Approximating the First-order Effects of AfCFTA Tariff Reductions on CO2 Emissions

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and
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Bringing Rigour and Evidence to Economic Policy Making in Africa

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Abstract

This paper explores the likely effects of tariff reductions under the African Continental Free Trade Area (AfCFTA) on carbon dioxide (CO2) emissions. It proceeds in three steps, with all estimates relying on the most recent, i.e. 2015, disaggregated data on emissions intensities. First, we show that, across African countries, CO2 intensities are higher in the more protected sectors, so that, at unchanged emission intensities, tariff elimination on intra-African trade during AfCFTA should favour CO2 intensive activities. Second, for the EAC and ECOWAS, the two RECs for which AfCFTA-compliant tariff reduction schedules are available, we estimate that removing tariffs on goods in the tariff elimination list would reduce progressively the carbon intensity of trade for these goods. The estimates suggest that an increase of 1% of the emission intensity is associated with a decrease of about 0.09% of the MFN tariff. Third, to see which effect will dominate, we estimate partial equilibrium effects of 'full' tariff elimination under AfCFTA and find that intra-African trade would increase by 32% and emissions embedded in trade by 24%, implying a CO2 elasticity to trade of 0.74, thus, reducing the CO2 emission intensity of Intra-African trade.

Keywords: *CO2; Africa; AFCFTA; emission intensity.*

JEL classification codes: *Q50; Q56; F18; F64.*

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1. Introduction

Even in the absence of the Climate Change (henceforth CC) threat, the challenge of lifting a growing population out of poverty was a formidable task for the many countries across Africa. Under the threat of CC, trade policy will play an important role in Africa's quest to embark on a sustainable development path. Several challenges are ahead. First, energy production, responsible for 87% of world CO2 emissions, has yet to take off across Africa. Second, Africa's export basket is skewed towards carbon-intensive goods (e.g., resource extraction products).[1] Third, as agricultural yields will fall unevenly, countries will have to resist imposing restrictions to intra-African trade in food products between food surplus and food deficit countries .[2] So far, measures that would tackle the consequences of CC are largely absent in the policy architecture of the African Regional Economic Communities (RECs). Neither does the trade-environment nexus figure in the recently concluded African Continental Free Trade Area (AfCFTA), in force since 2019.

Reducing CO2 emission intensity becomes an important environmental challenge at a time when Africa experiences rapid GDP and population growth while developing its energy production.[3] Even though, on equity grounds, African countries cannot be expected to join higher-income countries in their quest to reach zero net CO2 emissions by mid-century, they still face the challenge of reducing CO2 emission intensities in production and consumption while shifting production and trade patterns towards carbon-sober activities.

So far, phase I of the AfcFTA is the only flagship on the AU2063 agenda that addresses the trade-environment nexus, although indirectly since it deals with removing tariffs and non-tariff Barriers (NTBs). (Members are also committed to liberalize trade in services.) This paper explores the likely effects of eliminating intra-African tariffs on goods on CO2 emissions. Because there are large dispersions in CO2 emission intensities across countries and in intensities across products within countries, it is desirable to work with disaggregated data. In this paper we work with emission intensities for 2015 covering 163 sectors from the 'RMRIO' data base of Cabernard and Pfister (2021).

Negotiations for phase I are yet to be finalized.[4] So far, at the time of writing in mid-2023 only two-EAC and ECOWAS-of the 8 Regional Economic Communities (RECs) participating in the submission of tariff-reduction schedules under the AfCFTA, have submitted schedules acceptable by the AfCFTA secretariat. These unknowns about tariff schedules increases the guesswork of this exploratory exercise. We explore AfCFTA effects on CO2 in three steps.

Section 2 describes the data: country-level comparative and absolute advantage on CO2 emissions across sectors followed by correlations between tariffs and CO2 emission intensities used in later sections. Across African countries, CO2 intensities are higher in the more protected sectors. So, at unchanged emission intensities, tariff elimination on intra-African trade during AfCFTA should favour CO2 intensive activities.

Section 3 then analyses the evolving carbon content of production during AfcFTA implementation for ECOWAS and EAC, the only two Regional Economic Communities (RECs) that have submitted tariff offer schedules complying with AfcFTA guidelines. As often observed in FTA negotiations, for both ECOWAS and EAC, goods on the tariff exclusion list (schedules B and C) have higher tariffs than goods on the tariff elimination list (schedule A). Drawing on the product-level correlations between CO2 intensities and tariffs in section 2, we estimate that removing tariffs on schedule A goods would reduce progressively the carbon content of production for these goods. We estimate that an increase of 1% of the emission intensity is associated with a decrease of about 0.09% of the MFN tariff. These first-order estimates (no adjustment in production and trade patterns) under the assumption of unchanged sectoral emission intensities in both RECs, suggest that the trade policy bias favouring carbon-intensive sectors is likely to persist in both RECs, though less intensely than currently.

Sections 4 then reports estimates of a 'full' tariff elimination on intra-african trade using the Global Simulation Analysis of Industry-Level Trade Policy (GSIM) model of Francois & Hall (2009). GSIM is an extension of the bilateral SMART partial equilibrium model to include third-country effects. To explore the likely effects of AfCFTA on CO2 emissions, the model is solved for each sector under zero tariffs for African trade. Simplifying assumptions like unchanged emission intensities and no general equilibrium through input-output linkages that should be taken into account when tariff elimination is across-the-board, allows us to work at the 163 sector level. As example, take the elimination of tariffs for intra-African trade in plastics. Free intra-African trade increases the demand for plastics produced by African partners. Take the implications for Kenya. Under the assumption of no supply response, AfCFTA will make it more profitable for Kenya to buy plastics from African partners than from RoW (substitution effect in consumption) and to sell its plastics to African partners rather than to the ROW (substitution effect across destinations as Kenyan exports of plastics to African partners must pay tariffs on sales to African partners). Kenya will redirect some of its exports from ROW to African partners. Because, as shown in section 2, African CO2 emission intensities are higher than those of partners, AfCFTA implementation is expected to result in higher emission intensities. As a measure of the CO2 implications of AfCFTA, we report the elasticity of CO2 emissions to the change in trade induced by full AfCFTA implementation both at the country level, across countries, and on average at the product level. Central elasticity estimates suggest that intra-African trade in goods would increase Intra-African trade increases by about 32% and emissions embedded in trade by 24%, i.e. an implied CO2 elasticity to trade of 0.74.

2. Data sources and emission intensities across Africa

The paper draws on two data sources: applied MFN tariffs from WITS and the Resolved Multi-Regional Input-Output (RMRIO) database assembled by Cabernard & Pfister (2021) for trade flows and CO2 equivalent (CO2e)[5] estimates. RMRIO combines the broad sector coverage of EXIOBASE (Stadler et al. 2021) with a wider country support of Eora (Lenzen et al. 2013) making it the most comprehensive Multi-Regional Input-Output (MRIO) available. It includes 189 countries (of which 51 are in Africa). The data cover 163 sectors over the period 1995-2015.[6] RMRIO data is the only data set with large coverage of African countries allowing an analysis of sector-level CO2 emissions into direct and indirect emissions by sector-country, the level of disaggregation used in our earlier paper (Melo and Solleder (2023).

Distribution of CO2 emission intensities across sectors and countries

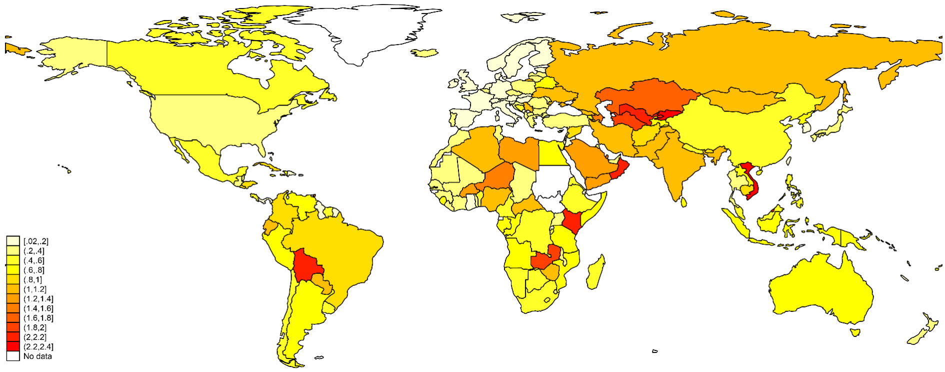
Emission intensities have declined across all regions over the period 1995-2015. Figure 1 shows the distribution of average direct emission intensities in RMRIO across countries for 2015, the most recent year with data on emission intensities at the disaggregated level. In 2015, Europe had the lowest average emission intensities, with Africa, and Asia the highest.

"Absolute" and "Relative" carbon intensities across countries and across sectors within countries indicate how global and country carbon intensities would be affected by a reallocation of production across countries and sectors. Here we concentrate on the landscape of carbon intensities across Africa. Country c has an "absolute" advantage in sector s, $CoAbs_{cs}$, when the CO2 emission intensity in sector s is lower in country *c* than the world's average emission intensity, i.e. when:

$$CoAbs_{cs} = \frac{CO2eint_{cs}^{tot}}{\frac{1}{N}\sum_i CO2eint_{is}^{tot}} < 1 \qquad (1)$$

where *c* indexes countries, *s* sectors, *N* the total number of African countries in the dataset and $CO2eint_{cs}^{tot}$ is the total emission intensity of sector *s* in country *c*. A lower value of $CoAbs_{cs}$ sector *s* in country *c* indicates an 'advantage', that is a lower CO2 emission intensity in sector *s* (so an absolute CO2 advantage for sector *s* in country *c*).

Figure 1: Average direct CO2e emission intensities



Source: Average emission intensities for 2015 from Cabernet and Pfister (2021).

Likewise, within country c, sector s has a comparative advantage, CoCA_cs, when:

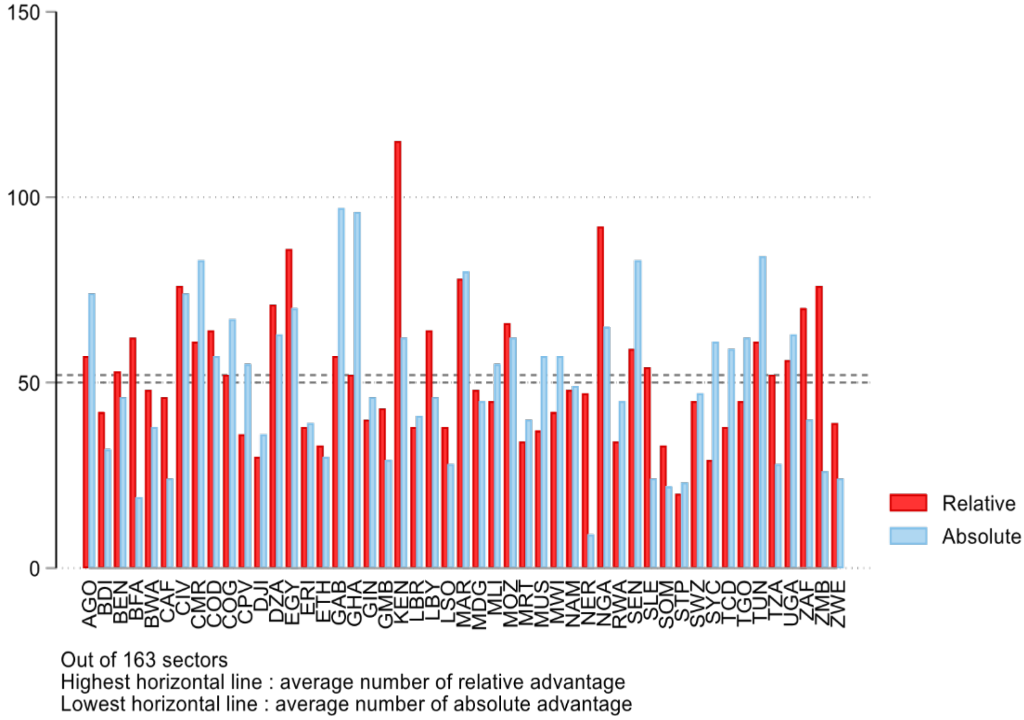
$$CoCA_{cs} = \frac{\frac{CO2eint_{cs}^{tot}}{\sum_j CO2eint_{cj}^{tot}}}{\frac{\sum_i CO2eint_{is}^{tot}}{\sum_{kl} CO2eint_{kl}^{tot}}} < 1 \tag{2}$$

where c indexes countries, s sectors and $CO2eint_{cs}^{tot}$ is the total emission intensity of sector s in country c where *j* Is an index covering African countries, and *k*, *l* are indexes over the whole sample. Country c has comparative advantage in emission in sector s when the ratio between the emission intensity in sector s and the country's average is smaller than the ratio of the world average of this sector and the world average emission of all sectors.

As CO2 is a global pollutant, moving production towards goods where a country exhibits an absolute advantage (in the sense of low $CoAbs_{cs}$ value) will reduce the world total CO2 emission for producing that production bundle. It is expected that changes in trade policy like the tariff reductions to take place under the AfCFTA will change the level and distribution of CO2e emissions across Africa. Likewise, within countries, a change in production towards sectors with a CO2 comparative advantage (i.e. low $CoCA_{cs}$ values) would reduce that country's territorial CO2e footprint.

Figure 2 shows the number of sectors with "relative" and "absolute" CO2e intensity advantage in each African country in the dataset[7]. Burundi (BDI) and Saõ Tomé (STP) have absolute and comparative advantage CO2 in few sectors. Ghana (GHA), Gabon (GAB), Senegal (SEN), Tunisia (TUN) have many sectors with an absolute advantage, that is global territorial CO2 emissions would fall if production for these products were relocated towards these countries. Kenya (KEN) and Nigeria (NGA) have a relative advantage in many sectors.

Figure 2: Distribution of "Relative" and "Absolute" CO2e intensity advantage across Africa



Notes: Countries are listed in alphabetical order.
Source: Authors' calculations based on RMIRO.

These measures are for the 163 sectors in RMRIO. Not all sectors are tradable (e.g., education) so, in this partial equilibrium setting, relocation would be be expected across tradable sectors. Table A1 identifies 77 sectors as tradable in the sense that changes in trade policy would be expected to result in some relocation in production across countries.

Africa subsidises CO2 intensive activities

To examine the effects of trade policy changes on emissions, we keep 77 tradable sectors out of the 163 original RMRIO sectors.(e.g., we exclude services sectors like education) that approximately map into activities to be affected by AfcFTA tariff (see table A1). From this list of 77 sectors, table 1 lists the 5 least followed by the 5 most CO2e intensive sectors for Africa and for Asia (the region most closely comparable to

Africa) for sectors accounting for at least 1% of output in 2015.

Table 1: Lowest and highest direct CO2 intensity sectors in Africa and corresponding intensities in Asia

	Africa				Asia			
Sector	**CO2 int.**	**Share output**	**CO2**	**Tariff**	**CO2 int.**	**share output**	**CO2**	**Tariff**
Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Manufacture of electrical machinery and apparatus n.e.c.	0,003	0,019	39	0,09	0,016	0,054	18272	0,06
Manufacture of machinery and equipment n.e.c.	0,006	0,034	168	0,06	0,041	0,084	74424	0,04
Manufacture of wood and of products of wood and cork, except furniture;								
Manufacture of articles of straw and plaiting materials	0,007	0,012	67	0,16	0,130	0,003	8642	0,06
Processing of Food products n.e.c.	0,007	0,029	174	0,17	0,032	0,038	26243	0,13
Manufacture of wearing apparel; dressing and dyeing of fur	0,008	0,015	93	0,25	0,040	0,021	17952	0,09
Manufacture of furniture; manufacturing n.e.c.	1,590	0,017	21700	0,17	0,349	0,035	261058	0,07
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	2,163	0,013	22721	0,08	1,535	0,055	1830308	0,04
Manufacture of rubber and plastic products	2,546	0,015	30390	0,14	0,616	0,036	473291	0,07
Other agricultural products	3,585	0,040	116695	0,09	2,883	0,026	1614354	0,08
Meat animals n.e.c.	4,052	0,012	40423	0,14	1,641	0,002	83094	0,08

Notes: Only sectors with a share of output larger than 0.01 in Africa are included (24 sectors).
Cols. 1 and 5: Direct emission intensities; Cols. 2 and 6 Output shares; Cols. 3 and 7: Sector's total CO2e emissions (tons); cols 4 and 8. Simple average sectoral tariff across countries.
Source: Authors' calculations based on RMRIO.

The least emission-intensive sectors account for approximately 10 percent of tradable of output in Africa and Asia, but the most emission intensive sectors in Africa occupy 20 percent of output in Africa against 15 percent for Asia.

In both regions, extraction activities and agriculture constitute the largest total contributions to CO2 emissions. Extraction industries are more CO2 intensive in Asia than Africa. At 15% on average for both the least and most CO2 intensive activities, tariffs are about twice as high on average than in Asia.

Shapiro (2021) estimates that both high-income, and emerging countries, subsidize carbon-intensive industries. For a sample of 48 high-income and emerging countries, he correlated CO2 emission intensity with tariffs in 2009. His results show that in his sample, on average, countries have lower tariffs (and non-tariff barriers) on carbon-intensive industries, i.e. carbon-intensive sectors are effectively subsidised. Exploring the omitted but likely factors accounting for this correlation in a two-stage IV regression, he shows that the correlation disappears when tariffs are correlated with a measure of upstreamness in the first stage, establishing that tariffs are higher on final (i.e., downstream) industries. This is a standard prediction from political-economy model of Grossman-Helpman (1994) focusing on lobbying activities. For example, in the automobile supply chain, an upstream sector like steel faces counter-lobbying activities from the downstream car assembly activity.

Here we check if in our sample of 44 African countries for 2021, the year with the most recent tariff data, countries have lower tariffs (and non-tariff barriers) on carbon-intensive industries. We estimate the following in cross-section:

$$\log(tariff_{is}) = \beta \log(E_{is}) + \mu_i + \epsilon_{is} \tag{3}$$

In (1), $tariff_{is}$ is the average tariff of sector $s = 1,\ldots,77$ in country $i = 1,\ldots,44$,E_{is} is the average of the indirect emissions from abroad and represents the emission intensity of imports, μ_i is a country fixed effect; and ϵ_{is} an iid error term.

We use the most recent MFN tariff available on the WTO website (see table A2 in annex for a country – year MFN correspondence). E_{is} is sourced from RMRIO using RMRIO's most recent year data: 2015. The coefficient of interest, β, measures the percentage association of the tariff to an increase of one percent of the emission intensity of imports, E_{is}. This specification in logs is slightly different from Shapiro (2021) which is in levels.

Table 2 reports results for all countries and by region. At the global level (col.1), and separately across all regions (cols.2-5), the estimated coefficient is negative and statistically significant confirming Shapiro's estimate of a negative relationship between emission intensity and tariffs heights. The magnitude of the coefficients is similar across regions, though the fit is less tight for Africa. An increase of 1% of the emission intensity is associated with a decrease of about 0.09% (not percentage point) of the MFN tariff.

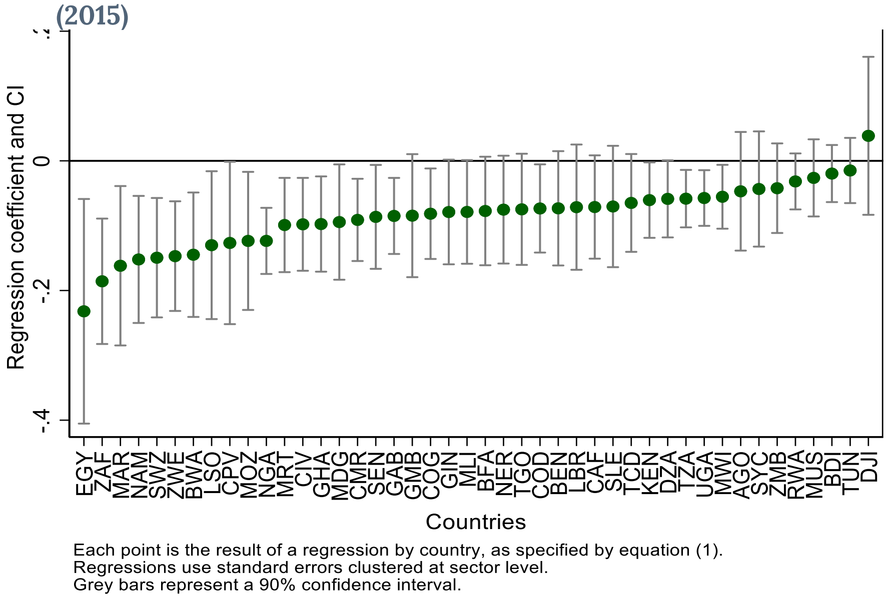
Table 2: Association of import tariffs and emission intensity of imports

	(1)	(2)	(3)	(4)	(5)
	Global (149 ctries) log(MFN)	**Africa (44 ctries) log(MFN)**	**Americas (30 ctries) log(MFN)**	**Asia (39 ctries) log(MFN)**	**Europe (36 ctries) log(MFN)**
Log(Emissions)	-0.0882***	-0.0824**	-0.0941***	-0.0850***	-0.0951**
	(0.0303)	(0.0405)	(0.0276)	(0.0220)	(0.0377)
Observations	429981	138571	85451	109268	96691
FE	Country	Country	Country	Country	Country
Adjusted R^2	0.350	0.188	0.328	0.282	0.228

Notes: Standard errors in parentheses, clustered at sector level; Number of countries in each region in parenthesis. Each regression has a constant. * p < 0.1, ** p < 0.05, *** p < 0.01
Source: Authors' estimates

Figure 3 displays the β coefficient estimates of equation (1) for each of the 44 African economies in the dataset, ordered by decreasing values of β. All coefficients are negative apart from Djibouti's (0.0386, not significant) with 24 that are statistically significant at a 90% level. Among the negative and statistically significant coefficients, the size of the effect ranges from a decrease 0.22% (not percentage point) of the tariff for a one percent increase in emission intensity (in Egypt) to a decrease of 0.046% of the tariff (in Uganda).

Figure 3: Covariance of log Tariffs and log CO2 emissions intensities by country (2015)



Notes: β coefficient estimates from (3) estimated at the country level.
Source: Authors' estimates.

3. AfCFTA mplementation: Emission intensities of tariff offers for EAC and ECOWAS

So far, links between trade and the environment are absent from the AfCFTA and, where they are mentioned- as in The Green Recovery Action Plan 2021-2027 of the AU- they are not well-substantiated (Briel, 2023). Adding a Protocol on Trade and Climate Change to the AfCFTA in phase II is the first step to mainstream the environment in the continent's trade policy architecture.[8] In short, integration efforts in Africa at the regional and continental level failed to attract attention on preservation of the environment at the time of drafting.[9] A first next necessary step is to amend the preamble to mention the environment, then to mainstream the preservation of the environment into the phase II agenda by including provisions to protect the environment and fight CC- in effect to 'Green the AfCFTA'.[10] In the meantime, reductions in tariffs and NTBs are the only levers at the disposal of negotiators. Below, the schedules and timetable for tariff liberalizations on intra-AFCFTA members.

Schedules and timetable

Implementation of AfCFTA is to follow the template in Table 3, which specifies the extent of permitted exclusions: a list of products not subject to tariff removal that is not to exceed 10% of imports from AfCFTA members in 2018; a list of sensitive products with a longer phase-down period; and longer time frames for LDCs to accommodate Special and Differential Treatment (SDT) for this group. The template shows that, as in all FTAs, there are exclusions and, because of SDT, all countries will not liberalize intra-African trade at the same speed. In the end, implementing the AfCFTA will be a long process, with the outcome depending crucially on, among others, the exclusion lists reflected in the schedules submitted by each one of the 8 participating Regional Economic Communities (RECs) following the template in table 1.

Table 3: Tariff liberalization under AfCFTA: Schedules and Timetable

	LDCs [1] (SDT)	Non-LDCs
Non-sensitive products Category A (IN)	90% of tariff lines 10-year phase down	90% of tariff lines 5-year phase down
Sensitive products Category B (OUT)	7% of tariff lines 13-year phase down (current tariffs can be maintained during first 5 years – phase down starting in year 6)	7% of tariff lines 10-year phase down (current tariffs can be maintained during first 5 years – phase down starting in year 6)
Excluded products Category C (OUT)	3% of tariff lines; up to 10% of intra-African imports	3% of tariff lines; up to 10% of intra-African imports
Observations: The tariff phase down will be linear. However, the parties can complement it with a request-offer approach. They can also accelerate tariff cuts on a reciprocal basis.		

Notes: 1/ Special and differential treatment (SDT) for 32 LDCs: Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, United Republic of Tanzania, Zambia.
The "non-sensitive" list (category A) is intended for immediate implementation starting from July 2021, is non-negotiable, and has been finalized. The "sensitive" (category B) and "exclusion" (category C) lists are negotiated between parties on a request and offer basis to facilitate the exchange of offers and requests by all parties. As of April 2023, two RECs, EAC and ECOWAS, have submitted compliant offers for their exclusion lists.
Source: Agreed negotiating modalities of AfCFTA (TI/AfCFTA/AMOT/3/TIG/MOD/FINAL, restricted). ITC https://m.macmap.org/en/learn/afcfta

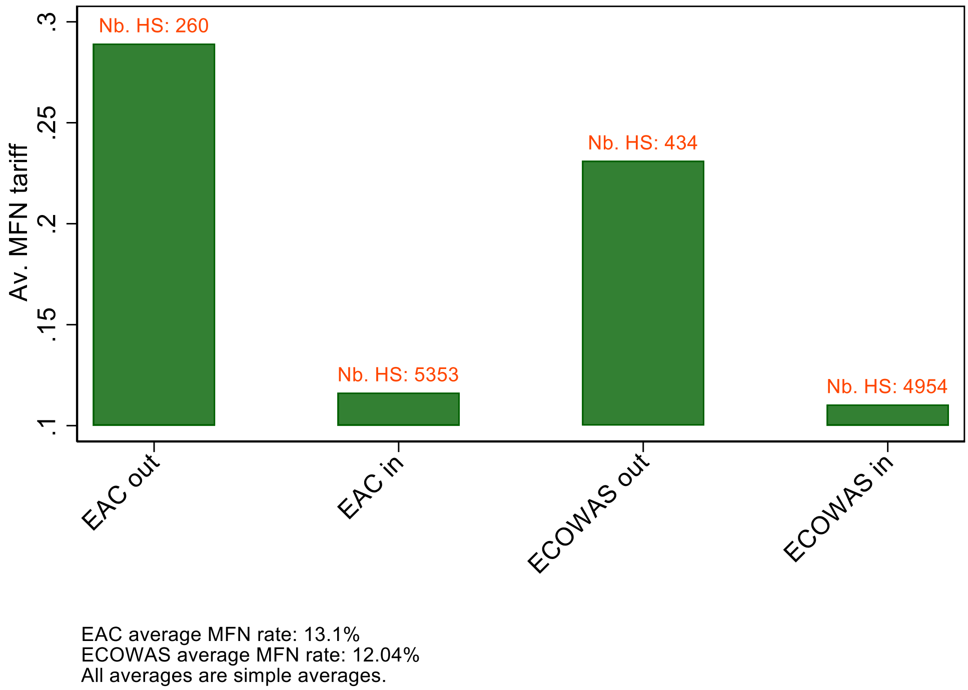
At the time of writing in mid-2023, Only EAC and ECOWAS have submitted offers that have been accepted by the AfCFTA secretariat (other RECs either have not submitted offers or had submissions not been approved for lack of consistency with the modalities described in table 3).

Section 3.2 contrasts tariff trajectories of EAC and ECOWAS countries towards AfCFTA partners with those for MFN trade flows for two categories of products: "Non sensitive products", up for tariff liberalization, collected in category A while "Sensitive products" are in category B, and "excluded" products in category C. Unfortunately, the available tariff schedules lump together products in categories B and C. Therefore, these two categories are lumped in an 'OUT' category, so the non-sensitive products are in the 'IN' category in the figures below[11]. Section 3,3 then compares the CO2e intensity of the IN and OUT categories during AfCFTA implementation.

Tariff liberalization trajectories: EAC and ECOWAS

Figure 4 compares the average tariffs for the goods in the IN group with those in the OUT group for both RECs. As usual in FTA negotiations, average applied tariffs are higher in the OUT than in the IN categories for both EAC and ECOWAS. Goods in categories B and C ('OUT')in EAC [ECOWAS] have an average tariff of 29% [23%], as opposed to 11% [11%] for goods in category A('IN'). Figure 4 shows that average tariff levels on the IN groups are about the same for both RECs. Figure 5 shows that the liberalization timetable differs between the two RECs.

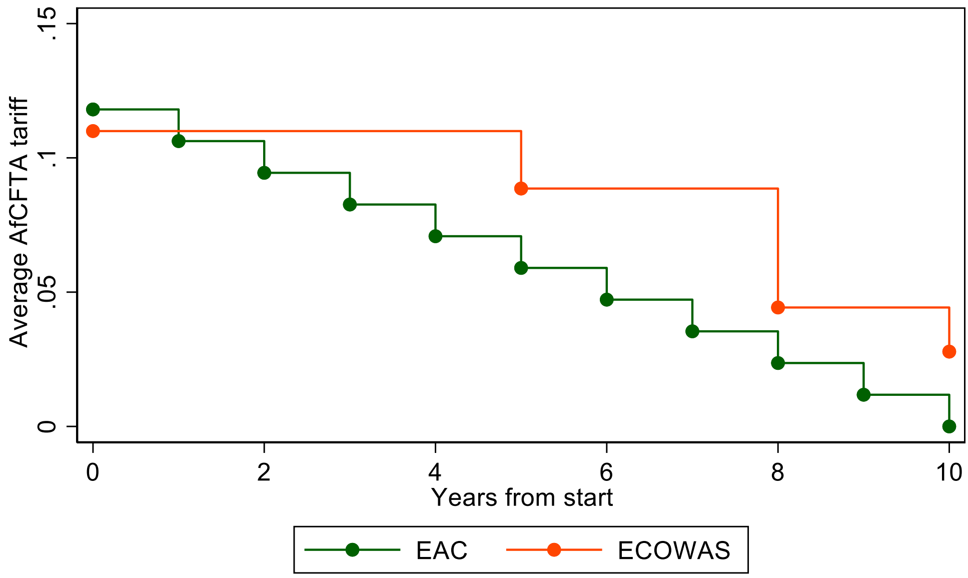
Figure 4 Average tariffs on goods by list
Submitted (category A) and Excluded (categories B and C)



Notes: The tariff reduction schedules are those submitted by EAC and ECOWAS. Number of HS6 goods in each category indicated on each schedule. The schedules do not consider the differences between the LDC and non-LDC countries in each REC.
Source: Authors' calculation from tariff schedules.

Figure 5 shows that EAC will reduce linearly all tariffs on category A goods during the 10 years of transition while ECOWAS, on the contrary, will keep the bulk of tariff reductions for the final years (in ECOWAS, by year 8, tariffs are barely reduced by half from their original levels). Postponing reductions to the end of the period often occurs when liberalization takes place in a large group of (typically) heterogeneous countries. Note also that tariffs will not go to zero at the end of the liberalization period for ECOWAS. Either ECOWAS will have to modify its schedule or there will be pressure to adjust schedules of RECs submitting full liberalization schedules.

Figure 5: Average tariff of category A goods during AfCFTA implementation



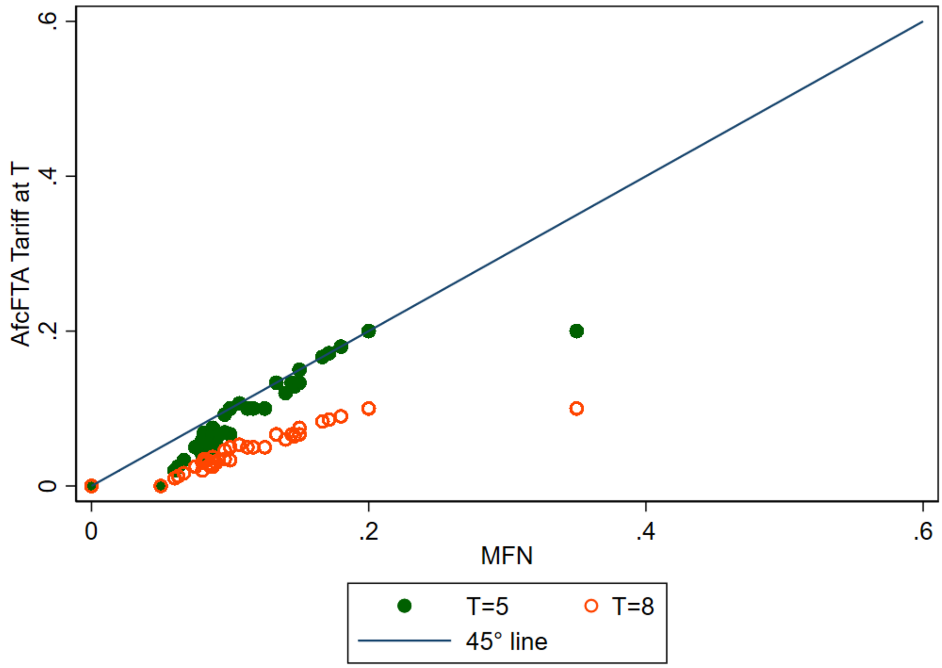
Note: Tariffs are simple average.
This only includes tariff lines that are listed in the proposed schedule (category A goods)
EAC schedules gives tariff values for each of the 10 years and ends with all tariffs at 0,
while the ECOWAS schedule only lists tariff values after five, eight, and ten years and
ends with some tariffs still positive

Source: Authors' calculations from schedules submitted to AfCFTA secretariat.

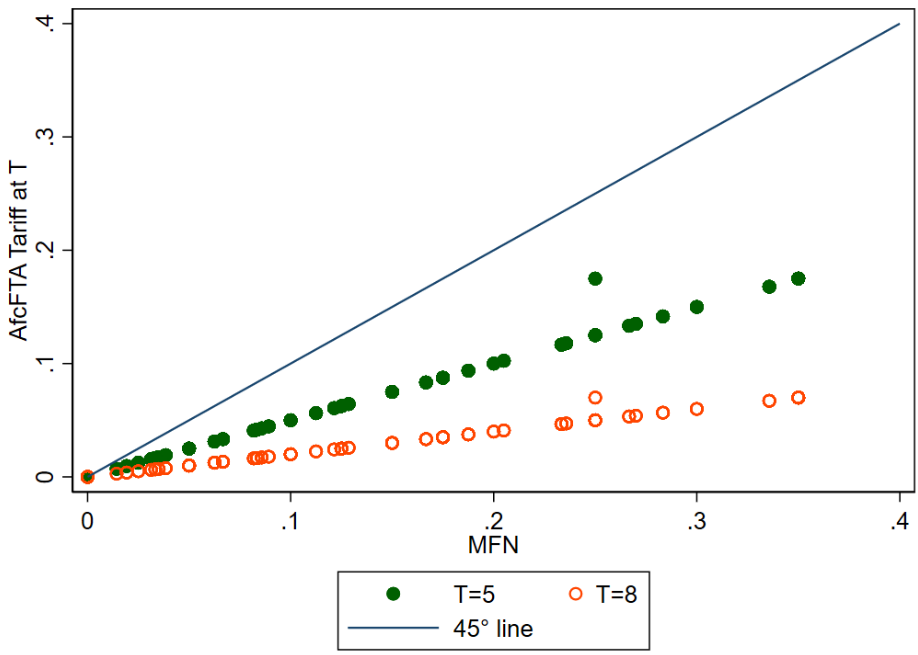
Figure 6 plots the average AfCFTA tariffs on the y-axis against the corresponding MFN tariff on the x-axis for years 5 and 8 of the timetables. Several differences between the two RECs are visible. First, category A tariffs are more widespread in EAC than in ECOWAS. Second, for EAC, applied intra-African tariffs are lower than applied MFN tariffs for each cluster (i.e. below 45^0 line) in both periods while they are close to the same (except for meats) for ECOWAS for the higher clusters. Third, almost no reductions occur for ECOWAS at T=5 for higher-tariff clusters (except for meat products). Fourth, whereas for EAC reduction is proportional and the same across tariff clusters (shown by equal size steps for each tariff category in figure 5 and reflected by straight lines for T=5 and T=8 in figure 6), for ECOWAS, tariffs are first reduced in the 'nuisance' category, i.e. on tariffs closest to the origin.

Figure 6: Average category A tariff at years 5 and 8 of liberalization

a) ECOWAS



b) EAC



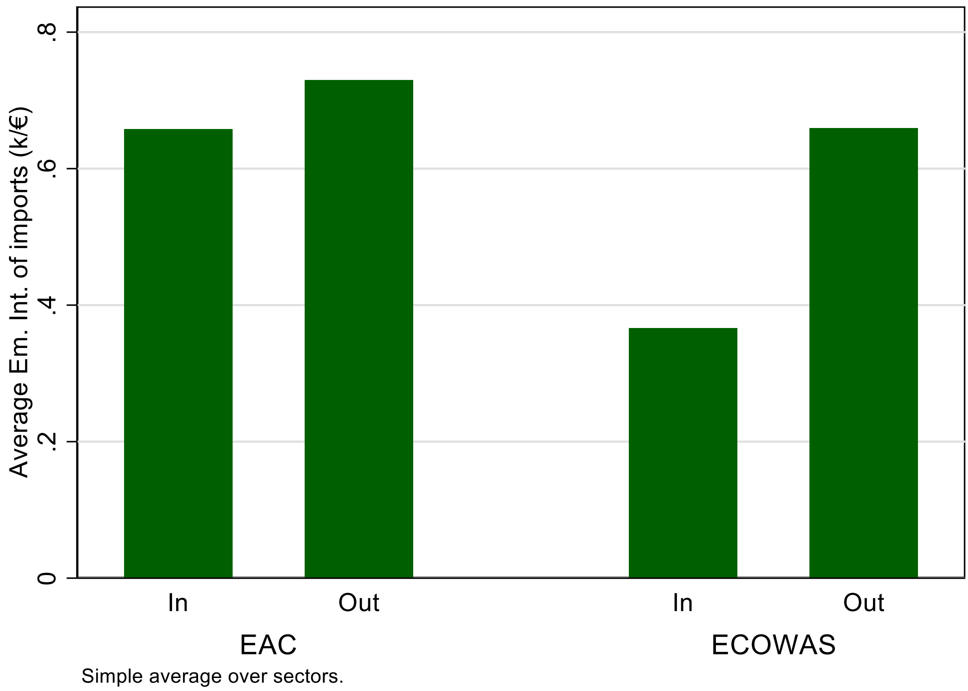
Notes: 4954 [5353] tariff lines for ECOWAS [EAC] The outlier in the ECOWAS graph is meat products (HS 020731, 020680, 020630). The point above average in the EAC graph is the AfcFTA tariff for "Bars and Rods Of Alloy Steel (other Than Stainless), Forged, Others" (HS 722840) which increases from 0.25 to 0.315 at T=1 (not represented), then decreases to 0 linearly.
Source: Authors' calculations

In ECOWAS, the higher tariffs above 10-15% remain at MFN levels at T=5. Since, for a given average tariff level, the efficiency costs of tariffs are proportional to tariff dispersion, during AfcFTA implementation, resource allocation is likely to be more inefficient for ECOWAS than for EAC.

Correlates of CO2 emission intensities by product categories

Figure 7 displays average imported CO2e emission intensities for goods in the OUT and IN categories for 2015, the latest year with emission intensities in RMRIO. On average, imported emission intensities are lower in the A (IN) goods than those in categories B and C (OUT) goods for both EAC and ECOWAS. The difference in emission intensity between the A and the B-C categories is greater for ECOWAS, and the average emission intensities of imports remain lower for ECOWAS than for EAC.

Figure 7: Average imported CO2e emission intensities by category of AcFTA goods: 2015 Submitted (category A (IN)) and Excluded (categories B and C(OUT))



Notes: GHG emissions are the CO2 equivalent (CO2e) of the following 8 GHGs: carbon dioxide (CO2), nitric oxide (NOx), methane (CH4), nitrous oxide (N_2O), carbon monoxide (CO), ammonia (NH_3), sulfur oxides (SO_x), non-methane volatile organic compounds (NMVOCs). Copeland, Shapiro, and Taylor (2021) discuss the merits of using pollution emissions based on end-of-pipe technologies vs. data on ambient pollution.
Source: Authors' calculations.

Next, we compare emission intensities across the IN and OUT categories using the model in equation (3). As we run one regression per country, country fixed effects are now omitted:

$$\log(tariff_{is}) = \beta \log(E_{is}) + \epsilon_{is} \tag{4}$$

As in (3), $tariff_{is}$ is the average tariff of sector s = 1,...,77 in country i = 1,...,6 for EAC and i = 1, ..., 14 for ECOWAS; E_{is} is the unweighted average of the indirect emissions from abroad; and ϵ_{is} an iid error term. Figure 8 confirms the negative association of import tariffs and emission intensity of imports of table 2 and figure 3 for each country. The association is statistically stronger for the OUT category in both RECs.

Figure 8: Average emission intensity across EAC and ECOWAS countries by category of goods (cross-section 2015)

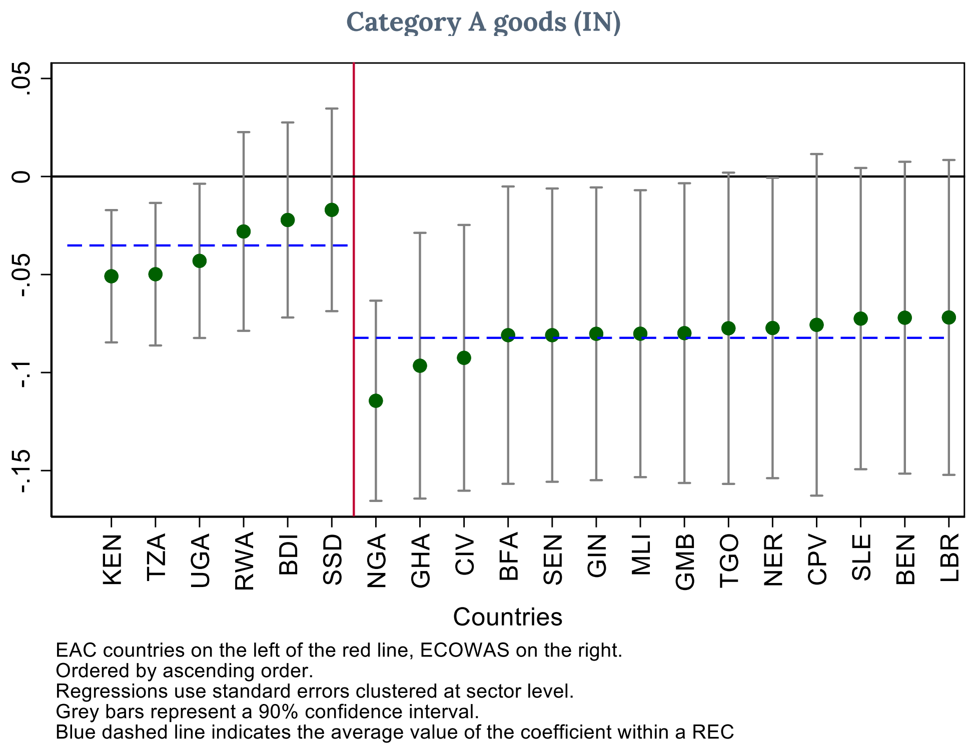
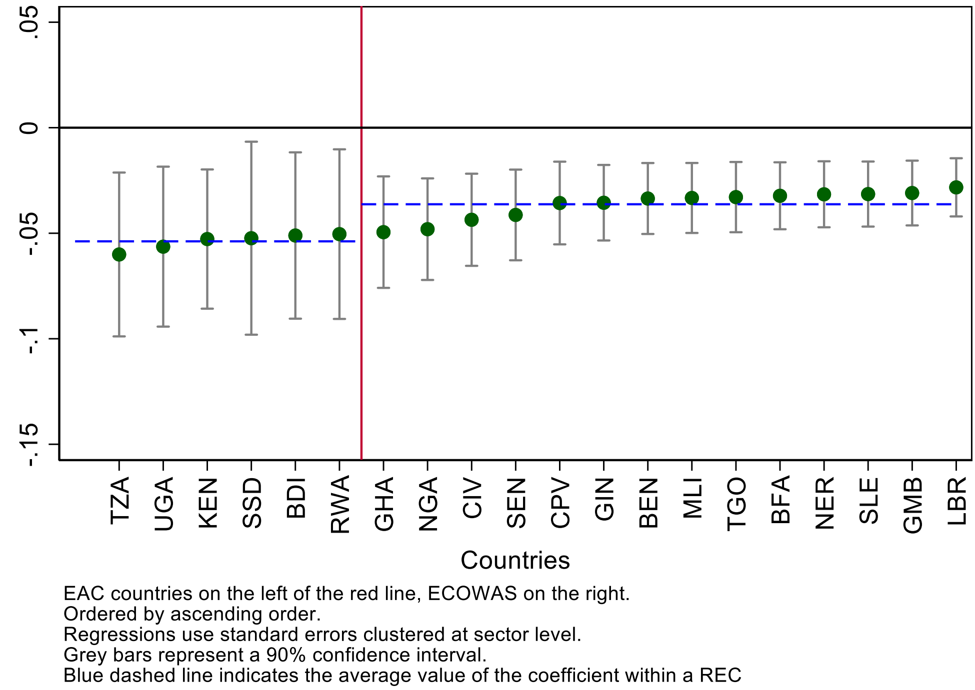


Figure 8 Continued

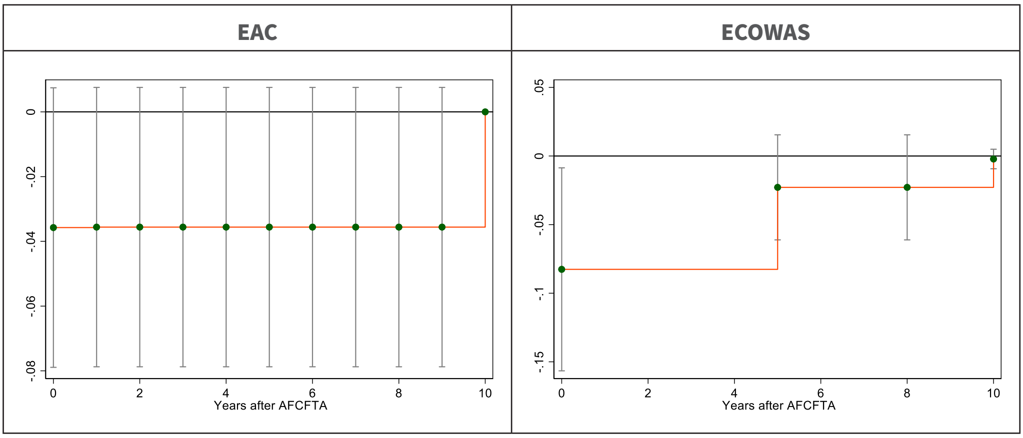
Categories B and C goods (OUT)



Notes: Authors' calculations based on tariffs from schedules provided by ECOWAS and EAC to the AfCFTA secretariat. Emission intensity from RMRIO for year 2015. See table 1 for definition of categories.
Source: Authors' calculations.

At the end of the transition, all category A goods will be traded freely within the AfcFTA and the question of a link between tariff and emission intensity will disappear. Yet, the question remains open during the transition phase. Figure 9 displays the result of equation (4) estimation for both EAC and ECOWAS each year during the 10-year implementation phase. For EAC the correlation remains the same until period 10 because the tariff reduction is the same for all goods and emission intensities remain at year 2015 estimates so the link between emission intensity and tariffs is unchanged until all tariffs move to 0 in year 10. For ECOWAS, however, tariff reduction follows the staircase pattern shown in figure 5. The estimated correlation (in absolute value) is lower in years 5 and 8, as the larger tariff reductions are initially larger for sectors with low emission intensities.

Figure 9: Tariff-CO2 emission intensity correlation during tariff liberalization phase



Notes: Standard errors clustered at the sector level. Gray bars represent 90% confidence intervals.
Source: Authors' estimates

4. Ex-ante estimates of AfcFTA on CO2 emissions

As a final exercise, we assess the impact of AfCFTA on CO2 embedded in trade flows using a Partial Equilibrium (PE) demand-supply model disaggregated over 54[12] sectors for 21 African countries and 104 other countries. We use the Global Simulation Analysis of Industry-Level Trade Policy (GSIM) model by Francois & Hall (2009), an extension of the SMART model to include third-country effects. The model is described in the annex B. The model's assumptions reduce to three the number of elasticities required for each product: a price elasticity of demand for imports, η, an elasticity of substitution between African imports and rest-of-the-world (RoW) imports, σ, and an elasticity of supply of exports, ε, which depends on the elasticity of supply. Because typically elasticities are not estimated precisely at a disaggregated level, for clarity and to simplify interpretation, in most simulations we impose the same elasticities across sectors and countries.

Since most countries taking part in AfCFTA have yet to publish their tariff schedule offers, we assume that African countries are all trading at MFN rates at the beginning of the exercise. The counterfactual consists of setting all tariff lines at zero for African trade after AfCFTA implementation, the situation we refer to as `full` implementation. In all the simulations, each African country removes tariffs on imports from African partners while maintaining MFN tariffs on RoW. RoW countries do not change tariffs.

As an example of adjustment under GSIM, take the elimination of tariffs for intra-African trade in plastics. Free intra-African trade increases the demand for plastics produced by African partners. Consider then the implications for Kenya (the same applies to all African countries since each African country consumes plastics). AfCFTA will make it more profitable for Kenya to buy plastics from African partners than from RoW (substitution effect in consumption) and to sell its plastics to African partners rather than to the RoW (substitution effect across destinations as Kenyan goods sold to African partners are no longer subject to import tariffs). Kenya will redirect some of its exports of plastics from RoW to African partners. The specifics of this adjustment will depend on elasticities, principally the elasticity of substitution in imports between plastics supplied by African partners and those supplied by the ROW.[13] If this increased demand for Kenyan plastics cannot be met from plastics previously sold to the RoW, the supply of Kenyan plastics will have to increase via an adjustment in the supply price of plastics.

Data requirements

Trade flows are sourced from UN COMTRADE. We calibrate the model on the year 2021, the most recent with reasonably complete data. For import demand, export supply and substitution elasticities across partners (σ), we take the values of -1, 1 and 5 from Francois and Hall (2009), as an alternative, we use import demand elasticities estimated by Kee, Nicita, and Olarreaga (2009). As these elasticities are estimated at 6-digit of HS, we aggregate them to our sector level, imputing missing values with countries averages. As some import demand elasticities exhibit very large value, we cap the resulting elasticities at 3. MFN tariffs are from the WTO tariff data download facility. Tariffs were downloaded for 2021 or, if 2021 was missing, the most recent year available (See table A2).

As for the estimates in section 3, CO2 emissions intensities are sourced from the highly Resolved Multi-Regional Input-Output (RMRIO) data set (Cabernard & Pfister, 2021). RMRIO offers good data coverage for Africa. We use 2015, the most recent year available for CO2e emissions. We delete the largest and smallest percentile of emissions. The annex of Melo and Solleder (2023) gives a discussion of the pros and cons of RMRIO for economic analysis of CO2 emissions.

While RMRIO provides great disaggregation for an input-output table, it is less disaggregated than the data on tariffs and elasticities. To match RMRIO data, we aggregate HS6 level data to the RMRIO sector. As trade in some RMRIO sectors was too low in Africa for GSIM to run properly, we further aggregated 27 sectors into four aggregates (Table A2 in annex list the sectors and indicates which sectors are from RMRIO or an aggregate). The simulations reported below are for 50 tradable sectors and 4 aggregates for 22 African countries.

Results

Table 4 reports aggregate changes in intra-African and RoW trade and CO2 emissions of a 'full' implementation of AfCFTA under different elasticity assumptions. Here 'full' refers to setting tariffs to zero for all products on all African countries while keeping MFN tariffs to the RoW unchanged. Each row reports aggregate results for AfCFTA countries (cols. 1-3) and RoW (cols. 4-6). Each row are the results for the set of elasticities listed in the last three columns of the corresponding row. Because elasticity estimates vary greatly across sectors within countries and across countries within sectors, except for the results in row 6, the same set of elasticities are imposed for each sector across countries and across countries.

Table 4: Aggregate results of AfCFTA full implementation: Intra-Africa and RoW

Simul	Intra-Africa			RoW			Simulation (elasticities)		
	(1)	(2)	(3)	(4)	(5)	(6)			
	Trade change (%)	CO2 change (%)	CO2 elasticity 3=(2)/(1)	Trade change (%)	CO2 change (%)	CO2 elasticity 6=(5)/(4)	ES	ID	SU
Column/row	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	**32%**	**24**	**0,74**	**-0,00080**	**-0,00003**	**0,04**	**1**	**-1**	**5**
2	31%	27%	0,88	-0,042%	-0,002%	0,04	1	-0.5	5
3	27%	13%	0,49	-0,335%	-0,009%	0,03	1	-2	5
4	13%	6%	0,48	-0,173%	-0,005%	0,03	1	-1	2.5
5	61%	54%	0,88	0,040%	-0,003%	-0,08	1	-1	10
6	24%	3.1%	0,12	-0,177%	-0,011%	0,06	1	KNO	5

Notes: Each row are results for the elasticities in the last three columns of the corresponding row.
ES: Export supply elasticities; ID Import demand elasticities; SU: Substitution elasticities. Elasticities from Kee, Nicita, Olarreaga (KNO, 2009).
Source: Authors' estimates from GSIM simulations.

Row 1 results in bold are for the base (i.e. judged most plausible) set of elasticities. Intra-African trade increases by about 32% and emissions embedded in trade by 24%. Column 3 gives an implied CO2 elasticity of 0.74 to a full AfCFTA implementation. Elasticities above (below) unity correspond to AfCFTA resulting in a relatively dirtier (cleaner) consumption, relatively because emissions increase in all simulations (see column 2). Columns 4 to 6 show that changes in RoW are negligible because AfCFTA countries' shares of world trade in the sum of the 54 sectors under scrutiny is less than 2%.

Rows 2 to 5 report results from a systematic change in elasticities, one at a time. Comparing rows 1 and 5 shows that it is the elasticity of substitution between imports from RoW and imports from African countries that determines the magnitude of CO2 changes. When the elasticity of substitution, σ, is doubled from 5 to 10, intra-African trade doubles (relative to the base scenario. And since African production is more CO2 intensive than in the RoW, the increase in CO2 emissions is 225% higher than in the base case reported in row 1. Halving the elasticity of substitution in row 4 reduces the increase in intra-African trade by half thereby reducing the increase in CO2 emissions by 30% because of the lesser shift towards intra-African imports that are about twice as CO2 intensive as those from high-income countries.

Varying import demand elasticities in rows 2 and 3 barely affect the percentage changes in trade in intra-African trade (col 1).[14] Doubling the import elasticity in row 3 doubles the intra-African trade response but does not affect CO2 emissions much as producers meet increased demand by diverting exports from RoW destinations towards African ones resulting in the small changes in CO2 emissions (+13%) reported in column 2. Likewise, halving the elasticity of substitution in row 4, leads to an increase in more carbon-intensive intra-African trade, resulting in approximately the same CO2 elasticity of 0.48.

Row 6 reports the results from replacing the uniform import demand elasticity with elasticities estimated by Kee, Nicita, and Olarreaga (KNO,2008). These elasticities vary across sectors and countries. Now, the distribution of percentage changes in imports by country-sector exhibit a variance of 0.63 against 0.39 for the baseline scenario in row 1. With KNO elasticities, CO2 emission embodied in trade also displays a larger standard deviation (0.24) than in the baseline (0.14). Both CO2 and trade change distributions are highly negatively skewed, which explains the large decrease in the percentage change of CO2 emissions between rows 1 and 6 of Table 4.

Despite uniform elasticities across sectors and countries, these aggregate results mask large discrepancies at the country and sector levels. Table 5 displays the results of simulation (1) at the country level ordered by decreasing CO2 elasticity to trade change.

Table 5: Country results of AfCFTA full implementation, all imports

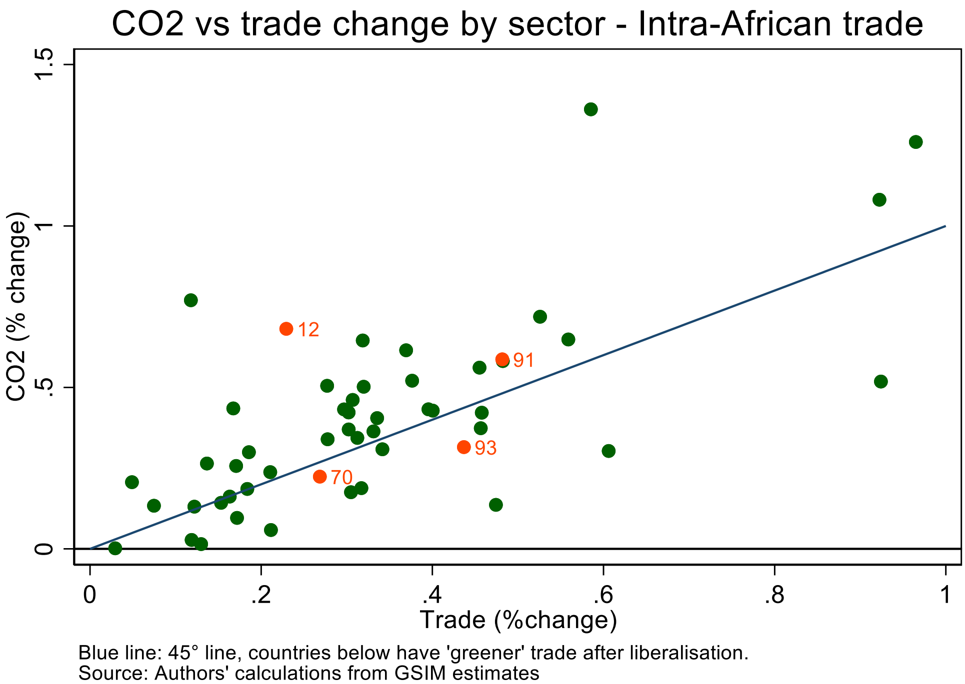
Country (iso3 code)	(1) CO2 change (%)	(2) Trade change (%)	(3) Average tariff before liberalisation	(4) CO2 elas. (2)/(1)
ZMB	22%	6.1%	0.129	3.610
BWA	20.1%	9.4%	0.075	2.125
ZWE	18.8%	21.9%	0.130	0.858
TZA	4.4%	5.7%	0.129	0.770
RWA	9.5%	14.6%	0.123	0.647
SWZ	17.5%	28.3%	0.075	0.619
KEN	2.6%	6.2%	0.129	0.430
TUN	0.1%	1.5%	0.108	0.087
MDG	0.2%	4.1%	0.117	0.057
ZAF	0.1%	3.6%	0.075	0.040
NGA	0.0%	1.1%	0.121	0.022
TGO	0.1%	7.7%	0.121	0.017
BDI	0.3%	23.1%	0.126	0.012
GMB	0%	3.8%	0.121	0.011
COG	0%	3.3%	0.179	0.004
SEN	0%	3.4%	0.121	0.004
BEN	0%	4.5%	0.121	0.003
MAR	0%	1.4%	0.123	0.003
BFA	0%	2.3%	0.121	0.002
EGY	0%	1.3%	0.190	0.001
MUS	-0.5%	0.9%	0.008	-0.579
Simple average	4.5%	7.3%	0.116	0.619

Notes: Results from GSIM simulation 1 presented in table 4. Results listed by descending order of col. (4)
Source: Authors' estimates from GSIM simulations.

Table 5 shows that AfCFTA leads to a dirtier mix for Zambia (ZMB) and Botswana (BWA) as the CO2 elasticities to trade are greater than one. This is to be expected since section 3 shows that low CO2e emission intensity sectors are, on average, subject to larger tariffs than dirtier goods. However, this trade policy characteristic phenomenon alone cannot entirely explain the results as, for example, Botswana was showing a statistically significant negative relationship between emission intensities and tariff (see figure 3) and, yet its import basket would turn dirtier under the AfCFTA. In the case of Botswana, the sectors "Cultivation of wheat", "Cultivation of cereal grains" that are relatively dirty expand more than other relatively cleaner sectors, such as "Sugar refining" that have originally low tariffs.

Mauritius is the only country with a reduction in trade that sees a decrease, albeit very small. Mauritius tariff schedule is close to 0 for all sectors except "Manufacturing of beverage" and "Sugar refining" sectors. The trade gains are mostly spread on those two relatively clean sectors, while all the other sectors, including some dirtier sectors such as "Cultivation of cereal grains" or "Meat animals" experience a small decrease in trade and, therefore, proportionally larger decrease in imported CO2. This combination of comparatively large increase in clean sectors, coupled with a decrease in most other sectors explains the opposite signs between the change in imported CO2 and the change in trade.

Figure 10: AfCFTA full implementation: Average change in CO2 and trade by sector



The heterogeneity in changes observed between countries is also apparent when comparing emissions across sectors, even though identical elasticities are used across countries and sectors (and the dispersion in tariffs across countries is small across African countries). Figure 10 plots the average percentage change in CO2 emissions intensities against the associated percentage change in intra-African trade for simulation (1) in Table 4 (see table A3 for details). About 35% of the sectors exhibit an increase in trade larger than an increase in CO2 emissions embedded in trade (i.e., 'relatively cleaner' as they are below the 45° line). The 4 sectors highlighted in red are the most polluting sectors listed in Table 1[15]. Sector 12 is the sector "Meat animals n.e.c.", 91 the sector "Manufacture of rubber and plastic products", 70 "Manufacture of basic iron and steel and of ferro-alloys and first products thereof", and 93 "Manufacture of furniture; manufacturing n.e.c.". For two sectors, 70 and 93, the AfCFTA results in relatively cleaner productions, and for the other two, 12 and 91, AfCFTA makes them relatively 'dirtier'.

Looking more closely at the sector "Meat animals n.e.c." (12), shows that both Kenya and Tanzania increased their imports by about 65% and 75%, respectively. This represented about 40% of imports from other African countries of this sector before liberalization. Imports of both Tanzania and Kenya are relatively dirtier than average for this sector, explaining the relatively large increase in CO2 relative to the change in trade. Sector "Manufacture of rubber and plastic products" (91), all countries with a significant share of CO2 emissions have a CO2 elasticity to trade between 1.09 and 0.81. Yet, South Africa represent 31% of "Manufacture of rubber and plastic products" before the liberalization and its imports become more CO2 intensive, in a large part due to a 59% increase in its imports from Zambia, the dirtiest of its trade partner for this sector.

Some sectors, however, end up relatively cleaner after liberalization. The sector "Manufacture of basic iron and steel and of ferro-alloys and first products thereof" (70) sees a decrease in the CO2 intensities of imports for almost all countries, except for Zambia (4% increase). The sector "Manufacture of furniture; manufacturing n.e.c." (93) also see a greening of its trade, due in most part from a decrease in CO2 intensities of Botswana's imports. In Botswana's case, most dirty imports are coming from South Africa and an increase in trade with its other partners diluted the dirtier trade flows originating from South Africa.

5. Conclusion

Currently, Climate Change (CC) challenges do not feature prominently in the continental level projects of the Africa Union (AU) 2063 agenda. The AfCFTA is the only initiative with measurable consequences for CO2 emissions, a key metric in the fight against CC. With per capita territorial emissions at 1 ton in 2021, which is two and half times less than Latin America, the next lowest region in per capita terms, African countries cannot be expected to join higher-income countries in their quest to reach zero net CO2 emissions by mid-century, but they still face the challenge of reducing CO2 emission intensities in production and consumption while shifting production and trade patterns towards carbon-sober activities.

This paper presents estimates of the likely effects on Green House Gas (GHG) emissions of reducing/eliminating intra-African tariffs on goods. Estimates are carried out for emission intensities for 2015 covering 187 products in 163 countries. Because of uncertainties about emission intensities and elasticities and that only ECOWAS and EAC have submitted tariff offers compliant with AfCFTA guidelines, the reported estimates are exploratory.

The paper shows that CO2 intensities are higher in the more protected sectors across African countries. For both ECOWAS and EAC, goods on the tariff exclusion list (schedules B and C) have higher tariffs than goods on the tariff elimination list (schedule A). Drawing on the product-level correlations between CO2 intensities and tariffs for all traded goods, we estimate that removing tariffs on schedule A goods would reduce progressively the carbon content of production for these goods. We estimate that an increase of 1% of the emission intensity is associated with a decrease of about 0.09% of the MFN tariff. These first-order estimates (no adjustment in production and trade patterns) under the assumption of unchanged sectoral emission intensities in both RECs, suggest that the trade policy bias favouring carbon-intensive sectors is likely to persist in both RECs, though less intensely than currently.

The paper concludes with illustrative partial equilibrium estimates of a 'full' AfCFTA scenario where all tariff lines are traded at zero tariffs for African trade while maintaining MFN tariffs on Rest-of-the-world (RoW) and RoW countries do not change tariffs. Under base elasticities (i.e. judged most plausible), intra-African trade increases by about 32% and emissions embedded in trade by 24%, implying a

CO2 elasticity of 0.74. Under all cases, CO2 emissions increase because the AfCFTA involves replacing less CO2 intensive products with more CO2 intensive African products. Depending on the assumed supply and substitution elasticities, CO2 elasticity estimates range for a full AfCFTA implementation between 0.5. and 0.9. Despite uniform elasticities across sectors and countries, these aggregate results mask large discrepancies at the country and sector levels. The disaggregated results indicate sectors that are likely to become relatively cleaner (dirtier) under AfCFTA.

Notes

1. Africa is the continent with the greatest share of known worldwide distribution of natural assets (renewable like forests, and non-renewable like sub-soil). It is engaging in international trade in these assets under poorly defined property rights making them vulnerable to 'tragedy of the commons' outcomes prone to be exacerbated by international trade. Regional trade agreements like the AfCFTA are yet to include provisions to limit environmental degradation, e.g., deforestation.

2. The Global Agro-ecological zones (GAEZ) project estimates that, for Africa, the average percentage fall in yield for 35 crops will be 40% by 2080, three times the world average.

3. In 2022, around 600 million Africans still did not have access to electricity, unchanged since 2010.

4. Currently, most trade in goods is not yet taking place under the AfCFTA regime because negotiations on tariff concessions and preferential rules of origin, both at the REC level, are ongoing.

5. CO2e estimates include CO2 emissions equivalent of the following 8 Green House Gases (GHGs): CO2, CH4, N2O, hydrofluorocarbons and perfluorinated compounds. Solazzo et al. (2021) estimate for 2021 that the combined accuracy of the three main GHGs: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) covered by RMRIO are accurate within an interval of −15 % to +20 %.

6. Melo and Solleder (2023) discuss the content, advantages, and limitations of RMRIO.

7. Sudan and South Sudan have been removed from the sample as they exhibited strong outliers.

8. AfCFTA objectives include cooperation on all trade-related areas from intellectual property rights and competition policy to customs matters and the implementation of the Trade Facilitation Agreement. Member States must adopt a mechanism for the settlement of disputes. An institutional framework for the implementation and administration of the AfCFTA considers the large disparities across members through Special and Differential Treatment (SDT) for LDCs.

9. The Agreement establishing the AfCFTA, the Protocol on Trade in Goods and the Protocol on Trade in Services contain minimal references to protection of the environment, although provisions in the Phase II protocols include environmental provisions in the Protocol on Investment. These provisions contain commitments not to lower environmental standards to encourage investment. These are included in Article 26 (Investment and Climate Change) and Article 34 (Environmental Protection) requiring investments to have an environmental impact assessment. Amending the AfCFTA protocol might come at the suggestion of the AfCFTA secretariat, a State Party, or a group of like-minded State Parties.

10. For example, the preamble would then recognize the necessity to balance environment and trade. Monteiro (2016) tallies that this language is in the preamble for more than 90% of the 280-trade agreement signed since 1956). When entering provisions in the data base, Monteiro measures depth by evaluating if the provision is: (i) aspirational or legally binding under international law; (ii) whether it is applicable in Dispute Settlement (DS) proceedings brought by other parties either in State-to-State or by private persons (state-private).

11. MFN tariffs are assumed to remain unchanged and EAC and ECOWAS members are assumed not to negotiate other FTAs with countries outside Africa.

12. GSIM requires that all sectors are traded. We therefore had to aggregate the 77 tradable sectors used in the rest of the paper, keeping 50 sectors and aggregating the 27 remaining sectors in 4 aggregates. See table A1, right column for details.

13. GSIM does not include inter-industry flows so one should not interpret results as pertaining to a simultaneous elimination of tariffs across all products. For an across-the-board tariff elimination, a more accurate estimate of the resource pull effects of tariff elimination would have to be based on changes in effective rates of protection at the sector level.

14. The sum absolute change for all countries moves, however, from about 43 billion with an import demand elasticity of -0.5 to 50 billion with an elasticity of -1, 123 billion with an elasticity of -2, and 114 billion with elasticities from Kee, Nicita & Olarreaga (2009).

15. The sector “Other agricultural products” is absent from Figure 9 as, for this exercise, it has been aggregated into one of our four aggregates the numbering of sectors is listed in table A1.

References

Armington, P. S. (1969). A Theory of Demand for Products Distinguished by Place of Production, Staff Papers (International Monetary Fund), 16(1), 159–178. https://doi.org/10.2307/3866403

Briel, G. (2023) "*Trade, Climate and Sustainability in the AfCFTA*", TRALAC

Cabernard, L. and S. Pfister. (2021) "A Highly resolved MRIO database for analysing environmental footprints and green economy progress". *Science of the Total Environment*, 755 (Part 1): 142587

Copeland. B., J. Shapiro, and S. Taylor (2021) "Globalization and the Environment", Chapter 2 in Gopinath et al. eds. *Handbook of International Economics*, vol. 5Pp. 61-146

Francois, J. and K. Hall (2009) "Global Simulation Analysis of Industry-Level Trade Policy: the GSIM model," IIDE Discussion Papers 20090803, Institute for International and Development Economics.

Grossman, G. M., and Helpman, E. (1994). "Protection for Sale". *The American Economic Review,* 84(4), 833–850. http://www.jstor.org/stable/2118033

Jammes, O. & Olarreaga, M. (2005). Explaining SMART and GSIM, http://wits.worldbank.org/witsweb/download/docs/explaining_smart_and_gsim.pdf

Kee, H.L. Nicita, A. & Olarreaga, M. (2008). "Import Demand Elasticities and Trade Distortions",. *The Review of Economics and Statistics*, 90 (4): 666-682

Lenzen, M., Moran, D., Kanemoto, K. and Geschke, A. (2013), "Building Eora: a global multi-region input– output database at high country and sector resolution", *Economic Systems Research* 25(1):20-49.

Melo, J. de and J.-M. Solleder (2023) "The Landscape of CO2 emissions across Africa", *The World Economy.* 46 (11),

Monteiro, J.-A. (2016), "Typology of environment-related provisions in regional trade agreements". WTO Staff Working Paper ERSD-2016-13.

Shapiro, J. (2021) "The Environmental Bias of Trade Policy", *Quarterly Journal of Economics,* 136(2), 831-886

Solazzo, E., Crippa, M., Guizzardi, D., Muntean, M., Choulga, M., and Janssens-Maenhout, G. (2021). "Uncertainties in the Emissions Database for Global Atmospheric Research (EDGAR) emission inventory of greenhouse gases". *Atmospheric Chemical Physics,* 21, 5655–5683, https://doi.org/10.5194/acp-21-5655-2021, 2021.

Stadler, K., R. Wood, T. Bulavskaya, C.-J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. AcostaFernández, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.-H. A. Koning and A. Tukker. 2021. EXIOBASE 3 (3.8.1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4588235

Annexes

A. Annex A: Additional tables

Table A1: Names and codes of sectors included in the analysis.

Tradable sector		**GSIM sectors and aggregate**	
Name	**#**	**Name**	**#**
Cultivation of paddy rice	1	Other agricultural products	1001
Cultivation of wheat	2	*Same as tradable.*	2
Cultivation of cereal grains nec	3	*Same as tradable.*	3
Cultivation of vegetables, fruit, nuts	4	*Same as tradable.*	4
Cultivation of oil seeds	5	*Same as tradable.*	5
Cultivation of sugar cane, sugar beet	6	**Other agricultural products**	**1001**
Cultivation of plant-based fibers	7	**Other agricultural products**	**1001**
Cultivation of crops nec	8	Same as tradable.	8
Cattle farming	9	**Other agricultural products**	1001
Pigs farming	10	**Other agricultural products**	1001
Poultry farming	11	**Other agricultural products**	1001
Meat animals nec	12	*Same as tradable.*	12
Animal products nec	13	*Same as tradable.*	13
Wool, silk-worm cocoons	15	**Other**	**1004**
Forestry, logging and related service activities	18	Same as tradable.	18
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing	19	Same as tradable.	19
Mining of coal and lignite; extraction of peat	20	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	21	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Extraction of natural gas and services related to natural gas extraction, excluding surveying	22	**Mining and other extracting industries (pertroleum, gas...)**	**1000**

Table A1 Continued

Tradable sector		**GSIM sectors and aggregate**	
Name	**#**	**Name**	**#**
Extraction, liquefaction, and regasification of other petroleum and gaseous materials	23	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of iron ores	25	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of copper ores and concentrates	26	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of nickel ores and concentrates	27	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of aluminium ores and concentrates	28	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of precious metal ores and concentrates	29	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of lead, zinc and tin ores and concentrates	30	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Mining of other non-ferrous metal ores and concentrates	31	**Mining and other extracting industries (pertroleum, gas...)**	**1000**
Quarrying of stone	32	*Same as tradable.*	32
Quarrying of sand and clay	33	*Same as tradable.*	33
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	34	*Same as tradable.*	34
Processing of meat cattle	35	**Processing of meat of pigs or cattles**	1003
Processing of meat pigs	36	**Processing of meat of pigs or cattles**	1003
Processing of meat poultry	37	*Same as tradable.*	37
Production of meat products nec	38	*Same as tradable.*	38
Processing vegetable oils and fats	39	*Same as tradable.*	39
Processing of dairy products	40	*Same as tradable.*	40
Processed rice	41	*Same as tradable.*	41
Sugar refining	42	*Same as tradable.*	42
Processing of Food products nec	43	*Same as tradable.*	43
Manufacture of beverages	44	*Same as tradable.*	44
Manufacture of fish products	45	*Same as tradable.*	45
Manufacture of textiles	46	*Same as tradable.*	46

Manufacture of wearing apparel; dressing and dyeing of fur	47	*Same as tradable.*	47
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	48	*Same as tradable.*	48
Tradable sector		**GSIM sectors and aggregate**	
Name	**#**	**Name**	**#**
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	49	*Same as tradable.*	49
Pulp	51	**Other**	**1004**
Paper	53	*Same as tradable.*	53
Petroleum Refinery	55	**Other**	**1004**
Plastics, basic	56	*Same as tradable.*	56
N-fertiliser	58	**Other**	**1004**
P- and other fertiliser	59	*Same as tradable.*	59
Chemicals nec	60	*Same as tradable.*	60
Manufacture of glass and glass products	61	*Same as tradable.*	61
Manufacture of ceramic goods	63	*Same as tradable.*	63
Manufacture of bricks, tiles and construction products, in baked clay	64	*Same as tradable.*	64
Manufacture of cement, lime and plaster	65	*Same as tradable.*	65
Manufacture of other non-metallic mineral products n.e.c.	67	*Same as tradable.*	67
Processing of nuclear fuel	69	**Other**	**1004**
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	70	*Same as tradable.*	70
Precious metals production	72	**Other**	**1004**
Aluminium production	74	*Same as tradable.*	74
Lead, zinc and tin production	76	*Same as tradable.*	76
Copper production	78	*Same as tradable.*	78
Other non-ferrous metal production	80	*Same as tradable.*	80
Manufacture of machinery and equipment n.e.c. (29)	83	*Same as tradable.*	83
Manufacture of office machinery and computers (30)	84	*Same as tradable.*	84

Manufacture of electrical machinery and apparatus n.e.c. (31)	85	*Same as tradable.*	85
Manufacture of radio, television and communication equipment and apparatus (32)	86	*Same as tradable.*	86
Manufacture of medical, precision and optical instruments, watches and clocks (33)	87	*Same as tradable.*	87
Tradable sector		**GSIM sectors and aggregate**	
Name	**#**	**Name**	**#**
Manufacture of motor vehicles, trailers and semi-trailers (34)	88	*Same as tradable.*	88
Manufacture of other transport equipment (35)	89	*Same as tradable.*	89
Manufacture of tobacco products (16)	90	**Other**	**1004**
Manufacture of rubber and plastic products (25)	91	*Same as tradable.*	91
Manufacture of fabricated metal products, except machinery and equipment (28)	92	*Same as tradable.*	92
Manufacture of furniture; manufacturing n.e.c. (36)	93	*Same as tradable.*	93
Manufacture of gas; distribution of gaseous fuels through mains	110	**Other**	**1004**
Publishing, printing and reproduction of recorded media (22)	134	*Same as tradable.*	134

Notes: Sector names are from Exiobase, one of the datasets used to compile RMRIO. N.e.c means not elsewhere covered. Left column shows the 77 tradable sectors used in sections 1-3, while the right columns shows the 50 sectors and 4 aggregates used in the GSIM simulations in section 4.

Table A2: Latest year of availability of applied MFN tariff

Country	Latest year	Country	Latest year
Angola	2019	Morocco	2020
Burundi	2020	Madagascar	2021
Benin	2020	Mali	2020
Burkina Faso	2020	Mozambique	2019
Botswana	2021	Mauritania	2017
Central African Republic	2016	Mauritius	2021
Côte d'Ivoire	2020	Malawi	2017
Cameroon	2019	Namibia	2021
Democratic Republic of the Congo	2019	Niger	2020
Congo	2014	Nigeria	2020
Comoros	2019	Rwanda	2020
Cape Verde	2021	Senegal	2020
Djibouti	2014	Sierra Leone	2020
Algeria	2017	Eswatini	2021
Egypt	2019	Seychelles	2021
Gabon	2019	Chad	2016
Ghana	2020	Togo	2020
Guinea	2020	Tunisia	2016
The Gambia	2020	Tanzania	2020
Guinea-Bissau	2020	Uganda	2020
Kenya	2020	South Africa	2021
Liberia	2020	Zambia	2016
Lesotho	2020	Zimbabwe	2020

Source: WTO tariff portal

Table A3: Simulation results by sector for intra-African trade, simulation 1

Sector name	(1) CO2 (% change)	(2) Trade (% change)	(3) Av. tariff	(4) Ratio (1)/(2)
Quarrying of stone	0.770	0.118	0.0667	6.531
Forestry, logging and related service activities	0.207	0.0490	0.0732	4.213
Meat animals nec	**0.681**	**0.229**	**0.115**	**2.972**
Manufacture of medical, precision and optical instruments, watches and clocks	0.435	0.167	0.0958	2.599
Cultivation of vegetables, fruit, nuts	1.361	0.585	0.188	2.326
Processed rice	0.645	0.319	0.0826	2.025
Quarrying of sand and clay	0.264	0.137	0.0559	1.935
Cultivation of oil seeds	0.505	0.277	0.0840	1.823
P- and other fertiliser	0.134	0.0747	0.0250	1.788
Animal products nec	0.615	0.369	0.119	1.665
Manufacture of radio, television and communication equipment and apparatus	0.299	0.186	0.105	1.613
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.502	0.320	0.156	1.570
Manufacture of bricks, tiles and construction products, in baked clay	0.257	0.171	0.185	1.503
Publishing, printing and reproduction of recorded media	0.461	0.307	0.112	1.503
Manufacture of glass and glass products	0.432	0.297	0.151	1.455
Processing of meat poultry	0.423	0.302	0.214	1.398
Processing of dairy products	0.521	0.376	0.193	1.384
Manufacture of textiles	0.719	0.526	0.161	1.367
Manufacture of wearing apparel; dressing and dyeing of fur	1.260	0.965	0.242	1.306
Processing of Food products nec	0.561	0.455	0.171	1.233
Cultivation of wheat	0.370	0.302	0.0447	1.224
Cultivation of crops nec	0.339	0.278	0.0960	1.223
Manufacture of rubber and plastic products	**0.587**	**0.482**	**0.144**	**1.219**
Manufacture of fabricated metal products, except machinery and equipment	0.582	0.482	0.149	1.206
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	1.081	0.922	0.212	1.172

Sector name	(1) CO2 (% change)	(2) Trade (% change)	(3) Av. tariff	(4) Ratio (1)/(2)
Manufacture of beverages	0.648	0.559	0.522	1.160
Manufacture of other transport equipment	0.238	0.211	0.0683	1.129
Manufacture of electrical machinery and apparatus n.e.c.	0.344	0.312	0.102	1.100
Manufacture of other non-metallic mineral products n.e.c.	0.364	0.331	0.143	1.098
Production of meat products nec	0.432	0.395	0.243	1.093
Manufacture of office machinery and computers	0.131	0.122	0.103	1.072
Processing vegetable oils and fats	0.428	0.400	0.130	1.069
Copper production	0.186	0.184	0.0846	1.009
Other non-ferrous metal production	0.162	0.163	0.0832	0.992
Manufacture of machinery and equipment n.e.c.	0.143	0.153	0.0688	0.931
Paper	0.422	0.458	0.116	0.921
Aluminium production	0.308	0.342	0.0977	0.903
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.224	0.269	0.0948	0.833
Manufacture of motor vehicles, trailers and semi-trailers	0.374	0.457	0.116	0.818
Manufacture of furniture; manufacturing n.e.c.	**0.315**	**0.437**	**0.181**	0.721
Cultivation of cereal grains nec	0.188	0.317	0.0993	0.593
Manufacture of cement, lime and plaster	0.175	0.305	0.153	0.575
Manufacture of ceramic goods	0.518	0.924	0.163	0.561
Plastics, basic	0.0959	0.172	0.0493	0.558
Manufacture of fish products	0.303	0.606	0.175	0.500
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing	0.136	0.474	0.153	0.287
Sugar refining	0.0583	0.211	0.146	0.276
Lead, zinc and tin production	0.0276	0.119	0.0614	0.233
Chemicals nec	0.0148	0.130	0.0666	0.114
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	0.00177	0.0294	0.0658	0.0603
Simple average across sectors	0.405	0.336	0.131	1.207

Sectors in bold: most polluting sectors from table 1.

B. Annex B: GSIM

B1. *Overview*

This annex describes the Global Simulation Analysis of Industry-Level Trade Policy (GSIM) of Francois and Hall (2009), an extension of the SMART model to include third-country effects. Third-country effects are important since the AfCFTA involves a reduction in tariffs across all African countries while maintaining MFN tariffs for trade with non-Africa regions. In GSIM, market clearing is at the global level for each sector (rather than at the bilateral level as in SMART). As in SMART, goods are differentiated by origin (Armington (1969) assumption). Since goods that compete with imports are also exported, GSIM also incorporates exports at the sector level.

For tractability, as in SMART, cross-price effects are constrained by two-stage budgeting embodied in the Armington assumption (i.e., Kenyan coffee variety is different from Ethiopian variety). There are no cross-price effects across goods (e.g., between coffee and tea). Income effects are suppressed. Intermediate flows are not incorporated. Since supply is not modelled at the sector level, general equilibrium repercussions through factor markets are not considered. These assumptions reduce to three the number of elasticities required for each product: a price elasticity of demand for imports, η, an elasticity of substitution between African imports and ROW imports, σ, and an elasticity of supply of exports, ε, which depends on the elasticity of supply. Often elasticities are not estimated precisely at a disaggregated level, so in most simulations we impose the same elasticities across sectors.

As example, consider a reduction in tariffs for intra-African trade in plastics increases the demand for plastics produced by African partners. Take Kenya as example. AfCFTA will make it more profitable for Kenya to buy plastics from African partners and to sell its plastics to African partners rather than to the ROW. Kenya will redirect some of its exports from ROW to African partners. The specifics of this adjustment will depend on elasticities, principally the elasticity of substitution in consumption. If this increased demand cannot be met from plastics previously sold to the ROW, the supply of Kenyan plastics will have to increase via an adjustment in the supply price of plastics.

B2. *Model structure*

Assume a two-stage budgeting procedure with a CES utility function where varieties are differentiated by country of origin (i.e. Armington assumption, σ) The two-stage budgeting assumption limits cross-price effects since cross-price effects across categories of goods are eliminated. The import demand function for country v for a variety coming from country r depends on the internal price of this variety (P_(v,r)), the prices of other varieties (P_(v,s≠r)), and total expenditure (y_v):

$$M_{v,r} = f\left(P_{v,r}, P_{v,s\neq r}, y_v\right) \tag{1}$$

Differentiating equation (1), applying the Slutsky decomposition, using the fact that Hicksian demand is homogeneous of degree zero in price and suppressing income effects, gives the following elasticities:

$$N_{v,(r,r)} = \theta_{v,r}E_m - \left(1 - \theta_{v,r}\right)E_s \tag{2}$$

$$N_{v,(r,s)} = \theta_{v,s}(E_m + E_s) \tag{3}$$

Where $N_{v,(r,r)}$ is the own-price elasticity of demand in country *v* for imports from country *r*; $N_{v,(r,s)}$, the cross-price elasticity of demand in country *v* for imports from country *s*; $\theta_{v,r}$ is the expenditure share in *v* for imports from country *r*; E_m, the import demand elasticity; and E_s, the elasticity of substitution between varieties.

Defining a supply side as a function of the world price $X_r = g(P_r^*)$, we can work out the equilibrium condition of the model :

$$\widehat{M_r} = \hat{X}_r \Longrightarrow E_{Xr}\widehat{P_r^*} = \sum_v N_{v,(r,r)}\left[\widehat{P_r^*} + \widehat{T_{v,r}}\right] + \sum_v \sum_{s\neq r} N_{v,(rs)}\left[\widehat{P_s^*} + \widehat{T_{v,s}}\right] \tag{4}$$

Where E_{Xr} is the export supply elasticity of country *r*; and $\widehat{T_{v,r}}$ is the percentage change of tariff in *v* for products from *r* where a 'hat' ^ over a variable indicates a percentage (or proportional) change, so that $\hat{x} = \frac{dx}{x}$.

Since intermediate flows are not considered, equilibrium can be calculated independently for each sector. To further simplify, we do not calibrate the model in the base year and we simulate tariff changes by computing percentages around the equilibrium as shown in (4) ("exact hat algebra"). We use the approach of Jammes and Olarreaga (2005), and define a matrix B with diagonal elements equal to $\sum_v N_{v,(rr)}$, divided by the export supply elasticity E_{Xr} and off-diagonal elements equal to $\sum_v \sum_{s\neq r} N_{v,(rs)}$ divided by the export supply elasticity E_{Xr}; a vector T, defined by the sum over the rows of matrix B multiplied by the respective change in tariffs. The problem can then be expressed in matrix form, as:

$$P^* = (I - B)^{-1}T \tag{5}$$

With P^* being a vector of export price change.

Finally, we can recover the change in imports as:

$$\widehat{M_{v,r}} = N_{v,(r,r)}\widehat{P_{v,r}} + \sum_{s\neq r} N_{v,(rs)}\,\widehat{P_{v,r}} \tag{6}$$

Multiplying $M_{v,r}$ by the embedded emission intensity ($e_{v,r}$) gives the percentage change in the volume of CO2e exchanged between countries *v* and *r* $(\widehat{Em_{v,r}})$ for the sector in the simulation.

$$\widehat{Em_{v,r}} = e_{v,r}\widehat{M_{v,r}} \tag{7}$$

The CO2e emission intensity embedded in trade $e_{v,r}$ is obtained from the MRIO dataset. To do this we first use the input-output matrix $A[r \times r]$ where each row lists the industry supplying inputs to generate the Leontief inverse $L = (I - A)^{-1}$. Multiplying L with the vector E^{direct} of direct emission intensities reported by RMRIO, we get E = LE^{direct}. Each cell of this new matrix E represent the emission intensity of the flow between country *r* sector *i* to country *v* sector *j* : $e_{v,r,(i,j)}$. .

To obtain the carbon intensity of a trade flow we then need to sum over destinations sectors for each country pair-source sector relationship. This is because goods are taxed based on the source sector which defines what they are, regardless of the destinations sector:

$$e_{v,r,(i)} = \sum_j e_{v,r,(i,j)} \tag{9}$$

where *i* index the source sector and *j* the destination sector.

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