A sustainable future for Africa through continental free trade and agricultural development

Charlotte Janssens[1,2], Petr Havlík[2], Esther Boere[2], Amanda Palazzo[2], Aline Mosnier[3], David Leclère[2], Juraj Balkovic[2], Miet Maertens[1]*

Authors' information

Affiliation

[1]University of Leuven (KU Leuven), Department of Earth and Environmental Sciences, Celestijnenlaan 200E, Heverlee, Belgium
[2]International Institute for Applied System Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria
[3]UN Sustainable Development Solutions Network (UNSDSN), 19, Rue Bergère, 75009 Paris, France

Corresponding author

Charlotte Janssens | E-mail: charlotte.janssens@kuleuven.be

This version of the article has been accepted for publication, after peer review (when applicable) but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: https://doi.org/10.1038/s43016-022-00572-1. Use of this Accepted Version is subject to the publisher's Accepted Manuscript terms of use https://www.springernature.com/gp/open-research/policies/acceptedmanuscript-terms

Abstract

Developing and integrating agricultural markets may be key to address Africa's sustainability challenges. By modelling trade costs from farm-gate to potential import markets across eight African regions, we investigate the impact of individual components of continental free trade and the complementary role of domestic agricultural development through increased market access for farmers and agricultural intensification. We find that free trade would increase intra-African agricultural trade six-fold by 2030, but – as it does not address local supply constraints – outside food imports and undernourishment would reduce only marginally. Agricultural development could almost eliminate undernourishment in Africa by 2050, at only a small cost of increased global greenhouse gas emissions. While continental free trade will be enabled in Africa through the African Continental Free Trade Area, aligning this with local agricultural development policies will be crucial to increase intra-African trade gains, promote food security and achieve climate objectives.

Main

Agriculture plays a key role in ensuring a sustainable future for Africa. Currently, about 19% of the African population is undernourished[1]. Despite rapid growth in agricultural production in Sub-Saharan Africa since 2000[2], food production did not keep up with increasing food demand thereby building up a high dependency on imports from outside Africa[3]. While international imports increase food availability and diet diversity[4], they also imply risk from global market uncertainty[5], especially for countries with high food insecurity and volatile export earnings[6]. Further, production growth in the past decades in Africa relied mainly on cropland expansion rather than yield intensification[2], driving deforestation and related greenhouse gas (GHG) emissions[7]. Future food demand is expected to continue to grow rapidly in Africa as income increases[8], the total population doubles[9] and the urban population almost triples[10] by 2050. Meeting this demand without increased import dependence or cropland expansion poses a major challenge[11,12]. In this context, the modernization and regional integration of agri-food systems can be key to eliminate hunger, ensure sustainable production growth and induce broader economic transformation in Africa[2,13–15]. In the past decades the modernization of developing countries' food systems lowered food prices and reduced seasonal variation in food supply[16]. Agricultural productivity growth under the Green Revolution in Asia, Latin America and Middle East tripled global crop production, while being land sparing and emission saving[17]. Improved access to domestic and international markets may in theory also reduce pressures on natural resources by relocating agriculture to the most productive areas, though impacts in the past decades have been negative instead due to deforestation and cropland expansion effects[18–20]. In Africa, there is still a huge potential to develop domestic agricultural markets and expand international agricultural trade, especially within the continent.

Only 21% of total African agricultural trade occurs within Africa, versus 51% in the Americas and 74% in Europe[5]. The intra-African trade that takes place is concentrated in African regional economic communities (RECs), with little trade between countries of different RECs[21]. Maize and palm oil for instance, which are among the agricultural commodities most traded within Africa[22], are almost exclusively traded within RECs, for about 99% and 98% respectively[21]. By linking African agricultural producers with the rapidly growing food demand of African consumers and exploiting variation in climate and agro-ecological conditions, continental trade integration could increase the availability, access and stability of food[3] and create incentives for economic growth and job creation in different segments of the food supply chain[5,23]. However, high trade costs are posing significant barriers to intra-African agricultural trade. The costs for logistics, transport and administrative procedures on existing African trade corridors are found to be the highest in the world[24,25]. African ports are characterised by low efficiency in handling vessels and (un)loading containers leading to the globally largest delays in customs clearance[26,27]. The costs of establishing new trade relations, so called entry costs, are generally larger in developing than in developed countries[28] and limit Africa's export diversification[29]. Import tariffs are low within most RECs in Africa, but have remained high across RECs[22]. Lastly, unpredictable trade policies like short-term export bans are common[3,23], reducing incentives for traders to invest in durable trade networks[30].

Accelerated development along the whole food supply chain is needed to improve the competitiveness of agriculture in Africa[5,15]. A first crucial element is agricultural productivity growth, for which especially in Sub-Saharan Africa the potential is huge[2,31]. Observed rainfed maize yields of 1 to 2 tons per hectare in Africa reach for example only 15% to 27% of their potential yield[11]. Sub-Saharan Africa faces high levels of soil nutrient depletion, maintained by the low average modern input use[31], while also the response of crop output to fertilizer applied is particularly low[2]. Yet, there are important differences in input adoption within and between countries, e.g. the use of nutrients ranges from 7.7 kg/ha in Tanzania and 25.2 kg/ha in Ethiopia to 64.3 kg/ha in Nigeria[32]. A second crucial element is investment in post-farm segments of the supply chain[16]. Transport and marketing costs to transfer products from farm to wholesale markets drive up the price of food for consumers, with farm-gate-to-wholesale price ratios documented to be as low as 40 to 60% in Sub-Saharan Africa[33–35]. High transport costs also limit the adoption of modern inputs by farmers[36], with fertilizer price increases due to transport costs estimated to be 12% to 50% in Ethiopia and Nigeria[37,38]. Between wholesale markets trade costs are estimated to be at median 5 times higher in African countries than the international benchmark[39]. The most widely mentioned factor explaining the high transport costs is the relatively low density and quality of road infrastructure in Africa compared to other regions[26,40]. Yet, the picture is changing, especially in Southern and Eastern Africa, with the emerging structural transformation of food systems in the past two decades[16]. The underlying development in coordination and logistics gradually improves price integration between and along supply chains[41,42]. This does not only reduce prices for consumers, but creates also incentives for producers to increase fertilizer use[13,37,38] and crop production[40,43].

Previous studies provide a detailed account of the economic impacts of continental free trade[26,44,45] or the food security and climate change impacts of domestic agricultural development policies[11,46,47] in Africa, but assessments linking both levels are rare and, when combined, remain coarse[17,48]. Yet, agricultural productivity, and domestic and international market access jointly determine the competitiveness and location of agricultural production, and their interactions may critically influence the potential for trade across the continent and the broader sustainability impacts. Our study fills this gap through a comprehensive integrated assessment of the impact of both continental free trade and domestic agricultural market development in Africa on agricultural trade, undernourishment and GHG emissions from the Agriculture, Forestry and Land Use (AFOLU) sector until 2050. To do this, we apply a modelling framework that consistently represents all relevant spatial scales. We also simulate new bilateral trade flows (i.e. the extensive margin of trade) given the scarcity of the current African continental trade pattern. For this purpose, we use the Global Biosphere Management Model (GLOBIOM), a spatially explicit partial equilibrium land use model that in the past has been widely applied to international trade, climate change mitigation, and food security analysis[49–51], and expands it by an unprecedented granularity of trade cost representation. Trade costs have been disaggregated into individual local (transport and marketing costs from farm-gate to market) and international cost components (costs of entry, export, import, international transport, trade expansion and tariffs), allowing to track the relative importance of each component (see Methods and Supplementary Methods).

We calibrate the GLOBIOM model to historical agricultural trends in eight African regions and assess the medium (2030) and long-term (2050) impacts of continental free trade and agricultural market development through explorative scenario analysis (**Table 1** and Methods). In the *Free Trade* scenario, trade policy costs (import tariffs), and transaction costs (international transport, import, export and entry) as well as expansion costs between African regions are reduced by 2030. The *Agricultural Development* scenario represents full yield and market potentials by closing infrastructure and yield gaps across the African continent by 2030. Local trade costs are reduced to an international benchmark of 0.05 USD/km everywhere in Africa while crop yields reach their potential levels under non-irrigated conditions and improved fertilizer use, increasing both the fertilizer rate, e.g. up to 200 kg / ha / year for nitrogen, and the yield response to fertilizer use. By increasing the resource use efficiency and profitability of agriculture, this may reduce food prices, alter the relative competitiveness within Africa and with the rest of the world, and increase or decrease GHG emissions. The scenarios are inspired by major policies of the African Union on continental trade – the African Continental Free Trade Area (AfCFTA) – and on agricultural development – the Comprehensive African Agricultural Development Programme (CAADP). The AfCFTA creates a single liberalized market for trade in goods and services in Africa as of January 1, 2021[52] and shapes the goal of the African Union to reduce food imports from outside Africa and raise intra-African agri-food trade[53]. The CAADP, adopted already in 2003, aims to foster agricultural-led economic growth and prioritizes sustainable land management, rural infrastructure development, hunger reduction and technology adoption[54]. The realization of the 'full potential' scenarios is ambitious for low-income countries in Africa as the gap between starting point and policy objective is wide and government budgets are limited[6]. To inform policy implementation, we therefore assess also the prioritization of individual measures of trade liberalization, facilitation, and development (decomposition of the main scenarios), as well as the prioritization of agricultural investments in certain locations (*Connect* scenario) or sectors (*Food* and *Export* scenario). Prioritization may not only be necessary given constraints on financial resources, but also to harmonize tradeoffs across different policy objectives, for example between food security and environmental impacts[15]. The scenarios results are presented as compared to a baseline that is quantified according to the second Shared Socio-Economic Pathway (SSP2)[55] in which local and international trade costs remain constant and crop yields develop according to historical trends. **Fig. 1**a illustrates how the *Free Trade* and *Agricultural Development* scenarios affect producer prices, and local and international trade costs for maize trade between two African regions (Rest of Southern Africa (RSouthAf) and Arab Maghreb Union (AMU), see African regions in **Fig. 1**b). The *Free Trade* scenario reduces international trade cost elements (red bar stacks), while the *Agricultural Development* scenario reduces regional market prices (blue bar stacks). Already this example illustrates that implementation of both continental trade integration and agricultural market development may be required to improve competitiveness of some regions and allow new trade flows to emerge.

Results and Discussion

Business as usual is not sustainable for Africa. Our baseline trend is in line with previous studies that indicate that large population growth is expected to increase net food imports in Africa by 2050[56], while crop yield improvements limited to historical growth rates would raise GHG emissions from land-use change[46]. We project that agricultural production in Africa doubles between 2020 and 2050 and agricultural imports from the rest of the world increase by almost one third to meet the population's food demand, which grows over the same period by 77%. Trade between the eight African regions (**Fig. 1**b), henceforth referred to as intra-African trade, remains low, representing only 2.6% of total African imports in 2050. This intra-African trade share is below the share of 21% reported in the introduction as we focus on trade between African regions, not within regions (where the majority of intra-African trade is currently concentrated). Although the increase in African production and outside imports raises total food availability, still 174 million people in Africa are projected to be undernourished by 2050 (8.4% of the population), compared to 237 million in 2020 (17.8% of the population). Crop production increases through crop yield growth, on average 50% between 2020 and 2050 (from 1.64 to 2.46 dry matter ton/ha), and cropland expansion, an increase of 62 Mha between 2020 and 2050 at the expense of primary forest, other natural land and grassland. Annual greenhouse gas (GHG) emissions from the AFOLU sector in Africa raise from 1.77 Gt CO_2eq/year in 2020 to 1.89 Gt CO_2eq/year by 2050. Thus, business-as-usual would leave a large gap with the SDG ambition and policy goals of the African Union to reduce outside food imports, raise intra-African trade, eliminate hunger and ensure sustainable forest management[53].

Intra-African has **no hunger and GHG emission impacts**. The impact of the *Free Trade* scenario on total agricultural trade, production, undernourishment and GHG emissions in Africa by 2050 is presented in **Fig. 2a** (Extended data Figure 1 for 2030 results). Continental free trade increases intra-African trade by 528% by 2030 and 922% by 2050, leading to a share of 22% intra-African trade in total African imports in 2050, a share ten times higher than in the baseline. The corresponding growth rate in trade volume of 111% per decade falls within the range of growth rates observed in past regional free trade agreements (Supplementary Figure 1). In line with previous assessments[26,44,45], we find that tariff liberalization alone is not sufficient to mobilize intra-African trade (see Supplementary Methods for a detailed study comparison). It is the interaction between tariff elimination, import and export cost reduction, and reduction in intensive margin expansion costs, i.e. addressing capacity constraints of trade expansion on existing trade routes, that drives growth in intra-African trade (**Fig. 2**b). The total number of intra-African trade relations almost doubles by 2030 compared to the baseline, though new trade flows are small and represent only 5.7% of total intra-African trade growth. Overall, intra-African trade remains small relative to African food demand – by 2050 the volume of total intra-African trade is only 5% of total African food consumption – explaining the limited impact on undernourishment (-1.4% in 2030, -0.6% in

2050 compared to the baseline). Only 6.1% of the total intra-African trade growth by 2050 replaces imports from outside Africa, which indicates that despite large reductions in trade costs within Africa, Africa's agricultural production is not able to compete with its outside trade partners. Lastly, the intra-African trade growth has almost no impact on AFOLU GHG emissions and total agricultural production as it is driven by relocation of production across African regions. Production tends to shift to less GHG emission intensive regions, but the size of the relocation is too small to generate large GHG emission saving.

***Agricultural Development* reduces hunger at low GHG impact.** Under the *Agricultural Development* scenario, we assume that by 2030 African farmers have full access to local markets (an average reduction of 87% in local transport costs and 62% in local marketing costs) and reach potential yield levels under improved fertilizer use (an average increase of 144% in crop yields). This leads to a large growth in total African agricultural production by 2050 (+76%) compared to the baseline scenario (**Fig. 2**a). The trade balance with the rest of the world improves as the production growth reduces outside imports (-36%) and increases outside exports (+52%). Food prices for consumers drop sharply (Supplementary Figure 2) and undernourishment is almost fully eliminated on the continent (-93%). AFOLU GHG emissions in Africa increase due to land use changes (+111 Mt CO_2eq/year, +6%), though the increase is small relative to the production growth and the GHG emission intensity of agricultural production reduces compared to the baseline. Global AFOLU GHG emissions increase to a lower extent (+81.4 Mt CO_2eq/year). The reduction in Africa's outside imports implies that increased GHG emissions within Africa are partly compensated by reduced emissions in the rest of the world. Looking at local trade costs, the decomposition shows that transport costs have about twice the impact of other marketing costs on production growth, hunger reduction and outside food imports (**Fig. 2**c). Crop yield improvements contribute most to the overall production growth and reduction in outside imports and hunger. The GHG emissions impact results from two opposite mechanisms: local trade cost reductions that increase GHG emissions by inducing expansion of agricultural land versus crop yield improvements that reduce GHG emissions by sparing cropland. Lastly, we find interactions between market access and crop intensification. When combined with improved yields, local trade cost reductions induce a smaller increase in GHG emissions (final < individual effect) and a larger increase in agricultural production (final > individual effect). Local trade cost reductions induce reallocation to more productive units within each region and the consequent increase in average yields is higher when overall yield levels are improved. Considering investment prioritization, it is relevant to note that the impact of reduced local marketing costs on increasing production and reducing hunger, though small compared to other agricultural development elements, is still much higher than any of the elements from the *Free Trade* scenario either separately or combined. The impact of agricultural market development on intra-African trade, on the other hand, is minor.

Complex impacts across African regions. There is a large diversity in current agricultural systems, growing conditions, and market access across Africa[57], and our baseline trends continue to project a diverse future (Supplementary Figure 3). **Fig. 3** shows that also the impact of the *Free Trade* and *Agricultural Development* scenarios differ across African regions (Extended data Figure 2 for 2030 results). Under the *Free Trade* scenario all African regions increase intra-African exports, raising the intensity of intra-African trade compared to trade with the rest of the world (Supplementary Tables 5 and 6). However, while export cost levels become more equal between African regions under *Free trade*, it are still the main baseline exporters (Southern Africa (SACU, RSouthAf), Egypt) that remain lead exporters (Supplementary Table 5) and not the regions with the largest absolute reductions in export costs (Central and Eastern Africa (ECCAS and RCEAf)) (Supplementary Figures 9 and 11). A large share of the intra-African trade growth is driven by relocation of sugarcane and maize production, which are increasingly produced for export in SACU (maize, sugarcane), Egypt (sugarcane) and RSouthAf (sugarcane). The *Agricultural Development* scenario on the other hand substantially raises agricultural production in all regions except for Egypt and SACU and leads to large reductions in undernourishment in all hunger-affected regions. Western (ECOWAS) and Central (ECCAS) Africa experience the largest absolute production increase. This is explained by the high crop yield growth potential from improved fertilizer use (Supplementary Fig. 13) and the high baseline levels of local trade costs in those regions (**Fig. 1**c). The land sparing effect of yield growth compensates for GHG emissions from the land expansion effect of local trade cost reductions in all regions except for ECCAS (Extended data Figure 3), where the reductions in local trade costs are particularly large (a reduction of 81% under *Agricultural Development* compared to baseline scenario in 2030).

***Free Trade* accompanied by *Agricultural Development* diversifies trade.** Agricultural development can interact in two different ways with intra-African trade integration (Supplementary Methods). A reduction of local trade costs and increased crop yields improves the competitiveness of local agricultural production, which can limit intra-African trade due to a reduced need for imports. Improved competitiveness may, on the other hand, also create new export opportunities and stimulate trade within Africa according to comparative advantage[30]. We find that the combined *Free Trade* + *Agricultural Development* scenario leads to a smaller total intra-African trade volume than *Free Trade* alone (**Fig. 2**a), but creates the same increase in number of trade flows and an intra-African trade pattern that is more diverse in terms of exporting regions and products traded. Due to a more competitive domestic production, total import demand in EAC, ECCAS and RSouthAf reduces (**Fig. 3**), lowering intra-African imports of sugarcane and maize in specific (Extended data Figures 4 and 5)**.** A higher competitiveness of domestic agricultural markets on the other hand also promotes export creation in various regions. New trade flows represent 43% of total trade growth by 2050 under the combined scenario (compared to 5.7% under *Free Trade*). Compared to the *Free Trade* scenario, intra-African exports from ECOWAS, ECCAS, AMU and RCEAf expand, raising intra-African trade in wheat, rice, oil palm, barley and cotton (Extended data Figures 4 and 5). This leads to growth in total agricultural production for ECOWAS, ECCAS and AMU, while the production gains and intra-African export shares of the main baseline exporters (SACU, RSouthAf and Egypt) reduce compared to *Free Trade* (**Fig. 3** and Supplementary Table 5). Overall, the altered trade pattern under the combined scenario implies that all African regions experience a (small) net gain in their agricultural trade balance by 2050 (Supplementary Table 7). For imports from outside Africa, a larger reduction occurs in the combined scenario (-42% in 2050) compared to the simple sum of the individual scenarios (-1.8% under *Free Trade* and -36% under *Agricultural Development*) (**Fig. 2**a). Intra-African trade increasingly replaces outside imports of for example maize in AMU and Egypt and oil palm in EAC, RCEAf and Egypt (Extended data Figures 4 and 5). Yet, the volume of surplus available within Africa remains below the total import demand, especially for wheat, soybean and oil palm (Extended data Figure 6). This explains why the combined scenario does not enhance reductions in undernourishment and additional changes in management practices such as irrigation or increased cropping intensity may be needed to achieve this[11]. Lastly, the impact of continental free trade on GHG emissions in Central Africa changes when combined with agricultural development – for other African regions the interaction is limited. Whereas the *Free Trade* scenario increases ECCAS's imports, reducing cropland expansion and forest loss compared to the baseline scenario, the combined scenario increases ECCAS's exports by lifting domestic production constraints, which increases forest loss and GHG emissions compared to the baseline (**Fig. 3**).

Smart strategies allow to reach policy goals. Targeting the development of road infrastructure to certain key trade corridors is suggested to result in efficient welfare gains[39] and limited deforestation impacts[43]. Further, governments typically prioritize agricultural investments to specific sectors in line with their main policy goals[6]. For Africa, different agricultural investment strategies have been proposed for the coming decades, targeted to either food self-sufficiency[58] or intra-African trade[21]. **Fig. 4** presents the results of three scenarios on different prioritization strategies (*Connect*, *Food*, *Export*) for agricultural market development in Africa (Extended data Figure 7 for regional results). The *Connect* scenario focuses on lowering transport costs in the first sections beyond the farm-gate and this in areas already connected to the primary road network (Extended data Figure 8, average reduction of 56% in local trade costs across Africa). While this presents a smaller reduction in local trade costs than the original *Agricultural Development* scenario, it creates reductions in hunger and outside imports of similar magnitude, and this at a lower GHG emission cost (in terms of both African and global emissions, Supplementary Figure 5). In ECCAS (local trade costs -47%), GHG emissions are lower as more productive mixed systems are favored over grazing systems in the ruminant sector (Supplementary Figure 6), reducing grassland expansion and deforestation. In ECOWAS (local trade costs -63%), GHG emissions are lower as the *Connect* scenario excludes natural land areas not connected to the primary road network, limiting the conversion of those areas to cropland (Supplementary Figure 7). The *Food* scenario targets marketing cost reductions and yield intensification to the main food and feed commodities in each region, reflecting a focus on regional food self-sufficiency. This obtains similar reductions in hunger and outside imports as the original *Agricultural Development* scenario. The intra-African trade growth under *Food* + *Free Trade* also remains similar for each region, indicating that regions' important food sectors also have an export potential on the African market. The *Export* scenario targets marketing cost reductions and yield intensification on the other hand specifically to commodities for which each region has a comparative advantage compared to other African regions. In such setting the export creation mechanism of agricultural development is prioritized over the import replacement mechanism. This leads to a smaller reduction in outside imports but, when combined with *Free Trade*, a larger growth in intra-African trade. ECOWAS, SACU and RSouthAf increase intra-African exports and EAC and ECCAS increase intra-African imports. The *Free Trade* + *Export* scenario has a GHG emission saving effect by preventing land use change emissions in the ECCAS region, but total hunger reduction is smaller than under *Agricultural Development*.

Conclusion

Continental trade integration in Africa holds the unique opportunity of linking African agricultural producers with rapidly growing food demand in African consumer markets. Our scenario analysis reveals that to mobilize continental agricultural trade in Africa, different policy measures will not bring substantial benefits on their own but are jointly needed. That is, for the AfCFTA to deliver on its African trade promise, tariff liberalization will not work if not combined with regulatory reform to address administrative import and export procedures and investments to increase port efficiency and reduce inland transport costs. The costs of these measures vary. Tariff liberalization reduces tariff revenue, but the reduction is expected to be small for most countries in Africa[26,44,59] and on average compensated by increased economic activity[59,60]. Regional integration can provide the necessary push for regulatory reform, exemplified by effective trade facilitation efforts in the EAC. Simplification and harmonization of customs procedures through the Single Customs Territory has substantially reduced customs clearance time along the corridors linking EAC's hinterland with the ports of Dar es Salaam and Mombasa[61]. Policy reform can however not address all barriers. Infrastructure investment needs in Africa remain high and current financing, mostly from national governments, is unable to bridge the gap[62]. Alternative financing mechanisms such as public-private partnerships may be crucial and successful, if building on lessons from past experiences such as the development of the port of Mabuto in Mozambique[63]. Yet, continental free trade alone will have only marginal impacts on total agricultural production, outside food imports and undernourishment if not combined with policies to accelerate agricultural development.

Under agricultural development, consisting of crop intensification and reduction in local trade cost, agricultural production in Africa increases substantially, the trade balance with the rest of the world improves and undernourishment is almost fully eliminated by 2050. Crop intensification, the increase of yields per unit of cropland, appears as a key component. The need for agricultural productivity growth in Africa is widely recognized[2,31]. The prevailing emphasis is on increasing fertilizer use and improving nutrient management practices[31], for example within an integrated soil fertility management strategy. This is a paradigm that stresses the combination of mineral fertilizers, organic inputs, improved seeds and locally adapted management practices to optimize nutrient use efficiency[64]. Another emerging paradigm is that of site-specific nutrient management advice, using plot-specific information to provide farmers with recommendations that fit the conditions of their field[31,65]. To support such technical innovations and to face future challenges of climate change, increased investment in agricultural research, development and extension is argued crucial[2]. Spending on agricultural research is on average low in Africa, while African countries with increases in R&D spending in the past decades are experiencing faster agricultural productivity growth[2,66]. Attention should also be given to weak rural credit markets[32] and high transportation costs that reduce access to modern inputs[37,38]. Complementing previous studies on road development in Sub-Saharan Africa[20,40], we find that reducing trade costs between farm-gate and local market would further increase agricultural production especially in West and Central Africa, where these cost are currently far above international benchmark levels. Reducing transport costs requires investments in the maintenance and construction of road infrastructure[67], the use of trucks with higher load capacity[42], and the provision of efficient and competitive trucking services[24,68]. The latter would address the high mark-ups that are found to be charged on transport costs in Central- and West-Africa due to low truck utilization and oversupply[24]. Reducing marketing costs requires improving the quality of warehouse and distribution services, by establishing regulatory frameworks for modern distribution services[3] and by expanding digitalization and access to finance for the mid- and downstream enterprises in the value chain[13]. Overall, our results reaffirm the importance of closing the gap that currently prevails between actual and targeted investments under the CAADP in most African countries[69].

Given limited government budgets we assess the potential of prioritization of agricultural and infrastructural investments. We find that even investments into specific sectors alone allow to reach policy goals, e.g. development of the main food sectors appears sufficient to reduce hunger and outside imports. When African regions prioritize investments in export sectors and implement continental free trade policies, intra-African trade is maximized and leads to GHG emissions saving, but progress on hunger reduction is slower. Determining optimal agricultural investments would require a careful balancing of costs and benefits, taking into account real-life constraints faced by farmers, including future climate change impacts. Lastly, infrastructure investments targeted to the first tens of kilometers beyond the farm-gate in areas close to the primary road network reduce the trade-off between hunger reduction and GHG emissions from deforestation. This is in line with other studies indicating that spatial planning of infrastructure development may be crucial to preserve highly biodiverse natural areas, especially in Central Africa[18,43]. Determining optimal infrastructure investments is an important avenue for further research. This requires using country-specific trucking data for realistic cost-benefit assessments and taking into account road maintenance, currently underrepresented in infrastructure spending in Africa but needed to ensure sustainable road networks[67].

Ultimately, international trade integration and domestic sector development crucially interact with each other. Agricultural productivity growth affects the competitiveness of regions, the Green Revolution for example contributed to India's relative export competitiveness in rice and cotton[70]. We demonstrate that taking into account the huge potential for future agricultural growth in Africa critically alters relative competitiveness within Africa and between Africa and the rest of the world. While the *Free Trade* scenario does not reduce outside imports, *Agricultural Development* does. Under the combined *Free Trade* and *Agricultural Development* scenario, the reduction in outside food imports is enhanced and production and trade gains are more equally distributed across African regions. While there is no additional reduction in undernourishment, food security benefits may still be strengthened as only under the combined implementation does the agricultural trade balance improve for all regions and does the diversity of the intra-African trade pattern increase. The former may improve food access, while the latter food stability. Regional food trade has been suggested to be able to reduce consumption and price volatility in Africa[71,72]. In the future, diverse continental African trade patterns might become more important than regional African trade in order to mitigate volatility from climate change-induced production shocks as these are likely to occur synchronously in neighboring African countries[73] but may differ across the African continent[74]. Overall, we demonstrate that aligning continental free trade and local agricultural development policies will be crucial to simultaneously achieve trade, food security and climate objectives. A close cooperation between the policy areas of African trade – the AfCFTA – and agricultural development – the CAADP – appears therefore to be of paramount importance.

Methods

Model description. We use the Global Biosphere Management Model (GLOBIOM) for our analysis, a recursive dynamic, spatially explicit, economic partial equilibrium model of the agriculture, forestry and bioenergy sectors. Starting in 2000, the model computes a market equilibrium in 10 year time steps by maximizing the sum of consumer and producer surplus minus international trade costs. Supply is modelled at the level of sub-national supply units (2 x 2 degree grid cells), while demand and trade modelled at the level of 39 economic regions. African countries are grouped in 8 regions based on the Regional Economic Communities (RECs) (Supplementary Table 1). The agricultural sector covers production of major crops (barley, beans, cassava, chickpeas, corn, cotton, groundnut, millet, palm oil, potato, rapeseed, rice, soybean, sorghum, sugarcane, sunflower, sweet potato, and wheat) and animal products (meat, milk, eggs) from bovines, sheep, goat, pigs and poultry. This covers all products identified as strategic for intra-African trade[21] (except for fisheries), as well as the main extra-African food imports[11]. Regarding extra-African exports, however, not all major commodities are represented (e.g. not coffee, tea, cocoa, or horticultural produce). GLOBIOM captures trade through Enke-Samuelson-Takayama-Judge spatial equilibrium assuming homogenous goods[75]. Compared to the trade implementation in GLOBIOM as described in Janssens et al.[49], trade costs are disaggregated in higher detail and the parameterization is adjusted according to empirical determinants of agricultural trade growth (Supplementary Methods). We add spatial explicit local trade costs to the supply side building on Mosnier et al.[76] and calibrate the model to approximate observed agricultural trends in the period 2000 – 2020 in Africa (Supplementary Figures 19 to 28). Below we briefly present the features important for this study, greater details on these and other aspects of the modelling framework are available in the Supplementary Methods.

International trade costs. International trade costs are composed of transaction costs (transport, import, export, entry), policy-related costs (tariffs) and non-linear trade expansion costs. Road and ocean international transport costs are compiled based on the estimation of Hummels[77] using distances from CERDI-seadistance database[78] and CEPII's GeoDist database[79]. For road transport between African countries, transport costs are calculated based on trucker surveys (Supplementary Table 9). Tariff data is from the MAcMap-HS6 2001 and 2010 releases from CEPII-ITC[80,81]. Import and export costs related to document and border compliance are from the World Bank Doing Business Survey, while inland transportation costs are calculated based on distance to port from the CERDI-seadistance database[78] or countries' average internal distance from the CEPII GeoDist database[79]. The non-linear trade expansion costs capture capacity constraints faced by the transport sector when expanding trade volumes, either on existing (the intensive margin) or new trade routes (the extensive margin). For growth of existing trade flows, trade expansion costs are parameterized based on port efficiency[27]. For new trade flows, trade expansion costs are related to trade facilitation indicators, while entry costs are calculated as a proxy on the exporter's market price and differentiated by bilateral trade determinants (Supplementary Table 8).

Local trade costs. Local trade costs consist of local transport and marketing costs to bring agricultural goods to the market and cover the gap between the (rural) farm-gate producer price and the wholesale (urban) market price. The distance from farm to market is estimated based on a spatial map of travel time to the closest city of 50,000 inhabitants[82]. The average derived distances range overall between 100 and 300 km (Supplementary Table 11). The transport cost per ton-km is calculated based on available survey evidence of variable and fixed transport cost components and trucker profit margins (Supplementary Table 10). Marketing costs include all costs other than transport, namely storage costs and wholesaler fees and profits, and are calculated as fixed mark-up on the purchase price. Based on literature[33,34,83], we assume a marketing margin of 30% in Sub-Saharan Africa (except for SACU) in the base year. For other countries, we assume a marketing margin between 10% and 30% depending on the quality of warehouse and distribution services as documented in the World Bank Domestic Logistic Performance Index. Supplementary Table 11 shows that our calculated local trade costs for the base year, ranging for example for maize from 35 USD/ton in North Africa to 195 USD/ton in Central Africa, correspond well with available literature.

Undernourishment. The number of people undernourished or at risk of hunger is calculated based on four parameters: average daily calorie availability, coefficient of variation (CV) of food distribution, average minimum dietary energy requirement and population. There are two changes compared to the calculation of undernourishment in previous work[49]. First, the input parameters are updated based on latest available FAO statistics[84]. Second, the CV value is kept fixed at 2020 value instead of adjusting it exogenously based on the income growth of the socio-economic pathway as FAO no longer calculates the CV based on macroeconomic variables[1]**.** The average daily calorie availability is endogenously determined in GLOBIOM, while the minimum dietary energy requirement and population are exogenously determined by future demography projections. Note that as intra-regional food distristribution is assumed constant across baseline and agricultural development scenarios, the impact of reducing local transport costs on food availability may be underestimated. Changes in local trade costs will also interact differently with food availability in rural vs. urban areas. Modelling food availability at subnational level and differentiating between rural and urban areas is outside the scope of current study, but a crucial area for further research.

Land-use greenhouse gas emissions. The reported greenhouse gas (GHG) emissions from land-use activities include NO_2 and CH_4 emissions from agricultural production (synthetic fertilizer, rice cultivation, manure management and application, and enteric fermentation), CO_2 emissions from conversion of land across the six different land cover types (cropland, grassland, managed forest, unmanaged forest, short rotation plantations and other natural land), and carbon sequestration from the establishment of short rotation plantations. GHG emissions from transportation are not covered (see Supplementary Methods).

Scenario design. Under the *Free Trade* scenario trade policy costs (import tariffs), transaction costs (international transport, import, export and entry cost) and expansion costs (port and customs efficiency) are reduced by 2030. Tariffs are fully eliminated by 2030, while international overland transport costs are reduced by 25%, which is the order of magnitude estimated to be attainable through joint border posts and simplified custom procedures[85,86]. Import and export costs are reduced to an international benchmark level and entry costs are reduced by half. Trade expansion costs are reduced to a level that reflects large improvements in port and customs efficiency between 2020 and 2030. The *Agricultural Development* scenario represents a yield and market potential scenario by removing all market access constraints and improving fertilizer use everywhere in African regions by 2030. Farm-gate to market transport costs are reduced to an international benchmark of 0.05 USD/ton-km by 2030, while marketing margins are reduced from the baseline level (which is 20% or 15%, cfr. Supplementary Table 12) to 10%. Crop yields are assumed to reach potential yield levels under improved fertilizer use (i.e. rate of up to 200 kg N/ha/year and higher agronomic nitrogen use efficiency) in all rain-fed commercial production systems in 2030 based on simulations with the global gridded crop model Environmental Policy Integrated Climate–International Institute for Applied Systems Analysis (EPIC-IIASA)[87] (Supplementary Figure 13 & Supplementary Table 3). Results when assuming fertilizer rates of up to 100 kgN/ha instead of 200 kgN/ha or when assuming an international benchmark of 0.1 USD/ton-km instead of 0.05 USD/ton-km for local transport costs, are similar to the main set-up (Supplementary Figure 14). For the *Agricultural Development* scenario, we assess three prioritization strategies: *Food*, *Export*, and *Connect*. The *Food* and *Export* scenarios apply the marketing cost reduction and yield intensification only to a selection of food or export commodity markets, respectively (Supplementary Table 4). The *Connect* scenario represents the local transport cost reduction that can be achieved by switching to high load capacity transport vehicles (load capacity = 12.5 ton) in the first 55km beyond farm-gate, and this only in areas connected to the current primary road network in Africa (Supplementary Fig. 4). Supplementary Table 2 summarizes the model adjustments across all scenarios and the Supplementary Methods provides further technical detail.

Data availability

The authors declare that the main data supporting the findings of this study are available within the Article, Source Data files and the Supplementary Information. Additional data are available from the corresponding author on request.

Code availability

Code used for the figures and statistical analyses is available from the corresponding author on request.

Acknowledgments

We acknowledge research funding from Research Foundation Flanders (FWO) (FWO contract / 180956 / SW). This research has also been supported by the European Union’s Horizon 2020 Research and Innovation programme (RECEIPT; grant no. 820712).

Contribution

C.J., P.H. and M.M. developed the concept and designed scenarios. C.J., A.M., J.B., D.L. and P.H. provided code and model simulations. C.J., P.H., E.B., A.P. and M.M. analyzed and interpreted the data. All authors edited and approved the manuscript.

Ethics declaration – Competing interests

The authors declare no competing interests.

Supplementary information

Supplementary Methods, Supplementary Figures 1-28, Supplementary Tables 1-12 and Supplementary References.

Tables

Table 1. Implementation of *Free Trade* and *Agricultural Development* scenarios by 2030. In the baseline scenario, international and local trade cost parameters remain constant and crop yields increase only through technological progress in line with historical trends (as assumed under SSP2). See Methods and Supplementary Methods for underlying data and assumptions. Intl.: international; int: intensive margin; ext: extensive margin.

	Free Trade	Agricultural Development
Import tariffs	↓↓ full elimination	=
Intl. transport cost	Overland: -25%; Ocean: =	=
Entry cost	20% → 10% margin	=
Import & export cost (inland transport)	↓ to intl. benchmark (0.05 USD/ton-km)	=
Import & export cost (administrative)	↓ to intl. benchmark (USA cost levels)	=
Expansion cost (int. & ext. margin)	↓ ~ increased port and customs efficiency	=
Local transport cost	=	↓ to intl. benchmark (0.05 USD/ton-km)
Local marketing cost	=	↓ to margin of 10%
Crop yields	↑ ~ technological progress (SSP2)	↑ ~ technological progress (SSP2) + improved fertilizer use

Figures

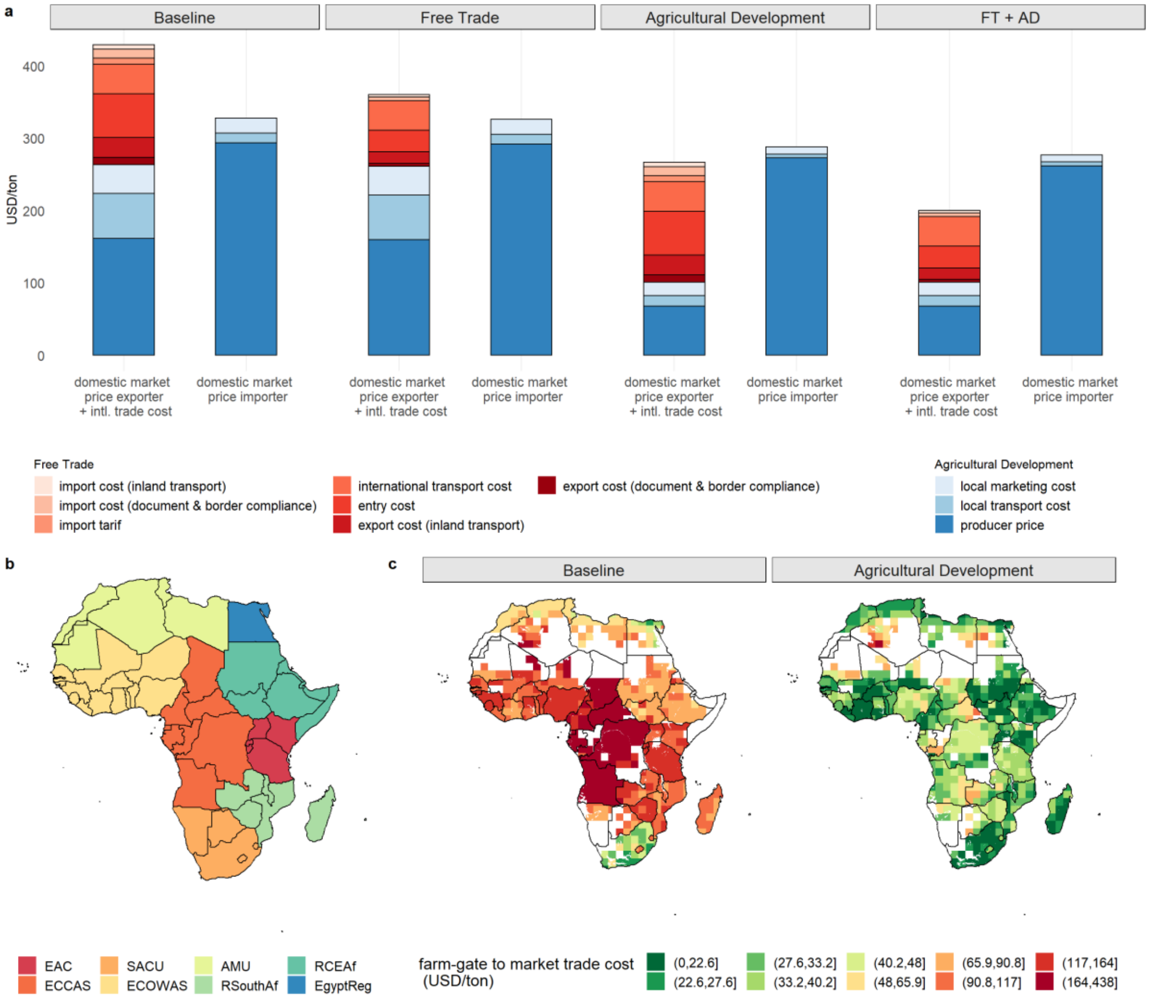


Figure 1. Trade costs under *Free Trade* and *Agricultural Development* (a,c) and regional aggregation (b). a) Impact of *Free Trade* and *Agricultural Development* scenarios on international (Intl.) and local trade cost for an illustrative trade link (maize from RSouthAf to AMU in 2030). FT + AD: combined *Free Trade* + *Agricultural Development* scenario. b) African regions: East African Community (EAC), Economic Community of Central African States (ECCAS), Arab Maghreb Union (AMU), Economic Community of West African States (ECOWAS), Southern African Customs Union (SACU), Rest of Southern Africa (RSouthAf), Rest of Central-East Africa (RCEAf), and Egypt (Supplementary Table 1). c) Impact of *Agricultural Development* scenario on local trade costs averaged across crops in Africa in 2030 (weighted average by baseline production). Local trade costs consist of local transport and marketing costs and are split according to deciles. Areas without local trade costs have no cropland area in the model input data.

Figure 2. Impact of *Free Trade* and *Agricultural Development* (a) and individual scenario elements (b,c) in 2050. Absolute differences in African agricultural trade, undernourishment, GHG emissions and production compared to the baseline scenario are shown. FT + AD: combined *Free Trade* + *Agricultural Development* scenario. GHG emissions present the average annual emissions in Africa in the period 2030 – 2050. Total effect = combined effect of all scenario elements; individual effect = sole effect of the specific scenario element; final effect = [total effect – effect without the specific scenario element], i.e. the effect of adding a specific component when all the others are present. A large difference between the individual effect and final effect indicates interaction among the scenario elements. Intl.: international; int: intensive margin; ext: extensive margin. Results for 2030 are presented in Extended data Figure 1.

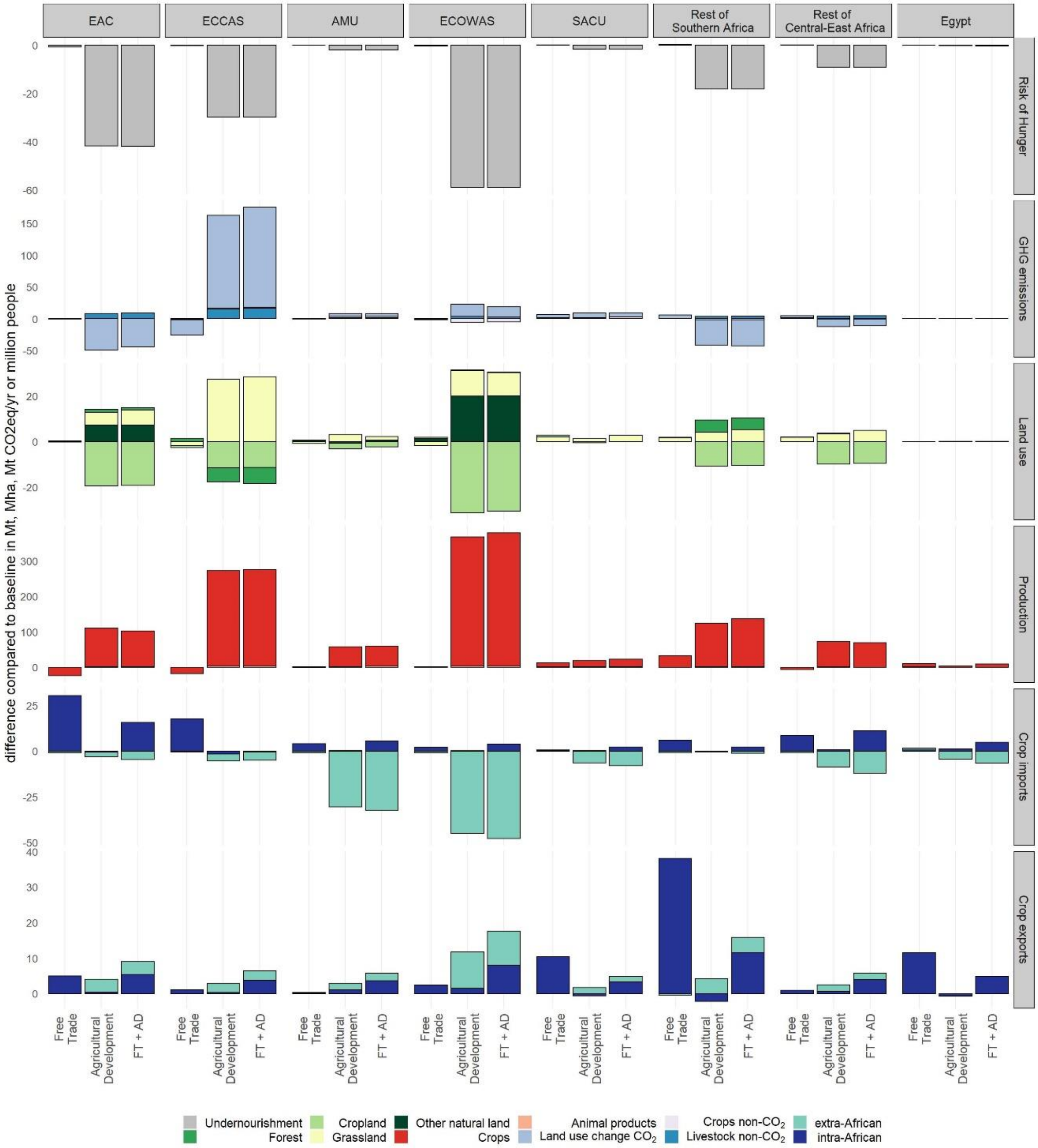


Figure 3. Impact of *Free Trade* and *Agricultural Development* across African regions in 2050. Absolute differences in undernourishment, GHG emissions, production, land use and crop trade compared to baseline scenario are shown. GHG emissions present the average annual emissions in each African region in the period 2030 – 2050. Livestock trade is not shown as this is much smaller in size compared to crop trade (Figure 2 and Supplementary Table 5). Results for 2030 are presented in Extended data Figure 2.

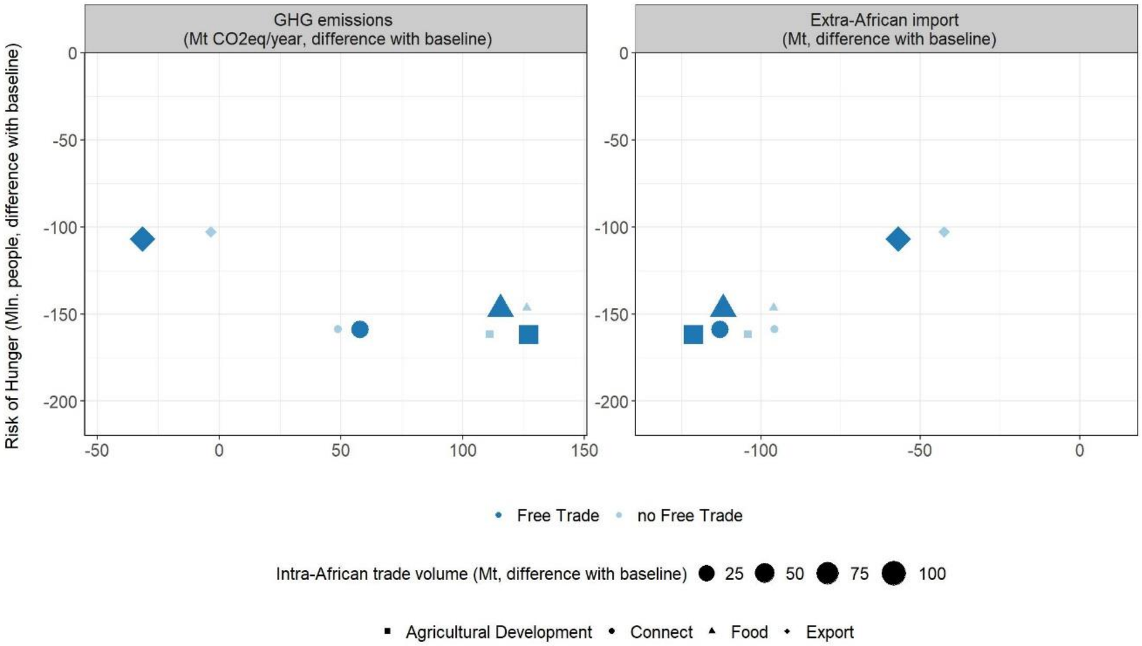
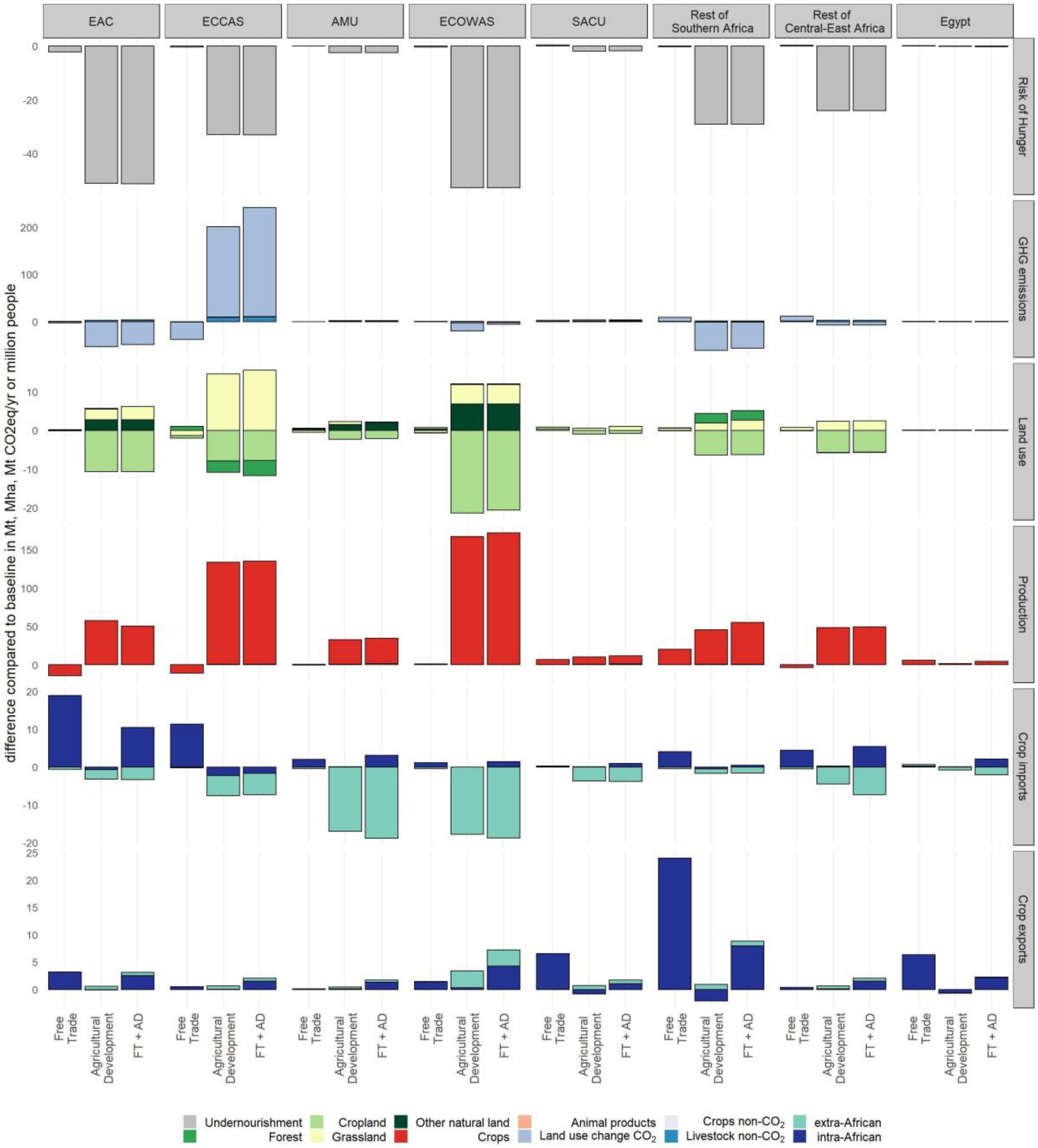


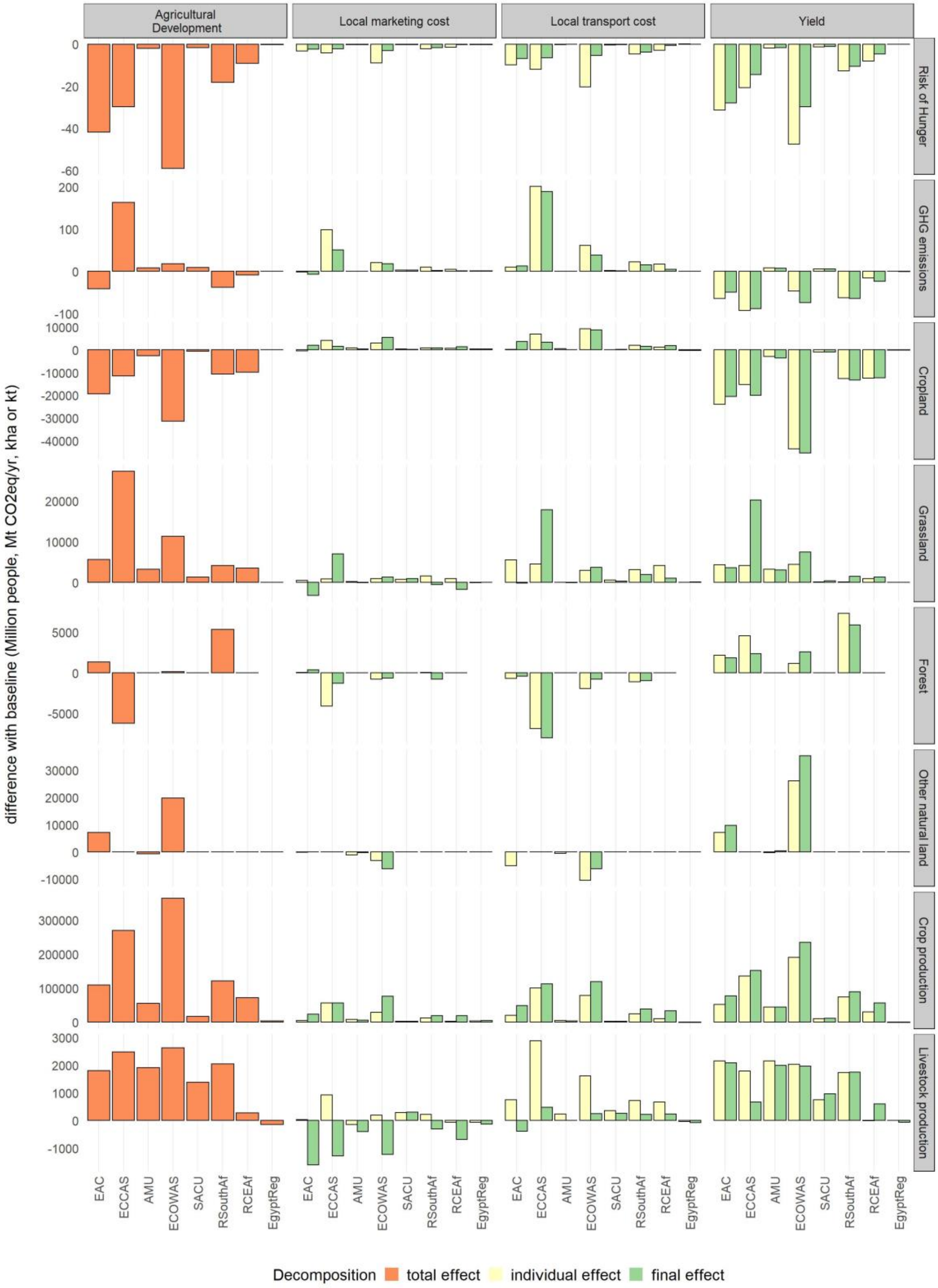
Figure 4. Impact of prioritization strategies (*Connect, Food, Export*) in 2050. Absolute differences in African agricultural trade, undernourishment, and GHG emissions compared to baseline scenario are shown. GHG emissions present the average annual emissions in Africa in the period 2030 – 2050. Regional results are shown in Extended data Figure 7. Global average annual emissions are shown in Supplementary Figure 5.

Extended Data

Extended Data Figure 1. Impact of Free Trade and Agricultural Development scenarios (a) and decomposition (b,c) on African trade, undernourishment, GHG emissions and production in 2030. GHG emissions present annual emissions in 2030. Total effect = combined effect of all scenario elements; individual effect = sole effect of the specific scenario element; final effect = [total effect – effect without the specific scenario element], that is the effect of adding a specific component when all the others are present. A large difference between the individual effect and final effect indicates interaction among the scenario elements.



Extended Data Figure 2. Impact of Free Trade and Agricultural Development across African regions in 2030. Impact of Free Trade and Agricultural Development scenarios on undernourishment, GHG emissions, production, land use and crop trade across African regions in 2030. GHG emissions present the annual emissions in 2030.



Extended Data Figure 3. Decomposition of the impact of Agricultural Development scenario on GHG emissions, land use, and production across African regions in 2050. Total effect = combined effect of all scenario elements, individual effect = sole effect of the specific scenario element, final effect=[total effect – without effect of the specific scenario element].


Maize Baseline
intra-Africa trade volume: 547 kt

Maize Free Trade
intra-Africa trade volume: 3758 kt

Maize FT + AD
intra-Africa trade volume: 3360 kt

Rice Baseline
intra-Africa trade volume: 164 kt

Rice Free Trade
intra-Africa trade volume: 1539 kt

Rice FT + AD
intra-Africa trade volume: 3696 kt

Wheat Baseline
intra-Africa trade volume: 482 kt

Wheat Free Trade
intra-Africa trade volume: 2529 kt

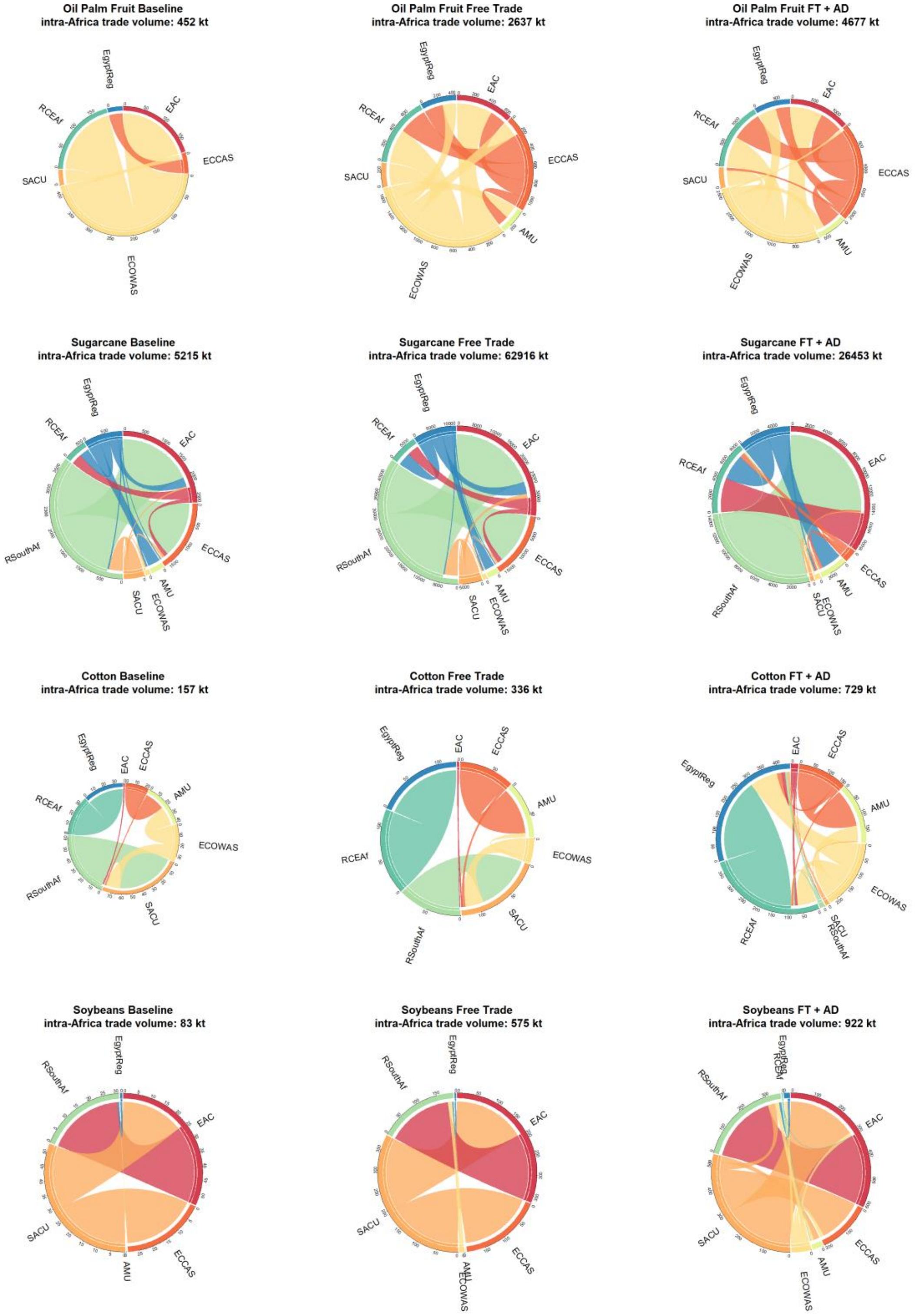
Wheat FT + AD
intra-Africa trade volume: 9022 kt

Barley Baseline
intra-Africa trade volume: 35 kt

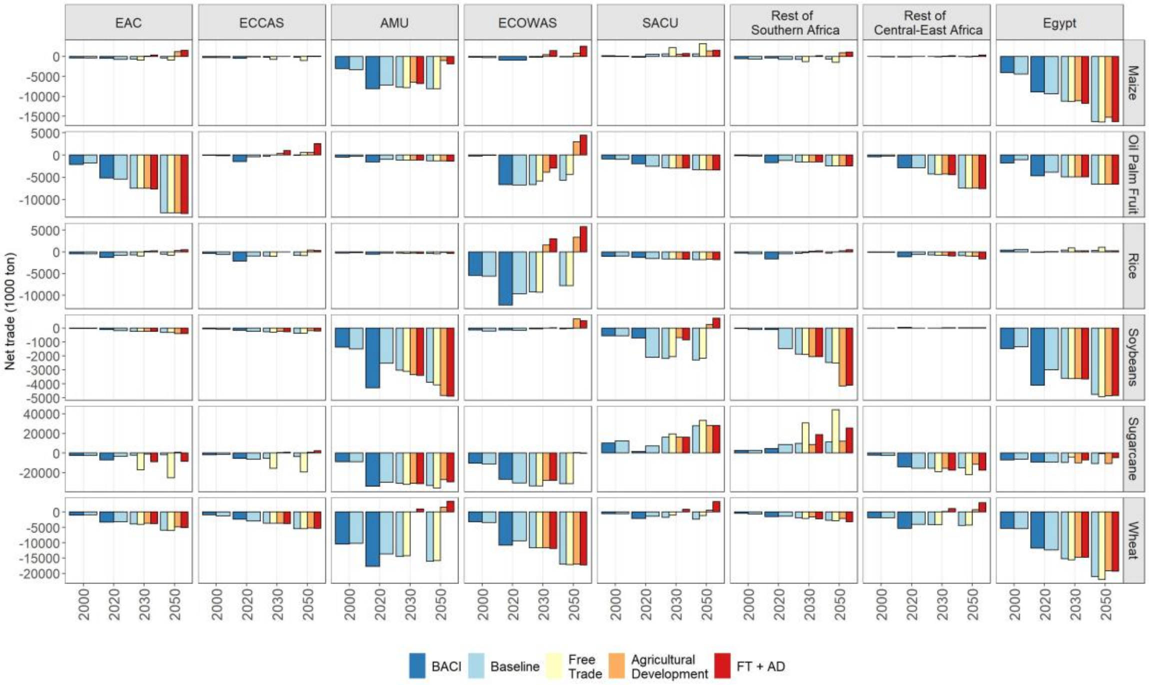
Barley Free Trade
intra-Africa trade volume: 265 kt

Barley FT + AD
intra-Africa trade volume: 1153 kt

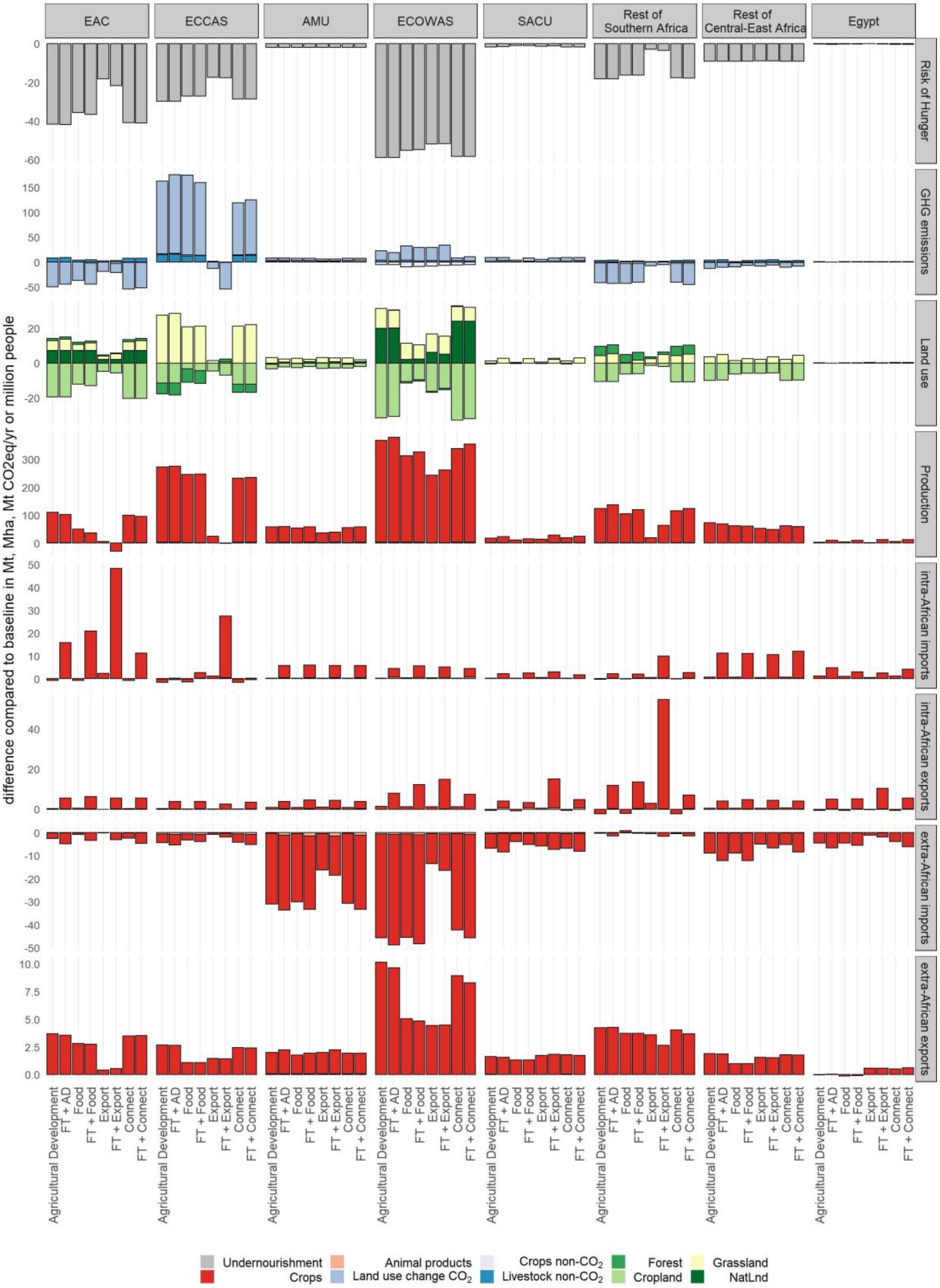
Extended Data Figure 4. The impact of the Free Trade and Agricultural Development scenarios on intra-African trade pattern of maize, rice, wheat and barley in 2050. The size of the individual flows reflects the magnitude of the trade flows (kton) and the color of the flow corresponds to the exporting region.



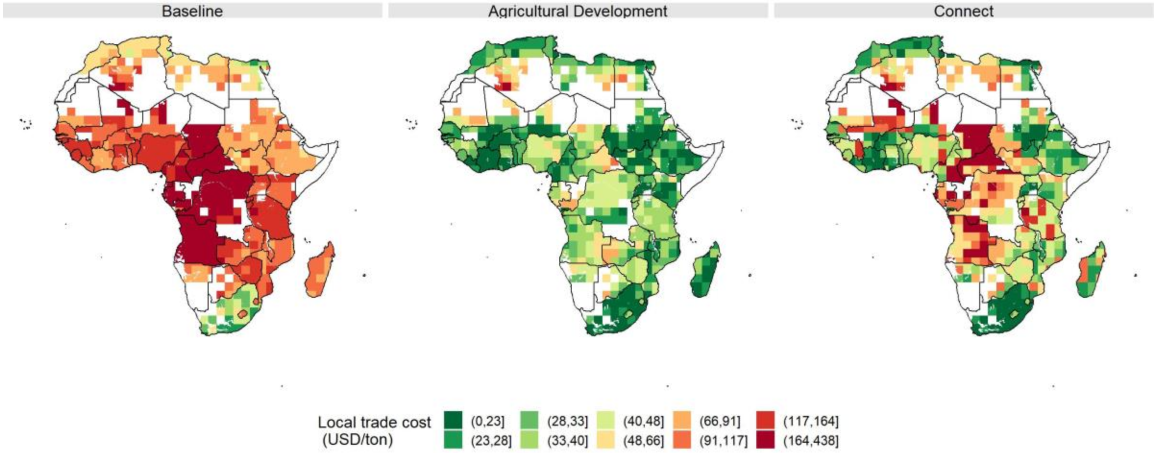
Extended Data Figure 5. The impact of the Free Trade and Free Trade + Agricultural Development (FT + AD) scenarios on intra-African trade pattern of oil palm, sugarcane, cotton and soybeans in 2050. The size of the individual flows reflects the magnitude of the trade flows (kton) and the color of the flow corresponds to the exporting region.



Extended Data Figure 6. Net trade across African regions under the baseline, Free Trade and Agricultural Development scenarios for key commodities imported outside Africa in 2050 (maize, oil palm, rice, soybeans, sugarcane and wheat). For 2000 and 2020, the GLOBIOM model output compared to the net trade in 2000 and 2018 in CEPII's BACI trade database (country-level trade aggregated to trade at GLOBIOM region level).



Extended Data Figure 7. Impact of Agricultural Development prioritization strategies on the risk of hunger, GHG emissions, land use and crop and livestock production, imports and exports by 2050 across African regions. GHG emissions present the average annual emissions in the period 2030–2050. FT + AD: combined Free Trade + Agricultural Development scenario.



Extended Data Figure 8. Impact of Agricultural Development and Connect scenario on local trade costs averaged across crops in Africa in 2030 (weighted average by baseline production). Impact of Agricultural Development and Connect scenario on local trade costs averaged across crops in Africa in 2030 (weighted average by baseline production). Local trade costs consist of local transport and marketing costs. Trade cost values are split according to deciles. Areas without trade costs have no cropland area in the model input data. In the Agricultural Development scenario, farm-gate to market transport costs are reduced to an international benchmark of 0.05 USD/ton-km by 2030. The Connect scenario represents the local transport cost reduction that can be achieved by switching to high load capacity transport vehicles (load capacity = 12.5 ton) in the first 55 km beyond farm-gate by 2030, and this only in areas connected to the current primary road network in Africa (Supplementary Fig. 10).

References

1. FAO, IFAD, UNICEF, WFP & WHO. *The State of Food Security and Nutrition in the World (SOFI)*. (FAO, IFAD, UNICEF, WFP and WHO, 2020).

2. Jayne, T. S. & Sanchez, P. A. Agricultural productivity must improve in sub-Saharan Africa. *Science (80-.).* **372**, 1045–1048 (2021).

3. World Bank. Africa Can Help Feed Africa. *Africa Can Help Feed Africa* (2012). doi:10.1596/26078

4. Dithmer, J. & Abdulai, A. Does trade openness contribute to food security? A dynamic panel analysis. *Food Policy* **69**, 218–230 (2017).

5. Morsy, H., Salami, A. & Mukasa, A. N. Opportunities amid COVID-19: Advancing intra-African food integration. *World Dev.* **139**, 105308 (2021).

6. Clapp, J. Food self-sufficiency: Making sense of it, and when it makes sense. *Food Policy* **66**, 88–96 (2017).

7. Hong, C. *et al.* Global and regional drivers of land-use emissions 1961-2017. *Nature* **589**, 1–6 (2021).

8. Colen, L. *et al.* Income elasticities for food, calories and nutrients across Africa: A meta-analysis. *Food Policy* **77**, 116–132 (2018).

9. United Nations. *World Population Prospects 2019 Volume I: Comprehensive Tables*. *Department of Economic and Social Affairs. World Population Prospects 2019.* **I**, (2019).

10. United Nations. *World Urbanization Prospects*. *Demographic Research* (2018).

11. Van Ittersum, M. K. *et al.* Can sub-Saharan Africa feed itself? *Proc. Natl. Acad. Sci. U. S. A.* **113**, 14964–14969 (2016).

12. Erb, K. *et al.* Exploring the biophysical option space for feeding the world without deforestation. *Nat. Commun.* **48**, 829–834 (2016).

13. Liverpool-Tasie, L. S. O. *et al.* A scoping review of market links between value chain actors and small-scale producers in developing regions. *Nat. Sustain.* **3**, 799–808 (2020).

14. Hoekman, B., Senbet, L. W. & Simbanegavi, W. Integrating African markets: The way forward. *J. Afr. Econ.* **26**, ii3–ii11 (2017).

15. Resnick, D., Diao, X. & Tadesse, G. *Sustaining Africa's Agrifood System Transformation: The Role of Public Policies*. (2020).

16. Reardon, T. *et al.* Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. *Agric. Syst.* **172**, 47–59 (2019).

17. Hertel, T. W., Ramankutty, N. & Baldos, U. L. C. Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. *Proc. Natl. Acad. Sci.* **111**, 13799–13804 (2014).

18. Perumal, L., New, M. G., Jonas, M. & Liu, W. The impact of roads on sub-Saharan African ecosystems: a systematic review. *Environ. Res. Lett.* **16**, (2021).

19. Pendrill, F. *et al.* Agricultural and forestry trade drives large share of tropical deforestation

emissions. *Glob. Environ. Chang.* **56**, 1–10 (2019).

20. Berg, C. N., Blankespoor, B. & Selod, H. Roads and Rural Development in Sub-Saharan Africa. *J. Dev. Stud.* **54**, 856–874 (2018).

21. UNCTAD. *From Regional Economic Communities to a Continental Free Trade Area: Strategic tools to assist negotiators and agricultural policy design in Africa*. (2018).

22. Bouët, A., Odjo, S. P. & Zaki, C. *Africa Agricultural Trade Monitor 2020*. (2020).

23. AGRA. *Africa Agriculture Status Report. A Decade of Action: Building Sustainable and Resilient Food Systems in Africa*. (2021).

24. Teravaninthorn, S. & Raballand, G. *Transport Prices and Costs in Africa - A Review of the Main International Corridors*. (The World Bank, 2009).

25. Portugal-perez, A. & Wilson, J. S. Why trade facilitation matters to Africa. *World Trade Rev.* **8**, 379–416 (2009).

26. African Development Bank. *African Outlook Economic 2019*. (2019).

27. Clark, X., Dollar, D. & Micco, A. Port efficiency, maritime transport costs, and bilateral trade. *J. Dev. Econ.* **75**, 417–450 (2004).

28. Kandilov, I. T. & Zheng, X. The impact of entry costs on export market participation in agriculture. *Agric. Econ.* **42**, 531–546 (2011).

29. Beverelli, C., Neumueller, S. & Teh, R. Export Diversification Effects of the WTO Trade Facilitation Agreement. *World Dev.* **76**, 293–310 (2015).

30. Jayne, T. S., Mather, D. & Mghenyi, E. Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Dev.* **38**, 1384–1398 (2010).

31. Dobermann, A. *et al.* Responsible plant nutrition: A new paradigm to support food system transformation. *Glob. Food Sec.* **33**, 100636 (2022).

32. Sheahan, M. & Barrett, C. B. Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy* **67**, 12–25 (2017).

33. Minten, B. & Kyle, S. The effect of distance and road quality on food collection, marketing margins, and traders' wages: Evidence from the former Zaire. *J. Dev. Econ.* **60**, 467–495 (1999).

34. Fafchamps, M., Gabre-Madhin, E. & Minten, B. Increasing returns and market efficiency in agricultural trade. *J. Dev. Econ.* **78**, 406–442 (2005).

35. Gollin, D. & Rogerson, R. Agriculture, roads, and economic development in Uganda. *NBER Work. Pap.* (2010).

36. Damania, R. *et al.* Agricultural technology choice and transport. *Am. J. Agric. Econ.* **99**, 265–284 (2017).

37. Liverpool-Tasie, L. S. O., Omonona, B. T., Sanou, A. & Ogunleye, W. O. Is increasing inorganic fertilizer use for maize production in SSA a profitable proposition? Evidence from Nigeria. *Food Policy* **67**, 41–51 (2017).

38. Minten, B., Koru, B. & Stifel, D. The last mile(s) in modern input distribution: Pricing, profitability, and adoption. *Agric. Econ. (United Kingdom)* **44**, 629–646 (2013).

39. Porteous, O. High trade costs and their consequences: An estimated dynamic model of african agricultural storage and trade. *Am. Econ. J. Appl. Econ.* **11**, 327–366 (2019).

40. Dorosh, P., Wang, H. G., You, L. & Schmidt, E. Road connectivity, population, and crop production in Sub-Saharan Africa. *Agric. Econ.* **43**, 89–103 (2012).

41. Sitko, N. J., Chisanga, B., Tschirley, D. & Jayne, T. S. An evolution in the middle: examining the rise of multinational investment in smallholder grain trading in Zambia. *Food Secur.* **10**, 473–488 (2018).

42. Minten, B., Stifel, D. & Tamru, S. Structural Transformation of Cereal Markets in Ethiopia. *J. Dev. Stud.* **50**, 611–629 (2014).

43. Damania, R., Russ, J., Wheeler, D. & Barra, A. F. The Road to Growth: Measuring the Tradeoffs between Economic Growth and Ecological Destruction. *World Dev.* **101**, 351–376 (2018).

44. World Bank. *The African Continental Free Trade Area: Economic and Distributional Effects*. (World Bank, 2020). doi:10.1596/978-1-4648-1559-1

45. Mevel, S. & Karingi, S. Towards a Continental Free Trade Area in Africa: A CGE Modelling Assessment with a focus on Agriculture. in *Shared Harvests: Agriculture, Trade, and Employment* (eds. Cheong, D., Jansen, M. & Peters, R.) 281–324 (International Labour Office and United Nations Conference on Trade and Development, 2013).

46. van Loon, M. P. *et al.* Impacts of intensifying or expanding cereal cropping in sub-Saharan Africa on greenhouse gas emissions and food security. *Glob. Chang. Biol.* **25**, 3720–3730 (2019).

47. Palm, C. A. *et al.* Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa. *Proc. Natl. Acad. Sci.* **107**, 19661–19666 (2010).

48. Porteous, O. Trade and agricultural technology adoption: Evidence from Africa. *J. Dev. Econ.* **144**, 102440 (2020).

49. Janssens, C. *et al.* Global hunger and climate change adaptation through international trade. *Nat. Clim. Chang.* (2020). doi:10.1038/s41558-020-0847-4

50. Frank, S. *et al.* Reducing greenhouse gas emissions in agriculture without compromising food security? *Environ. Res. Lett.* **12**, 105004 (2017).

51. Havlik, P. *et al.* Climate change mitigation through livestock system transitions. *Proc. Natl. Acad. Sci.* **111**, 3709–3714 (2014).

52. African Union. *Agreement Establishing the African Continental Free Trade Area*. (2018).

53. African Union Commission. *Agenda 2063 - The AFRICA We Want*. (2015).

54. AU. Continental Frameworks. (2021). Available at: https://au.int/agenda2063/continental-frameworks. (Accessed: 15th June 2021)

55. Fricko, O. *et al.* The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. *Glob. Environ. Chang.* **42**, 251–267 (2017).

56. Sulser, T. B. *et al.* Africa in the Global Agricultural Economy in 2030 and 2050. in *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes. ReSAKSS Annual Trends and Outlook Report 2014* (2015).

57. International Food Policy Research Institute (IFPRI). *Atlas of African Agriculture Research & Development*. **148**, (2014).

58. African Development Bank. *Feed Africa: Strategy for Agricultural Transformation in Africa 2016-2025*. (2016).

59. Simola, A., Boysen, O., Ferrari, E., Nechifor, V. & Boulanger, P. *Potential effects of the African Continental Free Trade Area (AfCFTA) on African agri-food sectors and food security*. (2021). doi:10.2760/531308

60. Saygili, M., Peters, R. & Knebel, C. *African Continental Free Trade Area: Challenges and Opportunities of Tariff Reductions*. (2018).

61. Eberhard-Ruiz, A. & Calabrese, L. Would more trade facilitation lead to lower transport cost in the East African Community? *ODI Brief. Pap. London, UK …* (2017).

62. African Development Bank Group. *African Economic Outlook 2018*. (2018).

63. Osei – Kyei, R. & Chan, A. P. C. Developing Transport Infrastructure in Sub-Saharan Africa through Public–Private Partnerships: Policy Practice and Implications. *Transp. Rev.* **36**, 170–186 (2016).

64. Vanlauwe, B. *et al.* Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook Agric.* **39**, 17–24 (2010).

65. Oyinbo, O., Chamberlin, J., Abdoulaye, T. & Maertens, M. Digital extension, price risk, and farm performance: experimental evidence from Nigeria. *Am. J. Agric. Econ.* **104**, 831–852 (2022).

66. Adetutu, M. O. & Ajayi, V. The impact of domestic and foreign R&D on agricultural productivity in sub-Saharan Africa. *World Dev.* **125**, 104690 (2020).

67. Beuran, M., Gachassin, M. & Raballand, G. Are There Myths on Road Impact and Transport in Sub-Saharan Africa? *Dev. Policy Rev.* **33**, 673–700 (2015).

68. Raballand, G. *et al. Are Rural Road Investments Alone Sufficient to Generate Transport Flows ? Lessons from a Randomized Experiment in Rural Malawi and Policy Implications*. (2011).

69. African Union Department of Rural Economy and Agriculture. *Comprehensive Africa Agriculture Development Programme (CAADP) Biennial Review Report 2015 - 2018*. **2**, (2020).

70. Narayan, S. & Bhattacharya, P. Relative export competitiveness of agricultural commodities and its determinants: Some evidence from India. *World Dev.* **117**, 29–47 (2019).

71. Minot, N. Food price volatility in sub-Saharan Africa: Has it really increased? *Food Policy* **45**, 45–56 (2014).

72. Dorosh, P. A., Dradri, S. & Haggblade, S. Regional trade, government policy and food security: Recent evidence from Zambia. *Food Policy* **34**, 350–366 (2009).

73. Verschuur, J., Li, S., Wolski, P. & Otto, F. E. L. Climate change as a driver of food insecurity in the 2007 Lesotho-South Africa drought. *Sci. Rep.* 1–2 (2021). doi:10.1038/s41598-021-83375-x

74. Almazroui, M., Saeed, F., Saeed, S., Islam, M. N. & Ismail, M. Projected Change in Temperature and Precipitation Over Africa from CMIP6. *Earth Syst. Environ.* (2020). doi:10.1007/s41748-020-00161-x

75. Takayama, T. & Judge, G. G. *Spatial and Temporal Price and Allocation Models*. (1971).

76. Mosnier, A. *et al.* Modeling Impact of Development Trajectories and a Global Agreement on Reducing Emissions from Deforestation on Congo Basin Forests by 2030. *Environ. Resour. Econ.* **57**, 505–525 (2014).

77. Hummels, D. *Toward a Geography of Trade Costs*. (2001).

78. Bertoli, S., Goujon, M. & Santoni, O. *The CERDI-seadistance database [Data set]*. (2016). doi:http://doi.org/10.5281/zenodo.46822

79. Mayer, T. & Zignago, S. *The GeoDist Database on Bilateral Geographical Information*. (2011).

80. Bouët, A., Fontagné, L., Jean, S. & Laborde, D. *Computing an exhaustive and consistent, ad-valorem equivalent measure of applied protection: a detailed description of MAcMap-HS6 methodology*. (2004).

81. Guimbard, H., Jean, S., Mimouni, M. & Pichot, X. *MAcMap-HS6 2007, an exhaustive and consistent measure of applied protection in 2007*. (2012).

82. Weiss, D. J. *et al.* A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature* **553**, 333–336 (2018).

83. The World Bank. *World Bank Report 2008: Agriculture for Development*. **53**, (2008).

84. FAO. Sustainable Development Goals - Indicator 2.1.1 Prevalence of Undernourishment. (2021). Available at: http://www.fao.org/sustainable-development-goals/indicators/211/en/.

85. Eberhard-ruiz, A. & Calabrese, L. Trade facilitation , transport costs and the price of trucking services in East Africa. (2017).

86. Teravaninthorn, S. & Raballand, G. *Transport Prices and Costs in Africa - A Review of the Main International Corridors*. (2009).

87. Folberth, C. *et al.* The global cropland-sparing potential of high-yield farming. *Nat. Sustain.* **3**, 281–289 (2020).