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A Review on the Impacts of Climate-Induced Migration on Carbon Footprints

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Abstract

This study examines the intersection of climate-induced migration and carbon footprint, focusing on how environmental stressors such as sea level rise, drought, and land degradation change human mobility in coastal and arid/ semiarid regions. Using regional case studies from Africa, Asia, the Pacific, and the United States, we examine how migration patterns, whether voluntary, forced, seasonal, or permanent, are shaped by socioeconomic vulnerability, governance capacity, and cultural norms. The analysis highlights that, while migration can serve as an adaptation strategy, it also leads to a redistribution of carbon emissions through urbanization, changing livelihoods, and altered energy consumption. Particular attention has been paid to the often-overlooked challenges of immobility, gender vulnerability, and carbon emissions from planned resettlement. This study emphasizes the need for inclusive, equity-oriented adaptation strategies that integrate both mobility and immobility into climate policy. It concludes by highlighting important gaps in current research and calling for interdisciplinary approaches to develop context-sensitive low-carbon development solutions.

Keywords

Climate-Induced Migration, Carbon Footprint, Coastal Displacement, Arid and Semi-Arid Regions, Planned Resettlement, Immobility, Climate Adaptation, Ecological Vulnerability, Low-Carbon Development

1. Introduction

Climate-induced migration has emerged as a pressing global concern, driven by increasingly frequent extreme weather events, rising sea levels, droughts, desertification, and other long-term shifts in climate patterns (Almulhim et al., 2024; Hoffmann & Muttarak, 2021; IPCC, 2023; McMichael et al., 2020). Defined as the movement of people compelled—directly or indirectly—to relocate due to environmental changes caused by climate variability, this form of migration differs from traditional movements triggered by conflict or economic opportunity (Çelekli et al., 2023; IOM, 2009; Prieur et al., 2008). It stems from deteriorating living conditions that threaten the habitability or productivity of affected regions, such as extreme heat, flooding, or cyclones. The Intergovernmental Panel on Climate Change (IPCC) has recognized climate-induced migration as one of the most significant socio-environmental challenges of the 21st century, projecting that up to 143 million people in sub-Saharan Africa, South Asia, and Latin America could be internally displaced by 2050 (Almulhim et al., 2024; Hoffmann & Muttarak, 2021; IPCC, 2023). Notably, the intensification of extreme weather events over the past six decades has had a measurable impact on migration patterns, with studies showing that net migration rates decline in correlation with more frequent days of extreme heat and precipitation (Beheshti & Eilam, 2025; Çelekli et al., 2023). Temporary or permanent, internal or international, voluntary or forced, climate-induced migration reflects the complex interplay between human settlements and an increasingly volatile climate system.

While climate-induced migration is often framed in terms of vulnerability, humanitarian needs, and adaptation strategies, the less-explored yet critical dimension is its environmental feedback, particularly in terms of carbon emissions. Migration alters spatial and temporal patterns of resource use, infrastructure demand, and energy consumption (Lincke & Hinkel, 2021; Vousdoukas et al., 2023). For example, rural-to-urban migration often leads to increase per capita emissions as new arrivals transition from subsistence livelihoods to urban lifestyles characterized by higher energy intensity, greater reliance on fossil fuels, and denser built environments (Ottelin et al., 2015; Ribeiro et al., 2019). Displaced populations may require emergency transport, temporary shelters, and resettlement infrastructure, all of which are carbon-intensive processes. Conversely, some forms of migration could reduce emissions if populations are relocated from high-emission zones to areas with cleaner energy sources and more efficient infrastructure (Tunio et al., 2025).

Moreover, forced migration due to climate change often leads to unplanned growth of informal settlements, especially in rapidly urbanizing cities in the Global South. These settlements frequently lack sustainable energy systems and public transportation networks, exacerbating emissions (Das et al., 2024; Hoffmann & Muttarak, 2021). Despite its significant policy implications, the link between climate-induced migration and carbon footprints remains underexamined, with few empirical studies explicitly addressing this intersection (Hauer, 2017; McMichael et al., 2020).

Building on these perspectives, this review aims to synthesize the research on how climate-induced migration affects carbon footprints. Its purpose is to examine the key migration drivers, their impact on emissions, and policy responses that can reduce environmental consequences. Using case studies from the U.S. and developing countries, this study addresses the research gap at the intersection of migration, climate change, and sustainability. Its significance lies in its interdisciplinary approach, which combines insights from climate science, migration studies, and policy to demonstrate how displacement drives and responds to environmental change. This review offers practical guidance for supporting low-carbon climate-resilient migration strategies.

2. Methodology

This study presents an in-depth review of climate-induced migration across global regions, emphasizing its environmental, social, and carbon implications. To ensure analytical rigor and comprehensive coverage, a total of 152 scholarly articles were systematically selected and analyzed. The review aimed to capture diverse regional experiences and policy responses, with particular attention to the interconnections between environmental stress, human mobility, and carbon transitions.

The literature search was conducted between January and May 2025 across major academic databases, including Scopus, ScienceDirect, Web of Science, JSTOR, and Google Scholar. Supplementary reports were also obtained from reputable institutional sources such as the United Nations High Commissioner for Refugees (UNHCR), International Organization for Migration (IOM), and the Intergovernmental Panel on Climate Change (IPCC). The search covered publications from 2005 to 2025, encompassing both foundational works and recent studies. Keywords and Boolean operators were used in various combinations, including "*climate migration*," "*environmental displacement*," "*carbon footprint*," "*climate adaptation*," "*resilience*," and "*low-carbon transitions*," to ensure comprehensive coverage of relevant literature.

A structured and transparent selection process guided the identification and refinement of sources. The initial database search produced 356 articles. After removing 111 duplicate and overlapping records, 245 unique papers remained for preliminary screening. Titles and abstracts were examined to determine their direct relevance to climate-induced migration, environmental stressors, adaptation frameworks, and carbon emission dynamics. Following this step, 182 full-text articles were assessed for methodological soundness, data quality, and thematic significance. Studies were included if they met at least one of the following conditions: they examined migration driven by environmental or climatic stressors; explored the relationship between migration and carbon emissions or energy use; or discussed adaptation, resilience, and policy frameworks related to climate mobility.

Through careful evaluation and quality checks for methodological transparency, regional balance, and empirical rigor, a total of 152 articles were retained for final synthesis. These studies represented a mix of peer-reviewed journal papers, policy reports, and case studies drawn from coastal, arid, semi-arid, highland, and island regions across the world. Collectively, they provided a robust foundation for cross-regional comparison and policy-oriented interpretation.

The analytical process employed a thematic content analysis approach, categorizing studies according to geographical context, type of migration, carbon implications, and socioeconomic dimensions such as gender, age, and livelihood. This approach allowed for the identification of key patterns and contrasts in vulnerability, adaptation strategies, and carbon redistribution associated with migration. Special emphasis was placed on understanding how environmental pressures shape mobility decisions and how migration, in turn, influences carbon intensity and sustainability outcomes. The selection process is summarized **Figure 1**.

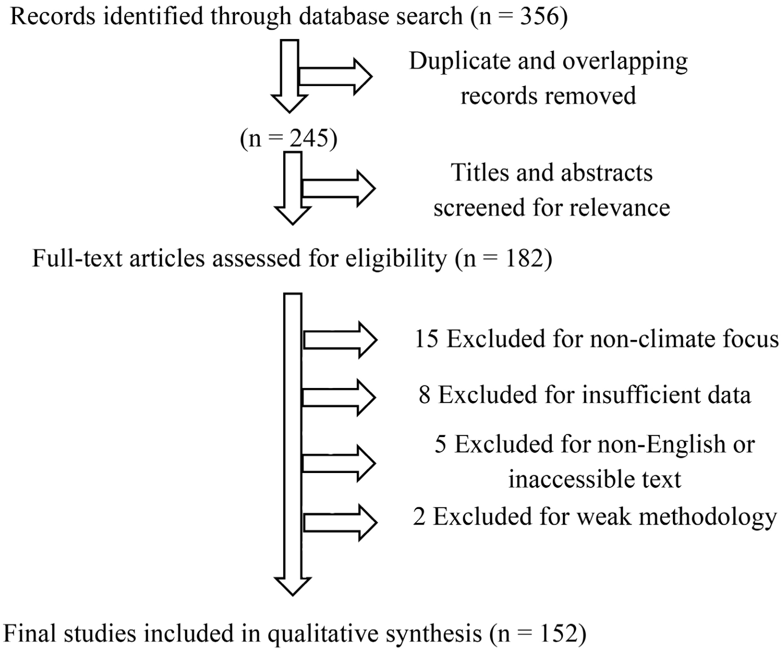

Figure 1. Flow diagram of literature selection process.

3. Overview of Climate Change-Induced Migration

3.1. Historical Context and Current Trends in Climate-Induced Migration

As summarized in **Table 1**, over the past century, environmental changes, ranging from droughts to sea level rise, have driven significant human migration, primarily within national borders. **Table 1** also highlights the major extreme weather events that caused large-scale displacement and increased carbon emissions. Key drivers include storms, floods, and heavy rainfall, resulting in millions being displaced in some cases. Early examples include the 1930s Dust Bowl in the United States, where drought and soil degradation forced hundreds of thousands from the Midwest to California (Stephens, 2023), and the drying of the Aral Sea in Central Asia since the 1960s, displacing entire communities and collapsing local economies (Gupta, 2020). These historical cases illustrate how environmental stress—whether slow-onset or sudden—has long triggered dramatic population shifts, well before “climate migration” became a focal policy concern.

In recent decades, the frequency and magnitude of environmental displacements have intensified. According to the Internal Displacement Monitoring Centre (IDMC), 30.7 million people were newly displaced by weather-related disasters in 2020 alone, with floods, storms, wildfires, and extreme heat among the main drivers (IDMC, 2021a). By the end of 2023, an estimated 7.7 million people remained displaced due to climate-related events, reflecting unresolved vulnerabilities and limited adaptation capacities (IDMC, 2025b). These trends highlight the persistent and evolving nature of environmental migration in the face of intensified climate risks.

Looking ahead, projections suggest that environmental migration will escalate both in scale and complexity. The World Bank forecasts that by 2050, between 44 and 216 million people could become internal climate migrants, particularly in sub-Saharan Africa, South Asia, and Latin America, driven by sea-level rise, declining crop yields, and worsening droughts (Clement et al., 2021). For instance, in Sub-Saharan Africa, recurrent wildfires displaced approximately 42,000 people between 2014 and 2023, while up to 25 million people could be exposed to fire hazards by 2090. Similarly, in Central America’s “Dry Corridor,” migration surged by nearly 500% between 2010 and 2015 due to persistent drought, with millions expected to relocate if aridity persists (Balsari et al., 2020). These patterns reflect a growing reliance on migration as a survival strategy, reshaping demographic landscapes and challenging conventional adaptation policies.

Table 1. Historical context and current trends in climate-induced migration.

Time/Event	Location	Displacement Estimate	Climate Driver	Ref.
1930s Dust Bowl	United States (Midwest → California)	Hundreds of thousands migrated to California for agricultural labor	Drought, soil degradation	(Stephens, 2023)
1960s-present Aral Sea shrinkage	Central Asia (Uzbekistan, Kazakhstan)	Displacement of fishing communities; collapse of local economies	Water mismanagement, desertification	(Gupta, 2020)
2005 Hurricane Katrina	United States (Gulf Coast)	- 1.5 million displaced; - 400,000 permanently	Storm surge, coastal flooding	(Sovacool & Linnér, 2016)
2007 Cyclone Sidr	Bangladesh (Coastal Delta)	- 3.2 million evacuated; 620,000 sheltered in cyclone centers	Storm surge, high winds	(OCHA, 2007)
2009 Cyclone Aila	Bangladesh, India	- 500,000 evacuated	Coastal flooding, salinization	(Action Aid, 2009)
2010-2015 Dry Corridor migration surge	Central America (El Salvador, Honduras, Guatemala)	- 500% increase in rural-to-urban and international migration	Drought, crop failure	(Balsari et al., 2020)
2017 Hurricane Harvey	United States (Texas)	- 30,000 sheltered; >100,000 affected	Extreme rainfall, flooding	(Wang et al., 2018)
2020 Cyclone Amphan	Bangladesh, India	- 2.4 million displaced (India), - 2.6 million (Bangladesh)	Storm surge, high winds	(WMO, 2020)

Continued

2020-2023 Horn of Africa drought	Ethiopia, Somalia, Kenya	- 13.5 million displaced internally and regionally	Prolonged drought	(WHO, 2023)
2020 Jakarta Floods	Indonesia (Jakarta)	- 60,000 temporarily displaced	Intense rainfall, drainage failure	(AHA, 2020)
2020 (annual)	Global	- 30.7 million newly displaced due to weather-related disasters	Floods, storms, wildfires, heatwaves	(IDMC, 2021a)
2021 Typhoon Rai (Odette)	Philippines	- 631,402 displaced	Tropical cyclone, storm surge	(HCT, 2021)
2021 European Floods	Germany, Belgium, Netherlands	- tens of thousands displaced	Extreme rainfall, river flooding	(Kimutai et al., 2024)
2022 Hurricane Ian	United States (Florida)	- 2.5 million	Storm surge, wind damage	(LaMarre, 2024)
2022 Pakistan Floods	Pakistan (Sindh, Balochistan)	- 8 million displaced	Monsoon intensification, glacial melt	(Rehmat et al., 2023)
2023 Cyclone Mocha	Myanmar, Bangladesh	- 750,000 people estimated evacuated (Bangladesh)	Storm surge, high winds	(IFRC, 2023)
2023 Libyan Floods	Libya (Derna region)	- 45,000 displaced	Extreme rainfall, dam collapse	(Salhi et al., 2024)
2023 (as of year-end)	Global	- 7.7 million people remained displaced due to unresolved climate impacts	Various	(IDMC, 2025b)
Projected 2050	Sub-Saharan Africa, South Asia, Latin America	44 – 216 million internal climate migrants expected	Sea-level rise, drought, crop failure	(Clement et al., 2021)
Projected 2090 (high-warming scenario)	Sub-Saharan Africa	Up to 25 million exposed to fire hazards; continued displacement expected	Wildfires	(IOM, 2023)

3.2. Key Drivers of Climate-Induced Migration

Climate-induced migration is driven by a complex interaction of environmental stressors that disrupts livelihoods, damages infrastructure, and renders regions uninhabitable. The three most consistently identified environmental drivers are extreme weather events, sea-level rise, and resource scarcity, all of which have intensified owing to global climate change (Almulhim et al., 2024; Duijndam et al., 2022; Hauer, 2017). These factors do not act in isolation; instead, they compound existing social and economic vulnerabilities, particularly in regions with weak adaptive infrastructure.

3.2.1. Extreme Weather Events

Extreme weather events such as tropical cyclones, floods, droughts, and heat waves are among the most immediate and decisive environmental stressors driving climate-induced migration, displacing millions of people annually and redistributing carbon burdens across regions. Their frequency and intensity have significantly increased owing to climate change, with rising global temperatures contributing to a 58% rise in such events since the 1980s (NOAA_NCEI, 2025). These sudden-onset hazards destroy homes, overwhelm coping capacities, and degrade infrastructure and natural resources, rendering continued habitation untenable for affected populations.

Table 2. Weather-related displacement and disaster event frequency (2008-2024).

Year	Flood	Storm	Drought	Wildfire	Wet mass movement	Extreme temperature	Number of events	Total displaced per year
2008	11,500,000	10,000,000	-	54,000	31,000	829,000	164	22,414,000
2009	7,400,000	7,800,000	-	8,400	24,000	22,000	104	15,254,400
2010	36,200,000	2,000,000	-	17,000	75,000	-	132	38,292,000
2011	10,300,000	3,100,000	-	4,300	403,000	88,000	117	13,895,300
2012	19,800,000	9,600,000	-	59,000	47,000	3,500	162	29,509,500
2013	6,100,000	14,100,000	-	85,000	5200	16,000	607	20,306,200
2014	8,200,000	9,100,000	-	48,000	64,000	6,000	649	17,418,000
2015	8,300,000	6,300,000	-	87,000	52,000	2,000	561	14,741,000
2016	10,200,000	13,100,000	-	336,000	19,000	85,000	552	23,740,000
2017	8,600,000	7,500,000	1,300,000	419,000	37,000	4,200	877	17,860,200
2018	5,400,000	9,600,000	766,000	425,000	192,000	24,000	1500	16,407,000
2019	10,000,000	13,400,000	294,000	528,000	67,000	24,000	1800	24,313,000
2020	14,100,000	14,800,000	62,000	1,200,000	101,000	46,000	1800	30,309,000
2021	10,100,000	11,500,000	256,000	454,000	37,000	20,000	1200	22,367,000
2022	19,200,000	10,000,000	2,200,000	369,000	37,000	15,000	2200	31,821,000
2023	9,700,000	9,500,000	491,000	460,000	120,000	4,700	3700	20,275,700
2024	9,700,000	9,500,000	491,000	460,000	120,000	4,700	4700	20,275,700
Total	204,800,000	160,900,000	5,860,000	5,013,700	1,431,200	1,194,100	20,825	379,199,000

Data Source: IDMC's global internal displacement database (IDMC, 2025a).

Specific cases illustrate the impacts of these disasters on migration. In Bangladesh, repeated cyclones, such as Sidr and Amphan, have devastated coastal districts, destroying homes, crops, and infrastructure and triggering both temporary evacuation and longer-term rural–urban and cross-border migration (Kartiki, 2011; Mustafa et al., 2023; Gupta et al., 2025; Ahsan & Özbek, 2022). Here, unplanned settlement expansion, increased energy demand, and rising transportation-related emissions create new environmental and social pressure. Similarly, across South and Southeast Asia, increased flood frequency and coastal salinization have driven significant rural migration (Almulhim et al., 2024; Çelekli et al., 2023; Duijndam et al., 2022; Martyr-Koller et al., 2021). In wealthier regions such as the U.S, hurricane-induced relocation from regions such as the Gulf Coast and southern Florida has caused long-term demographic shifts inland, exacerbating carbon emissions in recipient cities (Duijndam et al., 2022; Robinson et al., 2019, 2020). Vulnerable groups, particularly children and those in low-income countries, face disproportionate impacts from climate extremes, with over 43 million child displacements recorded between 2016 and 2021 and an estimated 113 million more projected by 2054 as risks intensify (UNICEF, 2023). Scientific studies confirm that human-driven climate change has intensified heavy rainfall events, as evidenced by catastrophic floods in Texas in 2025 (Faranda et al., 2025). As **Table 2** shows, between 2008 and 2024, floods and storms were the top drivers of climate-induced displacement, accounting for over 204 and 161 million displacements, respectively. Significant spikes occurred in 2010, mainly driven by floods in Pakistan that displaced around 20 million people (Shabir, 2013), and in 2020, Cyclone Amphan and global flood events contributed to over 30 million weather-related displacements (IDMC, 2021b).

Other hazards, such as wildfires and droughts, caused fewer but notable displacements. The 2020 Australian bushfires led to 65,000 new wildfire-related displacements (IDMC, 2021b), while the Horn of Africa drought (2020-2023) displaced millions due to prolonged water stress (WHO, 2023). These trends underscore the increasing influence of climate extremes on human migration. Although there is no consistent pattern in the level of displacements from year to year, the intensity and frequency of reported weather-related events have markedly increased over time, rising from just over 100 in 2008 to more than 4700 in 2024—nearly a 45-fold increase, as shown in **Table 2**. As these extreme weather hazards become increasingly common, migration, particularly internal displacement, serves as a primary adaptive response, underscoring the urgent need for resilient infrastructure, early warning systems, and inclusive climate adaptation policies.

3.2.2. Sea Level Rise

Sea level rise (SLR) is a gradual but disruptive climate stressor that steadily erodes the viability of coastal regions and amplifies their long-term displacement. It exacerbates tidal flooding, shoreline erosion, saltwater intrusion into groundwater, and the loss of arable land, all of which undermine food security, housing, and freshwater supply. Vousdoukas et al. (2023) projected that under a high-emissions scenario, SIDS could face a more than 14-fold increase in flood-related damages by 2100, while even a 1.5˚C warming threshold may render entire islands uninhabitable. In Bangladesh, Bhuiyan and Siddiqui [23] and Duque (Duque, 2024) observed a growing trend of inland migration from coastal deltas, primarily in under-resourced cities, such as Khulna and Dhaka. These urban centers are experiencing an increase in carbon emissions due to increased housing demand, transportation congestion, and the expansion of informal settlements. Hauer et al. (2016) similarly estimated that over 13 million U.S. residents could be displaced under 1.8 meters of SLR, reinforcing inland migration trends. Following displacement, migrants often transition from subsistence-based rural livelihoods to high-emission urban lifestyles, straining the existing infrastructure (Das et al., 2024; Hauer, 2017). **Table 3** summarizes the key impacts of sea-level rise on human migration and ecosystems in several vulnerable regions worldwide. Gradual sea-level rise and storm surges have led to significant displacement trends, primarily from rural coastal areas to urban centers.

Table 3. Projected impacts of Sea-Level Rise (SLR) on migration and ecosystems in vulnerable regions.

Region/ Country	SLR Impact Type	Primary Stressor	Displacement Trend	Urban Center (s)	Projected Displacement by 2100	Ecosystem Impacts	Ref.
Bangladesh	Saltwater intrusion, land loss	Gradual (SLR)	Inland rural-to-urban migration	Khulna, Dhaka	- 2 million at 1 m SLR, - 5.4 million at 3 m SLR	Sundarbans mangrove degradation	(Bhuiyan & Siddiqui, 2022; Dasgupta et al., 2021; Duque, 2024)
Pacific SIDS	Tidal flooding, coastal erosion	Gradual (SLR), storm surge	Internal displacement; international migration	Capitals or international resettlement	Potentially entire populations (50 cm - 1 m rise)	Land and coral reef loss, freshwater salinization	(Kumar et al., 2020; Martyr-Koller et al., 2021)
U.S. Gulf Coast	Tidal flooding, land subsidence	Gradual (SLR), storm surge	Inland migration	Houston, Atlanta, Orlando	- 13 million U.S. displaced under 2 m SLR	Wetland loss (Mississippi Delta)	(Hauer, 2017; Hauer et al., 2016, 2020)
Vietnam (Mekong Delta)	Land loss, salinization	Gradual (SLR)	Rural-to-urban movement	Ho Chi Minh City	- 12 millions	Wetland conversion, rice paddy disruption	(Ballesteros et al., 2025; Chapman & Tri, 2018; Lukyanets et al., 2015)
Egypt (Nile Delta)	Coastal flooding, saltwater intrusion	Gradual (SLR)	Rural exodus to cities	Cairo, Alexandria	- 887,000 at 1 m SLR	Loss of delta wetlands, cropland degradation	(Hasan et al., 2015; Sušnik et al., 2015)
Papua New Guinea (coastal)	Coastal erosion, saltwater intrusion	Gradual (SLR)	Internal relocation to inland highlands	Kerema region towns	- 40,000 displaced recently	Mangrove and beach erosion	(Connell & Lutkehaus, 2018; IOM, 2025b)
Fiji	Coastal erosion, saltwater intrusion	Gradual (SLR)	Village-level relocations	Interior towns	- 48 of 830 villages by 2100	Vegetation loss in resettlement zones	(McMichael et al., 2019; Sušnik et al., 2015)

3.2.3. Resource Scarcity

As illustrated in **Figure 1**, resource scarcity, particularly water and food shortages, has become a major driver of environmental migration, compelling millions to relocate, both internally and across borders. In sub-Saharan Africa, prolonged droughts have led to more frequent displacement, with an estimated 1.6 million new drought-linked displacements between 2009 and 2018, and Somalia alone experienced nearly 926,000 drought-related moves during 2016-17 (Ceola et al., 2023). These movements commonly flow toward rivers and urban areas, where displaced communities seek access to water and livelihoods. In the Horn of Africa (2020-23), severe drought has driven approximately 13.5 million people into displacement, exacerbating humanitarian crises and testing fragile societal systems

(WHO, 2023).

In rural Mexico, agricultural communities affected by droughts exhibit increased undocumented migration to the U.S., with individuals being less likely to return when extreme weather conditions persist (Zhu et al., 2024). Similarly, government reports in Iran indicate that approximately 800,000 people migrated to Mazandaran between 2021 and 2023, mainly from areas affected by climate-related water scarcity (Rostami & Paski, 2024). As illustrated in **Figure 2**, climate-induced resource scarcity causes migration for several reasons, including water scarcity, food insecurity, land degradation, energy shortages, and livelihood loss. These resource-driven migrations often strain urban infrastructure, exacerbate socioeconomic tensions, and serve as adaptation strategies and potential conflict triggers. As climate change intensifies, resource scarcity increasingly drives migration, rendering effective water management, climate resilience, and sustainable urban planning essential for large-scale mitigation.

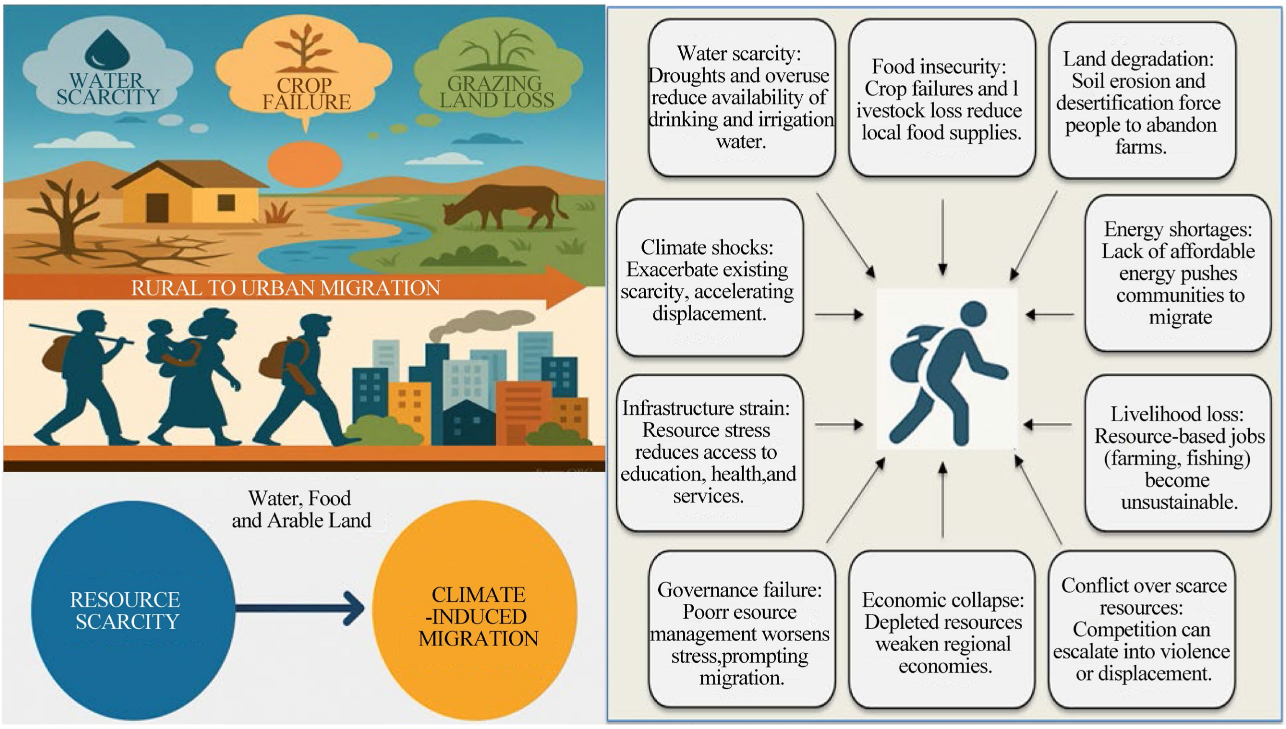

Figure 2. Reasons why resource scarcity drives climate-induced migration.

4. Carbon Footprint: Definition and Measurement

4.1. Definition of Carbon Footprint

A carbon footprint is broadly defined as the total greenhouse gas emissions, primarily carbon dioxide (CO_2), produced directly or indirectly by human activities, and expressed as carbon dioxide equivalent (CO_2e). As shown in **Table 4**, this general definition can be further refined into several categories based on contextual focus. Lifecycle-based definitions measure emissions throughout the lifespan of a product or service, from raw material extraction to disposal, highlighting impacts such as supply chain disruptions linked to climate migration. They often incorporate Life Cycle Assessment (LCA) methodologies and quantify scope 1, 2, and 3 emissions. Activity-based definitions focus on emissions from daily human or organizational activities, providing insight into personal carbon tracking and mobility patterns related to climate-induced migration. Quantification-focused definitions emphasize the precise measurement of multiple greenhouse gases using standardized metrics, such as Global Warming Potential over 100 years (GWP100). This enables consistent comparisons across sectors and regions, which are essential for modeling migration impacts. Lastly, ecological or hybrid definitions place carbon footprints within a broader environmental framework, including land use, biodiversity, and resource consumption, emphasizing planetary boundaries and resource scarcity, which contribute to ecosystem stress and influence climate migration. These varied definitions reflect the multifaceted nature of carbon accountability and its link to climate-induced migration.

Table 4. Definitions of carbon footprint.

Category	Conceptual Focus	Example Carbon Footprint Definition	Ref.
Lifecycle-Based	Emissions measured across the full life cycle—resource extraction, production, use, and disposal.	The exclusive total amount of CO_2 emissions directly and indirectly caused by an activity or accumulated over the lifecycle stages of a product.	(van Diemen et al., 2022)
		The total amount of CO_2 and other greenhouse gases emitted over the full life cycle of a product or activity, expressed in CO_2-equivalents.	(Durojaye et al., 2020)
		A measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product	(Wiedmann & Minx, 2008)
Activity-Based	Emissions linked to individual, organizational, or systemic daily activities and consumption.	The quantity of CO_2 emitted due to human daily activities, including direct and indirect emissions across the life cycle of goods and services.	(Durojaye et al., 2020)
		The total greenhouse gas emissions for which an organization, a product or a person is directly or indirectly responsible	(UNESCO, 2025)
Quantification-Focused	Emissions expressed in CO_2-equivalents using GWP100, often covering multiple GHGs and defined boundaries.	A measure of the total amount of CO_2 and CH_4 emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as CO_2e using the relevant 100-year global warming potential (GWP100).	(Wright et al., 2011)
Ecological/Systems Approach	Carbon footprint integrated within broader ecological or sustainability frameworks.	The biologically productive global hectares needed to absorb CO_2 emissions from fossil fuel use, forming part of the ecological footprint and reflecting human demand relative to Earth's biocapacity.	(GFN, 2025)

4.2. Methods for Calculating Carbon Footprints

As shown in Figure 3, various methods have been developed to effectively calculate carbon footprints to understand and manage the environmental impact of human activities. Each offers distinct details, scope, and applicability depending on the context of use. They also have different advantages and disadvantages, and have been categorized by application scale based on the intended users and the level at which decisions are made.

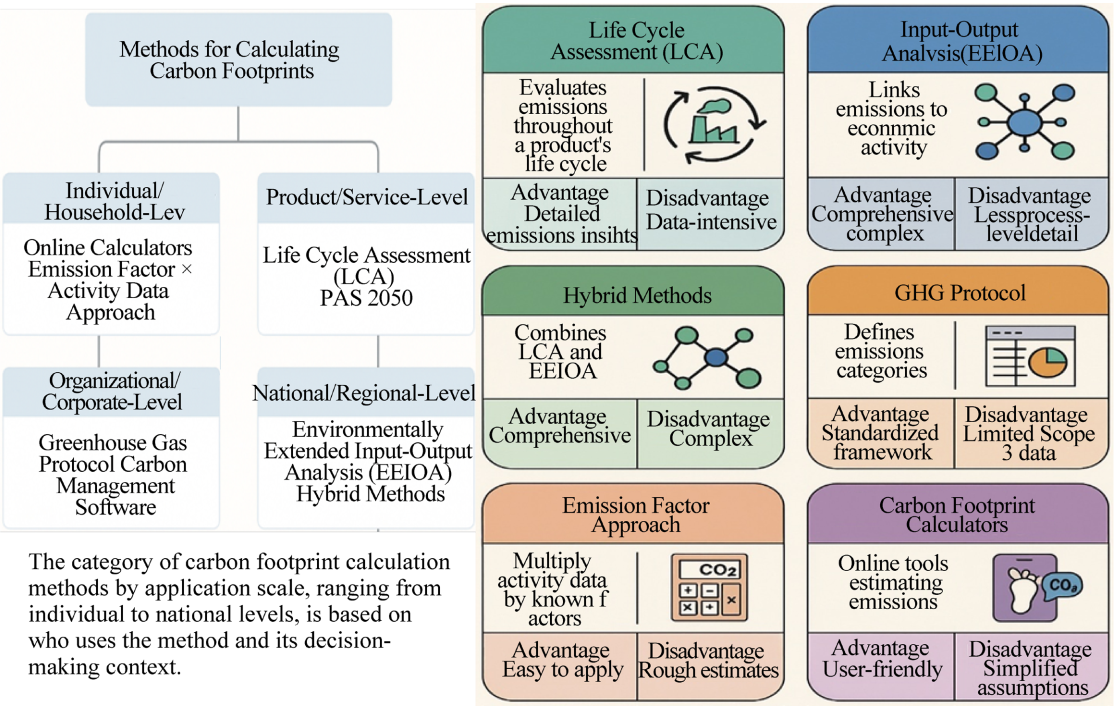

Figure 3. Categories, advantages, and disadvantages of carbon footprint calculation methods.

4.2.1. Individual and Household-Level Methods

Individual- and household-level methods help people understand and quantify greenhouse gas emissions from their daily activities, such as energy use, transportation, and consumption. These approaches are typically user friendly and aim to raise awareness and encourage low-carbon lifestyle choices. Online and mobile carbon footprint calculators have become increasingly popular in the interest of public awareness and engagement. Tools such as the UN Carbon Footprint Calculator, CoolClimate Calculator (UC Berkeley), and WWF footprint tool enable users to estimate their emissions based on lifestyle inputs (Spandonidis et al., 2024). These calculators are user-friendly and widely accessible; however, their simplification of assumptions and regional differences means that the results may be approximate rather than precise. Emission factor and activity data approaches are commonly used for more accessible and straightforward assessments. This involves multiplying activity levels (such as kilometer-driven or kilowatt-hours consumed) by established emission factors from authoritative sources such as the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2006). It is easy to apply, especially to individuals and smaller businesses. However, this method provides only rough estimates, and may not account for upstream or supply chain emissions.

4.2.2. Product- and Service-Level Methods

Product- and service-level methods focus on calculating the carbon footprint associated with the full lifecycle of specific goods or services. These approaches are often used in supply chain management, sustainability labeling, and environmental product declarations to support informed production and consumption decisions. One of the most comprehensive and standardized approaches for measuring carbon footprints is Life Cycle Assessment (LCA). This method evaluates the greenhouse gas emissions associated with every stage of a product's life, from raw material extraction through production, use, and disposal. LCA is internationally recognized and guided by ISO standards (ISO 14040 and 14044), making it highly reliable for product- and service-level assessments (Pandey et al., 2011). LCA's main advantage of LCA is its ability to provide detailed process-specific insights into emission sources. However, it is also data-intensive and time-consuming, often requiring extensive data collection and specialized expertise for effective execution. PAS 2050, developed by the British Standards Institution (BSI), is a standardized method for calculating the life cycle greenhouse gas emissions of goods and services. It uses Life Cycle Assessment (LCA) principles to evaluate emissions from raw material extraction through production, use, and disposal (Čapla et al., 2025). Its main advantage lies in its consistency and usefulness for carbon labeling and product comparisons. However, it is data intensive and limited to product-level assessments, making it less suitable for organizations or events.

4.2.3. Organizational and Corporate-Level Methods

Companies and institutions use these methods to quantify, report, and manage greenhouse gas emissions across operations and value chains. They provide a basis for regulatory compliance, sustainability reporting, emission reduction strategies, and alignment with international climate goals. The Greenhouse Gas (GHG) protocol is an essential framework that businesses, institutions, and governments use. It organizes emissions into three categories: scope 1 (direct emissions), scope 2 (indirect emissions from purchased energy), and scope 3 (all other indirect emissions, including those from supply chains and end-use) (Čapla et al., 2025). The protocol's biggest advantage is its standardization and global recognition, which makes it useful for corporate reporting and target setting. A limitation, however, is that Scope 3 emissions are often difficult to measure accurately because of the limited data availability and methodological variability. In addition, organizations and corporations frequently use carbon management software platforms, such as SimaPro, OpenLCA, and Carbon Trust Footprint Expert. These tools allow for the integration of detailed emissions accounting with monitoring, reporting, and policy alignment (e.g., CDP reporting and Science-Based Targets) (Sartori, 2023). Their main strengths include automation, comprehensiveness, and adaptability to institutional needs. However, these can be costly, require training, and depend on the availability of high-quality input data.

4.2.4. National and Regional-Level Methods

National and regional methods aim to assess carbon footprints on a macro scale, linking emissions to economic activity and consumption patterns across all economies or sectors. These approaches are essential for policymaking, environmental monitoring, and evaluating the effectiveness of climate-mitigation strategies. Environmentally extended input-output analysis (EEIOA) is a widely used method in this category. This approach links environmental impacts to economic activity using national input-output tables, allowing the calculation of indirect emissions associated with consumption, such as emissions embedded in imported goods (Aguilar-Hernandez et al., 2018). The EEIOA is especially useful for national or regional assessments, providing a broader, top-down perspective. Its main advantages lie in its scalability and ability to capture supply chain emissions. However, EEIOA is less detailed at the process level, and its accuracy depends on the quality and granularity of the national economic and environmental data. In addition, researchers often use hybrid methods to combine the strengths of LCA and EEIOA. These integrate the bottom-up details of LCA with the top-down coverage of EEIOA, resulting in more comprehensive and accurate carbon-footprint calculations. Hybrid approaches are ideal for complex systems or products with well-documented and data-limited components (Crawford et al., 2018). Their flexibility is a major advantage; however, they also inherit the complexity of both underlying methods, requiring advanced modeling skills and significant data harmonization.

4.3. Importance of Assessing Carbon Footprints for Individuals and Communities

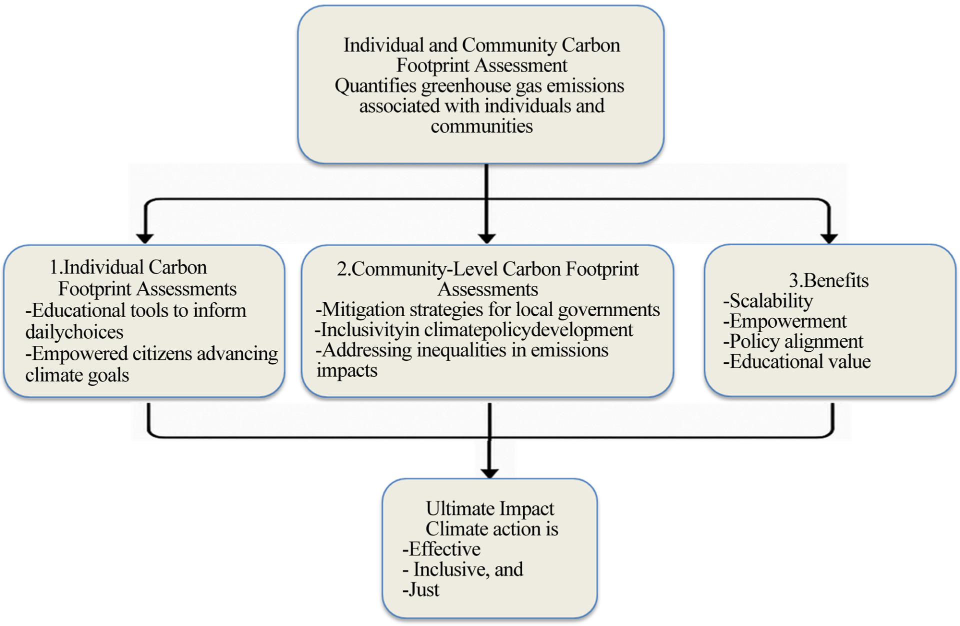

Figure 4. Importance of individual and community carbon footprint assessment.

Individual and community carbon footprint assessments quantify greenhouse gas emissions to evaluate the role of personal and local actions on climate change. Although these methods vary, they aim for comprehensive accountability. As shown in **Figure 4**, these assessments support education, inclusive policies, and mitigation strategies, laying the groundwork for scalable, just, and effective climate action, as discussed below.

4.3.1. Individual Carbon Footprint Assessments

The United Nations Environment Program emphasizes that individual carbon footprint calculators, such as those on its platform, are powerful educational tools (UNEP, 2016). They quantify emissions and help individuals understand the environmental impacts of daily choices from meat consumption to air travel. Studies (Thøgersen & Crompton, 2009) show that this awareness can lead to measurable reductions in emissions through voluntary behavior change, such as switching to public transportation or adopting plant-based diets. Increased carbon literacy is a prerequisite for the deep decarbonization of societies. The UNDP Human Development Report (UNDP, 2020) discusses the importance of "empowered citizens" empowering citizens to advance climate goals (UNDP, 2020). Individuals can take ownership of the issue by assessing their carbon footprints, transforming climate action from a distant policy goal to a personal commitment.

4.3.2. Community-Level Carbon Footprint Assessments

Communities, especially urban municipalities and rural localities, represent the nexus of energy use, transportation systems, waste management, and housing. Community-level carbon assessments allow local governments and grassroots organizations to identify high-emission sectors and implement tailored mitigation strategies. The UN-Habitat (OECD, UN-Habitat, UNOPS, 2021) report noted that local governments often lack comprehensive data to reduce emissions (UN-Habitat, 2022). By conducting community carbon audits, cities can prioritize energy-efficient infrastructure, promote green public transit, and enforce building codes to reduce carbon emissions. Community carbon footprint assessments foster inclusivity and the co-creation of climate policies. They allow citizens to participate in environmental governance, thereby increasing the legitimacy and effectiveness of policy interventions. Research by Middlemiss and Parrish (2010) indicated that such participatory approaches are crucial for sustained community engagement and emission reductions. Carbon assessments at the community level also illuminate inequalities in emissions and exposure to climate change risks. UNESCAP (UNESCAP, 2022) identifies that low-income communities often contribute less to emissions but are disproportionately affected by climate change. Thus, carbon footprinting has become a tool not only for environmental analysis but also for climate justice and equity.

4.3.3. Benefits

One of the principal benefits of individual- and community-level carbon footprint assessments is scalability. When aggregated, these assessments provide valuable input into national greenhouse gas (GHG) inventories, enhancing the accuracy and granularity of country-level emission reporting (Wiedmann & Barrett, 2010). This bottom-up approach complements traditional top-down accounting methods and allows for more targeted mitigation efforts. Empowerment is another significant advantage. Carbon footprint assessments encourage active engagement with climate solutions by enabling individuals and communities to understand their specific contributions to climate change (Thøgersen & Crompton, 2009; UNDP, 2020). This can foster a sense of responsibility and agency, particularly when paired with tools and policies that facilitate behavioral change. Policy alignment is thus a key benefit. Community-level assessments provide essential data for local governments to establish emission baselines and formulate informed place-specific climate action plans (Diedrich, 2024). This enhances policy coherence between the regional and national levels and supports the implementation of global climate agreements at the grassroots level. Finally, these assessments offer a considerable educational value. They help demystify climate systems and make abstract environmental issues tangible to the public (UNEP, 2016). Through increased carbon literacy, individuals are better equipped to make informed decisions regarding their consumption habits and support broader climate initiatives.

Therefore, assessing carbon footprints at the individual and community levels empowers informed action, supports targeted local mitigation, and enhances national climate strategies. It fosters behavioral change, participatory governance, and equity, ultimately contributing to effective, inclusive, and just climate solutions.

5. The Relationship between Migration and Carbon Footprints

Migration, both internal and international, is increasingly recognized as a factor influencing global and regional carbon footprints; however, its environmental dimensions remain underexplored in mainstream climate discourse. As people relocate due to economic opportunities, conflict, or climate stress, their movement alters patterns of energy use, land occupation, and resource consumption in both origin and destination regions. According to the International Organization for Migration (IOM, 2017), population movements can affect emissions directly through transportation and housing demands and indirectly by reshaping urban development, infrastructure needs, and consumption behavior. Recent studies (Dedeoğlu et al., 2021; Gao et al., 2022) have confirmed that migration can amplify or redistribute greenhouse gas emissions, depending on the socio-economic context and policy frameworks of host and sending areas. With increasing rates of climate-induced displacement and voluntary migration, it has become critical to understand how migration interacts with carbon-intensive systems and contributes to both mitigation challenges and opportunities.

As illustrated in **Figure 5**, climate-induced migration influences carbon footprints through direct impacts, such as emissions from transport, land conversion, and urban infrastructure stress, and indirect impacts, such as increased consumption from remittances, trade-related emissions, and long-term infrastructure effects. These interconnected dynamics emphasize the cross-regional nature of migration-driven emissions and the need for integrated climate, migration, and development planning, as detailed in the following sections.

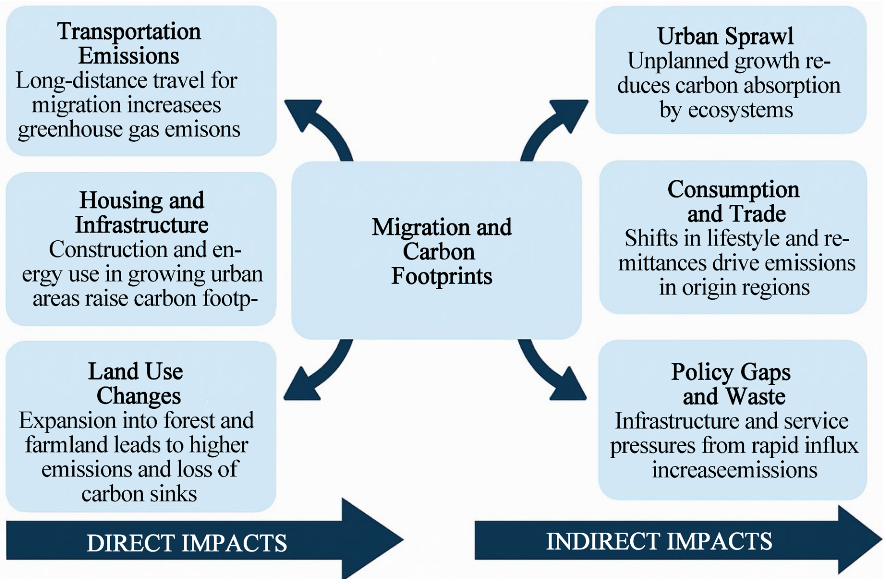

Figure 5. Direct and indirect impacts of climate-induced migration on carbon footprint.

5.1. Direct Impact

The direct impacts of climate-induced migration on carbon footprints are immediate GHG emissions from displacement activities, including transport, temporary housing construction, and increased energy use in host areas. Transportation emissions are direct and significant contributors to the carbon footprint of migration. Long-distance travel, especially by air, associated with international and rural-to-urban migration leads to short-term spikes in GHG emissions (Gao et al., 2022). Statista reported that, in 2023, transport is the second largest emitter of GHG, accounting for 15% of global emissions (Tiseo, 2025), with migration-related movements adding pressure, particularly in the absence of low-carbon transit options (IPCC, 2022). Emergency responses, aid logistics, and fossil-fuel-dependent mobility further inflate emissions, especially in crisis-driven migrations (Das et al., 2024). Over time, migrants often shift from low-emission rural lifestyles to carbon-intensive urban living, increasing long-term urban emissions and complicating mitigation efforts. These trends highlight the need to integrate low-carbon transport strategies into migration management and urban-planning frameworks.

Housing and urban infrastructure are major direct contributors to migration-related carbon footprints, particularly in fast-growing cities. As migrants settle, the demand for housing, transport, and services increases, driving construction and energy use. The sector accounts for 39% of global energy-related CO_2 emissions: 11% from materials and 28% from operations (Hamilton et al., 2020). Liu et al. (2020) estimated that without technological advances, urbanization in China could more than double energy demand and increase CO_2 emissions by 82% by 2050. Migration-linked urbanization also raises per capita emissions in host areas (Ottelin et al., 2015; Ribeiro et al., 2019) and often leads to inefficient, high-emission infrastructure, where planning is weak (Dedeoğlu et al., 2021). Without low-carbon strategies, such growth risks undermine broader climate goals.

Migration-driven land-use changes, such as deforestation, agricultural expansion, and urban sprawl, intensify carbon emissions and weaken ecosystem stability. Climate-induced migrants settling in sensitive or unregulated areas increase their demand for land, prompting forest and wetland conversion for housing and farming. Although migrants are not usually direct agents, their movement often triggers informal expansion that drives emissions (IOM, 2017; Van Der Geest, 2011). The AFOLU sector contributes 13% - 21% of global GHG emissions, with deforestation alone accounting for 45% (Nabuurs et al., 2022). Land conversion can release up to 750 tons of CO_2 per hectare (SL, 2015), and over 13 million hectares of forest are lost annually (Zipperer et al., 2020). In sub-Saharan Africa and Southeast Asia, over 80% of new farmland between 1980 and 2000 replaced forests (Gibbs et al., 2010). Without climate-informed planning, these trends worsen emissions and erode resilience.

Climate-induced migration often leads to a shift from low-emission rural lifestyles to more carbon-intensive urban habits, such as greater use of processed foods, appliances, vehicles, and fossil-fuel energy, increasing daily emissions in host regions. As urban population density increases due to migration, so does the demand for energy, housing, transport, and consumer goods, accelerating the development of high-emission infrastructure and straining local resources. This transition is not only demographic, but also economic and cultural, as migrants adapt to consumption behaviors embedded in urban environments. The UNEP Emissions Gap Report 2020 underscores that a large share of global emissions is driven by consumption patterns, while Hertwich and Peters (2009) estimate that household consumption—particularly food, housing, and transport—accounts for about 72% of global greenhouse gas emissions, with migrants often shifting into these high-emission categories (UNEP, 2020; Hertwich & Peters, 2009). Furthermore, urban growth linked to migration amplifies environmental pressure. These trends underscore the need to integrate low-carbon infrastructure and behavioral interventions into migration and urban planning.

5.2. Indirect Impacts

The indirect impacts of climate-induced migration on carbon footprints are secondary effects, such as changes in urban infrastructure, economic activity, and remittance-driven consumption, which influence greenhouse gas emissions over time in both origin and destination regions.

Climate-induced migration often accelerates urban sprawl and ecological degradation, as receiving regions expand to accommodate displaced populations. This unplanned growth frequently leads to the conversion of forests, wetlands, and agricultural land into built environments, thereby disrupting ecosystems, fragmenting habitats, and reducing natural carbon sinks. As impervious surfaces replace natural landscapes, the region's capacity to sequester carbon diminishes, while local temperatures and energy demand increase (IOM, 2017). At the same time, migrants are often absorbed into carbon-intensive sectors such as the construction, manufacturing, and transportation industries, which are heavily reliant on fossil fuels and are responsible for significant greenhouse gas emissions (Iqbal et al., 2025). Urban expansion and labor market shifts reinforce emission-intensive pathways, underscoring the need for climate-smart planning and low-carbon economic integration to mitigate the impacts of resettlement.

Climate-induced migration reshapes global carbon flows through interconnected shifts in remittances, trade patterns, and labor markets. As migrants relocate, their remittances often shift households from subsistence to more carbon-intensive lifestyles, increasing spending on goods, housing, and energy. According to the IOM (IOM, 2025a), such transitions are a key but overlooked driver of indirect emissions in sending regions. Empirical studies show that remittances drive emissions. Khatri et al. (Khatri et al., 2025) link remittance-led growth to rising CO_2 in top recipient countries, while Nwani et al. (Nwani et al., 2022) found similar effects in Sub-Saharan Africa due to increased consumption and trade. These changes often involve imported goods with high embodied emissions—greenhouse gases released during production and transport—that are frequently excluded from national carbon inventories. These dynamics show how migration links economies through shared emissions, complicating carbon accounting and calling for integrated climate, trade, and labor policies.

Climate-induced migration often exposes major policy and planning gaps as governments respond to infrastructure expansion that lacks a low-carbon or climate-resilient design. Without integrated frameworks, these reactive developments, such as roads, housing, and services, can lock in long-term emissions and degrade ecosystems (UN-Habitat, 2022). The IOM highlights that most countries lack strategies to align mobility with sustainable urban planning, leading to fragmented responses (IOM, 2025a). Similarly, the UNEP NDC Action Brief (UNEP & IOM, 2023) warns that uncoordinated planning risks reinforce fossil-fuel dependence. Bridging these gaps requires integrating migration into national climate policies and ensuring that resettlement supports decarbonization.

Climate-induced migration can overwhelm sanitation and utility systems, causing waste buildup, untreated water, and energy inefficiencies that increase GHG emissions. UN-Habitat (2023) highlighted that unmanaged waste and sanitation are major sources of methane and CO_2, particularly in rapidly expanding settlements (UN-Habitat, 2024). In Rohingya refugee camps, poor waste management and inadequate drainage have led to severe environmental and public health hazards (Uddin et al., 2022). Globally, over 2.7 billion people lack regular waste collection, with 40% of the collected municipal waste still dumped or burned (Whiteman et al., n.d.). The IOM further notes that informal settlements resulting from displacement often lack adequate water and waste services (IOM, 2025a). These pressures call for climate-resilient infrastructure, inclusive planning, and circular economic solutions to mitigate GHG emissions and environmental degradation in migrant-hosting regions.

6. Case Studies

6.1. Regional Examples of Climate-Induced Migration

Climate-induced migration is increasingly shaping demographic and socioeconomic landscapes worldwide. As environmental stressors such as sea-level rise, droughts, floods, and extreme weather intensify, many communities are forced to relocate either temporarily or permanently. These migration patterns vary by region, depending on the type and severity of climate impact. This section highlights case studies from coastal, arid, and semi-arid areas to illustrate how environmental changes drive migration and influence the associated carbon footprints. **Table 5** summarizes the climate-induced migration across coastal and arid/semi-arid regions. Coastal areas show diverse responses, such as planned relocation, urban migration, or immobility, driven by flooding, erosion, and sea-level rise. Arid zones face drought and land degradation, prompting seasonal and youth migration, although poverty and insecurity often limit their mobility. Together, these patterns underscore the need for equitable region-specific adaptation strategies that address both movement and immobility. This is discussed in detail in the following section.

Table 5. Regional patterns of climate-induced migration.

Region	Countries/Areas	Climate Stressors	Migration Pattern & Characteristics
West Africa (Coastal)	Ghana (Keta, Ada Foah), Côte d'Ivoire, Senegal	Flooding, erosion, saltwater intrusion	Seasonal and permanent migration; historical networks constrained by poverty and weak institutions
East & Southern Africa (Coastal)	Mozambique, Kenya	Floods, erosion	Planned relocation (Mozambique) with reversals due to livelihood loss; informal urban migration in Kenya
North Africa (Coastal)	Morocco	Sea-level rise, slow-onset changes	Voluntary immobility; strong cultural attachment and climate skepticism
South Asia (Coastal)	Bangladesh, India (Sundarbans, Ganges Delta)	Cyclones, floods	Urban migration to Khulna and Kolkata; shaped by tenure insecurity, gender norms, and economic precarity
Pakistan (Coastal)	Karachi, Thatta, Badin, Gwadar	Sea-level rise, saline intrusion	Reactive and anticipatory migration; often into informal settlements with poor infrastructure
Southeast Asia (Coastal)	Vietnam, Cambodia (Mekong Delta); Indonesia (Semarang, Bekasi, Demak, Jepara)	Tidal flooding, salinisation, land subsidence	Seasonal peri-urban migration; women disproportionately impacted due to labor and care burdens

Continued

Pacific Islands (Coastal)	Fiji (Vunidogoloa)	Sea-level rise	Planned relocation; emotional/cultural disruptions highlight importance of community-led planning
United States (Coastal)	Louisiana (Isle de Jean Charles), Florida (Miami), Alaska (Newtok), New Jersey, New York, California	Sea-level rise, hurricanes, permafrost melt	Mix of voluntary and planned relocation; federal efforts, FEMA buyouts, and urban displacement strain public infrastructure
Sahel (Arid/Semi-Arid)	Burkina Faso, Mali, Niger	Drought, desertification	Seasonal male migration; pastoralist mobility sparks resource conflicts; limited urban options and food insecurity
Transition Zones (Africa)	Ghana, Nigeria, Senegal	Erratic rainfall, land degradation	Gendered migration patterns; land access influences decisions; cities absorb displaced rural labor
Ethiopia & Tanzania (Arid)	Ethiopia (semi-arid highlands), Tanzania (Shinyanga)	Declining rainfall, crop failure	Youth and household migration; shifts from circular to permanent movement
Southern Malawi (Arid)	Southern Malawi	Drought, poverty	High desire to migrate, but many remain trapped by poverty and lack of mobility resources
Horn of Africa (Arid)	Somalia, Burundi	Conflict, weak governance	Limited migration options; many remain in worsening conditions due to insecurity and poor infrastructure
Pakistan (Semi-Arid)	Thatta, Badin, Southern Punjab	Heat stress, water scarcity, crop failure	Rural-to-urban migration to Karachi/Lahore; face precarious urban conditions
Tajikistan (Semi-Arid)	Southern regions	Drought, agricultural decline	Temporary international migration (to Russia); remittance dependency; women left behind with added burdens

Climate-induced migration significantly reshapes global carbon emissions, both directly and indirectly. Direct emissions stem from transportation, temporary housing, and energy use in receiving areas, with transport alone contributing 15% of global GHG emissions in 2023. Indirectly, migration leads to a shift from low-carbon rural lifestyles to more energy-intensive urban environments, increasing per capita emissions through higher fossil fuel reliance and infrastructure demands. Additionally, land-use changes, such as deforestation and urban sprawl, further exacerbate emissions, with the agricultural and forestry sectors accounting for 13% - 21% of global GHG emissions. Migration also alters global carbon flows through remittances, which often fund higher-carbon consumption in sending regions. Overall, migration could contribute up to 1.7 billion tonnes of CO_2 annually, highlighting the need for integrated low-carbon strategies in migration and urban planning.

6.1.1. Coastal Regions

Globally, coastal regions are increasingly becoming hotspots for climate-induced migration. Owing to their exposure to sea level rise, coastal erosion, storm surges, and saltwater intrusion, these areas experience both sudden and slow-onset displacement. However, migration patterns vary widely, depending on socioeconomic conditions, cultural norms, and institutional responses. This section synthesizes regional examples across Africa, Asia, and the Pacific, based on recent peer-reviewed literature and systematic reviews.

Climate-induced migration from coastal zones in West, East, and North Africa varies widely in form and intensity. In West Africa, regions such as Ghana's Keta and Ada Foah, as well as the coastal areas of Côte d'Ivoire and Senegal, face recurrent flooding, erosion, and saltwater intrusion, which have spurred both seasonal and permanent migration. These movements are often embedded in historical migration networks, yet constrained by poverty and weak institutions, particularly in vulnerable households (Codjoe et al., 2017; Hillmann & Ziegelmayer, 2016; Lietaer & Durand-Delacre, 2021; Ofori et al., 2023). In East and Southern Africa, responses are more structured: Mozambique implemented a government-led relocation program in its flood-prone Zambezi Valley, though many returnees cited livelihood loss and cultural ties as reasons for reversing the move, while Kenyan coastal migrants tend to relocate informally to urban slums vulnerable to new risks (Arnall, 2019). In contrast, North Africa shows a trend of voluntary immobility, as Moroccan coastal residents, especially the elderly, often remain in place because of strong cultural attachment and skepticism about the urgency of slow-onset climate change (Van Praag et al., 2021).

In South and Southeast Asia, as well as in the Pacific, climate-induced migration in coastal zones reflects a mix of displacement, adaptation, and structural vulnerability. In South Asia, the Sundarbans and Ganges–Brahmaputra Delta, shared by Bangladesh and eastern India, are among the most climate-vulnerable regions. Events such as Cyclone Aila have displaced thousands to urban centers such as Khulna and Kolkata, where Kartiki (2011) and Gupta et al. (2025) noted that tenure insecurity, gender norms, and economic precarity shape migration. However, many remain in hazard-prone areas because of place attachment and lack of resources. Along Pakistan's southern coast, including Karachi, Thatta, Badin, and Gwadar, sea level rise and saline intrusion have prompted both reactive and anticipatory migration. Daraz et al. (2024) highlighted how displaced families often settle in informal urban settlements where poor infrastructure and limited energy access exacerbate socio-environmental risks. Southeast Asia exhibits similar dynamics: in Vietnam and Cambodia's Mekong Delta, as well as in Indonesian cities such as Semarang, Bekasi, Demak, and Jepara, salinization, tidal flooding, and land subsidence prompt seasonal migration to peri-urban areas. According to Azumah and Ahmed (Azumah & Ahmed, 2023) and Handayani et al. (Handayani et al., 2025) these movements are strongly influenced by informal labor conditions, land insecurity, and gendered burdens, with women disproportionately affected by displacement-related job loss and care responsibilities. In the Pacific, the village of Vunidogoloa in Fiji represents one of the earliest examples of planned climate relocation (McMichael et al., 2025). Although hailed globally as a model, it also revealed significant emotional and cultural challenges owing to disrupted land tenure systems and deep ancestral ties, underscoring the importance of community-led, culturally sensitive relocation planning.

Climate-induced migration in U.S. coastal regions is becoming increasingly evident and is driven by sea-level rise, storm surges, and land subsidence. On the Gulf Coast, Louisiana's Isle de Jean Charles, home to the Biloxi-Chitimacha-Choctaw tribe, has lost over 98% of its land since the 1950s, prompting one of the first federally supported climate-relocation efforts (Naquin, 2020). Similarly, after Hurricane Katrina, Houston absorbed many displaced residents from New Orleans, straining local services (Junod et al., 2023). In Florida, cities like Miami face chronic flooding, leading to emerging "climate abandonment zones" as lower-income communities face rising displacement risks (Milton, 2021). In Alaska, the Yup'ik village of Newtok relocates to Mertarvik because of permafrost melt and erosion, highlighting the challenges of indigenous climate migration (Kieval, 2020). Along the Mid-Atlantic and Northeast, areas such as New Jersey and New York are facing increasing flood threats. While cities invest in infrastructure, smaller towns often rely on voluntary relocation through FEMA buyouts (Curran-Groome et al., 2021). On the Pacific Coast, rising seas are beginning to displace residents in low-lying parts of California, although patterns are less visible amid broader housing trends (Griggs et al., 2005). Together, these cases illustrate a spectrum of responses, from voluntary retreat and planned relocation to forced displacement and immobility, underscoring the need for tailored, equitable, and well-resourced adaptation strategies.

Climate-induced migration in coastal regions reflects the complex interplay between environmental hazards, social vulnerability, and institutional capacity. While migration can be an adaptive response, it is often inaccessible to poorer, older, or female populations, and some choose immobility because of cultural or economic ties. Urban areas increasingly absorb displaced people without adequate planning. Given the wide variation in responses from planned relocation to involuntary displacement, effective strategies must be inclusive, context-specific, and equity-driven, recognizing both mobility and immobility as valid forms of adaptation.

6.1.2. Arid and Semi-Arid Areas

The arid and semi-arid regions across Africa and Asia are experiencing complex and escalating climate-induced migration dynamics. These dryland zones are characterized by erratic rainfall, land degradation, drought, and host populations that are heavily reliant on natural resources and agriculture. Migration from these areas is shaped not only by environmental stressors, but also by socioeconomic vulnerability, institutional gaps, and cultural norms.

Persistent droughts, desertification, and declining agricultural productivity shape climate-induced migration in arid and semi-arid regions of sub-Saharan Africa. In Sahel—spanning Burkina Faso, Mali, and Niger, seasonal male migration is a typical response to agricultural collapse, but it can be maladaptive, exposing a combination of environmental shocks and economic opportunity structures that influence migration decisions, labor, and food insecurity (Vinke et al., 2022). Pastoralist movements across Niger and Northern Nigeria similarly seek water and grazing land but often lead to local tensions over scarce resources (Adaawen et al., 2019; Leal Filho et al., 2020). In Ghana, Nigeria, and Senegal's transition zones, migration decisions are increasingly driven by erratic rainfall and land degradation, with gendered differences in mobility shaped by access to land and livelihood (Akinbami, 2021; Codjoe et al., 2017; Lietaer & Durand-Delacre, 2021). A regional panel study by Marchiori et al. revealed how prolonged droughts and heatwaves reduce agricultural wages, pushing rural populations toward cities or international destinations. However, the outcomes vary depending on the level of legal protection and urban preparedness. In Ethiopia, youth migration from semi-arid highlands reflects declining agricultural viability and a lack of rural opportunities (Groth et al., 2020, 2021), while in Tanzania's Shinyanga region, circular migration evolves into permanent relocation as households seek income from more climate-resilient zones (Bushesha, 2020; Liwenga et al., 2012). Similarly, in southern Malawi, migration is a common survival strategy, but not universally feasible; many are trapped by poverty and lack access to transportation or support systems (Suckall et al., 2015, 2017). In Somalia and Burundi, weak governance, insecurity, and poor infrastructure limit migration options, exposing many to worsening hazards (Kolmannskog, 2009). Veronis and McLeman (Veronis & McLeman, 2014) further demonstrated that environmental degradation contributes to both internal and international migration, with emigrants later citing climate stress as a key yet often overlooked driver. Altogether, these cases reflect a complex landscape in which migration serves as a means of adaptation, survival, or for many, an unattainable option.

In both Pakistan and Tajikistan, semi-arid rural regions are experiencing rising climate-induced migration, driven by water scarcity, crop failure, and heat stress. In Pakistan's districts, such as Thatta, Badin, and southern Punjab, declining agricultural productivity and limited investment in rural climate adaptation have pushed residents toward cities such as Karachi and Lahore, where they often face precarious living conditions in informal settlements (Ofori et al., 2023; Waldinger & Fankhauser, 2015). Similarly, in Tajikistan's southern drylands, prolonged droughts and rising temperatures have undermined small-scale farming, prompting large-scale international labor migration, especially in Russia (Babagaliyeva et al., 2017). This migration is typically male dominated and temporary, with households becoming reliant on remittances and vulnerable to external economic and political disruptions. In both countries, migration serves as a key coping mechanism but also deepens social and institutional challenges for those left behind, particularly women.

Climate-induced migration in arid and semi-arid regions is a complex response to environmental stress, economic hardships, and weak institutions. Although it can be adaptive, its effectiveness depends on access to resources, networks, and governance. Many people face barriers to mobility and increased vulnerability after moving. These varied patterns underscore the need for integrated equity-focused strategies that support both those who move and those who remain.

6.2. Carbon Footprints in These Case Studies

Climate-induced migration is not only a response to environmental degradation but also actively reshapes carbon emission patterns across the origin and destination areas. The carbon footprint implications of such mobility depend on several factors, including the nature of migration (internal vs. international, temporary vs. permanent), migrants' livelihoods before and after movement, modes of transportation used, and characteristics of urban integration. This section examines the carbon dynamics associated with migration across both coastal and arid/semi-arid contexts by drawing on empirical studies and recent estimations of carbon displacement effects. The results are summarized in **Table 6** and are discussed in detail in the following paragraphs.

Table 6. Carbon footprint impacts of climate-induced migration.

Context/Region	Carbon Footprint Implications	Key Observations
Coastal Areas (e.g., Ghana, Bangladesh, Fiji)	Increased urban emissions due to construction, infrastructure, energy use, and transportation	Transition from low-emission rural livelihoods to high-emission urban jobs; erosion of carbon sinks like mangroves
Mozambique, Fiji (Planned Relocation)	Short-term emission spikes from housing/ infrastructure development	Carbon embedded in adaptation projects must be included in accounting
Remittance-affected areas (e.g., West Africa, South Asia)	Growth in consumption: cement housing, fossil-fuel appliances	Remittances can indirectly raise emissions at origin
Sahel, Ethiopia, Kenya (Drylands)	Shift of emissions to urban centers; increased reliance on fossil fuels	Urban migration results in higher per capita emissions, even if rural systems were carbon-light
Pastoralist Communities (e.g., Niger, Nigeria)	Vehicle use raises fossil fuel consumption	Emission trade-off: less pressure on land, more mobile fuel use
Trapped Populations (e.g., Somalia, Malawi)	Continued use of biomass (charcoal/ firewood) fuels deforestation and health risks	Immobility contributes to local emissions; often overlooked in carbon accounting
Urban Destinations (e.g., Accra, Nairobi, Karachi)	Higher energy and infrastructure demand increases urban emissions	Migrant influx can strain city systems and escalate local carbon intensity
International Migration (e.g., to EU, Gulf States, North America)	Up to 1.7 billion tonnes CO_2 added globally due to lifestyle changes post-migration	Emissions rise as migrants adopt host country consumption norms (Morris, 2021)
Gendered Patterns (e.g., Nigeria, Morocco)	Men contribute to sectoral emissions (e.g., construction); women rely on biomass, worsening indoor air pollution and emissions	Gender disparities affect carbon dynamics; both mobile and immobile groups generate emissions differently
Embedded Carbon Transfers (Global)	Trade and remittances reshape carbon footprints indirectly through demand and production	Emissions shifts are often invisible in national inventories but significant at household/municipal scales

Migration from low-lying, flood-prone coastal areas—such as Ghana's Keta, Bangladesh's deltaic settlements, and Fiji's Vunidogoloa—often results in increased urban population densities in receiving areas (Azumah & Ahmed, 2023; Codjoe et al., 2017; Gupta et al., 2025; Hillmann & Ziegelmayer, 2016; Kartiki, 2011; McMichael et al., 2019, 2025). This influx tends to elevate per capita emissions owing to the expanding demand for housing, transportation, energy, and waste management. The transition from subsistence-based, low-emission livelihoods (e.g., fishing and small-scale farming) to urban employment sectors, such as construction, transportation, and informal trade, contributes to a structural rise in emissions. Additionally, planned relocation schemes, as observed in Fiji and Mozambique, introduce short-term spikes in emissions owing to the construction of new housing, roads, and utilities (Arnall, 2019; McMichael et al., 2019, 2025). These embedded carbon costs, associated with land clearing, logistics, and materials, must be factored into the overall carbon accounting of adaptive strategies. Furthermore, remittance flows from migrants to communities of coastal origin often enable new consumption patterns (e.g., use of fossil-fuel-powered appliances or cement-based housing), which can incrementally increase local carbon footprints. Hence, in many coastal cases, the loss of traditional low-carbon livelihoods also means disconnection from natural carbon sinks (such as mangroves and wetlands), which are often degraded during urban expansion. As urban migrants adapt to higher-consumption lifestyles and move away from self-sustaining production systems, the carbon intensity of both the origin and destination contexts evolves.

In dryland contexts, such as the Sahel, Ethiopia, and northern Kenya, declining agricultural productivity and water scarcity prompt migration to urban centers, thereby shifting emissions geographically (Groth et al., 2020, 2021; Vinke et al., 2022). While subsistence agriculture and pastoralism typically have lower carbon footprints, urban livelihoods are more energy intensive, particularly when tied to transport, manufacturing, or informal urban economies. In Burkina Faso, Mali, and Ethiopia, such rural-to-urban transitions have led to localized increases in energy demand and reliance on fossil fuel-based systems.

Among pastoralist communities in Niger and northern Nigeria, seasonal mobility itself involves emissions, particularly where migration entails long-distance movement through trucks or motorbikes (Adaawen et al., 2019; Akinbami, 2021; Leal Filho et al., 2020; Vinke et al., 2022). While this may reduce localized land pressure, it also increases fossil fuel use, especially during prolonged drought seasons. At the same time, trapped populations—those unable to migrate from degraded environments due to financial or social constraints—continue to rely on biomass fuels, such as firewood and charcoal. This practice contributes to deforestation and localized emissions, which are often exacerbated by limited access to clean energy alternatives. Thus, migration often functions not as an emissions reduction mechanism but as a redistribution of carbon intensity, with urban hotspots absorbing much of the increased demand for energy, transport, and infrastructure. For example, cities such as Accra, Nairobi, and Karachi face growing environmental stress not only due to population pressure but also from the emission profiles of new urban residents.

At the global level, migration from low-emission regions (such as rural sub-Saharan Africa) to high-emission destinations (e.g., cities in Europe, North America, and the Gulf States) contributes to net increases in global carbon footprints. Morris (2021) estimated that such migration accounts for up to 1.7 billion tonnes of CO_2 annually, primarily as a result of post-migration lifestyle changes. Migrants often adopt the consumption norms of host societies, thereby dramatically increasing per capita emissions compared to their origins. Gao et al. (Gao et al., 2022) highlighted the link between migration and global carbon transfers embedded in trade and remittances. Migrants influence production and consumption patterns in both the sending and receiving regions, indirectly altering carbon outputs through demand-driven shifts. These changes are often invisible in national inventories but are significant at the household and municipal levels. Furthermore, gendered dimensions of carbon emissions have emerged. In Nigeria and Morocco, for instance, male migrants, such as construction and transportation migrants, are frequently employed in high-emission sectors. Simultaneously, female non-migrants often remain reliant on biomass fuels, contributing to localized emissions and related health risks (Burke & Dundas, 2015). This disparity underscores the importance of considering both mobility and immobility in emission analysis.

Climate-induced migration influences carbon emissions through urbanization, livelihood shifts, energy use, and redistribution rather than reducing emissions. Effective adaptation planning must integrate carbon accounting and promote low-emission livelihoods at both origin and destination, including access to clean energy, sustainable housing, and green infrastructure.

6.3. Lessons Learned from Different Contexts

Climate-induced migration yields have varied outcomes shaped by environmental stress, economic hardship, and governance. **Table 7** summarizes global lessons on climate-induced migration, which are further discussed in the following paragraphs. Migration is not always adaptive, and many remain immobile because of poverty or cultural ties. Gender and age shape outcomes, whereas planned relocation succeeds only with community engagement. Climate drivers are often mixed with conflict or weak governance, and mobility can increase emissions. Regional frameworks such as ECOWAS offer more targeted solutions than global approaches.

Although often viewed as adaptive, evidence from Burkina Faso, Mozambique, and Fiji shows that migration can also be harmful when poorly supported, exposing people to exploitation and insecure livelihoods (Arnall, 2019; Vinke et al., 2022). Immobility is also critical: in Morocco, Malawi, and Ghana, many stay in deteriorating environments due to poverty or cultural ties, highlighting the need for in situ adaptation like early warning systems and resilient infrastructure

(Codjoe et al., 2017; Suckall et al., 2017; Van Praag et al., 2021). Moreover, gender and age shape mobility: men often migrate seasonally, while women manage stressed households, and youth are more likely to leave due to declining opportunities, as seen in Nigeria, Senegal, Ethiopia, and Tajikistan (Akinbami, 2021; Babagaliyeva et al., 2017; Groth et al., 2020). Successful relocation, as in Fiji or Alaska, depends on inclusive, culturally sensitive planning, yet is often undermined by top-down approaches (McNamara et al., 2018). Migration is rarely driven by climate alone but also by conflict, land insecurity, and poor governance. Migration also reshapes carbon footprints; urban migration often increases emissions, while immobile groups may rely on unsustainable biomass fuels (Gao et al., 2022; Morris, 2021). Therefore, policies must be aligned with low-carbon developments. Regional mobility frameworks such as ECOWAS and IGAD offer promising alternatives to global refugee systems (Ayeb-Karlsson, 2021; Zickgraf, 2018), showing the importance of context-specific equity-driven responses that address both movement and immobility.

Table 7. Key lessons from global climate-induced migration contexts.

Theme	Lesson	Examples/References	Implications for Policy/Practice
Adaptive vs. Maladaptive Migration	Migration is not inherently beneficial; it can lead to exploitation and unstable livelihoods if not properly supported.	Burkina Faso, Mozambique, Fiji (Arnall, 2019; Vinke et al., 2022)	Livelihood support, monitoring, and infrastructure investment are needed in relocation contexts.
Immobility	Many people cannot or choose not to migrate due to poverty, cultural ties, or lack of alternatives.	Morocco, Malawi, Ghana (Codjoe et al., 2017; Suckall et al., 2017; Van Praag et al., 2021)	In situ adaptation (e.g., early warning systems, climate-resilient infrastructure) is critical.
Gender and Age Dynamics	Migration patterns are shaped by gender and age: men migrate for work; women remain and manage households; youth migrate due to limited opportunities.	Nigeria, Senegal, Ethiopia, Tajikistan (Akinbami, 2021; Babagaliyeva, et al., 2017; Groth et al., 2020)	Policies must be gender- and age-sensitive, addressing vulnerabilities and providing equitable access to resources.
Relocation Planning	Successful planned relocation depends on community engagement, cultural sensitivity, and participatory governance.	Fiji, Alaska (McNamara et al., 2018)	Top-down relocation approaches risk failure; local voices and traditions must be integrated into planning.
Multicausal Nature of Migration	Climate change interacts with other factors like conflict, poor governance, and land tenure insecurity.	General (multiple regions)	Solutions must be multisectoral, combining climate resilience with conflict resolution, land reform, and development.
Carbon Footprint Shifts	Migration often increases emissions due to urban transition; non-migrants may use biomass fuels, also contributing to emissions.	Urban migrants and rural immobile populations (Gao et al., 2022; Morris, 2021)	Low-carbon development strategies must accompany migration policy at both origin and destination.
Regional Mobility Frameworks	Regional solutions such as free-movement protocols may be more effective than global refugee systems for addressing climate migration.	ECOWAS, IGAD (Ayeb-Karlsson, 2021; Zickgraf, 2018)	Support for regional frameworks is key to enabling safe, orderly, and rights-based mobility responses.

7. Policy Implications

Climate-induced migration presents intertwined environmental, social, and developmental challenges, which call for coherent and forward-looking policy responses. As migration increasingly shapes both vulnerability and resilience, targeted strategies are needed to mitigate carbon impacts, support adaptation for migrants and host communities, and integrate mobility into national and regional planning frameworks.

Migration often reshapes carbon dynamics, especially when it leads to rapid urbanization and infrastructure expansion. Therefore, mitigation policies should prioritize low-carbon urban planning in migrant-receiving areas, such as adopting green building codes, expanding public transit, and deploying renewable energy (Rigaud et al., 2018). Promoting sustainable livelihoods in low-emission sectors such as agroecology or the circular economy can help migrants avoid dependency on high-carbon industries, such as construction or transport. Additionally, encouraging seasonal or circular migration may limit permanent urban relocation and preserve lower-emission rural ties (IOM, 2022). Financial remittances from migrants also offer opportunities for green investment in communities of origin, especially when aligned with clean energy, reforestation, or sustainable farming. Importantly, national climate frameworks, such as Nationally Determined Contributions (NDCs) should explicitly incorporate migration, ensuring that mobility is factored into emission targets and climate action planning (UNEP & IOM, 2023).

Adaptation efforts must be inclusive, recognizing the needs of both displaced populations and their host communities. Infrastructure expansion, including access to affordable housing, water, and sanitation, can help prevent overcrowded informal settlements and reduce environmental degradation in urban areas (Corburn & Sverdlik, 2016). Legal and social protections are also essential, ensuring that migrants have access to healthcare, education, work permits, and grievance mechanisms, particularly in planned relocation contexts (UNHCR, 2024). Community-based adaptation is most effective when both migrants and host residents participate in planning processes, including early warning systems, diversified livelihoods, and psychosocial support. Addressing trauma and stress among displaced people is vital for improving their integration and social cohesion. Moreover, linking migrant support to development assistance for host areas through aid grants or infrastructure co-financing can mitigate tension and promote shared benefits (Baseler et al., 2023).

Finally, integrating climate and migration policies is essential for coherence, efficiency, and equity. Migration should be mainstreamed into National Adaptation Plans (NAPs), climate finance strategies, and disaster risk frameworks (IOM, 2022). The humanitarian and development sectors must collaborate more effectively to align short-term displacement aid with long-term resilience building and sustainability goals (UNEP, 2023). Regional mobility frameworks, such as those established by ECOWAS, IGAD, and CARICOM, offer promising models for facilitating safe and orderly movements in climate-affected areas and should be further strengthened. Investment in data systems, climate-migration forecasting, and scenario modeling is also crucial to support anticipatory planning and responsive policy design (McLeman, 2020). Ensuring cross-sectoral collaboration across ministries of the environment, labor, migration, and urban development will be key to avoiding siloed interventions and maximizing the co-benefits of well-integrated climate mobility policies.

8. Future Research Directions

Despite growing attention to climate-induced migration, significant research gaps remain, particularly in the understanding of the long-term impacts of displacement on both migrants and host communities. Much of the current literature is case-specific or regionally fragmented, limiting generalizability and hindering a comprehensive policy design. Data on immobile populations—those unable or unwilling to move—are especially scarce, as longitudinal studies have tracked how migration shapes vulnerability, resilience, and carbon footprints over time.

Future research should focus on several key areas: first, improving climate–migration modeling that incorporates environmental, social, and economic drivers simultaneously; second, assessing the effectiveness of planned relocation efforts in different sociopolitical contexts; and third, exploring the intersection of migration and carbon emissions, including how livelihood transitions and settlement patterns influence energy use and infrastructure development. There is also a need to better understand the gendered, generational, and cultural dimensions of migration decisions, especially in underrepresented regions, such as Central Asia and the Pacific Islands.

Addressing these knowledge gaps requires interdisciplinary collaboration. Climate-induced migration lies at the intersection of environmental science, human geography, development studies, law and public health. Integrated research approaches, combining quantitative climate models with qualitative, community-based methods, are crucial for capturing the complex dynamics of mobility in the context of climate change. Strengthening cross-sectoral partnerships and building global interoperable data systems will be critical for advancing both academic insight and practical policy development.

9. Conclusion

Climate-induced migration is an increasingly urgent global phenomenon, particularly in vulnerable coastal and arid/semiarid regions. This study has highlighted how environmental stressors, such as sea-level rise, flooding, drought, and land degradation, interact with socio-economic inequalities, weak institutional frameworks, and cultural factors to shape complex patterns of displacement, immobility, and adaptation. Across the diverse case studies examined—from West Africa to the Mekong Delta, and from the Sahel to U.S. coastal regions—migration emerges as both a strategy of survival and a reflection of structural vulnerability.

Significantly, migration not only shifts population dynamics, but also redistributes carbon responsibilities. Transitions to urban settings and new livelihoods often result in higher per capita emissions, while those left behind may rely on unsustainable resources, such as biomass. These carbon implications must be recognized within climate and migration policy frameworks to avoid reinforcing environmental and social inequities.

This analysis underscores the need for integrated, inclusive, and regionally tailored responses that support both mobile and immobile populations. Policies must bridge humanitarian assistance with long-term resilience building, prioritize low-carbon development in host and origin areas, and ensure gender-sensitive and age-responsive interventions. Furthermore, effective planning should incorporate mobility considerations into national climate strategies and international development agendas. Future action must be grounded in interdisciplinary research and collaborative governance with improved data systems, participatory planning, and stronger regional mobility frameworks. Only then can climate-induced migration be transformed from a reactive crisis to an opportunity for equitable and sustainable adaptation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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