote D'Ivoire, and Togo, are all expected to increase significantly (47.6%, 18.6%, 16.3%, and 7.9%, respectively). For the 16 landlocked countries, where intra-regional trade is important, greater regional integration can help these countries become less constrained by unfavorable boundaries. Overall, our simulations project a continent-wide 5.6% increase in exports and a 6.1% increase in imports.

Table 2 summarizes the main macroeconomic results, GDP change, welfare effects, and emissions. Lower tariffs are shown to lead to a 1.2% increase in GDP for the continent as a whole. Our analysis shows that transit countries, such as Togo and Benin, stand to gain significantly from the agreement on the disaggregated level.[11] Here, Ghana and Cote d'Ivoire will experience a 9.9% and 6.2% increase in GDP, respectively, from reducing tariffs under the AfCFTA. Benin experiences the highest estimated GDP increase by 31.2%.[12] However, GDP in Senegal (–0.2%) and Mauritius (–2.2%) are expected to contract slightly as a result of the FTA.

With respect to changes in employment, Figure 2 shows the results by sectors. All countries will experience gains in employment growth except for Mauritius, Malawi, Senegal, and the rest of South African customs.

The corresponding environmental effects are reported in the Heatmaps (Figures 3–6). While the data for all countries are available in the Appendix, we focus on some countries of particular interest. Heatmap 1 (Figure 3) compiles the effects of the implementation of the AfCFTA on overall emissions. As can be seen from Figure 3, CO_2 emissions are expected to increase by 0.3%. For the continent, non-CO_2 GHGs emissions expand by 19.6%, while air pollutants decrease by 21.5%. The potential reduction of air pollutants is particularly relevant in Africa, which is in the grip of acute poverty and underdevelopment since health hazards associated with the air pollutants can worsen positive trade outcomes.

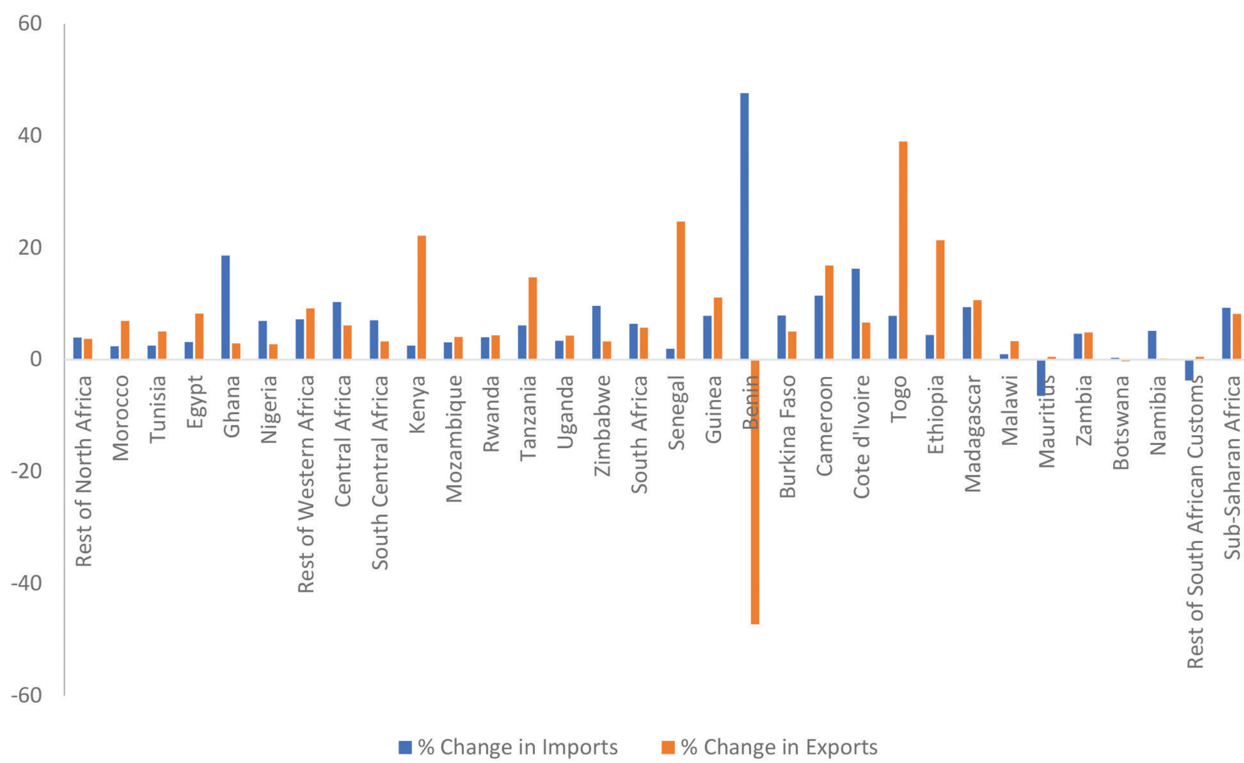

Figure 1 | Change in imports and exports in African subcontinent due to trade liberalization. *Source*: GTAP model results from the authors' analysis.

[10]Burkina Faso is one of the poorest nations in the world. Its exports mainly consist of primary goods like cotton and metals. Trade liberalization in the African continent would lead to the exports of Burkina Faso being uncompetitive and lead to a significant.

[11]Togo is estimated to experience an 8.2% increase in GDP. Its geographic position places it as an important country for transit trade through the Autonomous Port of Lome and two international airports.

[12]In relative terms, the increase is larger than the absolute figures for Benin, as this economy functions as a transit country for the transport of goods to and from Niger, Burkina Faso, Mali, Chad, and Nigeria through the Port of Cotonou.

Table 2 | Country specific effects – selected countries

Country	GDP (%)	Welfare (million $)	CO_2 emissions (% change)	Non-CO_2 (% change)	Air pollutants (% change)
Rest of North Africa	0.8	2436.1	−0.3	−11.3	47.1
Morocco	1.7	760.5	1.7	17.3	1.8
Tunisia	1.7	397	0.4	16.0	15.5
Egypt	1.9	3745.8	1.7	31.6	0.9
Middle East and North Africa	0.8	39745.8	−0.1	14.3	−45
Ghana	9.9	3587.7	9.0	74.9	121.3
Nigeria	0.8	6093.8	−0.5	3.8	−80.8
Rest of Western Africa	4.1	666.2	5.4	30.8	50.4
Central Africa	2.0	1684	3.2	2.8	−24.8
South Central Africa	1.6	3150.1	1.0	18.9	−76.8
Kenya	1.4	−517.4	1.8	14.0	56
Mozambique	2.0	178.8	3.0	22.8	−12.1
Rwanda	2.9	211.9	3.3	34.6	−98.8
Tanzania	2.5	353.9	2.8	46.8	−58.4
Uganda	0.7	176.3	1.0	22.0	−35.7
Zimbabwe	3.4	457.2	2.0	19.2	−54.1
South Africa	1.2	3034	0.7	19.6	8.8
Senegal	−0.2	−644.1	−0.4	−16.4	19.4
Guinea	4.2	217.5	3.7	48.2	52.1
Benin	31.3	2848.6	38.7	354.7	20.0
Burkina Faso	1.7	267.5	0.8	9.4	52.1
Cameroon	3.1	571.8	3.6	43.7	52.3
Cote d'Ivoire	6.3	2035.4	6.1	67.5	15.2
Togo	8.2	−80.2	5.7	−29.0	203.2
Ethiopia	1.6	196.3	2.2	18.2	89.5
Madagascar	1.3	46.8	1.1	18.5	−46.8
Malawi	0.3	−35.9	0.1	−27.2	10.2
Mauritius	−2.2	−435.1	−0.7	−2.6	6.4
Zambia	1.8	482.8	2.3	5.9	−18.9
Botswana	0.3	125.7	0.0	3.1	0.1
Namibia	2.5	417.4	2.1	17	−39.4
Rest of South African Customs	0.3	−55.1	0.0	1.5	23.6
Sub-Saharan Africa	3.1	2230.3	3.0	36.1	−31.4
Aggregate African continent	1.2	74351.2	0.3	19.6	−21.5

Source: GTAP model results from the authors' analysis.

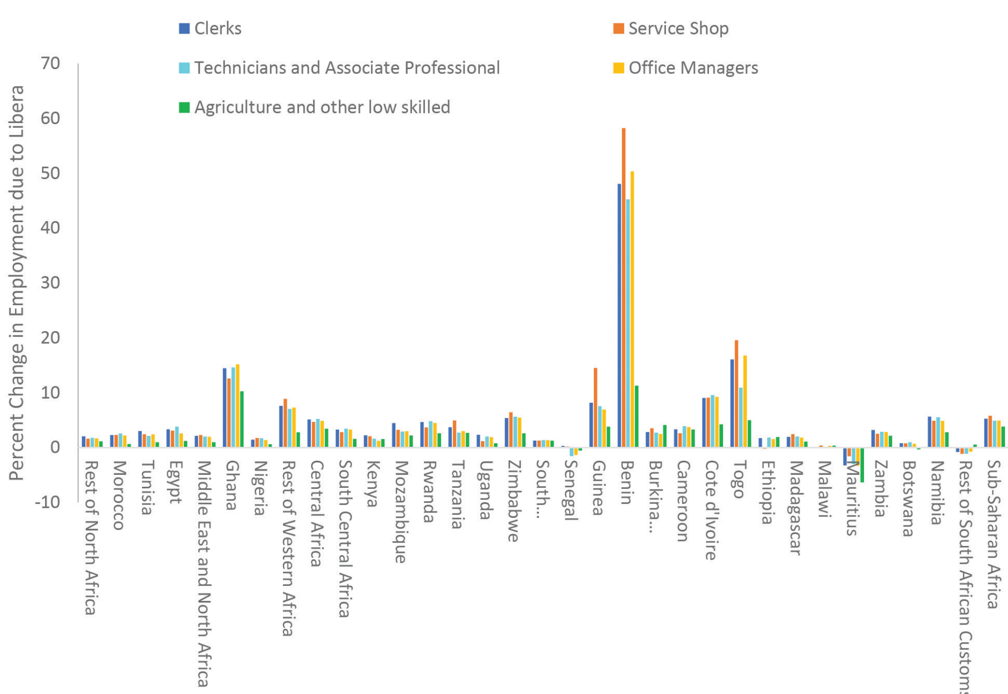

Figure 2 | Change in employment due to liberalization. *Source*: GTAP model results from the authors' analysis.

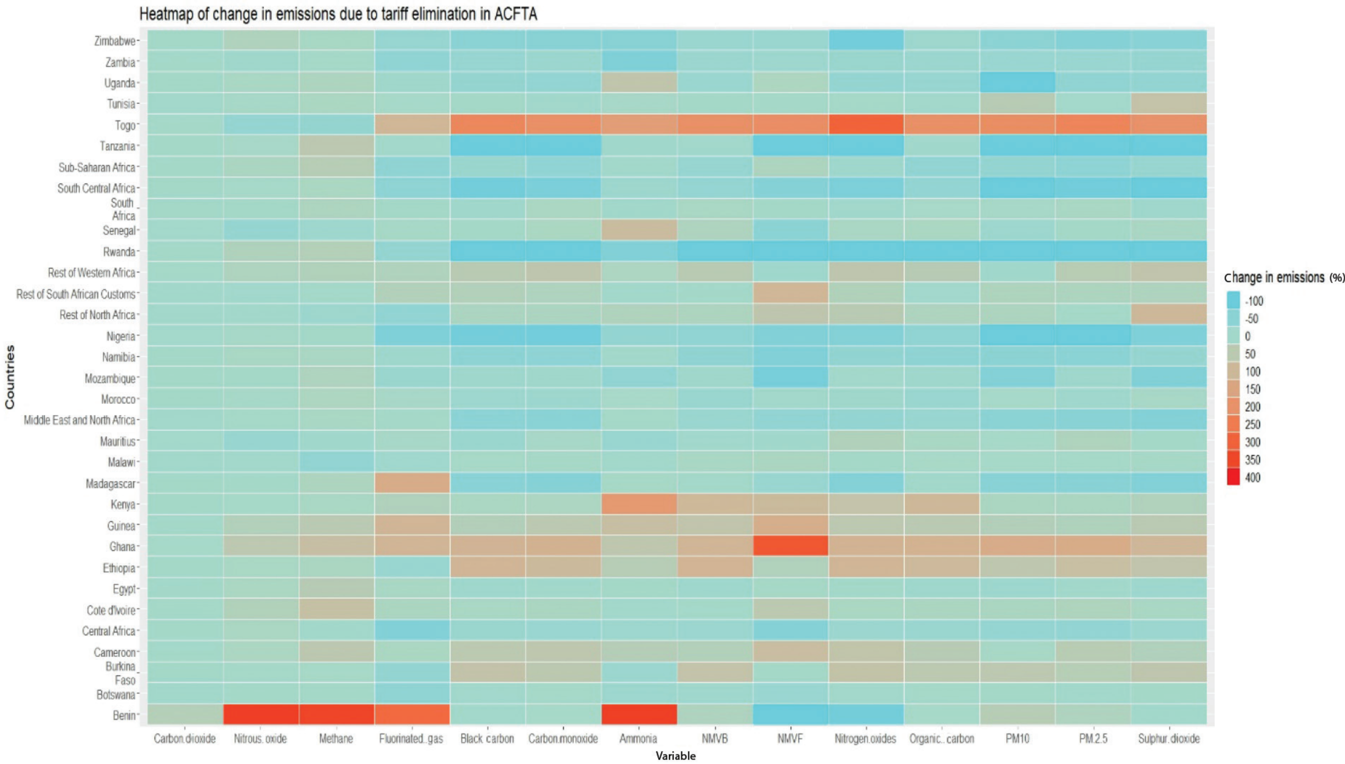

Figure 3 | Heatmap 1. *Source*: Model results from the authors' analysis.

Trade liberalization is estimated to lead to increased emissions in Ethiopia, Cameroon, and Burkina Faso. Furthermore, emissions in Togo and Benin are expected to increase manifold due to these countries' geographical positions as transit countries, connected to big ports. The estimated increase in trade will lead to an increase in the movements of vehicles in these countries, causing emission levels to rise as well. Similarly, many South-Central African Nations, like Congo, Democratic Republic of Congo, Angola, and Gabon, experience a reduction in emissions. About 29% of total imports in Kenya are attributable to intermediate products, which will become cheaper as tariffs are removed, which will increase production activity. The increase in economic activity leads to a rise in emissions. By contrast, Rwanda is a small landlocked country that imports food products, machinery and equipment, construction materials, petroleum products, and fertilizers. Here, the reduction of tariffs results in lower prices of imports and induces substitutions in production, which then has the potential effect of reducing emissions. In the same manner, the AfCFTA is expected to cut the emissions of air pollutants by half in Zimbabwe due to the availability of cheaper imports of mineral fuels and oils, machinery, pharmaceuticals, fertilizers, electrical machinery, and chemical goods. In Guinea, there is an increase in CH_4 and FAGS, and other air pollutants, which stems from an increase in the production of mining products such as Bauxite, iron ore, and crude oil.

Heatmap 2 (Figure 4) provides details of sector-wise CO_2 emissions post-implementation of AfCFTA. On the aggregate level, the agreement's implementation is expected to incur a marginal increase in CO_2 emissions in Africa (0.3%). As previously discussed, Benin's increase in CO_2 emissions is shown to be the highest (38.7%). Also, there is an increase in CO_2 emissions due to the expansion in the meat sector in Morocco, Ghana, Guinea, and Cote d'Ivoire. In Ethiopia, the (32.7%) increase is attributable to the growth of gas production. Meanwhile, the expected increase in CO_2 emissions in Morocco, Tanzania, and Uganda (44.6%, 41.1%, and 49.9%, respectively) stems from the expansion of the production of paddy rice. Nigeria experiences a reduction in emissions due to tariff elimination. Meanwhile, CO_2 emissions decrease (by –0.5%), with significant reductions in the sectors of coal and manufacturing of metal products.

Heatmap 3 (Figure 5) shows the sector-specific changes in non-CO_2 emissions.[13] Here, we note that Benin and Togo are outliers since they are the smallest economies, implying that the greatest relative changes are expected to occur there. The biggest increase in non-CO_2 emissions is shown to occur in Ghana. The emissions in the wool and silkworm sectors are estimated to increase by 1428.3%. Increased export and production leads to higher CH_4 emissions. Many countries, such as Namibia (458.2%), Ghana (318.2%), and Western Africa (310.4%), experience a significant increase in non-CO_2 emissions in the transportation sectors, which stems from an induced increase in trading activity. Other sectors that drive the expansion of non-CO_2 emissions are metals, construction, electrical equipment, chemical products,

[13]The term non-CO_2 emissions comprise CH_4, N_2O, and FAGS. CH_4 is emitted during the production and transport of coal, natural gas, and oil. CH_4 emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. N_2O is emitted during agricultural and industrial activities, combustion of fossil fuels, and solid waste, as well as during the treatment of wastewater.

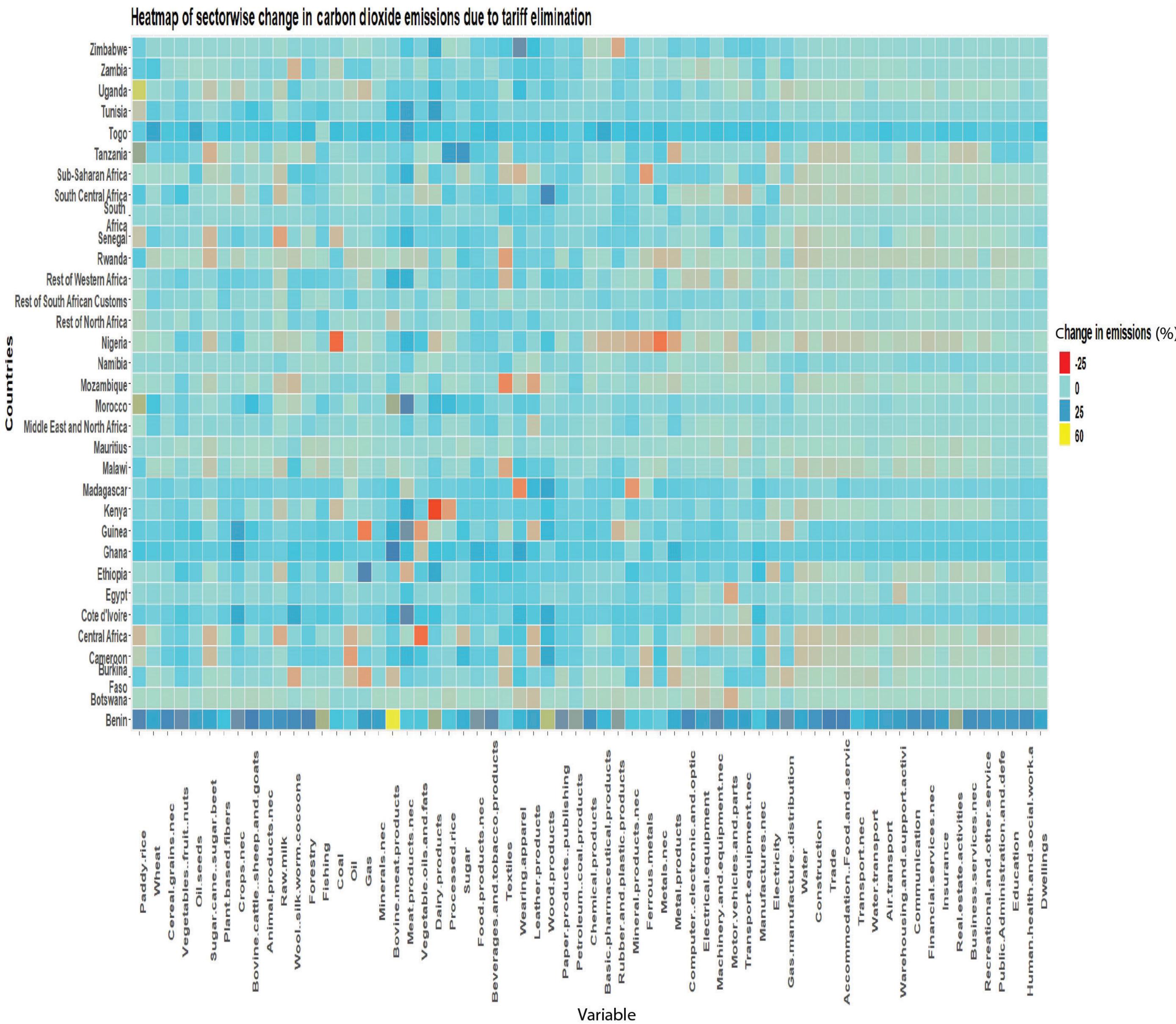

Figure 4 | Heatmap 2. *Source*: Model results from the authors' analysis.

and the wool sector. Meanwhile, reductions in non-CO_2 emissions are estimated to occur in sectors such as meat, vegetable oils, dairy, processed rice, sugar, textiles, apparel, leather, rubber, metal products, computer and electrical equipment, and motor vehicles parts sectors. Both Rwanda and Tanzania are sugar-deficit countries. Lowering tariffs leads to lower costs of imports and higher imports of sugar, hence reducing national sugar production and reducing their non-CO_2 emissions by 100%. Textiles is a well-established industry in Botswana, although it is small compared to the other countries in the region. With cheaper imports, the textile industry's production is impacted, resulting in a 100% reduction of non-CO_2.

Heatmap 4 (Figure 6) summarizes the effects on the results for one of the air pollutants, CO gas. Here, we observe that CO increases in areas with heavy traffic congestion, for example, in Namibia (403.1%,) Egypt (127.4%), and Ghana (81.1%). However, in sectors like electrical equipment, textiles, apparel, leather industries, and meat processing, the AfCFTA is expected to reduce CO gas emissions significantly. Our results for the rest of the air pollutants show a sharp decline for the continent, which on average, is estimated to decrease by 21.5%.[14]

[14]The simulations done for additional air pollutants, such as ammonia emissions, non-CH_4 volatile organic compounds (short cycle), non-CH_4 volatile organic compounds (long cycle), nitrogen oxide gases, and PM of 10 and 2.5 μm are available under request.

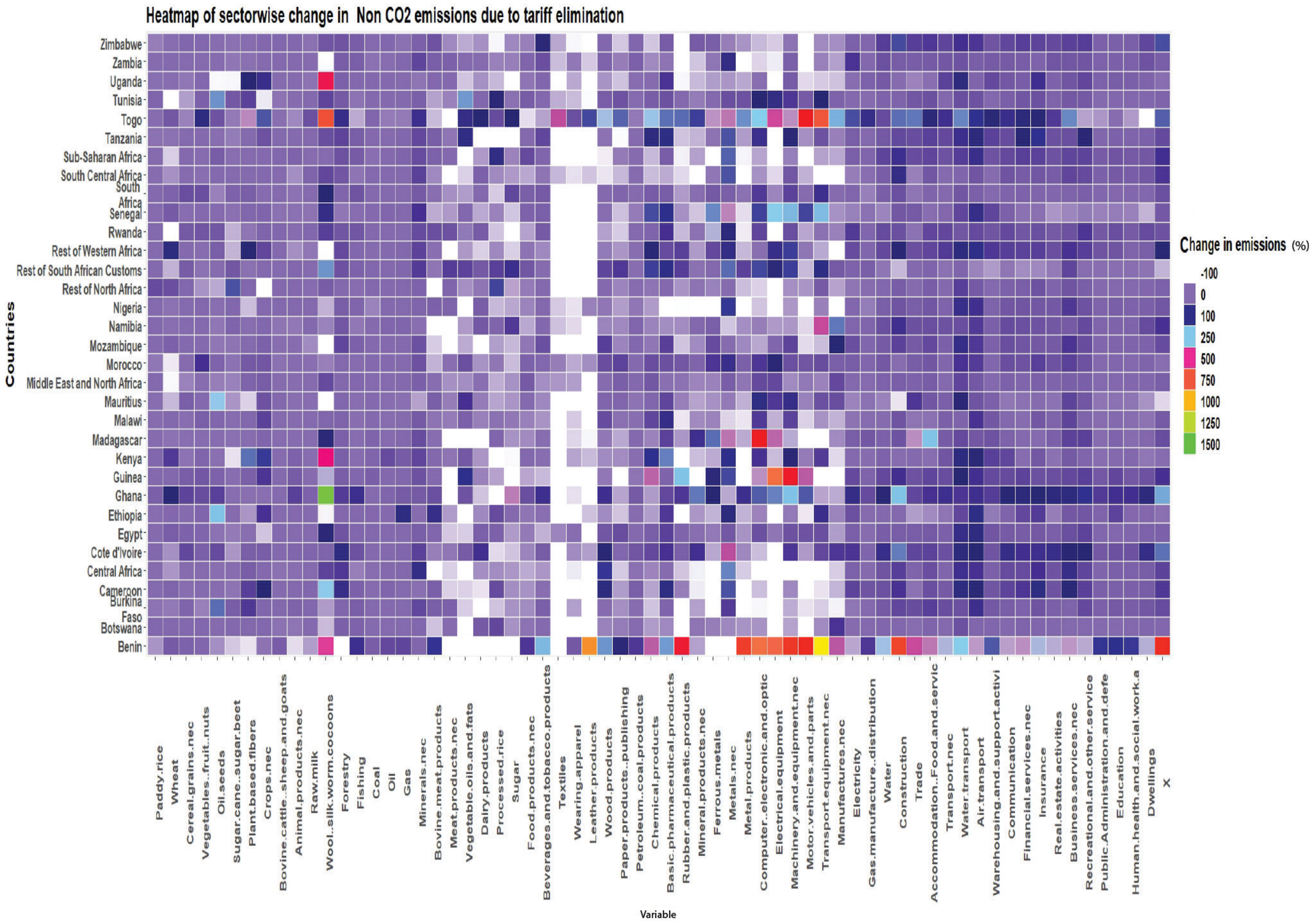

Figure 5 | Heatmap 3. *Source*: Model results from the authors' analysis.

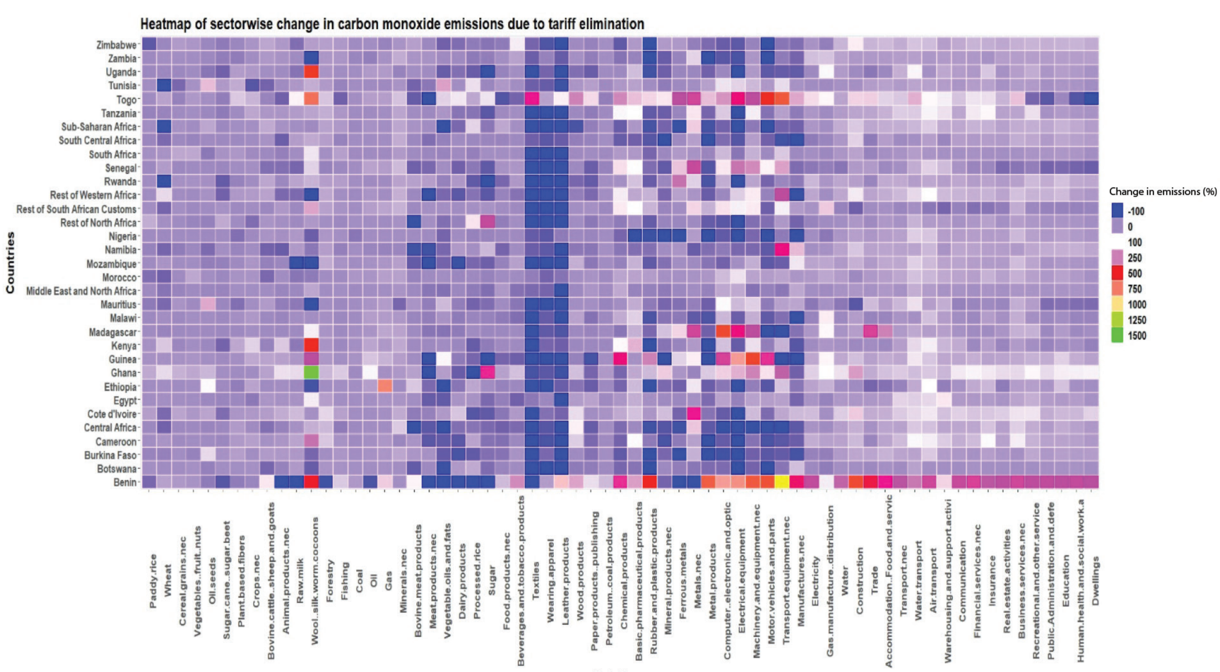

Figure 6 | Heatmap 4. *Source*: Model results from the authors' analysis.

5. CONCLUSION

In this study, we use the CGE model and a GTAP-based database for the 55 countries that are members of AfCFTA to estimate the macroeconomic and environmental impact of the trade agreement. From a macroeconomic – as well as from an environmental – perspective, the implementation of the agreement is estimated to induce mixed effects. Furthermore, the estimated impact of the agreement is shown to be heterogeneous across the continent. The analysis indicates that most African nations experience an increase in trade and GDP (except for Senegal and Mauritius) and significant employment creation effects. With respect to the environmental impacts, CO_2 emissions are expected to increase marginally, while non-CO_2 greenhouse gas (GHG) emissions increase significantly. By contrast, the implementation of the agreement is estimated to lead to a positive effect on air quality, stemming from decreased emissions of air pollutants.

From the analysis, we arrive at the following policy inferences. First, the findings of our study highlight the importance of conducting comprehensive environmental impact assessments of FTAs in general and AfCFTA in particular. Second, in AfCFTA, we find that the resulting increase in CO_2 emissions is small, whereas the corresponding one for non-CO_2 emissions is significant. These findings suggest that trade integration enhances production reallocation across sectors. In other words, the same trade policies that may lead to a large increase in non-CO_2 emissions may result in marginal changes in CO_2 emissions. Therefore, the overall impact of trade on GHGs is not obvious. This implies that, in addition to the trade integration, AfCFTA member countries should support each other in their efforts to reduce GHG emissions by investing in renewable energy infrastructure and work on environmentally sustainable practices and incentives, such as increasing trade in renewable energy equipment. Finally, the estimated reduction in air pollution indicates a potential trade-off among emissions, that is, activities that can increase GHG emissions may also decrease air pollutants. Reducing GHGs emissions is a desirable outcome of great significance in the context of global warming. The local impact of a reduction in air pollutants will have significant beneficial effects in the medium- to long-term in the majority of African countries. In that regard, policymakers can be satisfied with the potential positive impact on air quality resulting from this agreement.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

AUTHORS' CONTRIBUTION

MB and HN wrote the introduction, literature review, results and conclusions. SM analysed the results, wrote the methodology section and developed tables and charts. BN developed the model and ran the model simulations. All co-authors contributed to writing the whole paper.

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APPENDIX

Table A1 | Endowments as part of the model

No.	Endowment codes	Description
1	Land	Land
2	clerks	Clerks
3	service_shop	Service Shop
4	tech_aspros	Technicians and Associate Professionals
5	off_mgr_pros	Office Managers and Professionals
6	ag_othlowsk	Agricultural and Unskilled Workers
7	Capital	Capital
8	NatRes	Natural Resources

Source: Own elaboration using GTAP Database.

Table A2 | Sectors

S.No.	Sector code	Description	S.No.	Sector code	Description
1	pdr	Paddy rice	34	bph	Basic pharmaceutical products
2	wht	Wheat	35	rpp	Rubber and plastic products
3	gro	Cereal grains NEC	36	nmm	Mineral products NEC[1]
4	v_f	Vegetables, fruit, nuts	37	i_s	Ferrous metals

(*Continued*)

[1]NEC (Not Elsewhere Classified)

Table A2 | Sectors—*Continued*

S.No.	Sector code	Description	S.No.	Sector code	Description
5	osd	Oil seeds	38	nfm	Metals NEC
6	c_b	Sugar cane, sugar beet	39	fmp	Metal products
7	pfb	Plant-based fibers	40	ele	Computer, electronic and optic
8	ocr	Crops NEC	41	eeq	Electrical equipment
9	ctl	Bovine cattle, sheep and goats	42	ome	Machinery and equipment NEC
10	oap	Animal products NEC	43	mvh	Motor vehicles and parts
11	rmk	Raw milk	44	otn	Transport equipment NEC
12	wol	Wool, silk-worm cocoons	45	omf	Manufactures NEC
13	frs	Forestry	46	ely	Electricity
14	fsh	Fishing	47	gdt	Gas manufacture, distribution
15	coa	Coal	48	wtr	Water
16	oil	Oil	49	cns	Construction
17	gas	Gas	50	trd	Trade
18	oxt	Minerals NEC	51	afs	Accommodation, Food and services
19	cmt	Bovine meat products	52	otp	Transport NEC
20	omt	Meat products NEC	53	wtp	Water transport
21	vol	Vegetable oils and fats	54	atp	Air transport
22	mil	Dairy products	55	whs	Warehousing and support activities
23	pcr	Processed rice	56	cmn	Communication
24	sgr	Sugar	57	ofi	Financial services NEC
25	ofd	Food products NEC	58	ins	Insurance
26	b_t	Beverages and tobacco products	59	rsa	Real estate activities
27	tex	Textiles	60	obs	Business services NEC
28	wap	Wearing apparel	61	ros	Recreational and other service
29	lea	Leather products	62	osg	Public Administration and defe
30	lum	Wood products	63	edu	Education
31	ppp	Paper products, publishing	64	hht	Human health and social work a
32	p_c	Petroleum, coal products	65	dwe	Dwellings
33	chm	Chemical products			

Source: Own elaboration using GTAP Database.

Table A3 | Countries that have signed and ratified ACFTA. Region/Countries included in the GTAP model

S. No.	Regions	S. No.	Regions
1	Australia, New Zealand	22	Uganda
2	East Asia	23	Zimbabwe
3	Southeast Asia	24	South Africa
4	South Asia	25	Senegal
5	North America	26	Guinea
6	Latin America	27	Benin
7	European Union 28	28	Burkina Faso
8	Rest of North Africa	29	Cameroon
9	Morocco	30	Cote d'Ivoire
10	Tunisia	31	Togo
11	Egypt	32	Ethiopia
12	Middle East and North Africa	33	Madagascar
13	Ghana	34	Malawi
14	Nigeria	35	Mauritius
15	Rest of Western Africa	36	Zambia
16	Central Africa	37	Botswana
17	South Central Africa	38	Namibia
18	Kenya	39	Rest of South African Customs
19	Mozambique	40	Sub-Saharan Africa
20	Rwanda	41	Rest of World
21	Tanzania		

Source: Own elaboration using GTAP Database.