Received: 24 January 2024 | Revised: 24 September 2024 | Accepted: 26 September 2024

DOI: 10.1111/twec.13643

ORIGINAL ARTICLE

The World Economy WILEY

Carbon border adjustments or climate clubs: Impacts on African agricultural sectors under different cooperative scenarios

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Funding information
European Union's Horizon 2020 research and innovation programme, Grant/Award Number: 101000751

Abstract

Despite the rapid acceleration of climate change, international climate negotiations have yet to implement effective mitigation action. This failure can be attributed to the phenomenon of free-riding behaviours and the adverse effects of unilateral abatement policies, such as carbon leakage. The introduction of a Carbon Border Adjustment Mechanism (CBAM), as planned by the EU and the creation of climate clubs represent two potential solutions. However, both present uncertainties regarding their trade impacts, effectiveness and equity implications, particularly for developing countries. The outcome of these alternative unilateral or cooperative solutions is analysed using a dynamic CGE model, with a particular focus on the EU-Africa relations and the agricultural sector. The results indicate that the effectiveness of CBAM in preventing carbon leakage and supporting EU climate goals depends on foreign partners implementing domestic carbon pricing mechanisms. Conversely, for African regions, domestic mitigation efforts and exemption from CBAM can enhance export competitiveness on EU markets while reducing global carbon leakage. Overall, the establishment of climate clubs, coupled with the transfer of technology and the diffusion of best practices in agriculture, can support developing countries and facilitate an inclusive and environmentally beneficial development transition.

KEYWORDS

Africa, CBAM, climate Club, global value chain, mitigation policy, trade impact

1 | INTRODUCTION

As climate change is accelerating rapidly (IPCC, 2022), mitigation is necessary to avert the most detrimental consequences of extreme weather events and hence can be considered a global public good (Devarajan et al., 2022). However, free-riding incentives on abatement policies are strong and it is necessary to force supranational actions to avoid the risk of a 'tragedy of commons' (Böhringer et al., 2022). For this reason, major international climate negotiations have been unable to substantially reduce global emissions (Farrokhi & Lashkaripour, 2021; Hovi et al., 2016).

On the other hand, unilateral emission reduction policies present some risk of generating distortions in global prices, international competitiveness and geographical allocation of carbon-intensive production (Böhringer, Balistreri, & Rutherford, 2012). A particular risk is 'carbon leakage', that is, the increase in foreign emissions due to the aforementioned unilaterally-adopted policies and measures (Böhringer, Carbone, & Rutherford, 2012; Carbone & Rivers, 2017). While ex-post studies dealing with leakage effects are limited and suggest that small competitiveness effects from environmental regulations and energy price differences are observable (Dechezleprêtre & Sato, 2017), ex-ante analyses suggest that carbon leakage could be responsible for offsetting between 5 and 50 percent of primary emissions reductions (Antimiani et al., 2016; Branger & Quirion, 2014).

In order to prevent adverse effects associated to unilateral climate policies, with particular reference to carbon leakage, the European Union (EU) has adopted the Carbon Border Adjustment Mechanism (CBAM) under the EU Regulation n. 2023/956 of the Parliament and the Council in May 2023. This mechanism aims to adjust the price of imported goods to reflect the carbon content of their production processes, based on the carbon price to which these goods would have been subject to under the EU Emissions Trading System (ETS).

Theory suggests that Border Carbon Adjustments (BCAs) could be second-best instruments to improve the economic efficiency of such policies in the absence of universally applied emissions pricing (Hoel, 1996; Markusen, 1975). However, the effectiveness of this solution has been studied in the literature with inconclusive results, finding this mechanism to be effective (Fischer, 2015; Mörsdorf, 2022), or not (Babiker & Rutherford, 2005), depending on the theoretical assumptions and the empirical setting used.

Another challenge BCAs face is compliance with international law, particularly with respect to the World Trade Organisation (WTO) non-discrimination principles of most-favoured-nation treatment and the principle of common but differentiated responsibilities (CBDR) in the United Nations Framework Convention of Climate Change (UNFCCC) negotiations. The specific principles BCAs must adhere to depend on the form of carbon pricing they adopt (Cosbey et al., 2019).

A recent review by Böhringer et al. (2022) suggests that BCAs should be evaluated against four policy-relevant criteria: (a) the effectiveness of leakage reduction (Antimiani et al., 2016); (b) the competitiveness reinstatement capacity of Energy-Intensive Trade-Exposed (EITE) industries (Burniaux et al., 2013) given their position in the global value chain (GVC); (c) the potential to improve the global cost-effectiveness of unilateral emissions pricing via trade flows (Böhringer et al., 2014); and (d) the equity implication in shifting international climate policy burden sharing along the supply chain (Babiker & Rutherford, 2005; Böhringer et al., 2018).

An alternative solution to overcome free-riding and create a global framework for climate governance can be found in the literature on climate clubs (Hovi et al., 2016; Keohane & Victor, 2016; Paroussos et al., 2019). The concept of climate clubs was first proposed by Nordhaus (2015) as an agreement by participating countries to undertake harmonised emissions reductions focusing on a commonly agreed target based on a carbon price or abatement effort. To support this club, penalties should be introduced in the form of ad valorem tariffs on the imports of non-participants. These penalties should incentivise non-compliant countries to join climate clubs (Lessmann et al., 2009).

The international literature subsequently broadened this definition to include any form of cooperation in one or more climate change-related activities (Hovi et al., 2016). The distinction in the definition is contingent upon the conceptualization of the club proposed by scholars, whether they are à la Buchanan or voluntary clubs (Prakash & Potoski, 2007). This latter distinction is crucial, as the former type of club does not consider incentives for free riders outside the club. Therefore, while one type of club relies on facilitating benefits for members and issuing penalties to non-members (Nordhaus, 2015), the other aims to incentivise countries to undertake climate change mitigation beyond UNFCCC agreements (Hovi et al., 2019). Notwithstanding the criticism levelled at the concept of climate clubs, which was perceived as unrealistic, ineffective and incompatible with WTO rules (Chen & Zeckhauser, 2018; Hagen & Schneider, 2021; Zefferman, 2018), recent literature has built on this concept by examining its governance issues (Pihl, 2020; Szulecki et al., 2022) and comparing it to different forms of BCAs, particularly in those regions with ambitious abatement targets, such as the EU (Devarajan et al., 2022; Overland & Huda, 2022; Overland & Sabyrbekov, 2022).

The agricultural sector has frequently been excluded from this debate (OECD, 2019; Richards et al., 2018), even though the Agricultural Forestry and Other Land Uses (AFOLU) sector is a significant contributor to global greenhouse gases (GHG) emissions (Nabuurs et al., 2022) and the agri-food industry accounts for a substantial portion of total GHG emissions (FAOSTAT, 2023). The impacts of climate change on agriculture (Huang et al., 2011) make it crucial to include this sector in post-Paris Agreement (PA) environmental and trade policies (Baylis et al., 2021; Fellmann et al., 2018; Sovacool et al., 2021). Carbon pricing through a carbon tax is a potential solution (Baranzini et al., 2017), but its complexity in quantifying different gases and emission sources has led to the exclusion of agriculture in many countries (Domínguez & Fellmann, 2015). The implication is that the potential effects along the GVCs due to the inclusion (or exclusion) of the agricultural sector into active mitigation policies might be crucial to design the next agenda of bargaining positions into climate negotiations.

Implementing carbon taxes in agriculture can reduce emissions (Frank et al., 2021; Henderson et al., 2018; Wirsenius et al., 2011), but may also result in reduced output, income distribution issues, reduced competitiveness and potential food security problems (Arvanitopoulos et al., 2021; Dumortier & Elobeid, 2021; Fellmann et al., 2018; Frank et al., 2017; Himics et al., 2018). As previously mentioned, carbon leakage is a notable consequence of unilateral policies. Indeed, some studies that focus on agriculture have identified varying leakage rates (Dumortier & Elobeid, 2021; Zech & Schneider, 2019). It is worth mentioning that these studies differ from other relevant literature on the topic because they also have to include also non-CO_2 emissions, which are usually ignored in papers dealing with sectors such as EITE industries (Ghosh et al., 2012; Thube et al., 2021).[1]

Furthermore, carbon leakage in agriculture can be attributed to two distinct factors. First, the increase in food imports resulting from domestic production reductions due to climate change mitigation policies (Grosjean et al., 2018). Second, the relative carbon intensity (i.e. emissions per unit of output) of agriculture in exporting countries compared to the importing country (Domínguez & Fellmann, 2015).

Potential solutions to carbon leakage include the combination of carbon pricing with investment in research and development (Henderson & Verma, 2021), the strengthening of international agreements and cooperation, or the adoption of border adjustment measures (Fellmann et al., 2018; Zech & Schneider, 2019). Analyses on this last solution indicate that, while it is unclear if BCAs may reduce carbon leakage in agriculture (Carlson et al., 2023), these measures can result in welfare losses for developing countries heavily reliant on agricultural exports (Arvanitopoulos et al., 2021) and discriminate against environmental-friendly production methods in third countries (Wesseler, 2022).

Furthermore, it is important to emphasise the relevance of the agricultural sector in the economic development of less developed countries (LDCs), especially in Africa. This highlights the need for careful consideration of the potential burden-shifting problem. While some African economies may have growth potential outside of agriculture, the sector remains crucial for economic transformation and poverty reduction in the region (Dethier & Effenberger, 2012; Diao et al., 2010). Empirical evidence suggests a bidirectional causal link between agriculture and gross domestic product (GDP) growth in African countries (Awokuse & Xie, 2015), emphasising the need for increased investment, especially in research and development, to boost productivity (Adetutu & Ajayi, 2020) and adaptation to climate change (Barrios et al., 2008). However, economic development and climate adaptation strategies must be tailored to each country's specific circumstances due to heterogeneity (Dercon & Gollin, 2014).

Building on this debate, the policy scenarios examined in this study through a recursive dynamic Computable General Equilibrium (CGE) model are designed to address different aspects concerning the adoption of unilateral versus cooperative solutions (Zefferman, 2018). These scenarios include club agreements and external tariff penalties. The primary variables of interest in our analysis encompass emissions patterns, the potential rate of carbon leakage and changes in bilateral trade dynamics due to changes in comparative advantages along the GVCs.

Furthermore, the same impacts will be analysed in the presence of commitment by African countries to align their emissions standards with those required by the EU, thus creating a special 'climate club' resulting from the border adjustment policy. African countries are the most likely to be adversely affected by the implementation of CBAM (Eicke et al., 2021) and therefore the most interested in entering a climate club with the EU. This would enable them to exploit their relative advantages especially on the EU market by positioning their intermediate goods as relatively more efficient along the GVCs. In addition to recent studies that have shed light on the possible adverse effects on income distribution, particularly among lower-income households, this paper further investigates whether and to what extent the introduction of a carbon pricing mechanism (Fremstad & Paul, 2019; Oueslati et al., 2017) or, in a broader context, the tightening

[1]See Figures S1 and S2 in Appendix S1 to see the differences in emissions and the carbon intensity of agricultural production in agriculture-dependent regions, such as Africa.

of environmental regulations (Säll, 2018; Wang et al., 2019) is linked to a general rise in consumer prices and the subsequent impact on income distribution.

In light of the diverse characteristics of the African regions and sectors examined in our model, which may lead to varying impacts on specific regions and sectors under a shared policy implementation (Kjær, 2015), a further aspect of evaluation focuses on the implications for external competitiveness and the distribution of welfare. This evaluation pertains explicitly to applying socio-technical and environmental standards within the agricultural sectors to enhance the sustainability of production processes.

2 | MATERIALS AND METHODS

To answer the above questions, we develop a recursive dynamic model called GDynEP (Antimiani et al., 2023; Corradini et al., 2018), combining the latest GTAP models and data. GDynEP is derived from merging the dynamic GDynE (energy version of the dynamic GDyn), developed by Golub (2013) with the databases of GTAP-Power (Chepeliev & van der Mensbrugghe, 2020; Peters, 2016). This allows for the differentiation of electricity generated from fossil fuels, renewable sources and nuclear power.

Following Antimiani et al. (2023), we combine combustion-based CO_2 emissions from the GTAP-E database (McDougall & Golub, 2009) with the GTAP-NCO2 V10a database created by Irfanoglu and van der Mensbrugghe (2016). This allows us to also include non-energy use of fossil fuels in our analysis. The GTAP-NCO_2 database provides emissions for three major non-CO_2 groups of gases: methane (CH_4), nitrous oxide (N_2O) and the group of fluorinated gases (F-gases). Emissions are derived from three distinct drivers: consumption, endowment use (land and capital) and output. In order to include emissions related to output in the production process and the emissions related to the endowments used in the production function, a set of conversion matrices has been created to make such emissions compatible with the implementation of a carbon pricing system as modelled in GDynEP. The Input–Output tables related to the share in inputs use in all production processes have been used to assign the emissions related to the use of each endowment to the sector directly using that endowment.

2.1 | Model description

GDynEP is a recursive dynamic, multi-regional, multi-sectoral model that integrates real economic data with a set of equations derived from economic theory. The production side is modelled as a CES function, with capital (K), energy (E) divided into sources from fossil fuels (FF), nuclear power (NP) and renewable energy (RW), and all other intermediate inputs (Figure 1). The total amount of energy consumption (E) is thus given by the sum of the polluting sources (FF), which generates CO_2 emissions, and the clean ones (RW and NP). In physical terms, the emissions level (CO_2) is proportional to the quantity of fossil-based inputs (FF) used in the production/consumption process given the carbon content coefficient (β) that is directly related to the technology embedded in the process, resulting as $CO_2 = \beta FF$.

The GTAP10 original database (Aguiar et al., 2019) provides information on the global economy for the reference year 2014 distinguished in 65 sectors and 141 countries/regions.

Since this study aims to analyse the effect of the implementation of CBAM by the EU, both regions and sectors have been aggregated to express in the most detailed way regional trade

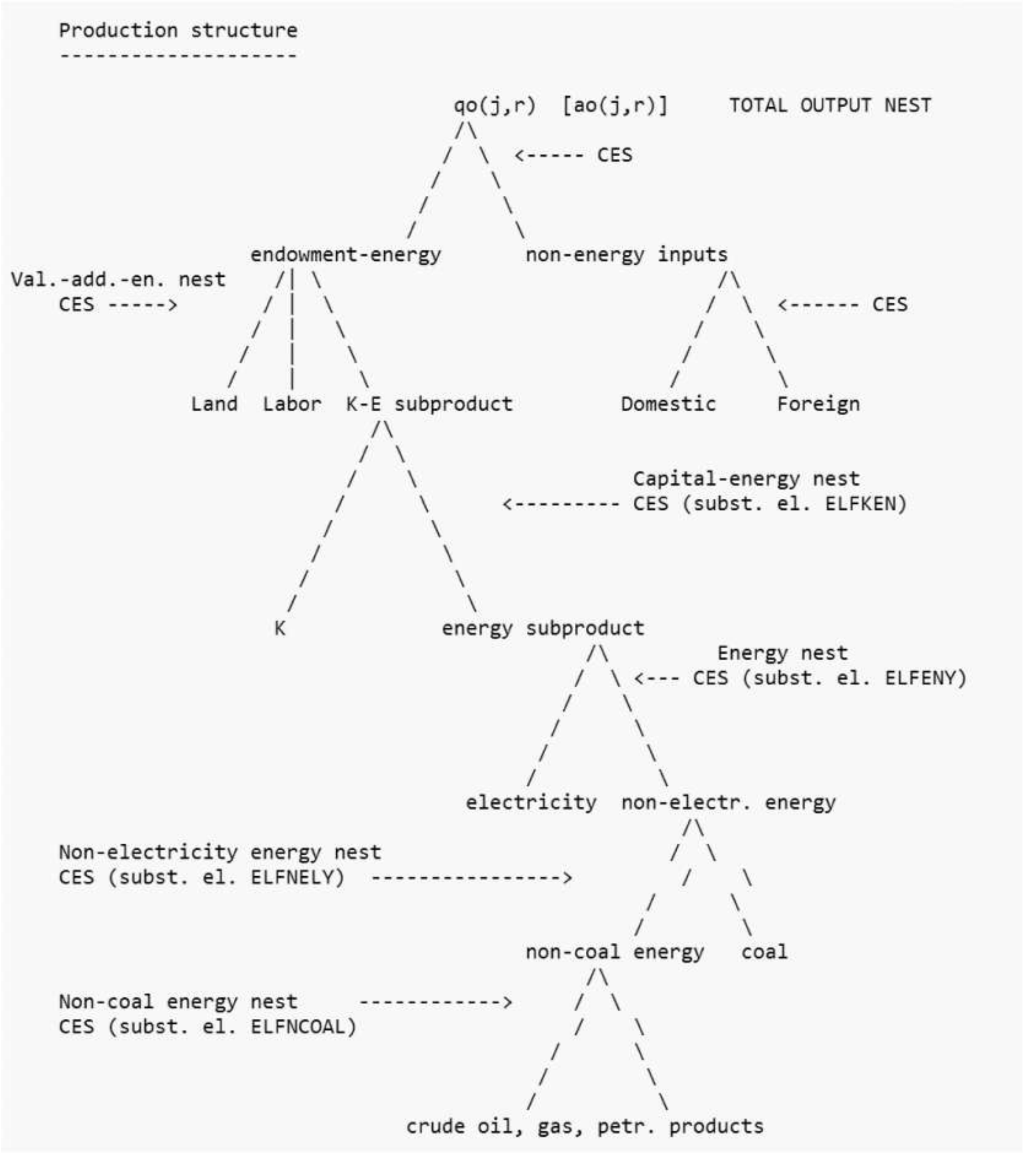


FIGURE 1 Nests in production output in GDynEP with GTAP-Energy and Power data.

preferential agreements and the most representative sectors for climate and trade policy in the EU. Therefore, 32 regions and 40 production sectors are considered in this study.[2]

Every scenario shares a temporal profile from 2014 to 2030. Starting from the base year 2014, up to 2022 the model is calibrated with historical data including shocks from the Covid-19 pandemic and related recovery measures (Antimiani et al., 2023). The following steps go annually from 2023 to 2030 and represent the timeline of our policy scenarios given the entry into force of

[2]The aggregation Tables (S1–S3) are available in the Appendix S1, along with the detailed description of GTAP regions, sectors, and endowments.

the CBAM policy in the EU. Accordingly, data sources on which the baseline and policy scenarios are based can be divided between the current period, 2014–2022, and ex-ante evaluation scenarios for the time 2023–2030.

2.2 | Baseline calibration

Calibrating the Business as Usual (BAU) scenario with historical patterns is a requirement for CGE modelling. Thus, shocks were set for the period 2014–2022 on the following exogenous variables: GDP, population, skilled and unskilled labour force, electricity production, and CO_2 and non-CO_2 emissions.

Data on population and GDP are gathered from Eurostat and the World Development Indicators (WDI) from the World Bank. Based on the methodology suggested by Fouré et al. (2013) for projections in macro-models, data on skilled and unskilled labour force are determined using International Labour Organisation (ILO) data on the labour force and Centre d'études prospectives et d'informations internationales (CEPII) statistics on the labour market structure.

Combustion-based and non-energy CO_2 emissions have been calibrated with data from Eurostat and IEA CO_2 emissions highlights. Data for non-CO_2 emissions have been calibrated based on Eurostat and IEA energy balances. According to the emissions typologies included in the model, there are two reference cases that constitute the baseline scenarios: (i) only CO_2-eq emissions associated with energy inputs (BAU); (ii) all GHG emissions, related to both energy inputs, and to outputs and endowments expressed in CO_2-eq (BAU-GH).

For projections in the time span 2023–2030, BAU is calibrated by combining data on population, GDP, skilled and unskilled labour force, energy mix (coal, natural gas, oil, oil products, electricity from fossil, nuclear and renewable sources), and emissions. The primary data source are the Global Energy and Climate Outlook 2021 (GECO) (Keramidas et al., 2021) and the European Commission reference case (EUREF) for single EU members based on the JRC-PRIMES model (Capros et al., 2016). The CEPII projections and the UN world population prospects for demographic trends were also used for population and labour force estimates.

In order to be compatible with a current policy scenario, where all currently in force policies are accounted for, the BAU case has also been calibrated with regard to the level of CO_2-eq emissions and the energy mix in the electricity sector (IEA, 2022). The BAU case has been calibrated with the Shared Socio-Economic Pathways (SSPs) scenarios used for the IPCC's 6th Assessment Report (Dellink et al., 2017; Riahi et al., 2017), producing a reference scenario consistent with the SSP2 'Middle of the road'.[3] As a general remark, in the BAU emissions are shocked exogenously and efficiency in energy use as an input for sectors and households is the corresponding endogenous variable. The trend in renewable energy is also shocked exogenously with endogenous output augmenting technical change. Accordingly, in the BAU there is no carbon price to obtain the emissions profile, while in all policy scenarios the exogenous emission targets are obtained with endogenous carbon price.

This modelling choice has been driven by the necessity to compare the effects of a carbon price imposed in the EU and in countries/regions (as the African ones) that in their BAU are not experiencing any attempt of a carbon market. As a result, the carbon price endogenously

[3]Data are available from the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

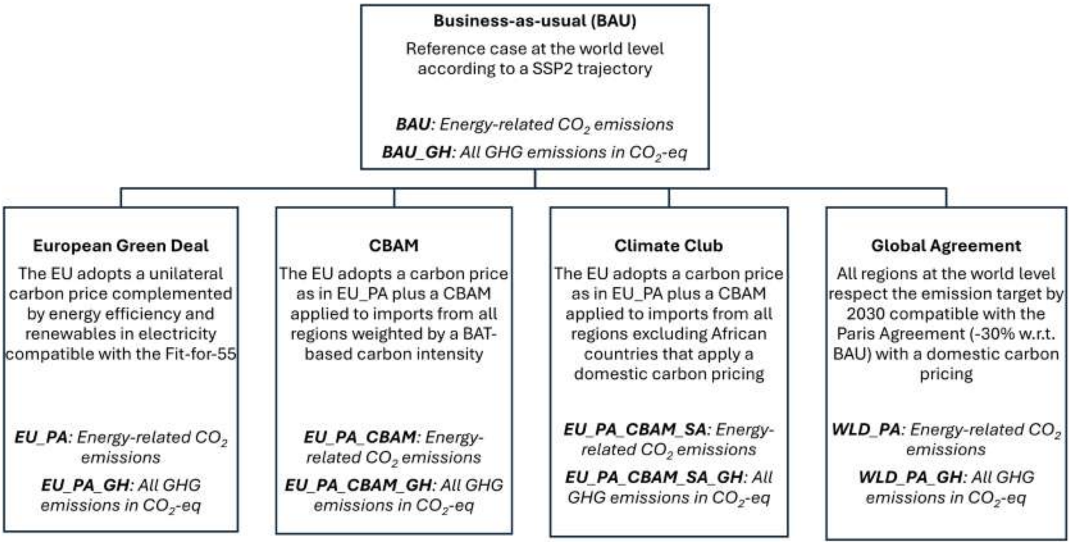


FIGURE 2 BAU and policy scenarios overview.

obtained in the policy scenarios can be considered as the marginal price required to move from the BAU to the compliance with the targets. Given that the EU is treated as a single region, the carbon price is coincident with the Pigouvian carbon taxation, aiming at comparing the same policy mechanism when the other regions are entering into the club as if the Emission Trading Scheme (ETS) includes all sectors and households.

2.3 | Policy scenarios

The two baselines serve as the foundation for four policy scenarios, which are presented in Figure 2. The first policy scenario (EU-PA) represents the implementation of a unilateral climate policy by the EU in the form of a carbon taxation applied to all CO_2-eq emissions related to economic activities by firms and households in the period 2023–2030 in order to be on track with the Paris Agreement (PA) target. The mitigation target is applied as an exogenous shock computed on the evolution of emissions according to a decarbonisation pattern compatible with the GECO-15C and the WEO-NZ (Net Zero Emission) scenario, which is coherent with the 2030 target designed into the Fit-for-55 package of the EU.

The exogenous emission target is obtained by endogenously computing the carbon tax, which is equivalent to an equilibrium carbon price (CP) of a permit market where all agents are involved. This is complemented by exogenous shocks to energy efficiency and to the output-augmenting technical change in renewable electricity production in order to respect the additional two pillars of the Fit-for-55 plan.[4]

The equation in GDynEP that allows the endogenous computation of the carbon price (CP) expressed as dollars per ton of CO_2 consists in an ad valorem equivalent of the carbon price (τ)

[4]Carbon price is designed assuming a common permits market where all agents participate, and free allowances are not allowed. This kind of design equates the implementation of EU-ETS on every sectoral level, addressing the critique Tol (2013) moved on ETS shortcomings.

expressed as percentage change of the initial price (P_{FF}) of fossil-based inputs (FF = coal, crude oil, natural gas and oil products):

$$\tau = \frac{CP\ \frac{CO_2}{Y}}{P_{FF}} = \frac{CP\ \frac{\beta FF}{Y}}{P_{FF}} \tag{1}$$

The transformation in an ad valorem equivalent of the carbon price is based on the carbon content of the production/consumption process ($\frac{CO_2}{Y}$) expressed as a standard carbon intensity measure given by the ratio between emissions and the output (Y).

The second policy scenario (EU-PA-CBAM) consists in complementing the EU-PA case with the application of a CBAM to all sectors belonging to the primary and industrial manufacturing activities (excluding services). This modelling choice allows us to obtain general results that can be interpreted under the driving multilateral mechanisms typically defined under a CGE approach. Therefore, the scenario provides benchmark results with respect to the BAU case going beyond the current EU regulation that would rapidly evolve by adding new sectors to the tariff scheme (Marcu et al., 2020).

The CBAM is modelled as an ad valorem equivalent applied to the internal market price of EU imports, whose impact is correlated to two key variables: (i) the EU carbon price endogenously computed given the mitigation target; (ii) the carbon content of the imported good computed based on best technology approach (BAT). In so doing, the CBAM policy aligns with WTO rules by applying the EU carbon content to imported goods for internal carbon pricing. The levy would mirror the EU's carbon market price to prevent carbon leakage.

In analytical terms, the CBAM is modelled following the approach developed by Antimiani et al. (2016),[5] with equations expressed in a log linear form to show the percentage change in results in a dynamic setting. The equation describing the impact of a CBAM is settled to apply the instrument only to goods imported by the EU from countries/regions that are not currently adopting any carbon pricing. In analytical terms, changes in final demand for domestic goods (x) can be expressed as a function of price elasticity ($\eta_x < 0$) and price change (p_x):

$$x = \eta_x p_x \tag{2}$$

while changes in final demand for the same goods produced abroad and imported by the EU (x_1) are expressed as:

$$x_1 = \eta_x \left(p_x + T_{x_1} \right) \tag{3}$$

Hence, the CBAM (T_{x_1}) is applied only to the portion of the good imported from outside EU (x_1), and it is a function of the ad valorem equivalent carbon price (τ) and the carbon content of the imported good (CC_x):

$$T_{x_1} = f\left(\tau, CC_x\right) \tag{4}$$

[5]Antimiani et al. (2016) modelled the CBAM in a dynamic version of the GTAP model building on previous approaches developed in a static setting (Di Maria & Van der Werf, 2008; Gerlagh & Kuik, 2007).

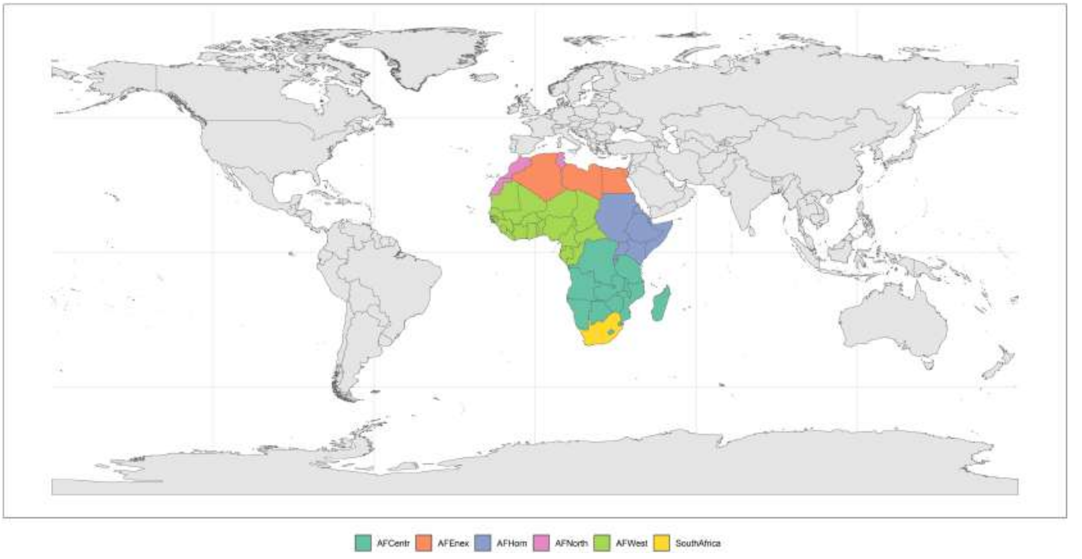


FIGURE 3 Regional mapping of African countries.

The third policy scenario (EU-PA-CBAM-SA) simulates a climate club approach as envisaged by the CBAM EU regulation in the case the exporter can demonstrate the payment for an internal carbon price applied to the domestic production process of the exported good. Accordingly, the regions exempted from the tariff scheme adopt an abatement target that corresponds to the emissions pattern compatible with the GECO-15C and WEO-NZE scenarios, with an endogenous carbon price resulting from the mitigation constraint in line with the mechanism applied to EU in the first policy case.

The regions adopting the domestic carbon price system are expected to invest in decarbonisation technologies as the EU with an increase in electricity produced by renewable sources and a reduction in energy intensity as projected in GECO-15C and WEO-NZE. The scenario is tested with a climate club formed by the EU and the regions belonging to the African continent, namely AFEnex, AFNorth, AFWest, AFCentr, AFHorn and SouthAfrica (Figure 3) that decide to go for a carbon neutral pattern and are exempted from the CBAM.

The fourth policy scenario (WLD-PA) is a reference case where the levy imposed by the EU is removed because every world region applies a domestic carbon price to emission intensive processes compatible with the Paris Agreement. From a modelling perspective, this corresponds to the adoption of domestic abatement targets by all regions in line with GECO-15C and WEO-NZE emissions trajectories, meaning that endogenous carbon taxation is applied at the region level.

As for the BAU, every policy scenario is built twice: firstly, it is based only on CO_2 emissions related to energy input, and then it is built based on all GHG emissions. This set of scenarios is identified with the acronym GH (e.g., WLD-PA-GH).[6]

In addition to the general organisation of alternative scenarios, starting from the Africa-EU climate club case (EU-PA-GH-CBAM-SA) case, the model is used for evaluating the impacts of complementary actions to enhance socio-technical sustainability in the agricultural sectors. Given that the model cannot disentangle all sectors and countries in detail, additional exogenous

[6]See Figures S3 and S4 in Appendix S1 for emissions trend in BAU, WLD-PA, and EU-PA scenarios, considering both only emissions associated with energy inputs and all GHG.

shocks can replicate the direct and indirect mechanisms into the production function when specific regulatory or voluntary sustainability instruments are included in the policy mix design. In this case, the assumptions are: (i) investments in new technologies aiming at enhancing the sustainability of the productive system can be assessed in the form of input-augmenting technical change of selected endowments (land and natural resources); (ii) improvements in labour standards and workers protection initiatives evolve into input-augmenting technical change and increase in labour productivity (with an equal percentage change both for skilled and unskilled labour force).

Given that there is no a priori empirical evidence on the effective quantification of productivity gains related to the introduction of standards or sustainable techniques, different productivity increases are tested with a +1%, 1.5%, and 2% increase in input productivity for all sectors classified in the agricultural aggregate.[7]

Some descriptive numbers can shed light on the efforts required by the EU to be on track on the PA decarbonisation target along with the Fit-for-55 package when tacking into account also the non-energy GHG emissions. The BAU scenario foresees that by 2030 the emission level with only energy-related emissions is around 3.074 Mton CO_2-eq while including all GHG the value is 3.466 Mton CO_2-eq (increasing by around 13%). Given the Net-Zero target by 2050, the intermediate abatement effort by 2030 to be compliant with the Fit-for-55 for the EU is a reduction by 28% of emissions with respect to the baseline case, resulting into a reduction by −55% with respect to the 1990 level (around 2.214 and 2.496 Mton of CO_2-eq in the two sets of emissions).

Additionally, in order to obtain a BAU consistent with the EU2030 energy policy strategy (corresponding to the WEO reference case) and the consequent shocks for the policy case, the share of renewable sources to produce electricity is fixed at 45% by 2030 as the BAU and at 55% as the policy. The modelling approach in this case is based on an exogenous shock to the evolution of electricity production disentangled by sources, while the endogenous variable is the output-augmenting technical change applied in the production process of each electricity source.

3 | RESULTS

Before presenting the results, a summary table (Table 1) is provided at the beginning of this section. This includes all the acronyms displayed in the subsequent graphs, thus facilitating the reading and interpretation of the results. The results will be analysed in terms of their effects on emissions and carbon leakage, trade and productivity.

3.1 | Emissions trends and carbon leakage

We start from the analysis of the impacts of the EU decarbonisation policy on the emission trends. It is important to recall that the general purpose of the EU regulation is to ensure that the implementation of a unilateral policy does not result in an increase in emissions abroad (carbon leakage). Focusing on the African regions, Figure 4 illustrates that, regardless of the emissions

[7]GDynEP sectors are: Rice, Cereal grains, Other primary, Vegetable and fruit, Cattle, Other livestock, Rumin meat, Other meat, Dairy, Sugar. Details on model coding are available in Table S2 in Appendix S1.

TABLE 1 Summary code reference table.

No.	Codes	Name	Description
Scenarios			
1	BAU	Business as Usual	Reference case at the world level, according to SSP2 trajectory. It comprises energy-related CO_2 emissions.
2	BAU_GH	Business as Usual	Reference case at the world level, according to SSP2 trajectory. It comprises all GHG emission in CO_2-eq.
3	EU_PA	European Green Deal	The EU adopts a unilateral carbon price complemented by energy efficiency and renewables in electricity compatible with the Fit-for-55. It comprises energy-related CO_2 emissions.
4	EU_PA_GH	European Green Deal	The EU adopts a unilateral carbon price complemented by energy efficiency and renewables in electricity compatible with the Fit-for-55. It comprises all GHG emission in CO_2-eq.
5	EU_PA_CBAM	CBAM	The EU adopts a carbon price as in EU_PA plus a CBAM applied to imports from all regions weighted by a BAT-based carbon intensity. It comprises energy-related CO_2 emissions.
6	EU_PA_CBAM_GH	CBAM	The EU adopts a carbon price as in EU_PA plus a CBAM applied to imports from all regions weighted by a BAT-based carbon intensity. It comprises all GHG emission in CO_2-eq.
7	EU_PA_CBAM_SA	Climate Club	The EU adopts a carbon price as in EU_PA plus a CBAM applied to imports from all regions excluding African countries that apply a domestic carbon pricing. It comprises energy-related CO_2 emissions.
8	EU_PA_CBAM_SA_GH	Climate Club	The EU adopts a carbon price as in EU_PA plus a CBAM applied to imports from all regions excluding African countries that apply a domestic carbon pricing. It comprises all GHG emission in CO_2-eq.
9	WLD_PA	Global Agreement	All regions at the world level respect the emission target by 2030 compatible with the Paris Agreement (−30% w.r.t. BAU at the global level) with a domestic carbon pricing. It comprises energy-related CO_2 emissions.
10	WLD_PA_GH	Global Agreement	All regions at the world level respect the emission target by 2030 compatible with the Paris Agreement (−30% w.r.t. BAU at the global level) with a domestic carbon pricing. It comprises all GHG emission in CO_2-eq.

TABLE 1 (Continued)

No.	Codes	Name	Description
African GTAP Regions			
1	AFCentr	Africa Central	Botswana, Madagascar, Mozambique, Mauritius, Namibia, Tanzania, Zambia, Zimbabwe, South Central Africa (*Angola, DRC*), Rest of South African Customs Union (*Lesotho, Swaziland*)
2	AFHorn	Africa Horn	Ethiopia, Kenya, Malawi, Rwanda, Uganda, Rest of Eastern Africa (*Burundi, Comoros, Djibouti, Eritrea, Mayotte, Seychelles, Somalia, Sudan*)
3	AFWest	Africa West	Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa (*Cape Verde, Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, Sierra Leone*), Rest of Central Africa (*CAR, Chad, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe*)
4	AFEnex	Africa North energy exporters	Egypt, Rest of North Africa (*Algeria, Libya, Western Sahara*)
5	AFNorth	Africa North rest	Morocco, Tunisia
6	SouthAfrica	South Africa	South Africa
Agricultural GTAP Sectors			
1	rice	Rice	Paddy rice, Processed rice
2	cer	Cereal grains	Wheat, Other grains (*maize, sorghum, barley, rye, oats, millets, other cereals*)
3	o_prim	Other primary	Oil seeds, Fibre crops, Wool, Other Crops
4	veg	Vegetable and fruit	Veg & Fruit: *vegetables, fruit and nuts, edible roots and tubers, pulses*
5	cat	Cattle	Cattle: *bovine animals, live, other ruminants, horses and other equines, bovine semen*
6	liv	Other livestock	Other animal products
7	r_meat	Ruminant meat	Cattle meat
8	o_meat	Other meat	Other meat
9	fish	Fishery	Fishing
10	dai	Dairy	Raw milk, Dairy products
11	bev_t	Beverages and tobacco	Beverages and Tobacco products
12	food	Processed food	Vegetable oils, Other food
13	sug	Sugar	Sugar and molasses

type under consideration, there is an increase in emissions from these regions when the EU implements a unilateral climate mitigation policy. This increase is particularly pronounced when energy-related CO_2-eq emissions are examined. More importantly, even when the carbon pricing policy is complemented by the full implementation of a CBAM scheme applied to all regions

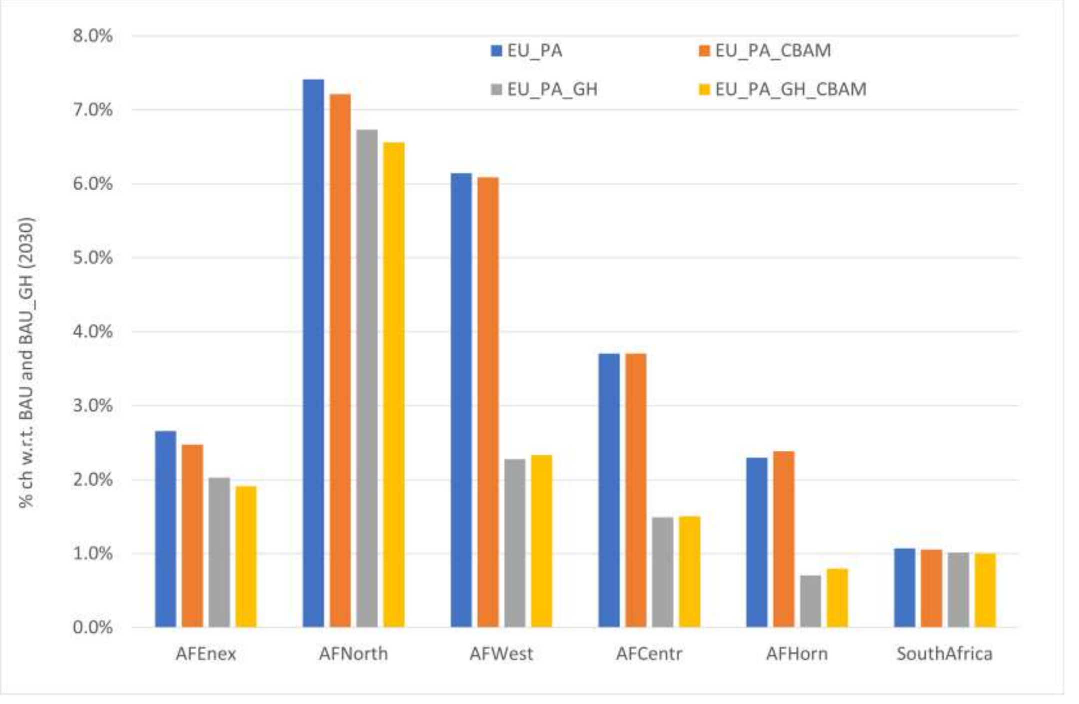


FIGURE 4 Change in CO_2-eq emissions w.r.t. BAU for African regions (2030). *Note*: Own elaboration on GDynEP results.

and all primary and manufacturing sectors, the reduction in emissions is not complete, with selected regions such as AFEnex, AFNorth and SouthAfrica remaining almost unaffected by the CBAM. Similar results can be found in the literature (Devarajan et al., 2022; Elliott et al., 2010; Winchester et al., 2011) indicating that the unilateral implementation of a carbon tax and a border carbon adjustment policy causes only minor changes in global emissions and may lead to an increase in emissions in other countries (Jansson et al., 2024; Peterson & Schleich, 2007; Winchester et al., 2011).

The limited effectiveness of the EU-CBAM in reducing the carbon leakage rate is confirmed at the global level in Figure 5, where the evolution of the leakage rate is reported for all scenarios embedding a unilateral EU policy. The maximum level of leakage is associated with the joint implementation of internal carbon pricing and an external CBAM scheme by the EU, encompassing all GHGs, reaching around +61% of carbon leakage by 2030. In comparison to the literature related to the EITE sectors (Böhringer, Balistreri, & Rutherford, 2012) this value results higher, while literature focusing on the carbon leakage deriving from the implementation of unilateral policies in the agricultural sector finds similar results (Irfanoglu et al., 2012; Van Doorslaer et al., 2015). Furthermore, several other papers find an almost null reduction of the leakage rate after the implementation of CBAM (Babiker & Rutherford, 2005; Kuik & Hofkes, 2010; Peterson & Schleich, 2007).[8] There are four factors explaining the limited effectiveness of CBAM in addressing carbon leakage and the increase in foreign emissions when the combination of carbon pricing and tariffs is implemented. The general increase in emissions produced by non-compliant regions in the case of a unilateral climate

[8]Reassuringly, our general results on the value of leakage are within the leakage rate range identified by recent research (Bauer et al., 2015; Misch & Wingender, 2024; Yu et al., 2021).

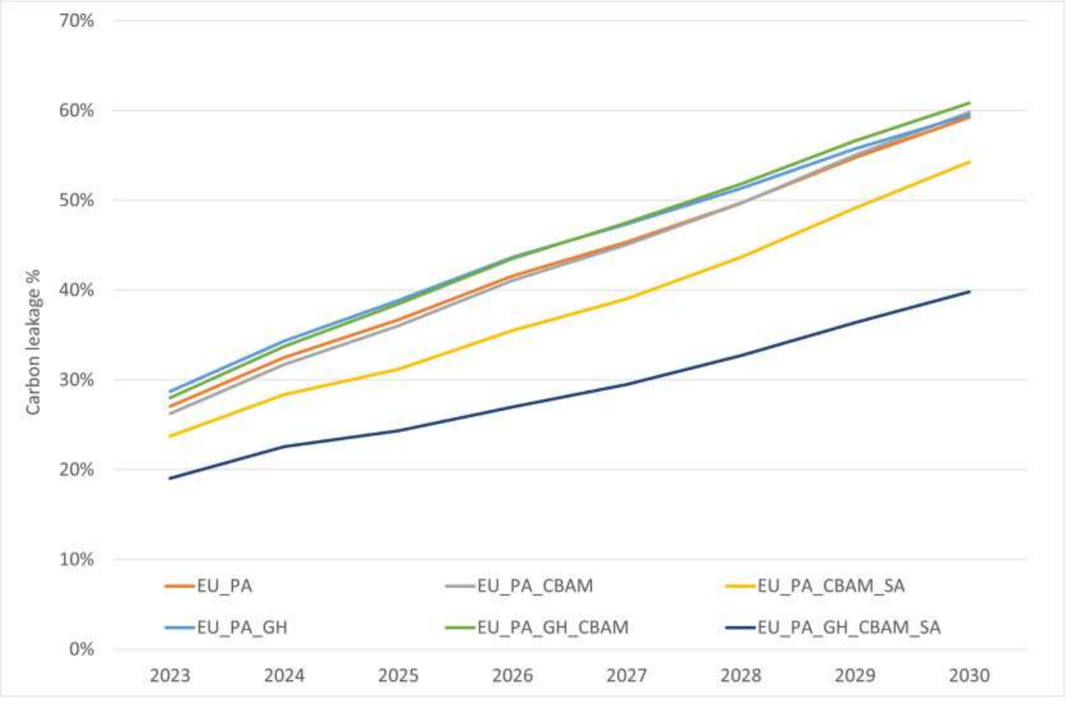


FIGURE 5 Carbon leakage under different EU policy scenarios. *Note*: Own elaboration on GDynEP results.

policy is strictly connected to several factors (Di Maria & Van der Werf, 2008): (i) the reduction in international energy prices and the consequent increase in energy demand by non-abating countries and (ii) the related increase in energy-intensive production processes as they result relatively more competitive due to the reduced factor cost of energy inputs. When the EU implements carbon pricing and CBAM, (iii) all intermediate goods imported by the EU and subject to the tariff are more expensive, with additional adverse effects on EU competitiveness. Looking at the web of bilateral trade linkages along the GVCs, (iv) the EU export flows are replaced on the international markets by non-EU (more carbon-intensive) products in a typical trade diversion effect. This occurs when the composition of export flows remains unchanged while only the final destination markets are different (Antimiani et al., 2016).

On the other hand, an analysis of the effectiveness of a climate club strategy (here modelled between EU and African regions) reveals a reduction in carbon leakage, particularly when considering all production processes, including the agricultural and livestock activities (EU-PA-GH-CBAM-SA scenario) and related GHG emissions. By accepting African regions in the climate club once they have introduced domestic carbon pricing systems aligned with PA targets, the reduction in leakage rate is significant, moving from 60% (EU-PA-GH-CBAM) to 40% (EU-PA-GH-CBAM-SA) by 2030.

3.2 | Trade effects for African regions

The inclusion of African regions into the climate club alongside the EU yields mixed outcomes concerning the economic effects experienced by different players from multiple perspectives. Also, when examining the sustainability of production and consumption practices adopted in African regions, divergent outcomes arise.

As a first general result, the overall impact on the EU's GDP favours the implementation of unilateral carbon pricing alone (EU-PA scenario), without the complementary aspect of a CBAM. However, this approach fails to curb carbon leakage, leading to complementing with CBAM and bringing to an additional loss in terms of GDP. Similar results on the loss of GDP by the country applying the border adjustment can be find in Bellora and Fontagné (2023) and Böhringer, Balistreri, and Rutherford (2012).[9]

As a second general result, when considering the African regions, impacts are highly heterogeneous: some regions benefit from joining the club, whereas others experience losses with respect to the policy case with CBAM when they do not take a domestic decarbonisation pattern. In other words, for selected regions (especially the African energy exporters) the extra-costs paid in terms of carbon tariffs is less impacting on export competitiveness than the adoption of a domestic carbon price. Such heterogeneity in a CGE-type model can be interpreted by looking at the web of bilateral trade mechanisms that are the basis of the economic linkages across sectors and regions along the GVCs.

More specifically, three key elements can be identified by comparing the ad valorem values of the carbon tariff expressed as a percentage change of the EU domestic price of imports by sector (Figure 6) when no climate club is enforced. First, the tariffs endogenously computed from the scenario with energy-related CO_2-eq emissions (EU-PA-CBAM) consistently yield lower values compared to those derived from the inclusion of all greenhouse gases (EU-PA-GH-CBAM). Second, the discrepancy between the two scenarios with different computations of emissions arises in those sectors that are less energy-intensive but are responsible for output and endowment-based non-CO_2 emissions, mainly the primary sector. Thirdly, the sectors exhibiting a significant increase in prices (excluding chemical, mineral and iron and steel sectors) are predominantly related to agriculture and livestock.

When the climate club opportunity is exploited by African regions (EU-PA-CBAM-SA), a general increase in the export share of African regions on both the EU and global market is observed with respect to the no club case with CBAM applied to all exporters. A detailed examination of the trade impacts on African regions in the two different emissions calculation scenarios (Figure 7), uncovers that some regions stand to benefit significantly from the potential expansion of the EU market as a primary destination for their domestic production when they're compliant with carbon abatement targets.[10]

The region that benefits the most from its inclusion in the EU climate club, regardless of the emission model considered, is AFWest. Across almost all primary sectors analysed, the region experiences an increase in export share both in the EU market and the rest of the world. This result indicates that AFWest's efforts to decarbonise its production processes yield positive outcomes, as the overall efficiency gains outweigh mitigation costs. Consequently, exports from AFWest become comparatively more competitive in the global market (and not only in the EU market). Sectors such as rice, cereals, raw meat, dairy products and sugar witness an expansion in their export share in both the EU and other markets, benefiting from a trade creation effect that is most pronounced when all GHGs are considered. Furthermore, the adoption of sustainable practices in the agricultural and livestock sectors, which goes beyond solely reducing energy intensity, appears to be a win-win strategy for this region. This results in a reduction in environmental pressure and an enhancement of the region's capacity to compete internationally, which in turn leads to an overall improvement in GDP (Figure 8).

[9]See Figures S1 and S6 in Appendix S1.
[10]See Table S4 in the Appendix S1.

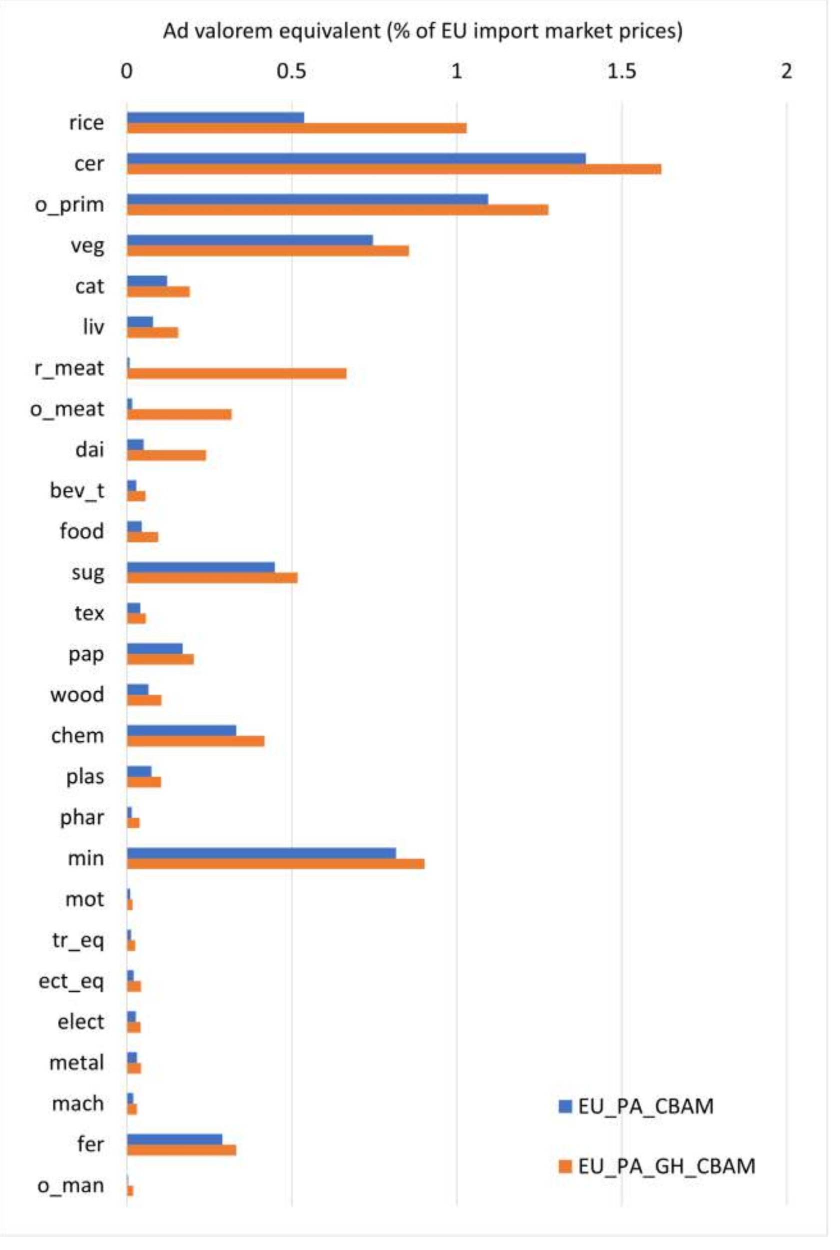


FIGURE 6 AVE from CBAM as % change of market prices of EU imports (2030). *Note*: Own elaboration on GDynEP results.

A comparable outcome is observed in the AFCentr region, where the implementation of less emission-intensive production methods, specifically in the rice and raw meat sectors, has led to increased export activities both to the EU and the global market. The overall economic impact in terms of GDP is even more significant for this region, experiencing a notable 3% increase in cumulative GDP when all GHGs are considered in the emissions reduction target.

The trade and economic impacts on the AFEnex region present a more varied picture, with interesting insights emerging from a comparison of relative export shares to the EU market at

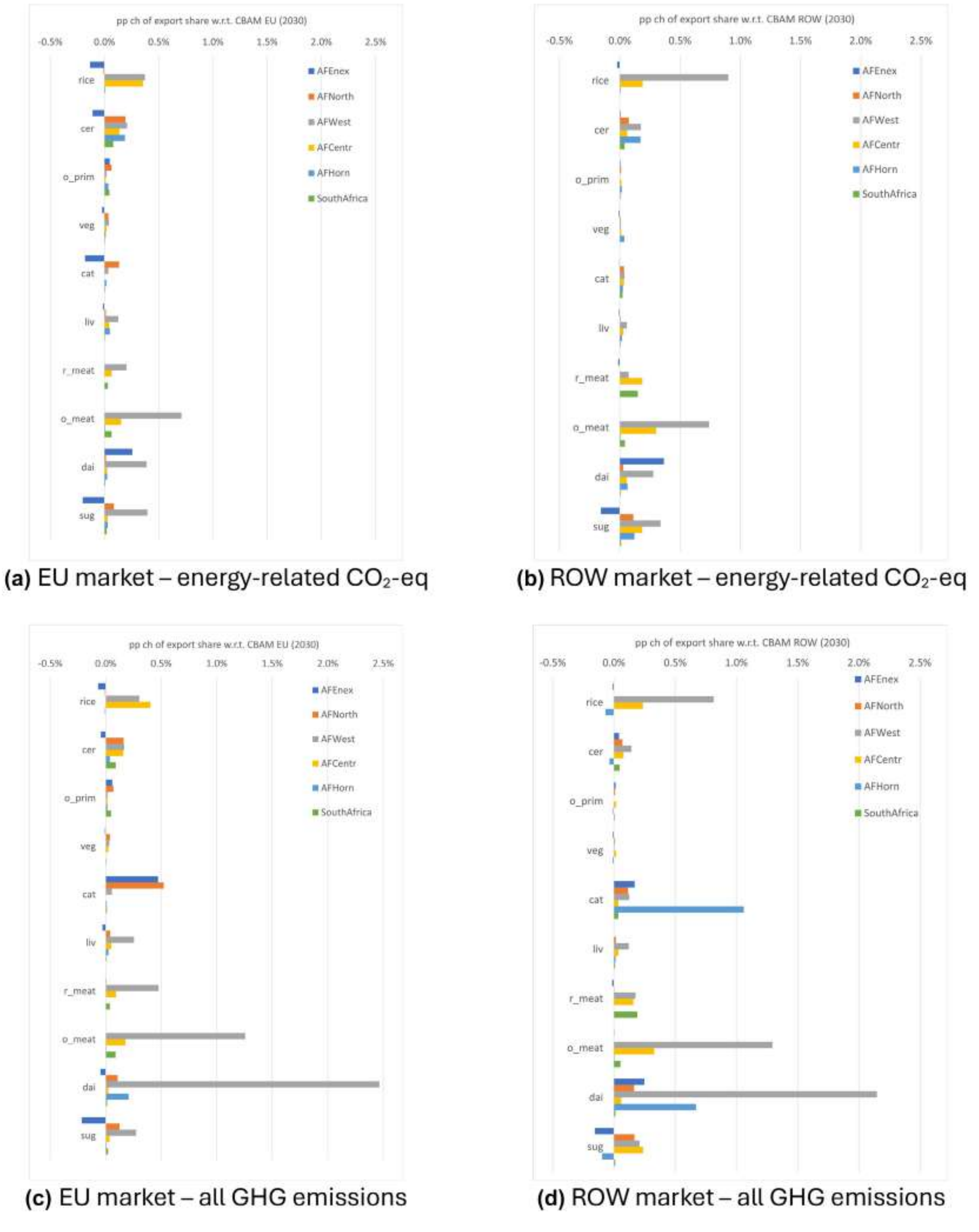


FIGURE 7 Export share percentage point change (%) in 2030 – Climate club vs. CBAM. *Note*: Own elaboration on GDynEP results. Comparison between Climate club vs. CBAM scenarios.

the sector level. In several sectors, products originating from AFEnex countries (Algeria, Egypt, Libya) have the highest export share to the EU market compared to other African regions (e.g., rice, cereals, cattle, fishery and sugar). However, for many of the mentioned sectors, the implementation of a domestic carbon pricing system able to qualify for exemption from the EU carbon tariff would result in lower export share to the EU market. Nevertheless, the trade diversion

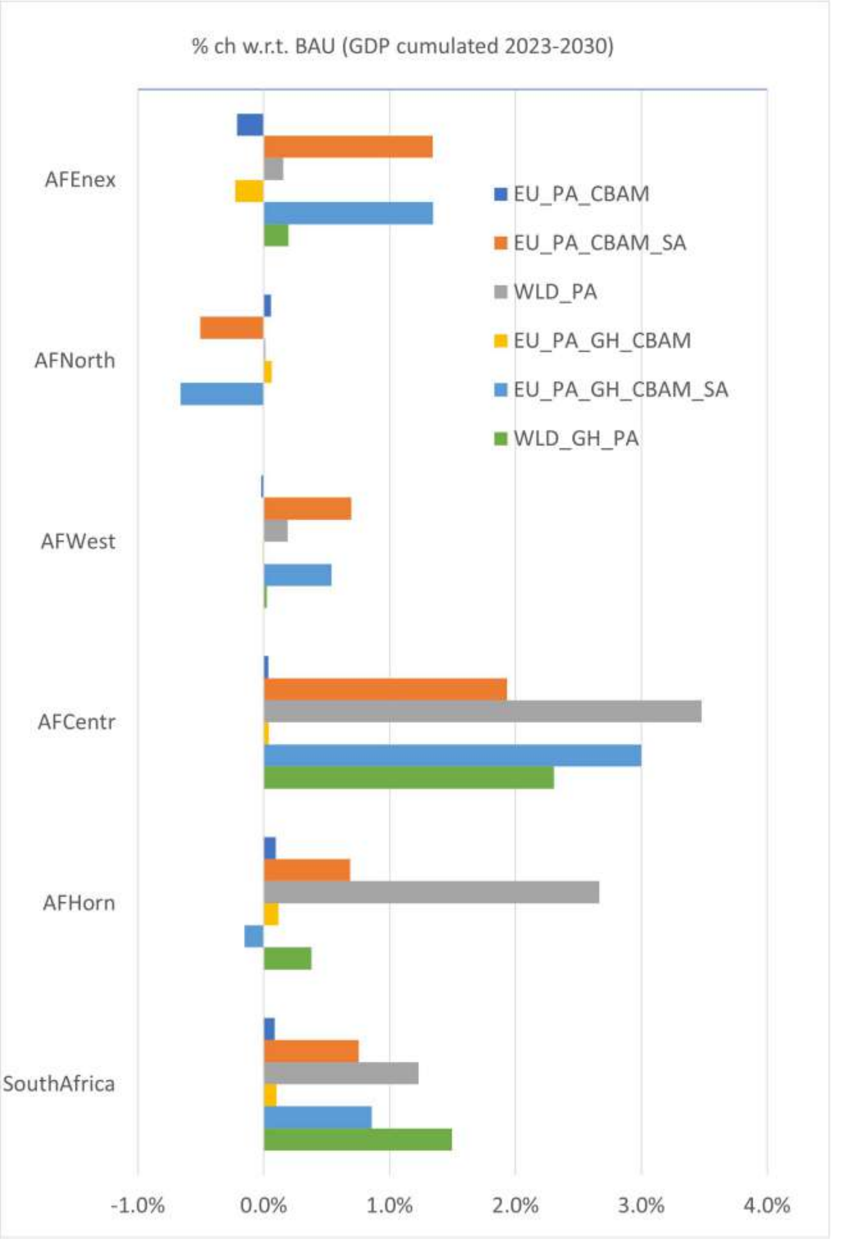


FIGURE 8 Change in cumulated GDP w.r.t. BAU for African regions (constant 2020 US$). *Note*: Own elaboration on GDynEP results. Given the dynamic nature of GDynEP, by applying a discount rate of 3%, we computed the cumulated difference in GDP w.r.t. the relative BAU case in net absolute present value in constant 2020 US$ in the time span 2020–2030.

resulting from the inclusion in the climate club would not lead to negative overall economic consequences.

Lastly, the AFHorn region appears to exhibit minimal impact from its inclusion in the EU climate club. However, there are benefits in terms of enhanced export capacity towards the EU market, primarily observed in the dairy sector. Additionally, a positive trade creation effect is observed in the cattle sector when all GHGs are incorporated into the model. While the trade effects in the primary sectors may be negligible, the efforts invested in reducing overall carbon intensity through a domestic carbon pricing system, coupled with improvements in resource efficiency and renewable energy production, prove economically advantageous within the context of a global climate club where all regions participate in a common abatement goal. In contrast, in a selective EU-Africa climate club scenario, exemption from the EU carbon tariff alone is insufficient to offset the burden of a domestic climate policy.

3.3 | Factor productivity effects in agriculture

Given the potential development opportunities associated with a sustainable and innovative trajectory in the agricultural sector, the final set of scenarios starts from the Africa-EU climate club case, including all GHGs (EU-GH-PA-CBAM-SA) and tests whether input-augmenting productivity investments in these sectors might improve the socio-economic sustainability of African regions. This scenario-setting can also provide a benchmark for the potential impact of effective actions dedicated to specific countries and sectors evaluated with single case studies.

It is also important to consider the potential socio-economic impacts of sustainable-oriented improvements in the production process, which may result in a distribution of these improvements across consumers. This is driven by indirect price adjustments resulting from the pass-through mechanism of carbon taxation (Bernard & Kichian, 2021).

Despite the positive general effects already discussed in terms of export shares, private consumers might experience a reduction in their welfare gains as a consequence of the rise in market prices across all agricultural sectors due to the introduction of a domestic carbon price (Figure 9).[11]

All regions and sectors are affected by higher consumer prices, but the impact varies greatly depending on the economic structure and the relative mitigation burden compared to the BAU scenario. For example, the rice sector appears particularly influenced by AFEnex and AFCentr, while consumers in SouthAfrica are particularly vulnerable to vegetables, cattle, livestock and raw meat. The regions significantly affected in many sectors are AFWest, AFCentr and AFHorn, indicating that final consumers in these LDCs are at risk of experiencing high redistributive effects, as also found by Jansson et al. (2024). In this modelling exercise, since it is not possible to precisely transform into productivity gains the multiple actions that can be adopted for specific inputs, sectors and single countries, we have chosen to evaluate the relative impact of different percentage change values in input-augmenting technical change for labour force, soil and natural resources, with three values, 1%, 1.5% and 2%, as a sort of sensitivity analysis.

Figure 10 illustrates that the difference (measured as percentage point changes) in consumer prices is consistently negative. This indicates that an improvement in factor productivity is negatively correlated with consumer prices. In other words, private consumers generally benefit from lower prices when there is an investment in sustainable production methods that increases production efficiency. When the maximum productivity gain of 2% is tested, sectors such as cereals, other primaries and vegetables and fruits could see more than 1% price reductions in almost all regions.

From a CGE perspective, the decrease in price changes can be interpreted as an increase in final domestic demand. This implies that the supply of primary items for domestic consumers is

[11] See Himics et al. (2018) for a similar result in European Union after the implementation of a carbon tax on non-CO_2 emissions.

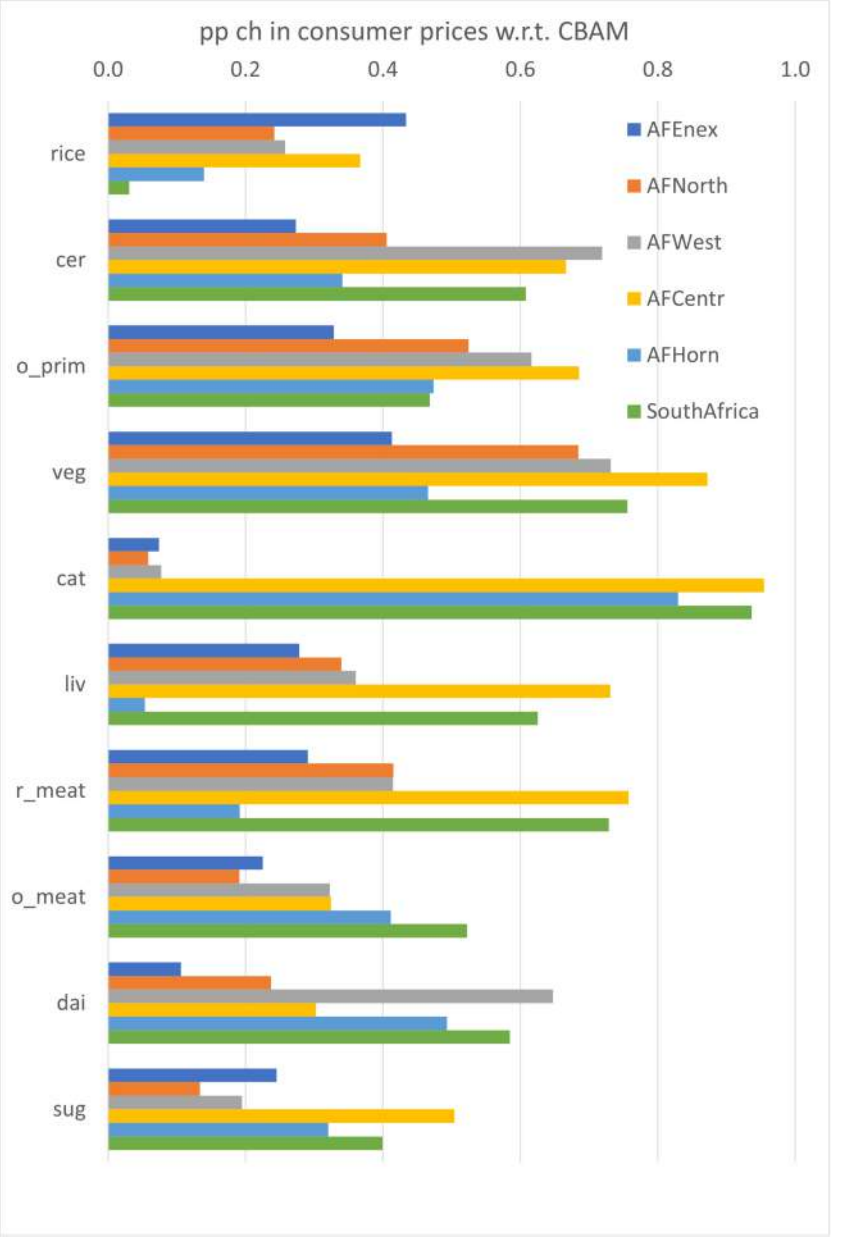


FIGURE 9 Perc. points change w.r.t. CBAM in domestic consumer prices (2030). *Note*: Own elaboration on GDynEP results.

performing better, leading to an expected improvement in food security. The relative increase in internal demand might result in changes in export composition, as shown in Figure 11, where the effects are reported for 2030, with the highest productivity improvement (a homogeneous input productivity gain of 2%). The results, which were calculated in the same manner as in Figure 7, indicate that increasing input productivity through sustainability investments, in addition to energy efficiency and renewable energy sources, may boost domestic consumption at the expense of export flows.

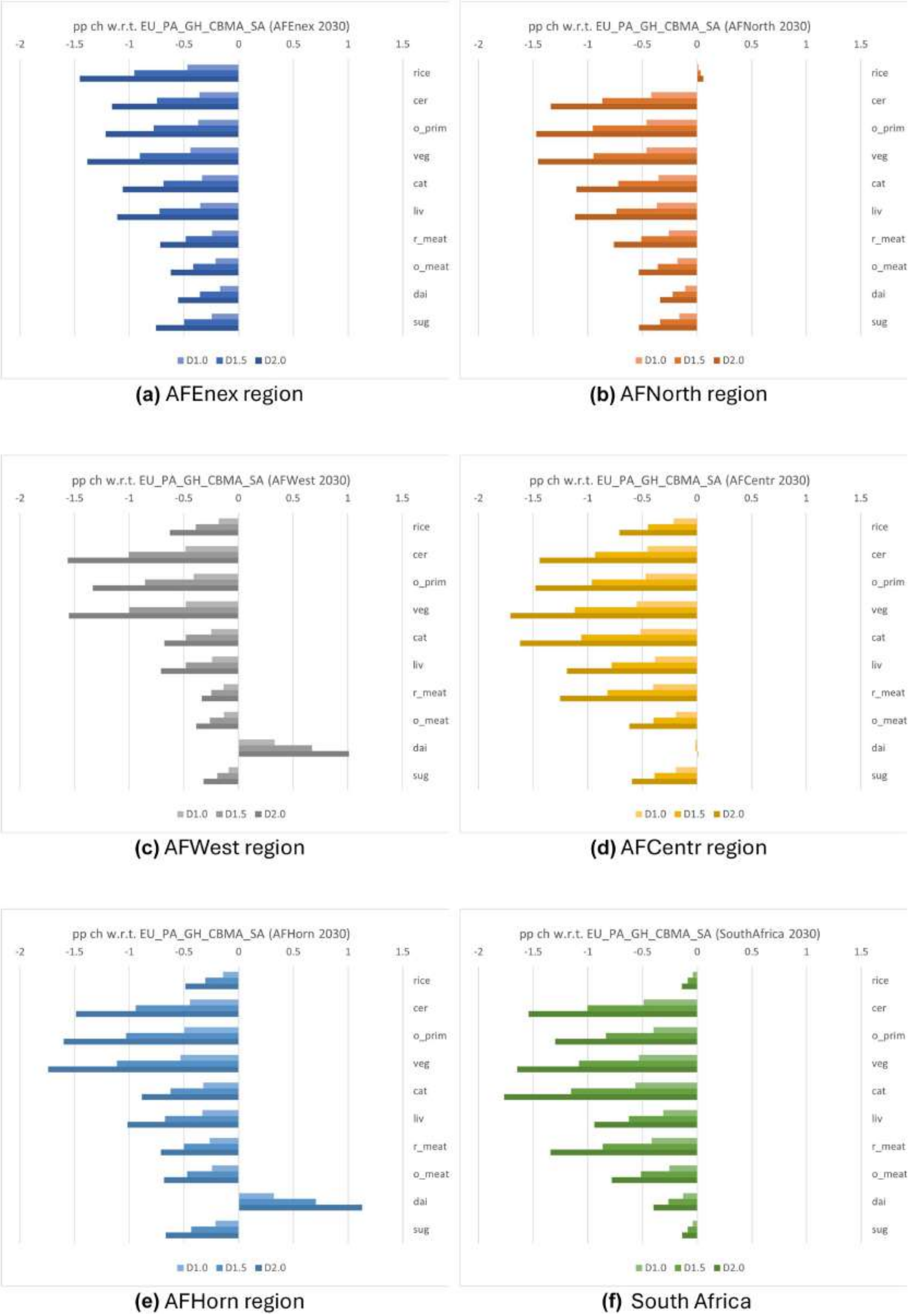
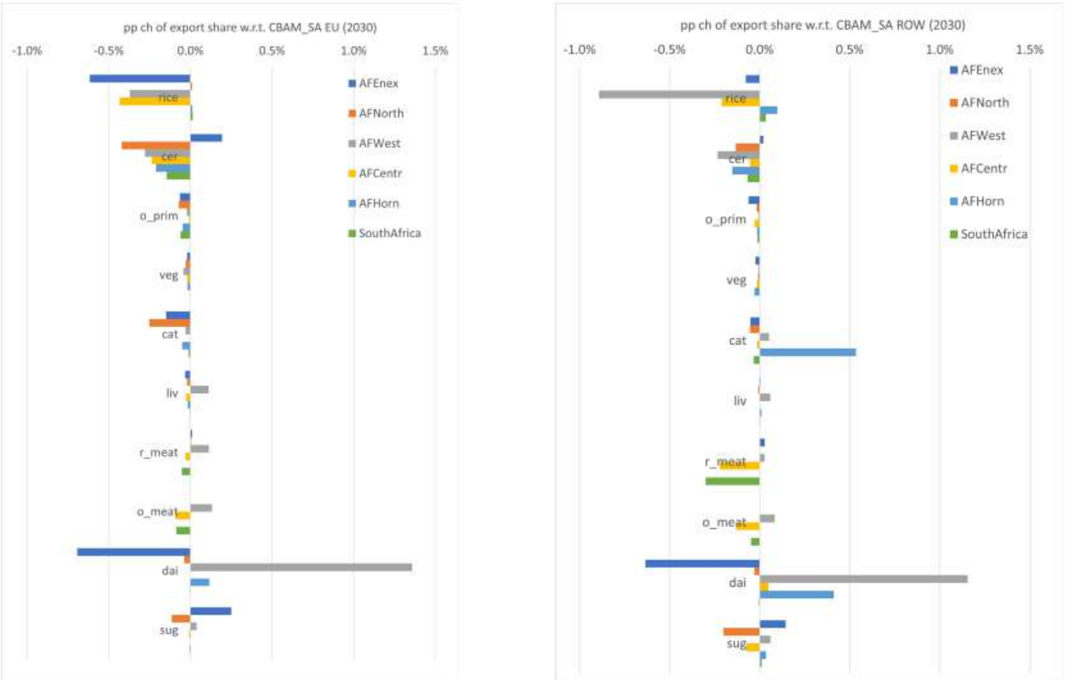


FIGURE 10 Perc. points change in consumer prices with alternative productivity gains (2030). *Note*: Own elaboration on GDynEP results.



(a) EU market **(b)** ROW market

FIGURE 11 Perc. points change w.r.t. CBAM_SA case in export share (2030 with 2% productivity). *Note*: Own elaboration on GDynEP results.

In order to provide a general assessment of the socio-economic impacts associated with the full set of sustainability practices, Figures 12 and 13 show the trajectories of GDP and welfare for the six African regions. Trends in GDP are reported in terms of the difference in GDP calculated as the net present value (NPV) at 2020 when productivity gains by 2% are introduced w.r.t to the EU-GH-PA-CBAM-SA scenario, with a uniform 3% discount rate applied to yearly GDP values. Results for GDP (Figure 12) show that, with the exception of AFCentre between 2023 and 2025, the homogeneous 2% productivity gain is always associated with a positive change in cumulated GDP. While all regions are positively impacted by the introduction of social and environmentally sustainable production techniques in agricultural sectors, AFWest and AFHorn achieve an increase in GDP by more than 5% by 2030 with respect to the scenario in which the carbon pricing system is complemented by only efficiency gains in energy consumption and in renewable energy production. This result appears to be consistent with the findings of Paroussos et al. (2019), which indicated that a coalition that enhances technological diffusion can yield higher economic benefits than one that solely focuses on a mitigation goal.

Change in welfare is here measured in terms of equivalent variation (EV), a measure of welfare change that considers both changes in prices and changes in income (Mas-Colell et al., 1995).[12] Similarly to previous results on GDP, the impact in EV terms (Figure 13) is always

[12]More specifically, the EV is the amount of money that would have to be given to a household after a price or policy change to make them as well off as they were before the change. It is called the EV because it represents the change in income that is equivalent in terms of welfare to the actual price or policy change. The monetary value of EV given by GDynEP is discounted with a social discount rate by 3% and reported to 2020 level as a standard procedure.

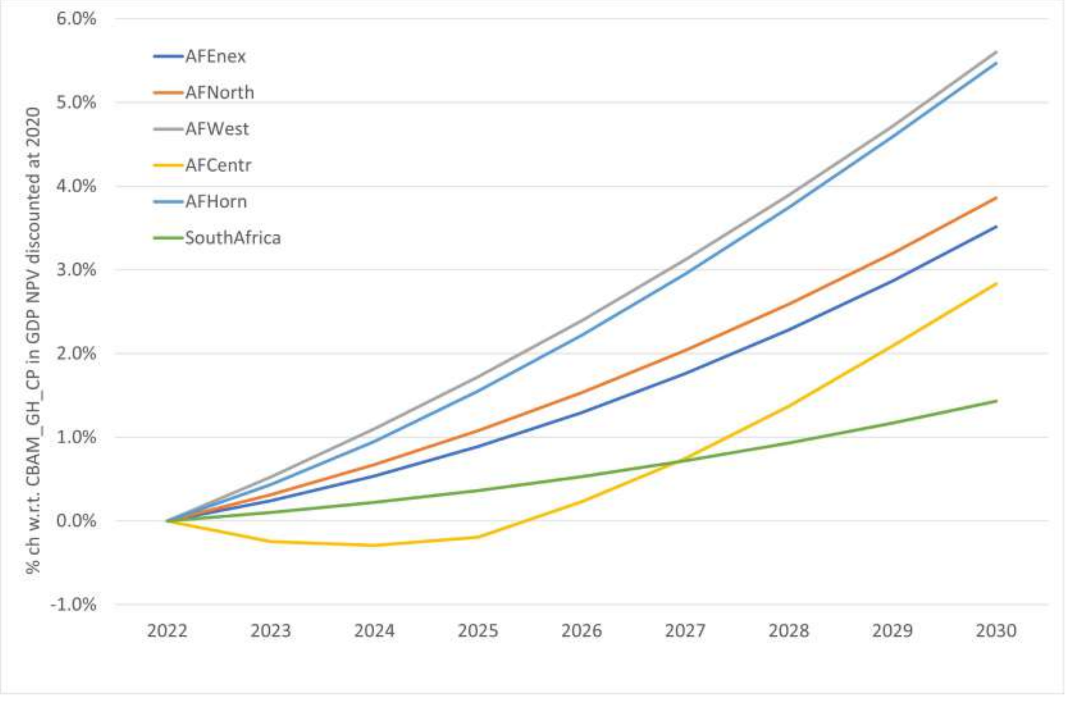


FIGURE 12 GDP % change w.r.t. EU_PA_GH_CBAM_SA at 2020 present value (with 2% productivity).
Note: Own elaboration on GDynEP results.

positive, although the magnitude of the impact varies considerably across regions. The most significant gain is observed in AFEnex, while the lowest, although positive, gain occurs in South Africa.

3.4 | Sensitivity analysis

Due to the strong uncertainty in CGE results mainly associated with the values imposed to exogenous parameters, in order to test the model sensitivity we have performed a standard robustness check on the relative impact of changes in relevant parameters on the carbon leakage rate.

The selected elasticity parameters refer to two main channels that drive the leakage rate, which are related to the bilateral trade links and the productivity and substitutability in the energy sector. These channels are the so-called *non-energy* and *energy* markets. The *energy* market channel operates through a reduction in global demand for carbon-intensive energy inputs resulting from unilateral abatement policies. This, in turn, will lead to a decline in international energy prices, stimulating an increase in fossil fuel consumption in non-regulated countries and consequently raising the leakage rate. The intensity of this mechanism is determined by the energy demand and supply elasticities. In contrast, in *non-energy* markets unilateral carbon abatement policies have the effect of increasing the production cost of energy-intensive industries, thus lowering their international competitiveness and may potentially result in a shift in production towards non-abating countries. The intensity of this mechanism depends on the magnitude of the trade substitution elasticities (Burniaux & Oliveira Martins, 2012).

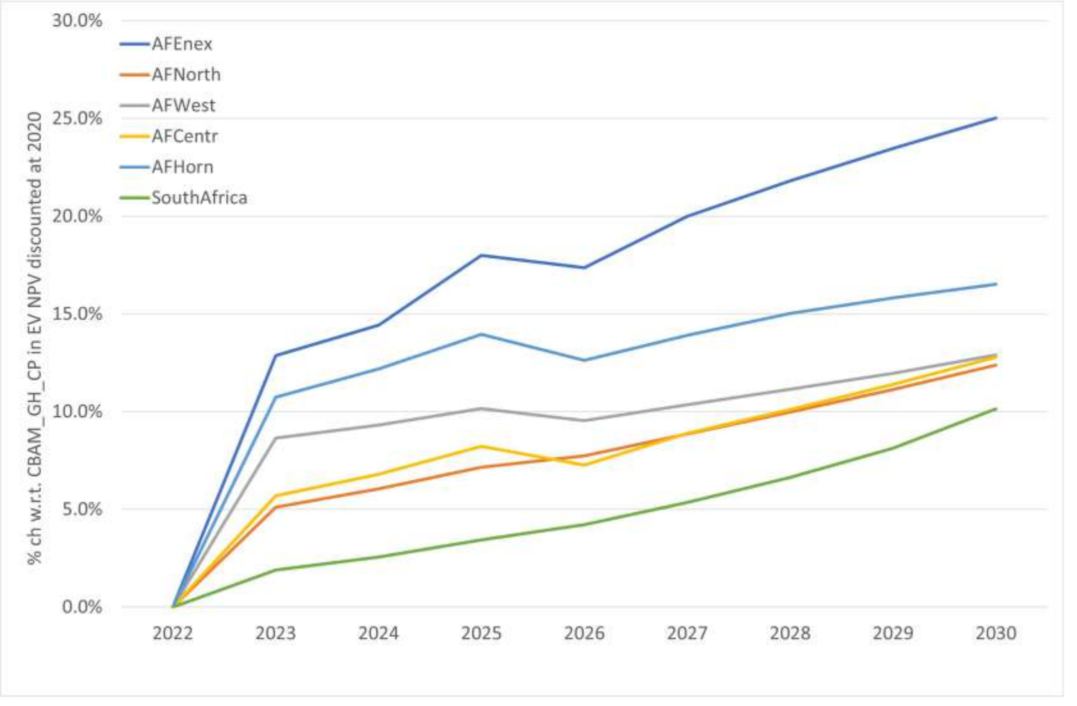


FIGURE 13 EV % change w.r.t. EU PA GH CBAM SA at 2020 present value (with 2% productivity). *Note*: Own elaboration on GDynEP results.

With respect to the latter channel related to trade in *non-energy* markets, we select the Armington elasticities, named in GDynEP the Armington constant elasticity of substitution (CES) for domestic/imported allocation (ESUBD) and the Armington CES for regional allocation for imports (ESUBM). ESUBD refers to the first choice in trade behaviour, if the domestic product should be consumed internally or exported and the opposite, if the domestic consumption should be satisfied by the internal production or by imports from abroad. ESUBM represents the second choice, once it has been decided to trade rather than internally consuming, this Armington elasticity quantifies at the global level how easy is to shift the trade flow from one region to another due to market-based and technical features. Both parameters are provided by the GTAP10 database, where ESUBD is country and sector specific while ESUBM is sector specific but uniform across regions.

The energy market is also characterised by different parameters, some of them more closely related to the standard determinants of carbon leakages and to the policy pillars of the EU Fit-for-55 package here tested. Accordingly, we select three elasticities representative of the demand and the supply side of the energy sector, and also in this case parameters are provided by the GTAP10 database. From the demand side, we test the impact on leakage related to the elasticity of substitution in value-added-energy sub-production for the demand of energy as an intermediate input in the production function by firm (ELFVAEN). From the supply side, we test two distinguished parameters that are also strictly related to the EU energy policy: the elasticity of substitution between electricity sources (ELFELY), and the elasticity of substitution between fossil fuels (i.e. non-coal and coal) in the non-electricity energy sub-production composite (ELFNELY). These two parameters are used both in the production function by firms and in the consumption decision by households and are equally relevant in shaping the reaction in sensitivity analysis (Antimiani et al., 2015).

All parameters' values related to trade substitution and energy demand and supply functions have been calibrated according to the latest contributions on global elasticities (Bajzik et al., 2020; Ivanic et al., 2023) validated with the contribution of energy experts from the Italian National Research Institute on New Energy Technologies (ENEA).

In conducting the sensitivity analysis, the shocks adopted are +/− 2.5%, 5% and 10%, and Figure 14 reports the trend in the carbon leakage rate according to the six different percentage change in the elasticity parameters. The sensitivity analysis has been carried out by isolating the effects related to international trade (*Panel a*) and to the energy markets (*Panel b*) parameters separately and as a third test a joint set of shocks has been imposed for all parameters simultaneously (*Panel c*). As emerging from Figure 14, the leakage rate is sensitive only to changes in the trade substitution elasticities, and the magnitude is less than proportional with respect to the shocks adopted. On the opposite, the leakage rate is slightly impacted from alternative values of the three energy-related elasticities as the trends in *Panel b* are almost completely overlapped. Furthermore, it is worth mentioning that the sign of the parameter shock for trade elasticities is positively correlated to the effect in terms of carbon leakage, since an increase in trade elasticities allows the possibility to shift from domestic production to imports. On the opposite, the reaction to shock in energy parameters is reversed, as an increased in the flexibility of the energy system reduces the technical constrains and consequently the impact on the cost of energy production, reducing the propensity to shift from domestic to imported goods. When the shocks to the two sets of parameters are jointly tested, the net effect is slightly reduced in *Panel c* w.r.t *Panel a* since energy elasticities counterbalance the trade-related effects. Overall, this evidence suggests that our results are relatively more sensitive to the *non-energy* channel, operating through changes in international competitiveness and trade, rather than the *energy* markets. Our results are of course driven also by the current model setting, that is, a dynamic CGE model, including both combustion-based and non-energy CO2 emissions, calibrated for specifically evaluating trade and emission outcomes under EU-Africa (cooperative) climate frameworks with a focus on agriculture rather than energy-intensive industries. Observe also that when testing the sensitivity to the energy markets we simultaneously shocked demand and supply parameters, thus resulting into a net lower impact on leakage. These results, and the fact that in Figure 14 the range of variation of the carbon leakage rate is always smaller relative to the magnitude of the parameters' shocks adopted, provide robust evidence that the impact of alternative climate policy remains stable under different elasticity values in GDynEP (Table 2).

4 | CONCLUSIONS AND POLICY IMPLICATIONS

The ex-ante analysis of the alternative climate policy solutions involving the EU and African countries, with particular reference to the agricultural sector, suggests that, unless foreign partners apply domestic carbon pricing mechanisms, the capacity of CBAM to jointly prevent the risk of carbon leakage and support the EU's increased ambition on climate mitigation (while ensuring WTO compatibility) is limited. Conversely, the implementation of domestic mitigation strategies by African regions, accompanied by an exemption from CBAM application, would result in enhanced export competitiveness on the EU market, while simultaneously reducing carbon leakage by 6 and 21 percentage point changes, respectively, in the case of fossil-based CO_2-eq emissions or all GHGs included in the model.

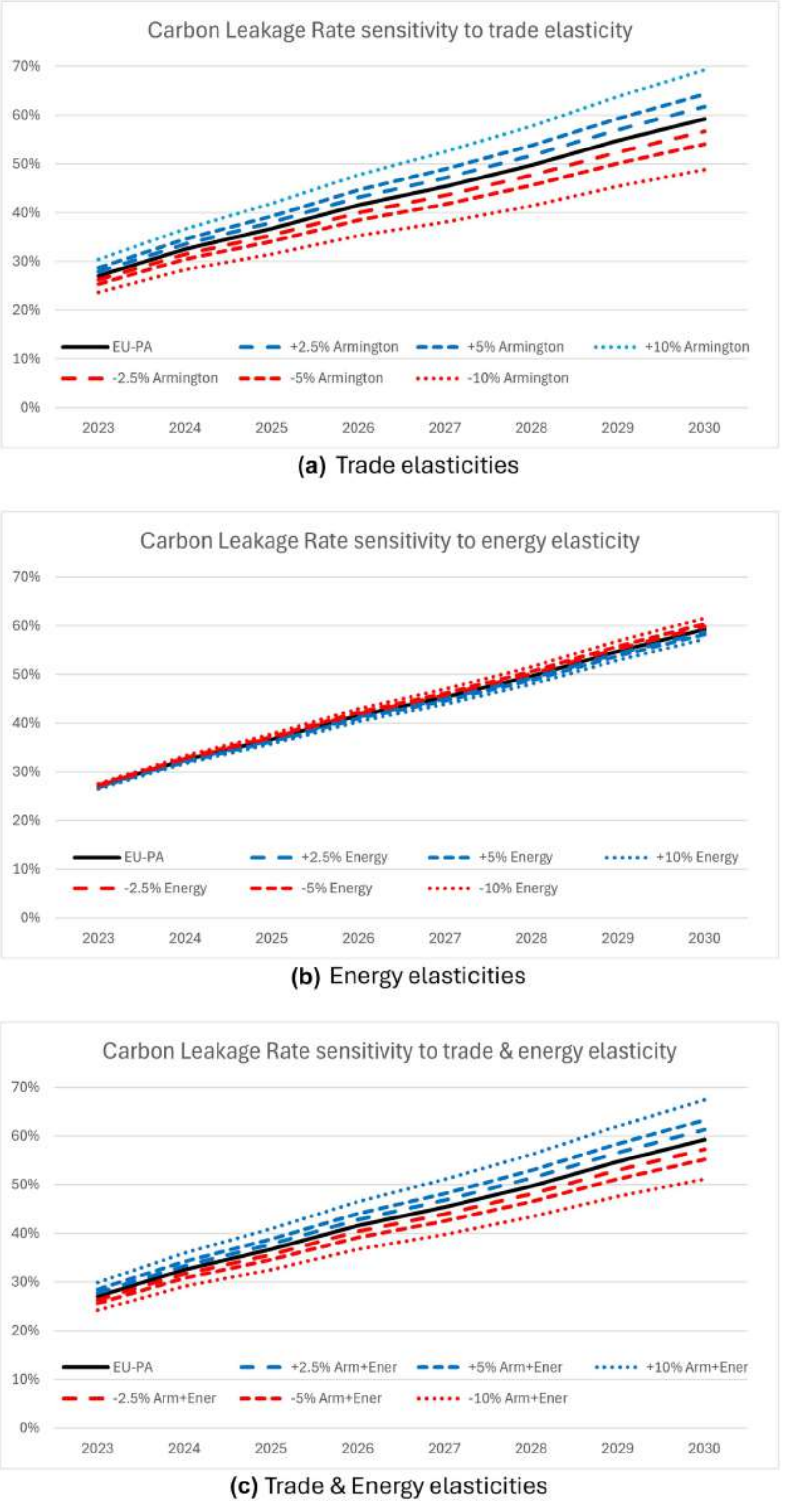


FIGURE 14 Sensitivity analysis to trade and energy elasticity parameters. *Note*: Own elaboration on GDynEP results.

TABLE 2 Main elasticity values for EU region trade and energy parameters from GDynEP model.

No	Sector	Trade		Energy		
		ESUBD	ESUBM	ELFVAEN	ELFNELY	ELFELY
1	rice	2.70	5.40	0.74	0.57	0.50
2	cer	2.85	5.70	0.26	0.57	0.50
3	o_prim	3.00	6.01	0.26	0.57	0.50
4	veg	1.85	3.70	0.26	0.57	0.50
5	cat	2.00	4.00	0.26	0.57	0.50
6	liv	1.30	2.60	0.26	0.57	0.50
7	r_meat	3.85	7.70	1.12	0.57	0.50
8	o_meat	4.40	8.80	1.12	0.57	0.50
9	fish	1.25	2.50	0.20	0.57	0.50
10	dai	3.65	7.30	0.67	0.57	0.50
11	bev_t	1.15	2.30	1.12	0.57	0.50
12	food	2.30	4.61	1.12	0.57	0.50
13	sug	2.70	5.40	0.94	0.57	0.50
14	tex	3.79	7.59	1.26	0.57	0.50
15	pap	2.95	5.90	1.26	0.57	0.50
16	wood	3.25	6.51	0.85	0.57	0.50
17	chem	3.30	6.60	1.26	0.57	0.50
18	plas	3.30	6.60	1.26	0.57	0.50
19	phar	3.30	6.60	1.26	0.57	0.50
20	min	1.66	3.32	0.95	0.57	0.50
21	mot	2.80	5.60	1.26	0.57	0.50
22	tr_eq	4.30	8.60	1.26	0.57	0.50
23	ect_eq	4.40	8.80	1.26	0.57	0.50
24	elect	4.40	8.80	1.26	0.57	0.50
25	metal	3.75	7.50	1.26	0.57	0.50
26	mach	4.05	8.10	1.26	0.57	0.50
27	fer	3.69	7.39	1.26	0.57	0.50
28	o_man	3.75	7.50	1.26	0.57	0.50
29	coal	3.05	6.10	3.53	0.00	0.50
30	oil	3.05	6.10	0.38	0.00	0.50
31	gas	3.05	6.10	0.69	0.00	0.50
32	oil_pcts	2.10	4.20	1.26	0.00	0.50
33	ely_f	2.39	4.77	1.26	0.57	0.50
34	ely_n	2.39	4.77	1.26	0.57	0.50
35	ely_rw	2.39	4.77	1.26	0.57	0.50
36	r_transp	1.90	3.80	1.68	0.57	0.50
37	a_transp	1.90	3.80	1.68	0.57	0.50

TABLE 2 (Continued)

No	Sector	Trade		Energy		
		ESUBD	ESUBM	ELFVAEN	ELFNELY	ELFELY
38	w_transp	1.90	3.80	1.68	0.57	0.50
39	serv1	1.91	3.82	1.41	0.57	0.50
40	serv2	1.91	3.83	1.26	0.57	0.50

Note: Parameters from GDynEP gdpar.har model file.

There is a valuable improvement in global emissions reduction from the implementation of a trade policy agreement between the EU and African regions where African countries are excluded from the CBAM policy application and engaged into a domestic emissions abatement policy. An average −27% reduction in emission intensity is registered by 2030 in African regions, with peaks by −19% in rice production in South Africa or by −35% for livestock production in North African countries.

In order for the EU carbon policy mechanism to be aligned with the Fit-for-55 targets, there is a need for an optimisation of the carbon neutrality outcome at the global level. This could be achieved by complementing the CBAM trade policy with efforts to establish as many climate clubs as possible, with the aim of building a global commitment towards carbon neutrality. Indeed, the inclusion of all GHGs in the climate policy strategy and related carbon pricing mechanism significantly changes the economic and emissions impact of different policies. This is particularly evident in the case of agricultural production and emission-intensive chemical industries, which are closely linked to the primary sector (including fertilisers and pesticides production). These industries are impacted by abatement policies through international supply chains. Trade gains for selected African regions participating into the climate club with the EU are significant, given that the European market represents a large quota of African exports. The region benefiting the most from inclusion in the EU climate club is AFWest with an in increase in the export share both on the EU market and on the rest of the world for all primary goods. Similar results are found for the AFCentr region, where export activities are improved especially in the rice and raw meat sectors.

Additionally, by sustaining technology transfer and the diffusion of best practices in agricultural production in less developed regions, the inclusion into a climate club could be complemented by ad hoc support instruments to ensure the carbon neutrality pathway is also compatible with a more inclusive and equitable development transition, resulting in a typical win-win solution with environmental gains followed by well-being improvements. The implementation of additional sustainable practices in agricultural production, with related investments in input productivity complementing achievements in energy efficiency and use of renewable sources might further increase domestic production and reduce food prices, simultaneously enhancing food security and improving the living conditions of households.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101000751 'MATS- Making Agricultural Trade Sustainable'. This paper and related research have been conducted during and with the support of the Italian national inter-university PhD course in Sustainable Development and Climate change.

DATA AVAILABILITY STATEMENT

Data used for building baseline and policy scenarios, and scripts for replication are fully available upon request from the authors.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Bassi, A. M., Calciolari, F., Costantini, V., D'Angeli, M., & Paglialunga, E. (2024). Carbon border adjustments or climate clubs: Impacts on African agricultural sectors under different cooperative scenarios. *The World Economy*, *00*, 1–34. https://doi.org/10.1111/twec.13643