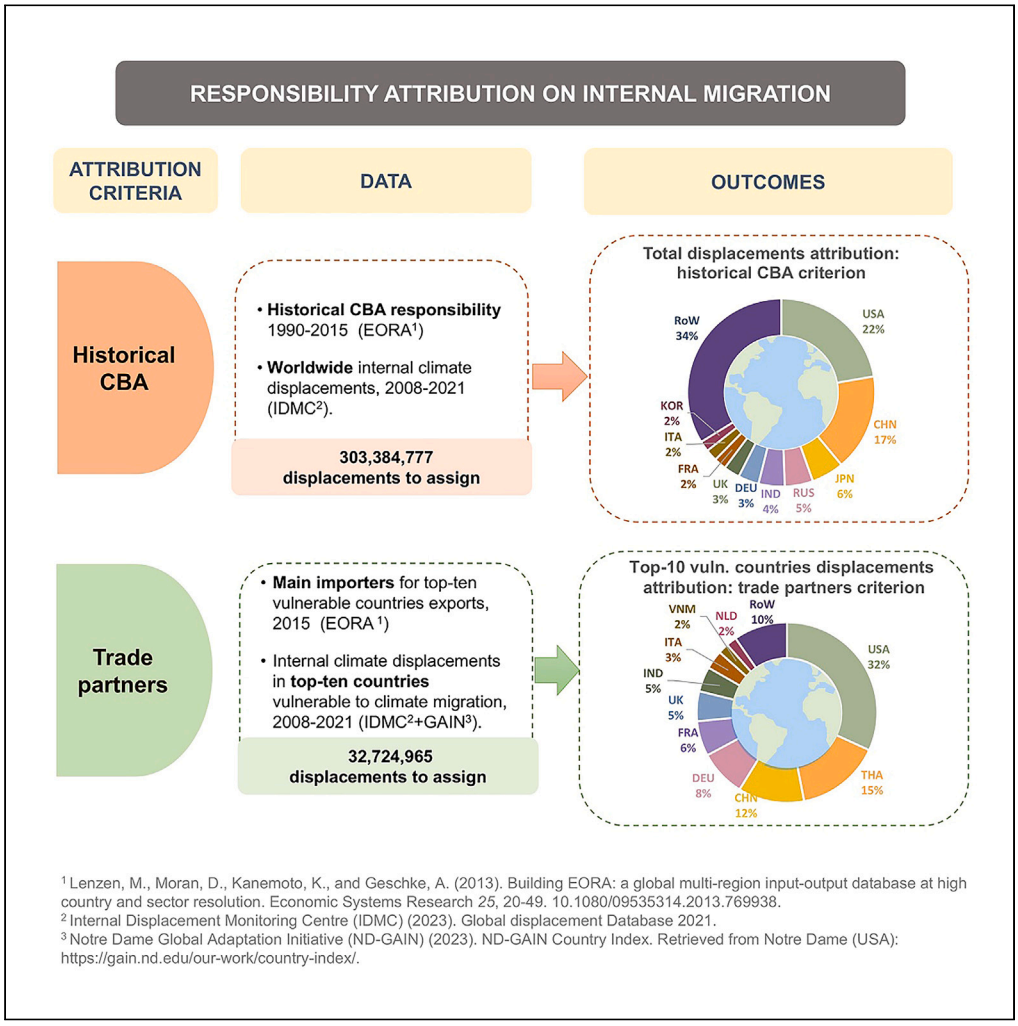
iScience

CellPress
OPEN ACCESS

Article

# Attributing climate-change-related disaster displacement responsibilities along global production chains




[1] Lenzen, M., Moran, D., Kanemoto, K., and Geschke, A. (2013). Building EORA: a global multi-region input-output database at high country and sector resolution. Economic Systems Research *25*, 20-49. 10.1080/09535314.2013.769938.
[2] Internal Displacement Monitoring Centre (IDMC) (2023). Global displacement Database 2021.
[3] Notre Dame Global Adaptation Initiative (ND-GAIN) (2023). ND-GAIN Country Index. Retrieved from Notre Dame (USA): https://gain.nd.edu/our-work/country-index/.

Guadalupe Arce, Ángela García-Alaminos, Mateo Ortiz, Jorge Zafrilla

angela.garcia@uclm.es

## Highlights

The most vulnerable countries to climate migration are mainly in Africa and Asia

Globalization has contributed to the increase in the Global South's vulnerability

Four countries are responsible for 50% of historical consumption-based emissions

Major economies should contribute 0.2%–0.5% of their GDP to a solidarity fund

Arce et al., iScience *27*, 111124
November 15, 2024 
https://doi.org/10.1016/j.isci.2024.111124

iScience

CellPress
OPEN ACCESS

Article

# Attributing climate-change-related disaster displacement responsibilities along global production chains

Guadalupe Arce,[1] Ángela García-Alaminos,[2,4,*] Mateo Ortiz,[3] and Jorge Zafrilla[2]

## SUMMARY

**Climate change creates hostile living conditions in various regions, provoking climate-driven migration. The literature points to a polarization between the countries responsible for climate change and the regions suffering its consequences. Given this dichotomy, this study analyses the link between unsustainable consumption by world powers and the increasing vulnerability of some developing countries. We identify the most vulnerable countries to climate migrations and perform a responsibility assessment on environmental migration through historical consumption-based contributions to climate change. The main results show that the areas most vulnerable to climate migration are low-income countries from Asia and Africa, whereas the US, China, Japan, and Russia are the major economies responsible for climate change driving those migrations. According to our estimations, top responsible countries should contribute 0.2%–0.5% of their GDP to a global financial fund for climate migrants. This work supports the principle of climate justice regarding worldwide current challenges.**

## INTRODUCTION

The current climate emergency is generating relevant losses in economic performance, human health, biodiversity, and food security, among other aspects,[1] where climate migration stands out as one of climate change's crudest silent consequences.[2,3] The recent debate proposed at the 28th UN Climate Change Conference (COP28) recognizes that displacement and migration driven by disasters and the collapse of livelihoods are some of the main consequences of climate change.[4] This forced decision to move is not an exclusive phenomenon of the Global South; however, the most vulnerable countries present more significant limitations in tackling current and future challenges.

Global South countries are more exposed to the risk of adverse events caused by climate change and present greater vulnerability and less adaptive capacity.[5,6] For many people in these contexts, migrating means surviving; hence, managing these migratory crises must involve climate justice and respecting and guaranteeing human rights. Despite the difficulty quantifying climate-induced migration, recent literature suggests that climate-induced internal migration affected 24 million people worldwide in 2016.[7] That figure reached 29 million in 2020 and 22 million in 2021 (the latest year with available estimates).[8] In addition, World Bank projections indicate that climate-induced internal displacement will reach 216 million people worldwide by 2050[9] and estimate that sub-Saharan Africa and South Asia (the most affected regions) will accumulate 110 million climate-induced internal migrants by 2050.[10]

Climate migration will increase in the coming years[11] and will be a crucial adaptation strategy for people in many countries.[12,13] The displacements linked to environmental hazards are primarily internal or to low- and middle-income countries.[9,14] Therefore, planning the migratory processes that guarantee migrants' freedom to move to areas of low risk and better opportunities becomes essential. The provision of financial support behind this planning is crucial. There is a general agreement on the necessity of establishing a loss and damage fund, as recently shown with more than $700 million at COP28[15]; however, current funds seem insufficient given the high losses of most vulnerable countries in the last two decades.[16] Global North commitments must be reviewed in the context of the open debate on assigning historical emissions responsibilities.[17] Consumerist lifestyles, consolidated in the North and rising in the South, have led to unsustainable increases in global $CO_2$ emissions, increasing the frequency and intensity of extreme weather events. This fact has been confirmed by NASA[18] and supported by the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report.[19]

Thus, there is an indirect link between high levels of consumption and climate migrations, which has not been assessed in previous literature and is the gap addressed in this paper. Such a link has the following transmission pathways: consumption decisions trigger production along GVCs and generate vast amounts of $CO_2$ emissions across countries and industries to satisfy affluent lifestyles.[20–23] These emissions are

[1]Higher Technical School of Agronomy and Forestry Engineering and Biotechnology, University of Castilla-La Mancha, Albacete, Spain
[2]Faculty of Economics and Business, University of Castilla-La Mancha, Albacete, Spain
[3]Faculty of Social Sciences and Law, University of Castilla-La Mancha, Toledo, Spain
[4]Lead contact
*Correspondence: angela.garcia@uclm.es
https://doi.org/10.1016/j.isci.2024.111124

the main cause of climate change and intensify its effects (including natural disasters),[18,19] and finally, those effects end up displacing families and communities for climatic reasons.[7,14,24–26]

Moreover, globalization has contributed to the growth of emissions by relocating production processes to developing countries,[27] which has facilitated the maintenance of affluent lifestyles at low cost while ignoring the worldwide spread of environmental impacts. Therefore, in the search for the main parties responsible for the historical generation of $CO_2$ emissions, we must focus on an analysis of the cumulative carbon footprint calculated from the consumer perspective. First, countries must be responsible for the emissions they generate through consumption throughout the global production chain.[28] Second, regarding productive specialization in developing countries, such an analysis should link the increase in climate vulnerabilities in developing countries with the growing integration of sectors at risk of extreme weather events along global production chains. In this study, we seek to determine the connection between international trade structures and the exposure to negative climate change consequences at the country level. Once this linkage is analyzed, we propose a fair method for attributing responsibility regarding climate migration.

The historical contribution of the Global South to climate breakdown is minimal compared to that of the Global North, which reaches 92%.[17] Hickel[17] proposes an equity-based attribution approach, which considers the principles of equal human rights, common but differentiated responsibility, and the ability of each country to reduce emissions. Other authors, such as Ahmed,[29] also believe that countries that have historically contributed significantly to cumulative $CO_2$ emissions should be responsible for protecting and assisting climate migrants, creating the category of climate refugees and supporting a juridical-legal framework at the international level that guarantees their rights.

Global North countries must be involved in managing climate migrations occurring in more vulnerable countries because of their role in the worldwide spread of global value chains. Developed countries have outsourced part of their production to countries with lower wages and weaker environmental and labor regulations.[30–32] These production phases tend to have lower embodied value added, leaving the stages that generate more wealth within developed countries.[33] Studies such as those of Peters and Hertwich[28] show that the increase in global emissions is explained mainly by the rise in imports from developed countries to developing countries, helping developed economies meet their emission reduction targets in some cases while preserving or increasing their consumption levels. Hickel et al.[34] show that the growth of advanced economies has been based on the net appropriation of resources (raw materials, land, energy) and labor from developing countries. Integration in global value chains can increase countries' vulnerability to shocks in global markets, as demonstrated during the 2008–2009 global financial crisis and, more recently, during the COVID-19 pandemic.[35] The current structure of international trade has played a significant role in perpetuating and exacerbating climate colonialism.[36] In the words of Martinez,[37] climate colonialism forces a re-embodiment and relocation of how, why, and who is responsible.

In this context, we analyze how the trade specialization and the integration in global value chains of countries most affected by internal migration have placed them in a more vulnerable situation, identifying the influence of developed regions on the vulnerability of economies in the Global South. Our approach focuses on internal migration because most migrants moving due to climate causes relocate within their own countries.[14,38] In addition, the most comprehensive database on displacement associated with sudden-onset natural-hazard-related disasters (the *Global Internal Displacement Database* [GIDD][8]) quantifies only internal movements. Consequently, we focus on internal migration as it is the best available measure to quantify the extent to which a country is affected by climate migration. To develop our proposal, first, we combine information on internal migrations provided by the GIDD[8] and the *Global Adaptation Initiative Index (ND-GAIN)* to identify countries where the most significant internal migration flows are taking place, and we elaborate a ranking based on their ND-GAIN as a synthetic measure of their vulnerability from the point of view of preparation and adaptation capacity to face the challenges of climate change.[39] Second, we analyze the sectoral structure of the selected countries and their integration into global value chains to determine whether their presence in global value chains has increased their vulnerability and what role developed regions play. We use the input-output data framework from the Eora Database,[40] employment and value-added indicators from the Food and Agriculture Organization,[41] and population and total labor force data from the World Bank.[42,43]

This paper appeals to climate justice, considering the contributions of Global North countries to historical emissions from a consumer perspective. The allocation of responsibility for the climate change displacement observed in the GIDD according to the consumer perspective of cumulative emissions since the globalization boom in the early 1990s builds on the contribution of Hickel.[17] Reshaping the production structures of vulnerable sectors and countries derived from enriching global production chains allows us to assess how globalization processes have increased climate vulnerability in developing countries. Following this idea, we propose countries' reasonable contributions to a fund to mitigate the enormous economic and personal costs of forced climate migration. Institutions such as the International Monetary Fund, the World Bank, and the European Commission have taken up this idea and have prepared different proposals, for instance, for estimating adaptation investment needs or policy response.[44–46] Although, so far, this idea of funds has not been raised directly for migrants, the particular need for this issue was mentioned already at COP28.[47] Our approach considers solidarity as the backbone of these compensation schemes. We want to contribute empirically to ensure that funds are allocated and received appropriately based on the level of vulnerability and responsibility. It is necessary to support these financing measures with scientific data so that it stops being considered as charity but rather as a right.

## RESULTS

This work is based on the identification of the top vulnerable countries to climate migration, which are shown in Table 1 together with the variables that have led to this selection. The selection procedure is detailed in the STAR Methods section.

The analysis consists of three different phases. In the first stage, the responsibility for historical emissions is assessed using a consumption-based account perspective, revealing each country's participation in the carbon emissions released from 1990 to 2015. Second, focusing on

**Table 1. Most vulnerable countries to climate displacements**

| | GAIN data | | Internal displacements | | |
|---|---|---|---|---|---|
| Country | GAIN Index (0–100) Higher is better | GAIN Sensitivity Score (0,1) Lower is better | Internal displacements 2008–2021 | Highest yearly incidence in 2008–2021 (displacements/ thousand inhabitants) | Frequency measure (number of years in which incidence > worldwide average in 2008–2021) |
| Bangladesh | 36.881 | **0.453** | 15,521,549 | 26.540 | **4** |
| Haiti | 35.028 | **0.432** | 528,271 | 16.867 | **4** |
| Cambodia | 38.732 | **0.413** | 827,237 | 14.684 | **6** |
| Lao PDR | 40.102 | **0.410** | 244,668 | 14.143 | **4** |
| Madagascar | 35.271 | **0.448** | 1,050,919 | 11.669 | **4** |
| Myanmar | 37.605 | **0.371** | 5,974,007 | 46.173 | **6** |
| Mozambique | 37.559 | **0.487** | 1,362,709 | 16.704 | **4** |
| Niger | 32.911 | **0.584** | 1,859,100 | 30.076 | **7** |
| Sudan | 32.283 | **0.576** | 1,850,830 | 10.216 | **5** |
| Somalia | 34.151 | **0.503** | 3,505,675 | 62.720 | **7** |

| Worldwide average 2021 | Worldwide average 2021 | Worldwide displacements 08-21 | Worldwide average incidence 2008–2021[a] |
|---|---|---|---|
| 0.363 | 49.106 | 303,384,777 | 4.379 |

Details on the GAIN index and sensitivity score are provided in the data section.

Source: Authors' own elaboration based on data from Internal Displacement Monitoring Center (IDMC),[8] Notre Dame Global Adaptation Initiative (ND-GAIN)[39] and The World Bank.[48]

[a]The average incidence of internal displacements for the period 2008–2021 was obtained as the geometric mean of the yearly average incidences.

**Table 2. $GtCO_2$ global emissions evolution (1990–2015) from the consumption-based responsibility criterion by region and selected country (vulnerable countries, top 15 historical higher emitters and rest of the world classified into broad regions)**

| *Group* | *Country* | *Historical emissions 1990–2015 ($MtCO_2$)* | *Historical emissions participation (%)* | *Variation rate of emissions 1990–2015* |
|---|---|---|---|---|
| VULNERABLE COUNTRIES | Bangladesh | 1,232 | 0.16% | 476% |
| | Cambodia | 72 | 0.01% | 149% |
| | Haiti | 147 | 0.02% | 1053% |
| | Madagascar | 107 | 0.01% | 167% |
| | Mozambique | 135 | 0.02% | 458% |
| | Myanmar | 217 | 0.03% | 343% |
| | Niger | 58 | 0.01% | 423% |
| | Lao PDR | 78 | 0.01% | 1050% |
| | Somalia | 59 | 0.01% | −65% |
| | Sudan | 7 | 0.00% | 44209% |
| TOTAL VULNERABLE COUNTRIES | | **2,109** | **0.27%** | **448%** |
| TOP 15 HISTORICAL HIGHER EMMITTERS | U.S. | 176,632 | 22.24% | 24% |
| | China | 132,732 | 16.71% | 357% |
| | Japan | 44,395 | 5.59% | −9% |
| | Russia | 38,487 | 4.85% | 1479% |
| | India | 35,783 | 4.51% | 233% |
| | Germany | 28,327 | 3.57% | −20% |
| | UK | 21,980 | 2.77% | −13% |
| | France | 16,816 | 2.12% | −6% |
| | Italy | 16,178 | 2.04% | −18% |
| | South Korea | 14,471 | 1.82% | 110% |
| | Canada | 14,186 | 1.79% | 29% |
| | Brazil | 12,471 | 1.57% | 122% |
| | Mexico | 11,918 | 1.50% | 54% |
| | Spain | 10,768 | 1.36% | 17% |
| | Iran | 10,557 | 1.33% | 154% |
| TOTAL TOP 15 | | **587,701** | **74.01%** | **85%** |
| ROW BY BROAD REGIONS | Rest of Africa | 22,927 | **2.88%** | 150% |
| | Rest of Central and South America | 22,927 | **2.81%** | 84% |
| | Rest of Asia | 53,270 | **8.66%** | 216% |
| | Rest of Europe | 74,028 | **7.20%** | 13% |
| | Oceania and the Pacific | 11,334 | **1.43%** | 47% |
| | Middle East countries | 22,421 | **2.66%** | 258% |
| TOTAL ROW | | **206,226** | **25.73%** | 106% |

Source: Authors' own elaboration

the most vulnerable countries, we analyze their trade characteristics, quantify their primary sectors' relevance, and evaluate their integration into global value chains. Finally, we propose several criteria to assign responsibilities for climate migration flows and propose a monetary contribution to a hypothetical solidarity fund for climate vulnerability.

## Evolution of the consumer perspective on emissions responsibility

There is an inequality issue behind the historical share of emissions under the consumption-based responsibility criterion by region (Table 2). The 10 vulnerable countries suffering the most significant population displacements because of climate change are responsible for only 0.27% of those historical emissions. However, the top 15 historical emitting countries account for 74.01% of emissions. The remaining 25.73% is

attributed to the rest of the countries. On the top 15 list, we find some of the most developed countries that have led the globalization process. The global spread of production phases seeking comparative advantages in developing countries' economies is behind this high share of emissions from the consumer perspective. The emissions-intensive Global South that has become the world's factory in the last 30 years led to the increase in global emissions.[49] The outstanding economic growth observed in some of these economies over these years, followed by domestic development and exceptionally emissions-intensive production structures, explains these results. The responsibility for the negative consequences of climate change must be concentrated in a short list of countries.[17]

The patterns observed since the beginning of the data series differ depending on the country of analysis. The world's average increase in global emissions is approximately 88%. However, for the vulnerable countries listed earlier, the increase observed in all the cases (except for Somalia) is much greater, with percentages such as 476% in Bangladesh or 1050% in Lao PDR. These countries' economic development and positioning within global production chains are behind these astonishing patterns. However, their final share of global responsibility remains inappreciable. The patterns observed for the top 15 countries are also interesting to highlight. Most of the developed countries present percentages of increases in emissions under the world average, such as in the case of the US (24%), or even reductions, such as in the cases of Japan (−9%), Germany (−20%), or the UK (−13%), and the developing countries present increases higher than the world average, as in the cases of China (357%), Russia (1479%) or India (233%).

These estimations allow us to allocate the responsibility for migration displacements derived from the disproportionate increase in emissions observed since the beginning of globalization, when global emissions grew much faster than ever due to anthropogenic causes. Although the most vulnerable countries are free of responsibility, few countries—mainly in the Global North and, in some cases, located far away from the vulnerable countries—account for most of the burden (the top 10 countries contributing to historical emissions account for more than 66% of them). This evidence shows an imbalanced distribution of the undesirable consequences of climate change.

## The dependency of most vulnerable countries' primary sectors

Globalization has influenced and reshaped production structures worldwide, including the production structures of the most vulnerable countries. Most of the developing countries and vulnerable economies evaluated in this paper have reshaped their production structures around the global provision of agricultural and fishing goods and services, putting them at a greater risk of suffering adverse climate effects. The globalization process has guided these countries to specialize in sectors where they provide comparative advantages to the rest of the world; the agricultural and fishing industries are good examples. However, the agricultural and fishing sectors are the most susceptible to adverse climate events.[50,51] The importance of employment in the primary sectors in the most vulnerable countries selected is noticeable. Most countries showed increasing agriculture, forestry, and fishing employment from 1990 to 2015 (Figure S1). Many people are at risk of directly suffering the negative consequences of adverse climate events.

Regarding exports, the insertion and subsequent dependency of those primary sectors along the global production chain via exports from 1990 until 2015 is evident for all countries except for Somalia and Niger (Figure S2). The shares of exports per unit of output ranged from 11%, 10%, and 30% in the agricultural sector in 1990 to 38%, 28%, and 69% in 2015 (see Table S2). Additional relevant data that reinforce this idea include the growing shares of land used for agricultural activities in all countries except Bangladesh, where in 2015, more than 80% of the land use was destined for agriculture (dots in Figure S2). The pattern observed by analyzing the percentage of employment in those primary sectors to total employment is also noteworthy (Figure S1). Although primary goods exports in those countries grew during the period, the share of employment decreased notably in the cases of Bangladesh, Cambodia, Mozambique, Myanmar, and Lao PDR. These results align with previous literature that documented that the reduction of the agricultural labor force since the 2000s in African countries is explained by two factors: technical progress within agriculture sectors and worker movements from agriculture to other sectors.[52,53] Agricultural employment exits were also found in countries from East and Southeast Asia between 1996 and 2011, especially in times of economic growth, as agricultural employment shows a countercyclical behavior.[54]

Focusing on trade patterns, total exports of agriculture and fishing fell from 1990 to 2015 in the vulnerable countries selected (Figure 1). The increase in mechanization in these sectors and the economic growth of these countries drive the results in this figure. However, the interpretation by country is very different. Countries such as Bangladesh, which developed the most economically during this period, presented a significant drop in exports and production in the agricultural sector, causing a diversion toward the manufacturing industry. Other countries, such as Lao PDR, Madagascar, and Myanmar, showed an increase in agricultural exports compared to domestic consumption.

Regarding the destination of exports, Figure 1 shows significant growth in intra-Asian trade, reaching 67.6% in 1990 and 75.1% in 2015. China was the leading importer (34.3% in 2015), followed by East Asia (32.1%) and Central and South Asia (8.7%). Outside the Asian market, the most important destination regions were the European Union (13.3%) and the US (5.4%). These figures indicate that agricultural and fishing goods production is not destined directly for developed countries. However, the clear destination pattern toward East Asia suggests that these regions are involved in intermediate production phases, and the final products are exported to the EU or the US. The complexity of global production chains could increase the vulnerability of these countries.

It is essential to highlight that for all the vulnerable economies considered, the domestic share is more significant than the exported share (the only cases in which the share of agricultural output devoted to exports is greater than 50% are Madagascar in 1995 and 2015 and Lao PDR in 2015, as shown in the Figure S2). This result indicates that these countries are self-sufficient economies and that climate-related disasters make them even more vulnerable to income loss due to the inability to cultivate and sell and potential shortages and extreme scarcity of food if they are not capable of satisfying their domestic agricultural and fishing demand.

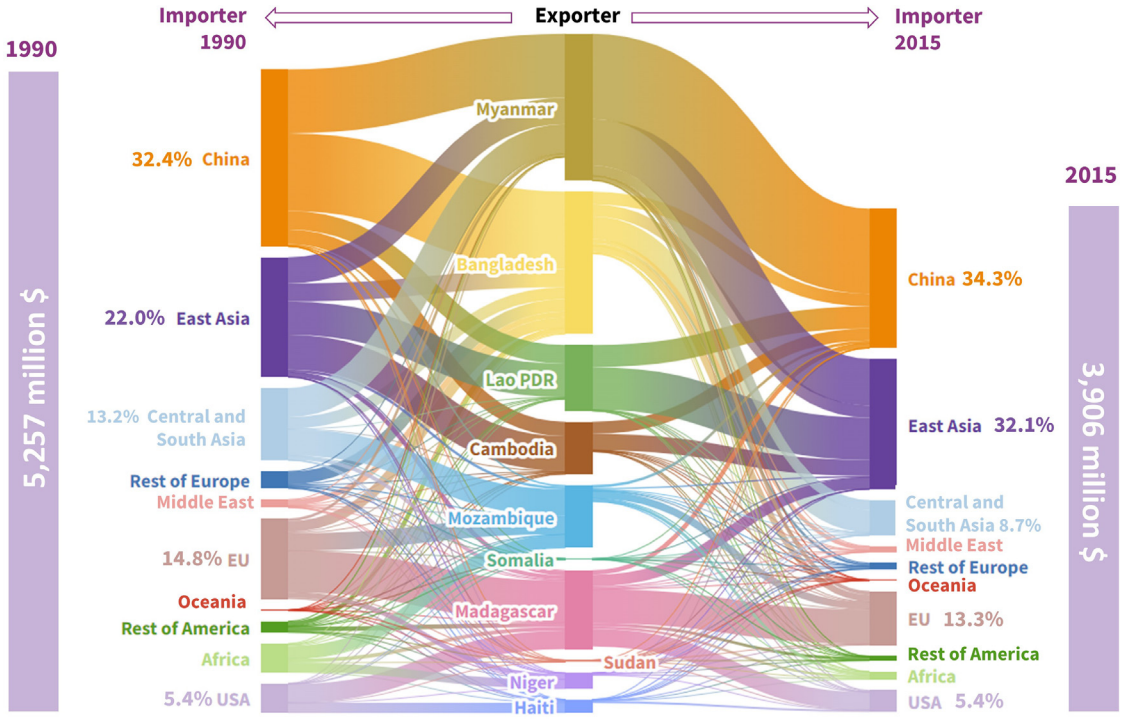



**Figure 1. Top 10 vulnerable countries' agriculture and fishing exports by country of destination. 1990 and 2015**
Source: Authors' own elaboration with data from Lenzen et al.[40]

In addition, we analyze trade specialization in the primary sector of the top 10 vulnerable countries. This assessment is implemented through the calculation of the Balassa index from 1990 to 2015 for each of these 10 countries as compared to the world. Figure 2 shows the results grouped by broad regions, displaying the regional Balassa indexes (red dotted lines). The data represented in Figure 2 is available in Table S3.

First, all the vulnerable countries assessed display a Balassa index greater than 1 in the whole period, and in all cases the index is greater than the respective regional index, except for Niger. This implies that the top 10 vulnerable countries display a high-trade specialization in agriculture and fishing compared to worldwide and regional trends.

Looking at the evolution of the index, Myanmar, Lao PDR, Bangladesh, Cambodia, Haiti, Mozambique, and Sudan have experienced an increase in their trade specialization in the primary sector from the year 2000 onwards (the index growth rates can be checked in Table S4). Before 2000, the trends were highly volatile for some countries (Myanmar, Cambodia, Madagascar, and Mozambique). This effect can be due to a mix of gains in productivity in agriculture and the increasing weight of manufacturing industries in the Global South (especially in Asian countries) since the last years of the XX century were characterized by trade expansion based on offshoring practices by Global North countries.

## Attribution of responsibilities for climate migration

In this section, we present two methods for attributing responsibilities for internal climate migration, as described in Figure 3. We also determine the extent to which countries should contribute to cooperation funds for climate migrants. Migrants often follow preestablished routes, as they usually base their destination choice on a risk-minimizing strategy that uses closeness in a broad sense as the main selection criterion (e.g., relatives or friends previously migrated there, cultural or linguistic affinity, geographical proximity).[55] Therefore, it is unreasonable to impose destinations or routes for climate migrants; instead, we propose alternatives for assigning economic and political responsibilities for such migrations.

Our proposal is aligned with the motion presented by the International Organization for Migration (IOM) at COP27, which calls for "strengthening solidarity with countries and people most vulnerable to climate change impacts, facilitating their access to just transition processes, as well as significantly scaling up sustainable and predictable finance for adaptation and resilience, including addressing climate change-related human mobility."

The proposed methods are based on the link between the unsustainable consumption of one group of countries (mainly developed countries) and the climate consequences suffered by other countries (vulnerable countries). The first method attributes responsibilities to countries based on their historical consumption-based accounting (CBA) emissions (Figure 4). The second method does so from the point of view of

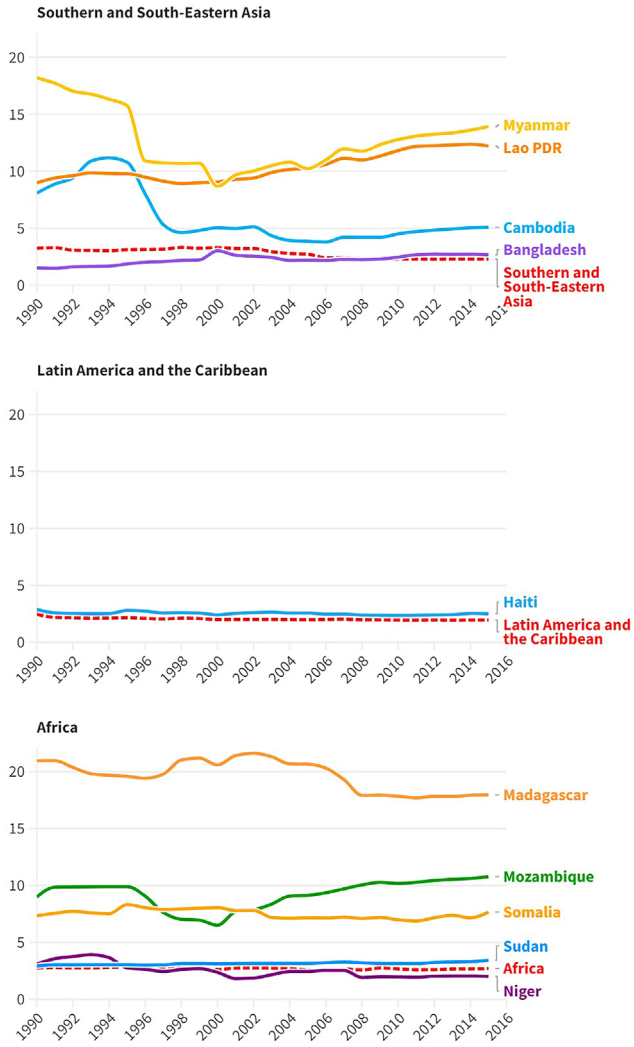


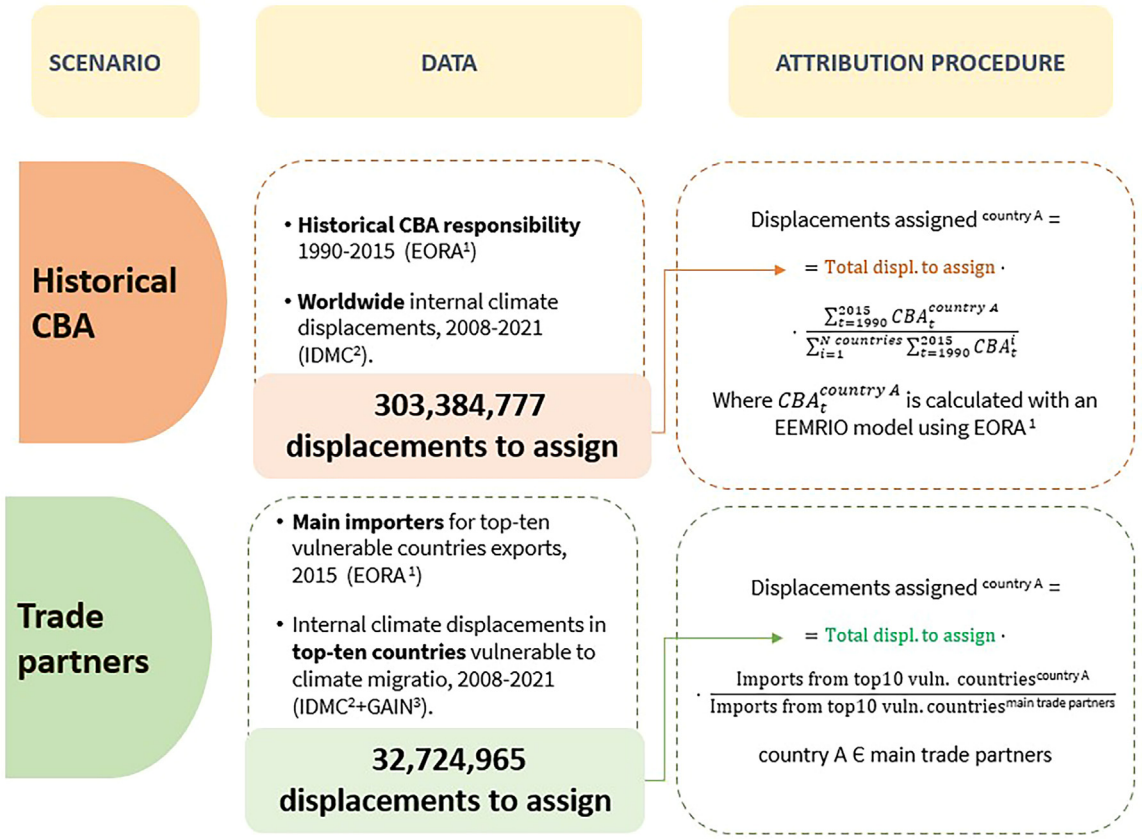

**Figure 2. Trade specialization in the primary sectors in the top 10 vulnerable countries (Balassa index as compared to the world)**
Source: Authors' own elaboration with data from Lenzen et al.[40]

trade, focusing on the influence of trade partners on the environmental impacts suffered by vulnerable countries (Figure 5). The two methods assign a number of migrants to each country that is virtually responsible for them.

Figure 4 shows the attribution of the total global climate-related internal migrations according to the historical CBA criterion. The total number of migrants for the entire period was 303,384,777 worldwide. According to this responsibility attribution criterion, the five countries with the most historical CBA emissions (the US, China, Japan, Russia, and India) would be responsible for more than 50% of the migrants (163,529,766 people). The greatest responsibilities fall on the countries with the highest consumption levels, of which two groups can be identified: developed countries with high per capita consumption levels and developing countries with large populations. When we focus on the most vulnerable countries (see Figure S3), the total climate-related internal migrants amount to 32,724,965 people, and the top five countries are responsible for 17,639,336 people (54% of the total). Although countries' responsibilities are allocated in the same proportions, the reduction in the magnitude of the migrants assigned to each country allows us to perform a hypothetical exercise regarding the economic cost responsible countries should bear for the climate migrations that affect the most vulnerable countries in the following section.

In Figure 5, we consider only trade flows, and we assign responsibility for migrants to the main trading partners (importers) of vulnerable countries. Although the countries with the most historical emissions according to CBA are still present, new countries emerge under this responsibility criterion. The US would continue to be the main recipient of migrants, accounting for 10,414,204 migrants, followed by Thailand with 4,950,676, China with 3,876,011 people, Germany with 2,740,466, and France with 2,060,370.

We note that this trade-based criterion charges responsibility to countries that are geographically and culturally closer to vulnerable countries, which include Thailand, Vietnam, Indonesia, and Malaysia. These countries are common receivers of climate refugees from vulnerable countries. The trade-based criterion highlights the link between consumption in importing countries (supported by the production and




[1] Lenzen, M., Moran, D., Kanemoto, K., and Geschke, A. (2013). Building EORA: a global multi-region input-output database at high country and sector resolution. *Economic Systems Research 25*, 20-49. 10.1080/09535314.2013.769938.
[2] Internal Displacement Monitoring Centre (IDMC) (2023). Global displacement Database 2021.
[3] Notre Dame Global Adaptation Initiative (ND-GAIN) (2023). ND-GAIN Country Index. Retrieved from Notre Dame (USA): https://gain.nd.edu/our-work/country-index/.

**Figure 3. Migratory flow attribution scenarios. (In the STAR Methods section)**
Source: Authors' own elaboration.

exploitation of resources in vulnerable exporting countries) and the massive immigration of people from vulnerable countries to importing countries.

## Attributing responsibilities in monetary terms

Considering the economic dimension is essential for addressing some of the issues discussed at COP28 regarding climate migration, such as strengthening resilience, offering people affected by a climate event the option to remain with dignity and safety in their areas of origin, facilitating people's movement out of danger when they face irreversible climate impacts through safe and regular migratory routes, promoting the integration of migrants at their destination, guaranteeing labor mobility, creating decent labor conditions, and tending toward economic diversification. An essential element is strengthening solidarity with the most vulnerable countries regarding climate migration involving diverse actors.[4] One way to implement this approach is by increasing adequate climate finance, including new funding arrangements and loss and damage funds. Recent estimations have set adaptation costs ranging from US$ 140 billion to US$ 300 billion by 2030.[56]

In a hypothetical exercise to create a solidarity fund for climate vulnerability, we attribute specific amounts (10,000 or 22,000 euros per migrant) to the countries identified as responsible for such migrations. The contributions per migrant are taken from the OECD estimates of refugee integration costs (€10,000 per person)[57] and the proposal of the European Commissioner for Home Affairs to oblige the Member States to accept illegal immigrants from Ukraine or pay a financial equivalent of €22,000 per person as part of "obligatory solidarity."[58]

Table 3 shows the monetary contributions of the countries based on their responsibility for climate migration from the most vulnerable countries from the perspective of historical CBA emissions. Table 4 refers to the monetary contribution based on the main trade partners of the most vulnerable countries, assigning 10,000 euros per migrant (following OECD criteria) and 22,000 euros per migrant (following

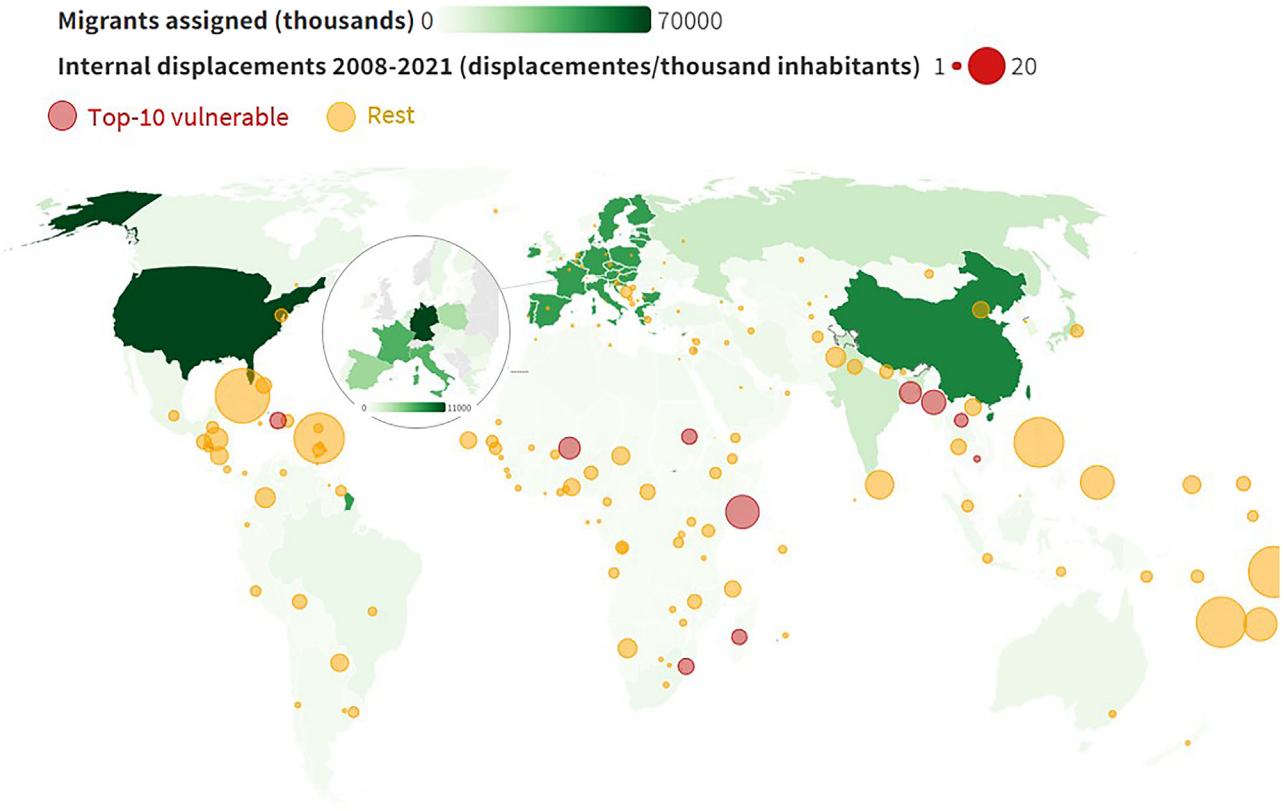



**Figure 4. Global migration attribution proposal using the historical CBA criterion**
Source: Author's own elaboration.

the amount stipulated by the EU). To calculate the monetary contribution, we consider the average of the entire period to prevent arbitrariness that may arise from extreme events that cause more displacement than usual in a specific year.

With contributions from the top 10 countries, the fund would be endowed with 143,498.14 million to 315,695.91 million euros under the criterion of the historical CBA. Considering the criterion of main trade partners, the potential fund would amount to 195,827.86 million to 430,821.29 million euros. By country, the US, which appears to be the main country responsible under both criteria, would have to contribute between 0.20% and 0.44% of its 2022 GDP according to the CBA criterion and between 0.29% and 0.63% according to the criterion of main trade partners. China, which ranks second and third according to the two criteria, would contribute between 0.21% and 0.47% of its 2022 GDP considering the CBA criterion (Table 3) and between 0.15% and 0.33% of 2022 GDP considering the main trade partners criteria (Table 4). Other countries, such as Germany or Italy, would have to significantly increase their contribution to the fund under the second criterion.

The case of Thailand is noteworthy. Thailand ranks second according to the criterion of main trade partners, as it has intense commercial connections with many vulnerable countries in Southeast Asia, and it would have to contribute between 6.97% and 15.33% of its 2022 GDP to the fund. Thailand is an example of a country where we must put these figures into perspective, considering not only responsibility but also the country's socioeconomic situation. The trade linkages between countries in the same region imply somewhat certain responsibility in terms of climate migration from more vulnerable countries, which actually happens as the migration occurs mainly internally or to low-income and close economies.[14,38] However, these neighbor countries might be vulnerable as well, both in climatic and socioeconomic terms (in fact, the GAIN sensitivity score of Thailand is 0.377, higher than the worldwide mean, as can be checked in Table S1), which makes them unable to deal with a high share of the migratory fluxes. For this reason, the share of the monetary attribution with respect to the country's GDP must be considered to guarantee fairness in the design of a compensation scheme.

## DISCUSSION

Climate migration is a worldwide phenomenon expected to increase in the coming years.[11] Although most regions already suffer such forced displacements, developing economies and low-income countries are especially prone to climate migration due to their lower adaptive capacity and less-developed socioeconomic structures.[5,6]

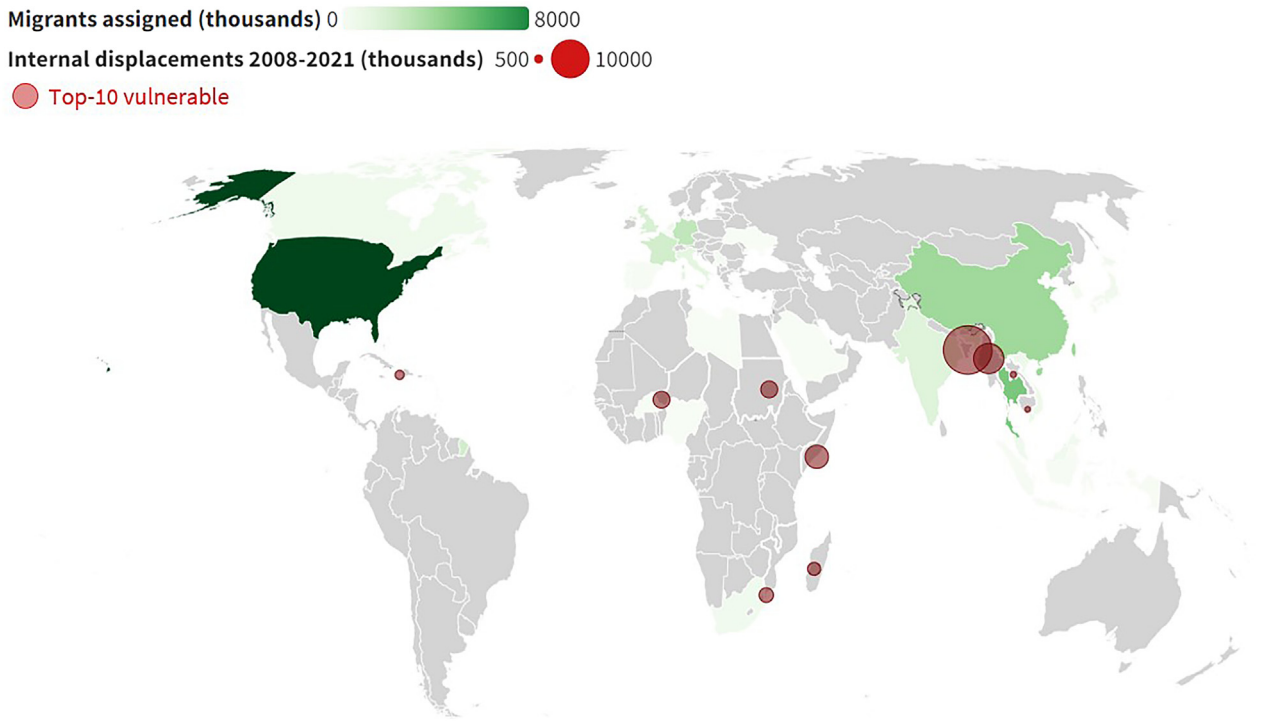



**Figure 5. Most vulnerable countries' migration attribution proposal to main trade partners**

Source: Authors' own elaboration.

Note: the different shades of green correspond to the migration attributed to the main trade partners of the top 10 vulnerable countries. The gray color stands for countries not involved in the migration attribution. Source: Authors' own elaboration.

In this context, the main goal of this work is to propose a fair method for attributing responsibility regarding climate migration. To do so, this paper explores the historical responsibility of nations for climate change based on a consumption perspective rather than a production criterion, given the role that globalization and trade dynamics have played in both the climate crisis and the vulnerability of the Global South.

The assessment of historical emissions under the consumption criterion reveals that the responsibility for the negative consequences of climate change must be concentrated in a short list of countries. The top 15 countries whose demand has generated the greatest share of historical emissions account for 74.01% of the total, most of them developed and high-income countries that have led the globalization process. This responsibility attribution contrasts with the assessment of vulnerability to climate migration, which points to developing economies in the Global South (such as Bangladesh, Haiti, Cambodia, Lao PDR, Madagascar, Myanmar, Mozambique, Niger, Sudan, and Somalia, selected as the top 10 most vulnerable counties) as those whose populations are more likely to suffer the consequences of climate change.

**Table 3. Monetary distribution under the historical CBA criterion for migrations from the most vulnerable countries (top ten) and annual average displacements (2008–2021)**

| State | OECD criterion (million €) | % of 2022 GDP (OECD) | EU criterion (million €) | % of 2022 GDP (EU) |
|---|---|---|---|---|
| USA | 48,205.30 | 0.20% | 106,051.65 | 0.44% |
| China | 36,224.33 | 0.21% | 79,693.53 | 0.47% |
| Japan | 12,115.98 | 0.30% | 26,655.16 | 0.66% |
| Russia | 10,503.70 | 0.49% | 23,108.15 | 1.09% |
| India | 9,765.62 | 0.30% | 21,484.36 | 0.67% |
| Germany | 7,730.71 | 0.20% | 17,007.56 | 0.44% |
| UK | 5,998.62 | 0.21% | 13,196.96 | 0.45% |
| France | 4,589.30 | 0.17% | 10,096.46 | 0.38% |
| Italy | 4,415.24 | 0.23% | 9,713.53 | 0.51% |
| South Korea | 3,949.34 | 0.25% | 8,688.55 | 0.55% |

Source: Author's own elaboration.

**Table 4. Monetary distribution under the criterion considering main trade partners of the most vulnerable countries (top 10) and annual average displacements (2008–2021)**

| State | OECD criterion (million €) | % of 2022 GDP (OECD) | EU criterion (million €) | % of 2022 GDP (EU) |
|---|---|---|---|---|
| USA | 68,962.44 | 0.29% | 151,717.37 | 0.63% |
| Thailand | 32,783.18 | 6.97% | 72,123.00 | 15.33% |
| China | 25,666.79 | 0.15% | 56,466.95 | 0.33% |
| Germany | 18,147.26 | 0.47% | 39,923.97 | 1.03% |
| France | 13,643.68 | 0.52% | 30,016.11 | 1.14% |
| UK | 11,576.19 | 0.40% | 25,467.62 | 0.87% |
| India | 9,685.94 | 0.30% | 21,309.08 | 0.66% |
| Italy | 7,251.87 | 0.38% | 15,954.12 | 0.84% |
| Viet Nam | 4,082.10 | 1.05% | 8,980.62 | 2.31% |
| Netherlands | 4,028.39 | 0.43% | 8,862.46 | 0.94% |

Source: Author's own elaboration.

This idea leads to an analysis of the influence of globalization and trade dynamics on the risk exposure of the top 10 vulnerable countries. The main result is that from 1990 to 2015, the integration of global value chains guided these countries to reconfigure their productive structures toward the global supply of goods in the primary sector, which is highly susceptible to negative effects from adverse climate events. This increasing specialization is revealed in most of these countries through the growth of employment in agriculture and fishing, the greater share of land devoted to agriculture, the increasing dependency of primary sectors on exports, and the higher trade specialization in primary goods. These exports are mainly imported by Asian countries, where the primary inputs enter into global value chains that end up in products consumed by developed regions. Another relevant result is the self-supply nature of these vulnerable countries, which exacerbates their exposure to climate disasters.

Developed regions, such as Europe, have identified the future climate-related migratory challenges they will face. Specific policy actions have been implemented. Besides the European Green Deal,[59] which is the EU's cornerstone on climate response, other external environmental and international cooperation actions have been held. The 25% of the upcoming Neighborhood, Development, and International Cooperation Instrument[8] budget will be allocated to climate-related objectives since the EU has recognized the role of climate change as a driver of forced migration and displacement, defining it as a "threat multiplier."[60] Efforts have been made to integrate climate change within migration policymaking beyond displacement. Policies like the Global Approach to Migration and Mobility (GAMM)[61,62] and the EU Strategy on Adaptation to Climate Change[63] consider environmentally induced migration and require comprehensive responses involving a broad range of issues and policies.

Besides the EU policy actions, global concerns regarding climate change migration trends at an international level have been growing since more than a decade ago.[60] We must highlight actions that try to strengthen opportunities for regular migration for those impacted by slow-onset natural disasters such as, for instance, the 2016 New York Declaration for Refugees and Migrants, which recognized climate change, natural disasters, and other environmental factors as drivers of migration.[64] In 2018, the Global Compact on Safe, Regular, and Orderly Migration (GCM) was the first intergovernmental agreement, prepared under the auspices of the United Nations, to cover all dimensions of international migration holistically and comprehensively. This agreement included environmental migration on addressing root causes of migration in the context of natural disasters, climate change, and environmental degradation.[65]

Given this conception of climate migration as a problem of global concern, the call for solidarity by the International Organization for Migration (IOM) at COP27 represents a fair and necessary compromise. According to the IOM,[66] policy proposals dealing with climate migration must address three possibilities: solutions to enable safe and regular migration as an adaptation strategy, solutions to help people move quickly following disasters, and solutions to help people stay focused on disaster risk reduction and *in situ* adaptation. These actions are necessary and urgent, but the lack of concrete results and the difficulty in reaching agreements regarding the degree of contribution of each nation hinder their applicability. Given these drawbacks, our proposal explores different ways of assigning responsibilities for climate change. This assessment is essential for proposing a contribution scheme to aid vulnerable countries and climate migrants.

The first method attributes responsibilities to countries according to their historical consumption-based emissions. In contrast, the second considers the role of trade partners in the economic dynamics linked to greater vulnerability. According to the first proposal, the top five countries according to historical CBA emissions (the US, China, Japan, Russia, and India) would be responsible for more than 50% of the persons internally displaced due to climate reasons. The second proposal includes additional countries that are responsible for such migrants, such as Thailand, Vietnam, Indonesia, or Malaysia; these countries are relevant trade partners of vulnerable countries and receivers of climate refugees due to their cultural and geographical proximity.

A significant increase in international public adaptation finance is urgently needed when considering monetary terms. The adaptation finance gap refers to the difference between the estimated costs of meeting a given adaptation target and the amount of finance available.[67] According to the United Nations Environment Program,[68] this gap has grown significantly in recent years, with an estimated adaptation cost

amounting to 10–18 times the international public adaptation finance flow. The results of this work point to major world economies as the main countries responsible for leading efforts (political and economic) to close this gap.

The high consumption levels of the world's major economies explain their high level of responsibility for climate migration. Nevertheless, simultaneously, their high GDP allows them to undertake more significant economic efforts to lead mitigation initiatives within and beyond their borders. The contributions to the hypothetical climate vulnerability fund by the US, China, Japan, Russia, or European Union countries represent relatively low percentages of their GDP and contrast with the excessively high percentages that vulnerable countries would have to face to mitigate the climate impacts suffered in their regions that trigger climate migration.

Regardless of the value per migrant considered, our analysis highlights the responsibility that the world's major powers must assume for the adverse consequences of the global economic system whose development they have driven and which is based on unlimited consumption, international trade, and unsustainable exploitation of natural resources. The attribution of responsibilities based on a historical criterion in which economic and environmental variables converge captures the long-term dynamics of economic and political relations between countries that have led to the current climate crisis and the unequal distribution of its consequences.

The proposal to assign responsibilities based on current trade relations addresses the unfair situation in which low-income countries assume high responsibilities. Consolidating global value chains, inherent to globalization, has given prominence to many Global South countries that act as crucial nodes in international trade networks. Nevertheless, the value added they retain from these chains is not proportional to their prominence.[69] These results show that country-specific contributions to financing a climate vulnerability fund cannot be based solely on the current structures of national and global economies but must also consider long-term circumstances and variables.

These historical variables must also be accounted for when analyzing migrant flows. Migration flows often follow preestablished routes, as migrants usually base their destination choice on a risk-minimizing strategy that uses closeness in a broad sense as the main selection criterion (e.g., relatives or friends previously migrated there, cultural or linguistic affinity, geographical proximity).[55] Culture, roots, identity, and community links, among others, are key issues to consider when developing policies regarding migration.[70] Proposals to facilitate mobility and migration are controversial, as migration implies higher costs when displacement is forced and rapid.[71,72] Therefore, responsible agents should offer alternatives that respect human dignity by considering migrants' individualities and communities' idiosyncrasies. For this reason, it would be unreasonable to impose destinations or routes for climate migrants; instead, we propose alternatives for assigning responsibilities, in an economic and political sense, for such migrations. Mobility as an adaptation strategy must be combined with other solutions, such as building resilience, to prevent involuntary mobility,[73] and coordinated worldwide financial support is essential to realize such solutions.

As a possible extension of this work, studies could assess the implications of the internal migration challenge in vulnerable countries. According to the World Bank, without early climate and development action, more than 216 million people could become internal climate migrants by 2050.[9] The demographic and environmental breakdown of some capital cities in developing countries—such as Dhaka in Bangladesh[74,75]—suggests the possibility that internal climate migration may lead to international migration toward more prosperous economies. The International Migration Stocks dataset[76] provides current migration routes that connect origins and destinations, and the Net Migration Prospects[77] estimates whether a country will be a net receiver or net emitter of migration up to 2050. Using these two sources, it would be possible to predict the routes internal migrants might follow when climate and demographic pressures force them to move abroad. When the responsibility for these migrations is allocated according to the historical emissions criterion, such studies could help match funding from historical polluters to the countries where the migrants are expected to move.

## Limitations of the study

The critical point of the proposal is how to assess responsibilities for climate migration considering historical consumption patterns and trade dynamics, as well as the need for solidarity when providing financial means for countries suffering environmental displacements. However, uncertainty in the results might arise since the selection of vulnerable and responsible countries can be performed using different criteria. In addition, the monetary attribution is based on estimates from external sources, which also introduces a source of variability in the results. Another limitation of this study is that it attributes responsibilities to internal environmental displacements. The proposal could be extended using data for environmental displacements regardless of whether they are internal or international. However, due to data availability and consistency, we have focused only on internal migration using actual data from the Internal Displacement Monitoring Centre.[8]

Finally, we work with a series of input-output tables from 1995 until 2015. Extending the historical responsibility calculation up to 2021 (the last year in the internal migration series employed) would be the ideal option. Still, the EORA input-output tables are publicly available up to 2015. The tables from 2016 onwards are available under payment, which would make our work non-replicable. The reason behind choosing EORA was its vast geographical disaggregation (189 regions), making it the only input-output database that provided information for the vulnerable countries of our interest. Although the historical emission responsibilities up to 2015 represent a limitation in terms of the timeliness of the data, they do not compromise the robustness of the research. During 2016–2019, there have been no long-term structural changes that would significantly modify the cross-country percentage distributions of historical emission responsibilities established by the trends observed in the 1990–2015 period, and the global economy trends from 2020 onwards are still unfolding (due to COVID-19 and recent war conflicts). Thus, the cross-country distribution of historical emission responsibilities during 1990–2015 is a suitable criterion to estimate the allocation of regions' responsibilities on climate-driven migrations during the time frame addressed in this study.

## RESOURCE AVAILABILITY

### Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Dr. Ángela García-Alaminos (angela.garcia@uclm.es).

### Materials availability

This study did not generate new unique materials.

### Data and code availability

- This paper analyzes existing, publicly available data that are listed in the key resources table.
- Code: the code for the analysis was written in MATLAB (R.2022a) and is available from the lead contact upon request.
- All other request: any additional information required to reanalyze the data reported in this paper is available from the lead contact (angela.garcia@uclm.es) upon request.

## ACKNOWLEDGMENTS

The Ramón Areces Foundation funds this work in the framework of the "XX Concurso Nacional para la Adjudicación de Ayudas a la Investigación en Ciencias Sociales" (CISP20A6656).

## AUTHOR CONTRIBUTIONS

G.A., investigation, conceptualization, methodology, formal analysis, and writing—original draft; Á.G.-A., conceptualization, data curation, visualization, formal analysis, and writing—original draft. M.O., data curation, software, formal analysis, and writing—original draft; J.Z., investigation, conceptualization, methodology, formal analysis, and writing—original draft.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

## STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- KEY RESOURCES TABLE
- METHOD DETAILS
  - Identification of the countries most vulnerable to climate displacement
  - Trade dynamics and their influence on regions' vulnerabilities
  - Historical responsibility and migratory flow attribution
  - Monetary quantification of responsibility for climate migration
- QUANTIFICATION AND STATISTICAL ANALYSIS

## SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2024.111124.

Received: February 13, 2024
Revised: May 1, 2024
Accepted: October 4, 2024
Published: October 9, 2024

## REFERENCES

1. IPCC (2018). Global Warming of 1.5°C. In An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, P.Z. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, and R. Pidcock, et al., eds. (Cambridge University Press, Cambridge, UK and New York, NY, USA), p. 616. https://doi.org/10.1017/9781009157940.
2. IOM (2020). In Migration, Environment and Climate Change: Policy Brief Series, I.O.f.M, ed. (IOM).
3. Black, R., Adger, W.N., Arnell, N.W., Dercon, S., Geddes, A., and Thomas, D. (2011). The effect of environmental change on human migration. Global Environ. Change *21*, S3–S11. https://doi.org/10.1016/j.gloenvcha.2011.10.001.
4. IOM (2023). Human Mobility at COP 28.
5. Neil Adger, W., Arnell, N.W., and Tompkins, E.L. (2005). Successful adaptation to climate change across scales. Global Environ. Change *15*, 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005.
6. UNDP (2016). Human Development Report 2016 (UNDP (United Nations Development Programme)).
7. Kaczan, D.J., and Orgill-Meyer, J. (2020). The impact of climate change on migration: a synthesis of recent empirical insights. Climatic Change *158*, 281–300. https://doi.org/10.1007/s10584-019-02560-0.
8. Internal Displacement Monitoring Centre (IDMC) (2023). Global displacement Database 2021.
9. Clement, V., Rigaud, K.K., de Sherbinin, A., Jones, B., Adamo, S., Schewe, J., Sadiq, N., and Shabahat, E. (2021). Groundswell Part 2: Acting on Internal Climate Migration (World Bank). http://hdl.handle.net/10986/36248.
10. Rigaud, K.K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McCusker, B., Heuser, S., and Midgley, A. (2018). Groundswell : Preparing for Internal Climate Migration (World Bank).

https://openknowledge.worldbank.org/handle/10986/29461.
11. Missirian, A., and Schlenker, W. (2017). Asylum applications respond to temperature fluctuations. Science *358*, 1610–1614.
12. Kattumuri, R., Ravindranath, D., and Esteves, T. (2017). Local adaptation strategies in semi-arid regions: study of two villages in Karnataka, India. Clim. Dev. *9*, 36–49. https://doi.org/10.1080/17565529.2015.1067179.
13. McNamara, K.E., Bronen, R., Fernando, N., and Klepp, S. (2018). The complex decision-making of climate-induced relocation: adaptation and loss and damage. Clim. Pol. *18*, 111–117. https://doi.org/10.1080/14693062.2016.1248886.
14. Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., and Peisker, J. (2020). A meta-analysis of country-level studies on environmental change and migration. Nat. Clim. Chang. *10*, 904–912. https://doi.org/10.1038/s41558-020-0898-6.
15. UN Climate Change (2023). COP28 Agreement Signals "Beginning of the End" of the Fossil Fuel Era. https://unfccc.int/news/cop28-agreement-signals-beginning-of-the-end-of-the-fossil-fuel-era.
16. United Nations Environment Programme, Imperial College Business School, and SOAS - University of London (2018). Climate Change and the Cost of Capital in Developing Countries: Assessing the Impact of Climate Risks on Sovereign Borrowing Costs. United Nations Environment Programme (Imperial College Business School and SOAS - University of London). https://wedocs.unep.org/20.500.11822/26007.
17. Hickel, J. (2020). Quantifying national responsibility for climate breakdown: an equality-based attribution approach for carbon dioxide emissions in excess of the planetary boundary. Lancet Planet. Health *4*, e399–e404. https://doi.org/10.1016/S2542-5196(20)30196-0.
18. NASA (2021). Extreme Makeover: Human Activities Are Making Some Extreme Events More Frequent or Intense. https://climate.nasa.gov/explore/ask-nasa-climate/3125/extreme-makeover-human-activities-are-making-some-extreme-events-more-frequent-or-intense/.
19. IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (The Intergovernmental Panel on Climate Change (IPCC)).
20. Turner, K., Lenzen, M., Wiedmann, T., and Barrett, J. (2007). Examining the global environmental impact of regional consumption activities — Part 1: A technical note on combining input–output and ecological footprint analysis. Ecol. Econ. *62*, 37–44. https://doi.org/10.1016/j.ecolecon.2006.12.002.
21. Wiedmann, T., and Minx, J. (2007). A Definition of 'Carbon Footprint. In Ecological Economics Research Trends, C.C. Pertsova, ed. (Carolyn C. Pertsova)), pp. 1–11.
22. Peters, G.P. (2008). From production-based to consumption-based national emission inventories. Ecol. Econ. *65*, 13–23. https://doi.org/10.1016/j.ecolecon.2007.10.014.
23. Hertwich, E.G., and Peters, G.P. (2009). Carbon Footprint of Nations: A Global, Trade-Linked Analysis. Environ. Sci. Technol. *43*, 6414–6420. https://doi.org/10.1021/es803496a.
24. Beine, M., and Jeusette, L. (2021). A meta-analysis of the literature on climate change and migration. J. Demogr. Economics *87*, 293–344. https://doi.org/10.1017/dem.2019.22.
25. Piguet, E., Pécoud, A., and de Guchteneire, P. (2011). Migration and climate change: an overview. Refug. Surv. Q. *30*, 1–23.
26. Weerasinghe, S. (2021). What We Know About Climate Change and Migration. Center for Migration Studies (CMS), Institute for the Study of International Migration (ISIM). https://www.cmsny.org/wp-content/uploads/2021/02/What-We-Know-About-Climate-Change-and-Migration-Final.pdf.
27. Jakob, M. (2022). Globalization and climate change: State of knowledge, emerging issues, and policy implications. WIREs Climate Change *13*, e771. https://doi.org/10.1002/wcc.771.
28. Peters, G.P., and Hertwich, E.G. (2008). CO2 Embodied in International Trade with Implications for Global Climate Policy. Environ. Sci. Technol. *42*, 1401–1407. https://doi.org/10.1021/es072023k.
29. Ahmed, B. (2018). Who takes responsibility for the climate refugees? Int. J. Clim. Chang. Strateg. Manag. *10*, 5–26. https://doi.org/10.1108/IJCCSM-10-2016-0149.
30. Le Quéré, C., Andrew, R.M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P.A., Korsbakken, J.I., Peters, G.P., Canadell, J.G., et al. (2018). Global Carbon Budget 2018. Earth Syst. Sci. Data *10*, 2141–2194. https://doi.org/10.5194/essd-10-2141-2018.
31. García-Alaminos, Á., Monsalve, F., Zafrilla, J., and Cadarso, M.-A. (2020). Unmasking social distant damage of developed regions' lifestyle: A decoupling analysis of the indecent labour footprint. PLoS One *15*, e0228649. https://doi.org/10.1371/journal.pone.0228649.
32. Wiedmann, T., and Lenzen, M. (2018). Environmental and social footprints of international trade. Nat. Geosci. *11*, 314–321. https://doi.org/10.1038/s41561-018-0113-9.
33. Ortiz, M., Cadarso, M.Á., López, L.-A., and Jiang, X. (2022). The trade-off between the economic and environmental footprints of multinationals' foreign affiliates. Struct. Change Econ. Dynam. *62*, 85–97. https://doi.org/10.1016/j.strueco.2022.05.005.
34. Hickel, J., Dorninger, C., Wieland, H., and Suwandi, I. (2022). Imperialist appropriation in the world economy: Drain from the global South through unequal exchange, 1990–2015. Global Environ. Change *73*, 102467. https://doi.org/10.1016/j.gloenvcha.2022.102467.
35. UNCTAD (2020). World Investment Report 2020: International Production Beyond the Pandemic. (UNCTAD/WIR/2020). https://unctad.org/publication/world-investment-report-2020.
36. Warlenius, R. (2018). Decolonizing the atmosphere: The climate justice movement on climate debt. J. Environ. Dev. *27*, 131–155.
37. Martinez, E.D. (2014). The Right to Be Free of Fear: Indigeneity and the United Nations. Wicazo Sa Rev. *29*, 63–87. https://doi.org/10.5749/wicazosareview.29.2.0063.
38. Clement, V., Kumari Rigaud, K., de Sherbinin, A., Jones, B., Adamo, S., Schewe, J., Sadiq, N., and Shabahat, E. (2021). Groundswell Part 2: Acting on Internal Climate Migration (The World Bank).
39. Notre Dame Global Adaptation Initiative (ND-GAIN) (2023). ND-GAIN Country Index (University of Notre Dame). https://gain.nd.edu/our-work/country-index/.
40. Lenzen, M., Moran, D., Kanemoto, K., and Geschke, A. (2013). Building EORA: a global multi-region input-output database at high country and sector resolution. Econ. Syst. Res. *25*, 20–49. https://doi.org/10.1080/09535314.2013.769938.
41. Food and Agriculture Organization of the United Nations (FAO) (2023). Crops and Livestock Products (FAOSTAT).
42. World Bank (2023). World Development Indicators: Total population. https://databank.worldbank.org.
43. The World Bank (2023). World development indicators: Total labour force. https://databank.worldbank.org.
44. European Commission (2024). Communication from the Commision to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Managing Climate Risks - Protecting People and Prosperity (European Commission). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0761.
45. Beltran, P., and Hadzi-Vaskov, M. (2023). Climate and Cross-Border Migration (IMF). https://www.imf.org/en/Publications/WP/Issues/2023/12/08/Climate-and-Cross-Border-Migration-542196.
46. The World Bank (2018). Adaptation & Resilience Action Plan (World Bank Group). https://thedocs.worldbank.org/en/doc/189851543772751358-0020022018/original/AdaptationandResilienceActionPlanKeyMessages.pdf.
47. UN (2023). COP28 talks open in Dubai with breakthrough deal on loss and damage fund. https://news.un.org/en/story/2023/11/1144162.
48. The World Bank (2023). World development indicators: Population.
49. Arce, G., López, L.A., and Guan, D. (2016). Carbon emissions embodied in international trade: The post-China era. Appl. Energy *184*, 1063–1072. https://doi.org/10.1016/j.apenergy.2016.05.084.
50. Thiault, L., Mora, C., Cinner, J.E., Cheung, W.W.L., Graham, N.A.J., Januchowski-Hartley, F.A., Mouillot, D., Sumaila, U.R., and Claudet, J. (2019). Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries. Sci. Adv. *5*, eaaw9976. https://doi.org/10.1126/sciadv.aaw9976.
51. Cai, R., Feng, S., Oppenheimer, M., and Pytlikova, M. (2016). Climate variability and international migration: The importance of the agricultural linkage. J. Environ. Econ. Manag. *79*, 135–151. https://doi.org/10.1016/j.jeem.2016.06.005.
52. McCullough, E.B. (2017). Labor productivity and employment gaps in Sub-Saharan Africa. Food Pol. *67*, 133–152. https://doi.org/10.1016/j.foodpol.2016.09.013.
53. McMillan, M., Rodrik, D., and Verduzco-Gallo, Í. (2014). Globalization, Structural Change, and Productivity Growth, with an Update on Africa. World Dev. *63*, 11–32. https://doi.org/10.1016/j.worlddev.2013.10.012.
54. HANUSCH, M. (2013). JOBLESS GROWTH? OKUN'S LAW IN EAST ASIA. Journal of International Commerce, Economics and Policy *04*. J. Intl. Econ. Comm. Policy *04*, 1350014. https://doi.org/10.1142/s1793993313500142.

55. Findlay, A.M. (2011). Migrant destinations in an era of environmental change. Global Environ. Change *21*, S50–S58. https://doi.org/10.1016/j.gloenvcha.2011.09.004.
56. UNEP (2016). The Adaptation Finance Gap Report 2016 (United Nations Environment Programme).
57. OECD (2017). Who bears the cost of integrating refugees?. https://www.oecd.org/els/mig/migration-policy-debates-13.pdf.
58. European Parliament (2023). Priority Question for Written Answer P-001869/2023 to the Commission Rule 138 Kosma Złotowski (ECR) (European Parliament).
59. European Commission (2021). Delivering the European Green Deal. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en.
60. Mcmahon, S., Tintori, G., Pérez-Fernández, M., Alessandrini, A., Goujon, A., Ghio, D., Petroliagkis, T., Conte, A., Minora, U., and Kalantaryan, S. (2021). Population Exposure and Migrations Linked to Climate Change in Africa (Publications Office of the European Union). https://publications.jrc.ec.europa.eu/repository/handle/JRC126594.
61. European Parliament (2011). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: The Global Approach to Migration and Mobility (E. Parliament).
62. Strik, T. (2017). The Global Approach to Migration and Mobility. GroJIL. *5*, 310–328.
63. European Parliament (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Forging a Climate-Resilient Europe - the New EU Strategy on Adaptation to Climate Change (E. Parliament).
64. UNHCR (2016). New York Declaration for Refugees and Migrants. The United Nations Refugee Agency.
65. OHCHR (2018). Global Compact for Safe, Orderly and Regular Migration (GCM) (Office of the High Commissioner of Human Rights and Migration).
66. IOM (2022). People on the Move in a Changing Climate – Linking Policy, Evidence and Action (International Organization for Migration). https://publications.iom.int/books/people-move-changing-climate-linking-policy-evidence-and-action.
67. United Nations Environment Programme (2014). The Adaptation Gap Report: A Preliminary Assessment. https://www.unep.org/resources/adaptation-gap-report-2014.
68. United Nations Environment Programme (2023). Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate Investment and Planning on Climate Adaptation Leaves World Exposed (UN).
69. Baldwin, R., and Ito, T. (2021). The smile curve: Evolving sources of value added in manufacturing. Canadian J. of Economics. *54*, 1842–1880. https://doi.org/10.1111/caje.12555.
70. Haines, D. (2013). Migration, Policy, and Anthropology. Int. Migrat. *51*, 77–89. https://doi.org/10.1111/imig.12080.
71. Yee, M., McNamara, K.E., Piggott-McKellar, A.E., and McMichael, C. (2022). The role of Vanua in climate-related voluntary immobility in Fiji. Front. Clim. *4*, 1034765. https://doi.org/10.3389/fclim.2022.1034765.
72. Wiegel, H., Warner, J., Boas, I., and Lamers, M. (2021). Safe from what? Understanding environmental non-migration in Chilean Patagonia through ontological security and risk perceptions. Reg. Environ. Change *21*, 43. https://doi.org/10.1007/s10113-021-01765-3.
73. Mombauer, D., Link, A.-C., and van der Geest, K. (2023). Addressing climate-related human mobility through NDCs and NAPs: State of play, good practices, and the ways forward. Front. Clim. *5*, 1125936. https://doi.org/10.3389/fclim.2023.1125936.
74. Castellano, R., Dolšak, N., and Prakash, A. (2021). Willingness to help climate migrants: A survey experiment in the Korail slum of Dhaka, Bangladesh. PLoS One *16*, e0249315. https://doi.org/10.1371/journal.pone.0249315.
75. Ahmed, S. (2020). Urban Resilience and Sustainable Development Trajectories: Insights from Dhaka. In The Routledge handbook of planning megacities in the Global South (Routledge)), pp. 231–242.
76. UN (2020). International Migrant Stock 2020 (UN population division).
77. UN (2022). 2022 Revision of World Population Prospects (UN Population Division).
78. ILO (2023). ILO Modelled Estimates (ILOEST). Employment by Sex and Economic Activity Annual (International Labour Organization).
79. IDMC (2023). Global Displacement Database: 2021 Internal Displacement. https://www.internal-displacement.org/database/displacement-data.
80. Lenzen, M., Kanemoto, K., Moran, D., and Geschke, A. (2012). Mapping the Structure of the World Economy. Environ. Sci. Technol. *46*, 8374–8381. https://doi.org/10.1021/es300171x.
81. Hinloopen, J., and Marrewijk, C. (2001). On the empirical distribution of the Balassa index. Weltwirtschaftliches Archiv *137*, 1–35. https://doi.org/10.1007/BF02707598.
82. Miller, R.E., and Blair, P.D. (2009). Input-output Analysis : Foundations and Extensions, 2nd Edition (Cambridge University Press).
83. Wang, Y., Li, J., Lee, L.-C., Wang, M., and Du, H. (2019). A review on hotspots of input-output model's applications in the energy and environment fields based on co-words network analysis. Environ. Rev. *27*, 567–574. https://doi.org/10.1139/er-2018-0110.
84. Malik, A., McBain, D., Wiedmann, T.O., Lenzen, M., and Murray, J. (2018). Advancements in Input-Output Models and Indicators for Consumption-Based Accounting. J. Ind. Ecol. *23*, 300–312. https://doi.org/10.1111/jiec.12771.
85. Wiedmann, T. (2009). A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecol. Econ. *69*, 211–222. https://doi.org/10.1016/j.ecolecon.2009.08.026.

## STAR★METHODS

### KEY RESOURCES TABLE

| REAGENT or RESOURCE | SOURCE | IDENTIFIER |
|---|---|---|
| EORA input-output Database: Global MRIO tables for 1995–2015 of 189 regions and 26 sectors, | Lenzen et al.[40] | https://worldmrio.com/ |
| Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index. 2023 | Notre Dame Global Adaptation Initiative (ND-GAIN)[39] | https://gain.nd.edu/our-work/country-index/ |
| Displacement associated with sudden-onset natural hazard-related disasters. 2008–2021. Global Internal Displacement Database. | Internal Displacement Monitoring Center (IDMC)[8] | https://www.internal-displacement.org/database/displacement-data2023) |
| Data on employment in agriculture, forestry, and fishing. 1991–2021. Food and Agriculture Organization. | Food and Agriculture Organization of the United Nations (FAO)[41] | https://www.fao.org/faostat/en/#home |
| Data on employment agriculture, forestry, and fishing. 1991–2021. The International Labor Organization. | ILOEST[78] | https://www.fao.org/faostat/en/#home |
| Population. 1990–2021. World Bank | The World Bank[48] | https://databank.worldbank.org/source/world-development-indicators |
| Total labor force. 1990–2021. The World Bank. | The World Bank[43] | https://databank.worldbank.org/source/world-development-indicators |
| Employment in agriculture. 1990–2021. The World Bank. | The World Bank. World development indicators: Employment in agriculture. Online; 2023. | https://databank.worldbank.org/source/world-development-indicators |
| Agricultural land. 1990–2021. The World Bank. | The World Bank. World development indicators: Agricultural land. Online; 2023. | https://databank.worldbank.org/source/world-development-indicators |
| MATLAB Softare | The MathWorks Inc. (2022). MATLAB version: 9.12.0 (R2022a), Natick, Massachusetts: The MathWorks Inc. | https://www.mathworks.com |

### METHOD DETAILS

The methods applied in this paper are developed in the following subsections. In the first one, we expose our approach to identifying those countries most vulnerable to climate displacement. In the second subsection, we show the indicators calculated for each country to analyze their trade characteristics, identifying key sectors and evaluating their integration in global value chains. Finally, we present the model used to calculate the historical responsibility in terms of emissions, and we design the allocation of migration flows.

#### Identification of the countries most vulnerable to climate displacement

This work relies on several complementary data sources to provide a global picture of internal displacements due to climatic reasons as a phenomenon linked to climate vulnerability and international trade dynamics. A selection of countries most vulnerable to climate displacements is made to develop a more in-depth analysis. This selection is based on two elements: internal displacements caused by climatic disasters and socioeconomic vulnerability to climate change.

Internal displacements caused by climatic disasters are retrieved from the Global Internal Displacement Database (GIDD).[8] This source provides comprehensive and reliable data on disaster-induced displacements on an event-by-event basis, with country-level detail from 2008 to 2021. In this way, we can account for the number of displacements caused by climatic disasters by ruling out the displacements generated by volcanic eruptions and earthquakes. To relativize the internal displacements of each country according to its population, we use the population figures provided by The World Bank.[48]

On the other hand, each country's socioeconomic vulnerability to climate change is retrieved from the ND-GAIN index.[39] This index summarizes a country's vulnerability to environmental challenges and its readiness to implement adaptation actions, providing a measure in the range (0.100). A higher index reflects a country's better situation in terms of vulnerability and readiness. Focusing on vulnerability to climate change, the index is disaggregated into several contributing factors. We work with the so-called sensitivity factor, which measures the extent

to which a country depends upon a sector negatively affected by climate change and the proportion of the population sensitive to climate hazards. The higher the score, the more vulnerable the country is regarding socioeconomic structures.

The selection criterion is based on two conditions that must be fulfilled simultaneously: first, countries must have an ND-GAIN sensitivity score higher than the worldwide mean in 2021.[39] Second, for more than three years between 2008 and 2021, countries must have an incidence of climate-related internal displacements (i.e., displacements per inhabitant) higher than the worldwide average incidence according to the Internal Displacement Monitoring Center data.[79] In this way, we consider each country's internal displacement intensity and frequency. Each year's worldwide average incidence is calculated excluding the countries with no internal displacements.

After applying these selection criteria, 12 countries were obtained, two of which were excluded due to their particularities (Tonga and Vanuatu). We assumed that the socioeconomic vulnerability of these small insular states is linked mainly to topographic and demographic issues rather than to a dependence on an economic sector strongly affected by climate change. The final selection is displayed in Table 1. More information about the scores for all the countries can be found in Table S1.

## Trade dynamics and their influence on regions' vulnerabilities

International trade dynamics and their role in the vulnerability of selected economies are analyzed using international trade data from the Eora database,[40,80] which provides the symmetric MRIO tables in basic prices for 189 regions and 26 sectors. We use the tables from 1990 to 2015 and combine this information with data on employment in key sectors such as agriculture, forestry, and fishing from the Food and Agriculture Organization of the United Nations (FAO)[41] and the International Labour Organization[78] and the total labor force by country from The World Bank.[43]

First, we use two measures to study which sectors are the most relevant economically in the selected countries. The first measure is the ratio of the value added by the industry to the total value added (Equation 1), and the second is the ratio of the sector's employment to the total labor force (Equation 2).

$$VA\ ratio\ =\ \frac{VA_i^s}{VA_{total}^s} \qquad \text{Equation (1)}$$

$$Labor\ ratio\ =\ \frac{L_i^s}{L_{total}^s} \qquad \text{Equation (2)}$$

In most cases of the countries identified as the most vulnerable to climate migrations, the primary sector is essential. However, we also analyze manufacturing sectors closely related to agriculture, livestock, and fishing, such as the agri-food industry.

Second, using input-output data,[40,80] we analyze the integration of these sectors in global value chains by calculating the evolution of the weight of the exports (intermediate and final) as a share of total output. The higher the share is, the greater the integration into GVCs. The destination country of these exports, whether developed or developing, is another relevant piece of information we consider.

Finally, we measure the specialisation degree in agriculture and fishing for each economy identified as vulnerable to climate migration. To do so, we calculate the Balassa index of revealed comparative advantage in the primary sector (Equation 3), which measures normalised export shares implementing the normalisation with respect to the exports of the same industry in the group of reference economies (in this case, the world).[81] In other words, the Balassa index calculates the share that primary exports in sector *j* represent in total exports in country *A* over the equivalent share of exports in sector *j* with respect to total exports at a worldwide level. If its value is greater than 1, country A has a comparative advantage in industry j, which means that this industry is more important for country A's exports than for the average worldwide exports.

$$BI_j^A\ =\ \frac{X_j^A \Big/ X^A}{X_j^{World} \Big/ X^{World}} \qquad \text{Equation (3)}$$

## Historical responsibility and migratory flow attribution

The detailed methodological framework of the Environmentally Extended Multiregional Input–Output (EEMRIO) models can be found in Miller and Blair.[82] These models have been widely used in recent literature toestimate the environmental impacts of production and international trade.[83] Specifically, the EEMRIO model is especially useful for assessing the emissions responsibilities of regions under consumption-based accounting (CBA), also known as the carbon footprint.[84,85] The general equation for such estimates is

$$F\ =\ \hat{e}(I\ -\ A)^{-1}\hat{\hat{Y}}\ =\ P\hat{\hat{Y}}$$

Where *F* contains all the $CO_2$ that has been emitted worldwide in the production of the final goods and services from the *n* countries and *m* sectors that are included in the analysis. $\hat{e}$ is the diagonalised vector of the $CO_2$ emissions coefficients (emissions per monetary unit of output) in each sector of every region. $(I\ -\ A)^{-1}$ is the *Leontief inverse matrix,* in which *A* is the technical coefficient matrix, and *I* is the identity matrix. Therefore, matrix $P = \hat{e}(I\ -\ A)^{-1}$ captures the interconnections and $CO_2$ emission flows among sectors and countries. It consists of $p_{ij}^{rs}$, which represents the quantity of $CO_2$ that is physically emitted by sector *i* in country *r* to produce one unit of output from sector *j* in country

$s$ ($i,j = 1,\ldots,m$; $r,s = 1,\ldots,n$). $\hat{\hat{Y}}$ is the total final demand matrix of $(m * n)$ x $(m * n)$ dimensions. The matrix $\hat{\hat{Y}}$ is diagonalized by blocks: the domestic final demand of every country in the main diagonal of the matrix ($\forall r = s$) and imports (exports) in off-diagonal positions ($\forall r \neq s$). In this work, the final demand includes household consumption, government consumption, investment, changes in inventories, and final exports.

Thus, adding matrix $F$ along the rows results in the total production-based accounting (PBA) of emissions by the producer country ($r$), and adding by columns results in the total CBA emissions by consumer country ($s$). The cumulative sum of CBA emissions for 1990–2015 is our measure of historical responsibility.

The source used to build the EEMRIO model is the Eora database,[40,80] which provides the symmetric MRIO tables in basic prices and the vector of $CO_2$ intensities from 1990 to 2015. The monetary units of the tables are thousand $US ('000), and the $CO_2$ emissions come in Gigagrams (Gg), which are equal to Mega-tonnes (Mt).

Regarding migration flows, the number of migrants we attribute is the number of disaster-induced displacements on an event-by-event basis from 2008 to 2021 (the entire period included in the Global Internal Displacement Database[8]). We propose two allocation scenarios in which we simulate the attribution of the total climate-induced migration worldwide and the climate-induced migration from the countries identified as the most vulnerable. In both cases, the international trade boom observed since the beginning of the globalisation era and the subsequent environmental impacts inform the allocation criteria.

In the first scenario, we attribute the migration flow responsibilities using the consumer perspective of cumulative emissions and globalisation-induced consumer historical responsibility to the total climate-induced migration. In the second scenario, we consider another perspective on the influence of the global value chain on the production structure of the most vulnerable countries by attributing migration responsibility to the main trading partners of the vulnerable countries (i.e., those countries that receive more than 2.5% of the total exports from each top-ten vulnerable countries). Figure 3 displays the main features of both scenarios.

### Monetary quantification of responsibility for climate migration

After quantifying responsibilities on climate migration considering the two criteria exposed in the previous subsection, the next step is to propose monetary contributions by responsible countries to a hypothetical solidarity fund.

We base the monetary quantification per migrant on official estimations: the OECD estimates of refugee integration costs establish a contribution of €10,000 per person,[57] and the European Commissioner for Home Affairs proposes to oblige the Member States to accept illegal immigrants from Ukraine or pay a financial equivalent of €22,000 per person as part of "obligatory solidarity".[58] Considering these two quantitative estimates, we apply the cost per migrant to the number of migrants assigned to each responsible country according to the two attribution scenarios exposed in the previous subsection.

## QUANTIFICATION AND STATISTICAL ANALYSIS

All empirical analyses were conducted using MATLAB software, with the specific version information listed in the key resources table. The code can be found in the Supplementary Information file. The datasets in which this analysis is based are publicly available as specified in the key resources tables.