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Making the EU Carbon Border Adjustment Mechanism acceptable and climate friendly for least developed countries

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A B S T R A C T

Implementation of CBAM to support EU climate neutrality by 2050 has raised several concerns. As the mechanism aims to minimise leakage through equal fairness in global mitigation, imposing carbon tariffs on the EU's imports of energy-intensive goods could curtail the export of EU trading partners. This might be detrimental, especially to the LDCs, due to their high exposures and vulnerability risks. This paper assesses and quantifies the implication of EU-CBAM and analyses eight complementary measures to mitigate the impacts on LDCs. Scenario developments are constructed by projecting the EU's new climate targets relative to the reference scenario of the EU's current policies. A more stringent climate target results in carbon leakage, and implementing CBAM will reduce the rate by one-third by 2040. The analysis also confirms significant welfare loss for LDCs through declining exports. Exempting LDCs from EU CBAM is less justifiable, as this measure results in greater leakage than other options. A further assessment confirms that policy recommendation for CBAM complementary measures should focus on the climate transformation pathway for LDCs. EU CBAM implementation with revenue-redistribution targeted to promote clean and efficient use of energy in LDCs has improved the welfare of recipient countries, substantially reduced leakage, and proven cost-efficient for the EU.

1. Introduction

As part of the new policy initiative of the European Green Deal, the European Union (EU) Commission has initiated the Carbon Border Adjustment Mechanism (CBAM) to reduce the risk of carbon leakage and to ensure competitive prices in the European market (European Commission, 2019). CBAM is proposed, amongst various policy measures, to support a newly defined emissions reduction target of 55% from 1990's level by 2030 and reach carbon neutrality by 2050. Achieving this new climate ambition needs a substantial and rapid reduction in the current emissions quota, and CBAM supports the transition to stop free allowances under the EU-ETS (Munro, 2018).

CBAM is a trade policy instrument that is increasingly being considered to create an equal level of playing field through carbon-based import tariffs on certain goods to the EU. Without the synchronous implementation of a CBAM, the EU would experience substantial carbon leakage and export declines (Marcu et al., 2020; Vögele et al., 2020). Despite the significance and the magnitude of the reported results not always being in agreement, most studies that focus on the EU confirm that CBAM reduces leakage (Elliott et al., 2010; Böhringer et al., 2012a; Bednar-Friedl et al., 2012). A recent study by the United Nations Conference on Trade and Development (2021) suggests that the CBAM can be an effective instrument to substantially reduce carbon leakage. A 44 US$ per tonne carbon tax cut leakage by more than half, from 13.3 to 5.2%.

Implementation of CBAM is not simple, as its complexity relates to the compatibility with World Trade Organisation (WTO) rules and EU Free Trade Agreement. This mechanism needs to be transparent and impartial without disguised restrictions and constitutions on international trade (European Commission, 2021c). From the legal perspective, the EU's CBAM can only be applied to sectors that are also subject to an internal EU carbon price in order to be compatible with the EU's WTO commitments (Cendra, 2006; Evans et al., 2021). At the initial stage, the domestic carbon price will likely be determined by the purchasing permit cost of domestic producers in the EU ETS (Lowe, 2021). This constraint limits the CBAM's scope to sectors currently covered by the EU Emissions Trading System (ETS), mostly the energy-intensive industries (EIIs). The latest EU legislative proposal targets the power sector and EII sectors, such as cement, steel, aluminium, and fertilisers, to be included in this mechanism (European Commission, 2021b).

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The CBAM is also controversial because it represents the external projection of a country or region's climate policies (Lehne and Sartor, 2020). The introduction of the EU CBAM will come with a high cost, especially for countries with a substantial share of export to the EU. Implementation of EU CBAM will reduce their export, and without any effective mitigation and environmental sustainability objectives into their national development strategies, the economic impacts maybe substantial (Mealy and Teytelboym, 2020; Ameli et al., 2021). Böhringer et al. (2018) argue that carbon tariffs theoretically shift the economic burden of developed-world climate policies to the developing world. Many of the EU's trading partners exporting carbon-intensive goods, especially developing countries, have raised concerns that the EU CBAM would substantially curtail their exports and competitiveness.

Yet developing countries hold a smaller share of the EU's imports of energy intensive goods. Furthermore, products covered by the CBAM proposal represent a relatively limited share of EU imports. The total export value of CBAM products to EU27 was 53 billion EUR in 2019, or 3% of total imports (Simola et al., 2021). More than half are of steels (65%) followed by aluminium (23%) and fertilisers (8%). The electricity share is only 4%, while that of cement is substantially insignificant (0%). Despite a relatively small share, in theory, an EU CBAM could negatively impact poorer countries and reduce opportunities for export-led development.

This paper aims to analyse the impact of different policy options of EU CBAM to Least Developing Countries (LDCs). It addresses the exemption and revenue allocation options of the EU CBAM and the implications on climate and economic indicators. The analysis is based on the development of eight different CBAM scenarios with exemptions and revenue redistributions on targeted countries/regions. Unlike previous studies of alternative designs of CBAM and studies investigating the impact of CBAM to EU trading partners, our analyses are based on multi-sectoral calibration, a dynamic global scope model in which the baseline or reference scenario is constructed based on the EU's current policies. EU Fit 55 target and climate neutrality in 2050 are then integrated into the climate policy scenario with the introduction of CBAM as a policy instrument to mitigate leakage. The magnitudes in leakage change, sectoral competitiveness, and welfare are quantified, then compared to a pure CBAM implementation. This approach enables us to provide a comprehensive analysis of this newly adopted policy instrument that contributes to the concrete adoption scheme, the transition and political acceptability of the EU CBAM.

The following Section 2 explores previous literature addressing the implications of EU CBAM, followed by an investigation of the potential risks of some developing countries based on their export exposures. This becomes the basis for countries' being a specific target for exemptions or revenue redistributions. Section 3 fits the modelling approach and baseline construction. Section 4 elaborates on scenario developments of CBAM exemptions, revenue redistribution and scrutinises numerical analysis of the results. It is then followed by conclusion and policy implications in Section 5.

2. CBAM on impacted countries: current literature, countries exposure and vulnerability risk

2.1. Literature review

In general, studies investigating CBAM (Babiker and Rutherford, 2005; Mattoo et al., 2009; Böhringer et al., 2010; Winchester et al., 2011), including to EU as a unilateral region (Elliott et al., 2010; Böhringer et al., 2012b; Bednar-Friedl et al., 2012) focus on the implication of leakage and competitiveness issue due to changes in production output. Previous studies on the alternative design of CBAM offer general analysis, from WTO compatibilities of determining optimal tariff (Balistreri et al., 2019) and credit mechanism (Trachtman, 2017) to general design of carbon tariff that covers commodities and countries to imposed (Monjon and Quirion, 2011; Kortum and Weisbach, 2017). While the design needs to consider an additional assessment of the implication for the affected countries (Eicke et al., 2021), this assessment is underrepresented (Magacho et al., 2022).

A recent study by Eicke et al. (2021) assess that relative risks from the EU CBAM vary among exporting countries, and suggests that future EU CBAM design should be equipped with complementary policies based on countries' exposure to export to the EU and the ability for countries to adapt, such as shifting trade flows, decarbonising or verifying carbon. Despite this study approaching CBAM through a broad socio-economic framework, it only emphasises the importance and the capacity of the affected countries on report and verification, instead of focusing on supplementary measures.

Addressing CBAM supplementary measures is critical as it is an injustice to expect poorer countries to shoulder the same burden as developed countries in mitigation by common, but differentiated, responsibilities (Davidson Ladly, 2012). Further, Lim et al. (2021) contend the detrimental effect of CBAM could trigger potential retaliation from other economies. And to be politically acceptable, the implementation of the EU CBAM should include the option of exemptions (Brandi, 2021; Zhong and Pei, 2022) or redistribution of revenue generated to address climate justice concerns and support countries in the decarbonisation process (Hillman, 2013; Pirlot, 2021).

While myriad studies focus on CBAM, particular analyses on exemptions or complementary policies with revenue reallocations are limited. Among these few, Böhringer et al. (2017) underline that CBAM may have different effects depending on the use of the revenue, and a lump sum exacerbates the impacts by lowering the domestic output than a unilateral tax without border tariff. This study touches on this issue of revenue reallocation by integrating the concept of revenue return directly into the analysis, but it does not directly address and compare complementary scenario designs.

Magacho et al. (2022) also evaluate CBAM on EU trading partners for developing countries using Input–Output analysis, yet emphasise more on the consequences, not to ease those consequences. Complementing Eicke et al. (2021), this study also reveal the uneven distribution of CBAM impacts and point out countries' export exposure as determinant factors for the high vulnerability of developing economies such as East European and African countries.

Although they currently account for a minimal share of EU-external trade in the CBAM commodities, developing economies, especially LDCs, have high exposures and vulnerability risks (European Commission, 2021c). Exports to the EU are the primary sources of their foreign income and represent a significant share of their Gross National Income (GNI). Many countries in the global south and African continent are potentially exposed.

Following this lack of empirical study, this paper fills the gap of EU CBAM impact on affected countries through a comprehensive analysis of CBAM complementary scenarios, focuses on different policy impacts on LDCs. The concepts of countries exposure and vulnerability are elemental, as it substantiates the importance of developing complementary measures for the EU CBAM. Subsequent subsection elaborates these concepts.

2.2. Countries exposure, vulnerability and the importance of complementary scenario

The European Commission released the first legislative proposals of CBAM on 14 July 2021, as part of the fit for 55 legislative packages (European Commission, 2021b). A concrete CBAM adoption scheme has not been defined, but is likely to follow the previously adopted resolution called 'a WTO compatible EU CBAM' that specifically links CBAM to the EU ETS.[3] The introduction of the EU CBAM emphasises fairness in global mitigation, where the EU's stringent commitment should not

[3] Resolution adopted 10 March 2021.

lead to carbon leakage that results in no global benefits of reduced carbon emissions, simply because of production reallocation.

Linking to the ETS means all products under the ETS must be included. Sectors already considered in the current proposal include the power sector and the EII sectors of cement, steel, aluminium and fertiliser. While the EU import share of the power sector is relatively insignificant,[4] particular attention needs to focus on the EIIs. The analysis follows the EIA definition of EII (Bassi et al., 2009), in which these industries are considered to be energy-intensive: pulp and paper, basic chemicals, refining, iron and steel, nonferrous metals (primarily aluminium), and nonmetallic minerals (primarily cement). EIIs represent 15% of industrial EU CO_2 emissions, and are often classified as one of the most difficult for full decarbonisation, thus continue to receive a substantial free allocation in the EU ETS market (European Commission, 2021c). CBAM intends to stop free permit allowances, which will lead to stringent carbon tariffs levied on EII imports.

While the EU's imports of EII are still dominated by developed countries where the US has the largest share of EU's imports by 21%, followed by Switzerland and China (both importing around 15%).[5] Only 35.1% of the EU import share derives from developing countries, whereas the import share from India is relatively significant (around 3% of EU total imports). Yet despite being only one-third, up to 16 billion US$ of developing country exports to the EU could face an additional charge to the new CBAM levy, assuming an EU CBAM initially only covers goods covered by its ETS.

The implication of CBAM is not conditional upon the developing countries' smaller share of the EU EII imports, but more on country exposures and vulnerability risks (Figs. 1 and 2). A particular concern is that some lower to middle-income, mainly African and Asian trade partners, will face the highest carbon tariffs, which will slow incentives for decarbonising. Here we follow Eicke et al. (2021) definition of countries' exposure and vulnerability. Countries' exposure is total EII export relative to overall export to the EU. It indicates the significance of trade with the EU for the national economy. Vulnerability risk reflects the diversification of exports and is estimated through the share of EIIs exported to the EU on the overall country's export worldwide.

There have been calls to support a smooth transition to help countries to adapt to the effects of the EU's climate change mitigation policies. One of the calls is for the exemption of CBAM for countries with specific conditions of a unilateral agreement with the EU (Cosbey et al., 2019; Brandi, 2021). For example, exports from 23 lower-middle-income countries are covered by the EU's Generalised System of Preferences (GSP and GSP+) schemes.[6] They benefit from conditional (and partial) preferential access to the EU, and they should be exempt from the CBAM up to a pre-determined threshold. Giving them trade benefit, and taking it back with CBAM would be politically un-acceptable.

There is also a call for an exemption on exports from the 46 least developed countries are covered by the EU's 'Everything But Arms' scheme (Brandi, 2021; Leal-Arcas, 2022). These countries enjoy duty and quota-free access to the EU market, and should be fully exempt from the EU's CBAM. Countries under these unilateral schemes also face high exposure to the EU CBAM. There are five countries that are highly exposed, whose share of EIIs export relative to total goods export to the EU is greater than 20%. Mozambique is at the top, with more than 56%, followed by Zambia (47%), Tajikistan (28%), Armenia (24%) and Kyrgyzstan (21%). Aluminium is the dominant share of their CBAM products, followed by steel. These highly exposured countries, also face high vulnerability risk. Mozambique is the most vulnerable; its share of EII export to the EU reached 15.35% compared to the total export worldwide.

Excluding LDCs from the CBAM should not prove to be a controversial proposal amongst the EU member-states. It is also consistent with the EU trade policy and development objectives. Cosbey et al. (2019) contend that exemptions help CBAM to align with the United Nations Framework Convention on Climate Change (UNFCCC principle) of common, but differentiated, responsibilities and the WTO principle of special and differential treatment. Also, CO_2 imported from developing countries accounts for a small proportion of the CO_2 embodied in the final EU demand. Imported CO_2 from India, for example, accounts for just over 1% (Lowe, 2021). Even for Mozambique, the country with the highest exposure and risk, has a CO_2 contribution on final demand less than 1%.

In addition to exemptions, a potential aim of the EU CBAM could include utilising some of the revenue generated. Since many countries are concerned about the potential creation of trade distortions and the need for special treatment, revenue redistribution to LDC can be a potential win-win solution, instead of working towards the EU's own budgetary objectives. Falcao (2020) assesses that CBAM detracts developing countries' right to benefit from the revenues derived from applying the domestic carbon tax. Therefore, the policy options should be directed towards revenue redistribution to impacted countries. These options could be, yet are not limited to, full or partial tax policy coordination or a fund to accelerate the diffusion and uptake of cleaner production technologies in developing countries. These countries will likely need support to incorporate green technologies in their production processes and reduce related CO_2 emissions (World Trade Organization, 2021). It could be in the CBAM's targeted sectors or other official development assistance (ODA) projects involving climate protection, disaster relief or others to improve development in a just and fair manner.

The revenue redistribution proposals are relevant for CBAM to remain a useful tool rather than a liability. These will be key to not losing sight of the wider policy package. Though several studies reveal that the EU CBAM potentially cause systemic implications, it is significant on most trade flow (Monjon and Quirion, 2011; Böhringer et al., 2016) with minor effects on emissions level (United Nations Conference on Trade and Development, 2021). In the later report, UNCTAD point out that doubling EU carbon prices from 44 US$ to 88 US$ results in higher global emissions reduction from 13 to 21%. The introduction of CBAM only adds 0.8 to 1.3 percentage points, indicating that a positive effect on reducing CO_2 emissions will come mainly as a result of domestic carbon pricing.

The EU proposal suggested 1.5 to 3.1 billion EUR potential additional revenue by implementing CBAM, depending on the price of the EU allowance (European Commission, 2021b). This additional revenue could be used as the country's 'own resources' to repay higher borrowing in response to the crisis (European Commission, 2021b), or an incentive for industrial stakeholders to make the necessary capital investments for decarbonisation. Lehne and Sartor (2020) argue that the latter option will be not sufficient to put EIIs on track towards climate neutrality without additional stringent policies. With all countries now focusing on fighting and easing detrimental impact made by the pandemic, putting CBAM revenue towards the crisis or using it as an 'incentive' for climate action risks will be seen as 'overly' punitive (Mörsdorf, 2021). Others suggest that revenues should be earmarked for international climate funds or disbursed to third countries to clearly position CBAM as a non-protectionist measure and garner support among international partners (Cosbey et al., 2019).

[4] EU imported 22,432 million US$ of electricity, or only 0.37% of the EU total import in 2019. Authors' estimation from Centre d'Etudes Prospectives et d'Informations Internationales (2021). For the same year, the EU net electricity trade was only 24 TWh. It imported 394 TWh, exported 370 TWh, and produced 3,231 TWh of electricity (International Energy Agency, 2022).

[5] Authors' estimation from GTAP 10 Database.

[6] The GSP and GSP+ fully or partially remove tariffs on two-thirds of tariff lines; These trade benefits are given to economically vulnerable countries if they implement 27 international conventions relating to the environment, human rights, labour rights and good governance. Countries under these schemes are indicated by an asterisk (*) in Figs. 1 and 2 (Refer to https://trade.ec.europa.eu/access-to-markets/en/content/unilateral-arrangements)

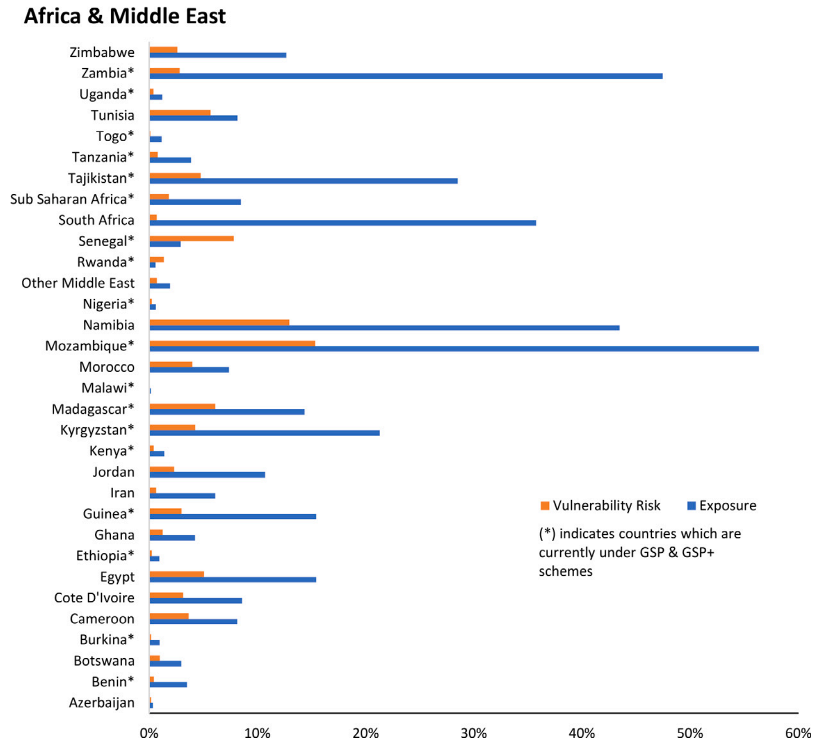

Fig. 1. Developing countries EII sectors exposure and vulnerability risks of EU CBAM - Africa & Middle East (Source: Authors' estimation as described in the text).

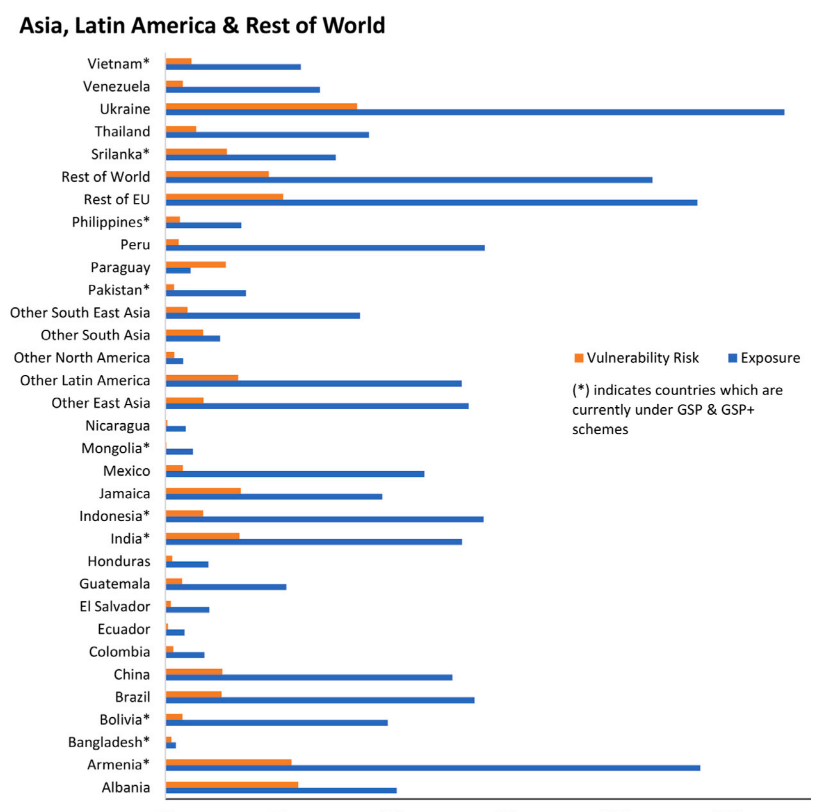

Fig. 2. Developing countries EII sectors exposure and vulnerability risks of EU CBAM — Asia, Latin America & Europe (Source: Authors' estimation as described in the text).

3. The GEMINI-E3 model and the current policies scenario

For simulations and analytical purposes, this study uses the latest modification of GEMINI-E3 based on the study by Bernard and Vielle (2008). The model's multi-sectoral calibration and dynamic global scope encompass international trade and emissions, and adequately address the impacts of production allocation, international trade and emissions of Greenhouses Gases (GHGs). GEMINI-E3 is multi-country, multi-sector, recursive dynamic computable general equilibrium model with backward looking (adaptive) expectations and total flexibility in both macroeconomic and microeconomic markets. Flexibility such as capital and international trade markets, with endogenously driven associated prices being the real rate of interest and the real exchange rate. The micro scale is represented with sectoral markets of goods, factors of production, etc. The current version is built on the GTAP 10 data base (Aguiar et al., 2019) with the year 2014 as reference, where countries are aggregated into eleven regions. Sectors are limited to eleven for a tractable and acceptable computation time. Critical features of GEMINI including its GHG emissions, and methods of welfare assessments, are detailed in Appendix. In all the scenarios performed in this paper, we assume that the government's deficit or surplus is fixed. When a CBAM is implemented, the revenue collected will be redistributed to households as lump sum transfer.

The impacts of a climate policies scenario of an EU CBAM are measured relative to a reference scenario based on the current policies per regions. This current policies scenario includes a subset of the high impact policies collected and analysed for the period 2015 to 2030. The scenario design follows the CD-Links policies database, documented in McCollum et al. (2018) and Roelfsema et al. (2020), along with the International Energy Agency (2020) to ensure a more updated complementary climate-development policy until the year 2030. The assumptions on demography, GDP, energy prices and technology costs follow our previous work on the H2020 Paris-Reinforce project, detailed in Giarola et al. (2021) and Sognnaes et al. (2021). For robustness, the scenario will be projected until 2040 to fit the undefined climate policies post-2030 and the feasibility of policy implementation due to technological and sectoral granularity in the model. The EU climate target in 2030 follows the Climate and Energy Framework of a -43% emissions decrease with respect to 2005 for ETS and the -30% for non-ETS emissions. These two carbon prices are then assumed to grow in line with GDP per capita rates until 2040. In the EU ETS market, we assume that all the permit allowances are auctioned, and there are no more free allowances. This assumption is also used in the climate policy scenarios described in the following sections.

4. Scenario development and analytical results

4.1. European climate policy without CBAM

Further, the scenario design now integrates the "Fit for 55" package and incorporates carbon neutral targets in 2050–2060 by adjusting the abatement target in precedent years. This EU new stringent policy results in a higher EU ETS price, from approximately 80 € per ton of CO_2 in 2040 (European Commission, 2021a) to 132 US$ in 2040 (Table 1). The CO_2 price applied in the EU ESR sectors reach 3,312 US$, showing the stringency of the emissions reduction in these sectors, especially in the transportation and in non-CO_2 GHG emissions.

The Fit for 55 package negatively impacts the European GDP, which is estimated to fall by 3.6% by 2040 (Table 2). The impacts on other countries in terms of GDP changes are rather limited. The European EII production falls by 13.8% by 2040. Other regions experience a production increase in EII goods, especially those that have a strong specialisation in these products, such as Russia and the Middle East. Production in India and China remain unchanged, with only a slight tendency to decrease by around −0.2% and −0.1%, respectively.

Compared to the impact assessment done by the European Commission (European Commission, 2021b) with the JRC GEM-E3 model, our prediction is closer to scenario "MIX with full auctioning for ETS" with 4% output losses and 9.9% EII imports increase by 2030. With GEMINI-E3, output decreases by 5.5% and import increases by 13.9% by 2030. For the same year, Mörsdorf (2021) predicts that output will reduced by 5.8% in the metal industry, 3.3% in the minerals sector and by 2.6% in the chemical sector. Comparable to GEMINI-E3 this study uses a multi-sectoral, multi-regional CGE model of the GTAP-E model as documented in McDougall and Golub (2007).

Table 1
European Carbon Prices US$$_{2014}$.

	2025	2030	2040
EU ETS price	48	75	132
EU ESD price	146	764	3,312

The leakage is significant and equal to 17% for CO_2 and 12.1% for all GHG emissions. This rate is statistically comparable with Branger and Quirion (2014) of 14% (5% to 25% leakage range) and a recent study by Mörsdorf (2021) of 22.2%. This leakage rate is higher, compared to an earlier study by Burniaux et al. (2013) of 8%, but still relevant following the assumption from this study resulted if the EU only cut their emissions by 30% in 2030 relative to 2005 levels.

For India and China, a fall in international fossil energy prices would reduce CO_2 emissions even further. As EU consumption of coal is relatively modest, the impact is stronger for gas and oil energy markets. This fall in international gas prices triggers substitution from domestic coal to gas in electricity generation in China and India, leading to a decline in their emissions. In regards to welfare change, the EU would be detrimentally impacted due to the imposed GHG taxation. Energy-exporting countries such as Russia, the Middle East, Africa and the Rest of the World (ROW) would experience revenue loss from energy exports.

4.2. European climate policy with CBAM

Following the existing EU regulation (European Commission, 2021c), CBAM is applied to EIIs (Sector 07 in GEMINI-E3 classification see the sectoral classification Appendix A)and electricity generation, based on the CO_2 content that includes only direct emissions. The exact formula used is given in Appendix B and Eq. (B.1).

Introducing CBAM would decrease the CO_2 leakage by approximately one-third, from 17% to 12.6%. And as shown in Table 3, and the decrease of European EII production is only reduced by 15% (from −13.8% to −11.6%). Reduction in leakage after the introduction of CBAM is within the range stated by Mörsdorf (2021) of 22.2% to 14.8%. The carbon tariffs shift the economic burden on non-European countries and especially on to the developing world. Region of Africa, India, Russia and ROW are negatively impacted by the implementation of CBAM. Declines in the production of energy intensive goods lead to a welfare loss. It is interesting to note that the US and China are slightly affected by the introduction of CBAM. The European welfare gain from CBAM is estimated at 47 billions US$.

The production loss of EII in 2030 reduced slightly from 5.5% to 4.7%. For comparison, the JRC GEM-E3 EU's prediction in 'MIX-full auctioning option 3' projects production loss shifted from 4.4% to 1.2% (European Commission, 2021a) for the same year. The JRC GEM-E3 model uses a CO_2 content that also includes indirect emissions. Using the same method, our model results in a more significant increase in production. The EII output loss is reduced to 3.8% with CBAM.

4.3. Limiting the burden of CBAM on the least developed countries

This section develops scenarios as complementary measures to the CBAM that can alleviate or limit the impact on LDCs, based on literature as elaborated in previous section (Brandi, 2021; Eicke et al., 2021; Lehne and Sartor, 2020). Here the definitions of LDCs are recognised under the UNDP Human Development Index (HDI), as being below 0.8 in 2020 (Majerová, 2012). This classification includes India and countries in our aggregated regions of Africa, the rest of Asia, and Central and South America. Aggregated Regions in the model constrain the preciseness of our simulation. CBAM effects tend to be underestimated, since non-LDCs countries such as Argentina and Costa Rica are

Table 2
Main results from EU climate policy scenario (changes w.r.t current policies scenario) - year 2040.

	Welfare change in % of household consumption	GDP change in %	EII production change in %	CO_2 emissions[a] change in Mt CO_2	GHG emissions[b] change in Mt CO_2-eq
EUR	−4.5%	−3.6%	−13.8%	−1,564	−1,849
USA	−0.4%	0.1%	2.5%	62	56
CHI	−0.8%	−0.1%	−0.1%	−21	−24
BRA	−0.9%	0.0%	1.7%	3	−2
RUS	−2.4%	0.7%	15.6%	75	64
MID	−1.6%	0.5%	6.4%	68	67
ROW	−1.5%	0.1%	4.0%	40	34
IND	−0.5%	−0.1%	−0.2%	−45	−48
CSA	−0.8%	0.0%	2.5%	24	29
ASI	−0.6%	0.0%	0.2%	18	20
AFR	−1.3%	0.0%	1.5%	43	29
LDCs	−0.8%	0.0%	0.6%	40	30
non-(EUR & LDCs)	−0.9%	0.1%	1.3%	226	195
World	−1.4%	−0.6%	−0.4%	−1,298	−1,625

[a] CO_2 emissions refer to CO_2 from energy, industrial processes and product use.
[b] Without LULUCF.

Table 3
Main results from EU climate policy scenario with CBAM (changes w.r.t current policies scenario) - year 2040.

	Welfare change in % of household consumption	GDP change in %	EII production change in %	CO_2 emissions[a] change in Mt CO_2	GHG emissions[b] change in Mt CO_2-eq
EUR	−4.2%	−3.5%	−11.6%	−1,564	−1,849
USA	−0.3%	0.1%	2.4%	64	58
CHI	−0.8%	−0.1%	−0.2%	−27	−30
BRA	−0.9%	0.0%	1.7%	3	−2
RUS	−2.7%	0.6%	14.6%	67	55
MID	−1.8%	0.5%	5.9%	62	60
ROW	−1.7%	0.1%	4.1%	36	30
IND	−0.9%	−0.2%	−1.1%	−87	−93
CSA	−0.8%	0.0%	2.5%	24	29
ASI	−0.7%	0.0%	0.0%	19	22
AFR	−1.6%	−0.1%	1.0%	36	20
LDCs	−0.9%	−0.1%	0.2%	−8	−22
non-(EUR & LDCs)	−0.9%	0.1%	1.2%	205	170
World	−1.5%	−0.6%	−0.4%	−1,366	−1,701

[a] CO_2 emissions refer to CO_2 from energy, industrial processes and product use.
[b] Without LULUCF.

included in Central/South America. This aggregation remains a limit of this current paper, and disaggregation is certainly a matter for future work. Simulation results of these scenarios are reported in Table 4. Results are in absolute change compared to the EU Climate Policy with the CBAM scenario.

4.3.1. *CBAM exemption*

The first scenario option is to exempt LDCs from CBAM. An exemption is possible in light of the "Common but Differentiated Responsibilities" principle of the UNFCCC and the WTO's Enabling Clause, which both allow for the special and differential treatment of developing countries (Brandi, 2021; Lowe, 2021). If the exemption fully offsets the cost of the CBAM for LDCs, it can create a significant advantage over non-EU countries that would result in welfare improvement. EII production in LDCs increased by 54 billion US$ with respect to the scenario with CBAM, while the EU's EII production decreased by 53 billion US$ (from 96 billion to 43 billion US$) by introducing an exemption. The impact on leakage is critical as the leakage rate is equal to 15.6%, which is higher than the 12.6% in the EU with the CBAM scenario. This scenario increases emissions by 47 million tonnes than when no exemption is implemented. While an exemption would limit the burden on the LDCs, it has a significant negative impact on the environment. Positive leakage works against this exemption scenario.

4.3.2. *Rebating revenue from the CBAM through lump-sum transfer*

Several studies propose using the revenue collected from CBAM as financial aid to LDCs (Pirlot, 2021; Keane et al., 2021). The aim is to retain CBAM's price incentive to limit CO_2 leakage and the competitiveness loss of European firms, while still limiting the welfare burden on poor countries. The following scenarios assume that EU redistributes the revenue through a lump sum rule with no-conditioning, to hold a sovereignty principle of third countries. From an economic and modelling point of view, this money transfer is represented as "current international cooperation" between governments. CBAM revenue is transferred to LDCs, goes into a government's budget, and is then distributed to households through lump sum transfer. The government saving is unchanged, and the international money transfer is also integrated into the current account like any unilateral transfer (which includes foreign aid). This transfer will therefore impact the exchange rates that clear this account. The money transfer from the EU to LDCs plays the same role as European imports from LDCs. It creates new income for LDCs, which improves the trade balance and reevaluates the relative exchange rate of LDCs currencies and adds the opposite effect of the Euro (€).

The first scenario under this scheme assumes all the revenue collected from the CBAM (including that perceived from non LDCs) is redistributed to our four developing regions on a per capita basis. Thus regions with a greater population get a higher share. The model predicts 29 billion US$ of CBAM revenue could be redistributed, or two-thirds of the estimated EU contribution towards the 100 billion US$ financial aid pledge made at Copenhagen (Timperey, 2021; Bos and Thwaites, 2021). The financial transfer improves welfare in these four regions by 36 billion US$. The EU's welfare then decreases by 40 billion

Table 4
Climate policies with support measure for LDCs (changes w.r.t to scenario with CBAM) - year 2040.

	Exemption	Per capita rule	You get what you contribute	Increase saving	Subsidy capital 07	Subsidy capital 08	Subsidy electricity renewable	Financing electric appliance
EII production change in billions US$								
EUR	−53.1	21.4	9.5	8.9	3.5	10.6	8.5	8.2
USA	1.1	1.4	0.7	0.6	−2.8	1.2	0.2	0.1
CHI	−0.8	1.4	0.7	0.0	−7.6	2.0	−0.9	−1.4
BRA	−0.5	0.0	0.0	0.0	−0.8	0.1	−0.1	−0.1
RUS	−3.2	−0.3	−0.2	−0.2	−1.2	−0.2	0.1	0.4
MID	−1.3	0.4	0.2	0.0	−5.3	0.3	0.4	0.8
ROW	−6.1	−0.2	0.0	−0.1	−2.8	0.2	0.6	1.1
IND	25.4	−8.9	−4.9	−2.5	2.8	−6.3	−4.2	−0.5
CSA	1.4	−1.7	−0.5	−0.2	2.9	−0.8	−0.3	0.3
ASI	13.7	−4.6	−1.2	−0.3	3.9	−2.0	−1.1	0.6
AFR	13.8	−7.1	−3.6	−1.8	9.3	−5.0	−1.5	−0.3
LDCs	54.2	−22.3	−10.2	−4.7	19.0	−14.1	−7.0	0.2
non-(EUR & LDCs)	−10.7	2.7	1.5	0.3	−20.4	3.7	0.3	0.8
World	−9.6	1.8	0.9	4.5	2.1	0.2	1.8	9.2
CO_2 Leakage in Mt								
USA	−1.1	−0.2	−0.1	−0.1	−1.1	−0.1	0.5	0.8
CHI	−2.3	0.6	0.3	0.0	−3.9	0.8	1.4	2.0
BRA	−0.2	0.0	0.0	0.0	−0.3	0.0	0.1	0.2
RUS	−3.6	−0.2	−0.1	−0.1	−1.3	−0.1	1.0	1.6
MID	−1.5	0.3	0.2	0.0	−3.3	0.2	2.4	2.7
ROW	−3.1	−0.1	0.0	−0.1	−1.3	0.1	1.5	2.2
IND	46.0	−5.0	−2.8	0.8	4.0	−5.1	−37.8	−46.0
CSA	1.0	−0.1	0.0	0.2	1.0	−0.3	−3.8	−5.9
ASI	2.3	0.4	0.2	0.7	0.8	−0.4	−12.8	−21.1
AFR	9.5	−1.9	−0.9	0.6	5.5	−2.2	−31.5	−17.3
LDCs	58.7	−6.6	−3.6	2.4	11.2	−8.0	−85.8	−90.3
non-(EUR & LDCs)	−11.7	0.3	0.3	−0.3	−11.1	0.9	7.0	9.4
World	47.1	−6.3	−3.4	2.0	0.1	−7.1	−78.9	−80.9
Leakage in %	−15.6%	−12.2%	−12.4%	−12.8%	−12.6%	−12.2%	−7.6%	−7.5%
Welfare change in billions US$								
EUR	−26.6	−39.8	−17.7	−17.5	−19.0	−17.7	−17.7	−17.3
USA	−5.2	−1.4	−0.6	−0.9	−2.6	−0.4	−1.0	−1.0
CHI	−0.6	0.5	0.2	0.2	−1.8	0.5	−0.1	0.3
BRA	0.1	0.1	0.1	0.1	−0.1	0.1	0.1	0.1
RUS	1.0	0.4	0.2	0.2	0.3	0.2	0.0	−0.1
MID	3.2	0.7	0.3	0.3	0.9	0.5	0.4	0.3
ROW	0.1	1.0	0.4	0.3	−0.4	0.7	−0.4	−0.8
IND	18.5	11.4	6.2	5.9	8.1	5.7	6.1	17.1
CSA	1.8	3.8	1.1	1.5	2.2	1.0	1.4	3.4
ASI	4.4	10.1	3.2	3.0	4.3	2.8	4.7	9.4
AFR	8.9	11.5	5.8	6.0	7.8	5.6	5.9	5.6
LDCs	33.6	36.7	16.3	16.4	22.4	15.0	18.2	35.6
non-(EUR & LDCs)	−1.4	1.4	0.6	0.2	−3.7	1.6	−1.1	−1.2
World	5.6	−1.7	−0.7	−0.9	−0.3	−1.1	−0.6	17.0

US$ due to the lower fiscal revenue. Leakage is 6 million tonnes lower than the only CBAM scenario. Production of LDCs' EII goods falls, most likely caused by re-evaluation of exchange rates after revenue transfers that induce a loss of competitiveness for their domestic firms.

The second option in the lump-sum scheme is to limit the transfer based on their export contributions. This scenario is called *what you get is what you contribute*. This scheme is likely more realistic, as it aligns with the proposal of "most revenues generated by CBAM will go towards the EU budget" (European Commission, 2021c). Therefore, the amount of transfer is now limited to 13 billion US$. As in the previous scenario, we assume that this revenue is redistributed to LDCs through a lump sum rule. Based on this same distribution model, yet with a smaller transfer fund, this scenario results in more moderate effects compared to the per-capita rule. Leakage is slightly reduced and European EII production increases by 10 billion US$. The following scenarios of increasing saving to LDCs, financing clean investment in production, promoting renewable electricity, and promoting efficiency measures in residential energy consumption, adopt this scheme for the share coefficient in allocating CBAM revenue.

4.3.3. *Increasing saving in developing countries*

It is often claimed that one significant issue in developing countries lies in limited investment (Demirgüc-Kunt, 2006). For this reason, the next scenario assumes that financial transfer increases domestic saving and induces additional investment without targeting any sector, technology or economic agent. Investment increases by 0.13% with respect to the scenario with CBAM, yet the results are not significantly different to the scenario *what you get is what you contribute*. The GDP very slightly increases (+0.03%) due to this additional investment, which induces an increase of CO_2 emissions by 2 million tonnes with respect to the scenario with CBAM.

4.3.4. *Financing clean investment in production*

Next, in CBAM, revenue returned scenarios are designed to facilitate the adoption of clean technology in certain targeted sectors. The first scenario aims to increase investment in the EII and limit the loss of competitiveness of recipient regions. The scenario is designed by simulating financial aids that reduce capital cost in the EIIs. This will stimulate additional investment and substitution of energy by more capital goods.[7] Our simulation results reveal that targeting subsidies fosters clean technology of EIIs. It makes LDCs better off, as they now gain from trade for more competitive EII products. A gain in competitiveness triggers the production reallocation outside the EU and increases leakage. Once revenue is used to subsidise non-EII (Subsidy Capital 08 in Table 4) for diversifying the industry of LDCs, impacts will be slightly different. It will decrease LDC production of EII goods, increase production of other goods, and reduce the leakage rate. However, results show no significant deviation from the scenario *what you get is what you contribute*.

4.3.5. Promoting renewable electricity

Following the objectives on global adaptation funds, the next scenario uses CBAM funds to promote climate-friendly transformations in developing countries (Brandi, 2021). The revenue will be used to subsidise electricity renewables (i.e. solar and wind) in LDCs. Impacts on welfare and EII production are almost the same magnitude as in *what you get is what you contribute*, but this scenario results in a very positive effect on leakage reduction. The global emissions are reduced by 79 Mt CO_2, with the leakage rate reduced by 7.6%. The increase of renewable electricity reduces CO_2 emissions from coal and gas power plants. The electricity from solar and photovoltaic increases by 168 TWh by 2040, and from wind by 107 TWh. Significant increases in renewable electricity happen mostly in India (+121 TWh) and Africa (+107 TWh).

4.3.6. Promoting efficiency measures in residential energy consumption

The last scenario assumes that the revenue will be assigned to LDCs' households to reduce fuel poverty. Under this scheme, households could buy efficient appliances and reduce their electricity bills. To simulate this, we use technological cost assumptions of TIAM Model (Loulou and Labriet, 2008) for electric appliances (such as refrigerators, dishwashers, washing machines, etc.), their purchasing costs and efficiency levels. The efficiency gain is calculated, followed by an investment cost estimation to transition the standard appliance to the most efficient one. Using Africa as a reference (as the costs are quite close among LDCs), the cost of a 1% efficiency improvement ranges from 1$ to 4$ per appliance.

As an illustrative example, we use a conservative value of 1% efficiency improvement costs of 3 US$ and consider the aid will be used to replace standard refrigerators with efficient ones. Revenue returned from EU CBAM is used to cover purchasing cost differences of 100 US$ per 300 liter refrigerator. The new refrigerator decreases electricity consumption by one-third. Assuming that the annual average electricity consumption of a refrigerator is equal to 400 KWh (Cardoso et al., 2010; Gürel et al., 2020), 100 US$ aid per refrigerator allows reducing electricity consumption annually by 133 KWh. The number of households that can benefit from this aid and the electricity saving is calculated based on the CBAM revenue collected. Table 5 provides the estimation by 2040.

By 2040, this scenario would benefit up to 107 million homes and save 26 TWh of electricity (around −0.8% of electricity consumed by households). This has strong implications on the welfare of LDCs by generating an increase of 36 billion US$, and by reducing their CO_2 emissions by 90 million tonnes. The cumulative impacts of replacing equipment between 2020 to 2040 results in efficiency of the final energy. The leakage rate is reduced to 4.9% and electricity used in LDCs decreases by 209 TWh in 2040.

[7] Standard nested production function (capital, labour, energy and material are nested at the top of the production function) in GEMINI E-3 means that subsidising capital will decrease energy consumption as well as labour and other materials. This model feature constrains the impact precisions, and tends to underestimate the gain of investing in clean-energy technology. This is clearly a matter for future work. Splitting capital into two: energy system capital and other capital, and nesting the energy system capital within energy could be a better approach to improve precision, as proposed by Zimmermann et al. (2021).

Fig. 3 summarises our findings, along with other complementary measurement scenarios on four key parameters: the cost for European countries, the welfare improvement for LDCs, the leakage and the production loss of European EIIs. Our results are comparable with those performed using the GTAP-E model (Mörsdorf, 2021) and the JRC GEM-E3 model (European Commission, 2021b).

4.4. Caveats and future research avenues

Most of the quantitative studies dealing with carbon leakage are dominated by CGE models (Mattoo et al., 2009; Antimiani et al., 2013; Fouré et al., 2016; Böhringer et al., 2017, 2021) as the design is well suited to perform international trade analysis (Branger and Quirion, 2014). In particular, some common assumptions in CGE related to constant return to scale, full employment, and technological change (Carbone and Rivers, 2017) tend to be less flexible and affect the predictive precision of our results. These assumptions deserve more attention in future works.

In addition to this model's common assumptions, a number of caveats should be raised from the analytical result of this paper. First, the sectoral classification used by the GEMINI-E3 model does not encompass exactly the sectors covered by the EU proposal. Similar to the limitation with aggregated regional classification that has been addressed in the scenario development section. A more appropriate industrial classification would require isolating the four sectors that are subject to CBAM, while regional disaggregation improves the representation of LDCs. This is certainly an important issue in future works.

Second, a critical dimension of a CGE model relates to elasticities. The Armington hypothesis (Armington, 1969) is commonly used for trade, assuming that goods from different regions are imperfect substitutes. For this, our analysis uses a high elasticity value for energy-intensive goods, as the goods are quite homogeneous across countries. A sensitivity analysis for this parameter used in GEMINI-E3, has been performed by Bernard and Vielle (2009). A more systematic analysis in the context of the current EU proposal should be a concern for future research.

5. Conclusion and policy implications

This paper assesses the implications of the new Fit for 55 package proposed by the European Commission in July 2021 and the decision to introduce the CBAM for energy-intensive products. We analyse the implications of this new economic instrument on European trading partners, in particular on LDCs. Our simulations prove that EU CBAM reduces leakage by one-third, from 17% to 12.6% by 2040. Yet, its implementation is detrimental to LDCs causing declines in EIIs, thus leading to significant welfare loss. Following this finding, we evaluate eight complementary measures to the EU CBAM that can alleviate or limit the impact on LDCs. These complementary measures include exempting and redistributing revenue to LDCs, either as a lump-sump transfer, as investment, or as a subsidy to promote clean energy.

Exemptions improve LDCs' welfare, yet the environmental implications and EU costs are too significant. This scheme results in higher leakage compared to other complementary scenarios. The other seven complementary measures with revenue redistribution scenarios also improve LDCs' welfare, however implications on leakage reduction vary. Redistributing revenue as a capital investment will potentially increase CO_2 compared with if no such policies are taken. Assigning the investment (as a capital subsidy) to EII sectors increases LDCs, comparative advantage, further triggering production reallocation with a higher potential of emission leakage. In contrast, specialising the redistribution to promote clean energy or improve energy efficiency substantially reduces leakage with relatively the same costs for the EU. Promoting efficiency measures in residential energy consumption significantly

Table 5
Gains in household electricity consumption from EU Financial Aid - year 2040.

	India	Central & South America	Rest of Asia	Africa
Financial aid by region in millions US$[a]	4,100	700	2,100	3,800
Number of refrigerators replaced in millions	41	7	21	38
Electricity consumption saving in TWh	11	2	6	10
Electricity consumption by household in TWh[a]	1,009	475	1,472	803
Decrease of electricity consumption in %	−1.1%	−0.4%	−0.4%	−1.3%

[a]Estimated by GEMINI-E3 model.

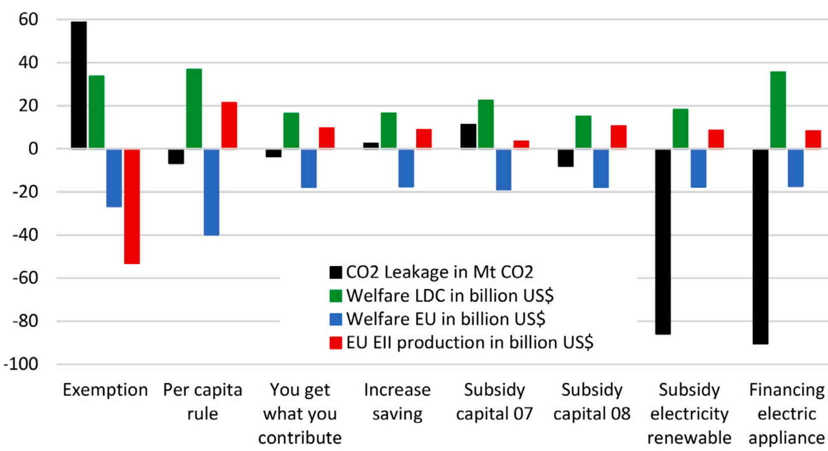

Fig. 3. Impacts of different redistributive measures on key figures by 2040 (changes w.r.t to EU fit 55 with CBAM).

improves LDCs' welfare with an equal rate of leakage reduction as the complimentary scenario promoting renewable electricity.

The complexity of confronting and adapting to climate change is a shared and global responsibility, and complementary measures alongside EU-CBAM implementation is a practical approach to realise these goals. Our analysis shows that CBAM will have a detrimental impact on LDCs, confirming recent concerns of some developing countries for the EU unilateral CBAM to be discriminatory and resonance against equity and common but differentiated principle, especially for LDCs (South African Government, 2021). Accompanying measures become an absolute need for the EU CBAM's political acceptability, stressing LDCs and Small Island Developing States for the potential negative impacts on their development.

Yet, contradicting several reviews, the complementary exemption measure for LDCs under GSP and GSP+ schemes (Lowe, 2021) is difficult to be implemented. Easing welfare cost of LDCs should not be traded-off with significant environmental implications resulting in higher carbon leakage, which is against the core principle of implementing CBAM. Other supports measures must therefore be considered.

European Parliament's support to use the CBAM revenue for climate actions in developing countries, particularly LDCs, should be directed towards a climate-friendly transformation pathway (European Parliament, 2021). In order to keep the price incentive of the CBAM, complementary measures should be directed to policies to promote energy efficiency improvement or renewable energy sources in developing countries, specifically in sectors that the CBAM faces. These measures can mitigate CO_2 emissions domestically and reduce the leakage rate. The cost is affordable for European countries and welfare improving for developing countries.

A concrete action of this revenue use should start from the current collaborative dimension between the EU and trading partners. The most pragmatic way is through the existing climate finance channel. This climate financing should be provided, preferably as grants or concession rates, which can also be integrated with ODA, to avoid saddling emerging countries with unsustainable debt.

The potential mechanism is the climate funds under European Green Deal (EGD). EGD seems to be the most feasible channel, for it is in line with EU parliament standing positions to use the possible revenue raised from CBAM to support the aim of the Green Deal (European Parliament, 2021).

In the first proposal, EGB is intended for domestic strategy inside the EU, such as integrated CBAM in Multiannual Financial Framework for debt payment (Titievskaia and Dobreva, 2022) or distributed across member states (European Parliament, 2020). However, there is currently no specific outline of spending plan. While some initiatives already consider projects outside Europe, CBAM revenue used for development programs could be extended further than the current Western Balkans, Eastern Partnerships, Southern Neighbourhood, and African Strategy, to include now LDC in Asia and Central South America regions. Notably, the amount of climate funds to developing countries from the European Commission and the EU's lending arm, the European Investment Bank (EIB), remained stagnant since 2018 and un-evenly distributed, focusing on wealthier, middle-income countries rather than low-income economies (Usman et al., 2021). Thus, the complementary proposal of CBAM revenue could be the right policy to redirect climate funds under EGD, focusing on LDCs and keeping the flagship initiatives on energy transition in line with their own stated development priorities.

However, there should be a conditional pre-requisite following the results of our methodological analysis. These funds must be dedicated to a specific policy of mitigation strategies to assist the LDCs in transforming their industries towards carbon neutrality. Priority should be given, but not limited to CBAM affected sectors. These specific funds designation will optimise CBAM revenue use and minimise its implementation challenges due to LDCs' political instabilities, complex social issues, and non-prioritisation of green economies, hindering these measures from hitting their targets. With the current strategies for Western Balkans, for example, the fund could support the transition from coal to more sustainable and green sources of energy production will be fundamental for the region to meet its commitments under the Paris Agreement (Sartor et al., 2022).

CRediT authorship contribution statement

Sigit Perdana: Conception and design of study, Acquisition of data and the analysis, Writing – original draft, Writing – review & editing. **Marc Vielle:** Conception and design of study, Acquisition of data and the analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.enpol.2022.113245.Sigit Perdana reports financial support was provided by Horizon 2020. Marc Vielle reports financial support was provided by Horizon 2020.

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Appendix A. Key features of the model - GEMINI-E3

This section describes the key features of the GEMINI-E3 model, more information be found on the web-page of the H2020 Paris-Reinforce project. See https://paris-reinforce.eu/i2am-paris/models.

Sectoral disaggregation distinguishes sectors participating in the ETS market from others, such as petroleum products, electricity generation, and energy-intensive industries. Energy-intensive industries comprise of the iron and steel industries, the chemical industry, the non-ferrous metals industry, the non-metallic mineral products, and the paper and paper products. Three other energy goods are described by the model: coal, crude oil, and natural gas. The remaining five sectors consist of agriculture, land transport, sea transport, air transport, and other goods and services that aggregates all other sectors. For each sector, the model computes the demand of its production based on household consumption, government consumption, exports, investment and intermediate uses. Total demand is then divided between domestic production and imports using the Armington assumption (Armington, 1969), which assumes that domestic and imported goods are not perfectly homogeneous.

Production technologies are described by a nested Constant Elasticity of Substitution (CES) functions. Simulations use endogenous carbon prices for CBAM tariffs, not a stylised unilateral carbon price, to tackle the possibility of endogenously decreasing supply elasticities and sharply increasing marginal leakage rates for large coalitions as indicated by Boeters and Bollen (2012). This technique avoids an overestimation of industrial output loss and underestimation of the increase in the CO_2 embodied in imports that affect the accuracy of efficiency of border carbon adjustments at reducing leakage (Caron, 2012).

Household behaviour consists of three interdependent decisions; (1) labour supply, (2) savings, and (3) consumption of the various goods and services. Labour supply and the rate of savings are exogenously driven, while the demand on different commodities employs prices of consumption and income (more precisely "spent" income, income after savings) as arguments, and is derived from a nested CES utility function. The government collects taxes and distributes the resulting revenues to households and firms through transfers and subsidies. Wage is chosen as a numeraire in each region.

Table A.6
Regional classification.

USA	United States of America	United States of America
EUR	European Union (28)	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom
CHI	China	China, Hong Kong
IND	India	India
BRA	Brazil	Brazil
RUS	Russia	Russia
CSA	Central and South America countries	Mexico, Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean, Rest of North America, Rest of South America, Rest of Central America
ASI	Other Asian countries	Japan, South Korea, Mongolia, Taiwan, Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Bangladesh, Nepal, Pakistan, Sri Lanka, Rest of East Asia, Rest of South Asia
MID	Middle East	Bahrain, Iran, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of Western Asia
AFR	Africa	Egypt, Morocco, Tunisia, Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Central Africa, South Central Africa, Ghana, Guinea, Nigeria, Senegal, Togo, Central Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Botswana, Namibia, South Africa, Rest of Western Africa, Rest of South African Customs
ROW	Rest of the World	Australia, New Zealand, Canada, Switzerland, Norway, Albania, Belarus, Ukraine, Kazakhstan, Kyrgyzstan, Tajikistan, Armenia, Azerbaijan, Georgia, Israel, Rest of Oceania, Rest of Former Soviet Union, Rest of the World

Table A.7
Sectoral classification.

Sector Id	Sector
1	Coal
2	Crude oil
3	Natural gas
4	Refined petroleum products
5	Electricity
6	Agriculture
7	Energy intensive industries
8	Other goods and services
9	Land sector
10	Sea transport
11	Air transport

Regional and sectoral classifications

Tables A.6 and A.7 provide the regional and sectoral classifications of the version of the GEMINI-E3 model used in this paper.

Table C.8
Main results from EU climate policy scenario with CBAM Scope 2 (changes w.r.t current policies scenario) - year 2040.

	Welfare change in % of household	GDP change in %	EII production change in %	CO_2 emissions[a] change in Mt CO_2	GHG emissions[b] change in Mt CO_2-eq
EUR	−4.0%	−3.5%	−9.7%	−1,563	−1,849
USA	−0.3%	0.1%	2.3%	66	59
CHI	−0.9%	−0.1%	−0.3%	−37	−41
BRA	−0.9%	0.1%	1.8%	3	−2
RUS	−3.1%	0.4%	11.9%	50	36
MID	−2.0%	0.5%	5.9%	62	60
ROW	−1.9%	0.1%	3.9%	34	27
IND	−1.0%	−0.3%	−1.4%	−100	−108
CSA	−0.9%	0.0%	2.5%	24	29
ASI	−0.7%	0.0%	−0.1%	18	21
AFR	−1.7%	−0.2%	0.5%	29	12
LDCs	−1.0%	−0.1%	−0.1%	−28	−45
non-(EUR & LDCs)	−1.0%	0.1%	1.0%	178	138
World	−1.5%	−0.6%	−0.4%	−1,413	−1,756

[a] CO_2 emissions refer to CO_2 from energy, industrial processes and product use.
[b] Without LULUCF.

Table C.9
Main results from EU climate policy scenario with CBAM Scope 3 (changes w.r.t current policies scenario) - Year 2040.

	Welfare change in % of household consumption	GDP change in %	EII production change in %	CO_2 emissions[a] change in Mt CO_2	GHG emissions[b] change in Mt CO_2-eq
EUR	−3.9%	−3.4%	−8.7%	−1,563	−1,849
USA	−0.3%	0.1%	2.2%	65	58
CHI	−1.0%	−0.2%	−0.5%	−50	−56
BRA	−1.0%	0.0%	1.7%	3	−2
RUS	−3.0%	0.5%	13.5%	60	47
MID	−2.0%	0.5%	5.8%	61	59
ROW	−2.0%	0.1%	3.9%	33	26
IND	−1.1%	−0.3%	−1.6%	−107	− 115
CSA	−0.9%	0.0%	2.4%	24	29
ASI	−0.7%	0.0%	−0.4%	12	14
AFR	−1.7%	−0.2%	0.4%	28	11
LDCs	−1.0%	−0.1%	−0.3%	−43	−61
non-(EUR & LDCs)	−1.0%	0.1%	0.9%	171	131
World	−1.5%	−0.6%	−0.4%	−1,435	−1,779

[a] CO_2 emissions refer to CO_2 from energy, industrial processes and product use.
[b] Without LULUCF.

Green House Gases (GHG) emissions covered

GHG emissions in GEMINI E-3 are calibrated from the most up-to-date policy databases that cover country to the sectoral level of disaggregation. Historical inventories for CO_2 and methane, are based on the Community Emissions Data System (CEDS) detailed in Hoesly et al. (2018). Nitrous oxide is aligned with the PRIMAP Dataset (Gütschow et al., 2019), and F gases are calibrated from the U.S. Environmental Protection Agency (United States Environmental Protection Agency, 2019). The non-CO_2 gases come from diverse sources such as agriculture, industries, transport, etc., and where emissions and mitigation options must be represented at the bottom-up level. These non-CO_2 gases represent 19% of EU28 GHG emissions in 2016 (United Nations Framework Convention on Climate Change, 2018). The agriculture sector contributes the most (52%), followed by the waste and wastewater sector (18%) and the energy sector (15%) (Höglund-Isaksson et al., 2012). Non-CO_2 GHG emissions included in the EU-ETS are nitrous oxide emissions from adipic and nitric acid production, and perfluorocarbons emissions from the aluminium industry. In constructing both reference and climate scenario, abatement for non-CO_2 gases are calculated based on the marginal abatement cost.

Assessing welfare cost

Welfare cost are measured through compensating variation of income (CVI) to capture the change in structure of prices, which is the main effects of climate change policies. The cost consists of the domestic component or deadweight loss of taxation (DWL) and the imported component or gains from terms of trade (GTT). The GTT represents spill-over effects due to changes in international prices, mainly from the drop in fossil energy prices that results from the decrease of world energy demand. Decomposition of the welfare cost aims to approximate decomposition between domestic and imported costs to obtain a general idea of their relative importance (Harrison et al., 2000; Böhringer and Rutherford, 2002). This approach is justified by the fact that the change in prices, in particular the prices of foreign trade, is fairly small. In practice, compensative variation income is first calculated from the results of the model, and the specification and coefficients of the demand function. GTT is then calculated based on the results of the involved scenario using the following equation:

$$GTT = \sum_i \Delta Pexp_i \cdot Export_i - \sum_i \Delta Pimp_i \cdot Import_i \tag{A.1}$$

where $\Delta Pexp_i$ and $\Delta Pimp_i$ represent changes in the exports and imports prices (for product i), with respect to the reference scenario; and $Export_i$ and $Import_i$ represent the levels of exports and imports, respectively, in the reference scenario. Finally, the DWL is the difference between the compensative variation income and the GTT.

Appendix B. Methodology for calculating emissions contents for CBAM

Computing the CO_2 content based on scope 1 is straightforward, it includes only the CO_2 emissions emitted by fossil energy combustion by the respective sector. The CO_2 content α_r^i for the sector i and region r, is equal to the following equation:

$$\alpha_r^i = \frac{\sum_j \beta_r^j \cdot IOV_r^{j,i}}{XD_r^i} \tag{B.1}$$

Where $IOV_r^{j,i}$ represents the intermediate consumption by sector i in fossil energy j (i.e. coal, petroleum product, natural gas) in region r, β_r^j the CO_2 emissions factor of fossil energy consumption j and XD_r^i the production level of sector i in region r.

Scope 2 includes, not only direct emissions from fuel combustion, but also the CO_2 content of electricity consumed by sector i, which can be produced domestically or imported. This CO_2 content, called δ_r^i, is therefore equal to the following equation:

$$\delta_r^i = \frac{\sum_j \beta_r^j \cdot IOV_r^{j,i} + IOV_r^{elec,i} \cdot \frac{\delta_r^{elec} \cdot XD_r^{elec} + \sum_{r' \neq r} \delta_{r'}^{elec} \cdot IMP_{r'}^{elec}}{YD_r^{elec}}}{XD_r^i} \tag{B.2}$$

In addition, if a country imports electricity produced from another country that is implementing a CO_2 tax, the CO_2 emissions of this import must not be taken into account (i.e. $\delta_{r'}^{elec} = 0$ if r' implements a CO_2 tax).

Scope 3 also considers the CO_2 content of non-energy intermediate consumption. Therefore, this CO_2 content called μ_r^i is computed by Eq. (B.3):

$$\mu_r^i = \frac{\sum_j \beta_r^j \cdot IOV_r^{j,i} + \sum_l IOV_r^{l,i} \cdot \frac{\mu_r^l \cdot XD_r^l + \sum_{r' \neq r} \mu_{r'}^l \cdot IMP_{r'}^l}{YD_r^l}}{XD_r^i} \tag{B.3}$$

If CBAM is only implemented as a border charge on imports, then it is assumed that the CO_2 content of goods exported by a country that is implementing a CO_2 tax are not considered and $\mu_{r'}^l$ is equal to zero, if r' implements a CO_2 tax.

Appendix C. Additional scenarios

European climate policy with CBAM and scope 2

The Table C.8 shows the scenario as detailed in Section 4.2 but takes into account scope 2 (direct and indirect emissions from electricity generation, see Eq. (B.2)) for the definition of the CO_2 content. This scenario is consistent with that performed using JRC GEM-E3 model titled "MIX-full auctioning option 3" (European Commission, 2021b).

European climate policy with CBAM and scope 3

Table C.9 shows the scenario outcomes as detailed in Section 4.2 but takes into account direct emissions and any indirect production-related emissions including all the intermediate CO_2 consumption by sector (called scope 3), see Eq. (B.3) for the definition of the CO_2 content.

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