UNITED NATIONS UNIVERSITY
UNU-WIDER

WIDER Working Paper 2022/115

Unravelling Africa's raw material footprints and their drivers

Albert Kwame Osei-Owusu,[1] Michael Danquah,[2] and Edgar Towa[3]

October 2022

Abstract: This paper applies an environmentally extended input–output analysis, leveraging the Eora database, to estimate the global raw material footprints of 51 African nations from 1995 to 2015. It employs least absolute shrinkage and selection operator and panel regression models to quantify the effects of diverse variables on Africa's raw material footprints. The findings show that the raw material footprints of Africa's production and consumption soared by 41 per cent and 38 per cent, respectively, from 1995 to 2015, mainly driven by biomass and construction materials. They show that Africa outsources 25 per cent of its raw material footprints from consumption, while over 60 per cent of its footprints from production arise from its exports. Our findings beckon African governments to reduce the excessive focus on exploitation and concentrate on combatting corruption and extreme rent-seeking while decoupling Africa's raw material footprints from rising public debt, carbon emissions, income levels, and population.

Key words: Eora database, material footprints, input–output analysis, least absolute shrinkage and selection operator model, Africa

JEL classification: C33, C67, F18

[1]Department of Planning, Aalborg University, Copenhagen, Denmark, email: ako@plan.aau.dk; [2] UNU WIDER, Helsinki, Finland, email: danquah@wider.unu.edu; [3] Institute for Environmental Management and Land-use Planning (IGEAT), Université Libre de Bruxelles (ULB), Brussels, Belgium.

This study is published within the UNU-WIDER project Extractives for development (E4D)—risks and opportunities, part of the Domestic Revenue Mobilization programme, which is financed by the Norwegian Agency for Development Cooperation (Norad).

Information and requests: publications@wider.unu.edu

ISSN 1798-7237 ISBN 978-92-9267-249-2

https://doi.org/10.35188/UNU-WIDER/2022/249-2

Typescript prepared by Lesley Ellen.

United Nations University World Institute for Development Economics Research provides economic analysis and policy advice with the aim of promoting sustainable and equitable development. The Institute began operations in 1985 in Helsinki, Finland, as the first research and training centre of the United Nations University. Today it is a unique blend of think tank, research institute, and UN agency—providing a range of services from policy advice to governments as well as freely available original research.

The Institute is funded through income from an endowment fund with additional contributions to its work programme from Finland, Sweden, and the United Kingdom as well as earmarked contributions for specific projects from a variety of donors.

Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

In 2018, before the COVID 19 pandemic, the world emitted 55 Gt CO_2e (Giga tonnes of carbon dioxide equivalents). Energy consumption and industrial processes accounted for four-fifths of the total, while agriculture and land use made up the remaining share (GCP 2020; Janssens-Maenhout et al. 2019). According to scientists (IPCC 2021), human activities, particularly fossil fuel combustion and land use changes, are unequivocally responsible for the rising global greenhouse gases (GHGs). Africa accounts for ~4 per cent of global energy-related CO_2 emissions (1.62 Gt CO_2 in 2020 (Ayompe et al. 2020)), with fossil fuels (coal and oil) and land use and land use changes representing more than half of Africa's GHG emissions (Minx et al. 2021). Despite having historically low emissions levels compared to other regions, Africa's CO_2 emissions are fast-growing due to increased emissions from its tropical lands (6 billion tonnes of CO_2 in 2016) (Palmer et al. 2019). This recent growth is driven by increased natural resource extraction and consumption linked to increasing material use on the continent and abroad in recent decades (UNEP 2016b). Against this background the discourse about and strategies for meeting the Sustainable Development Goals (SDGs) in Africa which have focused on climate change adaptation for the longest haul should integrate and prioritize sustainable natural resource management in national policies to decouple economic growth and human well-being from natural resource use and related environmental impacts.

By 2050 the global population is expected to have increased by 2 billion, having continued to rise steadily since it peaked in the 20th century (UNDESA 2019a). Compared to other continents, Africa has had the highest population growth in the last decades (UNDESA 2019a), with ten or more of the world's 20 most populous cities predicted to be African cities by 2100 (UNDESA 2019b). Modern life requires more energy and natural resources to produce goods and services to meet society's insatiable needs, including industrial production, cooling, and mobility (Smil 2013; UNEP 2016b). Africa's consumer markets are among the fastest-growing markets globally (AFDB et al. 2015). Over the last decade African household consumption has outgrown the continent's gross domestic product (GDP) (AFDB 2021) and is expected to reach US$2.5 trillion in 2030, driven partly by growing household discretionary spending (Fenech and Perkins 2014). Food demand in Africa is projected to increase by 60 per cent in 2030 compared to 2015 (FAO 2017). Africa's oil consumption increased by an astonishing 143 per cent, from 70.5 Mtoe (million tonnes of oil equivalent) in 1990 to 170 Mtoe in 2018 (IEA 2021). A scenario analysis by the International Energy Agency (IEA) suggests that the total demand for energy in Africa will double by 2040 when considering increasing energy demand by industries and households (IEA 2019a). As Africa's population continues to soar and many Africans are lifted out of poverty and income levels rise, the continent faces the enormous challenge of relying less on its climate-unfriendly primary energy sources (i.e. fossil fuels) and managing its natural resources efficiently to stimulate growth and prosperity in the face of ensuing green energy transitions in the developed world (IEA 2022). To this end comprehensive and reliable data, scientific knowledge, and policy-relevant information on the intricacies of Africa's resource exploitation, trade, and consumption are pertinent to global climate change mitigation, sustainable resource management, and resource efficiency.

In recent decades resource efficiency has been among the top priorities of environmental strategies and programmes worldwide (European Commission 2019; UNEP 2016c). Indeed two of the 17 global SDGs (i.e. see SDG 8.4.1[1] & 12.2.1[2]) are devoted to promoting the sustainable exploitation,

---

[1] https://unstats.un.org/sdgs/metadata/?Text=&Goal=8&Target=8.4

[2] https://unstats.un.org/sdgs/metadata/?Text=&Goal=&Target=12.2

management, and consumption of natural resources. Achieving these goals will require countries to track and monitor their production and consumption of raw materials by compiling consistent and timely raw material flow accounts (MFAs) and reporting globally comparable material footprint indicators (UNEP 2016a). Today, different material flow accounting approaches allow statistical agencies, researchers, and firms to track the movement of materials from their extraction through processing and final consumption by households to their disposal and recycling (Lutter et al. 2016). Economic-wide material flow analysis (EW-MFA) is a standardized and widely used approach for quantifying the raw material throughput or the material requirements of production systems and apparent consumption within national borders (Fischer-Kowalski et al. 2011). Most countries employ EW-MFA as a benchmark for measuring their progress toward natural resource use/material efficiency and overall resource productivity (Bringezu et al. 2017; Schandl et al. 2018). Many national statistical offices use domestic material extraction (DME), domestic material consumption (DMC), and direct material input (DMI) as the headline indicators for their EW-MFA, as the data required for their compilations are often easily accessible (see eurostat and Fischer-Kowalski et al. (2011) for detailed definitions of the EW-MFA indicators). However, a pitfall of the production-oriented EW-MFA indicators is the exclusion of all indirect/upstream raw material flows and requirements beyond national borders, especially materials embodied in internationally traded goods and services (Bruckner et al. 2012; Piñero et al. 2018). Thus a growing number of studies suggest that decisions and policies based on DMI and DMC indicators ignore the rising outsourcing/displacement of material extraction, over-exploitation, and use, mostly from importing (developing/resource-rich) countries to exporting (developed/wealthy) countries (Piñero et al. 2020; Schandl et al. 2018; Wiedmann et al. 2015).

Against this background a large body of research proposes the consumption-based indicator, raw material consumption (also referred to as raw material footprint (RMF)), as a 'holistic' measure of the 'true' supply chain material throughput related to a nation's final demand for goods and services irrespective of their place of production (Eisenmenger et al. 2016; Schoer 2018). Raw material consumption measures and expresses the mass of all direct and indirect raw material requirements associated with the final demand of domestic and traded goods and services in raw material equivalents (RMEs) (Schaffartzik et al. 2015). Several papers have evaluated the RMFs and related environmental burdens of different industries, products, and households at varying geospatial scales using: (i) top-down methods (e.g. environmentally extended input–output models) (see Giljum et al. 2019; Piñero et al. 2018; Wiedmann et al. 2015); (ii) bottom-up techniques (e.g. coefficient-based approaches/life cycle assessment (LCA) (see Fishman et al. 2014; Heeren and Hellweg 2019; Mostert and Bringezu 2019); and (iii) hybrid input–output (IO) LCA methods (see Schaffartzik et al. 2014; Schoer et al. 2012).

LCA methods are useful for quantifying in great detail the upstream material inputs and flows associated with a wide range of products over their entire life cycle for highly differentiated material types (Schoer et al. 2013). MFA approaches based on LCA and hybrid LCA rely largely on product- and resource-specific coefficients obtained from life cycle inventories (LCIs) (Lutter et al. 2016). LCA does not capture all the upstream material requirements along the global supply chain, products, and industries and is susceptible to double-counting material flows (Schaffartzik et al. 2015). Rapid globalization in the past few decades, aided by trade liberalization and technological advancement worldwide, has created increasingly fragmented and spatially differentiated global material supply and use chains (Peters et al. 2011; WTO 2010). By far, IO models, particularly multi-regional input–output (MRIO) models, are more applicable to estimating the global supply chain-linked direct and all indirect material requirements for the final consumption of goods and services of countries, including the raw materials embodied in traded products and services (Giljum et al. 2019). Moreover, IO databases are consistent with national accounts and ensure full coverage of national and global supply chains, thus circumventing the potential truncation errors arising from subjective system-boundary choices common to LCA approaches (Lenzen 2000; Ward et al. 2018).

Africa is endowed with abundant and diverse natural resources and natural capital wealth (AFDB 2020). Close to 8 per cent of the Earth's natural gas reserves, a third of global mineral reserves, and a tenth of the global oil reserves reside in Africa (UNEP 2018). Also, over two-thirds of the world's arable land and a third of the world's CO_2-storing tropical rainforests are domiciled in Africa (Bourne 2019; Lewis et al. 2009). Yet Africa has some of the poorest countries in the world and is plagued with the so-called natural resource curse (Badeeb et al. 2017; Henri 2019). While the literature is replete with studies on the material footprints (MFs) of nations and the world at large (Eisenmenger et al. 2016; Lenzen et al. 2022), there is a lack of studies focused on tracing the trends and understanding the determinants of Africa's raw material extraction and footprint.

Although the statistical agencies of most African countries' collect and report data on the volumes and economic values of different types of extracted materials, only a few keep consistent and yearly raw material accounts of their production, trade, and consumption activities. Hitherto, apart from a few isolated and often impotent national initiatives, Africa has had no flagship programme targeted at promoting resource efficiency on the continent within the planetary boundaries while recognizing the growing supply constraints worldwide (ANRC 2021). As part of the European Union's (EU) Resource Efficiency Initiative (European Commission 2011), the EU commission established the Raw Materials Information System platform to provide material flow data, tools, and indices covering some African countries to provide decision-making support toward resource efficiency and supply resilience. However, such data are limited and only track physical flows of raw materials from Africa to the rest of the world and vice versa, ignoring indirect raw material requirements (D'Elia et al. 2022). The existing paucity of data on Africa's RMFs remains a longstanding hindrance to implementing well-informed and effective policies to address the diverse sustainability challenges related to Africa's natural resource exploitation and use (AFDB 2013; Ayee 2014).

This paper addresses the knowledge gaps by estimating Africa's RMFs from 1995 to 2015. Unlike previous studies that focused only on Africa's domestic/production-based raw material extraction, this study goes further by evaluating the RMFs embodied in Africa's traded goods and services. To this end, we apply an MRIO technique to the Eora[3] global environmentally extended MRIO (EE MRIO) database to evaluate Africa's total RMF, distinguishing between consumption- and production-based and trade-linked MFs. Also, we combine lease absolute shrinkage and selection operator (LASSO[4]) and panel data regressions to ascertain the quantitative relation between Africa's RMFs and some socio-demographic, economic, and institutional indicators. Our findings suggest that Africa's production- and consumption-based RMF has been accelerating in the last decades and is yet to peak. The increase in Africa's MF is particularly influenced by a rise in MF for biomass, construction materials, and fossil fuels, in that order. The results support the export-oriented nature of extractive and raw material manufacturing industries in most African economies. Our study confirms Africa as a net exporter of RMFs for all material categories. Also, the RMFs embodied in Africa's imports increased by 18 per cent more than the increase in MFs embodied in Africa's exports. Prominent among the drivers of RMFs are population growth, natural resource rents, and political corruption and government debt. In the face of the mounting global pressures on the world's scarce natural resources, over-exploitation of natural resources in

[3] https://worldmrio.com/countrywise/

[4] https://www.sciencedirect.com/topics/engineering/least-absolute-shrinkage-and-selection-operator

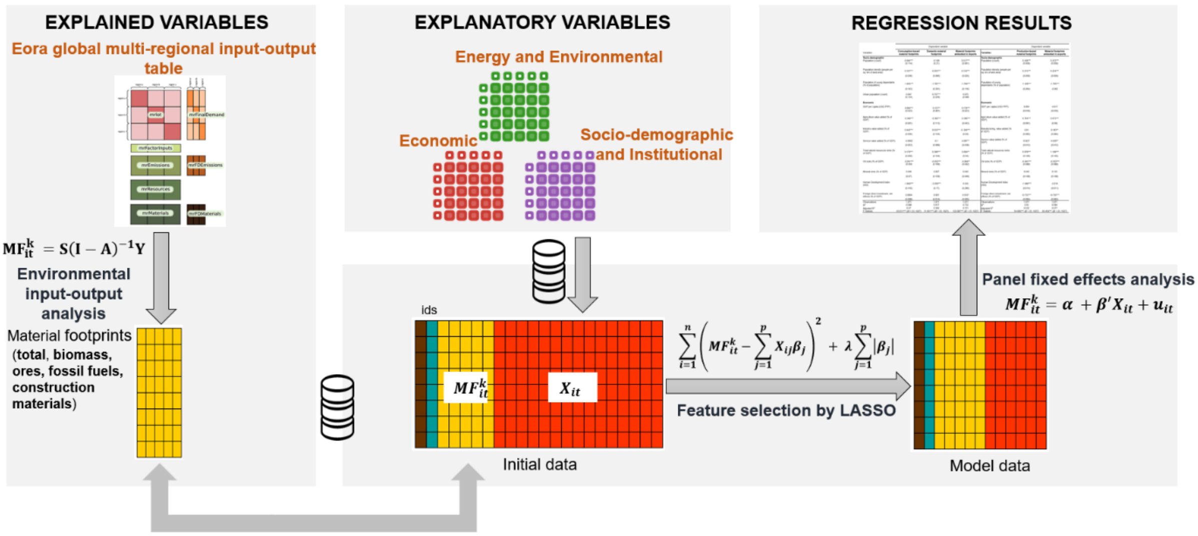
Africa[5] and their adverse environmental impacts, this paper provides a better understanding of Africa's RMFs and their drivers along with policy-relevant information for prioritizing areas for action and intervention towards decoupling Africa's economic growth from natural resource depletion and the related environmental burdens.

The remainder of the study is structured as follows. The next section provides an overview of the data and methods of analysis. Section 3 discusses the trends in RMFs and the regression results, while Section 4 presents the conclusion and policy implications.

2 Material and method

Figure 1 is an illustrative summary and representation of the data and approaches we have applied in this study. Further details are provided in the subsequent sections.

Figure 1: Data and methods schema of the present study



Source: authors' compilation.

2.1 Input–output analysis

Input–output analysis (IOA), developed by Leontief (1936), has been one of the go-to workhorses for sustainability assessments of supply chains at multiple scales (Leontief 1970). IO tables form the basis of IOA, documenting the financial and/or physical transactions/flows between various sectors in a given economy (Miller and Blair 2009) . However, supply and use tables (SUTs) form the bedrock of IO tables (Eurostat 2008). National IO tables are compiled and published by government statistical agencies following the United Nation's (UN's) System of National Accounts principles (UN 2010).

An IO table comprising more than one national IO table linked by trade data is called a multi-regional input–output (MRIO) table (Owen et al. 2016; Tukker and Dietzenbacher 2013). MRIO databases document intra-and inter-industry trade within and across national borders and the final demand for domestic and foreign goods and services by households, governments, and firms

[5] https://press.un.org/en/2017/ecosoc6831.doc.htm

(Stadler et al. 2018; Timmer et al. 2015; Yamano and Webb 2018). Most MRIO tables contain data measured in monetary units (see World Input-Output Database (Dietzenbacher et al. 2013) and Inter-Country Input-Output database (Yamano and Webb 2018)), while only a handful of MRIO databases comprise inter-industry and final demand data in physical units (see Vunnava et al. (2021)). Also, some hybrid MRIO databases combine data in physical (for tangible goods, energy, and energy carriers) and monetary units (for services) (Merciai and Schmidt 2018). MRIO tables embody industry- and country-specific production recipes/technologies and distinct household consumption patterns across nations/regions. Extended with satellite accounts[6] on emissions, energy, material and natural resource use, biodiversity loss, value added, and employment of source sectors per country (i.e. the so-called production-based accounts), MRIO databases have been widely used for evaluating the social, economic, and environmental pressures/footprints along global product and supply chains (Vita et al. 2021; Wiedmann and Lenzen 2018). Moreover, EE MRIO analysis is useful for identifying the product/industry and geographical hotspots of emissions and material use along global supply chains (Giljum et al. 2016; Yang et al. 2020).

2.2 Eora database

The Eora global MRIO database is the primary database for this study's RMF calculations. A team of researchers at the University of Sydney (Lenzen, Moran, Kanemoto et al. 2013) built the Eora database, starting with 187 countries, with industry resolutions ranging from 25 (for most developing countries) to over 500 sectors (mostly for developed countries) and slightly over 30 environmental indicators from 1990 to 2011. The Eora global MRIO table was constructed using the various national SUTs and the industry technology assumption (Eurostat 2008). However, the latest Eora database is a time series (i.e. 1990 to 2021) global MRIO table covering 189 countries and one rest of the world (RoW) region of 26 to 15,909 sectors. The data in Eora MRIO tables beyond 2011, particularly for inter-industry flows, are based on nowcasting and optimization algorithms underpinned by historical data on the economic structures of individual countries and their respective macroeconomic data (e.g., GDP, employment, incomes, etc.). Unlike other MRIO databases, the Eora database has an incomparable wider coverage of the global supply chain and types of material extraction data for primary sectors of significant African countries (51 in total). Eora's satellite accounts consist of about 2,720 socio-economic and environmental indicators, which include emissions to air and water, raw materials, energy, and labour requirements for primary production in all the industries and all the countries it covers (Moran 2015) (See Eora website for comprehensive information on all sources of extension data). However, this study's analyses are based on the raw material extensions of the Eora database (Lenzen, Moran, Kanemoto et al. 2013; Moran 2015).

The Eora global MRIO database is available in two forms: Full Eora[7] and Eora26[8]. The latter contains harmonized national IO tables[9] with 26 sectors per country, while the former includes national IO tables from statistical agencies, with varied and sectoral resolutions based on different regional industry and commodity classification schemes between countries (Lenzen et al. 2012). In other words, the Full Eora maintains the raw IO tables of nations, thus preserving sector details and IO table dimensions. Eora26 is a monetary and symmetric product-by-product global MRIO table founded on the industry technology assumption explained in depth in the Eurostat Manual of Supply, Use and Input–Output Tables (Eurostat 2008). It contains IO tables with the same

[6] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/satellite-account

[7] https://worldmrio.com/eora/

[8] https://worldmrio.com/eora26/

[9] https://worldmrio.com/countrywise/

sector classification and additional economic data (e.g., primary input requirements, value added) sourced from the UN National Accounts Official Country Database, with data measured in basic prices (USD). Based on a single automated reconciliation step (Geschke et al. 2014), Eora developers harmonize national IO tables in Eora and couple them with international trade data for products and services and their corresponding environmental and social satellite accounts (Lenzen et al. 2012; Lenzen, Moran, Kanemoto et al. 2013).

Since Eora's emergence, several researchers and sustainability practitioners have exploited Eora to ascertain the national and global trade-linked and supply chain carbon emissions (Kanemoto et al. 2016; Nansai et al. 2020), material (Giljum et al. 2019; Wiedmann et al. 2015), water (Lenzen, Moran, Bhaduri et al. 2013; Peters et al. 2021), labour (Alsamawi et al. 2014), corruption (Xiao et al. 2018), and slavery footprints (Shilling et al. 2021) for different products and services and consumer groups. Please refer to Lenzen, Moran, Kanemoto et al. (2013) and the Eora website[10] for detailed information on the model, data sources, and data resolution engine of the Eora database.

2.3 Footprint assessment

Following the standard Leontief demand-pull formulation (Leontief 1986), several studies have applied environmentally extended EE MRIO databases to quantify nations' so-called consumption-based (CB) environmental pressures/footprints. EE MRIO analysis assigns the direct socio-economic and environmental impacts of producing goods and services at the source industry to final consumers (Miller and Blair 2009). From a life cycle perspective, the IO Leontief calculus calculates the whole supply chain environmental pressures of final consumption, starting from the extraction of raw materials, through manufacturing to the treatment of waste from industries and households (Cabernard et al. 2019; Wood et al. 2018). One strength of MRIO analysis is its ability to trace the indirect and transboundary environmental pressures required along global supply chains for final consumption (Lafortune et al. 2020; Wiedmann et al. 2020).

Here we apply IO calculus to the Eora26 v199.82[11] for the reference years 1995 to 2015 to compute the RMFs of 51 African countries in the Eora database. The Eora MRIO database has some attractive features relevant to the paper's objectives: (i) it is the only global MRIO database with the most extensive coverage of African countries; and (ii) it embodies sufficiently long time series IO data required to assess the progress of Africa regarding its resource/material use productivity/efficiency based on the MF calculation results. Eora assembles the data on the economic structure of over 50 African countries supplemented with physical data (measured in tonnes) on material extraction of 36 material types from the EW-MFA database[12] maintained by the Commonwealth Scientific and Industrial Research Organisation (CSIRO[13]). For detailed information about integrating raw material data from EW-MFA with the Eora MRIO table, we refer the reader to Wiedmann et al. (2015) and Lenzen, Moran, Kanemoto et al. (2013). For our MF calculations, the 36 materials covered by Eora26 are classified into four broad material types: biomass, fossil fuels, mineral and metal ores (alias ores), and construction materials.

---

[10] https://worldmrio.com/countrywise/

[11] https://worldmrio.com/eora26/

[12] http://www.materialflows.net/

[13] https://www.csiro.au/en/

For the EE MRIO analysis, we extract the following three principal variables from the Eora database (Lenzen et al. 2017):

T: the monetary inter-industry transactions matrix with dimensions (r×n)+1-by-(r×n)+1, containing the inter-industry domestic and trade-related intermediate demand for goods and services for all countries.

Y: the final demand matrix of goods and services by countries with dimensions *(r×n)+1-by-r*k*. To obtain the total final demand for each country in Eora across six final demand categories (household consumption, non-profit institutions serving households, government spending, investment, changes in inventories, and acquisitions minus disposals of valuables), we derive the **y** matrix $(\sum_{k=1}^{n=6}\mathbf{Y}_{ik})$, with dimension, *(r×n)+1-by-r*

x: the economic output per sector for all countries and RoW region with dimensions, 1-by-*(r×n)+1* where *r (r=189)* is the number of countries ('+1', representing the RoW region), *n* $(n = 26)$ represents the number of products and services in Eora, and *k* $(k = 6)$ is the number of final demand categories.

Following the traditional IO Leontief inverse approach, the total direct and indirect (*upstream*) MF **(M)** by material type associated with final consumption in Africa by country and product of origin and destination is calculated as follows:

$$\mathbf{M}_{c} = \widehat{S_{m}}(I - A)^{-1}\widehat{y_{c}} \qquad c=1,\ldots,51,\ m=1,\ldots,5 \qquad (1)$$

Where *'c'* is the index per African country in Eora, and *'m'* represents the five raw material categories: biomass, fossil fuels, construction materials, ores, and total raw materials (the sum of the four material types); $\sum_{r}\sum_{n}\mathbf{M}_{c}$, gives the total MF of country 'c' by material category. **S** is the matrix of the material use intensities across all sectors per country/region (m-by--*(r×n)+1*), calculated as the ratio of the total material extraction by type per sector (tonnes) to the total economic output per sector (USD). **A** $(\mathbf{T}\hat{\boldsymbol{x}}^{-1})$, called the direct input-requirement coefficient/technology matrix, is the global transactions matrix normalized by the total output per sector; **I** is the identity matrix with the same dimension as **A**. The diagonal blocks of **A** with dimensions n-by-n represent the domestic production recipes of sectors for each country/region in Eora. In the same context, the off-diagonal blocks of **A** represent exported (row-wise) and imported (column-wise) components of the production recipes per country/region; $(\mathbf{I} - \mathbf{A})^{-1}$ is the well-known Leontief inverse formula, containing the direct and indirect multipliers related to a change in output per sector due to changes in the final demand of sectors' final products and services. $\widehat{\mathbf{S_m}}(\mathbf{I} - \mathbf{A})^{-1}$ gives a matrix of the total raw material use multipliers per sector and country, representing the total direct and indirect raw materials required to satisfy a unit of final demand.

Hertwich and Wood (2018) and Kitzes (2013) shed more light on the IO equations for modelling the socio-economic and environmental footprints using MRIO databases. Note that for this study, we do not include the direct raw material use related to household consumption in the use phase of the life cycle of products. This is partly because of the paucity of such data for most countries and their related uncertainties presented in Eora (Lenzen et al. 2010; Moran and Wood 2014; Rodrigues et al. 2018).

Although Equation (1) yields all African countries' RMFs by sector and country of origin and destination, we condense the RMF matrix into '**domestic**', '**imported**', and '**exported**' footprints using concordance matrices. Here, '**domestic**' RMFs refer to those associated with the consumption of goods and services produced and consumed in Africa, and '**imported**' RMFs **(also known as raw material equivalents (RMEs) of imports)** are those embodied in goods and services produced abroad but consumed in Africa. The RMFs embodied in imports are also defined as those RMFs displaced by Africa to the RoW through consumption of imported goods and services. By summing domestic and imported RMFs, we estimate the CB RMFs per African country by material type and total. '**Exported**' (**also known as RMEs of exports)** refers to RMFs embodied in Africa's exports of goods and services to the RoW, in other words the MFs outsourced to Africa by the RoW due to their consumption of African goods and services exports. Production-based (PB) RMFs are the sum of domestic and exported MFs. We refer the reader to Lenzen et al. (2022) and Kanemoto et al. (2016) for further explanation of the calculation of environmental footprints embodied in trade using MRIO analysis. Also, using concordance matrices, we aggregate and categorize Africa's trade-related MFs by source and destination world regions (Africa, Europe, North America, South America, and Asia) for Africa's sub-regions (Western, Eastern, Central, Northern, and Southern Africa). See Tables A1 and A2 in Appendix A for the list of African countries and sector classifications in the Eora database considered under this study.

2.4 Regression analysis

Empirical model

In this study, we extend the STIRPAT model (York et al. 2003) to include additional relevant covariates that empirically expound the African narrative on raw material exploitation and consumption. Consequently, we collate a panel dataset from multiple sources covering the period 1995 to 2016 for the main variables of the STIRPAT equation[14] and additional variables covering socio-demographic, economic, institutional, and environmental indicators. We set out to ascertain the effects of these explanatory variables on Africa's PB and CB RMFs separately. However, both regression models suffer from the high-dimensionality[15] problem, as our STIRPAT model has 57 predictors (see Table A3 in Appendix A for a list of all variables).

To reduce the high dimensionality of our model, we apply a shrinkage and feature selection method known as the least absolute shrinkage and selection operator (LASSO) regression (Tibshirani 1996). LASSO regression is a regularization technique useful for mitigating model bias and high variance related to the overfitting of regression models. From a computational perspective, the LASSO approach provides an optimization solution by assembling selected variables out of many variables of a given regression model (Tibshirani et al. 2005). It derives each variable's respective optimal regression coefficients while minimizing the mean sum of squared errors for the model's response variable by applying a penalty (Centofanti et al. 2022). Put differently, the regression coefficients of the model's less influential explanatory variables relative to the dependent variable approach zero or become zero and are dropped by LASSO. It is worth noting that a number of the predictors in our regression model are highly correlated, indicating the problem of multicollinearity, a limitation of the accuracy and reliability of regression coefficient results. However, an advantage of applying LASSO here lies in its in-built solution to multicollinearity by identifying and excluding highly correlated predictors with low explanatory effects (Zou and Hastie 2005). Additional theoretical explanations of the LASSO regressions can be obtained from Hesterberg et al. (2008). Within the STIRPAT framework, we performed multiple multi-variate panel regression analyses on our data, namely pooled ordinary least squares (OLS) regression,

[14] https://mahb.stanford.edu/library-item/a-brief-history-of-ipat-impact-population-x-affluence-x-technology/

[15] https://www.sciencedirect.com/topics/computer-science/high-dimensionality

country fixed effects (FE), two-way FE, time-effects, and random-effects (RE) models, to ensure the robustness of our estimates.

It should be noted that, based on the results of the LASSO regression, some predictors selected to model and identify the drivers of Africa's CB and PB RMFs did not appear in both regression models. To answer our research question regarding the factors influencing the trends of Africa's RMFs, we settle on and make inferences from the panel country FE regression model results. The FE regression model captures correlations between our observed variables in Equation (2) and unobserved variables, the effects of those variables that remain stable over the period studied (Greene 2017). The FE model tests our hypotheses by incorporating the within-country changes to the CB and PB RMFs per African country, eliminating the time-invariant country specific-properties. Also, the country FE model accounts for all heterogeneity among countries that our models' predictors do not capture. Using panel regression analysis, we estimate an extended version of the STIRPAT model for an African country, i *(i=1...51)* at time *'t' (t=1995…2015)* as follows:

$$\ln(MF_{it}) = \beta_0 + \beta_1 \ln(P_{it}) + \beta_2 \ln(A_{it}) + \beta_3 \ln(T_{it}) + \theta_1 \ln(Z_{1,it}) + \ldots + \theta_k \ln(Z_{k,it}) + \delta_i + \varepsilon_{it} \quad (2)$$

where MF_{it} is either the total PB RMF, CB RMF, RMF embodied in the imports or exports of country 'i' at time 't', Z_{it} is a set of 'k' additional predictors, δ_i is the country FE, and ε_{it}, is the error term.

Covariates data

The RMF, the dependent variable of our panel regression models, is measured in metric tonnes. The RMFs of 51 African countries in the Eora database are computed and obtained from Equation (1). To quantify the determinants of Africa's RMF, we identified various socio-demographic, economic, and institutional indicators correlated with environmental footprints established in previous studies by Bjelle et al. (2021), Ivanova et al. (2017), and Wiedmann et al. (2015). We employ the LASSO, a machine learning technique, to select the predictors strongly influencing African RMFs. Some notable strong predictors of RMFs used in this study include population, per capita GDP, natural resource rents, corruption, foreign direct investment (FDI), economic value added, and energy use. A full description of and sources for all the variables selected using LASSO are shown in Table A4 in Appendix A.

3 Results and discussion

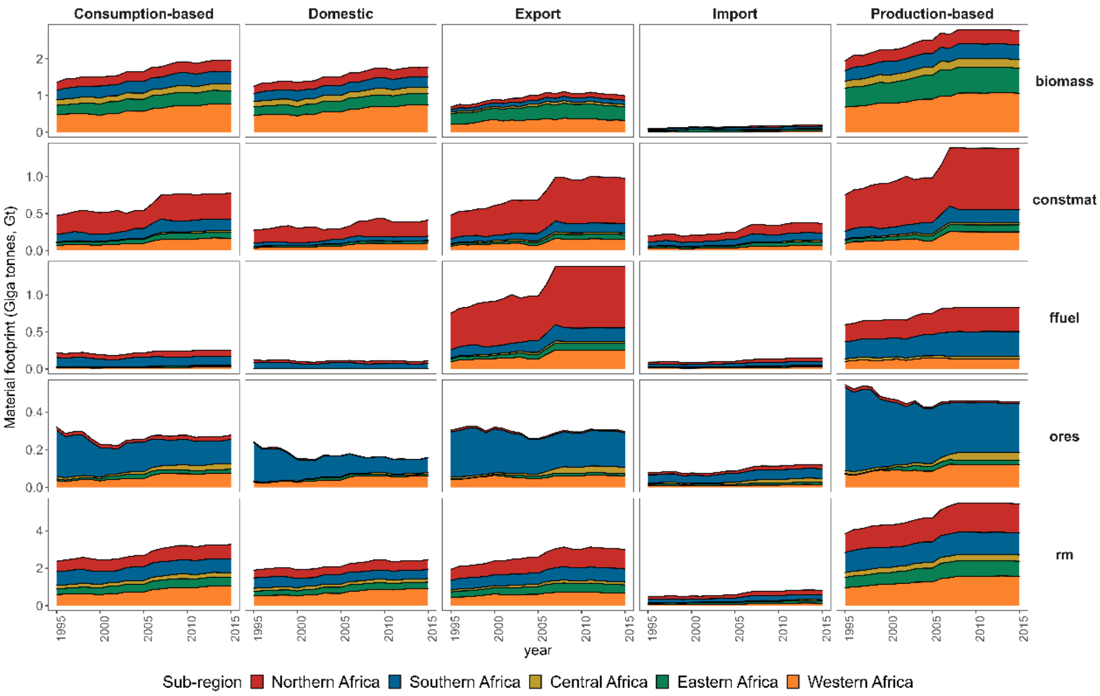
In this section, we present a summary of the pattern and composition of Africa's PB and CB RMFs between 1995 and 2015. We also present the trends in Africa's trade-related RMF compared to its domestic RMF.

3.1 Trends in production-based material footprints

Figure 2 illustrates the trends of Africa's total PB and CB RMFs by region and material type over the period studied, while Figure 3 demonstrates the trend in the PB and CB RMF of African nations. In 2015 Africa's total PB RMF was 5,436 Mt, up from 3,843 Mt in 1995 (+41 per cent). While Southern Africa accounted for the largest share of Africa's PB RMF in 1995 (28 per cent), Western Africa and Northern Africa were joint-top contributors in 2015, with 29 per cent of the total apiece. Nigeria (15.38 per cent), South Africa (14.48 per cent), and Egypt (13.14 per cent) accounted for slightly more than two-fifths of Africa's PB RMF in 2015. In 2015 Southern Africa dominated Africa's PB MF for ores (40 per cent) and fossil fuels (28 per cent), while Nigeria (22 per cent) and Egypt (29 per cent) were the largest contributors to Africa's PB biomass and construction MFs, respectively. In 2015 biomass comprised more than half of Africa's PB RMF (51 per cent), followed by construction materials (20 per cent) and fossil fuels (16 per cent). We observe that the share of ores in Africa's PB RMF declined sharply from 14 per cent in 1995 to 8 per cent in 2015, representing a 90 Mt dip in Africa's PB ore footprint in absolute terms during the period studied (-16 per cent).

While ores were the single largest category of Northern Africa's PB RMF in 2015 (53 per cent or 829 Mt), biomass formed the largest fraction of the PB RMF in all other African regions. Africa's PB biomass footprint increased by 42 per cent (+818 Mt) over the period studied, with Nigeria accounting for a quarter of this increase. During the period studied, the share of biomass in the PB RMF of African regions declined by 2–7 per cent, except for Southern Africa, where we observed an increase of 7 per cent. The PB construction materials footprint increased across all African regions over the period studied (+631 Mt), with Northern Africa (+338 Mt) and Western Africa (+156Mt) contributing to more than half of the increase. Egypt, Algeria, Nigeria, Morocco, and South Africa drove 67 per cent of Africa's PB construction MF growth over the period. Africa's PB fossil fuel footprint increased by 39 per cent (329 Mt) between 1995 and 2015. Angola (68 Mt), Algeria (49 Mt), South Africa (41 Mt), Nigeria (30 Mt), and Libya and Egypt (22 Mt apiece) accounted for close to 70 per cent of the rise. The PB fossil fuel footprint rose more than 1.4-fold in Southern Africa (+110 Mt) and Northern Africa (+94 Mt) between 1995 and 2015. In 2015 Eastern and Central Africa's PB ore footprints were five and three times larger, respectively, compared to 1995. We observed the largest drop in country-level PB ore footprint during the period studied for South Africa (196 Mt or 25 per cent), although it increased greatly in DR Congo (+31 Mt), Zambia (+24 Mt), Tanzania (+18 Mt), Mali (+17 Mt), and Ghana (+14 Mt).

Figure 2: Africa's total raw material footprint by source and material type from 1995 to 2015



Source: based on the authors' calculation from Equation (1) using Eora global MRIO database.

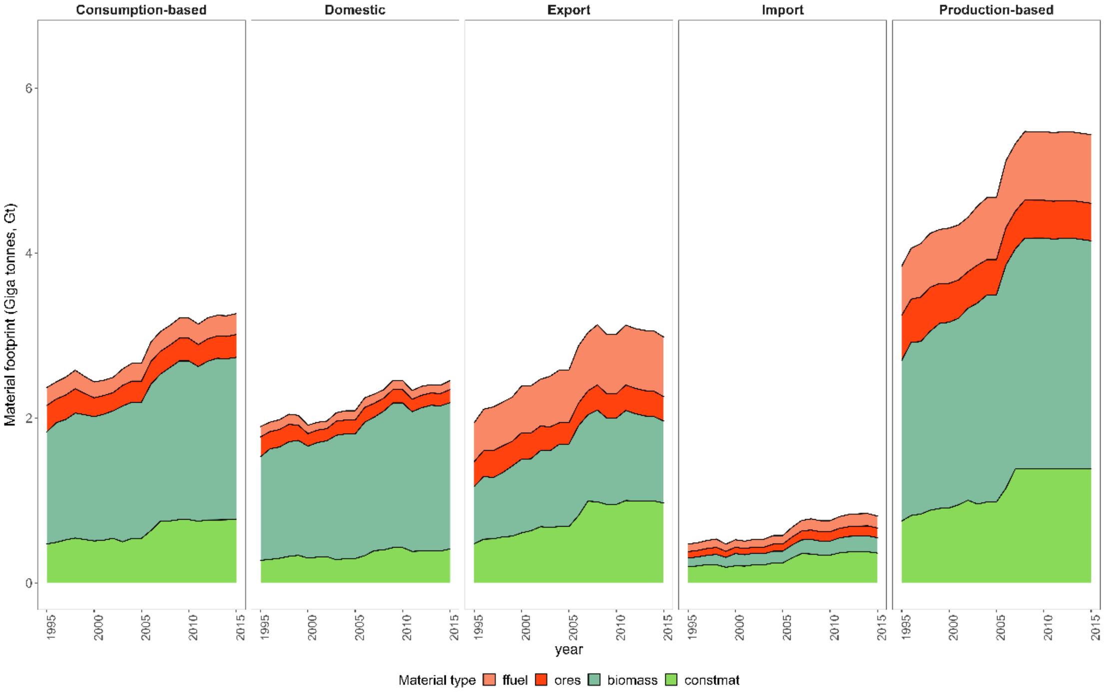
The material categories are as follows: (i) total raw materials (i.e. **rm**), which is the sum of biomass, construction materials (i.e. **constmat**), ores, and fossil fuels (i.e. **ffuel**); (ii) 'domestic', which refers to the MFs of Africa's consumption of locally produced goods and services; (iii) 'import', which refers to footprints embodied in African imports; and (iv) 'export', which refers to MFs embodied in African exports. 'consumption-based' MF is the sum of 'domestic' and 'import' while 'production-based' MF is the sum of ' domestic' and 'export'

3.2 Trends in consumption-based material footprints

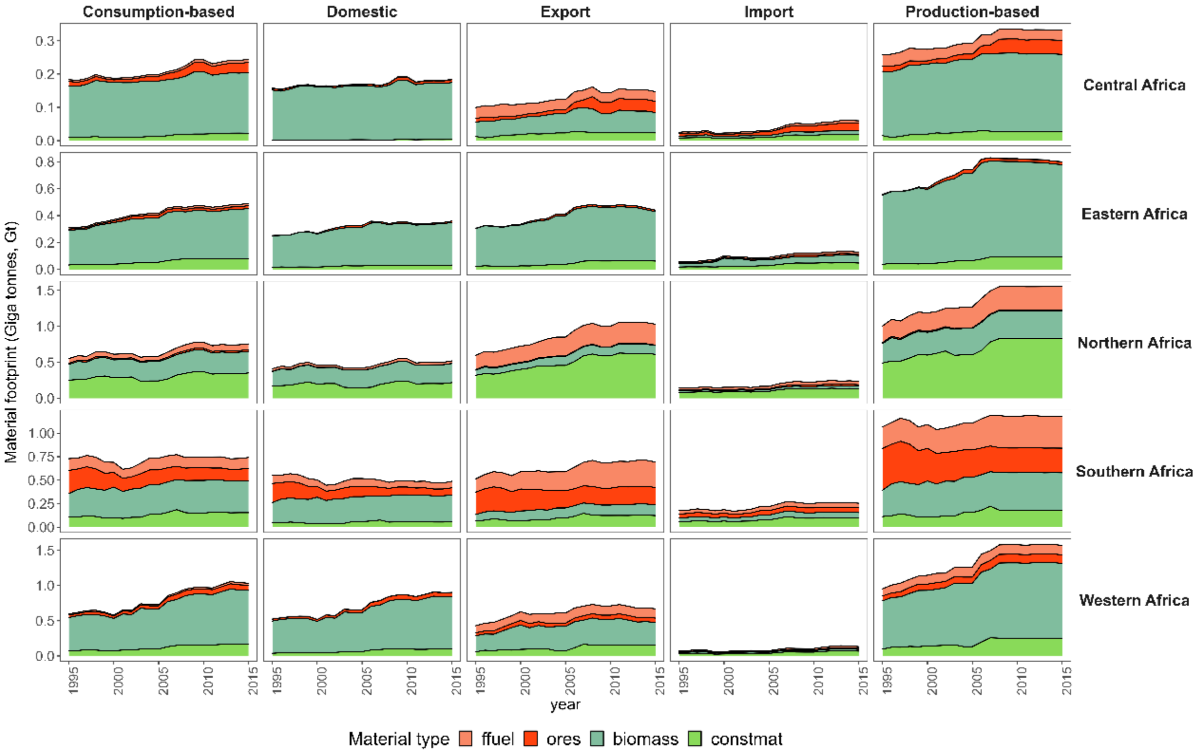
Figure 3 exemplifies the MFs of Africa by material type and African sub-regions over the period studied. Over the period Africa's CB RMF reached a peak of 3,266 Mt (3.39 t cap^{-1}) in 2015 from 2,371 Mt (2.84 t cap^{-1}) in 1995, representing growth of 38 per cent. The CB RMF growth in Western Africa accounted for 49 per cent (+438 Mt) of the total increase in Africa's CB RMF over the period. Indeed, Western Africa contributed the largest share of Africa's total RMF (32 per cent) in 2015, overtaking Southern Africa (31 per cent), the highest contributing region in 1995. Between 1995 and 2015 the CB RMF of all African regions increased, with the largest growth observed for Western Africa (+438 Mt or +73 per cent), followed by Northern Africa (+204 Mt or +37 per cent), and Eastern Africa (+180 Mt or +58 per cent). Ten African countries made up 70 per cent of Africa's CB RMF footprint in 2015—Nigeria (17 per cent), South Africa (15 per cent), Egypt (14 per cent), Kenya (5.02 per cent) and DR Congo (4.64 per cent) were among the top five (see Figure 4).

Figure 3: The trends in the raw material footprints of Africa (panel A) and African nations (panel B), by source and material type from 1995 to 2015

A.

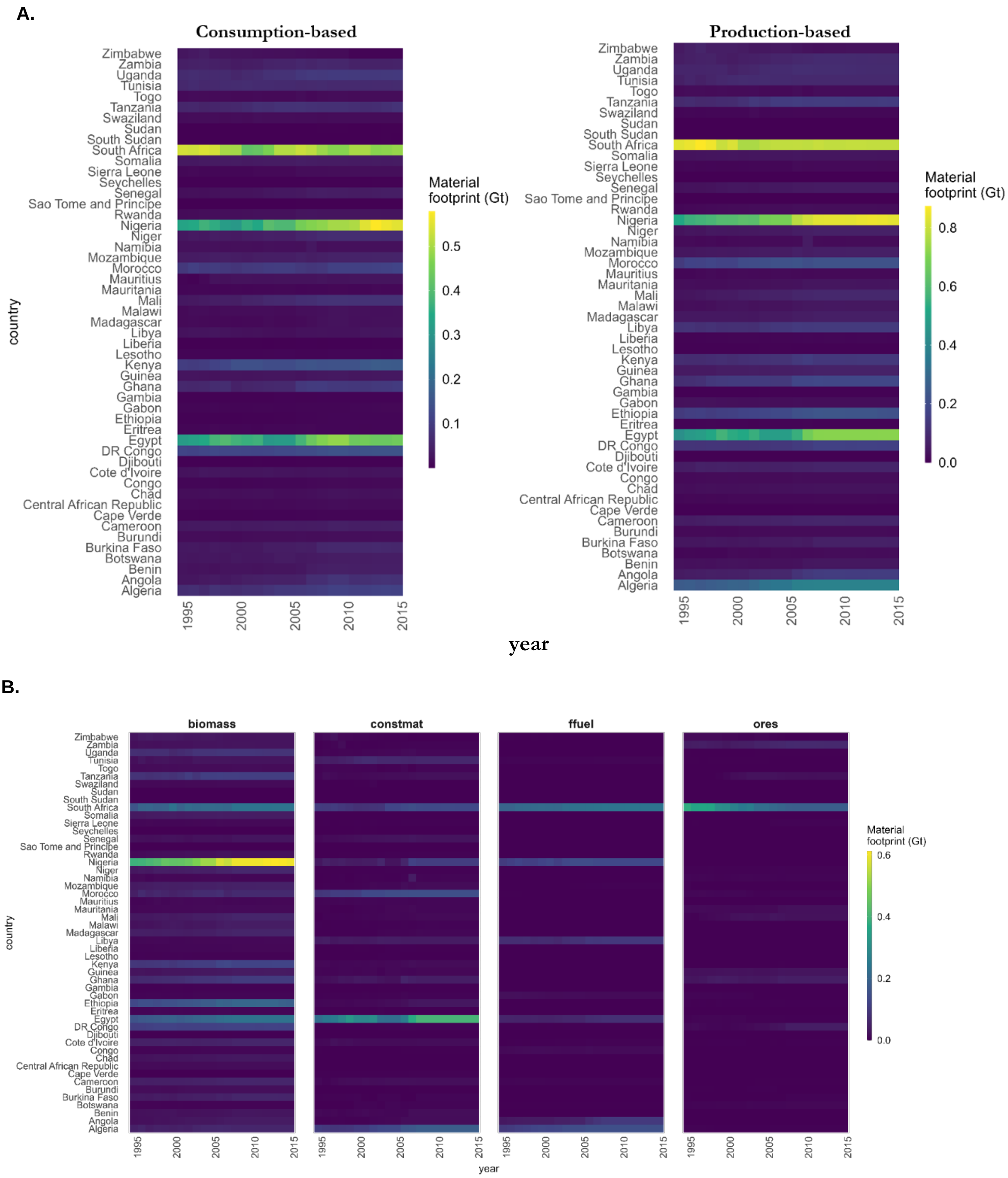


B.

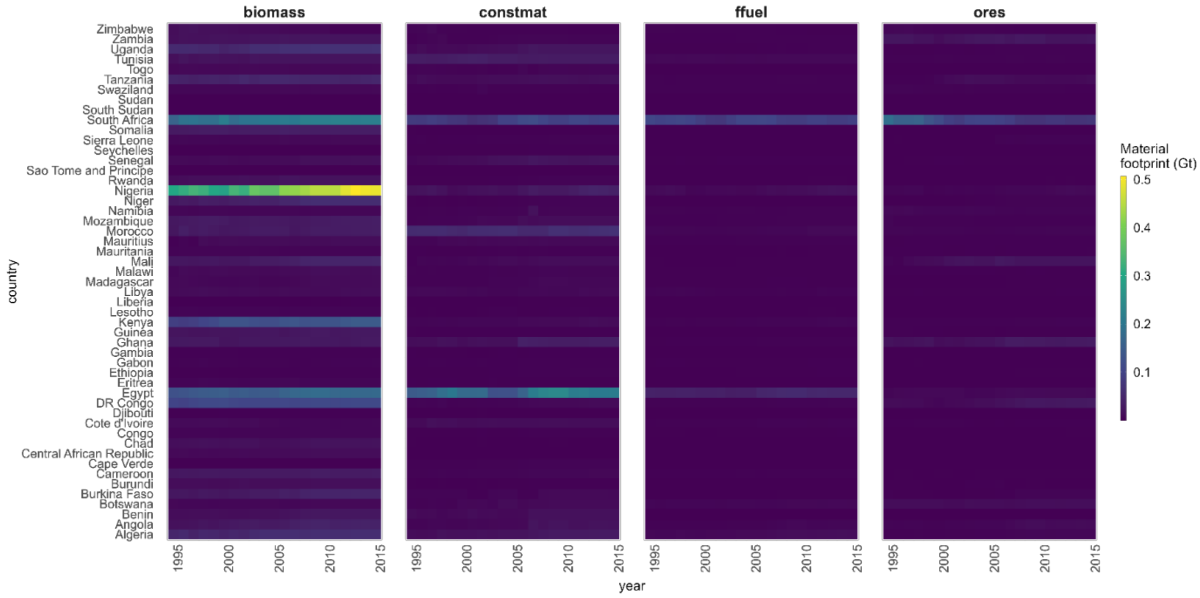


Source: based on the authors' calculation from Equation (1) using Eora global MRIO database.

Figure 4: The trends in African nations' total production (panels A & B) and consumption-based raw material footprints (panels A & C) by material category, from 1995 to 2015



c.



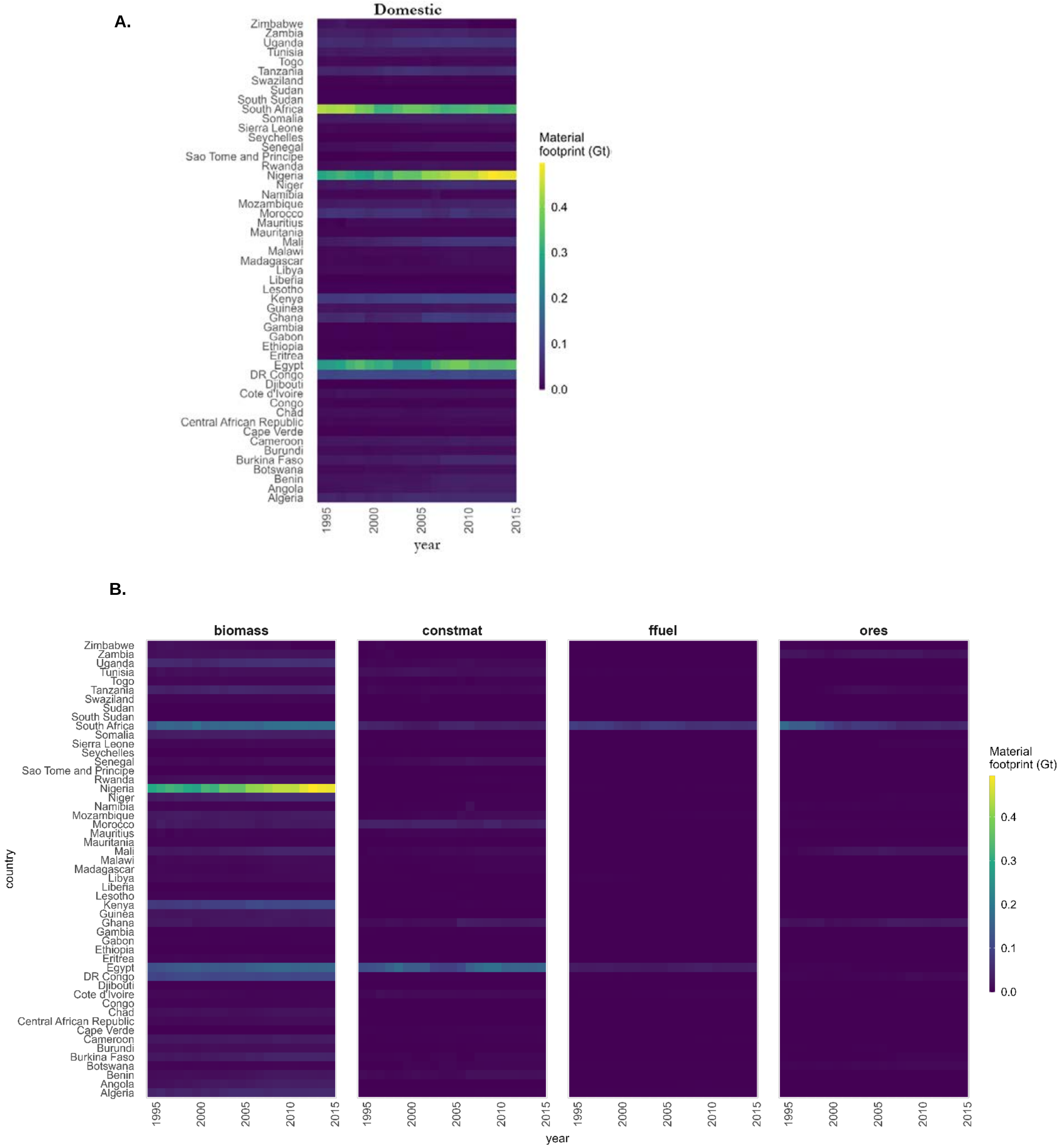
Source: based on the authors' calculation from Equation (1) using Eora global MRIO database.

In 2015 biomass constituted the largest portion of Africa's CB RMF (60 per cent), followed by construction materials (24 per cent), mineral ores, and fossil fuels (8 per cent apiece). The biomass share in national RMF ranged from 14 per cent for Cape Verde to 96 per cent for the Central African Republic and Chad. Zambia had the highest share of ores in the national CB RMF (44 per cent) in 2015, while Cape Verde had the highest share of construction materials in CB RMF (78 per cent) per country. In the same context South Africa and Botswana had joint-highest shares for fossil fuels (19 per cent) in national CB RMF. While Africa's CB mineral ores footprint decreased by 13 per cent (42 Mt) from 1995 to 2015, its CB biomass, construction materials, and fossil fuel footprints increased by 44 per cent (+601 Mt), 64 per cent (+302 Mt), and 16 per cent (+35 Mt), respectively. From 1995 to 2015 the CB mineral ores and fossil fuel footprints increased in all African regions except for Southern Africa, where we observed reductions of 48 per cent and 6 per cent, respectively. In 2015 Western Africa dominated Africa's CB biomass footprint (39 per cent), while Southern Africa dominated Africa's CB ores and fossil fuel footprints (46 per cent each). Northern Africa was an important contributor to Africa's CB construction materials footprint (45 per cent of the African total for that material category). Central Africa had the lowest CB RMF across all material types compared to the other African regions.

3.3 Domestic material footprints

Figure 4 displays the MFs within the borders of all African countries due to the final consumption of locally produced goods and services over the period studied. A chunk of Africa's MFs across the different material types occurred within the national borders of African countries. In 2015 the domestic RMF of Africa stood at 2,454 Mt, having risen by 29 per cent from 1,898 Mt in 1995. In 2015 Nigeria (20 per cent), Egypt (14.44 per cent), South Africa (13.62 per cent), DR Congo (4.60 per cent), and Kenya (4.46 per cent) ranked among the top five countries contributing to Africa's domestic RMF.

Figure 5. The trends in the domestic material footprints of African nations (Panel A) by material category (Panel B), from 1995 to 2015



Source: based on the authors' calculation from Equation (1) using Eora global MRIO database.

In 1995 and 2015 biomass was the single largest category of Africa's total domestic MF, even though its importance increased from 66 per cent in 1995 to 72 per cent in 2015. Next to biomass were construction materials (17 per cent) and ores (6 per cent) in 2015. Also in 2015 Nigeria (27 per cent) and Egypt (39 per cent) dominated Africa's domestic MFs for biomass and construction materials, respectively, while South Africa contributed the most to the continent's domestic ore (32 per cent) and fossil fuel (60 per cent) footprints. Southern Africa, closely followed by Western Africa at the regional level, accounted for more than half of Africa's domestic MFs in 1995. However, Western Africa and Northern Africa's share in Africa's total domestic MFs exceeded Southern Africa's in 2015, with Western Africa making up the single largest share of 37 per cent of Africa's domestic RMFs. Western Africa and Northern Africa had the largest biomass and construction MFs, respectively, compared to other regions. Over the period studied, national domestic MFs increased for all countries except South Africa (101 Mt), Zimbabwe (18 Mt), and Namibia (0.05 Mt). Nigeria (+181 Mt), Egypt (+87 Mt), Mali (+47 Mt), and Niger (+35 Mt) were observed to have the biggest increase in domestic MF at the country level. Africa's domestic MF decreased by 34 per cent (82 Mt) for ores and by 14 per cent (17 Mt) for fossil fuels over the period studied but increased by 41 per cent (518 Mt) for biomass and by 50 per cent (137 Mt) for construction materials.

3.4. Trade-linked material footprints

Figure 6 presents the African nations' RMF from the production of exports and final consumption of imports between 1995 and 2015. Over the period, the RMF embodied in African exports increased by 53 per cent, from 1.95 Gt in 1995 to 2.98 Gt in 2015. The MF embodied in African exports increased for almost all African countries, except for Zimbabwe, Mauritius, Gabon, Benin, Niger, Uganda, Somalia, and Eritrea. South Africa (15 per cent), Egypt (12.08 per cent), and Nigeria (11.95 per cent) accounted for 39 per cent of the RMF embodied in African exports in 2015. However, together, Egypt (+192 Mt), Nigeria (+132 Mt), Algeria (+124 Mt), Angola (+79 Mt), and Ethiopia (+75 Mt) were responsible for 60 per cent of the growth in RMF embodied in African exports between 1995 and 2015. Biomass accounted for the single largest share in the RMF embodied in African exports (36 per cent) in 2015, followed by construction materials (25 per cent), which was closely followed by fossil fuels (24 per cent). Interestingly, ores contributed the least share of RMF embodied in Africa's exports (16 per cent) that year.

The construction MF embodied in African exports increased two-fold from 447 Mt in 1995 to 971 Mt in 2015. This growth was mainly driven by a large increase in the construction materials footprint embodied in exports for some countries, particularly Egypt (+141 Mt), Nigeria and Algeria (+75 Mt each), Morocco (+56Mt), and South Africa (+41.27 Mt). In 2015 Eastern Africa contributed 37 per cent of the biomass footprint embodied in African exports, followed by Western Africa (33 per cent) and Northern Africa (12 per cent). That year, Ethiopia had the largest biomass footprint embodied in African exports (186 Mt or 19 per cent of total), while South Africa dominated the ore footprint embodied in Africa's exports (131 Mt or 44 per cent of total). In 2015 three Northern African countries, Egypt (25 per cent), Algeria (18 per cent), and Morocco (11 per cent), contributed to over half of Africa's construction MF embodied in exports.

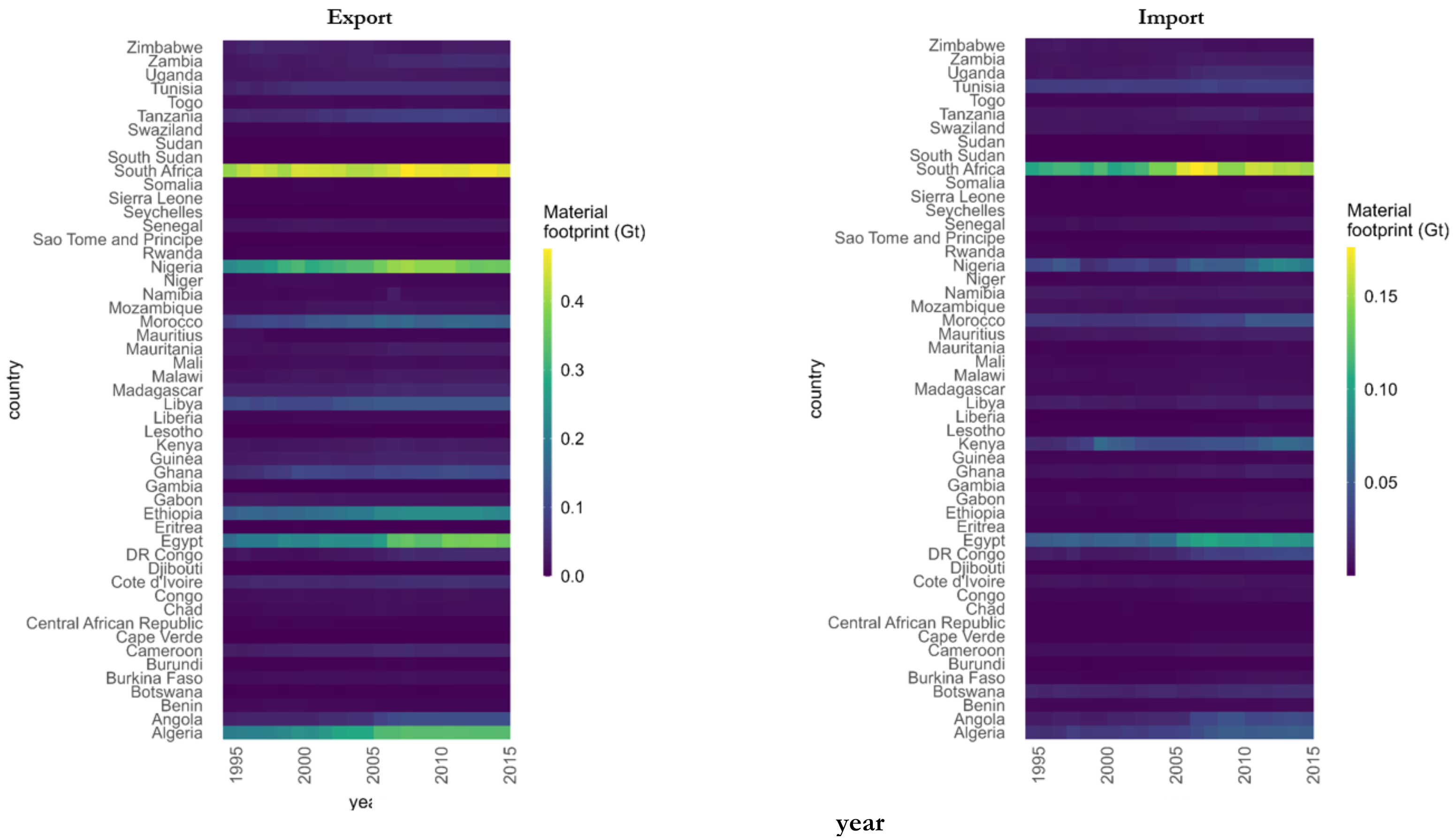
The fossil fuel footprint embodied in African exports was highest in South Africa (170 Mt), representing 23 per cent of the African total in 2015, followed by Algeria (144 Mt or 20 per cent), and Nigeria (130 Mt or 18 per cent). Western Africa and Central Africa made up more than a third (32 per cent) of the ore footprint embodied in Africa's export in 2015—DR Congo (11 per cent), Mauritania (8 per cent), Guinea (6 per cent), and Ghana (4 per cent) were notable contributors to the continent's total. Over the period studied the share of Northern and Southern Africa in the ore footprint embodied in African exports dropped (from 79 per cent to 62 per cent and from 3 per cent to 2 per cent, respectively), while that of Western, Central, and Eastern African increased, particularly for Central Africa (from only 3 per cent in 1995 to 11 per cent in 2015). However, the reduction in the continents' ore footprint embodied in exports between 1995 and 2015 was marginal (8 Mt) as the increase in ore footprint embodied in Western, Eastern, and Central African exports outweighed reductions in the ore footprint embodied in Northern and Southern Africa. At the country level the reduction was driven by significant reductions in the ore footprint embodied in the exports of South Africa (76 Mt), Zimbabwe (6 Mt), and Gabon (4 Mt).

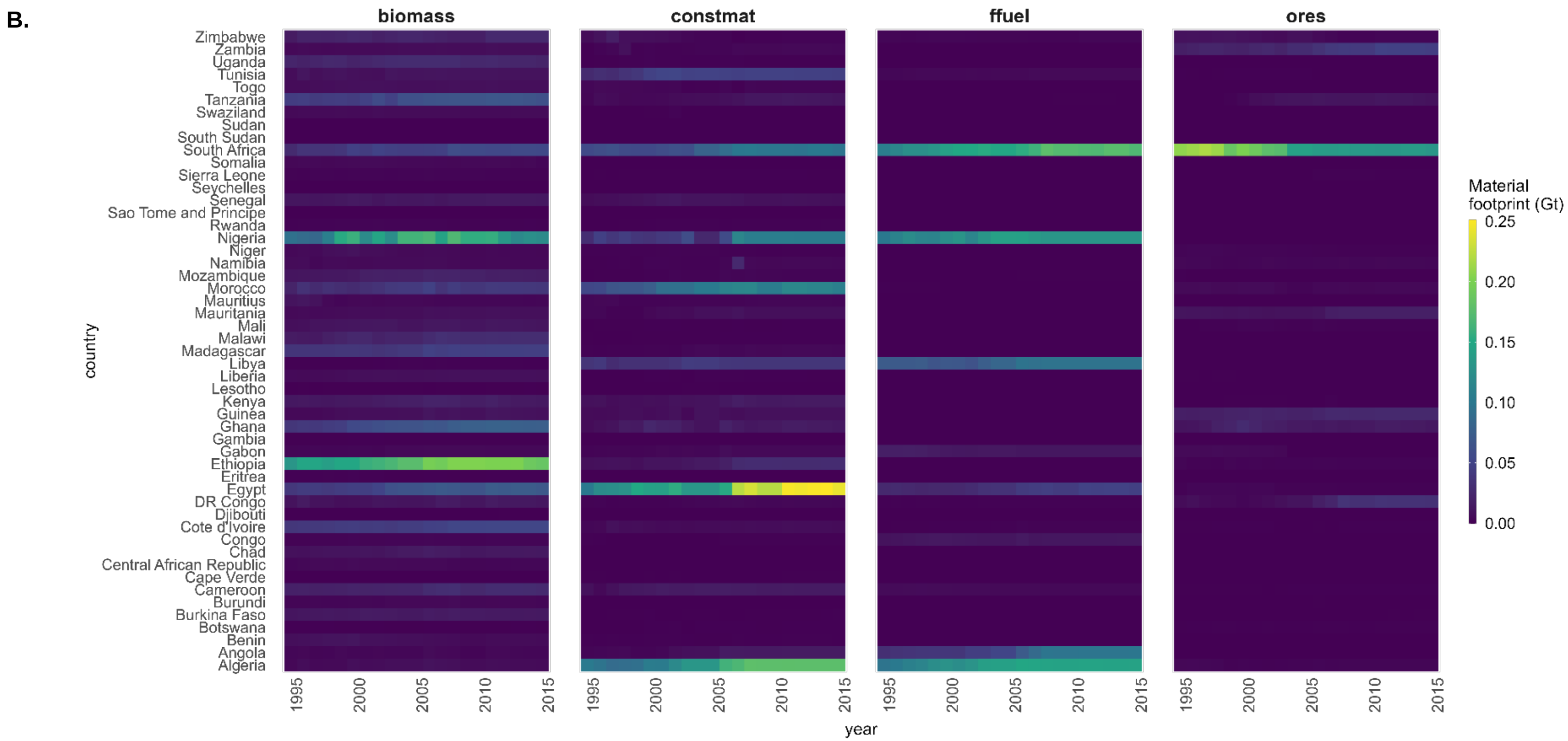
The RMF embodied in Africa's imports rose two-fold from 473 Mt in 1995 to 812 Mt in 2015. Indeed, it was 20 per cent of Africa's CB RMF in 1995 and increased to 25 per cent in 2015. Over the period studied the RMFs embodied in African imports increased for all material types, ores (+285 Mt), construction materials (+165 Mt), fossil fuels (+52 Mt), and biomass (+82Mt). In 2015 the RMFs embodied in Africa's imports ranged from 118 Mt for ores to 364 Mt for construction materials. The construction materials (45 per cent) and biomass (23 per cent) categories comprised 68 per cent (550 Mt) of the RMFs embodied in African imports in the same year.

At the regional level the two biggest importers of RMFs in 1995 and 2015 were Northern and Southern Africa. Compared to all regions Northern Africa outsourced the highest RMF from abroad for the biomass, ores, and fossil fuels categories, and Southern Africa was highest for construction materials. Moreover, in 2015 South Africa accounted for the single largest share of the RMFs embodied in African imports for ores (20 per cent), construction materials (17 per cent), and fossil fuels (19 per cent). That year, the top two biggest importers of biomass footprints on the continent were Kenya (36.43 Mt) and South Africa (36.16 Mt). DR Congo and Angola were biggest for ore footprints, and Egypt and Nigeria for both construction materials and fossil fuel footprints. The RMF embodied in African imports increased for more than two-thirds of the African countries in our study between 1995 and 2015, with South Africa (+47 Mt), Egypt (+39 Mt), Kenya (+37 Mt), Nigeria (+35 Mt), and Angola (+28 Mt) ranked among the top five countries with the highest growth. Across the continent, South Africa was observed to have recorded the highest increase in the construction material (+23 Mt) and fossil fuel (+8 Mt) footprints embodied in its imports, while Kenya (+25 Mt) and DR Congo (+13 Mt) dominated growth in imported biomass and ore footprints, respectively, at the national level.

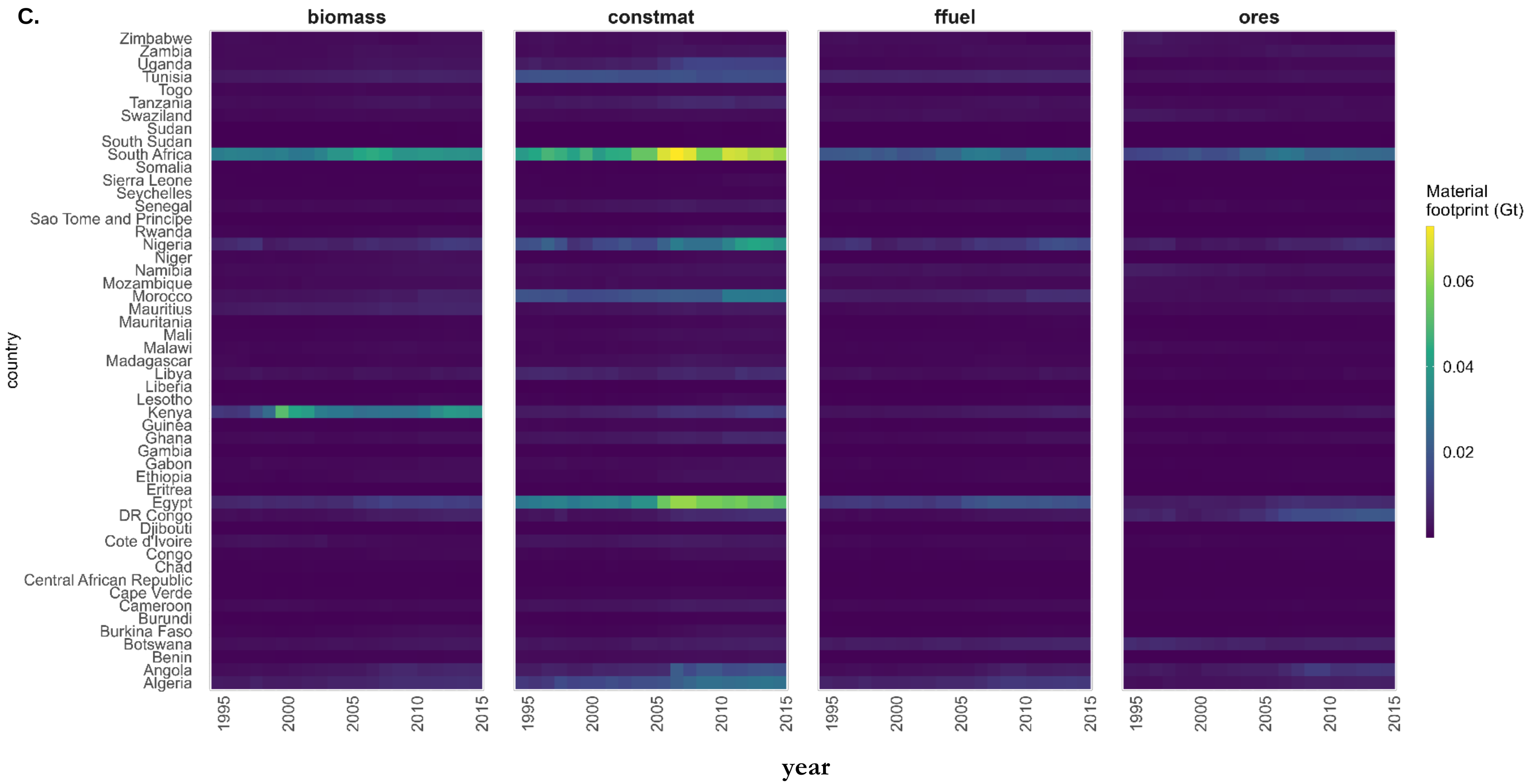
Figure 6: The trends in the raw material footprints embodied in the African exports (Panel A & B) and imports (Panel B & C) by material category from 1995 to 2015

A.




B.
biomass
constmat
ffuel
ores
country
Zimbabwe
Zambia
Uganda
Tunisia
Togo
Tanzania
Swaziland
Sudan
South Sudan
South Africa
Somalia
Sierra Leone
Seychelles
Senegal
Sao Tome and Principe
Rwanda
Nigeria
Niger
Namibia
Mozambique
Morocco
Mauritius
Mauritania
Mali
Malawi
Madagascar
Libya
Liberia
Lesotho
Kenya
Guinea
Ghana
Gambia
Gabon
Ethiopia
Eritrea
Egypt
DR Congo
Djibouti
Cote d'Ivoire
Congo
Chad
Central African Republic
Cape Verde
Cameroon
Burundi
Burkina Faso
Botswana
Benin
Angola
Algeria
1995
2000
2005
2010
2015
year
Material footprint (Gt)
0.25
0.20
0.15
0.10
0.05
0.00

year



Source: based on the authors' calculation from Equation (1) using Eora global MRIO database.

3.5 Regression results

In this section, we outline and discuss the relationship between all RMFs (CB RMF and PB RMF) and their components (domestic, imports, and exports) and the selected socio-demographic, economic, and institutional indicators based on the LASSO regression. To throw more light on our discussions, we also present regression estimates of the relationship between the sub-components of RMF-biomass, construction, fuel, and iron ores (see Tables B1–B3 in Appendix B).

Consumption-based footprint drivers

We begin with the panel regression estimates of all the selected indicators on the CB RMF and its domestic and imported components (see Table 1). Starting with the socio-demographic indicators, we find a positive and significant relationship between the total population, population density, and CB RMF. Population density seems to have a much stronger effect on CB RMF than the total population. Our findings largely agree with studies which suggest that population growth is often associated with rising demand for goods and services, invariably driving higher raw material extraction and consumption (see Schandl et al. 2018). We also observe a significant positive relationship between the urban population and domestic RMF. This observation supports the earlier empirical evidence that urban population growth is associated with a rise in household consumption and MFs.

Table 1: Panel fixed effects regression results: consumption-based footprints and components

	Dependent variables		
Variables	**Consumption-based material footprints (1)**	**Domestic material footprints (2)**	**Material footprints embodied in imports (3)**
Socio-demographic			
Population (count)	0.594*** (0.114)	-0.106 (0.21)	0.517*** (0.081)
Population density (people per sq. km of land area)	0.107*** (0.036)	0.203*** (0.066)	0.134*** (0.025)
Population of young dependants (% of population)	-1.855*** (0.163)	-1.787*** (0.301)	-1.769*** (0.116)
Urban population (count)	0.067 (0.124)	0.757*** (0.229)	0.075 (0.088)
Economic			
GDP per capita (USD PPP)	0.094*** (0.033)	0.157** (0.061)	0.178*** (0.023)
Agriculture value added (% of GDP)	-0.368*** (0.061)	-0.382*** (0.113)	-0.396*** (0.043)
Industry value added (% of GDP)	0.442*** (0.056)	0.633*** (0.104)	0..304*** (0.04)
Service value added (% of GDP)	-0.0002 (0.053)	-0.1 (0.099)	0.097** (0.038)
Tot. nat. resources rents (% of GDP)	0.178*** (0.056)	0.388*** (0.104)	0.094** (0.04)
Oil rents (% of GDP)	-0.261*** (0.059)	-0.555*** (0.109)	-0.094** (0.042)
Mineral rents (% of GDP)	0.046 (0.07)	0.007 (0.129)	0.045 (0.049)
Human Development Index	-1.950*** (0.416)	-3.259*** (0.77)	0.435 (0.296)
Foreign direct investment, net inflows (% of GDP)	0.0004 (0.008)	0.001 (0.014)	0.010* (0.005)

Economic			
Real effective exchange rate index (2010=100)	0.033*** (0.018)	0.108*** (0.034)	-0.005 (0.013)
Central government debt (% of GDP)	-0.021 (0.033)	-0.054 (0.06)	-0.003 (0.023)
Income of top-10 (% of GDP)	0.051* (0.028)	0.075 (0.052)	0.047** (0.02)
Institutional and governance			
Additive polyarchy index	-1.025 (0.738)	-2.542* (1.365)	0.447 (0.524)
Political corruption index	3.096*** (0.472)	6.417*** (0.873)	-0.443 (0.335)
Rule of law index	1.294** (0.514)	2.995*** (0.95)	-0.593 (0.365)
Multiplicative polyarchy index	-0.119 (0.537)	-0.522 (0.994)	-0.794** (0.382)
Government accountability index	1.037*** (0.136)	1.975*** (0.251)	0.687*** (0.097)
Government effectiveness	-0.055 (0.042)	-0.086 (0.077)	1.513*** (0.03)
Environment			
Energy use (oil-eq ktoe)	0.019 (0.013)	-0.02 (0.023)	0.043*** (0.009)
Observations	*1,071*	*1,071*	*1,071*
R^2	*0.588*	*0.417*	*0.732*
Adjusted R^2	*0.57*	*0.393*	*0.721*
F Statistic	*63.611*** (df = 23; 1027)*	*31.951*** (df = 23; 1027)*	*122.087*** (df = 23; 1027)*

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses. PPP means purchasing power parity.

Source: based on authors' regression modelling of Equation (2).

The portion of young dependents in Africa's population has a negative and significant relationship with its RMFs, implying a decrease in RMFs from growth in the population of young dependents. This finding confirms the paltry contribution of the young global population to RMFs, mainly due to their low consumption levels. Regarding the economic indicators, we observe a significant and positive correlation between GDP per capita, industry value added, total natural resource rents, the income share held by the highest 10 per cent of the population, real exchange rate, and CB RMF. Our results align with earlier studies which indicate that the demand for raw material-reliant goods and services increases income levels in countries and potentially increases CB RMF.

Turning to the share of industry value added in GDP, a proxy for industrialization, the estimate suggests that CB RMF is likely to rise as African countries become more industrialized. The rise in CB RMF can be linked to increased exploitation of natural resources in Africa to meet local and foreign demand for goods and services, as shown in the effects of the industry value added on domestic and imported RMFs (see columns 2 and 3 in Table 1).

Research which addresses income inequality and environmental pressures worldwide reveals that the rich tend to have high levels of spending and MFs. The positive relationship for the income of the top ten is more pronounced for RMFs embodied in imports. Our result points to the well-documented changing appetite, diverse tastes, and affluent lifestyles of Africa's wealthy elite population (The Economist 2017). The positive relationship between the real effective exchange rate and the CB RMF and its domestic component can be explained by the pass-through effect of exchange rates on the price, trade, and consumption of goods and services. The real exchange rate increase results in reduced inflation locally, which could boost domestic consumption of local goods and exports in the long run.

The following variables negatively affect CB RMF: agriculture value added, oil rents, and human capital index. Our findings suggest that increased value addition in Africa's agricultural sector will likely reduce Africa's CB RMF. These results are likely related to the fact that most African countries are producers and mostly export primary agricultural products, often converted into processed/manufactured foods with soaring demand overseas. Another explanation could be the growing share of manufactured raw materials and final products in Africa's production and gross output, respectively, both signifying important strides on the continent towards industrialization and less dependence on raw materials. Indeed, Africa's output of manufactured goods has increased two-fold over the last decade (AFDB 2011).

For oil rents our results reflect the story of the natural resource curse in Africa, which is replete in the literature. Africa's over-reliance on the windfalls from primary raw material exports exposes the continent to the damming repercussions of global recessions, including a fall in commodity prices and rents. Moreover, corruption and extreme rent-seeking imply that most oil rents received by African governments are enjoyed by a few elites, mismanaged, and unevenly distributed across the population (van der Ploeg 2010). To this end higher oil rents may not instigate the high levels of local production and private and public investment/spending needed to drive material consumption and footprints. Researchers have established a connection between oil rents and capital flight (Ndikumana and Sarr 2019), a possible explanation for the propensity for lower CB RMFs in Africa from increasing oil rents.

The Human Development Index (HDI) regression estimate implies that, as the African population becomes more developed, Africa's CB RMF may diminish through strong and comprehensive education and health systems that empower Africans to be resource use-efficient. Well-educated populations tend to be informed about the diverse benefits of producing more with fewer resources and sustainable lifestyles that alleviate the increasing pressure on natural ecosystems. A higher HDI could signify better chances and flexibility for households, firms, and governments to shift to material-efficient products and technologies that reduce natural resource consumption, waste, and CB RMFs.

Institutional and governance indicators, such as political corruption, the rule of law, and government accountability, positively correlate with CB RMF. Political corruption has by far the largest positive effect on Africa's CB RMF in this study. This result supports endemic political corruption's role in fostering high and needless discretionary spending in most African states, which tends to ramp up raw material extraction and consumption in different sectors of the economy. Some authors suggest that the public spending of most African governments seems to peak in the run-up to elections, fuelled by vote-seeking measures such as illicit money handouts to electorates and increased quick and shoddy infrastructural projects (Lindberg 2003). Many studies have shown that capital expenditures are higher in high natural resource-consuming countries under high-quality governance (Sedgo and Omgba 2022). The results for the rule of law and government accountability support the argument that Africa's CB RMF is likely to rise when effective governance on the continent advances inclusive development and public expenditure, lifts Africans out of poverty, and increases the demand for goods and services (Dramane 2021).

We find a positive and significant relationship between energy use and the RMFs embodied in African imports. Our finding points to the high dependence of African countries on the rest of the world for their energy consumption, particularly refined oil and fuel products—a significant share of whose feedstocks are sourced from Africa. Also, our findings corroborate earlier studies which associate high energy consumption with increasing global material demand, particularly for petroleum and coal, primary metals, and non-metallic minerals and chemicals (IEA 2019b). Here we observe a positive and significant correlation between Africa's CB ore and fossil fuel footprint, stressing the importance of fossil fuels in meeting the continent's energy needs (see Tables B1 and B2 in Appendix B). Our results support calls for improvements in the energy efficiency of manufacturing industries and households to meet the global SDGs and climate goals against the backdrop of Africa's increasing population, income, and material consumption growth (Allwood et al. 2011).

Production-based footprint drivers

We now focus on the results of the regression estimates of the study's predictors concerning the PB RMF and its RMF embodied in the African exports component (see Table 2). It is worth noting that additional predictors not under consideration in the former section are included here based on the LASSO predictor selector.

Table 2: Panel fixed effects regression results: production based footprints and components

	Dependent variables	
Variables	Production-based material footprints (1)	Material footprints embodied in exports (2)
Socio-demographic		
Population (count)	0.438*** (0.058)	0.572*** (0.058)
Population density (people per sq. km of land area)	0.215*** (0.059)	0.224*** (0.059)
Population of young dependants (% of population)	-1.429*** (0.264)	-1.765*** -0.262
Economic		
GDP per capita (USD PPP)	0.004 (0.018)	-0.017 (0.018)
Agriculture value added (% of GDP)	0.794*** (0.091)	0.673*** (0.09)
Manufacturing, value added (% of GDP)	0.01 (0.085)	0.183** (0.084)
Service value added (% of GDP)	0.023* (0.012)	0.029** (0.012)
Total natural resources rents (% of GDP)	0.979*** (0.106)	1.108*** (0.105)
Oil rents (% of GDP)	-0.491*** (0.088)	-0.352*** (0.088)
Mineral rents (% of GDP)	0.045 (0.109)	0.155 (0.108)
Human Development Index	-1.696*** (0.614)	-0.219 (0.611)
Foreign direct investment, net inflows (% of GDP)	-0.733*** (0.094)	-0.735*** (0.093)
Real effective exchange rate index (2010=100)	-0.078*** (0.029)	-0.112*** (0.029)
Central government debt (% of GDP)	0.108** (0.054)	0.148*** (0.053)
Tax revenue (USD)	0.004 (0.006)	0.010* (0.006)
Institutional and governance		
Additive polyarchy index	-1.306	-0.007

	(0.956)	(0.951)
Political corruption index	6.629*** (0.671)	4.717*** (0.668)
Rule of law index	2.579*** (0.811)	-0.459 (0.807)
Political stability no violence index	-0.103 (0.087)	-0.159* (0.087)
Government accountability index	1.513*** (0.206)	1.703*** (0.205)
Government effectiveness	-0.200*** (0.067)	-0.236*** (0.066)
Environment		
Energy use (oil-eq ktoe)	0.02 (0.021)	0.029 (0.021)
Total GHG emissions (Mt CO2e)	0.205*** (0.059)	0.201*** (0.059)
Observations	*1,071*	*1,071*
R^2	*0.55*	*0.594*
Adjusted R^2	*0.532*	*0.577*
F Statistic	*54.666*** (df = 23; 1027)*	*65.454*** (df = 23; 1027)*

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses. PPP means purchasing power parity.

Source: based on authors' regression modelling of Equation (2).

We observe a positive and significant correlation between PB RMF and population and population density. Our result indicates that population growth in Africa is likely to be accompanied by PB RMF for all material categories under this study. We observe a positive correlation between population density, biomass, and construction MFs. This finding affirms the conclusions of previous studies that population growth drives raw material production upwards (IEA 2019b). For all material categories the population of young dependents has a negative relationship with PB RMF and the RMF embodied in African exports.

Our estimates show a positive correlation between agriculture value added, service value added, natural resource rents, and central government debt. The results indicate that biomass is a significant share of Africa's PB RMF. Our results imply that adding more value to Africa's primary agricultural commodities will likely increase the extraction of all material types, especially biomass. Adding value to primary agricultural output in Africa comes with increasing demand for various materials, including agricultural produce, construction materials for building food processing hubs, and material-based energy sources. The regression estimates of service value added are consistent with earlier findings which suggest that service industry activities, such as wholesale, retail, and hospitality, are generally natural resource reliant. In this paper the effect of service value added on PB RMF and the MF embodied in African exports is prominent for biomass, among other materials.

We find that manufacturing value added has a positive but insignificant relationship with PB RMF, but a positive and significant correlation with the RMF embodied in African exports. The former result may be explained by the fact that value addition in the manufacturing industry of Africa remains largely untapped potential. The latter points to the reality that the few existing value-adding manufacturing industries in Africa prioritize meeting demands in foreign markets, particularly in developed and emerging countries. Mirroring earlier studies we find evidence that Africa's manufacturing firms' value addition is driven by exports and centred on biomass and ores.

Our results indicate that increasing value addition in the manufacturing industry could correspond to a decrease in PB RMF only for construction materials. Also, fossil fuels is the only material category for which an increase in manufacturing value added could lower the RMF embodied in African exports (see Table B3 in appendix B).

For natural resource rents and central government debt, our regression estimates highlight the reliance of African economies on raw material extraction and trade for revenue generation to fund their national budgets and the payment of their public debt. For both predictors the effects are much more eminent for the RMF embodied in African exports, pointing to Africa's longstanding raw material export-oriented approach. Interestingly, the positive impact of natural resource rents on PB RMF was highest for biomass, followed by fossil fuel and construction materials.

Our findings largely agree with a strand of literature which suggests that debt-stressed African governments often tend to pay their debt with mineral and oil revenues, which motivates further exploitation and production of raw materials on the continent destined for rich industrialized nations (Greco 2020; The Economist 2018).

In contrast we observe a negative and significant correlation between FDI, oil rents, real exchange rate, and HDI. The estimate for FDI may be explained by the fact that FDI inflows to Africa are linked to the transfer of the best available technologies and know-how from developed countries (Staritz and Whitfield 2017), which may foster material efficiency, thus lowering PB RMF. However, our results support the hypothesis that FDI inflows in Africa are often linked to rising investments in the oil and mining industries, besides manufacturing (FDI Intelligence 2016; Toews et al. 2017). We find evidence that FDI growth diminishes Africa's PB biomass footprint and construction materials footprint embodied in African exports, pointing to the merits of linkages between local African producers and multinationals via FDI (Hirschman 2013).

Regarding oil rents the resulting estimates support the scientific evidence on the ramifications of the Dutch disease, denoting reduced investment in other extractive industries (e.g., agriculture, mining) over time in oil-producing and exporting African countries. The observed correlation between the real exchange rate and PB RMF can be explained by the expected decline in Africa's exports because the local currency's appreciation implies that imports are cheaper than exports—this makes exports less attractive and profitable.

Increases in HDI may translate to labour productivity and material efficiency, negatively impacting PB RMF. Our finding indicates that as countries become more developed, their economic structures experience a paradigm shift from natural capital dependence toward human, social, and produced capital.

The following institutional indicators have a significant and positive correlation with PB RMF: political corruption, the rule of law, and government accountability. Starting with the rule of law and government accountability variables, both measures of democracy, the estimates validate the logic that democratic and resource-endowed African countries tend to attract higher foreign capital and investment, which is likely to increase PB RMF across material categories (Hayat 2018). Regarding political corruption, a possible explanation of our finding is the well-documented resource rent-seeking and state capture in Africa's extractives industry linked to the over-exploitation of natural resources, which invariably increases PB RMF. From our results improvements in government effectiveness in Africa are likely to lead to lower PB RMF and RMF embodied in African exports, especially for biomass, fossil fuels, and construction materials. This finding highlights the role that quality institutions could play in the sustainable management of natural resources, which is important for eradicating the challenge of illicit and over-extraction of raw materials on the continent that are likely to increase PB RMF unsustainably. We find evidence that political stability and no violence could lower the RMF embodied in African exports.

Our estimates for GHG emissions align with earlier findings of a positive correlation between the activities of extractive industries and related GHG emissions. Our findings support evidence from a growing body of research which suggests that the oil and gas, mining, and agriculture industries are primary drivers of Africa's GHG emissions (Bennetzen et al. 2016; IEA 2019a; PWC 2021). We observe that Africa's PB RMFs are likely to rise in tandem with GHG emissions. Our results show that the increase in RMFs from an increase in GHG emissions is highest for the ore category.

4 Conclusions and policy implications

Since 2000 Africa's population has more than doubled, with its share in the global population increasing from 13 per cent to 17 per cent in 2018. Although Africa accounts for <10 per cent of global resource consumption, its population trends in recent decades imply possible growth in its demand for raw materials requirements for socio-economic development. Nonetheless, Africa faces the challenge of decoupling its raw material use from population and economic growth without over-exploitation of natural resources and degradation of the environment. In this paper we had two aims: (i) to evaluate the RMFs of Africa's production, consumption and trade of goods and services from 1995 to 2015 and (ii) to investigate the effects of specific socio-economic and institutional variables on Africa's RMFs. We capitalize on the Eora global MRIO database's availability—a global supply chain database with environmental extensions with by far the highest representation of African countries compared to other MRIO databases to estimate Africa's RMF. The second objective was undertaken by applying LASSO and panel regression analyses.

The most obvious finding from this study is that the MFs of Africa's production and consumption between 1995 and 2015 increased by 41 per cent and 38 per cent, respectively. Additionally, we find that biomass and construction material categories drove the ascendancy of both footprints. Western, Northern, and Southern Africa accounted for over three-quarters of Africa's RMF. Moreover, Nigeria, South Africa, Egypt, Algeria, and Angola were responsible for over half of the African RMF on average during the period studied. Unlike the ores, fossil fuels, and construction material categories, the share of PB biomass footprint embodied in African exports was about 36 per cent in 2015, implying that most of Africa's biomass production is consumed on the continent. These results align with earlier studies which suggest that, at some point, developing nations in the Global South may be within reach of the levels of raw material consumption in the Global North.

Another major finding is that even though the domestic and imported components of Africa's CB RMF increased over the studied period, the share of imported RMF increased from a fifth to a quarter of Africa's CB RMF. A striking result of the study is that Africa's PB RMF increased by nearly twice the increase in its CB RMF. It is worth noting that more than two-thirds of Africa's PB RMF growth between 1995 and 2015 can be attributed to a 53 per cent increase in the RMF embodied in African exports. Excluding ores, biomass, fossil and construction materials are an increasing share of the RMF embodied in African exports. Indeed, 65 per cent and 87 per cent of Africa's PB ores and fossil fuels footprint were embodied in African exports consumed by the rest of the world. We find evidence that Africa is a net exporter of RMFs for all material categories for the period studied. Indeed, 35 of the 51 African countries under the current study were net exporters of RMFs in 2015.

We find that demographic factors such as population, particularly urban population and population density, and economic factors like GDP per capita, industry value added, natural resource rents, the income share held by the highest 10 per cent of the population, and real exchange rate have a positive influence on CB RMF, while factors such as agriculture value added, oil rents, and HDI have a negative effect on CB RMF. Concerning PB RMF, an increase in population and population density, agriculture value added, service value added, natural resource rents, and central government debt tends to increase PB RMF. Other factors such as FDI, oil rents, real exchange rate and HDI have a negative influence. Institutional factors such as political corruption also ramp up CB RMF and PB RMF.

4.1 Policy implications of the findings

No one-size-fits-all policy measure to reduce material footprints

The overall results indicate the importance of complementing PB measures of material consumption with CB methods regarding pro-material-use efficiency decisions and policy support. In this study our findings suggest that Africa's dematerialization efforts should be focused on reducing its colossal PB RMF relative to its CB RMF. Our results are consistent with the conclusions that population growth drives up global raw material extraction and use, particularly in urban areas. Compared to other regions, Africa's population is the fastest growing (UNDESA 2019a). Africa's population is predicted to double by 2050, with over half (~600 million) domiciled urban areas (OECD/SWAC 2020). The population growth will occur in tandem with increased demand for food, energy, and the other raw materials needed to expand housing and infrastructure, thus increasing RMFs, as indicated by the present study's results. Most African countries are currently grappling with diverse challenges ranging from lack of universal access to electricity, failure to meet the rapidly growing energy demand, insufficiency of local food production, and infrastructural deficit. Against this backdrop adequate planning and innovative policy approaches backed by unwavering policy actions in Africa are indispensable in managing the continent's natural resources efficiently to improve the well-being and livelihoods of Africans.

Our findings indicate that Africa's RMF will likely increase as income levels rise. However, some researchers assert that, all else equal, the RMF could reach a peak and level off as people become wealthier, as they become flexible in their choices and climate-friendly products and technologies become affordable. Also, the wealthy could use their financial resources, social network, and political influence to engender national and global pro-decarbonization and dematerialization initiatives (Feng et al. 2021).

As African countries develop and attempt to add value to industry, they tend to increase their CB RMF—a clear indication to policy makers of the benefit of resource-based manufacturing and industrialization towards creating more local jobs and increasing firm productivity and intermediate and finished manufactured exports in Africa. A key policy priority should be creating avenues for integrating African industries into the global value chain while attracting the requisite domestic and foreign investments to take full advantage of Africa's abundant raw materials, surplus labour, and increasing global markets.

The effect of natural resource rents and political corruption on both the CB RMF and PB RMF shows the urgent need for countries on the continent to reduce the excessive focus on exploitation and concentrate on the governance of raw materials to reduce corruption and extreme rent-seeking. The effect of government debt on PB RMF sends a strong signal to policy makers and development partners as many African countries are close to being or are already debt distressed (World Bank and IMF 2021). Debt-distressed African governments often tend to service their debt with mineral and oil revenues, which motivates further exploitation and production of raw materials on the continent (The Economist 2018). It is therefore important for Africa's lenders to do more to lower interest rates and accelerate debt restructuring to support and put countries back on a more sustainable fiscal path. As a policy measure to reduce Africa's CB RMF and PB RMF, government debt-funded spending on quality education and health could boost economic growth and raise a well-informed and sustainability-conscious citizenry (Flatø et al. 2017; Hoffmann et al. 2020). Also, a renewed political effort to improve energy efficiency and invest in green energy in Africa would go a long way to reduce the CB RMF and PB RMF and protect Africa's natural ecosystem.

The massive influence of agriculture on Africa's material footprint

The significant portion of biomass in Africa's MF, as shown by our results, is consistent with findings that: (i) most African economies are typically agrarian, with food making up two-fifths of household expenditures and a third of Africa's merchandise trade (AFDB 2020); and (ii) traditional biomass, including fuelwoods, is the predominant primary energy source in most parts of Africa, excluding Northern and Southern Africa, where oil, gas, or coal dominates the energy mix (IEA 2019a). The biomass footprint embodied in African exports increased by 43 per cent over the period studied. The increase reflects Africa's increasing agricultural commodities exports, such as cocoa, palm oil, coffee, tea, and cotton, among other cash crops, a few processed foods, and horticultural products, particularly to Europe and Asia. Policy makers should focus on reducing the share of bulk goods in Africa's agricultural exports by developing local high-value-adding agri-food supply chains to reduce the RMF embodied in African exports while undertaking the necessary reforms to make the food manufacturing companies profitable and competitive on the global market. Today there are increasing global concerns about the raging deforestation in Africa, spearheaded by cocoa, palm oil, and timber exporting African countries. Consuming countries of deforestation-linked African exports should insist on purchasing only products that meet international sustainability standards.

Traditional biomass remains Africa's biggest energy source and a principal driver of its GHG emissions. However, Africa is well positioned to adequately support global climate change mitigation, given its rich endowment with critical minerals (cobalt, copper, manganese, and platinum) essential to modern and renewable energy transitions. These rare earth elements and recent natural gas reserve discoveries on the continent present new export revenue opportunities for Africa's green transition. However, Africa needs the appropriate regulatory policies, infrastructure, and investment both to responsibly exploit resources to deliver economic prosperity and support inclusive and sustainable economic growth while protecting the environment.

Increasing burden shifting of raw material extraction to Africa

Our results are consistent with scientific evidence that most high-income and industrialized nations, together with emerging economies like China and Russia, rely heavily on raw materials sourced from Africa's natural resources.

The rising fossil fuel footprint embodied in African trade during the period studied is worthy of policy attention regarding global climate goals. Although Africa's share in global fossil fuel emissions is only 3.7 per cent, its rising fossil fuels footprint embodied in exports requires concerted private and public efforts to mitigate the related GHG emissions and transition to cleaner energy sources. Some scientists assert that Africa's emissions are rising partly due to the expansion of coal mines, increasing oil and gas exploration, and energy use and transportation emissions (Ayompe et al. 2020; Canadell et al. 2009). In this regard, Africa's largest oil, gas, and coal producers should make the necessary investments toward increasing the share of renewable energy sources in their primary energy mix.

Africa's resource-rich countries remain dependent on oil and gas export revenue to finance their national budgets and developmental plans, exposing them to external shocks such as global oil price dips. An effective policy push, governance and regulatory framework are needed to ensure that the continent's windfalls from exporting its raw materials do not end up in corrupt hands and are invested in stimulating local production, consumption, and economic growth (Transparency International 2015). As a large part of Africa's MF from production is to satisfy consumption beyond Africa's borders, pragmatic national policies overseas, especially in the high-income countries and big import partners of Africa, are necessary to incentivize sustainable lifestyles and industrial processes. Moreover, Africa's resource efficiency transition will be partly impossible without knowledge sharing and the transfer of modern technologies by advanced economies which are already experiencing increased resource productivity and material use efficiencies.

From resource exporter to resource-embodied in products importer

Our results show that Africa's imported RMF has increased in the last decades, indicating Africa's increased dependency on imported goods to meet its consumption needs. Based on our results, construction materials drove 48 per cent of the RMF embodied in African imports, followed by biomass (24 per cent) and fossil fuels (15 per cent). Data reveal that imports are an ever-increasing part of Africa's production recipe, particularly for local manufacturing firms on the continent (Bernard et al. 2018).

According to the IEA, the total output of African refineries fell by more than 50 per cent in the last decade despite increased demand for fossil fuels on the continent (IEA 2019a). The results illustrated in this paper support scientific claims that, compared to other regions in the world, Africa is the highest importer of refined crude products—75 per cent of its total fossil fuel imports (IEA 2022). The few operational oil refineries on the continent are poorly maintained, have low capacity, and tend to produce low-grade petroleum products and low yields of high-value petroleum products. Strategic policy choices are imperative to attract the funding and investment required to provide ultra-modern infrastructure and cost-efficient oil refineries with the capacity and networks to meet Africa's rising demand for refinery products, especially gasoline and diesel.

These findings confirm that Africa's construction industry thrives partly on imported building and construction materials. Also, the results mirror Africa's increasing and widespread material-intensive infrastructural projects, often aimed at public goods and services provision and industrialization in the last two decades

Our results underscore the food self-sufficiency of Africa regarding biomass supply. However, we observe a significant increase in Africa's imported biomass footprint (79 per cent) over the period studied, an increase higher than the growth in the biomass footprint embodied in African exports (43 per cent). Despite being home to 60 per cent of the world's uncultivated arable land, Africa remains a net food importer of staple foods such as cereals, vegetable oils, meat, and dairy products. Perhaps these findings shed light on the new challenges Africa faces with increasing yields and growing enough food to feed itself in the face of the adverse ramifications of climate change on agriculture in the continent, particularly in Central and Eastern Africa (Brown 2015; WMO 2020). With Africa's food import volumes expected to double in half a decade along with its population, African countries need to pursue effective policies backed by well-intentioned actions to fully harness Africa's food self-sufficiency potential by increasing agricultural productivity and yields, while improving country adaptation and resilience to climate change and erratic supply chain disruptions. However, it is equally important that African industries and consumers make considerable efforts to reduce their biomass footprint overseas.

4.2 Limitations of the study, and future research

The MF calculations in this paper are based on the Eora global MRIO database. We acknowledge the uncertainties related to the data and the specific algorithms and models applied to model data and harmonize data from different data sources to form Eora. The scope of this study does not cover the quantification of uncertainty related to the RMF calculations and results. However, the uncertainties about the data points of Eora are extensively covered by Moran and Wood (2014), while estimates on the standard deviations of data points are available in the documentation at Eora global MRIO. MRIO analysis has weaknesses that could bias its environmental footprint results despite its ability to cover entire global supply chains while differentiating production systems and consumption patterns worldwide. The main drawback of applying IO analysis for the study's material footprint analyses is that monetary IO tables typically do not accurately capture material flows in the global economy like physical IO tables based on data measured in mass. A growing body of research comprehensively addresses the uncertainties related to MRIO-based material footprint assessments (see Giljum et al. 2019; Schaffartzik et al. 2015).

Our results confirm the varied contributions of different raw material types to the RMFs of different African nations and sub-regions. While this paper only considered the effects of different variables on Africa's aggregate RMF, further research needs to examine more closely how similar or other variables distinctively influence RMFs embodied in the African exports of individual African countries and sub-regions. Future studies might explore the product(s) and geospatial hotspots of Africa's RMF to provide profound insights to support specific industry interventions and trade agreements that are imperative for Africa's resource and energy efficiency transitions. More work will need to be done to provide multiple comparable, reliable, and timely high-resolution products and industry and household data sources on Africa's raw material extraction, processing, trade, and consumption. Such work will aid improved, detailed, and accurate modelling of Africa's RMF to properly understand Africa's environmental challenges regarding its natural resource management and governance. While this paper considered 51 African countries, our study was short of three African countries because the Eora database does not capture those countries. The statistical offices of most African countries featured in Eora do not officially publish IO tables, or the latest IO tables that they published are lagging at least four years. Therefore, Eora developers have modelled the IO tables of such countries using macroeconomic data and a weighted average of the IO tables of countries considered similar based on their economic structures. Greater efforts are needed to provide the logistics and funding as well as the technical know-how and skills required to collate the big data required to publish high-dimensional IO tables regularly in African countries.

Global supply chains are under increasing scrutiny, given the increasing global scope-3 environmental impacts. As Africa deepens its participation in globalization and trade, it will need science-based information to minimize its environmental footprints at home and abroad in line with global climate and environmental targets. We hope this study's findings can inspire multi-stakeholder collaboration to develop further research and targeted interventions and innovative solutions aimed at making Africa a resource-productive, efficient, and prosperous continent.

References

AFDB (2011). *Africa in 50 Years' Time. The Road Towards Inclusive Growth*. Tunis: African Development Bank.

AFDB (2013). *At the Center of Africa's Transformation: Strategy for 2013-2022*. Abidjan: African Development Bank.

AFDB (2020). Rethinking Land Reform in Africa: New Ideas, Opportunities and Challenges. Abidjan: African Natural Resources Centre.

AFDB (2021). *African Economic Outlook 2021 - Building Today, a Better Africa Tomorrow*. Abidjan: African Development Bank.

AFDB, OECD, and UNDP (2015). *African Economic Outlook 2015: Regional Development and Spatial Inclusion*. OECD Publishing, Paris, France. https://doi.org/10.1787/fa724c7c-fr

Allwood, J.M., MF. Ashby, T.G. Gutowski, and E. Worrell (2011). 'Material Efficiency: A White Paper'. *Resources, Conservation and Recycling*, 55(3): 362–81. https://doi.org/10.1016/j.resconrec.2010.11.002

Alsamawi, A., J. Murray, M. Lenzen, D. Moran, and K. Kanemoto (2014). 'The Inequality Footprints of Nations: A Novel Approach to Quantitative Accounting of Income Inequality'. PLoS One 9. https://doi.org/10.1371/JOURNAL.PONE.0110881

ANRC (2021). *Rare Earth Elements (REE): Value Chain Analysis for Mineral Based Industrialization in Africa*. Abidjan: African Natural Resource Centre.

Ayee, J. (2014). 'The Status of Natural Resource Management in Africa: Capacity Development Challenges and Opportunities'. In K.T. Hanson, C. D'Alessandro, and F. Owusu (eds), *Managing Africa's Natural Resources*. London: Palgrave Macmillan UK. https://doi.org/10.1057/9781137365613_2

Ayompe, L.M., S.J. Davis, and B.N. Egoh (2020). 'Trends and Drivers of African Fossil Fuel CO2 Emissions 1990–2017'. *Environmental Research Letters*, 15(12): 124039. https://doi.org/10.1088/1748-9326/abc64f

Badeeb, R.A., H.H. Lean, and J. Clark (2017). 'The Evolution of the Natural Resource Curse Thesis: a Critical Literature Survey'. Resources Policy, 51: 123–34. https://doi.org/10.1016/j.resourpol.2016.10.015

Bennetzen, E.H., P. Smith, and J.R. Porter (2016). 'Agricultural Production and Greenhouse Gas Emissions from World Regions: The Major Trends over 40 Years'. *Global Environmental Change*, 37: 43–55. https://doi.org/10.1016/j.gloenvcha.2015.12.004

Bernard, A.B., J.B. Jensen, S.J. Redding, and P.K. Schott (2018). 'Global Firms'. *Journal of Economic Literature*, 56(2), 565–619. https://doi.org/10.1257/JEL.20160792

Bjelle, E.L., K. Kuipers, F. Verones, and R. Wood (2021). 'Trends in National Biodiversity Footprints of Land Use'. *Ecological Economics*, 185. https://doi.org/10.1016/j.ecolecon.2021.107059

Bourne, J.K.J. (2019). 'The Next Breadbasket'. *National Geographic Magazine*. Available at: https://www.nationalgeographic.com/foodfeatures/land-grab/ (accessed June 2022).

Bringezu, S., A. Ramaswami, H. Schandl, M. O'Brien, R. Pelton, J. Acquatella, and S. Giljum (2017). *Assessing Global Resource Use: A System Approach to Resource Efficiency and Pollution Reduction*. UNEP. Available at: https://www.resourcepanel.org/sites/default/files/documents/document/media/assessing_global_resource_use_amended_130318.pdf (accessed September 2022).

Brown, A. (2015). 'Climate Change and Africa'. *Nature Climate Change*, 5: 811. https://doi.org/10.1038/nclimate2789

Bruckner, M., S. Giljum, C. Lutz, and K.S. Wiebe (2012). 'Materials Embodied in International Trade: Global Material Extraction and Consumption between 1995 and 2005'. *Global Environmental Change*, 22(3): 568–76. https://doi.org/10.1016/j.gloenvcha.2012.03.011

Cabernard, L., S. Pfister, and S. Hellweg (2019). 'A New Method for Analyzing Sustainability Performance of Global Supply Chains and its Application to Material Resources'. *Science of the Total Environment*, 684: 164–77. https://doi.org/10.1016/j.scitotenv.2019.04.434

Canadell, J.G., M.R. Raupach, and R.A. Houghton (2009). 'Anthropogenic CO2 Emissions in Africa'. *Biogeosciences*, 6: 463–68. https://doi.org/10.5194/bg-6-463-2009

Centofanti, F., M, Fontana, A.Lepore, and S. Vantini (2022). 'Smooth LASSO Estimator for the Function-on-Function Linear Regression Model'. *Computational Statistics & Data Analysis*, 176: 107556. https://doi.org/10.1016/j.csda.2022.107556

D'Elia, E., T. Hamor, S. Manfredi, and D. Pennington (2022). *Building Africa-EU Raw Materials Knowledge Base – Proceedings of the 'Knowledge Needs – EU-Africa Focus' event Raw Materials Week*. Brussels: Publications Office of the European Union. . https://doi.org/10.2760/542952

Dietzenbacher, E., B. Los, R. Stehrer, M. Timmer, and G. de Vries (2013). 'The Construction of World Input–Output Tables in the WIOD Project'. *Economic Systems Research*, 25: 71–98. https://doi.org/10.1080/09535314.2012.761180

Dramane, A. (2021). 'Effect of the Size of Government Spending on Corruption in Sub-Saharan African Countries'. *Economics Bulletin*, 41(1): 167–81.

Eisenmenger, N., D. Wiedenhofer, A. Schaffartzik, A. Giljum, M. Bruckner, H. Schandl, T.O. Wiedmann, M. Lenzen, A. Tukker, and A. Koning (2016). 'Consumption-based Material Flow Indicators: Comparing Six Ways of Calculating the Austrian Raw Material Consumption Providing Six Results'. *Ecological Economics*, 128: 177–86. https://doi.org/10.1016/j.ecolecon.2016.03.010

European Commission (2011). 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Roadmap to a Resource Efficient Europe'. Brussels: European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0571 (accessed September 2022).

European Commission (2019). *A European Green Deal*. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed August 2022).

Eurostat (2008). 'Eurostat Manual of Supply, Use and Input-Output Tables'. Methodologies and Working Papers. Luxembourg: Eurostat. Available at: https://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39 (accessed September 2022).

FAO (2017). *The Future of Food and Agriculture–Trends and Challenges*. Rome: Food and Agriculture Organization of the United Nations.

FDI Intelligence (2016). *The Africa Investment Report 2016: Foreign Invesment Broadens Its Base*. Available at: https://www.camara.es/sites/default/files/publicaciones/the-africa-investment-report-2016.pdf (accessed September 2022).

Fenech, C., and B. Perkins (2014). *The Deloitte Consumer Review Africa: A 21st-century View*. London: Deloitte.

Feng, K., K. Hubacek, and K. Song (2021). 'Household Carbon Inequality in the U.S.'. *Journal of Cleaner Production*, 278. https://doi.org/10.1016/j.jclepro.2020.123994

Fischer-Kowalski, M., F. Krausmann, S. Giljum, S. Lutter, A. Mayer, S. Bringezu, Y. Moriguchi, H. Schütz, H. Schandl, and H. Weisz (2011). 'Methodology and Indicators of Economy-wide Material Flow Accounting: State of the Art and Reliability Across Sources'. *Journal of Industrial Ecology*, 15(6): 855–76. https://doi.org/10.1111/J.1530-9290.2011.00366.X

Fishman, T., H. Schandl, H. Tanikawa, P. Walker, and F. Krausmann (2014). 'Accounting for the Material Stock of Nations'. *Journal of Industrial Ecology*, 18(3): 407–20. https://doi.org/10.1111/jiec.12114

Flatø, M., R. Muttarak, and A. Pelser (2017). 'Women, Weather, and Woes: The Triangular Dynamics of Female-Headed Households, Economic Vulnerability, and Climate Variability in South Africa'. World Development, 90: 41–62. https://doi.org/10.1016/j.worlddev.2016.08.015

GCP (2020). Global Carbon Budget. Available at: https://www.globalcarbonproject.org/index.htm (accessed September 2022).

Geschke, A., R. Wood, K. Kanemoto, M. Lenzen, and D. Moran (2014). 'Investigating Alternative Approaches to Harmonise MRIO Data'. *Economic Systems Research*, 26(3): 354–85. https://doi.org/10.1080/09535314.2014.937069

Giljum, S., H. Wieland, S. Lutter, M. Bruckner, R. Wood, A. Tukker, and K. Stadler (2016). 'Identifying Priority Areas for European Resource Policies: An MRIO-based Material Footprint Assessment'. *Journal of Economic Structures*, 5: 17. https://doi.org/10.1186/s40008-016-0048-5

Giljum, S., H. Wieland, S. Lutter, N. Eisenmenger, H. Schandl, and A. Owen (2019). 'The Impacts of Data Deviations Between MRIO Models on Material Footprints: A Comparison of EXIOBASE, Eora, and ICIO'. *Journal of Industrial Ecology*, 23(4): 946–58. https://doi.org/10.1111/jiec.12833

Greco, E. (2020). 'Africa, Extractivism and the Crisis This Time'. *Review of African Political Economy*, 47(166): 511–21. https://doi.org/10.1080/03056244.2020.1859839

Greene, W.H. (2017). *Econometric Analysis, 8th Edition*. London: Pearson.

Hayat, A. (2018). 'FDI and Economic Growth: The Role of Natural Resources?'. *Journal of Economic Studies*, 45(2), 283–95. https://doi.org/10.1108/JES-05-2015-0082

Heeren, N., and S. Hellweg (2019). 'Tracking Construction Material over Space and Time: Prospective and Geo-referenced Modeling of Building Stocks and Construction Material Flows'. *Journal of Industrial Ecology*, 23(1): 253–67. https://doi.org/10.1111/jiec.12739

Henri, P.A.O. (2019). 'Natural Resources Curse: a Reality in Africa'. Resources Policy 63: 101406. https://doi.org/10.1016/j.resourpol.2019.101406

Hertwich, E.G., and R. Wood (2018). 'The Growing Importance of Scope 3 Greenhouse Gas Emissions from Industry'. *Environmental Research Letters*, 13(10): 104013. https://doi.org/10.1088/1748-9326/aae19a

Hesterberg, T., N.H. Choi, L. Meier, and C. Fraley (2008). 'Least Angle and ℓ1 Penalized Regression: A Review'. *Statistics Surveys*, 2, 61–93. https://doi.org/10.1214/08-SS035

Hirschman, A.O. (2013). 'A Generalized Linkage Approach to Development, with Special Reference to Staples'. In A.O. Hirschman and J. Adelman (eds), *The Essential Hirschman*. Princeton, NJ: Princeton University Press. https://doi.org/10.23943/princeton/9780691159904.003.0007

Hoffmann, R., A. Dimitrova, R. Muttarak, J. Crespo Cuaresma, and J. Peisker (2020). 'A Meta-analysis of Country-level Studies on Environmental Change and Migration'. *Nature Climate Change*, 10: 904–912. https://doi.org/10.1038/s41558-020-0898-6

IEA (2019a). *Africa Energy Outlook 2019. World Energy Outlook Special Report*. Paris: International Energy Agency.

IEA (2019b). *Material Efficiency in Clean Energy Transitions*. Paris: International Energy Agency. https://doi.org/10.1787/aeaaccd8-en

IEA (2021). *Oil Market Report*. Available at: https://www.iea.org/topics/oil-market-report (accessed September 2022).

IEA (2022). *Africa Energy Outlook 2022. World Energy Outlook Special Report*. Paris: International Energy Agency

IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Ivanova, D., G. Vita, K. Steen-Olsen, K. Stadler, P.C. Melo, R. Wood, and E.G. Hertwich (2017). 'Mapping the Carbon Footprint of EU Regions'. *Environmental Research Letters*, 12(5): 054013. https://doi.org/10.1088/1748-9326/aa6da9

Janssens-Maenhout, G., M. Crippa, D. Guizzardi, M. Muntean, E. Schaaf, F. Dentener, P. Bergamaschi, V. Pagliari, J.G.J. Olivier, J.A.H.W. Peters, J.A., van Aardenne, S. Monni, U. Doering, A.M.R. Petrescu, E. Solazzo, G.D. Oreggioni, A.M. Roxana Petrescu, E. Solazzo, and G.D. Oreggioni (2019). 'EDGAR v4.3.2 Global Atlas of the Three Major Greenhouse Gas Emissions for the Period 1970-2012'. *Earth System Science Data*, 11(3): 959–1002. https://doi.org/10.5194/essd-11-959-2019

Kanemoto, K., D. Moran, and E.G. Hertwich (2016). 'Mapping the Carbon Footprint of Nations'. *Environmental Science & Technology*, 50(19): 10512–17. https://doi.org/10.1021/acs.est.6b03227

Kitzes, J. (2013). 'An Introduction to Environmentally Extended Input-Output Analysis'. *Resources*, 2(4): 489–503. https://doi.org/10.3390/resources2040489

Lafortune, G., G. Fuller, G. Schmidt-Traub, and C. Kroll (2020). 'How is Progress Towards the Sustainable Development Goals Measured? Comparing Four Approaches for the EU'. *Sustainability*, 12(18): 7675. https://doi.org/10.3390/SU12187675

Lenzen, M. (2000). 'Errors in Conventional and Input-Output—based Life—Cycle Inventories'. *Journal of Industrial Ecology*, 4(4): 127–48. https://doi.org/10.1162/10881980052541981

Lenzen, M., A. Geschke, M.D. Abd Rahman, Y. Xiao, J. Fry, R. Reyes, E. Dietzenbacher, S. Inomata, K. Kanemoto, B. Los, D. Moran, H. Schulte in den Bäumen, A. Tukker, T. Walmsley, T. Wiedmann, R. Wood, and N. Yamano (2017). 'The Global MRIO Lab–Charting the World Economy'. *Economic Systems Research*, 29(2): 158–86. https://doi.org/10.1080/09535314.2017.1301887

Lenzen, M., A. Geschke, J. West, J. Fry, A. Malik, S. Giljum, L. Milà i Canals, P. Piñero, S. Lutter, T. Wiedmann, M. Li, M. Sevenster, J. Potočnik, I. Teixeira, M. Van Voore, K. Nansai, and H. Schandl (2022). 'Implementing the Material Footprint to Measure Progress Towards Sustainable Development Goals 8 and 12'. *Nature Sustainability*, 5, 157–66. https://doi.org/10.1038/S41893-021-00811-6

Lenzen, M., K. Kanemoto, D. Moran, and A. Geschke (2012). 'Mapping the Structure of the World Economy'. Environmental Science & Technology, 46(15): 8374–81. https://doi.org/10.1021/ES300171X

Lenzen, M., D. Moran, A. Bhaduri, K. Kanemoto, M. Bekchanov, A. Geschke, and B. Foran. (2013). 'International Trade of Scarce Water'. *Ecological Economics*, 94: 78–85. https://doi.org/10.1016/j.ecolecon.2013.06.018

Lenzen, M., Kanemoto, K., Moran, D., Geschke, A., 2012b. Mapping the structure of the world economy. Environ. Sci. Technol. 46, 8374–8381. https://doi.org/10.1021/es300171x

Lenzen, M., D. Moran, K. Kanemoto, and A. 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. https://doi.org/10.1080/09535314.2013.769938

Lenzen, M., R. Wood, and T. Wiedmann (2010). 'Uncertainty Analysis for Multi-region Input-Output Models: A Case Study of the UK'S Carbon Footprint'. *Economic Systems Research*, 22(1): 43–63. https://doi.org/10.1080/09535311003661226

Leontief, W.W. (1936). 'Quantitative Input and Output Relations in the Economic Systems of the United States'. *The Review of Economics and Statistics*, 18(3): 105–25. https://doi.org/10.2307/1927837

Leontief, W. (1970). 'Environmental Repercussions and the Economic Structure: An Input-Output Approach'. *Review of Economics and Statistics*, 52(3): 262–71. https://doi.org/10.2307/1926294

Leontief, W.W. (1986). 'Input-output Economics'. *Scientific American*. Available at: https://www.scientificamerican.com/article/input-output-economics/ (accessed September 2022).

Lewis, S.L., G. Lopez-Gonzalez, B., Sonké, K. Affum-Baffoe, T.R. Baker, L.O. Ojo, O.L. Phillips, J.M. Reitsma, L. White, J.A. Comiskey, M.N.K. Djuikouo, C.E.N. Ewango, T.R. Feldpausch, A.C.

Hamilton, M. Gloor, T. Hart, A. Hladik, J. Lloyd, J.C. Lovett, J.R. Makana, Y. Malhi, F.M. Mbago, H.J. Ndangalasi, J. Peacock, K.S.H. Peh, D. Sheil, T. Sunderland, M.D. Swaine, J. Taplin, D. Taylor, S.C. Thomas, R. Votere, and H. Wöll (2009). 'Increasing Carbon Storage in Intact African Tropical Forests'. *Nature*, 457: 1003–06. https://doi.org/10.1038/nature07771

Lindberg, S.I. (2003). 'It's Our Time to "Chop": Do Elections in Africa Feed Neo-Patrimonialism rather than Counter-Act It?'. *Democratization*, 10(2): 121–40. https://doi.org/10.1080/714000118

Lutter, S., S. Giljum, and M. Bruckner (2016). 'A Review and Comparative Assessment of Existing Approaches to Calculate Material Footprints'. *Ecological Econmoics*, 127: 1–10. https://doi.org/10.1016/j.ecolecon.2016.03.012

Merciai, S., and J. Schmidt (2018). 'Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database'. *Journal of Industrial Ecology*, 22(3): 516–31. https://doi.org/10.1111/JIEC.12713

Miller, R.E., and P.D. Blair (2009). *Input-Output Analysis: Foundations and Extensions, Second Edition*. Cambridge, Cambridge University Press. https://doi.org/10.1017/CBO9780511626982

Minx, J.C., W.F. Lamb, R.M. Andrew, J.G. Canadell, M. Crippa, N. Döbbeling, P.M. Forster, D. Guizzardi, J. Olivier, G.P. Peters, J. Pongratz, A. Reisinger, M. Rigby, M. Saunois, S.J. Smith, E. Solazzo, and H. Tian (2021). 'A Comprehensive and Synthetic Dataset for Global, Regional, and National Greenhouse Gas Emissions by Sector 1970–2018 with an Extension to 2019'. *Earth System Science Data*, 13: 5213–52. https://doi.org/10.5194/essd-13-5213-2021

Moran, D. (2015). 'The Eora MRIO Database'. Sustainable Practical Guide to Multi-Regional Input–Output Analysis Available at: http://worldmrio.com/ (accessed March 2021).

Moran, D., and R. Wood (2014). 'Convergence Between the Eora, WIOD, EXIOBASE, and Open EU's Consumption-based Carbon Accounts'. *Economic Systems Research*, 26(3): 245–61. https://doi.org/10.1080/09535314.2014.935298

Mostert, C., and S. Bringezu (2019). 'Measuring Product Material Footprint as New Life Cycle Impact Assessment Method: Indicators and Abiotic Characterization Factors'. *Resources*, 8(2): 61. https://doi.org/10.3390/resources8020061

Nansai, K., J. Fry, A. Malik, W. Takayanagi, and N. Kondo (2020). 'Carbon Footprint of Japanese Health Care Services from 2011 to 2015'. *Resources, Conservation and Recycling*, 152. https://doi.org/10.1016/j.resconrec.2019.104525

Ndikumana, L., and M. Sarr (2019). 'Capital Flight, Foreign Direct Investment and Natural Resources in Africa'. *Resources Policy*, 63: 101427. https://doi.org/10.1016/j.resourpol.2019.101427

OECD/SWAC (2020). *Africa's Urbanisation Dynamics 2020: Africapolis, Mapping a New Urban Geography*. Paris: OECD and Sahel and West Africa Club, West African Studies. https://doi.org/10.1787/b6bccb81-en

Owen, A., R. Wood, J. Barrett, and A. Evans (2016). 'Explaining Value Chain Differences in MRIO Databases Through Structural Path Decomposition'. *Economic Systems Research*, 28(2): 243–72. https://doi.org/10.1080/09535314.2015.1135309

Palmer, P.I., L. Feng, D. Baker, F. Chevallier, H. Bösch, and P. Somkuti (2019). 'Net Carbon Emissions from African Biosphere Dominate Pan-tropical Atmospheric CO2 Signal'. *Nature Communications*, 10: 1–9. https://doi.org/10.1038/s41467-019-11097-w

Peters, G., M. Li, and M. Lenzen (2021). 'The Need to Decelerate Fast Fashion in a Hot Climate - a Global Sustainability Perspective on the Garment Industry'. *Journal of Cleaner Production*, 295: 126390. https://doi.org/10.1016/j.jclepro.2021.126390

Peters, G.P., J.C. Minx, C.L. Weber, and O. Edenhofer (2011). 'Growth in Emission Transfers Via International Trade from 1990 to 2008'. *PNAS*, 108(21), 8903–08. https://doi.org/10.1073/pnas.1006388108

Piñero, P., I. Cazcarro, I. Arto, I. Mäenpää, A. Juutinen, and E. Pongrácz (2018). 'Accounting for Raw Material Embodied in Imports by Multi-regional Input-Output Modelling and Life Cycle Assessment, Using Finland as a Study Case'. *Ecological Economics*, 152: 40–50. https://doi.org/10.1016/J.ECOLECON.2018.02.021

Piñero, P., D. Pérez-Neira, J. Infante-Amate, M.L. Chas-Amil, and X.R. Doldán-García (2020). 'Unequal raw material exchange between and within countries: Galicia (NW Spain) As a Core-periphery Economy'. *Ecological Economics*, 172. https://doi.org/10.1016/j.ecolecon.2020.106621

PWC (2021). *Africa Energy Review 2021*. Available at: https://www.pwc.com/ng/en/publications/africa-energy-review.html (accessed September 2022).

Rodrigues, J.F.D., D. Moran, R. Wood, and P. Behrens (2018). 'Uncertainty of Consumption-Based Carbon Accounts'. *Environmental Science & Technology*, 52(13): 7577–86. https://doi.org/10.1021/acs.est.8b00632

Schaffartzik, A., N. Eisenmenger, F. Krausmann, and H. Weisz (2014). 'Consumption-based Material Flow Accounting'. *Journal of Industrial Ecology*, 18(1): 102–12. https://doi.org/10.1111/jiec.12055

Schaffartzik, A., D. Wiedenhofer, and N. Eisenmenger (2015). 'Raw Material Equivalents: The Challenges of Accounting for Sustainability in a Globalized World'. *Sustainability*, 7(5): 5345–70. https://doi.org/10.3390/su7055345

Schandl, H., M. Fischer-Kowalski, J. West, S. Giljum, M. Dittrich, N. Eisenmenger, A. Geschke, M. Lieber, H. Wieland, A. Schaffartzik, F. Krausmann, S. Gierlinger, K. Hosking, M. Lenzen, H, Tanikawa, A. Miatto, and T. Fishman (2018). 'Global Material Flows and Resource Productivity: Forty Years of Evidence'. *Journal of Industrial Ecology*, 22(4): 827–38. https://doi.org/10.1111/JIEC.12626

Schoer, K. (2018). Estimating Raw Material Equivalents with Multi-Regional Input-Output Models: The Impact of Sectoral Disaggregation.

Schoer, K., J. Weinzettel, J. Kovanda, J. Giegrich, and C. Lauwigi (2012). 'Raw Material Consumption of the European Union: Concept, Calculation Method, and Results'. *Environmental Science & Technology*, 46(16): 8903–09. https://doi.org/10.1021/es300434c

Schoer, K., R. Wood, I. Arto, and J. Weinzettel (2013). 'Estimating Raw Material Equivalents on a Macro-level: Comparison of Multi-regional Input-output Analysis and Hybrid LCI-IO'. *Environmental Science & Technology*, 47(24): 14282–89. https://doi.org/10.1021/es404166f

Sedgo, H., and L.D. Omgba (2022). 'Corruption and Distortion of Public Expenditures: Evidence from Africa'. *International Tax and Public Finance*, 1–34. https://doi.org/10.1007/s10797-021-09718-6

Shilling, H., T. Wiedmann, and A. Malik (2021). 'Modern Slavery Footprints in Global Supply Chains'. *Journal of Industrial Ecology*, 25(6): 1518–28. https://doi.org/10.1111/jiec.13169

Smil, V. (2013). *Making the Modern World: Materials and Dematerialization*. Hoboken, NJ: Wiley.

Stadler, K., R. Wood, T. Bulavskaya, C.-J.J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernández, J. Kuenen, M. Bruckner, S. Giljum,S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.-H.H. Erb, A. de Koning, and A. Tukker (2018). 'EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables'. *Journal of Industrial Ecology*, 22(3): 502–15. https://doi.org/10.1111/jiec.12715

Staritz, C., and L. Whitfield (2017). 'Made in Ethiopia: The Emergence and Ethiopian Apparel Export Sector. CAE Working Paper 2017:3. Roskilde: Roskilde University.

The Economist (2017). 'South Africa's Inequality is No Longer About Race'. 20 May. Available at: https://www.economist.com/middle-east-and-africa/2017/05/20/south-africas-inequality-is-no-longer-about-race?utm_medium=cpc.adword.pd&utm_source=google&utm_campaign=a.22brand_pmax&utm_content=conversion.direct-response.anonymous&gclid=CjwKCAjwyaWZBhBGEiwACslQo7qVLBXHYVD8F7IWy3rHzBMstIJIdn6pp92clMRrSHpclnX71k2GbxoC5twQAvD_BwE&gclsrc=aw.ds (accessed September 2022).

The Economist (2018). 'Increasing Debt in Many African Countries is a Cause for Worry'.8 May. Available at: https://www.economist.com/middle-east-and-africa/2018/03/08/increasing-debt-in-many-african-countries-is-a-cause-for-worry (accessed September 2022).

Tibshirani, R. (1996). 'Regression Shrinkage and Selection Via the Lasso'. *Journal of the Royal Statistical Society: Series B*, 58(1): 267–88. https://doi.org/10.1111/j.2517-6161.1996.tb02080.x

Tibshirani, R., M. Saunders, S. Rosset, J. Zhu, and K. Knight (2005). 'Sparsity and Smoothness Via the Fused Lasso'. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 67(1): 91–108. https://doi.org/10.1111/j.1467-9868.2005.00490.x

Timmer, M.P., E. Dietzenbacher, B. Los, R. Stehrer, and G.J. de Vries (2015). 'An Illustrated User Guide to the World Input-Output Database: The Case of Global Automotive Production'. *Review of International Economics*, 23(3): 575–605. https://doi.org/10.1111/roie.12178

Toews, G., P.-L. Vezina, N. Berman, M. Brueckner, J. Cust, D. Giles, D. Gollin, R. Hausmann, B. Javorcik, G. Michaels, P. Neary, R. Van Der Ploeg, S. Poelhekke, S. Quinn, V. Ramey, M. Ross, L., Sheng, B. Smith, R. Stefanksi, K. Tsui, T. Venables, and W. Vermeulen (2017). 'Resource Discoveries and FDI Bonanzas: an Illustration from Mozambique'. (No. OxCarre Working Papers 199).

Transparency International (2015). *Exporting Corruption Progress Report 2015*. Berlin: Transparency International.

Tukker, A., and E. Dietzenbacher (2013). 'Global Multiregional Input–Output Frameworks: An Introduction and Outlook'. *Economic Systems Research*, 25: 1–19. https://doi.org/10.1080/09535314.2012.761179'

UN (2010). *System of National Accounts 2008*. New York, NY: United Nations.

'UNDESA (2019a). *World Urbanization Prospects: The 2018 Revision*. New York, NY: United Nations. Available at: https://population.un.org/wup/publications/Files/WUP2018-Report.pdf (accessed September 2022).

UNDESA (2019b). *World Population Prospects: 2015 Revision*. New York, NY: United Nations.

UNEP (2016a). *Global Materials Flow and Resource Productivity. Assessment Report for the UNEP International Resource Panel*. Available at: https://www.resourcepanel.org/reports/global-material-flows-and-resource-productivity-database-link (accessed August 2022).

UNEP (2016b). *Global Material Flows and Resource Productivity - Summary for Policymakers*. Geneva: United Nations Environment Programme.

UNEP (2016c). *Resource Efficiency: Potential and Economic Implications: A Report of the International Resource Panel*. Geneva: UNEP.

UNEP (2018). 'Our Work in Africa'. Available at: https://www.unep.org/regions/africa/our-work-africa (accessed June 2022).

van der Ploeg, F. (2010). 'Why Do Many Resource-rich Countries Have Negative Genuine Saving?. Anticipation of Better Times or Rapacious Rent Seeking'. *Resource and Energy Economics*, 32(1), 28–44.

Vita, G., N.D. Rao,A. Usubiaga-Liaño, J., Min, and R. Wood (2021). 'Durable Goods Drive Two-Thirds of Global Households' Final Energy Footprints'. *Environmental Science & Technology*, 55(5): 3175–87. https://doi.org/10.1021/acs.est.0c03890

Vunnava, V.S.G., J. Shin, L. Zhao, and S. Singh (2021). 'PIOT-Hub: A Collaborative Cloud Tool for Generation of Physical Input–Output Tables Using Mechanistic Engineering Models'. *Journal of Industrial Ecology*, 26: 107–20. https://doi.org/10.1111/jiec.13204

Ward, H., L. Wenz, J.C. Steckel, and J.C. Minx (2018). 'Truncation Error Estimates in Process Life Cycle Assessment Using Input-Output Analysis'. *Journal of Industrial Ecology*, 22(5): 1080–91. https://doi.org/10.1111/jiec.12655

Wiedmann, T., G. Chen, A. Owen, M. Lenzen, M. Doust, J. Barrett, and K. Steele (2020). 'Three-scope Carbon Emission Inventories of Global Cities'. *Journal of Industrial Ecology*, 25(3): 735–50. https://doi.org/10.1111/jiec.13063

Wiedmann, T., and M. Lenzen (2018). 'Environmental and Social Footprints of International Trade'. *National Geoscience*, 11: 314–21. https://doi.org/10.1038/s41561-018-0113-9

Wiedmann, T.O., H. Schandl, M. Lenzen, D. Moran, S. Suh, J. West, and K. Kanemoto (2015). 'The Material Footprint of Nations'. *PNAS*, 112(20): 6271–76. https://doi.org/10.1073/pnas.1220362110

WMO (2020). *State of the Climate in Africa*. Geneva: World Meteorological Organization.

Wood, R., D. Moran, K. Stadler, D. Ivanova, K. Steen-Olsen, A. Tisserant, and E.G. Hertwich (2018). 'Prioritizing Consumption-Based Carbon Policy Based on the Evaluation of Mitigation Potential Using Input-Output Methods'. *Journal of Industrial Ecology*, 22(3): 540–52. https://doi.org/10.1111/jiec.12702

World Bank and IMF (2021). 'Factsheet: The Joint World Bank-IMF Debt Sustainability Framework for Low-Income Countries'. Available at: https://www.imf.org/en/About/Factsheets/Sheets/2016/08/01/16/39/Debt-Sustainability-Framework-for-Low-Income-Countries (accessed January 2022).

WTO (2010). *World Trade Report 2010. Trade in Natural Resources*. Geneva: World Trade Organization.

Xiao, Y., M. Lenzen, C. Benoît-Norris, G.A. Norris, J. Murray, and A. Malik (2018). 'The Corruption Footprints of Nations'. *Journal of Industrial Ecology*, 22(1): 68–78. https://doi.org/10.1111/jiec.12537

Yamano, N., and C. Webb (2018). 'Future Development of the Inter-Country Input-Output (ICIO) Database for Global Value Chain (GVC) and Environmental Analyses'. *Journal of Industrial Ecology*, 22(3): 487–88. https://doi.org/10.1111/JIEC.12758

Yang, L., Y. Wang, R. Wang, J.J. Klemeš, C.M.V.B. Almeida, M. de, Jin, X. Zheng, and Y. Qiao (2020). 'Environmental-social-economic Footprints of Consumption and Trade in the Asia-pacific Region'. *Nature Communications*, 11: 4490. https://doi.org/10.1038/s41467-020-18338-3

York, R., E.A. Rosa, and T. Dietz (2003). 'STIRPAT, IPAT and ImPACT: Analytic Tools for Unpacking the Driving Forces of Environmental Impacts'. *Ecological Economics*, 46(3): 351–65. https://doi.org/10.1016/S0921-8009(03)00188-5

Zou, H., and T. Hastie (2005). 'Regularization and Variable Selection Via the Elastic Net'. Journal of the Royal Statistical Society Ser. B (Statistical Methodology), 67(2): 301–20. https://doi.org/10.1111/j.1467-9868.2005.00503.x

Appendix A: Supporting information

Table A1: List of African countries and corresponding sub-regions

Regions				
Western Africa	**Eastern Africa**	**Central Africa**	**Northern Africa**	**Southern Africa**
Benin	Burundi	Cameroon	Algeria	Angola
Burkina Faso	Djibouti	Central African Republic	Egypt	Botswana
Cape Verde	Eritrea	Chad	Libya	Lesotho
Cote d' Ivoire	Ethiopia	Congo	Morocco	Mozambique
Gambia	Kenya	DR Congo	Sudan	Namibia
Ghana	Madagascar	Gabon	Tunisia	South Africa
Guinea	Malawi	Sao Tome and Principe		Swaziland
Liberia	Mauritius			Zambia
Mali	Rwanda			Zimbabwe
Mauritania	Seychelles			
Niger	Somalia			
Nigeria	South Sudan			
Senegal	Uganda			
Sierra Leone	Tanzania			
Togo				

Source: Eora website[16] and UN ESA classification and definition of regions.[17]

[16] https://worldmrio.com/metadata.jsp

[17] https://esa.un.org/MigFlows/Definition%20of%20regions.pdf

Table A2: Eora database sectors

Eora sector	ISIC Rev.3 correspondence
Agriculture	1,2
Fishing	5
Mining and quarrying	10, 11, 12, 13, 14
Food and beverages	15, 16
Textiles and wearing apparel	17, 18, 19
Wood and paper	20, 21, 22
Petroleum, chemical, and non-metallic mineral products	23, 24, 25, 26
Metal products	27, 28
Electrical and machinery	29, 30, 31, 32, 33
Transport equipment	34, 35
Other manufacturing	36
Recycling	37
Electricity, gas, and water	40, 41
Construction	45
Maintenance and repair	50
Wholesale trade	51
Retail trade	52
Hotels and restaurants	55
Transport	60, 61, 62, 63
Post and telecommunications	64
Financial intermediation and business activities	65, 66, 67, 70, 71, 72, 73, 74
Public administration	75
Education, health, and other services	80, 85, 90, 91, 92, 93
Private households	95
Other	99

Note: International Standard Industrial Classification of All Economic Activities (ISIC).

Source: Eora website[18].

[18] https://worldmrio.com/metadata.jsp

Table A3: List of all explanatory variables

Total greenhouse gas emissions (kilotonnes)
Energy-related greenhouse gas emissions
Energy use in kilotonnes of oil equivalent
Expenditure share of high technology in manufacturing expenditure
GDP
Per capita GDP
Inflation, GDP deflator (annual %)
Inflation
Real effective exchange rate index
Population
Population density (people per sq. km of land area)
Urban population
Share of urban population in total population
Agriculture value added (% of GDP)
Industry value added (% of GDP)
Service value added (% of GDP)
Manufacturing value added (% of GDP)
Population of young dependants (% of population)
Population of old dependants (% of population)
Life expectancy
Human Capital Index
Educational attainment, at least secondary or equivalent, population 25+, total (%) (cumulative)
Educational attainment, at least post-secondary or equivalent, population 25+, total (%) (cumulative)
Educational attainment, at least Bachelor’s or equivalent, population 25+, total (%) (cumulative)
Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
Multidimensional poverty index
Income of top 10 (% of GDP)
Central government debt, total (% of GDP)
Total reserves (% of total external debt)
Tax revenue (% of GDP)
Tax revenue (current LCU)
Total natural resources rents (% of GDP)
Foreign direct investment, net inflows (% of GDP)
Oil rents (% of GDP)
Mineral rents (% of GDP)
Foreign direct investment, net inflows (% of GDP)
Foreign direct investment, net (BoP, current USD)
Democracy scores
Human Development Index (unitless)
Literacy rate
Household size
V-dem Electoral democracy index
V-dem Additive polyarchy index
V-dem Multiplicative polyarchy index
V-dem Government accountability index
V-dem Political corruption index
V-dem Rule of law index
Political rights rating
Civil liberties rating
Democracy score

Government control of corruption
Rule of law index
Political stability no violence index
Voice and accountability index
Government effectiveness index
Regulatory quality index

Source: authors' selection, see Table A4 for data sources of respective variables.

Table A4: Selected high-ranking explanatory variables based on the LASSO and used for the panel regression and source

Variable	**Source**
Population	World Development Indicators
Urban population	World Development Indicators
Population of young dependants (% of population)	World Development Indicators
Population density (people per sq. km of land area)	World Development Indicators
GDP per capita (USD PPP)	World Development Indicators
Agriculture value added (% of GDP)	World Development Indicators
Industry value added (% of GDP)	World Development Indicators
Service value added (% of GDP)	World Development Indicators
Oil rents (% of GDP)	World Development Indicators
Human Development Index	World Bank
Foreign direct investment, net inflows (% of GDP)	World Development Indicators
Income of top 10 (% of GDP)	World Development Indicators
Real effective exchange rate index (2010=100)	World Development Indicators
Central government debt, total (% of GDP)	World Development Indicators
Additive polyarchy index	The V-Dem Dataset
Political corruption index	The V-Dem Dataset
Rule of law index	The V-Dem Dataset
Multiplicative polyarchy index	The V-Dem Dataset
Accountability index	The V-Dem Dataset
Government effectiveness	World governance indicator (World Bank)
Energy use (oil-eq ktoe)	International Energy Agency

Source: see hyperlinks in table.

Appendix B: Supplementary regression results

Table B1: Panel fixed effects regression results: biomass and ores categories for consumption-based footprints and components

	Dependent variable					
	Biomass			Ores		
Variable	**Total CB MF**	**Domestic**	**Imports**	**Total CB MF**	**Domestic**	**Imports**
Socio-demographic						
Population	0.949*** (0.137)	0.351 (0.224)	0.901*** (0.076)	0.598*** (0.115)	0.13 (0.236)	0.555*** (0.095)
Urban population	-0.307** (0.149)	0.318 (0.244)	-0.398*** (0.082)	-0.068 (0.126)	0.580** (0.257)	-0.073 (0.103)
Population density (people per sq. km of land area)	0.088** (0.043)	0.124* (0.071)	0.126*** (0.024)	-0.122*** (0.036)	-1.139*** (0.074)	0.055* (0.03)
Population of young dependants (% of population)	-1.794*** (0.196)	-1.627*** (0.321)	-1.615*** (0.108)	-1.427*** (0.165)	-1.959*** (0.338)	-1.336*** (0.136)
Economic						
GDP per capita (USD PPP)	0.076* (0.04)	0.08 (0.065)	0.190*** (0.022)	0.140*** (0.033)	-0.102 (0.068)	0.138*** (0.028)
Agriculture value added (% of GDP)	-0.430*** (0.073)	-0.451*** (0.12)	-0.379*** (0.041)	-0.320*** (0.062)	0.690*** (0.126)	-0.563*** (0.051)
Industry value added (% of GDP)	0.498*** (0.068)	0.692*** (0.111)	0.301*** (0.037)	0.358*** (0.057)	0.333*** (0.116)	0.308*** (0.047)
Service value added (% of GDP)	-0.045 (0.064)	-0.141 (0.105)	0.002 (0.035)	0.178*** (0.054)	0.009 (0.111)	0.266*** (0.044)
Total natural resources rents (% of GDP)	0.226*** (0.068)	0.432*** (0.111)	0.047 (0.038)	0.097* (0.057)	-0.161 (0.117)	0.180*** (0.047)
Oil rents (% of GDP)	-0.304*** (0.071)	-0.548*** (0.116)	-0.071* (0.039)	-0.164*** (0.06)	-0.680*** (0.122)	-0.174*** (0.049)
Mineral rents (% of GDP)	-0.009 (0.084)	-0.063 (0.137)	-0.005 (0.046)	0.735*** (0.071)	1.934*** (0.144)	0.157*** (0.058)
Human Development Index	-2.362*** (0.502)	-2.805*** (0.821)	0.444 (0.277)	-0.536 (0.422)	0.062 (0.863)	0.06 (0.347)
Economic						
Foreign direct investment, net inflows (% of GDP)	-0.002 (0.009)	0.001 (0.015)	0.006 (0.005)	0.016** (0.008)	0.004 (0.016)	0.019*** (0.006)
Income of top 10 (% of GDP)	0.053 (0.034)	0.076 (0.056)	0.045** (0.019)	0.049* (0.029)	0.110* (0.058)	0.038 (0.024)
Real effective exchange rate index (2010=100)	0.056** (0.022)	0.145*** (0.036)	-0.021* (0.012)	0.073*** (0.019)	0.256*** (0.038)	0.015 (0.015)
Central government debt, (% of GDP)	-0.080** (0.039)	-0.139** (0.064)	0.004 (0.022)	0.038 (0.033)	0.013 (0.068)	0.011 (0.027)
Institutional and governance						
Additive polyarchy index	-0.774 (0.89)	-3.312** (1.456)	1.328*** (0.491)	-2.483*** (0.749)	-5.911*** (1.531)	0.009 (0.616)
Political corruption index	4.316*** (0.569)	7.278*** (0.931)	-0.029 (0.314)	1.095** (0.479)	4.049*** (0.98)	-0.781** (0.394)
Rule of law index	0.98 (0.62)	1.937* (1.014)	-0.856** (0.342)	1.208** (0.521)	9.059*** (1.066)	-1.004** (0.429)
Multiplicative polyarchy index	-0.482 (0.648)	0.894 (1.06)	-0.506 (0.358)	1.818*** (0.545)	3.170*** (1.115)	-0.284 (0.448)

Government accountability index	1.150*** (0.164)	1.872*** (0.268)	0.589*** (0.09)	0.839*** (0.138)	0.007 (0.282)	0.669*** (0.113)
Government effectiveness	-0.107** (0.05)	-0.186** (0.083)	-0.071** (0.028)	-0.076* (0.042)	0.104 (0.087)	-0.019 (0.035)
Environment						
Energy use (oil-eq ktoe)	0.024 (0.015)	-0.006 (0.025)	0.059*** (0.008)	0.043*** (0.013)	-0.015 (0.026)	0.076*** (0.011)
Observations	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*
R^2	*0.52*	*0.398*	*0.719*	*0.643*	*0.592*	*0.656*
Adjusted R^2	*0.5*	*0.373*	*0.708*	*0.628*	*0.574*	*0.642*
F Statistic	*48.401*** (df = 23; 1027)*	*29.537*** (df = 23; 1027)*	*114.447*** (df = 23; 1027)*	*80.278*** (df = 23; 1027)*	*64.665*** (df = 23; 1027)*	*85.180*** (df = 23; 1027)*

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Source: based on authors' regression modelling of Equation (2).

Table B2: Panel fixed effects regression results: fossil fuels and construction materials categories for consumption-based footprints and components

	Dependent variable					
	Fossil fuels			Construction materials		
Variable	Total CB MF	Domestic	Imports	Total CB MF	Domestic	Imports
Socio-demographic						
Population	0.404*** (0.091)	-1.567*** (0.17)	0.462*** (0.085)	-0.284*** (0.091)	-1.653*** (0.216)	0.184** (0.078)
Urban population	0.287*** (0.099)	2.608*** (0.185)	0.148 (0.093)	1.010*** (0.1)	2.518*** (0.235)	0.487*** (0.084)
Population density (people per sq. km of land area)	0.084*** (0.029)	-0.095* (0.054)	0.090*** (0.027)	0.251*** (0.029)	0.273*** (0.068)	0.197*** (0.024)
Population of young dependants (% of population)	-2.080*** (0.13)	-2.374*** (0.244)	-1.913*** (0.122)	-2.115*** (0.131)	-3.018*** (0.309)	-1.959*** (0.111)
Economic						
GDP per capita (USD PPP)	0.214*** (0.026)	-0.191*** (0.049)	0.217*** (0.025)	0.123*** (0.027)	0.123* (0.063)	0.151*** (0.022)
Agriculture value added (% of GDP)	-0.510*** (0.049)	-0.835*** (0.091)	-0.425*** (0.046)	-0.025 (0.049)	1.116*** (0.116)	-0.343*** (0.042)
Industry value added (% of GDP)	0.276*** (0.045)	0.280*** (0.084)	0.268*** (0.042)	0.286*** (0.045)	0.025 (0.107)	0.271*** (0.038)
Service value added (% of GDP)	0.226*** (0.043)	0.603*** (0.08)	0.165*** (0.04)	0.032 (0.043)	-0.215** (0.101)	0.104*** (0.036)
Total natural resources rents (% of GDP)	0.108** (0.045)	0.469*** (0.085)	0.073* (0.042)	0.114** (0.045)	0.156 (0.107)	0.125*** (0.039)
Oil rents (% of GDP)	-0.121** (0.047)	0.103 (0.088)	-0.078* (0.044)	-0.156*** (0.047)	-0.634*** (0.112)	-0.05 (0.04)
Mineral rents (% of GDP)	0.053 (0.056)	-0.427*** (0.104)	0.113** (0.052)	0.003 (0.056)	0.388*** (0.132)	0.012 (0.048)
Human Development Index	0.32 (0.333)	0.577 (0.623)	0.191 (0.312)	0.074 (0.335)	1.848** (0.791)	0.366 (0.284)
Foreign direct investment, net inflows (% of GDP)	0.014** (0.006)	-0.01 (0.011)	0.015*** (0.006)	-0.006 (0.006)	-0.029** (0.014)	0.005 (0.005)
Income of top 10 (% of GDP)	0.057** (0.023)	0.051 (0.042)	0.048** (0.021)	0.072*** (0.023)	0.137** (0.054)	0.052*** (0.019)
Real effective exchange rate index (2010=100)	0.003 (0.015)	0.128*** (0.028)	-0.004 (0.014)	0.003 (0.015)	0.137*** (0.035)	0.001 (0.013)
Central government debt, (% of GDP)	-0.019 (0.026)	-0.120** (0.049)	0.011 (0.024)	-0.037 (0.026)	0.046 (0.062)	-0.027 (0.022)
Institutional and governance						
Additive polyarchy index	0.262 (0.591)	-3.327*** (1.105)	0.945* (0.553)	-1.846*** (0.593)	-5.749*** (1.402)	-0.296 (0.503)
Political corruption index	-0.916** (0.378)	-0.636 (0.707)	-1.136*** (0.354)	0.418 (0.38)	0.273 (0.897)	-0.079 (0.322)
Rule of law index	-0.754* (0.411)	2.480*** (0.769)	-1.064*** (0.385)	1.718*** (0.413)	5.707*** (0.976)	0.272 (0.351)
Multiplicative polyarchy index	-0.916** (0.43)	-1.039 (0.804)	-1.242*** (0.403)	0.117 (0.432)	2.040** (1.021)	-0.853** (0.367)
Government accountability index	0.719*** (0.109)	0.333 (0.204)	0.728*** (0.102)	0.829*** (0.109)	1.149*** (0.258)	0.669*** (0.093)
Government effectiveness	-0.080** (0.034)	0.032 (0.063)	-0.088*** (0.031)	-0.064* (0.034)	0.02 (0.08)	-0.087*** (0.029)

Environment						
Energy use (oil-eq ktoe)	0.050*** (0.01)	0.157*** (0.019)	0.042*** (0.01)	-0.001 (0.01)	-0.055** (0.024)	0.008 (0.009)
Observations	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*
R^2	*0.746*	*0.742*	*0.732*	*0.731*	*0.581*	*0.758*
Adjusted R^2	*0.736*	*0.731*	*0.721*	*0.719*	*0.563*	*0.748*
F Statistic	*131.335*** (df = 23; 1027)*	*128.094*** (df = 23; 1027)*	*122.144*** (df = 23; 1027)*	*121.096*** (df = 23; 1027)*	*61.833*** (df = 23; 1027)*	*140.075*** (df = 23; 1027)*

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Source: based on authors’ regression modelling of Equation (2).

Table B3: Panel fixed effects regression results: biomass, ores, fossil fuels, and construction materials categories for production-based footprints and components

	Dependent variable							
	Biomass		**Ores**		**Fossil fuels**		**Construction materials**	
Variables	**Total PB MF**	**Exports**	**Total PB MF**	**Exports**	**Total PB MF**	**Exports**	**Total PB MF**	**Exports**
Socio-demographic								
Population	0.504*** (0.057)	0.541*** (0.055)	0.788*** (0.08)	0.792*** (0.075)	0.633*** (0.065)	0.669*** (0.073)	0.669*** (0.073)	0.804*** (0.069)
Population density (people per sq. km of land area)	0.223*** (0.058)	0.225*** (0.056)	-1.099*** (0.081)	-0.977*** (0.077)	-0.019 (0.067)	0.354*** (0.074)	0.354*** (0.074)	0.289*** (0.07)
Population of young dependants (% of population)	-1.354*** (0.259)	-1.500*** (0.251)	-2.634*** (0.362)	-2.510*** (0.342)	-1.527*** (0.298)	-2.940*** (0.33)	-2.940*** (0.33)	-3.119*** (0.312)
Economic								
GDP per capita (USD constant)	-0.028 (0.018)	-0.041** (0.017)	-0.02 (0.025)	-0.026 (0.024)	-0.027 (0.021)	0.075*** (0.023)	0.075*** (0.023)	0.058*** (0.022)
Foreign direct investment, net inflows (% of GDP)	-0.513*** (0.092)	-0.311*** (0.089)	0.290** (0.129)	-0.022 (0.122)	-1.741*** (0.106)	0.077 (0.117)	0.077 (0.117)	-0.188* (0.111)
Agriculture value added (% of GDP)	0.737*** (0.089)	0.541*** (0.086)	0.465*** (0.125)	0.435*** (0.118)	0.614*** (0.103)	0.380*** (0.114)	0.380*** (0.114)	0.340*** (0.108)
Manufacturing, value added (% of GDP)	-0.019 (0.083)	0.167** (0.081)	0.097 (0.116)	0.290*** (0.11)	0.721*** (0.096)	-0.196* (0.106)	-0.196* (0.106)	-0.006 (0.1)
Service value added (% of GDP)	0.024** (0.012)	0.035*** (0.011)	0.013 (0.016)	0.017 (0.016)	0.022 (0.014)	0.0004 (0.015)	0.0004 (0.015)	0.011 (0.014)
Total natural resources rents (% of GDP)	1.058*** (0.104)	0.975*** (0.101)	0.292** (0.145)	0.285** (0.138)	0.502*** (0.12)	0.356*** (0.133)	0.356*** (0.133)	0.460*** (0.126)
Oil rents (% of GDP)	-0.752*** (0.087)	-0.718*** (0.084)	-0.664*** (0.121)	-0.616*** (0.115)	1.191*** (0.1)	-0.12 (0.111)	-0.12 (0.111)	-0.068 (0.105)
Mineral rents (% of GDP)	-0.182* (0.106)	-0.108 (0.103)	2.187*** (0.149)	2.218*** (0.141)	-0.152 (0.123)	0.652*** (0.136)	0.652*** (0.136)	0.715*** (0.129)
Real effective exchange rate index (2010=100)	-0.064** (0.028)	-0.081*** (0.027)	0.153*** (0.039)	0.162*** (0.037)	0.142*** (0.032)	-0.033 (0.036)	-0.033 (0.036)	-0.044 (0.034)
Economic								
Tax revenue	0.006 (0.006)	0.016*** (0.005)	-0.021*** (0.008)	-0.022*** (0.007)	-0.004 (0.006)	-0.003 (0.007)	-0.003 (0.007)	-0.006 (0.007)
Central government debt (% of GDP)	0.052 (0.053)	0.104** (0.051)	0.117 (0.074)	0.109 (0.07)	-0.156** (0.061)	0.055 (0.067)	0.055 (0.067)	0.062 (0.064)
Human Development Index	-2.961*** (0.603)	-2.578*** (0.585)	-0.362 (0.843)	0.207 (0.798)	1.906*** (0.694)	4.501*** (0.769)	4.501*** (0.769)	5.007*** (0.728)
Institutional and governance								
Political stability/no violence index	-0.158* (0.086)	-0.219*** (0.083)	-0.252** (0.12)	-0.144 (0.114)	-0.129 (0.099)	-0.123 (0.109)	-0.123 (0.109)	-0.093 (0.104)
Additive polyarchy index	-0.434 (0.938)	1.148 (0.911)	1.963 (1.314)	2.615** (1.242)	-2.862*** (1.081)	-0.569 (1.198)	-0.569 (1.198)	-0.087 (1.134)
Political corruption index	6.406*** (0.659)	4.808*** (0.64)	2.201** (0.922)	1.774** (0.872)	2.434*** (0.759)	1.707** (0.841)	1.707** (0.841)	1.495* (0.796)
Rule of law index	1.630** (0.796)	-1.081 (0.773)	5.938*** (1.114)	3.823*** (1.054)	0.653 (0.917)	2.240** (1.016)	2.240** (1.016)	0.327 (0.961)
Government accountability index	1.405*** (0.202)	1.517*** (0.196)	-0.497* (0.283)	-0.624** (0.267)	1.020*** (0.233)	1.334*** (0.258)	1.334*** (0.258)	1.167*** (0.244)
Government effectiveness	-0.209*** (0.065)	-0.233*** (0.064)	-0.091 (0.092)	-0.116 (0.087)	-0.04 (0.075)	-0.309*** (0.084)	-0.309*** (0.084)	-0.312*** (0.079)

Environment								
Total GHG emissions (Mt CO2e)	0.213*** (0.058)	0.152*** (0.057)	0.261*** (0.082)	0.140* (0.077)	0.205*** (0.067)	0.038 (0.074)	0.038 (0.074)	-0.034 (0.07)
Energy use (oil-eq ktoe)	0.028 (0.021)	0.045** (0.02)	0.026 (0.029)	0.077*** (0.027)	0.299*** (0.024)	0.105*** (0.026)	0.105*** (0.026)	0.144*** (0.025)
Observations	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*	*1,071*
R^2	*0.568*	*0.583*	*0.624*	*0.627*	*0.796*	*0.584*	*0.584*	*0.623*
Adjusted R^2	*0.55*	*0.565*	*0.608*	*0.612*	*0.787*	*0.566*	*0.566*	*0.607*
F Statistic	*58.702*** (df = 23; 1027)*	*62.343*** (df = 23; 1027)*	*74.058*** (df = 23; 1027)*	*75.120*** (df = 23; 1027)*	*173.800*** (df = 23; 1027)*	*62.641*** (df = 23; 1027)*	*62.641*** (df = 23; 1027)*	*73.652*** (df = 23; 1027)*

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Source: based on authors' regression modelling of Equation (2).