The Landscape of CO2 Emissions Across Africa: A Comparative Perspective

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List of abbreviations and acronyms

ADB	Asia Development Bank
CH4	Methane
CO2	Carbon Dioxide
CO2e	CO2 Equivalent
EDGAR	Emissions Database for Global Atmospheric Research
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GDP	Gross Domestic Product
GHGs	Green House Gases
GVCs	Global Value Chains
ID	Input Downstreamness
IEA	International Energy Agency
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land-Use, Land-Use Change, and Forestry
MRIO	Multi-Regional Input-Output
N2O	Nitrous Oxide
OU	Output Upstreamness
RMRIO	Resolved Multi-Regional Input-Output
TiVA	Trade in Value-Added
WIOD	World Input-Output

Abstract

Expansion of Global Value Chains (GVCs) is a mixed blessing for the environment. Effects of growth and emissions from transport associated with international trade have negative effects; but greater flows of knowledge and associated spillovers, and adoption of environmentally innovative products have positive effects. This paper gives evidence on carbon dioxide (CO2) emissions for 51 African countries and 132 other countries for 163 products over the period 1995–2015. The resulting landscape is summarized in six patterns. Patterns identified for the Africa region differ from those identified for other regions, but are closely related to a synthetic aggregate comparator constructed on the basis of three characteristics (per capita income, share of manufacturing in GDP, and distance to trading partners).

1. All regions have reduced emission intensities over the period 1995–2015. Africa's share of global CO2 emissions has remained constant over the period 1995–2015. Asia, already the region with the largest share of global emission in 2000, has strengthened its leading position. Europe and the Americas have reduced their share of emissions by nine and eight percentage points, respectively. Asia is decarbonizing; Africa not yet.

2. Carbon intensity of production has increased in Africa in both decades, though much less so over the period 2005–2015 when, on average, emissions grew less rapidly than population. Over half of the 20 African top emission growth emitters shifted towards more carbon-intensive techniques.

3. Source of regional total emissions: Over the period 1995–2015, intra-regional shares of emissions fell by seven, ten, and two percentage points to 84%, 75%, and 88% for Africa, Europe, and Asia, respectively. Africa's share of emissions originating from Asia rose from 4% to 11%. Europe's share of emissions originating from Africa and Asia rose from 2% and 8% to 4% and 16%, respectively.

4. The Spearman rank correlation of emissions across regions over 163 sectors is high, around 0.7. Almost half of top five cleanest and top five dirtiest sectors are the same across regions, but there are some sharp differences in rankings for some of the highest emitter sectors. In general, dirtiest sectors are more upstream.

5. Downstreamness is increasing over time. Output upstreamness (OU) from final consumption and input downstreamness (ID) from primary factors are needed jointly to indicate a sector's position in a supply chain. At a 7-sector aggregation level, Mining is the most upstream sector for all regions followed by Agriculture; Electricity and Utilities, Services, and Transports are the upstream broad sectors in all regions. Manufactures and Construction are downstream for all regions.

6. The export basket of Africa is skewed towards high CO2e intensity products. CO2 emission intensities are positively correlated with both the upstreamness (OU) and downstreamness (ID). The OU/ID indicator of position in a supply chain is negatively correlated with CO2 emission intensities within regions. A stronger fit is obtained within sectors in each region. For manufactures, being more upstream by 1% is associated with a higher emissions intensity of 0.61%. For the other sectors, the relation is negative, and larger for Agriculture and Construction.

Key words: *CO2; Africa; Export potential; Environmental goods.*

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

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1. Introduction

Reduction in transport and communication costs has stimulated the fragmentation of production into tasks across countries. This offers countries the opportunity to enter into different stages of production along supply chains without having to produce at scale along all stages of the chain. So far, Africa has remained a marginal participant in global supply chain trade (or Global Value Chains (GVCs)).[1] At the same time, absent performing environmental policies, growth is typically harmful for the environment, which is an increasing concern particularly across fast-growing African economies where population growth is also the highest in the world.

Expansion of GVCs is a mixed blessing for the environment. On the negative side, scale effects of trade and growth increase the environmental footprint of economic activity, producing more shipping across countries and more waste in the aggregate (e.g., in electronics via a higher rate of technological innovation, or more plastics). The Asia Development Bank (ADB, 2021) estimates that, about 2.1 gigaton of CO2 equivalent (CO2e) emissions is associated with international trade. If so, lengthening supply chains is likely to increase the role from transportation and expand the scope of potential pollution haven effects as industries in jurisdictions with tight environmental policies might migrate to jurisdictions with lax environmental policies (known as the 'pollution haven hypothesis').

On the positive side, knowledge flowing across firms in supply chains might lead to the adoption of environmentally innovative products and technologies—known as Porter's 'pollution halo' hypothesis (Porter & van der Linde, 1994). Also, lead firms in GVCs have brand names to protect in relational GVCs, hence they have incentives to minimize the footprint of their activities. Lead firms can reduce emissions (those they control directly 'scope 1' and indirectly 'scope 2') from upstream suppliers in other jurisdictions. Typically, environmental impacts are borne upstream where African countries are located while value creation takes place downstream.

Only detailed firm-level evaluations along supply chains can hope to disentangle these effects. The most widespread measure of the extent of environmental damage from economic activity is the CO2 equivalent (CO2e) of Green House Gases (GHGs) usually available at the sector level, the measure of emissions used in this paper.[2] CO2e emission-based evidence is mostly at the macro level for high-income and emerging economies (e.g., Ferrarini & de Vries (2015), Brenton and Chemutai (2021), Asia Development Bank (2021)). When available, evidence covering most of Africa is fragmented (e.g., Ibrahim and Hook (2016), Steckel et al. (2020) on coal, Liu and Zhao (2021), the exception being Ayompe et al. (2021) covering CO2 emissions across 27 African countries over 1990–2017. To our knowledge, no study with a focus on GVCs covers the quasi-entirety of Africa. This paper fills this gap.

To narrow the scope of this inquiry, we do not consider the additional CO2 emissions caused by the transport of goods associated with the lengthening of GVCs.[3] Our focus is on comparisons across regions and some of the largest emitters in Africa. Since policies to protect the environment are increasingly formulated at the regional level in 'Deep' regional trade agreements that include provisions to protect the environment (Mattoo et al., 2020), it is instructive to report on the evolution of emissions at a regional level. However, because of the great heterogeneity within regions, we also report on emissions from a built synthetic comparator (a weighted sum of countries selected on the basis of three similar per capita GDP, manufacturing shares and distance from trade partners).

Our estimates are derived from Cabernard and Pfister (2021) highly disaggregated "Resolved Multi-Regional Input-Output" (RMRIO) database well-suited to analyse the environmental footprint of production and trade activities. The richness of the data set explains the large number of tables and figures, with characteristics and patterns of CO2e emissions for 49 African countries for 163 sectors over the period 1995–2015. Main results are summarized in "patterns" across regions, countries, or sectors, most in the spirit of the stylized facts in the survey by Copeland et al. (2021) compiled for 35 sectors across 43 high-income and emerging countries contained in the World Input-Output (WIOD) database.

The rest of this paper is organized as follows. Section 2 presents the construction of the data set, which results in a 'resolved' multi-regional input-output table (RMRIO) assembling production and trade flows for 183 countries and 163 sectors for the period 1995–2015. Section 3 traces the evolution of global CO2e emissions across regions and decomposes this growth in scale, composition, and technique effects across regions and across African countries. Section 4 reports the results of decompositions of direct and indirect measures of CO2e emissions (in kg) and emission intensities (in kg/€) by origin and destination across regions. This decomposition reveals sharp changes in origin and destination by region over the 20-year period. Section 5 traces the evolution of Output Upstreamness (OU) (distance from final consumptions) and Input Downstreamness (ID) (distance from primary factors). A measure of a sector's position along a supply chain (OU/ID) shows a general trend towards increased downstreamness (i.e., greater roundaboutness in production across sectors over time reflected in falling value-added to gross output ratios across sectors). Section 6 reports on correlates of CO2e emission intensity (e.g., export shares and GVC position). Section 7 concludes the study.

2. Data set construction

Assessing the environmental effects of fragmentation of tasks across activities (many sectors help) and of offshoring (many countries help) along supply chains requires estimates of emissions. This calls for a finely disaggregated Multi-Regional Input-Output (MRIO) data set as pollution intensive sectors are better identified at a disaggregated level (Copeland et al., 2021). Furthermore, a large country coverage is desirable to analyse GVC activity in Africa where the small size of many countries could be reflected in greater participation in GVCs. MRIO tables are balanced by extrapolating or intrapolating values through cross-entropy methods for countries that do not have an IO table, which is the case for all African countries.

Among MRIO data sets, EORA (Lenzen et al., 2013) covers 189 countries, including 54 African economies, and a "Rest of the World" region, for 26 sectors in each country.[4] More recently, EXIOBASE 3 (Stadler et al., 2021) provide greater sectoral coverage (163 sectors and 200 products) but for less countries (44 countries and 5 world regions). EXIOBASE includes few African economies. On the one hand, with 26 sectors, EORA is not sufficiently disaggregated for this paper. On the other hand, with 44 countries, EXIOBASE does not cover enough African countries for a meaningful analysis. Fortunately, Cabernard and Pfister (2021) combine those two data sets (and others) to build a "Resolved Multi-Regional Input-Output" (RMRIO) database. RMRIO covers 189 countries, including 54 African economies[5], and 163 sectors. It provides environmental stressor matrices for material extraction, blue water consumption, climate change impacts, PM health impacts, water stress, and land-use related biodiversity loss. The data cover the period 1995—2015.[6] This highly disaggregated database is well-suited to analyse the environmental footprint of production and trade activities.

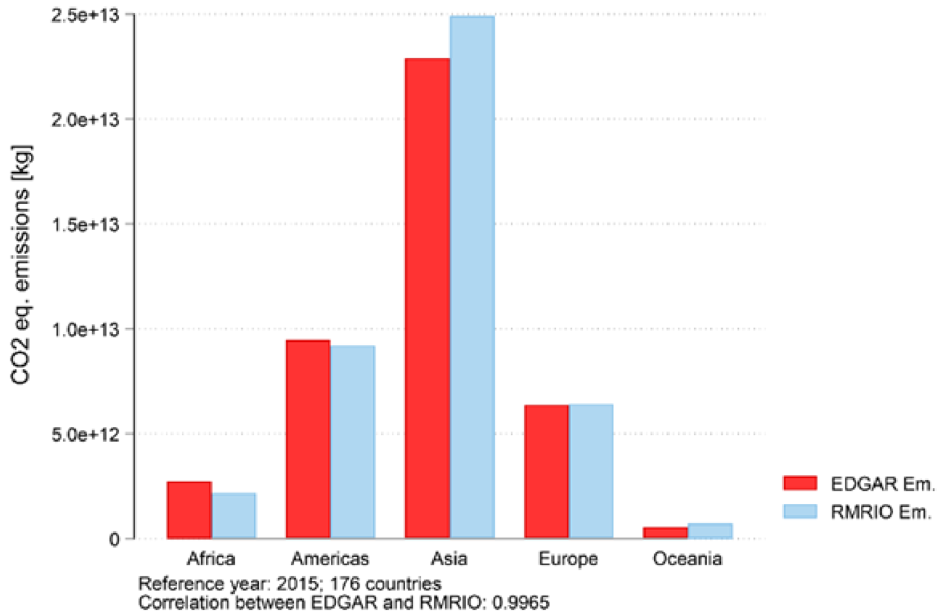
Reaching this level of granularity comes at a cost for a study on GHGs in developing countries, especially across Africa. RMRIO disaggregates EXIOBASE data by weighting it with information extracted from EORA, FAOSTAT, and previous studies.[7] Data on most African countries are not collected but the result of estimations and imputations for missing data. For example, no African country included in EORA has an Input-output table for a single year. This is likely to lead to errors in the calculation of the total and direct emissions of each country-sector, even though, in the aggregate, these errors are likely to be confined to small sectors having little effect on estimates of footprint aggregates.[8] RMRIO is, however, the most comprehensive data set at our disposal and we believe that the benefits of its extended coverage outweigh its shortcomings. For example, based on the RMRIO data set used in this paper, Cabernard and Pfister (2021) estimate that, a third of the EU's water stress in 2015 originates in other countries, notably Egypt and Madagascar.

Another shortcoming of RMRIO is that it aggregates EORA's emissions of CO2, CH4, N2O, hydrofluorocarbon, and perfluorinated compound weighted by their respective warming potential into a single measure of climate change impact, measured in CO2 equivalent (CO2e). As pointed out by Copeland et al. (2021) in their second stylized fact, different types of pollution are correlated, so the aggregation of those pollutants should not drastically change the results when compared to studies looking at a single pollutant. Furthermore, for our purposes, we ultimately need a single metric to identify what we will define as a ‘clean’ sector. In that context, using an aggregate of all harmful gases makes sense.[9] All figures reported on emissions reported here refer to CO2e.

Data on emissions originate from EORA, which source them, in turn, from European Union's Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al., 2021). Note that EDGAR, and by extension EORA and RMRIO, does not account for large scale biomass burning (such as forest or savannah fires) and other emissions from Land-Use, Land-Use Change, and Forestry (LULUCF). Accounting for LULUCF would significantly increase CO2 equivalent emissions for Africa. Intergovernmental Panel on Climate Change (IPCC, 2014) estimates that, LULUCF emissions can account for a large share, between 11% and 17%, of total anthropogenic emissions.

EDGAR derives CO2 and other GHG emissions from information on activity and technology by country-sector and multiplying it by country-specific emission factors (Crippa et al., 2021). EDGAR covers 218 countries. Underlying data from IEA doesn’t have that level of disaggregation, which is important for this study focusing on African countries which need to be disaggregated to be added in EDGAR.[10] This, added to the fact that RMRIO further disaggregates this data into 163 sectors, is likely to add uncertainty to results concerning these countries. However, as shown in Figure 1, differences in emission estimates between EDGAR and RMRIO remain small. This justifies using the more disaggregated RMRIO data.

Figure 1: CO2e emission - EDGAR vs RMRIO



Source: Authors' own calculations from EDGAR and RMRIO databases.

3. CO2e emissions across regions: 1995-2015

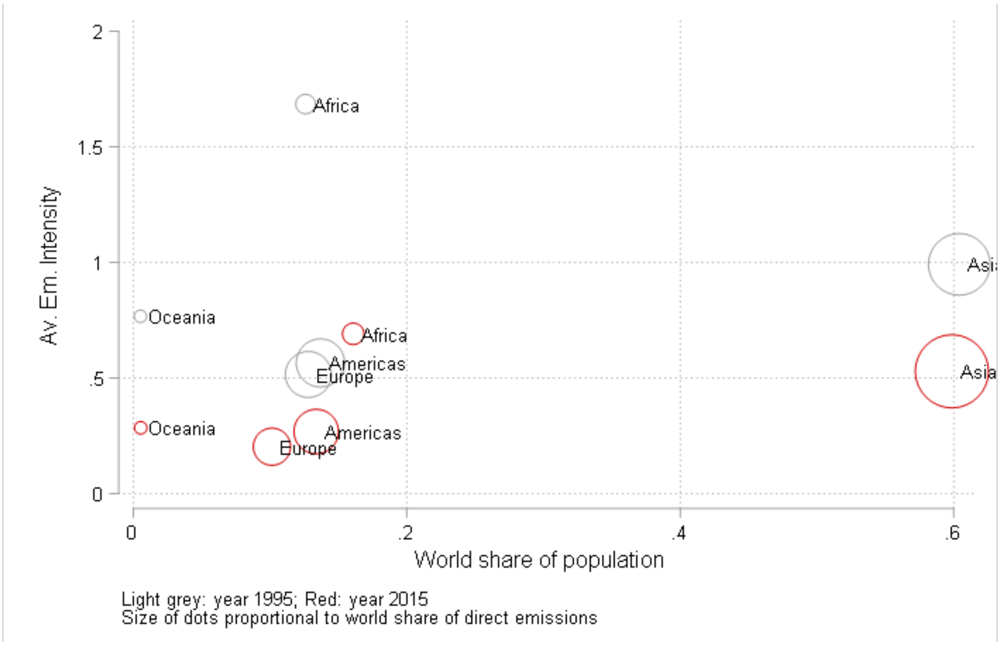
We report on CO2e emissions by region (see tables A1–A5 for list of countries in each region), starting with intensities and growth in total emissions. We then report direct and indirect emissions across regions, where indirect emission are emissions originating outside the region in imported intermediate inputs, which is also a measure of involvement in extra-region GVC trade. To take an example, CO2e emissions in the production of basic plastics (a high CO2e-intensity activity across Africa emitting 16kg of CO2 equivalent per € produced) are decomposed into direct emissions coming from production in any African country and indirect emissions embodied in intermediate inputs originating in any one of the other regions. For basic plastics, only 2.2% of emissions originate in Africa.

CO2e emission by region

Figure 2 shows the regional shares (country gross-output weighted) of CO2e emissions (bubble size), average emission intensities (vertical axis), and population shares (horizontal axis) for 1995 and 2015. The size of the bubbles is proportional to the region's share in world's total CO2e emissions. The change in bubble size for each region reflects the combined effects of growth (scale effect), a shift in output across sectors (and countries) with different emission intensities (composition effect), and a technique effect (change in emission intensity within sectors). In developing countries, especially Africa, changes in emissions also reflect ongoing urbanization.[11] This decomposition is presented in the next subsection. Keep in mind that since these regional estimates are aggregated from country-level emissions, they double count emissions along supply chains. This can be important if a country (or here a region) imports intermediates with high CO2e intensities.

Looking first at total emission intensities, in 2015, Asia that includes China is by far the largest emitter with 24.6 billion kilograms of CO2e in 2015, followed by the Americas with 9.19 billion kilograms. In comparison, Africa emits little, with 2.18 billion kilograms of CO2e. Five well-documented patterns stand out. First, regional average CO2e intensities have fallen across all regions. Second, Asia already the largest emitter in 1995 increased its share over the period even though its population share declined slightly. Third, apart from Oceania, Africa has the smallest share of CO2e emissions in spite of a population share higher than Europe or the Americas. Fourth, Africa is the only region with a growing population share. Fifth, Africa experienced the largest drop in average emissions over the period.

Figure 2: Total CO2e emissions intensities (kg/€) and population shares by region: 1995 and 2015



Source: Authors' own estimates from RMRIO.

By 2015, Africa's population share was larger than Europe's or the Americas', but its share in global emissions remained unchanged. By 2015, in spite of a large drop, emission intensities in Africa and Asia were more than twice as high as those of the other regions (see Figure 4 for the time trend). It is immediately apparent from this figure that it is difficult to convince African countries that they should cut emissions if this cut comes at a cost. Financial support to build a low-carbon urbanization would be promising (Bigio, 2015).

Decomposing emissions growth

Table 1 and Figure 3 decompose emissions growth. Table 1 decomposes CO2e emissions per unit of output (CO/Y) into the product of the CO2e emission intensity of energy consumption (CO/CE) times the energy intensity of gross output (CE/Y); that is:

$$\frac{CO}{Y} \equiv \frac{CO}{CE}\frac{CE}{Y} \tag{1}$$

Where: *CO* stands for emissions (in kilograms of CO2 equivalents), *Y* is gross output in € and *CE* is primary energy consumption in kWh. A high emission intensity per unit of output (CO/Y) can be the outcome of a high emission per kWh of energy consumed (CO/CE), or of a high energy consumption per unit of output (CE/Y), or both. The former is likely to imply that "dirty" energy sources are used primarily in the economy. The latter suggests that either the country is specializing in energy intensive activities or that it lacks abatement technology—or incentives—necessary to reduce emissions.

Table 1 shows that, CO2e emissions per unit of GDP are the highest in Africa, especially in 1995, but the gap with Asia fell sharply over the 20-year period, a change also shown in Figure 2. Total emission intensities (CO/Y) have fallen across all regions, largely because of the sharp fall in the energy consumption per unit of output (CE/Y), across all regions. However, the emission per kWh of energy consumed (CO/CE) increased in all regions except Europe, with the sharpest rise in Africa and Asia.

Table 1: Decomposition of total CO2e emissions by region

	1995			2015		
Region	**Em/output (CO/Y)**	**Em/En (CO/CE)**	**En/output (CE/Y)**	**Em/output (CO/Y)**	**Em/En (CO/CE)**	**En/output (CE/Y)**
Africa	1.683	0.228	7.380	0.664	0.383	1.732
Americas	0.565	0.182	3.106	0.268	0.211	1.273
Asia	0.988	0.154	6.394	0.529	0.298	1.777
Europe	0.515	0.221	2.329	0.204	0.197	1.034
Oceania	0.760	0.260	2.927	0.285	0.356	0.800

Note: Decompositions of Equation 1.
Source: Authors' own calculations from RMIRO.

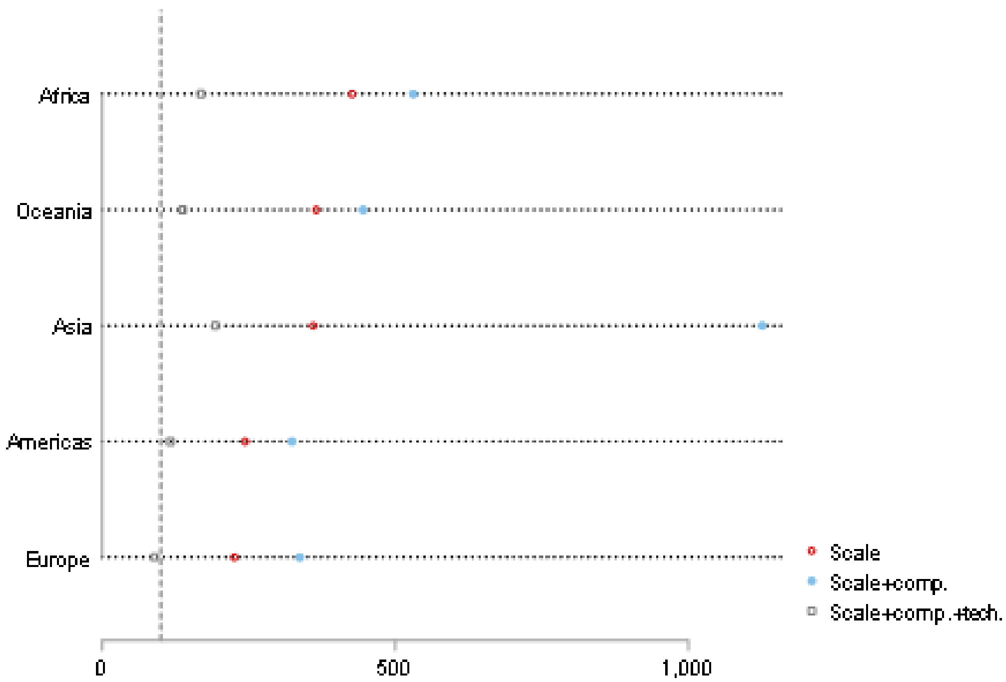
Total differentiation of (1) decomposes CO2 emissions growth, $\widehat{CO}$, between the two periods[12] into three components: growth (scale effect), $\hat{Y}$; change in energy intensity (composition effect where emissions intensities at the sector level are kept at their 1995 values), $\widehat{E_Y}$; and technique effect (change in the carbon intensity of output), $\widehat{C_E}$, i.e.,

$$\widehat{CO} = \hat{Y} + \widehat{E_Y} + \widehat{C_E} \tag{2}$$

Figure 3 applies the decomposition by region with regions sorted by decreasing GDP growth (hollow circle) over the period. If technique and composition effects across countries and sectors remained unchanged, this would represent emissions growth over the period. The filled blue circles show how emissions would have changed if composition and scale changed but techniques were unchanged. The horizontal distance between the hollow and blue circles represents how composition alone affected emissions. The huge positive composition effect for Asia reflects China's growth (about 10% per year on average). For all regions, the composition effect contributed to growth in emissions. The squares show how emissions actually changed. The technique effect, which is the difference between the (scale+ composition+ technique) effect and the (scale + composition) effect contributed to reduce emissions growth.[13]

Two patterns appear across regions. First, the scale effect is largest in the poorest regions, with no growth in Europe and the Americas (stylized fact #6 in Copeland et al.[2022]).[14] Second, for all regions except Asia, the technique effect is larger than the composition effect, a result that also corroborates stylized fact #9 of Copeland et al. (2022) observed at the country-level. This somewhat puzzling result according to Copeland et al. suggests that theories of the determination of international trade carry little weight in the overall contribution to the growth in CO2 emissions.[15]

Figure 3: Decomposition of emissions growth by region (Scale, composition, and technique effects)

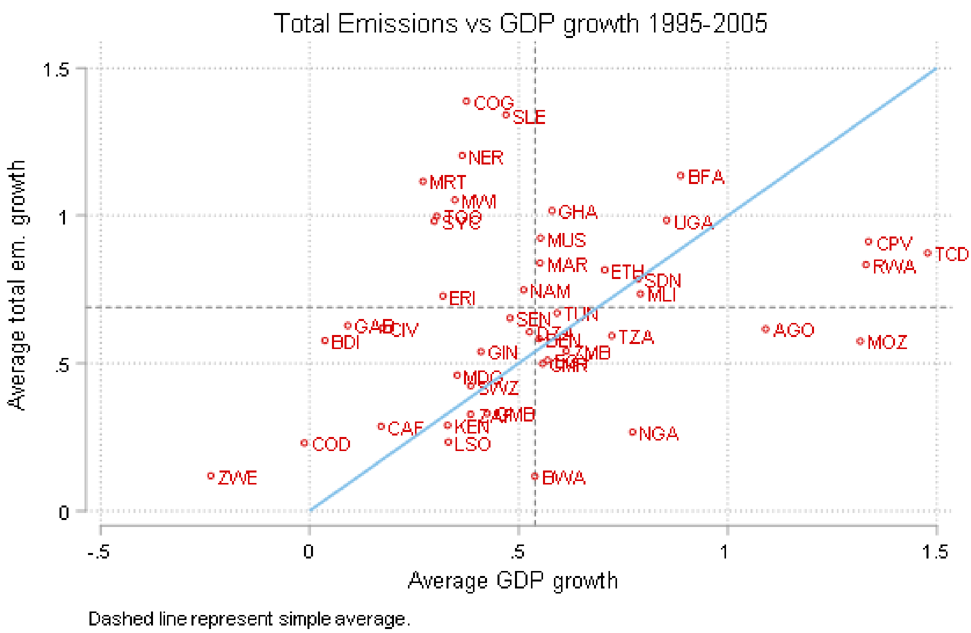


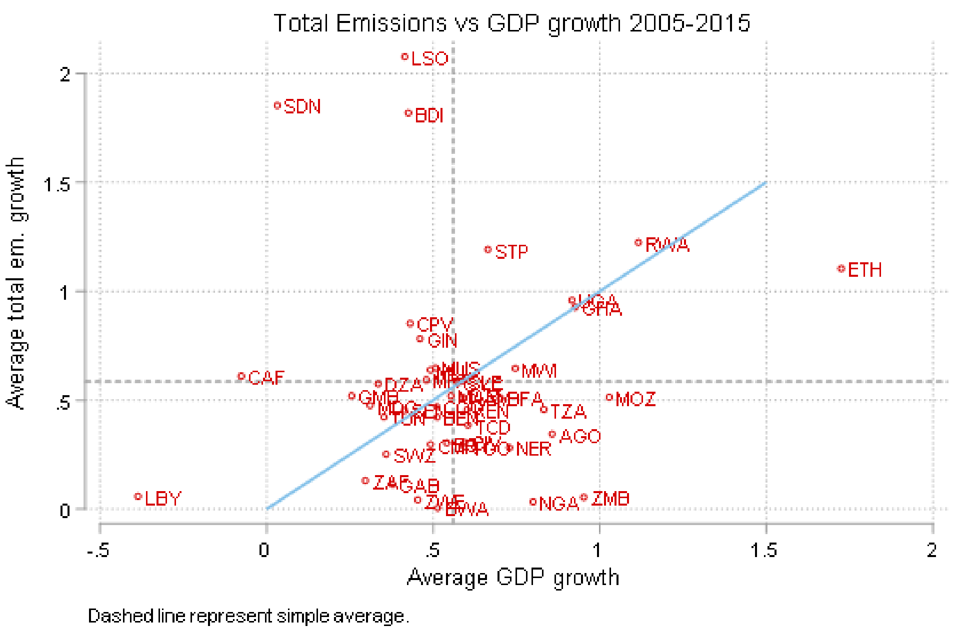
Note: Regions ranked by descending order of scale. Scale represents 100 times output in 2015 divided by output in 1995. Scale + composition modifies the scale value to keep technique (emission rate) constant for each (country*sector), i.e., as it was in 1995. Scale +composition + technique represent 100 times emissions in 2015 divided by emissions in 1995. Vertical line at "change in emissions" = 100 represents the value of no change in emissions between 1995 and 2015.

Emissions growth across Africa

Figure 4 plots decadal growth or CO2e emissions against decadal GDP growth rates for each African country. For most African countries, emissions growth exceeded GDP growth (points above the 45° line in Figure 4) over the period 1995–2005, that is, most African countries were still carbonizing, albeit at a slower rate during 2005–2015 when emissions and GDP were growing at about the same rate (average emission growth and average GDP growth intersected close to the 45° line).

Figure 4: Decadal growth rates: CO2e emissions vs. GDP across Africa



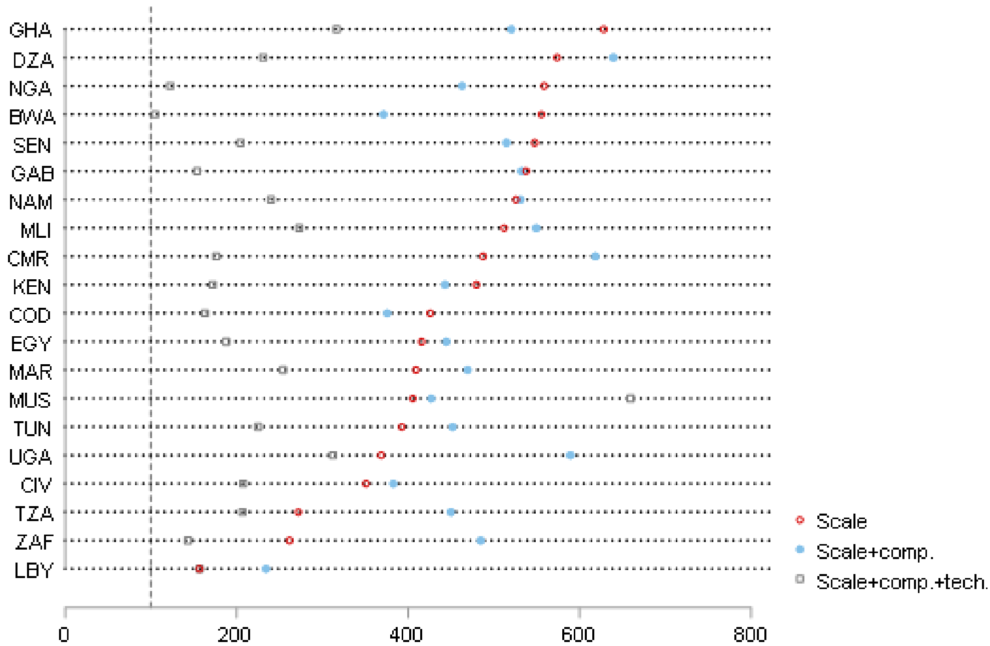


Notes: Values represent growth over the decade. Vertical and horizontal dashed lines indicate simple average growth rates for GDP and CO2 emissions, respectively, over the sample. Intersection of the two lines below (above) the 45° line indicates that average emissions are growing slower (i.e., decoupling) or faster (i.e., carbonizing) than average GDP. On average, Africa is carbonizing over both periods, but much less so over 2005–2015. ISO country codes in Table A1 (in the appendix).
Source: Authors' own estimates from RMRIO.

Some countries have switched status between the two decades. Ethiopia was carbonizing during 1995–2005, but decarbonizing during 2005–2015, the fast-growth decade. Ghana also switched from carbonizing to decarbonizing during the 20-year period. Lesotho switched from decarbonizing to carbonizing.

Figure 5 reproduces the decomposition of Figure 3 for the 20 African countries with the largest scale effects, ranked in descending scale order. This time, the composition effect is entirely within-country. From the figure, 12 of the 20 countries have shifted towards more CO2-intensive sectors, all but three in the bottom of the figure. For all countries except Mauritius, the technique effect contributed to reduce the growth of emissions. For many countries, the technique effect was large, although the difference with composition effects is generally smaller than those reported by Copeland et al. (2021: Figure 6). For all but four countries, the technique effect was larger than the composition effect, a confirmation of Copeland et al. (2021) stylized fact #9.[16] This result is noteworthy since RMRIO has a much larger number of sectors than EORA, which should contribute to larger composition effects.

Figure 5: Decomposition of emissions growth by country: 1995-2015 (Scale, composition, and technique effects)



Notes: The figure reports the 20 largest scale effects. Figure B1 (in the appendix) reports the decomposition for all African countries. Same presentation as in Figure 3 except that composition effects only apply to changes across sectors within countries. Countries ordered by descending scale values. Scale represents 100 times value-added in 2015 divided by GDP in 1995. Scale + composition modifies the scale value to keep technique (emission rate) constant for each country*sector as it was in 1995. Scale +composition + technique represent 100 times emissions in 2015 divided by emissions in 1995. Vertical line at "change in emissions" = 100 represents the value of no change in emissions between 1995 and 2015. Angola, Ethiopia, and Zambia excluded.
Source: Authors' own calculations inspired by Copeland et al. (2021: Figure 6).

Patterns 1: All regions have reduced emission intensities over the period 1995–2015. Africa's share of global CO2 emissions has remained constant over the period 2000–2015. Asia, already the region with the largest share of global emission in 2000, has strengthened its leading position. Europe and the Americas have reduced their share of emissions by nine and eight percentage points, respectively. Asia is decarbonizing; Africa not yet.

Patterns 2: Kaya decomposition. Carbon intensity of production has increased in Africa in both decades, though much less so over 2005–2015 when, on average, emissions grew less rapidly than population. Over half of the 20 African top emission growth emitters shifted towards more carbon-intensive techniques.

4. Emission intensity, direct and indirect

To get a more thorough view of the total carbon emission generated by production along supply chains, one must take into account both direct and indirect emissions. To do this, we use the MRIO table described above to compute indirect CO2 equivalent emissions, as is common in the literature (e.g., Shapiro, 2021; Copeland et al., 2021).

The CO2e emission matrix E_{is}^{direct} associated with RMRIO provides direct emission intensity for each country *i* and sector *s*. The total emission rate $E_{i,s}^{T}$ across sectors and countries is then given by:

$$E_{i,s}^{T} = \sum_{j,t} L_{ijst}\, E_{jt}^{direct} \tag{3}$$

Where: $L = (I - A)^{-1}$ is the Leontief inverse derived from the input-output matrix *A* where each row lists the industry supplying inputs and each column lists the industry demanding outputs. The *L* matrix used in Equation 3 is the same Leontief inverse used to calculate the measures of participation in GVCs (see Section 5 for details). Indirect emissions are calculated from (3) as the difference between the total and direct emissions:

$$E_{is}^{indirect} = E_{is}^{T} - E_{is}^{direct} \tag{4}$$

One must be careful when aggregating these values to avoid double counting for intermediate use. For example, emissions in the production of plastics should not also be included as emissions of vehicles that use plastics as an input. Indirect emissions $E_{is}^{indirect}$ account for emissions caused by the production of intermediates (from sector *j*, for example) that will be used to produce goods in sector *i*. When aggregating both sectors, summing respectively direct and indirect emission intensities *s* to obtain an aggregate emission will result in double counting of indirect emissions as part of the direct emissions generated by sector *j* also counted as indirect emissions in sector *i*. To circumvent this, only the indirect emissions of sectors outside the aggregate (country or region) are considered for the indirect emission of the aggregate.

This paper's scope covers the whole of Africa, the continent with the largest number of highly heterogeneous countries, economically (rich-poor, large-small) and geographically (landlocked, coastal, far away from trading routes and partners). Comparing Africa's emissions with those of other regions, which are often heterogeneous, can help in the design of environmental policies. Short of looking for comparators by sub-region or individual countries, an alternative is to construct a synthetic comparator. Nearest neighbour and propensity score matching methods are often used, but the entropy balancing method proposed by Hainmueller (2012) presents advantages and is easily implementable in STATA (see Hainmueller & Xu, 2013).

Given a set of characteristics to incorporate (here: per capita income, share of manufacturing in GDP, and distance to trading partners), entropy balancing chooses the set of comparator countries assigning them weights so that the sample moments (means, standard deviations, and skewness) minimize the difference between the covariate distributions of the selected characteristics for all African countries and the endogenously selected comparator group. Table 2 lists the 20 countries with the largest weights in the comparator group.

Table 2: Country weights in Africa comparator group

Country	Weight (share)	Country	Weight (share)
Iraq	0.128	Sri Lanka	0.0295
Yemen	0.0794	Myanmar	0.0235
Bolivia	0.0793	Afghanistan	0.0209
Bangladesh	0.0714	Paraguay	0.0201
Fiji	0.0608	Papua New Guinea	0.0197
Cambodia	0.0420	Laos	0.0179
Peru	0.0406	Samoa	0.0177
Pakistan	0.0397	Cuba	0.0173
Philippines	0.0371	Brazil	0.0166
Vietnam	0.0300	Armenia	0.0165

Notes: The table lists the 20 countries with the largest weights for 2015. Rankings and weights for 1995 are close to those for 2015. Complete list of 86 countries in Table A6 (in the appendix). High-income countries receive negligible weights. Source: Authors' own calculations.

The source of emissions by regions

Table 3 displays total CO2e emissions by region for 1995 and 2015 in the last two columns with the origin and destinations across regions in a matrix of shares. For both years, around 80% of emissions originate within each region, although the effect of offshoring of activity is apparent in the fall of intra-regional shares in all regions in 2015. Several patterns are apparent. First, embodied carbon in trade grew among all regions, albeit to a lesser extent in the Americas where the intra-regional share only fell four percentage points over the period. Second, the importance of Europe and, to a lesser extent, the Americas, sourcing their emissions from low-income regions, especially Asia (stylized fact #8 in Copeland et al., 2021). Between 1995 and

2015, Europe doubled its share of emission from Asia to (16.2%) mirrored by a sharp reduction in emissions sourced from within Europe. As to Africa, the share of CO2e emissions originating from Asia rose from 4% to 11% over the 20-year period but stayed flat for Europe. Africa's exports of CO2e emissions are low with the highest share destined to Europe.

Table 3: CO2e emissions and intensities by source

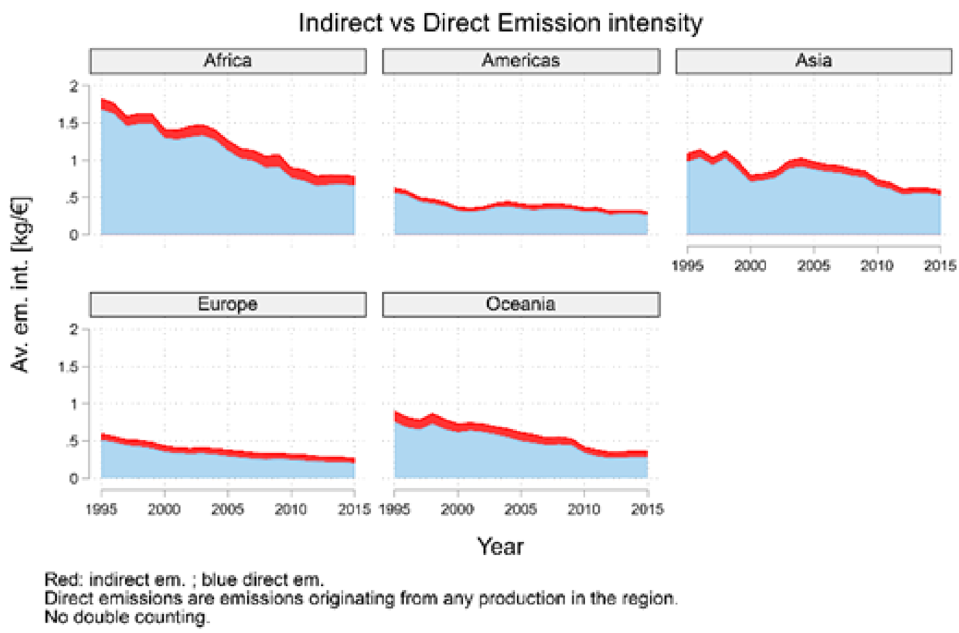
(a)1995							
Destination	**Source**						
	Africa (Share)	**Americas (Share)**	**Asia (Share)**	**Europe (Share)**	**Oceania (Share)**	**CO2e (kg)[a]**	**Intensity (kg/€)[b]**
Africa	0.917	0.010	0.039	0.029	0.003	1.41·1012	1.835
Americas	0.012	0.891	0.054	0.038	0.003	8.90·1012	0.634
Asia	0.011	0.035	0.898	0.045	0.009	1.44·1013	1.100
Europe	0.019	0.035	0.083	0.858	0.003	8.40·1012	0.599
Oceania	0.003	0.028	0.098	0.030	0.837	6.25·1011	0.908
(b)2015							
Destination	**Source**						
	Africa (Share)	**Americas (Share)**	**Asia (Share)**	**Europe (Share)**	**Oceania (Share)**	**CO2e (kg)[a]**	**Intensity (kg/€)[b]**
Africa	0.843	0.014	0.109	0.031	0.002	2.58·1012	0.788
Americas	0.010	0.849	0.104	0.032	0.003	1.08·1013	0.316
Asia	0.017	0.041	0.882	0.047	0.013	2.83·1013	0.600
Europe	0.037	0.050	0.162	0.745	0.004	8.62·1012	0.273
Oceania	0.013	0.025	0.149	0.027	0.786	9.13·1011	0.363

Notes: Share of direct (within region) emissions in grey. Numbers rounded to three decimals. Rows sum to 1.
[a]/ from Figure 2; [b]/ from Figure 6. In 2015, Africa sources 10.9% of its emissions from Asia and 3.1% from Europe. Europe sources 3.7% of its emissions from Africa. Last two columns show total emissions and total emission intensity.
Source: Authors' own calculations from RMRIO estimations.

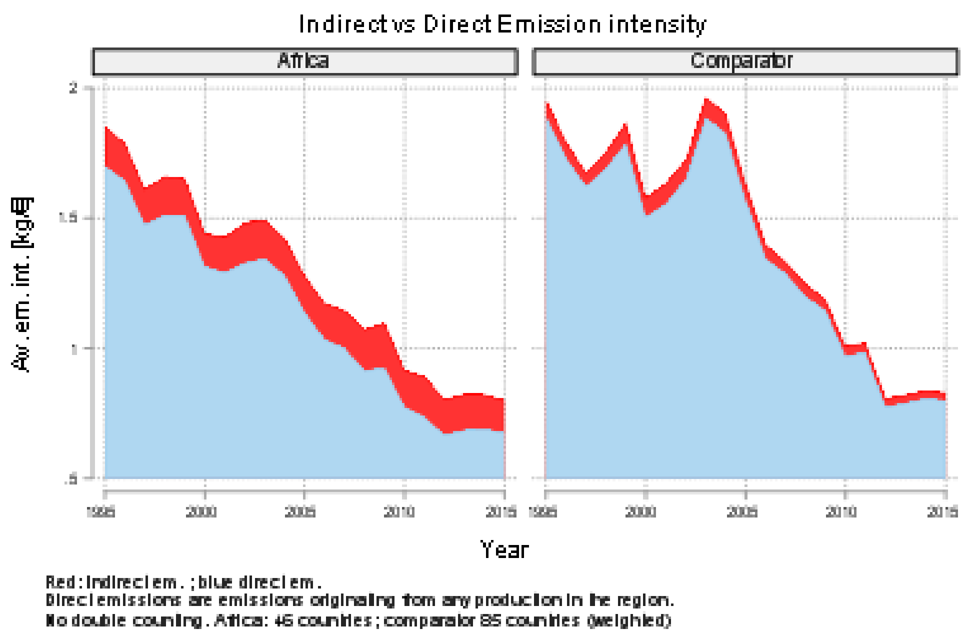
Emissions intensities: Direct and indirect

Figure 6(a) displays direct and indirect CO2e (i.e., CO2e originating from another region than the one under scrutiny) by regions. Four patterns stand out. First, the Africa region stands apart with the highest average total CO2e emissions intensities. Second, there is a downward trend in emissions intensities across all regions over the period 1995–2015. Third, in spite of a reduction, emission intensities remain highest in the Africa and Asia regions. Fourth, indirect emission intensities appear to be lower for Europe and the Americas. For the seven countries in Oceania, the small size of eight economies and no resource extraction contribute to low emissions; while for New Zealand and Australia, geographic distance from many trade partners represent an obstacle to GVC participation.

Figure 6: Trends in CO2e emissions intensities (direct and indirect)
(a) By region



(b) Africa and synthetic comparator



Notes: Gross output weighted country average in each region.
Source: Authors' own calculations from RMRIO.

Turning to the synthetic comparator presented on figure 6(b), two facts emerges. First, the comparator, built to match more closely the composition of African economies in terms of the three structural indicators (per capita income, the share of manufacturing in GDP, and distance from trading partners), follows more closely the trajectory of intensities than the other regions. This is not surprising since the other regions include several high-income countries with more environmental policies that weigh heavily in the regional average intensities. The closeness in trajectories is also evidence that a few characteristics are good indicators of emission intensities. Second, the total CO2e emissions (represented by the sum of the blue and red areas) are at times higher than CO2e emissions in Africa, suggesting that the high level of emission intensities exhibited by African economies is closely correlated with their intrinsic characteristics. Note that the lower level of indirect emissions displayed by the comparator is mostly due to the way indirect emissions are constructed. To avoid double counting, we consider as indirect emissions only emissions coming from outside of the aggregate under scrutiny. As our synthetic comparator comprises more than 80 countries, it will mechanically have less indirect emissions than the other aggregates presented in Figure 6.

Heterogeneity in sector-level emission intensities

The large granularity in the RMRIO database also invites for emission comparisons across sectors. One must keep in mind, however, that especially for Africa, even at the level of aggregation in EORA, there are large discrepancies in calculated multipliers across countries with those reported in other MRIO like TiVA. This must be kept in mind especially when the focus is on Africa where not a single country disposes of an IO table for one year.[17] Here, we ask three questions: (i) are the patterns of clean and dirty sectors (direct and indirect) the same across regions and, especially across countries in Africa; (ii) are dirty sectors more exposed to trade than clean sectors; (iii) are dirty sectors more upstream, and if so, across countries. To narrow the comparison, only the five dirtiest and cleanest sectors are evaluated. Note that the selection of sectors will not be the same across regions (and countries within Africa), in part because of differences in aggregate emission rates at the country-level.

As a prelude, Table 4 shows a very high Spearman rank correlation of sector's direct emission intensities across regions, especially between Europe, the Americas, and Asia. For the correlation coefficient of Africa's emission intensities with those in other regions, it varies between 0.68 (with Americas and Asia) and 0.8 (with Oceania). The average correlation of about 0.71 is high.[18] Regional correlation of total CO2e emissions intensities (in parenthesis in Table 4) exhibit similar patterns with slightly lower correlation on average for total than for direct emissions, an indication that intermediate purchases rarely change overall rankings. Oceania stands out in this respect as its correlation coefficient on total emissions are usually larger than those on direct emissions.

Table 4: Spearman rank correlation of emission intensities across regions

	Spearman Correlation of Direct (Total) CO2e Emission Intensities Across Regions				
	Africa	**Americas**	**Asia**	**Europe**	**Oceania**
Africa	1.00 (1.00)				
Americas	0.68 (0.68)	1.00 (1.00)			
Asia	0.68 (0.70)	0.82 (0.71)	1.00 (1.00)		
Europe	0.70 (0.58)	0.81 (0.75)	0.81 (0.68)	1.00 (1.00)	
Oceania	0.80 (0.73)	0.66 (0.72)	0.62 (0.65)	0.69 (0.71)	1.00 (1.00)

Note: Regional correlation of total CO2e emissions intensities in parenthesis.
Source: Authors' own construction from RMRIO data.

Table 5: Cleanest and dirtiest sectors by region

Sector	Total CO2e int.	Direct CO2e int.	Share of Direct	Share of Output	Upstream.
Africa					
Manufacture of wood	0.248	0.00774	0.0312	0.0209	2.073
Manufacture of beverages	0.407	0.0228	0.0560	0.0156	1.964
Production of meat products	0.417	0.0739	0.177	0.0523	1.566
Publishing, printing	0.489	0.0104	0.0213	0.0207	1.526
Processing vegetable oils	0.630	0.0955	0.152	0.0115	1.922
Manufacture of precision instruments	4.101	3.424	0.835	0.0172	1.172
Processing of dairy products	4.646	0.0312	0.00672	0.0148	1.431
Manufacture of rubber /plastic	4.934	2.495	0.506	0.0251	2.128
Processing of meat cattle	5.570	0.0566	0.0102	0.0327	1.580
Plastics, basic	16.81	0.377	0.0224	0.0123	2.648
Americas					
Publishing, printing	0.167	0.0379	0.227	0.0374	1.909
Manufacture of radio equip.	0.292	0.0226	0.0775	0.0409	1.791
Manufacture of computers	0.300	0.00970	0.0323	0.0160	1.287
Manufacture of other transport equipment	0.348	0.0291	0.0835	0.0379	1.694
Manufacture of electrical machinery	0.357	0.00605	0.0169	0.0255	1.926
Petroleum Refinery	1.333	0.494	0.371	0.0878	1.731
Re-processing of secondary steel	1.336	0.350	0.262	0.0104	3.033
Processing of dairy products	1.533	0.0222	0.0145	0.0174	1.474
Manufacture of basic iron and steel	1.535	0.886	0.577	0.0156	2.877
Processing of meat cattle	7.012	0.0639	0.00911	0.0126	1.453

continued next page

Table 5 Continued

Sector	Total CO2e int.	Direct CO2e int.	Share of Direct	Share of Output	Upstream.
Asia					
Copper production	0.507	0.123	0.242	0.0102	3.053
Processing of food products	0.603	0.0326	0.0540	0.0428	1.832
Publishing, printing	0.764	0.0218	0.0286	0.0178	2.918
Manufacture of radio equip.	0.832	0.0307	0.0369	0.0591	2.341
Manufacture of computers	0.843	0.0200	0.0237	0.0280	2.376
Manufacture of ceramic goods	1.973	0.243	0.123	0.0144	2.263
Manufacture of rubber /plastic	1.985	0.759	0.382	0.0395	3.066
Re-processing of secondary steel	2.541	0.558	0.219	0.0130	3.495
Manufacture of basic iron and steel	3.131	1.541	0.492	0.0614	3.549
Manufacture of non-metallic mineral	3.964	1.475	0.372	0.0124	2.889
Europe					
Publishing, printing	0.195	0.0468	0.240	0.0388	2.179
Manufacture of precision instruments	0.234	0.0471	0.202	0.0340	1.780
Manufacture of radio equip.	0.321	0.0380	0.118	0.0270	1.846
Manufacture of electrical machinery	0.324	0.0144	0.0445	0.0511	2.357
Manufacture of machinery	0.329	0.0164	0.0499	0.0881	1.840
Processing of dairy products	1.047	0.0398	0.0381	0.0203	1.726
Petroleum refinery	1.500	0.396	0.264	0.0512	2.161
Re-processing of secondary steel	1.533	0.898	0.586	0.0106	3.125
Manufacture of basic iron and steel	1.592	1.007	0.632	0.0187	3.119
Manufacture of cement	2.340	1.911	0.817	0.0128	2.567
Oceania					
Production of meat products	0.120	0.0202	0.168	0.0465	1.871
Publishing, printing	0.169	0.0535	0.317	0.0525	2.060
Precious metals production	0.172	0.157	0.912	0.0503	3.064
Manufacture of electrical machinery	0.284	0.00649	0.0228	0.0139	2.221
Manufacture of textiles	0.302	0.0412	0.136	0.0105	2.231
Processing of dairy products	0.869	0.0337	0.0388	0.0346	1.738
Manufacture of basic iron and steel	1.241	0.480	0.387	0.0292	2.993
Petroleum refinery	1.454	0.421	0.290	0.0457	1.906
Manufacture of cement	2.269	1.687	0.743	0.0192	2.860
Processing of meat cattle	5.067	0.0327	0.00645	0.0354	1.852

Notes: White background=five most polluting sectors; dark background=five least polluting sectors.
Source: Authors' own calculations from RMRIO.

Table 5 presents the five most (white background) and five least (dark background) polluting sectors in each regional aggregate by total emission intensity. None of these sectors account for more than 8.8% of total output. With five regions and ten sectors per region, if there were no overlap across regions in each category, the rankings would show 50 different sectors. Table 5 only displays 25 different sectors, among which 11 of those appear more than once in the ranking. For example, "Publishing, printing" appears as a low emission sector in all aggregates; "Manufacture of basic iron and steel" appears as a high emitting sector in all regions but Africa, and "Processing of dairy products" is among the top five emitters in all aggregates but Asia. There are also some sharp differences in rankings. The sector "Manufacture of precision instruments" is classified as high emitting in Africa (total emissions intensity: 4.1), but it appears as a low emitting sector in Europe (total emissions intensity: 0.234). Taking into account that the share of direct emissions in the total is high for this sector (20% for Europe and 83% for Africa), this suggests a large difference in technology between the two regions.

In a much smaller sample including only 35 sectors, Copeland et al. (2021) show that the dirtiest industries are generally more upstream than the cleanest. We find similar patterns for Americas (average upstreamness 2.11 for the dirtiest industries versus 1.72 for the cleanest), Asia (3.05 vs 2.50), Europe (2.53 vs 2.00) but not for Oceania (2.27 vs 2.29) and Africa (1.79 vs. 1.81). The average of the cleanest sector across regions exhibit a bit of variation, Asia and Africa seeing the highest values (0.71 and 0.44 kg/€, respectively). Looking at the average emissions of the most polluting sectors exhibits greater discrepancies. Africa's top five emitters exhibit an average of 7.21 kg/€, all the other regions showing averages between 1.6 and 2.7 kg/€.

Table B1 (in the appendix) displays the cleanest and dirtiest sectors for the five largest African economies (Algeria, Egypt, Morocco, Nigeria, and South Africa). The share of output of a single sector is now much larger compared to Table 5, reaching, for example, 16.3% for "Public administration and defence", one of the least polluting sector in Nigeria. Sectors also exhibit a greater variability with less sectors appearing more than once in the ranking. "Construction" and "Real estate" both appear, respectively, as dirtiest and cleanest sectors in all countries but South Africa. Dirtiest sectors are more upstream (see definition of OU upstream in Equation 5a) than clean sectors for Egypt, Nigeria, and Algeria, but not for Morocco and South Africa.

Patterns 3: Over 1995–2015, intra-regional shares of emissions fell by 7, 10, and 2 percentage points to 84%, 75%, and 88% for Africa, Europe, and Asia, respectively. Africa's share of emissions originating from Asia rose from 4% to 11%. Europe's share of emissions originating from Africa and Asia rose from 2% and 8% to 4% and 16%, respectively.

Patterns 4: The Spearman rank correlation of emissions across regions over 163 sectors is high around 0.7. Almost half of top five cleanest and dirtiest sectors are the same across regions, but there are some sharp differences in rankings for some of the highest emitter sectors. In general, dirtiest sectors are more upstream.

5. CO2e emissions along supply chains

Supply chains are mostly analysed in terms of positioning measures along output supply chains which measure the distance of industries selling their output to other sectors or final consumers. A complete picture of the entire production process also requires measures of the input demand chains of firms, that is, of how far industries are of primary factors of production. The distinction between what Miller and Termushoev (2017) call OU (for 'output upstreamness') and ID (for 'input downstreamness') is important because, for the same producer in an industry, the structure of output sales is different from that of input purchases. We present briefly the OU and ID measures and their relation before comparing them across regions and countries to see where African countries stand in supply chains.

Measures of GVC participation

We use two measures, upstreamness (Antràs & Chor, 2019) that measures how far the sector under scrutiny is from final demand, and downstreamness (Miller & Termushoev, 2017) measuring the distance from primary inputs.

To capture the average position of each country-industry in the global production chain, one must account to what extent each country-industry pair in the chain is sold directly to consumers or to other industries in other countries. Antràs and Chor (2019Equation 5, define the upstreamness measure OU_i^r:

$$OU_i^r = \mathbf{1}\frac{F_i^r}{Y_i^r} + \mathbf{2}\frac{\sum_{s=1}^{S}\sum_{c=1}^{C} a_{ic}^{rs} F_c^s}{Y_i^r} + \mathbf{3}\frac{\sum_{s=1}^{S}\sum_{c=1}^{C}\sum_{t=1}^{S}\sum_{d=1}^{C} a_{ic}^{rs} a_{id}^{st} F_d^t}{Y_i^r} + \cdots \quad \text{(5a)}$$

Where: Y_i^r is the gross output of sector *r* in country *i*; F_i^r is the final consumption flow of sector *r* in country *i*; is the monetary amount of sector *r*'s output from country *i* needed to produce one dollar worth of industry *r*'s output in sector *s* in country *j*; *C* is the number of countries (183 in RMRIO); and *S* the total number of sectors (163).

If, plausibly, the input-output matrices are viable (i.e., satisfy the Hawkins-Simon (1949) conditions that the sum of intermediate demands on a sector do not exceed its gross output), and the stacked column of gross output satisfies $Y = [I - A]^{-1}F$, then upstreamness for sector *r* in country *i* is given in matrix form by:

$$OU = [I - A]^{-1}Y \tag{5b}$$

Each term in (5a) evaluates what share of the total output of *Y* is reaching the final demand *F* at each step of the chain, weighted by the position in the chain. The lowest value OU_i^r can take is 1 when $Y_i^r = F_i^r$ (i.e, when all output reaches final demand). The higher the value of OU_i^r, the more upstream sector *r* in country *i* is. Note that a high value of OU_i^r may mean two things: (a) a large share of gross output are intermediates, (b) the value chain is more complex.

Downstreamness, proposed by Miller and Termushoev (2017), captures the positioning of production processes in the entire production chain across countries. As above for upstreamness, to capture the average downstreamness of sector *r* in country *i*, one must measure how distant the sector is from primary inputs considering heterogeneity across the supply chain. The corresponding measure is:

$$ID_i^r = \mathbf{1}\frac{VA_i^r}{Y_i^r} + \mathbf{2}\frac{\sum_{s=1}^{S}\sum_{c=1}^{C} b_{ic}^{rs} VA_c^s}{Y_i^r} + \mathbf{3}\frac{\sum_{s=1}^{S}\sum_{c=1}^{C}\sum_{t=1}^{S}\sum_{d=1}^{C} b_{ic}^{rs} b_{id}^{st} VA_d^t}{Y_i^r} + \cdots \tag{6a}$$

Where: VA_i^r is value-added of industry r in country i; b_{ij}^{rs} is the monetary amount of sector *r*'s output from country *i* needed to produce one dollar worth of industry *r*'s output in country *j*. As for the upstreamness indicator, the ID's numerator can be expressed in matrix form by the formula by $[I - B]^{-2}F$ where $[I - B]^{-1}$ is the Ghosh (1958inverse. Miller and Termushoev (2017) show that, the ID measure can also be derived from the Leontief matrix itself using the formula[19]:

$$ID' = \iota' L \tag{6b}$$

where ι is a column vector of ones.

Miller and Termushoev (2017) show that taking the gross output-weighted average of all two *ID* and *OU* measures—in effect reducing the world economy to a single country-sector system—delivers the same average aggregate positioning numbers.[20] However, for a given country-sector pair U and D need not be equal because of compositional effects across countries.

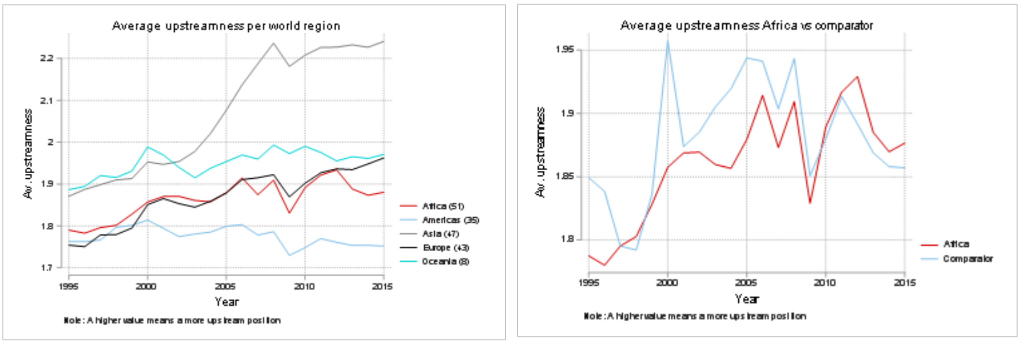
Together, OU and ID capture part of important characteristics of a value chain. The ratio OU/ID gives an indication on the position of the sector in the value chain. A value larger than one indicates a more upstream position, and conversely. In sum, rising values of OU and ID are compatible with expanding supply chain trade.

Value chain positioning

Figure 7(a) shows the evolution over time of the upstreamness (OU) indicator described above for all regions. All, except the Americas, exhibit an increase in upstreamness between 1995 and 2015. The magnitude of this increase is, however, very heterogeneous. Asia sees the largest increase moving from a value below 1.9 to the largest upstreamness among regions, slightly above 2.2. Africa's increase is more modest, from 1.8 to about 1.9.

Figure 7: Evolution of upstreamness (OU/ID) over time

(a) All regions (b) Africa vs. Synthetic comparator



Notes: A value less than (greater than) 1 for OU/ID indicate a more downstream (upstream) position.
Source: Authors' own estimates.

The evolution over time of the ID indicator (see Figure B2 in appendix) shows a similar pattern to the one for OU in Figure 7(a), indicating a positive correlation between OU and ID. Asia also registers the largest increase in the ID indicator between 1995 and 2015 with a magnitude similar to the one observed for OU in figure 12. As for OU, the Americas are the only region experiencing a decline in ID. This pattern (see, for example, Antràs & Chor, 2019), Miller & Termushoev, 2017) stems from OU and ID capturing other characteristics of the value chain than the position (length and complexity, for example). Taking the ratio of both indicators, OU/ID gives a more accurate estimate of a sector in the supply chain. A value less than (greater than) 1 for OU/ID indicate a more downstream (upstream) position.

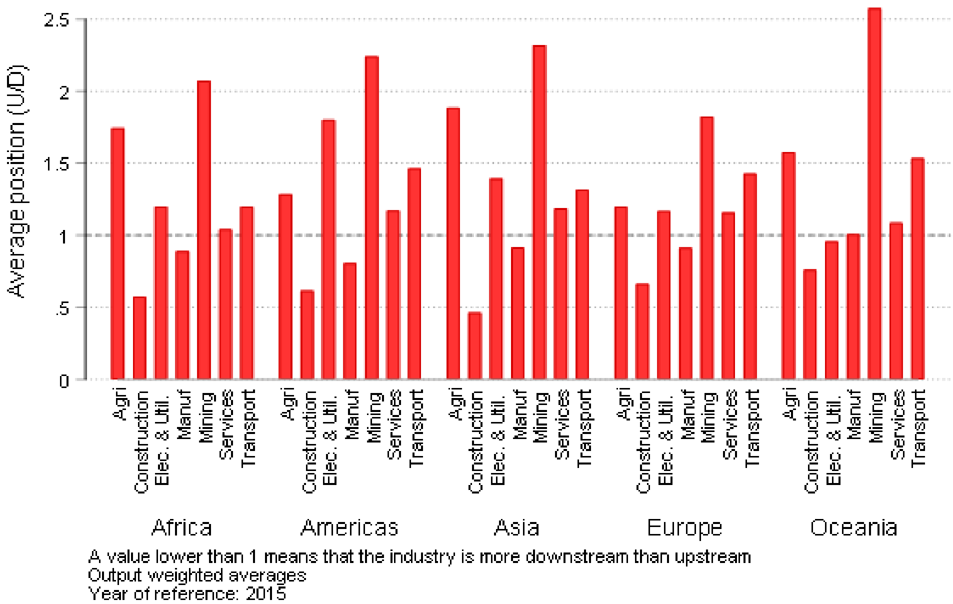
Figure 7(b) comparing Africa with the synthetic comparator shows that the comparator again matches more closely Africa than any other aggregates in Figure 7(a). Once again suggesting that inter regional discrepancies highlighted by Figure 7(a) are mostly arising because of some particular characteristics of African economies.

Figure 8(a) shows OU/ID ratios for seven broadly aggregated sectors as defined in EXIOBASE. The similarities across regions are strong with quasi identical rankings. Mining is the most upstream sector for all regions followed by Agriculture; Electricity and Utilities, Services, and Transports. The two remaining sectors, Manufactures, and

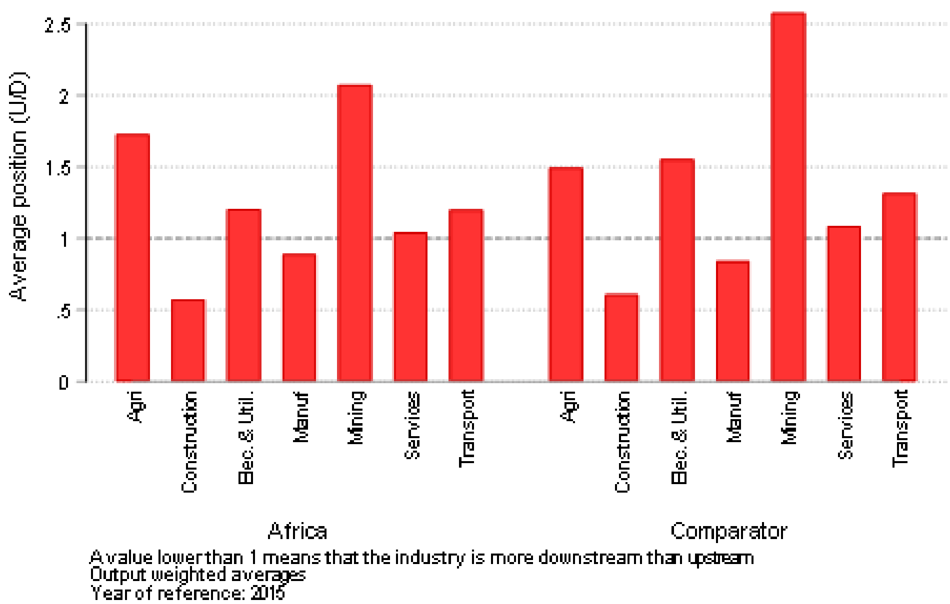
Construction, are downstream for all regions. Figure 8(b) shows the same comparison between the comparator and Africa. As with inter-regional comparisons, both graphs display similar patterns.

Figure 8: Position of sectors in regional supply chains

(a) Across regions



(b) Africa and synthetic comparator



Source: Authors' own calculations from RMRIO data.

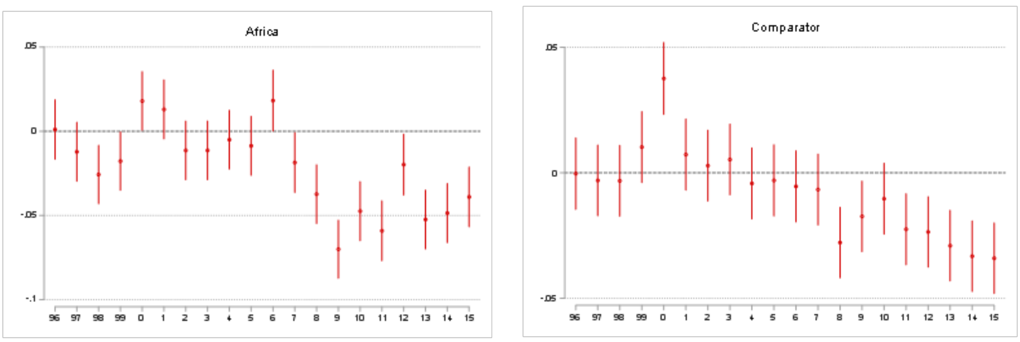
Regressing the OU/ID indicator on a time trend gives an estimate of the evolution of the indicator

$$\left(\frac{OU}{ID}\right)_{ist} = \alpha + \gamma_t + \mu_{ist} \quad (7)$$

Where: *i* is the index country, *s* is the sector, and *t* is the years. γ_t is a time fixed effect. Equation 7 is estimated for all regions and the seven sectors reported in Figure 8. Figure 9 present the evolution of the time fixed effect for Africa and the comparator group. Year 1995 serves as a reference so each coefficient should, therefore, be interpreted as a departure from 1995 base level. Ninety per cent confidence intervals are represented on the graph.

For Africa, first we see that the average position does not change significantly before 2008, except for small deviations between 1998 and 2000. The year 2008 see sectors moving downstream by a large value (average OU/ID in Africa in 2008 is about 1), and then slowly increase from 2010.[21] The comparator groups display a similar, though smoother general pattern, but differ in a few points. First, the increase seen in 2000 is of a much larger magnitude than for Africa; second, the decrease since 2008 is less and does not exhibit the rebound experienced by Africa at the end of the sample period.[22]

Figure 9: Evolution of upstreamness



Note: The figure is a plot of the time fixed effect γ_t in Equation 7.
Source: Authors' own estimates.

Pattern 5: Downstreamness is increasing over time. Output upstreamness (OU) from final consumption and input downstreamness (ID) from primary factors are needed jointly to indicate a sector's position in a supply chain. At a 7-sector aggregation level, Mining is the most upstream sector for all regions followed by Agriculture; Electricity and Utilities, Services, and Transports are the upstream broad sectors in all regions. Manufactures and Construction are downstream for all regions.

6. Correlates of emissions intensity and GVC positioning

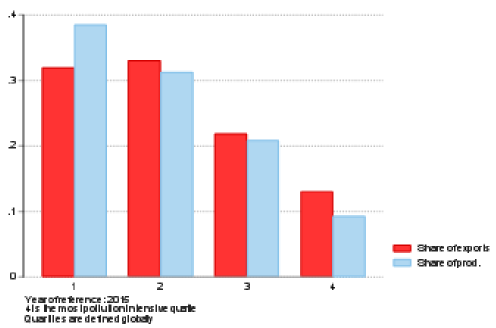
The composition of regions is highly heterogeneous. To explore patterns across regions (and across aggregated sectors within regions), we correlate emissions with export shares and indicators of participation in supply chains, starting with the emission intensity of exports across regions.

Emission intensity of export baskets

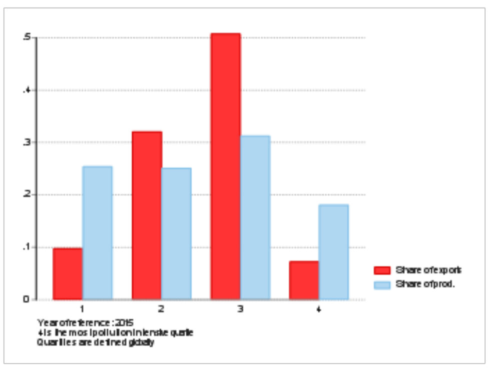
Figure 10 shows the distribution of production and exports for Africa and Asia for 2015, the two regions with the highest CO2e intensities in Figure 2 for both 1995 and 2015. Figure 10 shows quartile (about 40 sectors per quartile) ranked by increasing CO2e intensities. For Africa, both distributions are left skewed at this relatively high level of disaggregation (163 sectors), an indication that exports and production are concentrated. For Asia, about half of exports are in the third quartile of emission intensities; while for Africa, about 60% of exports are in the two lowest quartiles. The share of CO2e intensive exports in the most emission-intensive production quartile is much lower in Asia than in Africa.

Figure 10: CO2e emission intensities of exports and production: Africa and Asia (By quartile of total emission intensities)

Africa



Asia



Source: Authors' own estimates.

Equation 8 correlates direct emission intensities with export shares for the world, and separately for each region:

$$lnCO2e_{i,j} = \gamma_k + \beta \log(XS_{i,j}) + \epsilon_{ij}\,; \;\; k = 1,\cdots,5; \;\; i = 1,\cdots 183, j = 1,\cdots 163 \qquad (8)$$

Where: i indexes country; j the sectors; and γ_k is a dummy variable for each region. Table 6 displays the results for the world, and separately for each region.

Table 6: CO2e direct emission intensities of exports, 2015

	Log (Direct Em. Intensity)					
	(1)	(2)	(3)	(4)	(5)	(6)
	World	Africa	Asia	Americas	Europe	Oceania
Log(export share)	-0.0815***	0.0722***	-0.0851***	-0.152***	-0.0980***	-0.157***
	(0.00842)	(0.0268)	(0.0158)	(0.0137)	(0.0161)	(0.0320)
Constant	-2.950***	-1.887***	-2.707***	-3.566***	-3.219***	-3.972***
	(0.0562)	(0.167)	(0.108)	(0.0962)	(0.117)	(0.207)
R^2	0.132	0.0732	0.142	0.246	0.134	0.0779
FE	Country	Country	Country	Country	Country	Country
Obs.	22644	5918	6187	5362	4249	928

Notes: Cross section for year: 2015. Robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: Authors' own estimations.

Table 6 confirms the patterns in Figure 10 where exports are concentrated in the most pollution-intensive production quartile. Africa stands out as the only region where export shares and CO2e direct emission intensities are positively significantly associated: an increase in the share of exports of 1% is associated with an increase of direct emissions of 7.2%. For other regions, the correlation between export shares and emissions growth is negative, showing that exports are not concentrated in the pollution-intensive sectors in part because they outsource pollution intensive activities. These patterns are consistent with Africa being the most upstream region as it exports mostly intermediates undergoing further transformation in recipient countries. It is also consistent with high-income countries outsourcing the most pollution-intensive activities in supply chains to low-income countries.

Emission intensities along GVCs

To investigate the link between CO2e emissions and GVC participation, we correlate emission intensities with per capita GDP, the position of sectors and estimate the following model:

$$\log(Em\_int_{ist}) = \alpha + \beta \log(GVC\_pos_{ist}) + \delta GDP\_pc_{it} + \gamma_i + \gamma_t + \mu_{ist} \qquad (9)$$

Where: s indexes sectors, i countries, t years, and Em_int_{ist} is the direct emission intensity. Direct emission intensity is selected over total emission intensity because, by construction, total emissions are positively impacted by GVC participation. GDP_pc_{it} is GDP per capita for country i in year t. GVC_pos_{ist} is a measure of GVC position. γ_i and γ_t are country and time fixed effects, respectively.

Table 7 reports the results. Columns (1)–(3) report those for African economies only, while columns (4)–(6) report results for the rest of the world (excluding Africa). The fit is stronger for the RoW estimates, notably with the expected negative significant coefficient for GDP per capita. Insofar as per capita income is a proxy for environmental policies curtailing CO2 emissions, the non-significant GDPpc coefficient for Africa would be suggestive that Africa has not yet engaged in environmental policies. Perhaps more plausibly, this could be due to the set of fixed effects (country and year) capturing the influence of GDPpc. Estimating the model without the fixed effects returns the expected negative and significant coefficient on GDP per capita without altering significantly the magnitude and significance of our measure of position, at least for Africa.[23]

Table 7: CO2e emission intensity and GVC position: Africa and the RoW

	(1)	(2)	(3)	(4)	(5)	(6)
	Africa			RoW		
	Log(CO2e)	Log(CO2e)	Log(CO2e)	Log(CO2e)	Log(CO2e)	Log(CO2e)
Log(Upstream.)	1.541***			1.265***		
	(0.0266)			(0.0147)		
Log(Downstr.)		0.973***			1.078***	
		(0.0192)			(0.0104)	
Log(OU/ID)			-0.220***			-0.316***
			(0.0154)			(0.00901)
Log(GDPpc)	0.0670	0.0674	-0.00257	-0.521***	-0.522***	-0.570***
	(0.0768)	(0.0767)	(0.0774)	(0.0361)	(0.0357)	(0.0363)
Constant	10.02***	10.21***	11.41***	15.70***	15.80***	17.01***
	(0.548)	(0.548)	(0.552)	(0.326)	(0.323)	(0.328)
Observations	113845	113861	113845	319072	319099	319072
FE	Country, year	Country, year	Country, year	Country, year	Country, year	Country, year
Adjusted R2	0.083	0.082	0.064	0.165	0.175	0.150

Notes: Direct CO2e emissions. Robust standard errors are in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01
Source: Authors' own estimations.

At this level of aggregation, OU (upstreamness) (column 1 and column 4) is associated with higher emission intensities for both Africa and RoW, though more strongly for Africa (again perhaps an indication of differences in the stringency of environmental policies). Defining OU as in this paper, Copeland et al. (2021) also estimate that more upstream industries are more pollution-intensive.[24] We also report that the ID (downstreamness) correlation (column 2 and column 5) goes in the same direction, though the magnitude is lower than for OU. That OU and ID are positively correlated is well-established in smaller samples (see Section 4, Antràs & Chor 2019 Miller & Timurshoev, 2012). Hence it is not surprising, but comforting, to observe a similar correlation for both measures in this larger sample.

To disentangle the effect of OU and ID, we use once again the "position" indicator (OU/ID) introduced above. Results in column (3) and column (6) show a negative and statistically significant sign, suggesting that being 1% more upstream on the position indicator decreases CO2e emissions intensity by about 0.22% for Africa (0.32% for RoW). This is coherent with the patterns highlighted earlier showing that: (a) CO2e emission intensity decreases over time, and (b) in recent years, Africa tended to move more upstream.[25]

The results in Table 7 are mute on the heterogeneity likely to arise across broad sector groups. Table 8 reports the results for Africa and RoW for the seven sectors using the OU/ID as indicator of the position in the value chain. As expected, the fit is much stronger for the sector-level estimates in Table 8. For Africa, the GDPpc coefficient has now the expected negative sign except for manufactures where it is not significant, and services where it is positive.

Table 8: Impact of GVC position on CO2e emission intensity: Africa

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Agri.	**Construct.**	**Electricity & Utility**	**Manuf.**	**Mining**	**Services**	**Transport**
	Log (CO2e)	**log (CO2e)**	**Log (CO2e)**	**Log (CO2e)**	**Log (CO2e)**	**Log (CO2e)**	**Log (CO2e)**
Log(OU/ID)	-1.880***	-1.740***	-0.303**	0.476***	-0.510***	-1.403***	-1.390***
	(0.0288)	(0.0890)	(0.130)	(0.0293)	(0.0536)	(0.0355)	(0.0213)
Log(GDPpc)	-0.201*	-0.229**	-0.799**	-0.174	-0.326**	0.540***	-0.562***
	(0.121)	(0.0929)	(0.342)	(0.109)	(0.159)	(0.179)	(0.101)
Constant	15.59***	12.63***	18.18***	12.49***	13.94***	6.171***	16.83***
	(0.853)	(0.677)	(2.482)	(0.785)	(1.144)	(1.294)	(0.725)
Observations	12329	917	7082	41665	10518	29920	5049
FE	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector
Adjusted R2	0.461	0.969	0.074	0.169	0.468	0.122	0.657

Notes: The figure reports direct CO2e emissions. Robust standard errors are in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01
Source: Authors' own estimations.

As for the country-level estimates, CO2e emission are negatively correlated with OU/ID, for all broad sectors but for Manufactures. For Manufactures, being more upstream by 1% is associated with higher emissions intensity by 0.476%. For the other sectors, the relationship is negative and larger for Agriculture and Construction, and smaller for Mining.

Patterns are similar for the comparator group: CO2e emission intensity decreases with a more upstream position for all broad sectors but Manufactures. Results are reported in Table B2 (in the appendix). In a broad sense, Africa is not different from the RoW even though the magnitude of the coefficients differs between Africa and the RoW. Agriculture, Construction, Manufactures, and Services display a larger elasticity in absolute terms in Africa than in the rest of the world, while Electricity and Utilities, Mining, and Transports exhibit a larger effect in the rest of the world. The effect is particularly marked for Electricity and Utilities, with a coefficient of -0.341 in Africa and -2.438 in the rest of the World. This could stem from a lack of availability of clean energy source.

Pattern 6: The export basket of Africa is skewed towards high CO2e intensity products. CO2 emission intensities are positively correlated with both the upstreamness (OU) and downstreamness (ID). The OU/ID indicator of position in a supply chain is negatively correlated with CO2e emission intensities within regions. A 1% higher upstreamness is associated with a decrease of CO2e emissions intensity of about 0.22% for Africa and 0.31% for the rest of the world. A stronger fit is obtained within sectors in each region. For Manufactures, being more upstream by 1% is associated with a higher emissions intensity of 0.61%. For the other sectors, the relation is negative and larger for Agriculture and Construction.

7. Conclusions

Africa's participation in supply chain trade has been limited, mostly in upstream activities. African exports contain few imports and its exports mostly undergo further processing in destination countries before reaching final consumption. Yet, the carbon equivalent (CO2e) of its footprint, while following the worldwide downward trend over the period 1995–2015, is still the highest in the world. At the same time, its share of the world's global CO2e emissions is the smallest.

Documenting how these emissions have evolved is challenging, not least because it is difficult to trace the origin (domestic or foreign) in countries with scant information on sufficient granularity in production chains. This paper exploits a recently prepared Multi-Regional Input-Output (MRIO) data set covering Green House Gases (GHGs) emissions for 189 countries disaggregated into 163 sectors covering the period 1995–2015 (Cabernard & Pfister, 2021). This data set (RMRIO) is the most comprehensive at our disposal. For reasons discussed in the paper, we argue that the benefits of its extended coverage outweigh its shortcomings, allowing us to draw an informative of landscape of the evolution of emissions in Africa over the period 1995–2015 across 49 African countries that are compared with those in other regions. Highlights, some are more detailed update of trends already identified in the literature, include the following.

The average carbon intensity of production has increased across Africa both over 1995–2005 and 2005–2015, though much less so during the second decade. Africa is not yet decarbonizing. For over half of African countries (12), the structure of production has been shifting towards dirty sectors. The contribution of the technique effect towards reducing the growth of CO2e has been greater than the contribution of the composition effect for 17 countries. The Spearman rank correlation of 0.7 for sectorial emissions across regions shows promise for decarbonization efforts at the disaggregated sector level. Almost half of the cleanest and dirtiest sectors are the same across regions, but there are sharp differences in rankings for some of the dirtiest sectors. In general, the dirtiest sectors are more upstream. The export basket of Africa is skewed towards high CO2e intensity products.

In all regions, the intra-regional share of emissions has fallen between the first and second decades documented. Notably, Africa's share of emissions originating from Asia rose from 4% to 11%. Europe's share of emissions originating from Africa has double to 4%, while from Asia it has quadrupled to 16%. These changes unmistakably document that high-income countries have been increasingly outsourcing pollution.

Measures of output upstreamness (OU) from final consumption and input downstreamness (ID) from primary factors have been increasing, an indication that worldwide production chains have become more roundabout as the share of value-added in gross output has fallen from 3% in 1995 to 4% in 2015. At a 7-sector aggregation level, Mining is the most upstream sector for all regions, a challenge for many African countries. Mining is followed by Agriculture; Electricity and Utilities, Services, and Transports are the upstream broad sectors in all regions. Manufactures, and Construction, are downstream for all regions. For Manufactures, being more upstream by 1% is associated with a higher emissions intensity of 0.61%. For the other sectors, the relation is negative and larger for Agriculture and Construction.

Notes

1. At 13%, SSA's share of value-added imported in gross exports (the backward share of GVC participation) was less than half the world average, the lowest across regions in 2015. Melo and Solleder (2022: Table 1). Participation in GVCs is also low for non-SSA developing countries.

2. Different types of pollutants are highly correlated. Copeland et al. (2021) report that pairwise correlations across eight pollutants in the World Input-Output Database (WIOD) are positive and statistically significant for 13 out of 28 pairwise combinations. This justifies focusing on a CO2 aggregate in this paper.

3. Copeland et al. (2021) also review the literature on the additional CO2 emissions associated international trade. They conclude that, different approaches yield an estimate of around 5% additional emissions from international trade.

4. A version with a broader sectorial disaggregation is available but sector coverage varies by country.

5. CO2 equivalent emissions are available for 49 of those 54 countries, see Table A1 (in the appendix) for a full list.

6. With 193 countries and 163 sectors, there is a potential of Zijrs = (163*193)2 ≈ 109 input purchases across country-industry pairs. About 22% of lines at sector level have 0 total emissions, reflecting that some sectors are not being produced in some countries.

7. Based on Montecarlo simulations showing that errors on small flows do not affect multiplier estimates justifying using all available information and the observation that MRIO tables are dominated by elements of $10,000 or less, they argue that the methodology allows to obtain 'holistic' accuracy. Holistic accuracy results from the observation that a large number of small elements in an IO table can be removed before multipliers show a significant change (Jensen, 1980). Unreliable elements in the MRIO tables result from the choices to deal with the interplay of data conflict that create 'tensions' and lack of information that create 'dustbins'.

8. Lenzen et al. (2015) discuss the philosophy of the EORA project: develop "a method for rapid, timely, and at the same time low labour and time intensive construction and updating of high-resolution MRIO tables by focusing on standardization, automation,

and advance computation". Lenzen et al. state that, construction choices emphasized representing large data items and fulfilling balancing conditions for large countries.

9. Three sectors in RMRIO record no direct emission for any country; these are: "Extra-territorial organizations and bodies", "Manure treatment (biogas), storage and land application", and "Manure treatment (conventional), storage and land application". While our IO-based methodology may be able to identify indirect emissions for those sectors, we discard them as, in any case, at best only provide a partial picture of emissions related to these sectors.

10. According to Crippa et al. (2021), the following countries belong to the group "Other Africa" in IEA's data: Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Djibouti, Equatorial Guinea, Eswatini, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Réunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, and Uganda.

11. On average, per capita C02e emissions are three times higher in urban than in rural areas.

12. The IPAT identity decomposes the impact of human activity on environmental damage. It states that Impact=Population*Affluence*Technology. Applied to CO_2 emissions, these are decomposed into GDP*(energy intensity of GDP)*(carbon intensity of energy). In the version here: $CO \equiv P*(Y/P)*(E/Y)*(C/E) = Y(EY)(CE)$

13. As pointed out by Copeland et alonce fossil fuel is burned, there is no viable end-of-pipe pollution control technologies (like scrubbers); so the technique effect represents a shift towards cleaner energies or factor productivity growth.

14. The high scale effect for Oceania is dominated by Australia, a coal-intensive country.

15. Gravity estimates of clean vs dirty industries for a large sample of developing countries over the period 1980–1999 reported in Grether and de Melo (2004) showed that the magnitude of the coefficient of distance on trade flows was about three times higher for dirty than for clean industries, suggesting that theories of comparative advantage may have little impact on the location of dirty industries, and hence contribute to the weak composition effects reported by Copeland et al

16. Corresponding patterns for all of Africa, all countries shifted towards more CO_2-intensive activities and the technique effect contributed more than the composition effect to reducing CO_2e emissions.

17. See the comparisons of GVC indices from different MRIO in Kowalski et al. (2015).

18. However, some sectors exhibit large differences in emission intensity between regions (for example: the sector "Poultry farming" has a total emission intensity of 1.12 kg/€ CO_2e in Africa, while only about 0.4 kg/€ of CO_2e in other regions).

19. One can also derive OU from the Ghosh inverse G in a similar manner with the formula $OU=G\iota$. See Miller and Termushoev (2017) equations 5–9 for details.

20. We have verified that the two output-weighted averages of U and D deliver the same positioning in our data set.

21. Regressing a time trend of the form: $(OU/ID)\_ist=\alpha+ \beta t+\mu\_ist$ from 2009 in Africa yields a β coefficient of 0.0040, significant at a 99% confidence level.

22. The same regression as in footnote 19 for the comparator group yields a β of -0.0036 significant a 99% confidence level.

23. Results are in the appendix.

24. This result is reported as stylized fact #3 in Copeland et al. (2021).

25. Africa moved more upstream from 2009. Estimating the model excluding years prior to 2009 returns a larger coefficient for U/D in absolute term (-0.342 instead of -0.220).

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Appendixes

Appendix A: List of countries in RMRIO and in synthetic comparator

Names and abbreviations of the list of countries with availability of CO2e estimates

Table A1: African economies in RMRIO

ISO code	Name	CO2e available?
CMR	Cameroon	Yes
NGA	Nigeria	Yes
UGA	Uganda	Yes
BFA	Burkina Faso	Yes
NER	Niger	Yes
MRT	Mauritania	Yes
TGO	Togo	Yes
AGO	Angola	Yes
BDI	Burundi	Yes
DZA	Algeria	Yes
COG	Congo	Yes
ETH	Ethiopia	Yes
BEN	Benin	Yes
RWA	Rwanda	Yes
EGY	Egypt	Yes
ZWE	Zimbabwe	Yes
MAR	Morocco	Yes
GMB	Gambia	Yes
SOM	Somalia	Yes
CIV	Cote d'Ivoire	Yes
ZMB	Zambia	Yes
ERI	Eritrea	Yes
NAM	Namibia	Yes

continued next page

Table A1 Continued

ISO code	Name	CO2e available?
SWZ	Swaziland	Yes
TCD	Chad	Yes
LSO	Lesotho	Yes
KEN	Kenya	Yes
TUN	Tunisia	Yes
ZAF	South Africa	Yes
MLI	Mali	Yes
GAB	Gabon	Yes
TZA	Tanzania	Yes
MUS	Mauritius	Yes
MWI	Malawi	Yes
DJI	Djibouti	Yes
CAF	Central African Republic	Yes
BWA	Botswana	Yes
MOZ	Mozambique	Yes
SYC	Seychelles	Yes
CPV	Cape Verde	Yes
MDG	Madagascar	Yes
GHA	Ghana	Yes
LBR	Liberia	Yes
STP	Sao Tome and Principe	Yes
GIN	Guinea	Yes
SLE	Sierra Leone	Yes
SEN	Senegal	Yes
COD	Democratic Republic of Congo	Yes
LBY	Libya	Yes
GNB	Guinea-Bissau	No
GNQ	Equatorial Guinea	No
SDN	Sudan	No
COM	Comoros	No
SSD	South Sudan	No

Table A2: American economies in RMRIO

ISO code	Name	CO2e available?
CRI	Costa Rica	Yes
ANT	Netherlands Antilles	Yes
PAN	Panama	Yes
TTO	Trinidad and Tobago	Yes
BHS	Bahamas	Yes
VGB	British Virgin Islands	Yes
SUR	Suriname	Yes
GUY	Guyana	Yes
VEN	Venezuela	Yes
HTI	Haiti	Yes
URY	Uruguay	Yes
ARG	Argentina	Yes
HND	Honduras	Yes
GTM	Guatemala	Yes
JAM	Jamaica	Yes
PRY	Paraguay	Yes
BOL	Bolivia	Yes
SLV	El Salvador	Yes
PER	Peru	Yes
CHL	Chile	Yes
CAN	Canada	Yes
NIC	Nicaragua	Yes
BRB	Barbados	Yes
CYM	Cayman Islands	Yes
ECU	Ecuador	Yes
CUB	Cuba	Yes
BLZ	Belize	Yes
BMU	Bermuda	Yes
ABW	Aruba	Yes
USA	United States	Yes
BRA	Brazil	Yes
ATG	Antigua and Barbuda	Yes
DOM	Dominican Republic	Yes
COL	Colombia	Yes
MEX	Mexico	Yes
TCA	Turks and Caicos Islands	No
LCA	Saint Lucia	No

continued next page

Table A2: Continued

ISO code	Name	CO2e available?
DMA	Dominica	No
CHI	Channel Islands	No
CUW	Curaçao	No
MAF	Saint Martin (French part)	No
VCT	Saint Vincent and the Grenadines	No
PRI	Puerto Rico	No
VIR	United States Virgin Islands	No
SXM	Sint Maarten (Dutch part)	No
GRL	Greenland	No
KNA	Saint Kitts and Nevis	No
GRD	Grenada	No

Table A3: Asian economies in RMRIO

ISO code	Name	CO2e available?
TJK	Tajikistan	Yes
OMN	Oman	Yes
ARM	Armenia	Yes
SAU	Saudi Arabia	Yes
KGZ	Kyrgyz Republic	Yes
JOR	Jordan	Yes
SGP	Singapore	Yes
LBN	Lebanon	Yes
GEO	Georgia	Yes
CHN	China	Yes
PRK	North Korea	Yes
JPN	Japan	Yes
IRQ	Iraq	Yes
BTN	Bhutan	Yes
LAO	Laos	Yes
KHM	Cambodia	Yes
ISR	Israel	Yes
BRN	Brunei	Yes
MYS	Malaysia	Yes
UZB	Uzbekistan	Yes
QAT	Qatar	Yes
IRN	Iran	Yes
KWT	Kuwait	Yes

continued next page

Table A3 Continued

ISO code	Name	CO2e available?
MMR	Myanmar	Yes
TWN	Taiwan	Yes
LKA	Sri Lanka	Yes
AZE	Azerbaijan	Yes
MAC	Macao	Yes
ARE	United Arab Emirates	Yes
TUR	Turkey	Yes
MNG	Mongolia	Yes
BHR	Bahrain	Yes
VNM	Vietnam	Yes
NPL	Nepal	Yes
IND	India	Yes
BGD	Bangladesh	Yes
MDV	Maldives	Yes
AFG	Afghanistan	Yes
SYR	Syria	Yes
HKG	Hong Kong	Yes
PAK	Pakistan	Yes
CYP	Cyprus	Yes
PHL	Philippines	Yes
THA	Thailand	Yes
KOR	South Korea	Yes
IDN	Indonesia	Yes
TKM	Turkmenistan	Yes
YEM	Yemen	Yes
KAZ	Kazakhstan	Yes
TLS	Timor	No
PSE	Palestine	No

Table A4: European economies in RMRIO

ISO code	Name	CO2e available?
ALB	Albania	Yes
LUX	France	Yes
FIN	Finland	Yes
LTU	Lithuania	Yes
PRT	France	Yes
BEL	Belgium	Yes
SRB	Yugoslavia	Yes
DNK	Denmark	Yes
SVK	Slovak Republic	Yes
BIH	Bosnia and Herzegovina	Yes
DEU	Germany	Yes
CHE	Switzerland	Yes
LIE	Liechtenstein	Yes
IRL	Ireland	Yes
ESP	Spain	Yes
GRC	Greece	Yes
SMR	San Marino	Yes
NLD	Netherlands	Yes
FRA	France	Yes
LVA	Latvia	Yes
CZE	Czech Republic	Yes
ROU	Romania	Yes
MDA	Moldova	Yes
NOR	Norway	Yes
MCO	Monaco	Yes
SVN	Slovenia	Yes
UKR	Ukraine	Yes
ITA	Italy	Yes
GBR	United Kingdom	Yes
EST	Estonia	Yes
AUT	Austria	Yes
HUN	Hungary	Yes
SWE	Sweden	Yes
MKD	Macedonia	Yes
MLT	Malta	Yes
MNE	Montenegro	Yes
RUS	Russia	Yes

continued next page

Table A4 Continued

ISO code	Name	CO2e available?
HRV	Croatia	Yes
BGR	Bulgaria	Yes
BLR	Belarus	Yes
POL	Poland	Yes
ISL	Iceland	Yes
GIB	Gibraltar	No
XKX	Kosovo	No
FRO	Faeroe Islands	No
AND	Andorra	No
IMN	Isle of Man	No

Table A5: Oceanian economies in RMRIO

ISO code	Name	CO2e available?
AUS	Australia	Yes
NCL	New Caledonia	Yes
NZL	New Zealand	Yes
VUT	Vanuatu	Yes
PYF	French Polynesia	Yes
WSM	Samoa	Yes
PNG	Papua New Guinea	Yes
FJI	Fiji	Yes
PLW	Palau	No
NRU	Nauru	No
SLB	Solomon Islands	No
TUV	Tuvalu	No
ASM	American Samoa	No
FSM	Micronesia	No
TON	Tonga	No
MHL	Marshall Islands	No
GUM	Guam	No
MNP	Northern Mariana Islands	No
KIR	Kiribati	No

Table A6: Countries included in the comparator group

ISO code	Name	Region	Weight in comparator group
IRQ	Iraq	Asia	0.128
YEM	Yemen	Asia	0.0794
BOL	Bolivia	Americas	0.0793
BGD	Bangladesh	Asia	0.0714
FJI	Fiji	Oceania	0.0608
KHM	Cambodia	Asia	0.0420
PER	Peru	Americas	0.0406
PAK	Pakistan	Asia	0.0397
PHL	Philippines	Asia	0.0371
VNM	Vietnam	Asia	0.0300
LKA	Sri Lanka	Asia	0.0295
MMR	Myanmar	Asia	0.0235
AFG	Afghanistan	Asia	0.0209
PRY	Paraguay	Americas	0.0201
PNG	Papua New Guinea	Oceania	0.0197
LAO	Laos	Asia	0.0179
WSM	Samoa	Oceania	0.0177
CUB	Cuba	Americas	0.0173
BRA	Brazil	Americas	0.0166
ARM	Armenia	Asia	0.0165
VUT	Vanuatu	Oceania	0.0147
SYR	Syria	Asia	0.0145
DOM	Dominican Republic	Americas	0.0138
CHL	Chile	Americas	0.0108
JOR	Jordan	Asia	0.0107
NPL	Nepal	Asia	0.01000
GEO	Georgia	Asia	0.00979
AZE	Azerbaijan	Asia	0.00879
ECU	Ecuador	Americas	0.00808
KGZ	Kyrgyz Republic	Asia	0.00729
ARG	Argentina	Americas	0.00710
MDV	Maldives	Asia	0.00701
TKM	Turkmenistan	Asia	0.00575
IRN	Iran	Asia	0.00567
COL	Colombia	Americas	0.00561
NIC	Nicaragua	Americas	0.00556
IDN	Indonesia	Asia	0.00503

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Table A6 Continued

ISO code	Name	Region	Weight in comparator group
GTM	Guatemala	Americas	0.00462
LBN	Lebanon	Asia	0.00417
JAM	Jamaica	Americas	0.00412
KAZ	Kazakhstan	Asia	0.00372
BTN	Bhutan	Asia	0.00366
MNG	Mongolia	Asia	0.00350
IND	India	Asia	0.00243
THA	Thailand	Asia	0.00219
SLV	El Salvador	Americas	0.00187
HND	Honduras	Americas	0.00153
SAU	Saudi Arabia	Asia	0.00141
SUR	Suriname	Americas	0.00139
BLZ	Belize	Americas	0.00138
VEN	Venezuela	Americas	0.00129
PAN	Panama	Americas	0.00116
URY	Uruguay	Americas	0.000742
MEX	Mexico	Americas	0.000715
OMN	Oman	Asia	0.000550
MYS	Malaysia	Asia	0.000492
CYP	Cyprus	Asia	0.000442
CRI	Costa Rica	Americas	0.000189
PYF	French Polynesia	Oceania	0.000189
TUR	Turkey	Asia	0.000162
CHN	China	Asia	6.14e-05
BHR	Bahrain	Asia	4.62e-05
BRB	Barbados	Americas	3.59e-05
ATG	Antigua and Barbuda	Americas	2.94e-05
TTO	Trinidad and Tobago	Americas	2.93e-05
BHS	Bahamas	Americas	2.72e-05
NCL	New Caledonia	Oceania	1.97e-06
NZL	New Zealand	Oceania	1.29e-06
JPN	Japan	Asia	1.02e-06
BRN	Brunei	Asia	4.02e-07
ABW	Aruba	Americas	2.98e-07
QAT	Qatar	Asia	2.27e-07
HKG	Hong Kong	Asia	1.98e-07
ARE	United Arab Emirates	Asia	1.51e-07

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Table A6 Continued

ISO code	Name	Region	Weight in comparator group
AUS	Australia	Oceania	1.48e-07
USA	United States	Americas	9.38e-08
KWT	Kuwait	Asia	7.50e-08
KOR	South Korea	Asia	3.51e-08
CAN	Canada	Americas	3.19e-08
ISR	Israel	Asia	2.46e-08
MAC	Macao	Asia	5.82e-10
GRL	Greenland	Americas	6.06e-11

Annex B: Additional tables and figures

Figure B1: Scale-composition-technique decomposition for all African countries

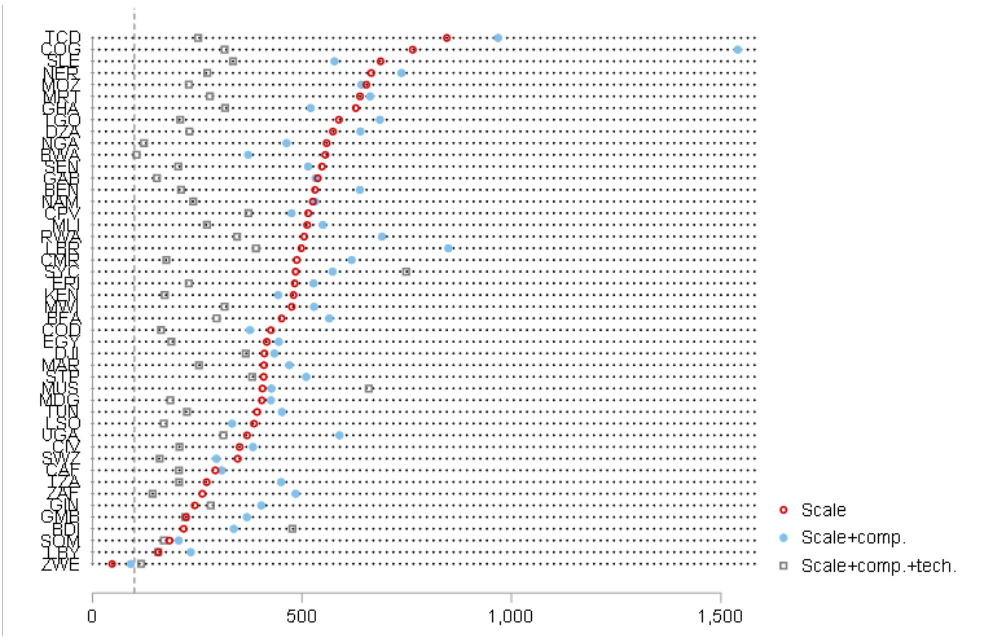
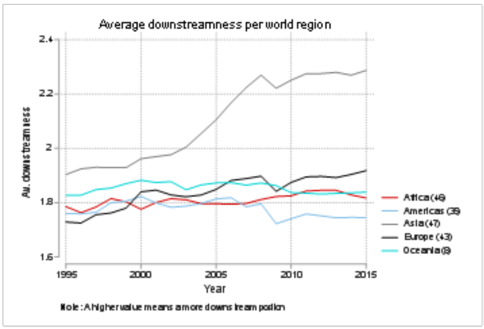


Figure B2: Downstreamness by region vs comparator

(a) by region



(b) versus comparator

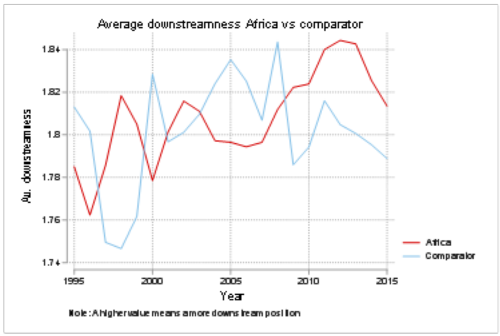


Table B1: Least and most polluting sectors in the five largest African emitting countries

Sector	Total CO2e int.	Direct CO2e int.	Share of Direct	Share of Output	Upstream.
Algeria					
Other business activities	0.119	0.0117	0.0979	0.0272	1.877
Real estate activities	0.124	0.0122	0.0984	0.0320	1.038
Post and telecommunication	0.134	0.0108	0.0804	0.0255	1.922
Sea and coastal transport	0.163	0.0945	0.580	0.0412	1.211
Vehicles sales	0.181	0.0860	0.475	0.0151	1.930
Petroleum refinery	0.477	0.236	0.495	0.0429	2.838
Construction	0.841	0.0992	0.118	0.127	1.078
Manufacture of vehicles	0.879	0.00628	0.00714	0.0123	1.026
Mining of copper ores	1.823	1.422	0.780	0.0345	1.928
Extraction of petroleum	4.380	3.546	0.810	0.0305	2.903
Egypt					
Manufacture of wood	0.0962	0.00173	0.0180	0.0197	1.936
Real estate activities	0.173	0.0198	0.114	0.0679	1.087
Mining of copper ores	0.202	0.0703	0.348	0.0361	2.176
Quarrying of sand	0.250	0.191	0.763	0.0307	1.999
Insurance and pension	0.292	0.137	0.469	0.0139	1.106
Wholesale trade	1.212	1.081	0.891	0.0333	2.285
Processing of food	1.219	0.00217	0.00178	0.0113	1.264
Construction	1.495	0.659	0.441	0.0793	1.107
Petroleum refinery	1.547	1.080	0.698	0.0199	2.071
Chemicals	2.359	1.390	0.589	0.0110	1.988

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Table B1 Continued

Sector	Total CO2e int.	Direct CO2e int.	Share of Direct	Share of Output	Upstream.
Morocco					
Mining of copper ores	0.0624	0.0161	0.258	0.0763	2.003
Post and telecommunication	0.155	0.0146	0.0940	0.0242	1.923
Real estate activities	0.169	0.0198	0.117	0.0340	1.037
Cultivation of wheat	0.176	0.124	0.705	0.0164	2.717
Other business activities	0.190	0.0241	0.127	0.0227	1.984
Chemicals	0.428	0.00110	0.00256	0.0103	2.464
Manufacture of machinery	0.491	0.00164	0.00334	0.0189	1.354
Construction	0.622	0.0699	0.112	0.126	1.181
Petroleum refinery	0.702	0.351	0.500	0.0193	2.686
Public administration and defence	0.718	0.130	0.181	0.0477	1.004
Nigeria					
Real estate activities	0.0612	0.00233	0.0381	0.0598	1.015
Public administration and defence	0.108	0.00124	0.0115	0.163	1.001
Post and telecommunication	0.131	0.0379	0.288	0.0237	1.516
Activities organization	0.136	0.00540	0.0397	0.0133	1.002
Financial intermediation	0.136	0.0149	0.109	0.0126	1.223
Construction	0.853	0.0483	0.0566	0.0604	1.039
Mining of copper ores	1.624	1.330	0.819	0.0300	1.547
Hotels and restaurants	1.697	0.127	0.0747	0.0345	1.203
Meat animals	3.185	1.852	0.581	0.0114	1.929
Extraction of petroleum	4.560	4.310	0.945	0.0250	3.067
South Africa					
Financial intermediation	0.0537	0.0144	0.268	0.0358	2.351
Activities auxiliary to financial intermediation	0.0564	0.00493	0.0874	0.0168	5.907
Insurance and pension	0.0679	0.0324	0.478	0.0193	1.361
Mining of precious metal	0.0906	0.0801	0.884	0.0471	3.133
Supporting transport	0.101	0.0291	0.290	0.0102	2.819
Cultivation of vegetables	2.396	0.346	0.144	0.0120	1.437
Manufacture of basic iron and steel	2.609	2.310	0.886	0.0162	2.709
Processing of food	3.002	0.00573	0.00191	0.0197	1.415
Manufacture of rubber/plastic	5.366	1.112	0.207	0.0105	2.389
Chemicals	6.442	0.218	0.0339	0.0209	1.992

Table B2: Impact of GVC position on CO2e emission intensity: Comparator

	(1) Agri.	(2) Construct.	(3) Electricity & Utility	(4) Manuf.	(5) Mining	(6) Services	(7) Transport
	Log (CO2e)	log (CO2e)	Log (CO2e)	Log (CO2e)	Log (CO2e)	Log (CO2e)	Log (CO2e)
Log(U/D)	-1.253***	-0.693***	-1.813***	0.177***	-1.711***	-0.361***	-1.667***
	(0.0206)	(0.205)	(0.0844)	(0.0150)	(0.0650)	(0.0227)	(0.0440)
Log(GDPpc)	-0.206**	-0.441***	-0.710***	-0.515***	-1.082***	-0.517***	-0.609***
	(0.0867)	(0.0703)	(0.181)	(0.0572)	(0.116)	(0.0800)	(0.0851)
Constant	15.60***	15.89***	19.58***	16.35***	22.87***	14.87***	19.24***
	(0.738)	(0.633)	(1.589)	(0.501)	(1.023)	(0.702)	(0.744)
Observations	20857	1723	14745	76898	17777	58723	9865
FE	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector	Country, Sector
Adjusted R^2	0.282	0.887	0.283	0.256	0.368	0.211	0.460

Notes: The table shows direct CO2e emissions. Robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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