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INEQUALITY AND CLIMATE CHANGE: MEASURING INTERLINKAGES TO INFORM EQUITABLE CLIMATE POLICY

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Inequality and climate change: Measuring interlinkages to inform equitable climate policy

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Abstract
The interlinkages between climate change and socioeconomic inequality are increasingly acknowledged, yet analytical frameworks and empirical tools that jointly address these dimensions remain limited. This paper contributes to these discussions by distilling the key channels through which climate change and inequality mutually reinforce one another and by identifying a set of indicators to measure these linkages and inform policies in different country contexts.

Drawing on the literature, the authors examine these relationships at both the global scale – across countries- and the national scale – within countries, including subnational and socio-economic dimensions.

At the global level, they highlight how economic inequalities shape greenhouse gas emissions trajectories, adaptive capacity, and mitigation burdens, while climate change itself entrenches disparities in income and development prospects, particularly for low- and middle-income countries. At the national level, the authors document how inequalities in income, wealth, assets, and access to services influence emissions patterns, exposure to climate risks, and resilience, and how climate shocks exacerbate existing spatial and socioeconomic inequalities.

With this evidence on the interlinkages between climate change and inequalities and the distillation of indicators to profile these interlinkages, the aim is to inform key policy issues and choices. The proposed framework informs both equitable international climate cooperation and national policy strategies aimed at structural transformation towards inclusive and climate-resilient pathways.

Keywords
Climate change; inequality; exposure; climate vulnerability; adaptation; sustainability

Classification JEL
D31; D63; O44; Q54; Q56

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Introduction

The interlinkages between inequality and climate change are commonly acknowledged today (Drupp et al., 2024; Emmerling et al., 2024; IPCC, 2022). On the one hand, it is clear that climate change disproportionately impacts the most vulnerable people, locking populations and sub-populations within countries into poverty traps and thereby entrenching inequalities (Hallegatte et al., 2017). On the other hand, the production and consumption patterns driving the climate change crisis at the aggregate level are built off the base of global and national socio-economic inequalities (Pauliuk, 2024). In societies where individual wealth is strongly linked to an extractive system and economic power is correlated with political power, net zero development trajectories are effectively an illusion (IPCC, 2022).

Despite broad recognition that fighting climate change and its consequences needs to go hand in hand with the reduction of socioeconomic inequality, there are few frameworks and tools that address the two objectives jointly. Indeed, the complexity and multidimensional features of both climate change and inequalities can be overwhelming. It is understandable then that many current frameworks and tools focus on one or two dimensions or impacts. For instance, when we talk about climate change and inequality, the most common discussions focus on inequality in terms of carbon footprint (Chancel et al., 2023), differentiated vulnerabilities to climate change impacts (Shifa et al., 2023; Zhou et al., 2022) and the distributional impacts of climate policies (Drupp et al., 2024; Känzig, 2023).

Nonetheless, giving detailed attention to a broad set of specific linkages is very important. In framing national responses to climate change, it is crucial for each country to know how it is being impacted at the national level by the key dimensions of global climate change as well as by collective global agreements. These multilateral agreements involve a national response and many countries have already made commitments and nationally determined contributions as part of this response. In many cases such responses and the formulation of national policies to overcome climate change have been made based on climate related evidence, but the same cannot be said about the impact of these policies and responses on households' welfare and its distribution. At a minimum, each country needs to have a profiling of the aggregate consequences of global climate change on its economy and its people alongside the country's contribution to global climate change. This should also be accompanied by a profiling of that country's unique climate change landscape that shapes both the unequal impacts of climate change within it as well as the country's adaptation possibilities.

Despite the importance of these linkages between climate change and inequalities, a collated set of grounded manifestations of these linkages and indicators for use in assessing policy are not readily available right now. This is especially the case in recognizing that these linkages may differ across low-, middle- and high-income countries. For instance, while inequality in access to energy or differentiated exposure to agricultural shocks that impact incomes might be less important in rich countries, they are key in LMIC. Based on the existing literature, we thus need to identify the most relevant linkages and which indicators we should use to measure them and inform policies in the relevant country contexts.

This paper aims to distil such a profiling of key linkages between climate change and inequalities for a particular country alongside a set of corresponding indicators that can be used to correlate a country's climate change/inequality situation. In terms of scales, we will first look at these correlations between countries (global scale) and within countries (national scale). While the focus of this overview is to identify relevant indicators that can inform national policy making, the global nature of climate change means its implications extend across time and borders. Thus, the international comparative dimension is crucial in understanding the linkages between climate change and inequalities within countries. In terms of the within country dimension, the disaggregation is often at the level of individuals or relevant groups for horizontal inequalities. But in some instances, the appropriate disaggregation is at the sub-national scale, where the unit of observation is a relevant geographical unit (e.g., rural/urban, province or local municipality) with a country. This approach of profiling at countries within global, national and sub-national scales builds on the experience of developing inequality diagnostics (see Shifa and Ranchhod, 2019), a series of country reports which provide an exhaustive analysis of multidimensional inequalities, over time and at different scales. While these diagnostics have enabled evidence-based policy discussions in the countries where they have been conducted, the lack of a comprehensive section on climate-related inequalities emerged as an important omission that needed filling for future exercises.

Given the complex and multifaceted nature of both inequalities and climate change, we have limited the scope of our overview of linkages to those more commonly studied in the economics literature. Inequality refers to the unequal distribution of a specific outcome, most often income or wealth in this literature, across a given population. While inequality is multidimensional and it can cover a wide array of outcomes, from education, access and affordability of public services to voice and representation, we will mostly focus on economic inequality as it often allows other forms of inequality to accumulate and persist.

These limitations aside, we believe that such evidence will inform key policy issues and choices. The global climate change policy discussion is presented as focusing on collective solutions required to shift the planet onto a sustainable path. However, we and many others have flagged vast inequalities in country contributions to the problem and in the resultant socio-economic impacts. Both contributions and consequences are very different for different regions and for low- and middle-income countries compared to rich countries. There are notable differences within each of these groupings too. Our proposed approach for highlighting the linkages at the global scale will make clear how each country articulates into the global situation and how this aligns with their climate change commitments and actions.

Within-country disparities—both spatial and socio-economic—are substantial, and they shape how different groups experience and can respond to climate change. As such, it is crucial to build and disseminate a robust within-country evidence base to inform national climate policy responses. This is especially important given what we already know about how poverty and inequality can stifle broad-based economic growth (Bergstrom, 2022; Fofana et al., 2023; Fosu, 2018; Thorbecke & Ouyang, 2022). Shifting onto a more inclusive development pathway requires inequality reducing structural reorientations of economies (Clementi et al., 2019; Fosu, 2023; Odusola, 2019). Similarly, responses to climate change that will move a country onto a sustainable development pathway also require structural reorientations. Indeed, the required responses to climate change bring a new urgency and a longer-run perspective to these policy discussions (Chancel et al., 2023; IPCC, 2022; Taconet et al., 2020). Profiling within-country correlations between climate change and socio-economic inequalities will provide a valuable evidence base to inform what is possible in shifting a country's development pathway onto a high employment, more inclusive, low emissions, and climate resilient trajectory.

We proceed as follows: Section 2 presents key linkages between inequality and climate change both at the global and national scale, then Section 3 identifies a set of key indicators that can be used to measure these linkages, before summing up and concluding in Section 4.

1. Key linkages between inequality and climate change

The literature on the linkages between inequality and climate change is quite extensive, with a significant number of publications even over the last 5 years (Drupp et al., 2024; Emmerling et al., 2024; IPCC, 2022; Millward-Hopkins et al., 2025; Pauliuk, 2024). In this paper, we do not give a full overview of this literature but rather highlight some of the key linkages that we've identified, based on our reading of the relevant literature.

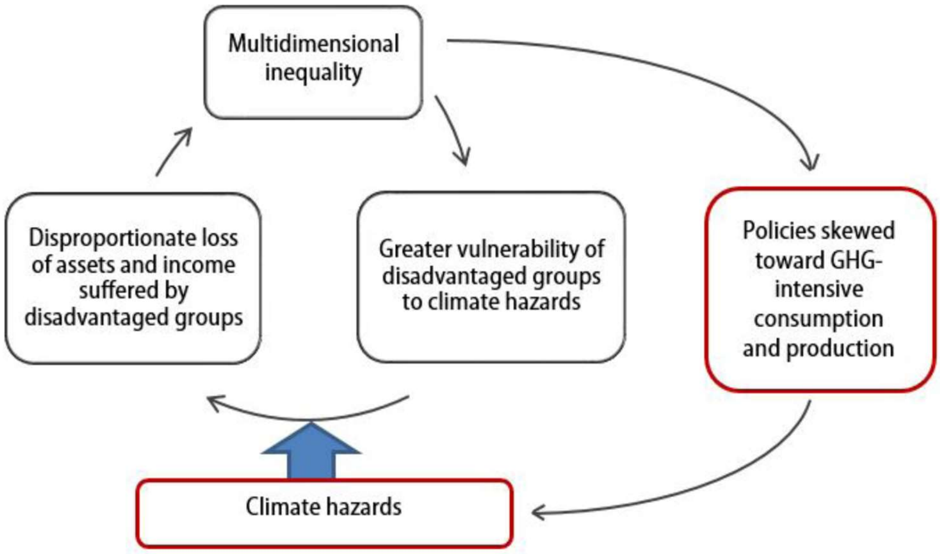
In order to structure these linkages, we will proceed to an analysis by global, national and sub-national scales. We organize each scale in a 2x2 matrix (Table A1) that allows us to overview the consequences of inequalities on climate change and the consequences of climate change on inequalities. We proxy the latter proxied either through the Greenhouse Gas (GHG) emissions path or through its impacts.

1.1. Global scale

The approach that we took in our country-level inequality diagnostics was to focus on national indicators of multiple dimensions of inequality. However, given the global implications of climate change we cannot overlook the global scale when considering climate change. As such, our units of observation for the distribution-related outcomes can either be countries or the global population of individuals (e.g., considering the distribution of income among all people on the planet). Thus, we look at how economic inequalities between countries shape climate change, but also how climate change entrenches inequalities between countries.

Figure 1 below highlights the main linkages that we identified in the literature. First of all, we consider that inequality aggravates the situation of disadvantaged groups in regards to climate change impacts through different channels: increase in the exposure to climate hazards, increase in the vulnerability to damage caused by climate hazards and decrease in the ability to cope and recover from the hazards. These three effects can also be transmitted through a political channel by which multidimensional inequality results in the capture of political power by the rich and powerful skewing the policies toward GHG-intensive consumption and production. In an unequal society, the advantaged groups usually exert their influence on the state and skew its policies in their favour, deploying more policies toward GHG-intensive activities that serve their utilities. The result is public policies that leave the disadvantaged groups more exposed and vulnerable to climate hazards. As a result, climate change and inequality are locked in this vicious cycle, whereby climate change hazards also aggravate inequality.

Figure 1. Reinforced vicious cycle between inequality and climate change.



Source: Islam & Winkel (2017)

1.1.1. From economic inequalities to climate change

a) How do global inequalities shape GHG emissions paths?

Chancel (2022), building on Piketty and Chancel (2015), show that inequality of wealth, either between countries or between individuals at the global scale, results in inequalities of GHG emissions. The top 10 percent of global carbon emitters generate almost one-half of all greenhouse gas emissions (Chancel et al., 2023). Meanwhile, the bottom 40 percent account for 12 percent of emissions. According to Chancel (2022) , the top 1 percent per capita emission levels were more than 16 times the global average in 2019.

In terms of emissions growth, between 1990 and 2019, the per-capita emissions of the bottom 50 percent grew faster than the average (26 percent), while those of the middle 40 percent as w hole was negative (-1.2 percent). Per-capita emissions of the top 1% grew by 26% and top 0.01% emissions by 80%. In terms of contribution of each group to the overall share of total emissions growth, the top 1 percent of global emitters were responsible for 23 percent of the total growth in emissions, while the bottom 50 percent were responsible for only 16% of all emissions growth (Chancel, 2022).

Between countries, Bruckner et al. (2022) analysed the contributions of different groups to global emissions. Countries such as Australia, Canada, the Russian Federation, and the United States have among the highest per capita emissions (14.5t CO_2 in the United States), while in many of the countries in SSA, such as the Central African Republic, Chad, and Niger, the average footprint is around 0.1 tonnes per year.

SSA is the only region where average per capita emissions currently meet the levels required to achieve the target of limiting the temperature increase to less than 1.5 degrees Celsius by 2030. The current emissions of low-income countries are often near the targets set by high-income countries for 2030.

Beyond simply CO2 emissions, a significant part of the literature has explored international inequalities in ecological footprints (Duro & Teixidó-Figueras, 2013).

b) How do global inequalities shape the impacts of climate change?

The ability to adapt across countries is one of the main drivers of how global inequalities shape the impacts of climate change (Taconet et al., 2020). There is an unequal global distribution of adaptation needs and capacities, with countries in the Global South typically encountering the most significant challenges.

Richer countries have a higher capacity to respond to climate shocks. Income is therefore a protective factor against climate change impacts as it increases adaptive capacity (Chancel et al., 2023). The linkage between poverty and adaptive capacity is largest in SSA where 28% of the population are both poor and have to respond to climate change, followed by South East Asia. In more developed areas the share is less than 5% (Chancel et al., 2023).

Richer countries also have a higher financial and human capacity to transform their systems in order to adapt to climate change. Inequitable access to energy resources, such as fossil fuels and electricity, can influence the capacities for countries to transition to clean energy (Zahnow et al., 2025). Analysing the relationship between inequality and climate change adaptation, Nyiwul (2021) finds that every 1% rise in energy inequality at the national level was associated with a 23% decrease in mitigation actions employed.

1.1.2. From Climate change to inequalities

Climate change shapes inequalities at the global level in different ways. Rising temperatures and extreme weather events impact low-income countries more heavily, while the costs of mitigating climate change through reduced emissions could hamper poorer countries' economic catch-up.

a) How does climate change shape inequalities in GHG emissions paths?

Climate change creates the need to shift countries' productive systems towards less GHG emitting ones, but the pace of this shift results in differentiated emissions paths and needs. Beyond the unequal emissions legacy left by the historical responsibility of high emitters, countries' choices for development pathways will result in unequal emissions. In the short or medium terms, low-income countries advocate for the right to increase their emissions in order to grow economically. In addition, the power asymmetries in international negotiations can result in unequal carbon budgets. At the same time, these countries have a lower capacity to reduce their emissions as, compared to many high-income countries, they have less access to clean technologies, financing, and institutional capacities that allow a rapid decarbonization. In addition, low-income countries are also more vulnerable to climate change, which implies that they need to divert their resources towards adaptation and might be even more constrained in investing in low carbon technologies.

b) How does climate change have unequal impacts?

Economic losses and growth potential

Climate change primarily impacts the poorest countries. While high-income countries, which are relatively cold, may profit from climate change, low-income countries in warmer regions will face significant losses (Diffenbaugh & Burke, 2019; Taconet et al., 2020). Many low-income countries are significantly poorer today than they would have been in the absence of climate change. Meanwhile, many rich countries that bear the highest responsibility for climate change have benefited from climate change in terms of income.

Diffenbaugh and Burke (2019)[1] find that global warming has increased economic inequalities between countries, with warming increasing growth in relatively cool (typically high-income) countries and

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[1] They combine counterfactual historical temperature trajectories with empirical evidence on the relationship between historical temperature fluctuations and economic growth.

decreasing growth in low-income countries in warm regions. It has been estimated that in Mozambique, the impacts of climate change on the economy will reduce the GDP by about 13 percent by 2050 (Arndt & Thurlow, 2015). Similar results were obtained in other countries in Southern Africa, such as Angola, Mozambique, Namibia and Zambia (Ayanlade et al., 2022).

Exposure to extreme weather events

Extreme weather events such as heatwaves, droughts, and flooding do not have the same impacts across countries. Southern Africa is among the regions disproportionately affected by adverse climate consequences such as droughts and floods (Ayanlade et al., 2022). Projections have indicated that about 43.5 percent of the agricultural land in SSA will be affected by dry conditions, in contrast to the world average of 29 percent.

Li et al. (2025) focus on the exposure to extreme heat at workplaces and quantify the risk associated with trade-related occupations, showing that the trade effect increases inequality in heat exposure between developed and developing countries.

Food security and agricultural production

Extreme weather events caused by climate change can have significant consequences on the agriculture sector and have intensified in recent years, affecting people's activities and livelihoods disproportionately, with poor countries facing the most-adverse effects (Ajetomobi, 2016; Ayanlade et al., 2022; Emediegwu et al., 2022; Fuller et al., 2018; Trisos et al., 2022). Studies have highlighted impacts such as reduced crop yields and quality of crops, dried-up streams and rivers, heat fluxes, loss of land, reduced vegetation and biodiversity, and decreased incomes for farm households.

SSA is the second-most-likely region to be confronted with the challenge of insufficient food as an impact of drought. Chancel et al. (2023) show that, in Africa, average agricultural productivity is estimated to be 35 percent below its potential value because of drought. In contrast, other countries such as Canada and Russia have seen their productivity increase as a consequence of climate change. Countries such as Mali, Niger, and Sudan face the most-extreme adverse effects, with losses of as much as 40 percent due to climate change. The latest IPCC report has estimated that agricultural productivity growth in Africa has been reduced by 34 percent since 1961 due to climate change, more than any other region in the world.

SSA, the region with the highest poverty levels and highest rates of food insecurity, must cope with significant yield losses. This issue increases the incidence of hunger among the populations who rely on agricultural incomes or are vulnerable to the volatility of food prices.

Health

Climate change has significantly increased the risk of diseases such as malaria, dengue fever, and Zika virus, especially in poor countries. The burden of malaria is greater in Africa, where more than 90 percent of all malaria-related deaths occur. Cissé et al. (2022) showed that these impacts are unevenly distributed across countries, and wider geographic areas are becoming more suitable for transmission.

More-frequent flooding contributes to increases in water-borne diseases such as cholera, especially in areas where water, sanitation, and hygiene deficiencies are significant.

In Ethiopia, Mozambique, Senegal, and South Africa, increases in temperatures and rainfall are associated with increases in diarrhoea and childhood diarrhoea (Cissé et al. 2022). The relationship between poor sanitation infrastructure and increased risk of outbreaks in low-income countries illustrates the interlinkages of different climate impacts. Drawing on individual data from 30 SSA countries from 1991 to 2017, Cissé et al. (2022) found that Central Africa is projected to face the greatest temperature-induced risk of diarrheal episodes (Flückiger & Ludwig, 2022).

Unequal mitigation costs

Trying to limit the impacts of climate change through greenhouse gas reduction policies can have severe consequences for inequalities, as these mitigation policies can hamper the development of low-income countries. Few studies have explored the impact of reduced climate change on inequalities between countries via mitigation costs, but Taconet et al. (2020) have analyzed how mitigating climate change affects future inequalities, showing that the costs of reducing greenhouse gas emissions vary across countries and can be more burdensome for low-income countries, as low-income countries can lose a greater share of their potential GDP for the same amount of reduced emissions. Similarly, low-income economies are often characterized by higher energy and carbon intensities. Therefore, raising the price of energy as a mitigation policy can be more burdensome in these countries.

1.2. National scale

1.2.1. From economic inequalities to climate change

a) How do national inequalities shape GHG emissions paths?

According to the recent climate inequality report, in the past 30 years, "while cross-country emission inequalities remain sizeable, overall inequality in global emissions is now mostly explained by within-country inequalities by some indicators" (Chancel et al., 2023). In 1990, most global carbon inequality (62%) was due to differences between countries. Now, within-country emission inequalities account for nearly two-thirds of global emissions inequality (Chancel, 2022). This implies that in addition to the high international inequality in carbon emissions, there are also even greater emission inequalities between individuals within countries.

Chancel (2022) splits personal carbon footprints into emissions generated by private consumption, investments and government spending[2]. The bulk of emissions generated by the top 1% is found to come from their investments rather than their consumption (over 70% in 2019). This is partly due to the rise in wealth inequality. The high concentration of wealth, income, and carbon-intensive activities in a small population group leads to a significant degree of carbon inequality in most countries in Africa.

In SSA, the bottom 50 percent of the population emit around 0.5 tonnes per capita of carbon dioxide each year, compared to 7.5 tonnes per capita by the top 10 percent in 2019 (Chancel, 2022). In Nigeria, the per capita emissions of the top 10 percent are five times higher than those of the bottom 50 percent (Chancel et al., 2023).

b) How do national inequalities shape the impacts of climate change?

Current levels of inequality exacerbate climate shocks whereas, in highly unequal societies the rich household disproportionate economic and political power and tend to foster more carbon-intensive futures. Inequality also impedes social cohesion and the sense of social responsibility that is crucial to advance national welfare-maximizing pro-environmental policies, and holds back the development of environmental technologies (Vona & Patriarca, 2011).

An analysis of resilience is useful for detailing and understanding the agency, responsiveness, and resourcefulness of vulnerable and poor populations in trying to sustain their livelihoods in the face of climate shocks and change. Within-country inequalities are fundamentally consequential in allowing better-off households to withstand shocks, or to invest in and make longer-run adjustments. At the

[2] Consumption-related emissions come from the carbon released by the direct use of energy (fuel in a car) or its indirect use (energy embedded in the production of goods and services consumed by individuals). Investment-related emissions are emissions associated with choices made by capital owners about investments in the production process (construction of machines and factories). Emissions from government spending come from collective consumption expenditure or investments (government administration, public roads, and defense).

same time, within-country inequalities severely limit or absolutely prevent vulnerable and poor households from such responses despite their best efforts to adapt.

The choices of coping strategies can largely depend on the level of asset ownership and the extent of the shocks. Research has shown that, in a drought context, rural households are generally unable to restore lost livelihoods and assets. Even among farm households, the poor population is unequally affected and does not recover from shocks sufficiently to rebuild their assets. As evidence from Senegal has shown (Faye et al., 2019), rich households are more advantaged when coping with climate shocks due to their higher levels of savings and wealth, which allow them to diversify their crops and maintain their incomes and consumption when faced with weather shocks. A study of South Africa found that adaptive capacity relies on five types of capital—human, physical, financial, natural, and social—and that poverty is the greatest limitation in adapting to climate change (Zhou et al., 2022). An analysis to identify the factors determining households' resilience in Ethiopia indicated that access to assets, such as farmland and livestock holdings, along with infrastructure and social capital, is key (Asmamaw et al., 2019).

1.2.2. From Climate change to inequalities

a) How does climate change shape inequalities in GHG emissions paths at the national level?

In their conceptual framing of the inequality-environmental policy linkages and the review of evidence, Drupp et al. (2024) highlight that environmental benefits tend to be progressive, benefiting mostly the poorest members of society. They further disentangle the different paths of interaction between climate change policies and income distributions, separating the non-market benefits and market mediated effects from improved environmental quality, the costs from the policies, both on the use-side effects and the source-side effects, and the government redistribution mechanisms. We will focus on two channels through which climate change impacts income inequality: (i) income composition and (ii) price effects.

In terms of income composition, the effect of curbing GHG emissions paths on inequalities comes down to which share of the income is derived from highly GHG emissive activities or sectors for each income decile.

In terms of price effects, we limit our scope of review on the price effects induced by climate change to two dimensions: price volatility driven by extreme weather events and carbon prices. With regards to carbon prices, Drupp et al. (2024) report conflicting evidence on how different income groups react differently to price changes. Ohlendorf et al. (2021)'s meta-analysis suggests that carbon pricing is more progressive in developing countries, but the incidence remains country-specific.

Empirical research from developed nations shows that carbon pricing is regressive, with low-income households being disproportionately affected in terms of reduced income, consumption, and employment (Känzig, 2023). In the context of developed countries, carbon pricing raises energy prices in the short and medium term and demand for energy is generally inelastic (Känzig, 2023). Given that low-income households spend a large share of their income on energy, an increase in energy prices has an impact on their spending patterns (Känzig, 2023). Furthermore, the low-income households experience relatively large income declines because they disproportionately work in industries that are most affected by carbon regulations (Känzig, 2023).

In the case of environmental policies aiming for improved environmental quality, lower prices for certain agricultural products (as a result of fewer crop failures) can benefit poorer individuals disproportionately, since agricultural products have a higher consumption share in the total budget of lower-income households.

b) How does climate change have unequal impacts at the national level?

The unequal impacts of climate change within countries can be explored based on the three dimensions of exposure, vulnerability and resilience based on the IPCC conceptual framework. Similar to the unequal distribution of climate impacts across the world, poor populations within countries live in more-exposed areas or are more likely to work in jobs with higher exposure, such as agricultural work. Moreover, poorer populations are more vulnerable when exposed to adverse climate effects, as their housing is likely to be more prone to storm and flood damage. Finally, the losses incurred by the poor populations can also undermine their resilience, which is their capacity to adapt to and recover from the damages of adverse climate effects.

Exposure

Poor households tend to be more exposed to the effects of climate change than non-poor households. Poor households are unequally exposed to droughts, floods, and heat stress (Hallegatte et al., 2017). Contrasting a case with and without adaptation, Gilli et al. (2024) find that income elasticities of climate damages decrease after adaptation, indicating that while the poor are disproportionately impacted by climate damages, adaptation may exacerbate the regressivity of these effects.

For food security, smallholder farmers are exposed to prolonged droughts that lead to crop losses and livestock deaths. This issue reduces the agricultural outputs of rural farmers, who are mostly poor and vulnerable, especially in the Sudan-Sahel zone (Ayanlade et al., 2022). In Ethiopia, South Africa, and other countries in SSA, farming households are exposed to rainfall variability without the necessary means to reduce their exposure to such variability.

In South Africa, rural areas with agriculture as their main economic activity, such as the Eastern Cape Provinces, KwaZulu-Natal, and Limpopo, have the highest exposure to droughts and increased and variable temperatures (Zhou et al., 2022). In Ethiopia, most farm households are recurrently exposed to drought (Gebrehiwot et al., 2021). In Mauritania during the 2014 drought, households living in the districts where the drought was more intense had a higher likelihood of falling below the poverty line, compared to households that faced less-intense drought (Ba & Mughal, 2022).

Beyond direct exposure, defensive expenditures and avoidance behaviour are also closely linked to the income distribution. For China, Sun et al. (2017) shows that defensive expenditures, such as expensive air filters, increase inequality in exposure to air pollution. Concerning avoidance behaviour, Zivin et al. (2011) find that when exposed to water risks, high income households are more likely to increase their consumption of bottled water compared to low-income households.

Vulnerability

The poor population is usually the most vulnerable and incurs heavy losses when faced with a disaster. Rural and urban areas experience these direct impacts disproportionately. In addition, important indirect impacts can occur such as an increase in food prices due to weather shocks, which increases the negative impact of the shock, especially for poor rural households that depend on the local market to satisfy their food needs and are more vulnerable to food price volatility in markets and shops.

Most SSA countries depend largely on smallholder-based agriculture, rendering them more vulnerable to climate change. In Mauritania, when faced with the 2008 drought, 45 percent of rural households reported loss of livestock (Ba & Mughal, 2022). In Kenya, an analysis of the effects of climate shocks on household well-being shows how climate shocks affect the assets that rural households own, thus affecting their welfare. This is in contrast to urban areas where asset ownership and access to credit can help smooth consumption, leading to no significant impact on household welfare (Manda, Oleche, et al., 2023). Another analysis of multidimensional vulnerability in Kenya has shown that rural areas are more vulnerable than urban areas, with poor nutrition and living conditions contributing more to vulnerability in rural areas (Manda, Kipruto, et al., 2023).

Poor households are also more adversely affected by climate change shocks than rich households in the short term. In Ghana, drought had a significant negative effect on the consumption expenditures of rural households as opposed to no significant impact on urban households (Danso-Mensah & Oduro, forthcoming). In South Africa, a systematic review of the literature has shown that, compared to urban households, rural households are more vulnerable to climate change due to the differences in infrastructure, typical livelihoods, and income-generating activities (Zhou et al., 2022).

The impacts of climate shocks can also disproportionately affect households according to their occupation and level of education. For example, in Kenya, vulnerability decreases with the level of education (Manda, Kipruto, et al., 2023). In South Africa, shocks to mining have adverse direct consequences on workers' earnings and their households, which experience reduced remittances (World Bank, 2022). Rural residents, those with lower incomes, and the Black population are disproportionately affected by multidimensional vulnerability in South Africa (Shifa et al., 2023).

Resilience

The IPCC (2023, p. 7) define resilience as "the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation". Resilience often overlaps with adaptive capacity.

Amongst other factors, his capacity to react and adapt to climate change and shocks depends on financial savings or wealth (Chancel et al., 2023). Households that can draw on financial savings or wealth tend to face smaller losses when hit by a natural disaster. However, poor households do not have the same levels of savings or wealth, therefore a lower adaptive capacity. For example, some of the lowest global wealth shares are in Southern Africa, where the population is the most exposed to severe impacts from droughts and other extreme weather events (Hallegatte et al. 2017). Inequalities in asset ownership also play a significant role in households' capacity to cope with external shocks (Asmamaw et al., 2019; Gebrehiwot et al., 2021; Janzen & Carter, 2019; Zhou et al., 2022). At this point though, evidence is limited on the effectiveness of assets in mitigating the effects of climate shocks in Africa.

In some African countries, rural households rely on crop production and livestock farming as the basis for their own consumption and livelihoods. However, droughts often result in low production, which considerably reduces both home consumption and the purchasing power of rural households, leading to greater food insecurity. Selling livestock as a coping strategy to generate more income is often met with reticence, as poor households that sell their livestock are more likely to experience a decline in future consumption and welfare, which can lead to a poverty trap in the future (Ba and Mughal, 2022).

Studies have investigated the relationships between financial capability, level of education, income, and ability to cope. Evidence from Mauritania has highlighted the importance of wealth as a coping strategy (Ba and Mughal, 2022). When faced with drought, household asset portfolios changed, with household wealth falling during the two periods of drought in 2008 and 2014, implying that rural households maintained consumption by liquidating their livestock assets. However, although selling livestock helped maintain consumption levels during the 2008 drought, it did not compensate for the losses entirely or prevent households from reducing consumption during the 2014 drought.

Thus, assets can moderate the negative effects of climate change shocks. However, when asset depletion occurs or the magnitude of the shock exceeds the compensation by the existing assets, assets are less likely to help households cope with shocks or support their resilience (Díaz Pabón et al., 2023). For example, in Kenya, asset ownership and access to credit only partially protected households from the negative effects of climate shocks due to asset destruction (Manda, Oleche, et al., 2023). Evidence from South Africa has confirmed that the impact of climate change shocks is lower for households that have access to assets, compared to other households (Díaz Pabón et al., 2024). A randomized controlled trial in rural Kenya showed how wealthier households cope by selling assets, while poorer households cope primarily by cutting food consumption (Janzen and Carter, 2019).

Consumption adjustment strategies were also used in rural Ethiopia, reducing the quality and quantity of food consumption, which exacerbated households' vulnerability to further shocks (Gebrehiwot et al., 2021). In Ghana, the mitigating role of asset ownership depends on the length of the shock and the type of assets, as asset portfolios remained unchanged during a short-term drought and changed only as the drought stretched beyond 24 months (Danso-Mensah and Oduro, forthcoming). Assets that are easier to liquidate, such as financial assets, were more easily used as a coping mechanism as opposed to productive assets, such as livestock and agricultural tools, which were generally maintained throughout the period of drought.

Alternatively, farmers can use their savings to smooth consumption. However, many poor households do not have savings, and those with savings risk depleting them if the duration of the shock is long, thereby falling into a poverty trap. Households can also attempt to diversify their sources of income by engaging in non-farm activities (Ba, Anwar, and Mughal, 2021). However, such activities are not always readily available in all rural areas. Therefore, due to the limited availability of efficient coping tools, rural households continue to face structural difficulties in their strategies to mitigate the effects of weather shocks on income. Rural households may be stuck in poverty traps where they remain persistently poor and their incomes continue to deteriorate. Moreover, households with limited assets are unable to borrow because they do not have sufficient access to credit.

These inequalities in exposure, vulnerability, and resilience are partly due to the low incomes of the poor population. These inequalities are also due to low-quality housing, which faces greater damage when struck by floods, for example. Poor households in Africa are more likely than elsewhere to rely more on agricultural jobs and incomes, rendering them more exposed to such climate shocks. In contrast, high-income households rely more on formal-sector labour incomes for their livelihoods and less on sectors directly affected by natural disasters. As households in poorer groups experience larger shocks, they are inevitably forced into adopting coping mechanisms that lead to lower productivity and consumption (World Bank, 2022; Zhou et al., 2022). Multidimensional poverty remains a great limitation in adapting to climate change.

The impact of climate change on inequality also largely depends on the structure of the economy and the texture of each society's inequalities. In almost all African contexts, agriculture is a crucial channel through which climate change exacerbates existing inequalities as poor households are disproportionately likely to be actively involved in the agricultural sector. With large shares of the population in rural areas and working in agriculture, temperature increases and volatility caused by climate change have significant effects on within-country inequality (Paglialunga et al., 2022).

Several mechanisms are involved. First, extreme weather events reduce yields and agricultural output, therefore reducing farmers' incomes. Second, disadvantaged households often live in rural areas and are more exposed to extreme weather events as their assets (livestock and land) are more affected. Finally, climate change leads to food price volatility impacting consumption patterns, especially for the poorest households, who spend a higher share of their budget on food.

2. Measuring climate change impacts and economic inequality linkages

The previous section focused on identifying a set of key climate change and inequality linkages. In this section, we look at indicators that are useful for assessing the relationship between climate change and inequality. Nevertheless, discussing the indicators and the methods used to assess all of the potential relationships between climate change and inequality is a complex task. In this section, we only focus on some of the key indicators used in the literature to empirically assess the relationship between climate change and inequality.

2.1. From economic inequalities to climate change

As discussed in Section 2, economic inequality across countries and within countries can result in inequities in contributions to climate change. In addition, economic inequalities can lead to inequalities in terms of who will be affected by climate change contributions (mainly through greenhouse gas emissions) and climate change impacts.

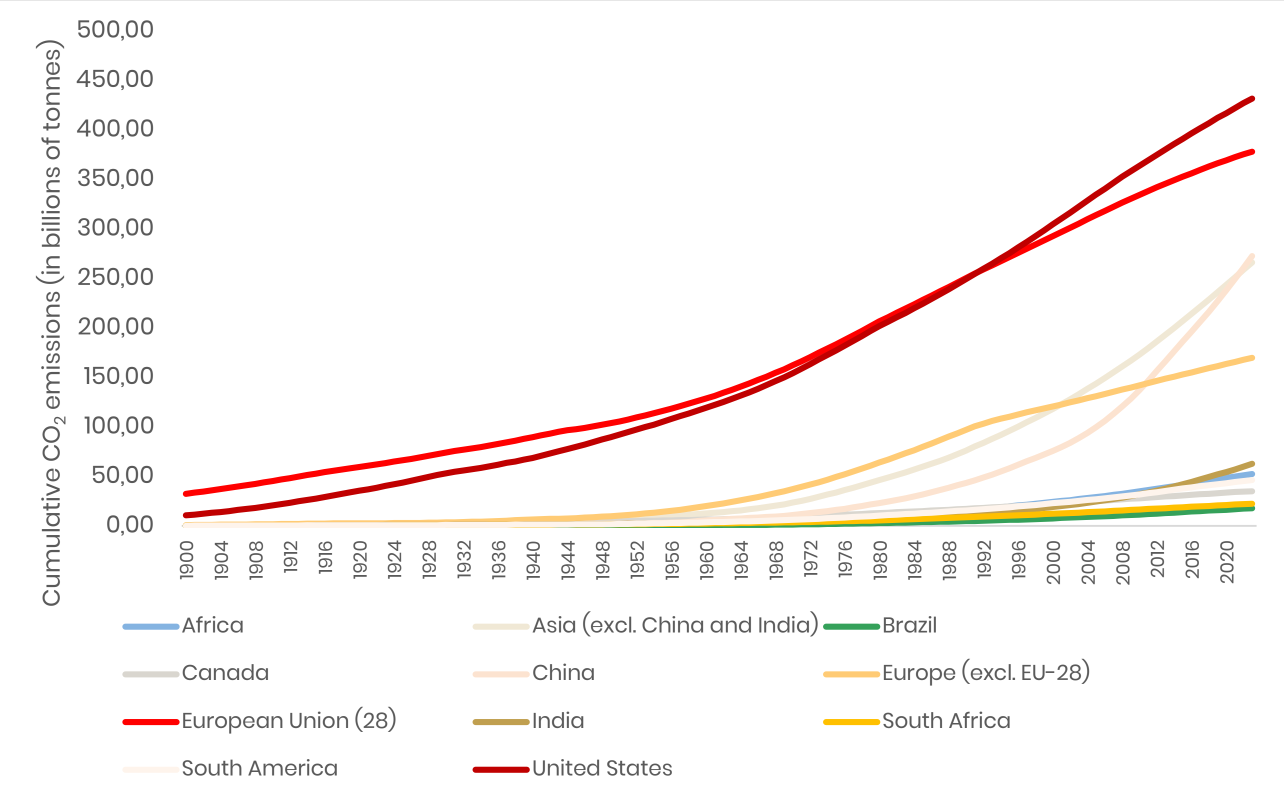
a) Measuring how economic inequalities shape GHG emission paths

As already mentioned, economic inequalities can shape inequalities in GHG emission patterns. For example, richer/industrialized countries emit significantly more GHG than developing/poorer countries, even in per capita terms, through their production and consumption behaviours. Similarly, within countries, the rich emit more greenhouse gases than the poor and emissions differ across sectors of a given economy. Measuring this relationship requires data on production and consumption as well as on GHG contributions resulting from these activities. There are numerous well-known indicators and methodologies for measuring economic inequality across and within countries. Economic inequality, for example, can be measured by comparing GDP per capita or wealth data across countries. Within a country, economic inequality can be measured using data on income/consumption, assets, multidimensional well-being indicators, and wealth. Next, we focus on indicators and data used to measure inequalities in climate change contributions. The discussion is structured by indicator types and their corresponding measurements, discussing both global (cross-country) and national (intra-country) inequality.

GHG emissions are the primary drivers of climate change. Greenhouse gases comprise carbon dioxide, methane, and nitrous oxide; with carbon dioxide (CO_2) being the predominant contributor to greenhouse gas emissions. Historically, significant disparities in greenhouse gas emissions have existed globally. National level data on greenhouse gas emissions, namely CO_2 emissions, are available for many countries to analyse such inequalities. One such indicator is cumulative CO_2 emissions. Cumulative CO_2 emission serves as a crucial indicator, as global warming is more closely associated with the stock of CO_2 emissions than with the flow (Allen et al., 2009; Rhys, 2011). Consequently, cumulative CO_2 emissions are crucial for discussions around climate policies and climate justice. Figure 2 illustrates the cumulative CO_2 emissions from fossil fuels and industry since 1750, quantified in tonnes.[3] The figure illustrates significant inequality in cumulative CO_2 emissions, with the United States and the European Union being the primary contributors.

[3] This data is based on territorial emissions and excludes emissions embedded in traded goods. The emissions from international shipping and aviation are not included. Emissions from changes in land use are not considered.

Figure 2: cumulative CO_2 emissions by selected major regions and countries



Source: Authors elaborations using data from Our World in Data.

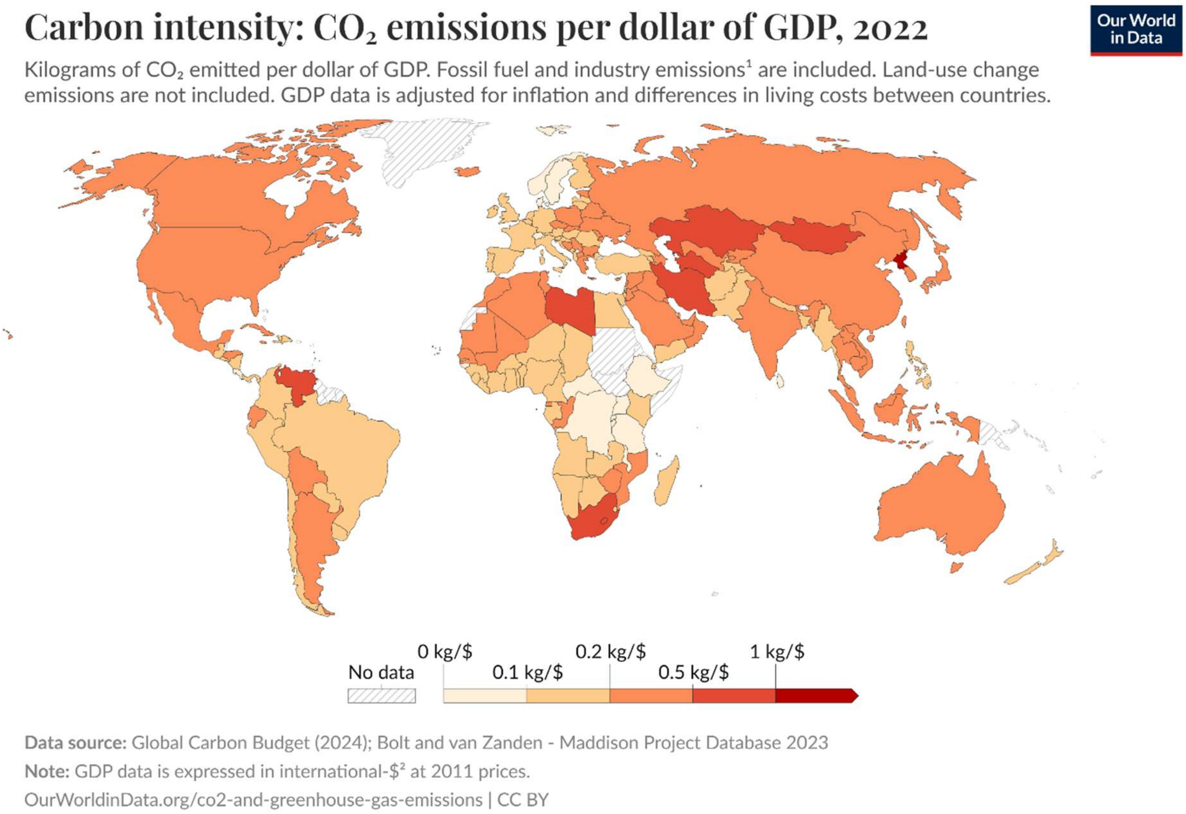
A frequently utilised metric for assessing disparities in contemporary CO_2 emissions among countries is CO_2 emissions per capita. Contemporary CO_2 emissions levels can be assessed using either production-based emissions or consumption/income-based emissions. Figure 3 illustrates carbon intensity of GDP, which quantifies production-based CO_2 emissions. The estimate depicted in the figure illustrates significant disparities in carbon intensity of GDP across countries, with the majority of African countries contributing minimally.

To measure global carbon inequality, two broad approaches can be identified. First, bottom-up approaches use household-level microdata to produce macroestimates. This approach is used by Bruckner et al. (2022) Hubacek et al. (2017) and Oswald et al. (2020), who use consumption surveys linked to Environmental Multi-Regional Input-Output models (EMRIOs) to provide estimates of energy consumption or emissions per consumption group. This approach presents however the limitation of not looking at the evolution of global emissions and underestimating the consumption levels of the richest groups.

Top-down approaches use the regularities of micro-level data to provide modelled estimates on the basis of elasticity parameters and income or consumption inequality distributions. This approach is used by Chakravarty et al. (2009), Chancel and Piketty (2015), Semieniuk and Yakovenko (2020) and Kartha et al. (2020). The approach presents the limitations of using one elasticity for all countries, which limits the precision of country-level estimates.

Chancel (2022) uses income and wealth inequality data from the World Inequality Database, combined with GHG footprints from input-output models, a newly assembled set of country-level information on the link between individual emissions, consumption and income in more than 100 countries. This makes it possible to track individual GHG emission levels with more precision than longitudinal carbon inequality estimates (such as in Chancel and Piketty, 2015) and allows him to distinguish between emissions from private consumption and investments and to better understand the drivers of emissions among wealthy groups. Using EMRIOs, Chancel (2022) obtains country-level GHG emissions for the household sector, the investment sector, and the government sector across countries (emissions are net of imports and exports embedded in goods and services traded with the rest of the world). These emissions are distributed to individuals in each country using country-level data profiling levels of emissions to levels of income and wealth.

Figure 3: Carbon intensity of GDP across countries

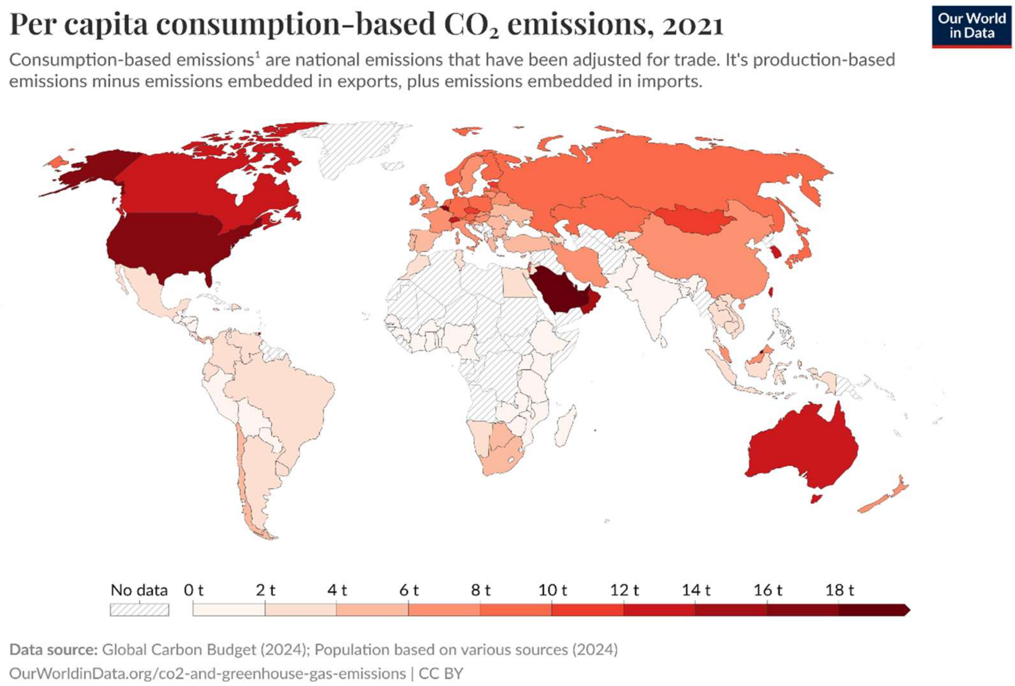


Source: Our World in Data.

The estimates in Figure 3 above are based on territorial emissions, excluding emissions inherent in traded goods. Current climate agreements are primarily based on national-level territorial emissions; however, to account for emissions transfers linked to trade and to more effectively align responsibility with the flow of benefits, proposals have emerged to estimate CO_2 emissions based on consumption or income (Starr et al., 2023b). Consumption-based emissions assign the emissions produced during the production of goods and services to the location of consumption, rather than the location of production. Figure 4 presents per capita consumption-based CO_2 emissions for the year 2021. Nonetheless, numerous African countries lack data for this estimation. Based on the available data, countries in Africa and Latin America contribute the least when it comes to the consumption-based CO_2 emissions. On the other hand, the United States, Canada, Australia, and Saudi Arabia are among the most contributors to consumption-based CO_2 emissions[4].

[4] While other indicators relevant to the fossil-fuel dependence, such as local air pollutants, also reveal disparities that are correlated with wealth inequality, we do not include them in our review as they are not greenhouse gases and not directly relevant to climate change

Figure 4: per capita consumption-based CO_2 emissions

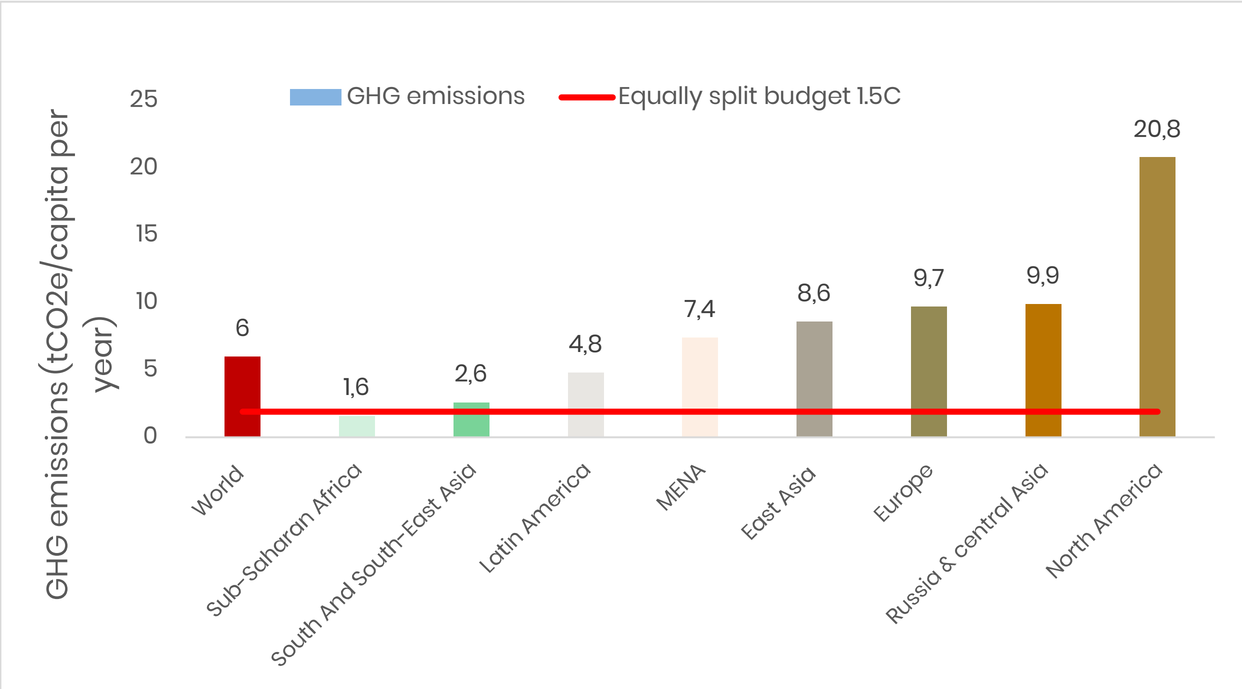


Source: Our World in Data.

Overall, current evidence demonstrates substantial disparities in contributions to climate change globally. Although emissions are rising rapidly in certain emerging nations like China, industrialised countries contribute substantially more than the global average, indicating differential responsibilities for climate change mitigation (see Chancel et al., 2023). The differential mitigation responsibilities can be highlighted by comparing current emission levels to hypothetical per capita carbon budgets. According to Chancel et al. (2023, p.19), the hypothetical per capita carbon budgets are calculated by equally distributing the remaining CO_2 emissions permissible until 2050 to remain below the 1.5◦C threshold target among the projected global population. The global equally distributed carbon budget is 1.9 tCO2e per capita per year until 2050 to accomplish climate targets with an 83% probability (Chancel et al., 2023: p.19). Figure 5 compares GHG emissions per year with carbon budget for 2019. The results reveal that Sub-Saharan Africa is the only region where current average per capita emissions conform to the 1.5°C target, and even an annual per capita emission increase of approximately 20% would be in line with the 1.5°C target (see Chancel et al., 2023: pp. 22). Despite per capita emissions in South and South-East Asia and Latin America exceeding the budget, it remains achievable within the confines of the Paris target. Conversely, emission levels in North America exceeded the 1.5°C target threshold by over a factor of ten (see Chancel et al., 2023: pp. 22).

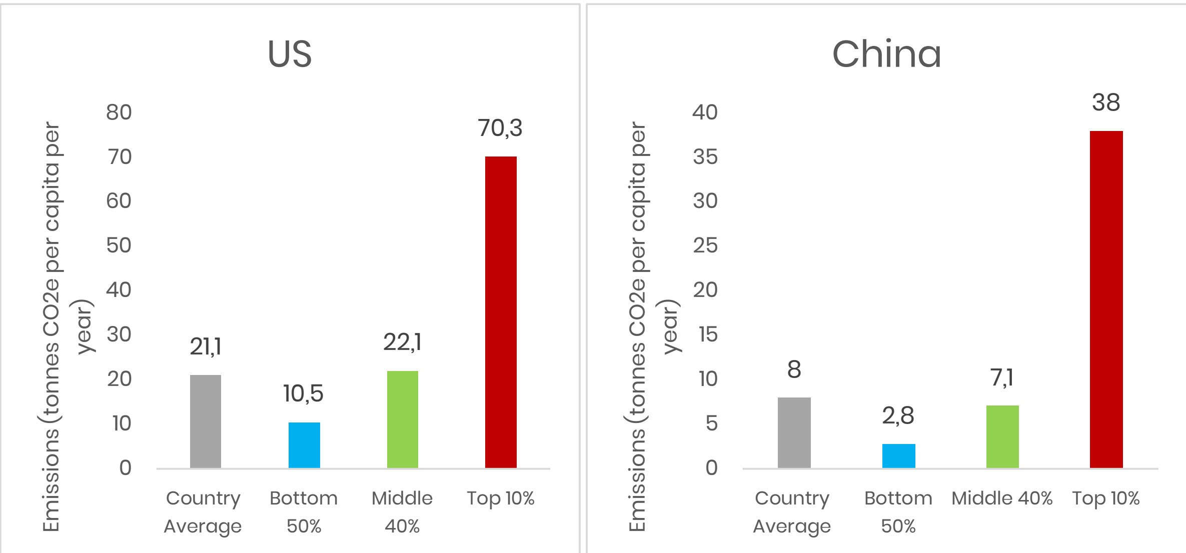
Recent evidence shows that inequalities in CO_2 emissions are higher within countries than between countries (Chancel et al., 2023; Starr et al., 2023b, 2023a). This indicates that within countries there are inequalities in CO_2 emissions contributions across income groups with the rich contributing more than the poor. However, although we can find data on CO_2 emissions per sector within countries, disaggregated data on CO_2 emissions by income groups is not readily available. Figure 6 shows per capita emissions by income groups for the US and China. In both countries emissions by those in the richest income decile is significantly higher than the rest of the population indicating large inequalities in CO_2 emissions contributions across income groups.

Figure 5: tCO2e/cap per year by region vs remaining budgets for 1.5.C (2019)



Source: Chancel et al (2023).

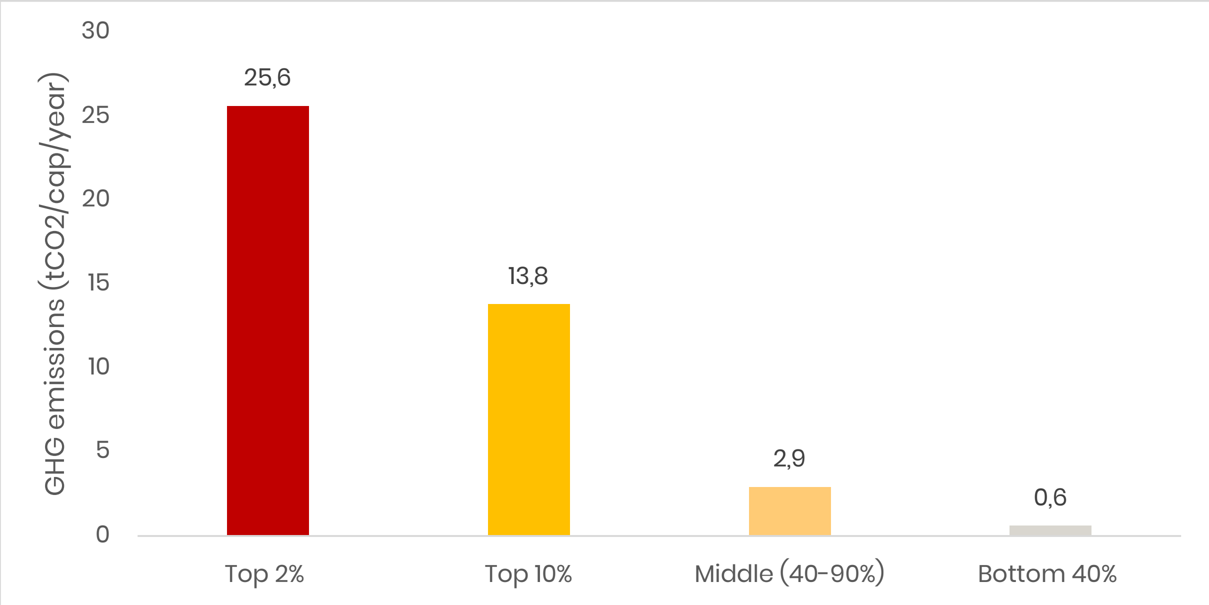
Figure 6: Per capita emissions by income group



Source: Chancel et al. (2023).

Estimating CO_2 emissions contributions using consumption or income-based frameworks requires detailed consumption item data and income source data and data on energy consumption by sector. Household level data on income and consumption can then be linked with economic input and output data to estimate CO_2 emissions contributions by income groups. Although we can find data on CO_2 emissions per sector for most countries in global databases such as the ones from the International Energy Agency or from EDGAR - Emissions Database for Global Atmospheric Research, due to data limitations, disaggregated data on CO_2 emissions by income group is not readily available for many countries in the global South. Available evidence indicates significant intra-country inequality in CO_2 emissions among income groups. Figure 7 illustrates substantial disparities in CO_2 emissions across income groups in South Africa, with the richest 2% contributing over 42 times more than the bottom 40% of the population (Reeler, 2021).

Figure 7: Per capita emissions by income groups for South Africa (2015)



Source: Reeler (2021)

b) Measuring how economic inequalities shape the impacts of climate change

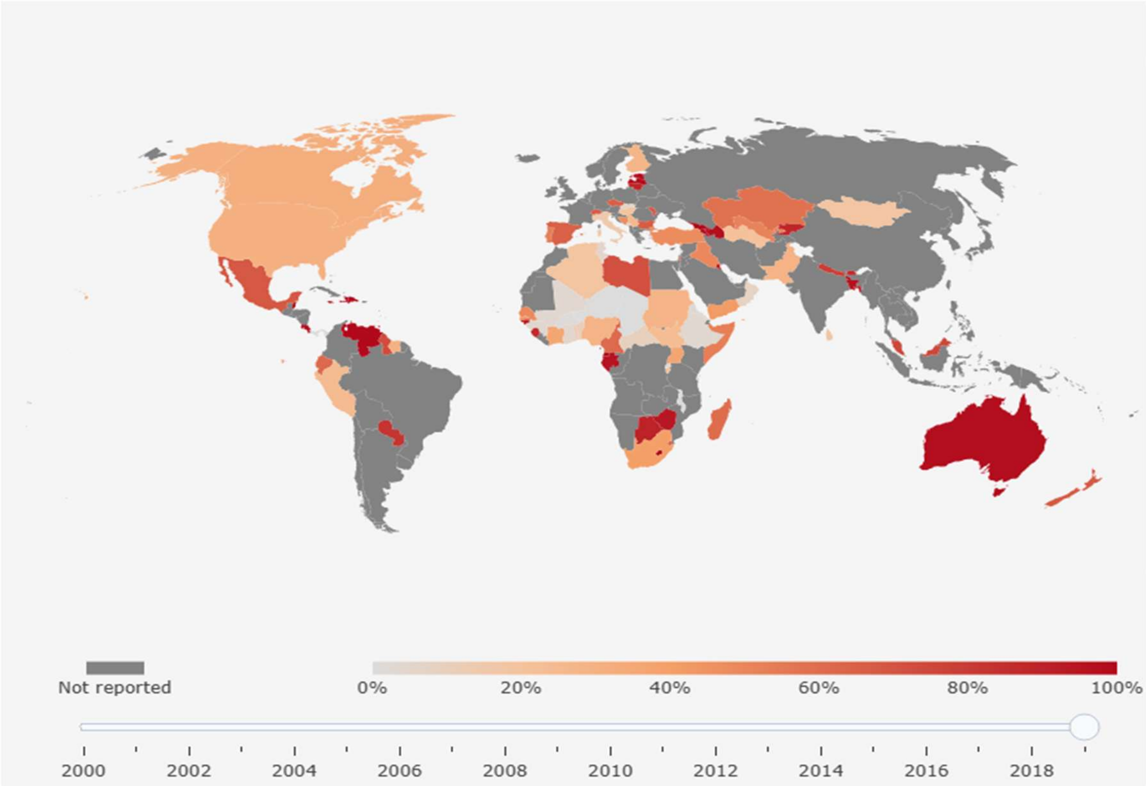
Economic disparities are associated with disparities in the effects of climate change. The causal pathway in this case is from economic inequality to inequalities in the exposure and vulnerability of individuals and society to the effects of climate change, resulting in the disproportionate loss of life, human capital, assets, and income among disadvantaged groups. For instance, poor countries are disproportionately impacted by the effects of climate change. Similarly, disadvantaged groups within countries are disproportionately affected by the repercussions of climate change. Measuring this relationship requires data on economic indicators as well as data on the effects of climate change.

Climate change has numerous repercussions. These can broadly be classified into primary and secondary effects of climate change. The primary effects of climate change encompass increasing sea levels, heatwaves, droughts, water scarcity, flooding, glacial melting, wildfires, soil erosion, cyclones, hurricanes, land degradation, diminished vegetation, and biodiversity loss. For example, we can evaluate inequalities in the effects of climate change by analysing inequalities in exposure to climate-related hazards such as flooding and droughts. Disparities can be observed in exposure to numerous climate-related risks across countries and among population groupings within countries.

Numerous indicators and indices exist for assessing climate change-related shocks, including droughts and floods. For example, the World Meteorological Organisation (WMO) and Global Water Partnership (GWP) proposed over 35 indices for assessing drought situations (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016). One common approach is to use meteorological data, including precipitation or temperature anomalies, which enables the estimation of the proportion of the population exposed to climate change related hazards such as flooding or droughts. Meteorological data are used to calculate standardised indicators, such as the Standardised Precipitation-Evapotranspiration Index (SPEI), for assessing the prevalence of drought or flooding across and within countries (Vicente-Serrano et al., 2010). Indices such as SPEI quantify the deviation of measured temperature or precipitation from long-term averages. Based on the SPEI, large negative SPEI values indicate arid circumstances (drought), whilst large positive SPEI values denote very rainy conditions (flooding).

An alternative to the use of meteorological data for analysing exposure to climate change related hazards is to use survey data that enquires whether households or individuals anticipate or have encountered climate-related hazards. Some data on reported experiences of climatic change related hazards are available at the national level (Manda et al, 2023a). Collating such studies, the UN reports the percentage of the population exposed to drought based on reported drought events since 2000 (Figure 8). There are issues in using such data for cross-country comparisons, as it's indicated on the data portal that "not all parties have reported all indicators" (UNCCD).

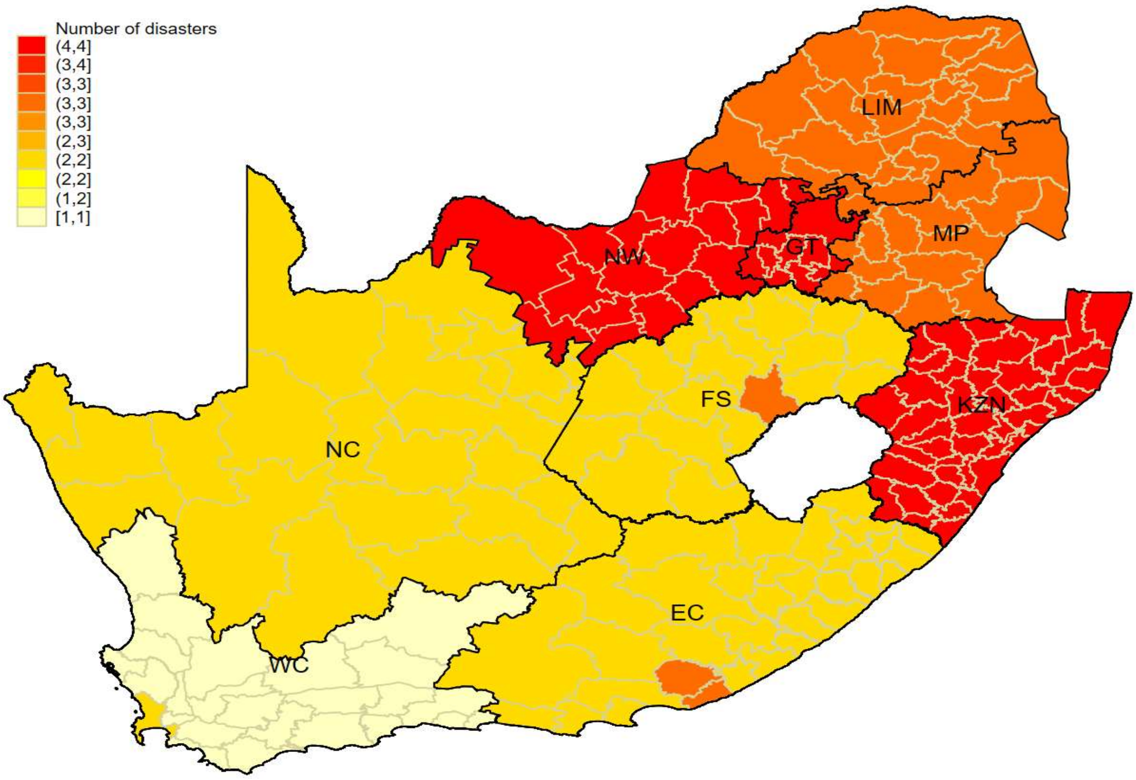
Figure 8: Proportion of the population exposed to drought in 2019



Source: United Nations convention to combat desertification (UNCCD).

The Emergency Events Database (EM-DAT) from the Centre for Research on the Epidemiology of Disasters (CRED) serves as another data source, providing information on natural disasters and their estimated human and economic costs since 1960. The EM-DAT disaster database provides geocoded disaster locations, facilitating sub-national level analysis of the effects of climate change-related within countries (Rosvold & Buhaug, 2021). Figure 9 shows the spatial distribution of the number of climate-related disasters between 2010 and 2014 in South Africa. The Figure shows that the incidence of disaster experience varies across spatial locations with the number of disaster experiences being relatively higher in provinces such KwaZulu-Natal, North West and Gauteng.

Figure 9: Number of climate-related disasters in South Africa by location (2010-2014)



Source: Shifa et al. (2023).

Assessing the secondary effects of climate change entails evaluating disparities in loss and damage resulting from exposure to a given climate-related hazard. For example, exposure to flooding can lead to the loss of properties, livelihoods, and an increased risk of waterborne infections. This means we have to analyse the loss and damage that accrue due to specific types of climate-related hazard.

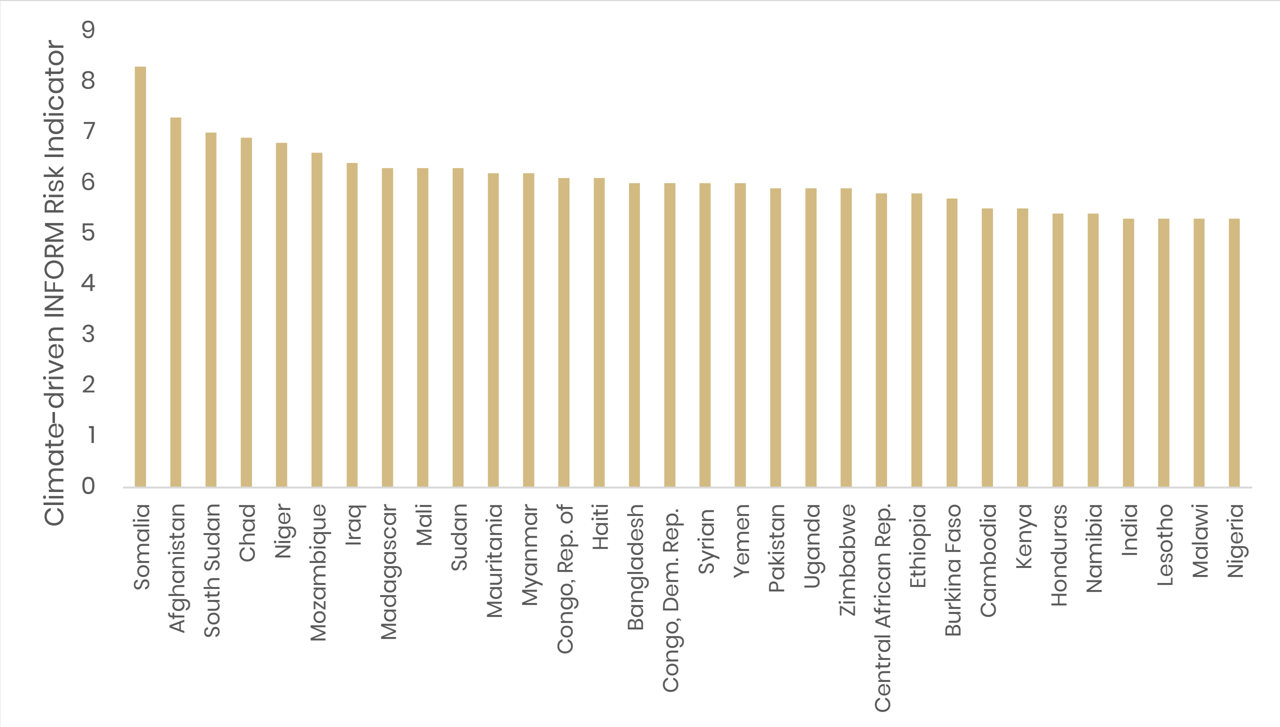
The impact of exposure to climate climate-related hazards can vary across countries. For example, exposure to heatwaves can result in detrimental health effects and fatalities with significant inequalities across countries. Similarly, exposure to severe droughts can lead to reduced agricultural and livestock production or productivity losses. This may lead to increased food prices and an increased incidence of food insecurity, along with a decline in income and livelihoods. Numerous indicators and methodologies exist to assess the direct and indirect effects of droughts. However, estimating agricultural production or productivity losses due to droughts involves the application of some modelling methodologies (Ajetomobi, 2016; Ayanlade et al., 2022; Emediegwu et al., 2022; Fuller et al., 2018; Trisos et al., 2022). Cross-country data regarding agricultural production, productivity losses, or food insecurity directly associated with droughts is not readily available.

A key point of this paper is to emphasise that the costs and damages incurred as a result of climate change-related hazards are determined by exposure to hazards *as well as by vulnerability* (sensitivity, coping, and adaptive capacity). The analysis of the secondary effects of climate change reveals that, in addition to disparities in exposure to climate hazards, there are also inequalities regarding the degree to which individuals/society are affected by these hazards (i.e., vulnerability). Even when exposed to identical hazards, the costs and damage can vary among countries and population groups within countries due to diverse underlying socioeconomic and political factors. For this reason, inequalities in climate change impacts can also be indirectly assessed through the underlying factors that influence exposure and vulnerability in a specific society or system. These factors include geographic location such as the proportion of the population residing in low-elevation coastal zones and arid regions, predominant economic activities such as the percentage of individuals engaged in subsistence agriculture or coal mining, inadequate infrastructure and services resulting in poor drainage and housing, housing costs, and limited access to safe drinking water and sanitation, and the capacity to adapt and recover through livelihood diversification, access to insurance, social assistance, social capital, assets, savings, access to credit, and the utilisation of technology such as water-saving and irrigation systems.

Measuring the effects of climate change using underlying socioeconomic factors entails considering a variety of factors that determine a population's exposure and vulnerability to a specific climate-related hazard. Furthermore, the underlying factors that determine exposure and vulnerability differ depending on the nature and type of climate-related hazards being considered. As a result, there is no standardised method for quantifying the full impacts of climate change. Despite this, numerous indices have been proposed to assess inequalities in exposure and vulnerabilities to climate change hazards (Doan et al., 2023; European Commission, 2017). An ambitious example is the Climate-driven INFORM Risk Indicator (DRMKC, 2022). This is based on the INFORM Risk indicator (DRMKC, 2022) but has been adjusted by IMF experts to focus solely on climate risks.

The Climate-driven INFORM Risk indicator is a multidimensional index with three dimensions: hazard and exposure, vulnerability, and lack of coping capability. The hazard and exposure dimension constitutes climate-related hazards (i.e. flood, tropical cyclone, and drought). The vulnerability index is calculated using 18 indicators, including the human development index, multidimensional poverty index (MPI), food insecurity, aid dependency, and health outcomes (e.g. malnutrition and HIV prevalence). The coping capability is assessed using 13 indicators, which include institutional factors (e.g., government effectiveness index, corruption perception index), communication (electricity, internet), physical infrastructure (road density, access to improved water, access to improved sanitation), and health systems (e.g., health expenditure per capita, full immunisation of 1-year-olds against measles). Figure 10 depicts the Climate-driven INFORM Risk Indicator for the top 32 countries, ordered by their level of risk. The Climate-driven INFORM Risk varies from a high value of 8.3 to a low value of 0.3, with a larger index value indicating greater climate-related risk. The assessment indicates a substantial amount of inequality in climate-related risk across countries. Out of 32 countries with an index value above 5 points, 21 are from Africa.

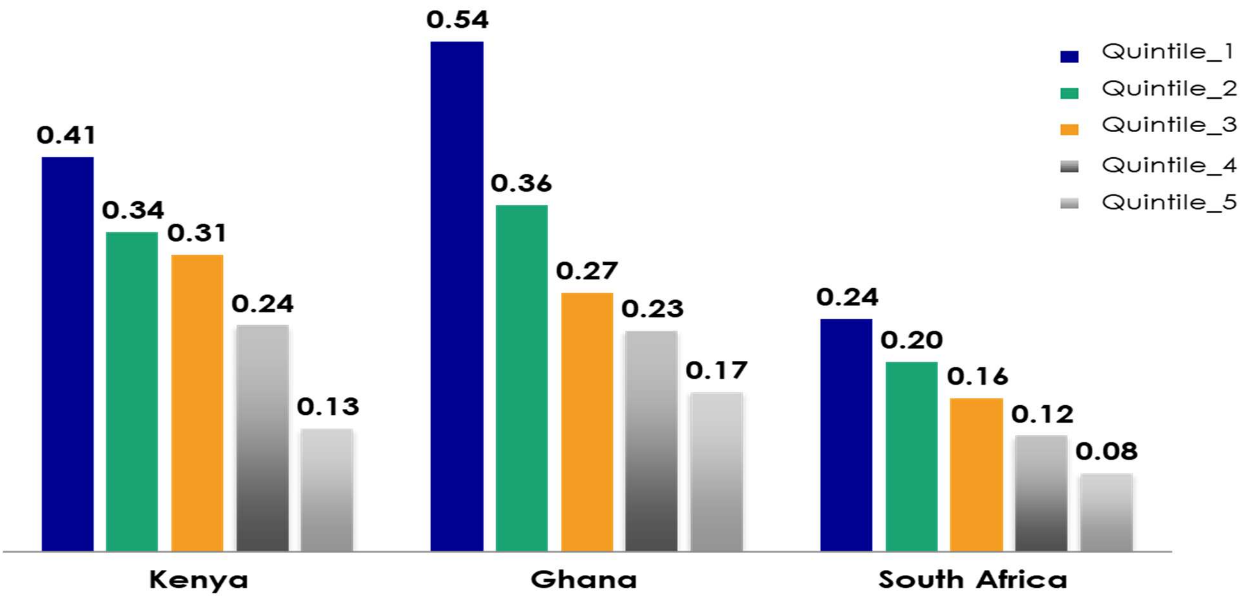
Figure 10: Climate-driven INFORM Risk Indicator



Source: Author(s) elaborations using data from IMF (DRMKC, 2022).

There exist disparities within countries in the effects of climate change, based on geographic location and population groups. Again, there is a paucity of comprehensive data sources that can be used to analyse disparities in the impacts of climate change, disaggregated by location and population groups within countries. Depending on purpose, research will derive and use different indicators and aggregation approaches for measuring within country inequality in vulnerability to climate change impacts. For instance, Zhang et al. (2023) used four dimensions to measure multidimensional vulnerability to climate change impacts: demographic, economic, housing conditions, and nutrition. In measuring the four dimensions, eleven indicators were used. These indicators can be categorised as "generic" vulnerability determinants (Brooks et al., 2022, p. 152). Such indicators are useful for assessing vulnerability to climate change impacts in a variety of contexts and climate change-related hazard types (Zhang et al., 2023).[5] Using data from South Africa, Ghana, and Kenya a study by Zhang et al. (2023) shows that vulnerability to climate change impacts is significantly higher among the poor compared to the rich in all three countries (Figure 11).

Figure 11: Multidimensional vulnerability to climate change impacts

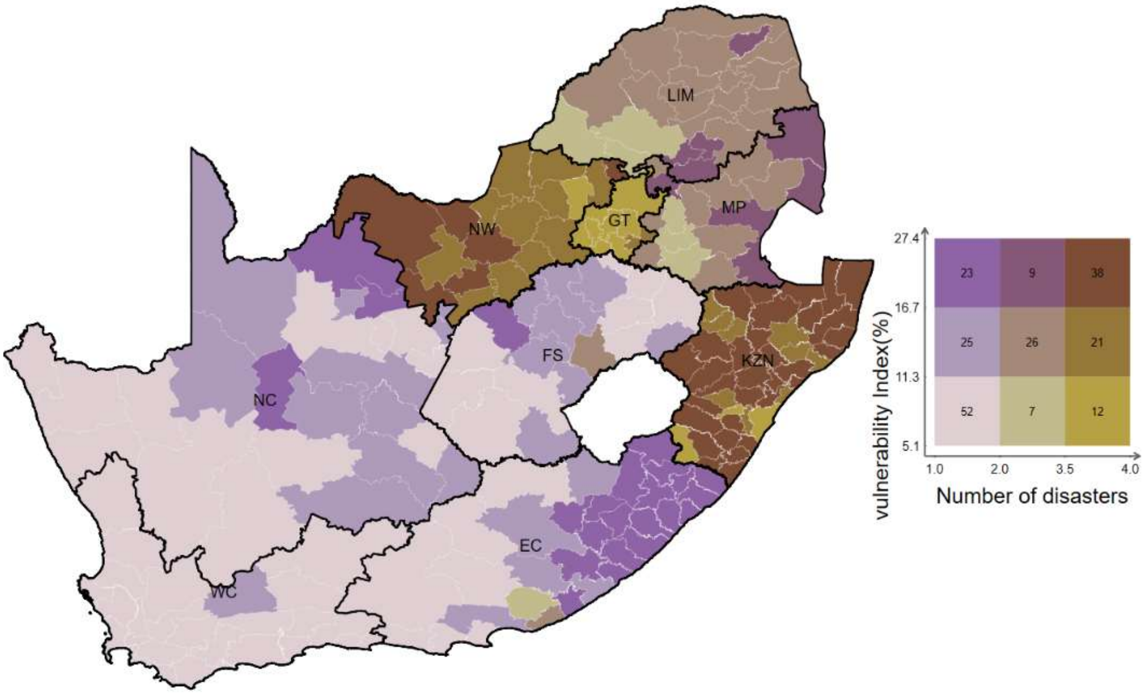


Source: Zhang et al (2023).

The EM-DAT disaster database provides geocoded disaster locations, facilitating sub-national level analysis of the effects of climate change-related disasters within countries (Rosvold & Buhaug, 2021). For instance, utilising the EM-DAT disaster data, we can analyse the correlation between experiences of climate-related hazards and social vulnerability. Figure 12 illustrates that populations with greater social vulnerability are more prone to climate-related hazards in South Africa, highlighting disparities in both exposure to climate change disasters and social vulnerability across different spatial units.

[5] Table A2 in the Appendix provides the list of indicators proposed to measure vulnerability to climate change impacts.

Figure 12: Relationship between number of climate-related disasters (2010-2014) and social vulnerability

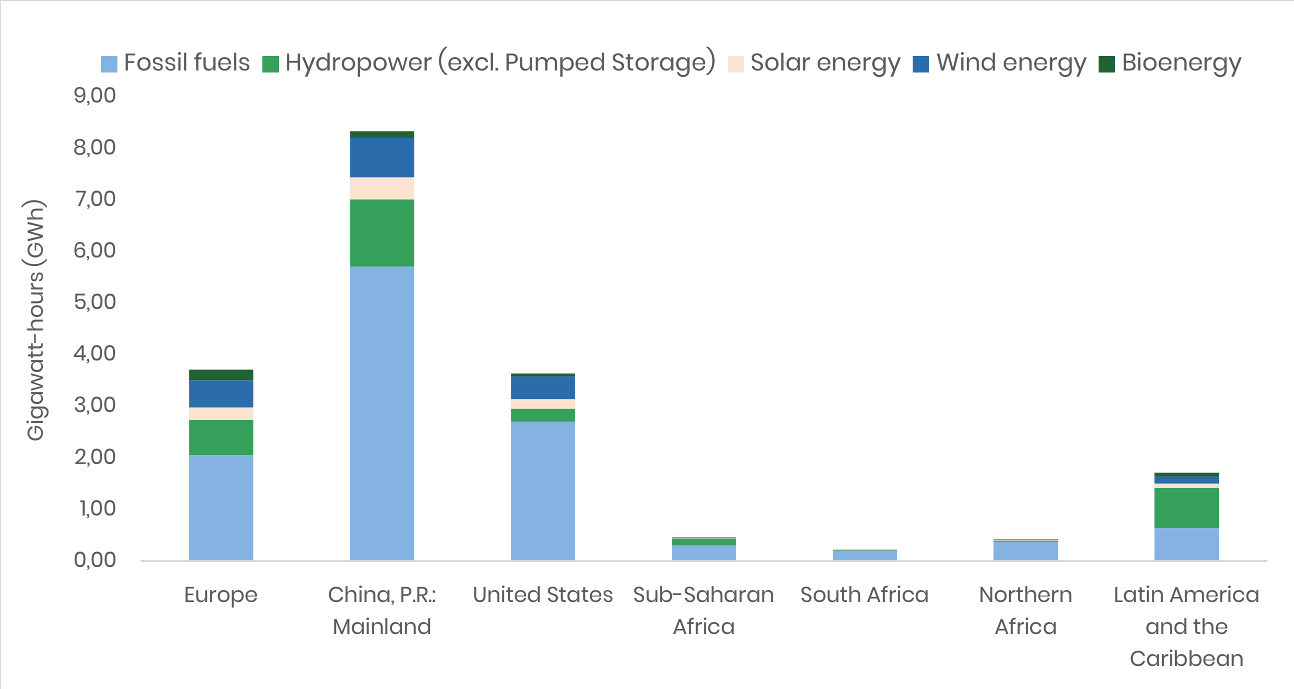


Source: Shifa et al. (2023)

A comprehensive analysis requires combining disaggregated EM-DAT with similarly disaggregated household survey. For example, linking meteorological data with household survey data enables the assessment of inequality in climate change impacts based on socioeconomic characteristics.

Mitigation of climate change requires the capacity to implement various mitigation strategies. Current disparities in the capacity to implement mitigation strategies are linked to present and future vulnerability to the impacts of climate change. The IMF has identified six indicators to assess mitigation efforts per country. These encompass renewable energy, environmental taxes, government expenditure on environmental protection, fossil fuel subsidies, trade in low carbon technology, and the proportion of forest area. For example, Figure 13 illustrates power generation by technology for selected countries and regions in 2022. Power generation in African countries is significantly lower than in other regions and countries indicating substantial energy poverty. Renewable energy generation is comparatively greater in China and developed nations, like the United States and other European countries. These estimates show that economic inequities translate to inequality in the ability to invest in mitigation and adaptation strategies. Poor countries typically have a lower capacity to invest in mitigation and adaptation policies than wealthier countries.

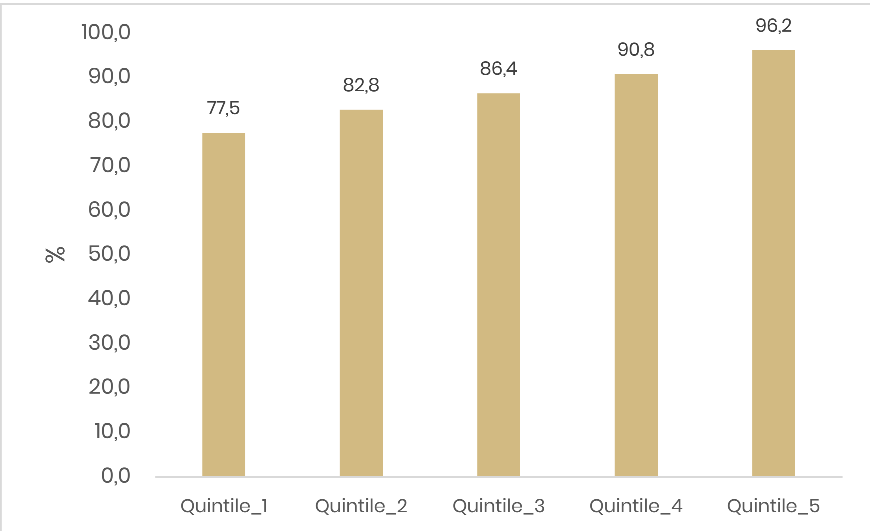
Figure 13: Power generation by technology for selected regions and countries (2022)



Source: Author(s) elaborations using data from IMF

The absence of access to clean and renewable energy sources in Africa corresponds with increased indoor and outdoor pollution, leading to detrimental health effects. Clean cooking sources include the use of electricity, natural gas, and solar energy. There are large disparities in access to clean energy within countries (Figure 14). Figure 14 shows that the use of clean energy for cooking is South Africa is relatively lower among those in the poorest income quintile. The use of electricity does not inherently signify the use of renewable energy, as the production source may be coal, as is the case in South Africa. However, the use of electricity for cooking rather than wood and coal can reduce indoor air pollution and the associate health risks. The use of wood and coal for cooking among developing countries may signify a lack of renewable energy sources.

Figure 14: Share of the population with access to clean cooking energy (South Africa)



Source: Author(s) elaborations using data from GHS,2019.

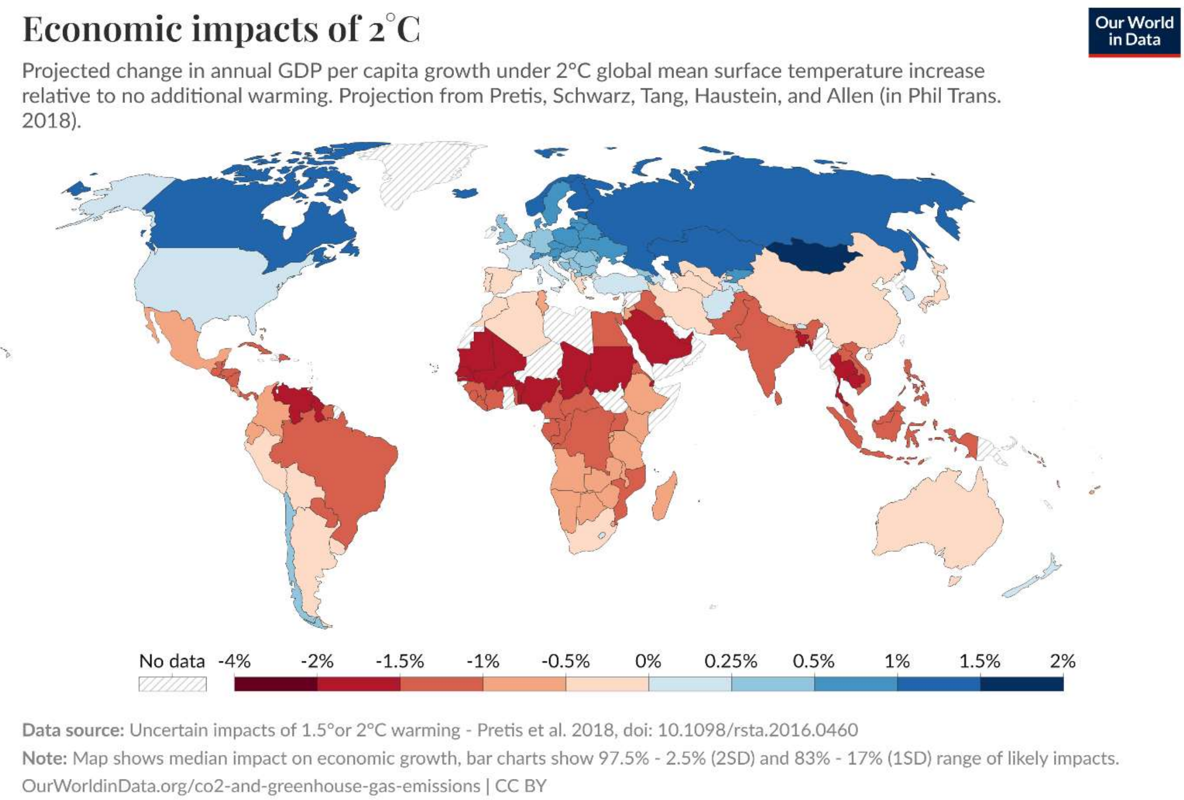
2.2. From climate change impacts to economic inequalities

Just as economic inequalities can lead to unequal contributions and impacts of climate change, another causal pathway that we demonstrated looks at how inequalities in climate change can increase economic inequalities across and within countries.

Although both developed and developing countries are affected by climate change and its consequences, developed countries have the financial and institutional resources to invest in mitigation and adaptation strategies without compromising other economic priorities to the same extent. However, in the case of developing countries, mitigation and adaptation costs might increase their existing high debt burden, resulting in trade-offs between financing climate action and other social and economic development priorities. Adaptation and mitigation cost estimates reveal that adaptation costs can be beyond the fiscal space of many developing countries (Aligishiev et al., 2022; Buchner et al., 2019).

Without mitigation and adaptation efforts, the cost of climate change will be significantly higher for developing countries. One way to measure this is to examine the effect of climate change-induced temperature increases on GDP per capita growth across countries. Existing evidence suggests that warmer and poorer countries are most vulnerable to climate change-induced temperature shocks (Bilal & Känzig, 2024; Pretis et al., 2018). Figure 15 depicts the expected change in GDP per capita under the 2°C global mean surface temperature compared to no additional warming (Pretis et al., 2018). The findings indicate that poor and developing countries will see a relatively big reduction in GDP per capita as a result of global warming. Given the existing inequalities in GDP levels across countries, a disproportionate reduction in economic growth in poor and developing countries is predicted to exacerbate existing inequities.

Figure 15: Impacts of 2°C global mean surface temperature on GDP per capita growth



Source: Pretis et al. (2018) data processed by Our World in Data.

In addition to climate change related disasters, mitigation and adaptation policies can affect inequality. Climate policies, such as carbon pricing, are critical strategies for mitigating climate change. However, mitigation policies can have significant distributional and welfare effects (Känzig, 2023; Soergel et al., 2021).

The empirical evidence on the distributional effects of carbon pricing in developing countries is limited and inconclusive (Dorband et al., 2019; Steckel et al., 2021). The inconclusive results are attributable to the different contexts and methodologies used to assess the impacts of carbon pricing. Estimating the distributional impact of policies like carbon pricing is data-intensive and requires sophisticated estimation techniques. Dorband et al. (2019) used expenditure data from 87 developing and emerging countries to investigate the distributional effects of carbon pricing. They used multi-regional input-output tables (MRIO) to calculate the fossil energy-related carbon footprints of households across income groups and then used microsimulation to estimate the effects of carbon pricing on income. Dorband et al. (2019) demonstrate that adopting modest carbon pricing policy (USD 30/tCO2) is regressive in richer countries yet progressive in poorer countries. Steckel et al. (2021) found similar results using data from developing countries in Asia. One reason for the observed progressivity of carbon pricing in developing nations is that the poor consume less energy than the national average, and increases in energy prices are the primary channel through which carbon pricing influences income or expenditure. Thus, whereas carbon pricing policies can exacerbate inequality in developed countries, this may not be the case in developing countries. However, even progressive outcomes would affect household welfare in absolute terms (Soergel et al., 2021; Steckel et al., 2021). For example, Soergel et al. (2021) demonstrate that without redistribution policies, mitigation efforts will lead to an increase in poverty under various development pathway scenarios.

Conclusion

Climate change not only exacerbates existing inequalities but is itself fuelled by entrenched inequalities at both the global and national levels. While these interlinkages between inequality and climate change are now widely acknowledged, the tools and frameworks to measure and assess them jointly are few and often limited to specific dimensions such as carbon inequality and climate vulnerability. This paper gives detailed attention to these linkages and to identifying the most relevant indicators to be used to measure them and to inform national policies to address them.

To do this, we provide an overview from the existing literature of the key linkages between climate change and inequalities both between countries (the global scale) and within countries (the national scale). At the global scale, we highlight how economic inequalities between countries shape climate change, and also how climate change entrenches inequalities between countries. Economic inequalities shape climate change through the consequent disparities in GHG emissions paths and also through uneven abilities to adapt across countries. The richest countries have higher capacities to adapt and respond to climate shocks. On the other hand, climate change shapes inequalities at the global level in different ways. We show how temperatures and extreme weather events impact low-income countries more heavily, while the costs of mitigating climate change through reduced emissions could hamper poorer countries' economic catch-up if they are not designed to recognise these prevailing inequalities.

At the national scale, within-country inequalities in income, wealth and private and public services and assets also shape GHG emissions paths and exacerbate climate shocks for those who do not have the income and assets to withstand and respond to such shocks. On the other hand, climate change shapes inequalities within-countries through disparities in exposure, vulnerability and resilience. Poor populations within countries live in more exposed areas and are more likely to work in jobs with higher exposure. They are more vulnerable when exposed to adverse climate effects and their capacity to adapt and recover from these adverse effects is undermined by the losses they incur.

It is our intent that this evidence on the interlinkages between climate change and inequalities and the distillation of indicators to profile these interlinkages can and will inform key policy issues and choices. The global scale framework informs policy debates at the global level about the effective and equitable collective solutions required to steer the planet towards a sustainable path. Most importantly, it informs each country how articulates into this global situation and how well-aligned its global commitments are with its climate change policies. All countries are formulating such policy responses. At the national scale, providing evidence on the substantial within-country spatial and socio-economic disparities of climate change contributions and abilities to respond provides a basis to steer national policy responses towards economic restructuring that will mitigate climate change in a way that allows all to make necessary responses and thereby sets the country on an inclusive and climate resilient trajectory.

Our approach distils these key linkages as a pragmatic and urgent first step. That said, such a highlighting of interlinkages and the multiple channels through which climate change and inequality reinforce one another is not a comprehensive review. It does not offer a full-scale explanatory model that captures the complex interactions among these dimensions. Given the multidimensionality of both climate change and inequalities, developing such an explanatory model is inherently challenging. Further research should focus on identifying and modelling the interactions between these indicators to move toward an explanatory framework that can more robustly inform policy design.

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Appendix

Table A1 : Interlinkages between climate change and inequalities

Global scale - unit of observation → countries (or individuals)

	GHG emissions path	Impacts
From economic inequalities to climate change	1. Inequality of wealth results in inequality of GHG emissions 2. Inequality of wealth results in inequality of ecological footprint - Carbon footprint/CO2 emission per country and per/capita - Carbon footprint/CO2 emission per population decile - intensity of CO2 per GDP Tons of CO2 per international $ GDP - unequal access to energy and affordable energy	1. Richer countries have a higher capacity to respond to climate shocks 2. Richer countries have a higher capacity (finance, human capacity) to transform their systems
From climate change to inequalities	Differentiated pace of the ecological transition between countries	1.loss & damage (targets from Dubai COP) – biophysical measures, cost measures (decision 2/CMA 5) • Water • Food/agricultural production • Infrastructure and settlements • Health 2.worsening fiscal burden (CC limits the growth potential between countries) Income/GDP 3.debt (debts for climate)

National scale - unit of observation → Households or individuals

	GHG emissions path	Impacts
From economic inequalities to climate change	- GHG inventory - GHG inventory per sector - intensity of CO2 per product - carbon emissions per decile/percentile (carbon household footprint inequality – Irfany & Klasen, 2017) - emissions linked to ensuring the basic needs – what are the decent standards • Shelter	- Different adaptive capacity - Access to insurance/asset ownership

	• Food • mobility - emissions by appliance type - energy access, affordability and use	
From climate change to inequalities	-Income composition/dependence of incomes to emissions - Price effects	- Different resilience levels - Different exposure and vulnerability levels (either in terms of phenomenon or in terms of impacted area/population) - Dependence of incomes to climate impacts

Source: Authors' elaboration

Table A2: Proposed List of Vulnerability Dimensions and Corresponding Indicators

Dimensions	Indicators
Demographic	1) **Younger children** (under 10) are known to be vulnerable to harm during flooding as they are relatively short and light and cannot swim very well or flee quickly (Mort et al., 2018; Muttarak & Dimitrova, 2018). Babies (under 12 months) are also at risk of heat stress as they have more limited temperature regulation than older children and adults. 2) **Pregnant women** are at a higher risk of spontaneous abortion, low birth weight, neonatal deaths, congenital anomalies, and maternal mortality due to flooding (Mallett & Etzel, 2017). 3) **Older people** (aged 60 and 60+) are known to be vulnerable to heatwaves with circa 80-90% of excess mortality from heat stress occurring in this age group (Kenny et al., 2010), particularly amongst those suffering from obesity, cardiovascular disease, respiratory disease, and diabetes. 4) **Disabled people** are often at greater risk of harm during extreme climate events (Gutnik & Roth, 2018). Disability is measured in many ways, but ideally, the results from an international harmonised measure should be used, such as the Washington Group Short Question Set[6] or the WHO Model Disability Survey[7] questions.
Economic	5) **Subsistence farmers, fishers, hunters and gatherers** (ISCO-08 = 63) 6) **Building and related trades workers** (excluding electricians) (ISCO-08 = 71) 7) **Agricultural, forestry and fishery labourers** (ISCO-08 = 91) 8) **Street and related sales and service workers** (ISCO-08 = 95)

[6] See http://www.washingtongroup-disability.com/

[7] See https://www.who.int/disabilities/data/brief-model-disability-survey5.pdf?ua=1

Household	9) **Inadequate housing construction**: mud/earth floor, and natural materials for walls/roofs are vulnerable to storms. 10) **Inadequate water supply:** surface water as defined by the JMP drinking water ladder[8] makes households vulnerable to both drought and floods. 11) **Inadequate sanitation:** open defecation and unimproved sanitation as defined by the JMP sanitation ladder[9] make households vulnerable to sewerage contamination during floods. 12) **Inadequate information access:** not having a radio, TV, mobile or landline telephone or internet access reduces the likelihood of receiving disaster warnings and other relevant and potentially life-saving information.
Nutrition	13**) Food Insecurity:** FAO Food Insecurity Experience Scale[10] (SDG threshold moderate to severe food insecurity). 14) **Anthropometric failure**: Comprehensive Index of Anthropometric Failure (CIAF), i.e., children (under 5) who are stunted, wasted or underweight (< 2SD below the WHO international reference population; see Nandy & Svedberg, 2011).

Source: Zhang et al (2023).

[8] See https://washdata.org/monitoring/drinking-water
[9] See https://washdata.org/monitoring/sanitation
[10] See https://www.fao.org/in-action/voices-of-the-hungry/en/

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