Sustainable development impacts of climate change and natural disaster

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The consequences and costs of climate change on our world will define the 21st century. Even if nations across the planet were to take immediate steps to curb carbon emissions—a warmer climate is inevitable. As the recent report by the U.N. Intergovernmental Panel on Climate Change noted, human-created warming will persists for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise. As these effects progress they will have serious impacts on human society. In the coming decades climate change will increasingly threaten human security in many parts of the world, disproportionately affecting the least developed countries. Climate change will pose economic, social, and political predicaments that will challenge the successful implementation of the Sustainable Development Goals (SDGs).

This is a stocktaking piece on the physical and social consequences of climate change, with a specific focus on whether and how climate change via its effects on economic growth, migration, and conflict challenges the implementation of Sustainable Development Goals. This paper surveys the recent relevant literatures to identify the mechanism and contexts that give generate the interconnection between climate-economy-migration-conflict and evaluate the relative importance of climate as a hindrance to SDGs.

Figure A depicts how climate, the economy, migration, and conflict fit together. Consequently, my analysis commences with the main impacts of global warming on natural systems. Section 2 discusses the interlinkages between climate change, and in particular natural disasters with economic outcomes. Section 3 focuses on climate change and migration, while section four looks at the climate-conflict nexus. The final section offers a set of policy recommendations that derive from the analysis.

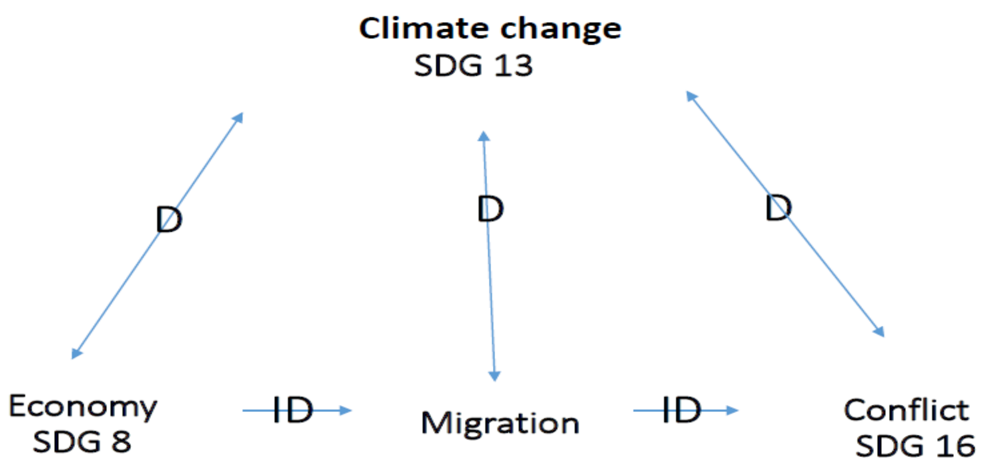


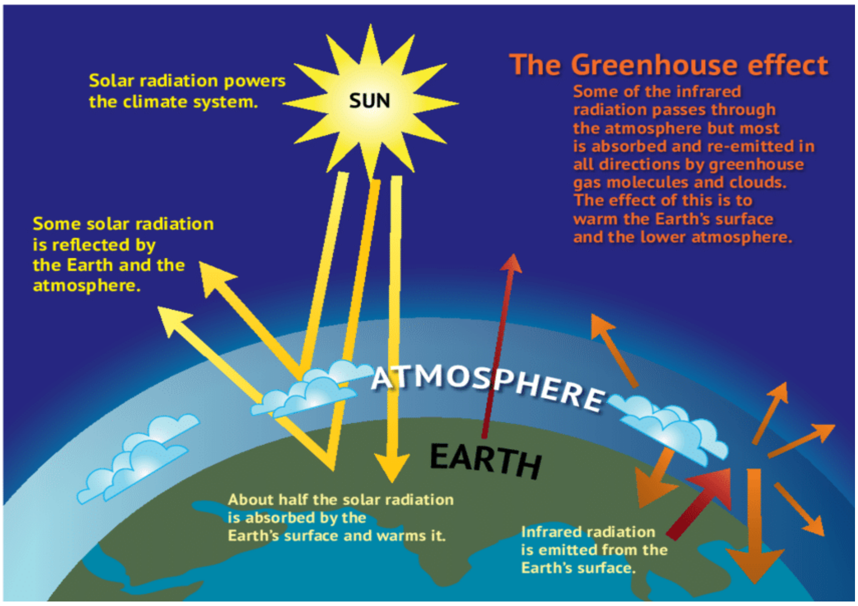
Figure A: Conceptual map including SDGs

1. Causes and consequences of climate change

The "greenhouse effect"

Scientists have been aware since the late 1960's of high concentrations of carbon dioxide (CO2) and other greenhouse gases (GHG) such as methane (CH_4) and nitrous oxides (N_2O) in the atmosphere. It is in recent decades, though, that the link between greenhouse gases and climate warming has caught the attention of scientists and politicians, as well as the general public, via the well-known "greenhouse effect". Graph 1 illustrates the basic processes behind the greenhouse effect. As the sun's energy hits the Earth, some of that energy is absorbed by the earth's crust and by the oceans, warming the planet. The rest of the energy is radiated back toward space as infrared energy. While some of this infrared energy does radiate back into space, some portion is absorbed and re-emitted by water vapor and other greenhouse gases in the atmosphere. This absorbed energy helps to warm the planet's surface and atmosphere just like a greenhouse.

Graph 1. The "greenhouse effect"



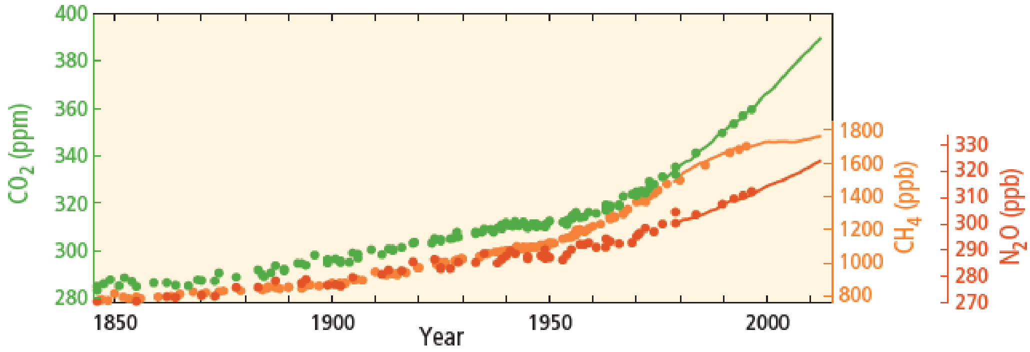
Source: IPCC WG1 AR4 SPM

While the greenhouse effect is a naturally-occurring process and in fact, is quite necessary for survival on Earth, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (2014) provides evidence that human activity has amplified this natural effect. In particular, anthropogenic greenhouse gas (GHG) emissions, mainly driven by economic and population growth have increased since the pre-industrial era, leading to atmospheric concentrations of carbon dioxide, methane, and nitrous oxide that are 'unprecedented in at least the last 800,000 years' (IPCC AR5 SPM-4).[1] In particular, long stable

[1] Carbon dioxide (CO_2) is a byproduct of the incomplete combustion of fossil fuels, and in particular coal; methane (CH_4) is emitted from agriculture and farming processes; and nitrous oxide (N_2O) is the

in the range of about 280 parts per million (PPM) in the atmosphere, CO_2 concentrations reached 398.93 PPM in (August) 2015 and increased to 406.99 PPM in (August) 2018 (a 2% increase), despite a growing number of climate change mitigation policies (Figure 1).

Figure 1: Globally averaged greenhouse concentrations



Source: IPCC AP5 Figure SPM.1c

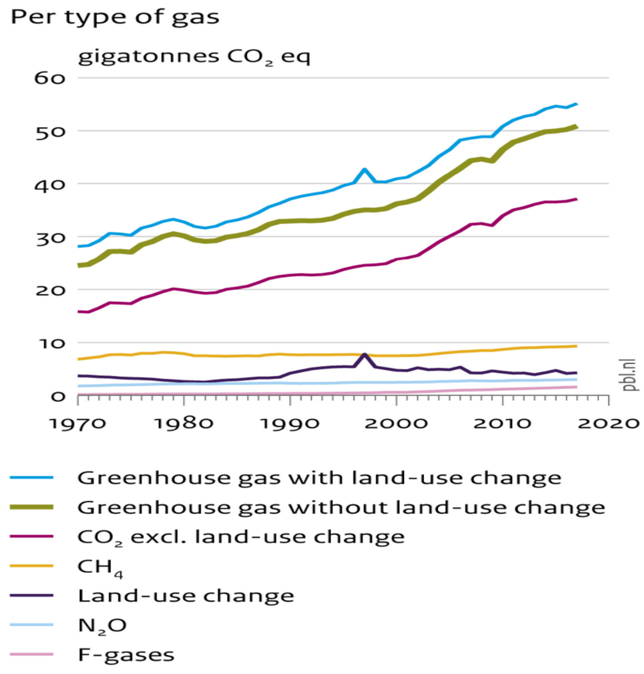
Trends in greenhouse gases emissions

Figure 2 shows that total GHG emissions have increased steadily since 1970, with trend variations usually explained by changes in economic output, for instance the 2008-2009 recession is clearly visible in the figure. During the years 2012 to 2014, however, global GHG emissions slowed down, especially the CO_2 emissions, and remained flat in 2015 and 2016 (estimated in 2015 to be 35.9 $GtCO_2$), bringing renewed optimism to climate policy discussions, since it may indicate a necessary peak in global GHG emissions. This decline is partly explained by a slowing down of global economic growth, especially with a decrease in China's economic growth rate. It also reflects new energy investments in renewables, in particular solar and wind in the United States and the European Union (Olivier and Peters 2018). Yet, initial data for 2017 reported by UNEP (2018) indicated GHG emissions have started to increase again, both globally and in key countries, reaching a new record of about 50.9 gigatonnes of CO_2 equivalent (Gt CO_2 eq) excluding those greenhouse gases from land-use change and 55.1 Gt when including the very land-use change emissions.[2] The increase in global CO_2 emissions in 2017, which reached 36.2 megatons was mainly due to the increase in global coal consumption led by China and India, and oil consumption led by China, the European Union, and the United States (Olivier and Peters 2018). However, the upward trend in CO_2 emissions continued in 2018, reaching 37.1 megatons an increase of 4.7% relative to 2015.

Figure 2: Global greenhouse gas emissions

product of a wide variety of human activities such as agriculture, fossil fuel combustion, wastewater management and industrial processes.

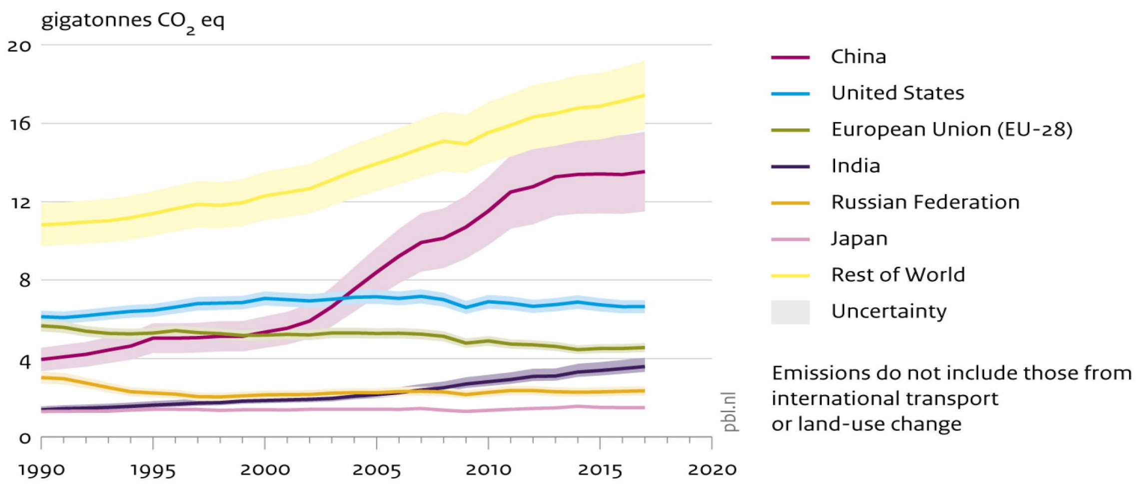
[2] The non-CO2 greenhouse gas emissions are much more uncertain than CO2 emissions because they originate from many different sources. Their uncertainty on a country and global level is of the order of 30% or more, whereas for CO2 this is about ±5% for OECD countries and ±10% for most other countries (Olivier et al 2016).



Source: Olivier and Peters 2018, Figure S.1

Figure 3 shows the distribution of CO_2 emissions among the main emitters: In absolute values, the largest emitters for CO_2 (and total greenhouse gas emissions) are China (10.92 Gt CO_2), the United States (5.11 Gt CO_2), and the European Union (3.55 Gt CO_2), followed by India (2.45 Gt CO_2), the Russian Federation (1.76 Gt CO_2), and Japan (1.32 Gt CO_2). For non-CO2 emissions only, India and the European Union switch rank (Olivier and Peters 2018). It is worth noting that in 2018, almost all countries are contributing to the rise, with emissions in China up 4.7%, in the US by 2.5% and in India by 6.3% (EU's emissions are near flat). Most of the future growth in carbon emissions is expected to come from rapidly expanding developing countries such as China and India.

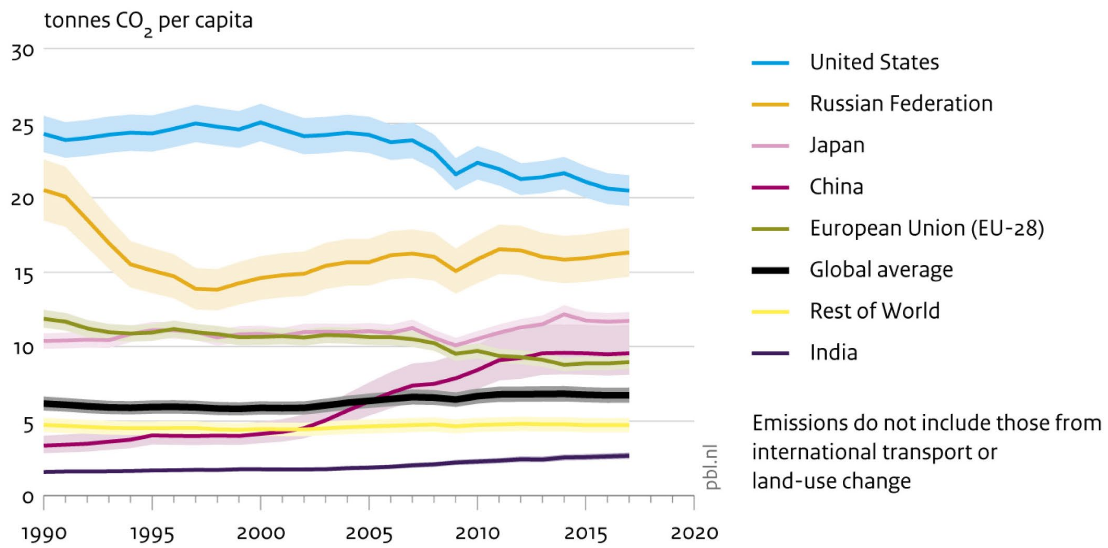
Figure 3: CO_2 emissions per country and region, 1990-2017



Source: Olivier and Peters 2018, Figure 3.1

In addition to total emissions by country, it is important to consider per capita emissions. Figure 4 shows CO_2 emissions per capita for the five main emitting countries, the European Union, the rest of the world, and for the world average. Except for India, all main emitters have per capita emission levels that are significantly higher than those for the rest of the world and the world average. China, in this measure, has rank 4, rather than rank 1, which it has for absolute emissions. With a few exceptions (e.g., Saudi Arabia and Qatar), there is an important north-south divide in terms of per capita emissions. Most nations across sub-Saharan Africa, South America and South Asia have per capita emissions below five tonnes per year (e.g., Nigeria, Egypt, Mexico, and Indonesia have 1.63, 3.35, 3.93, and 3.43 tonnes of CO_2 per person respectively). This contrasts with the global north where emissions are typically above five tonnes per person (e.g., United States at 20, Russia at 16.3, and the EU at 6.97 tonnes of CO_2 per person). The largest emitter, Qatar, has per capita emissions of 50 tonnes per year, which is 1243 times that of Chad, the lowest emitter (Olivier and Peters 2018).

Figure 4: CO_2 emissions per capita, per country and region, 1990-2017

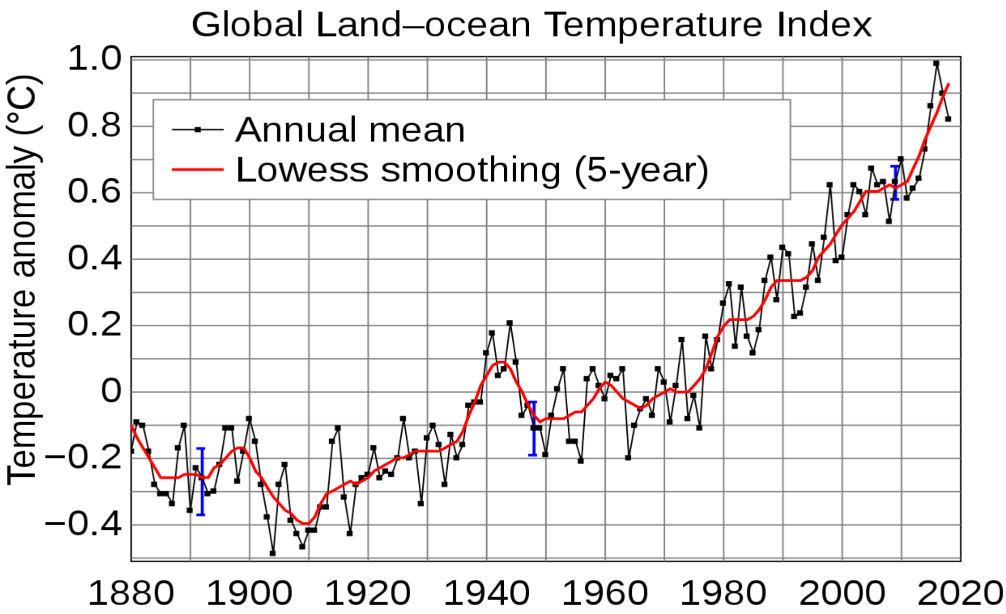


Source: Olivier and Peters 2018, Figure 3.2

Global Warming Trends

The enhanced greenhouse effect by disrupting the Earth's climate equilibrium has led to a warmer world. The global average *temperature* has risen by around 0.8^0C since 1880 (IPCC AR5, SPM-5). While a clear long-term global warming trend is observed, temperatures do not rise every single year and some years show greater temperature changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Ninos, La Ninas, and the eruption of large volcanoes. Nevertheless, eighteen of the nineteen warmest years in the modern meteorological record have occurred from 2000 to 2018 (Figure 5).

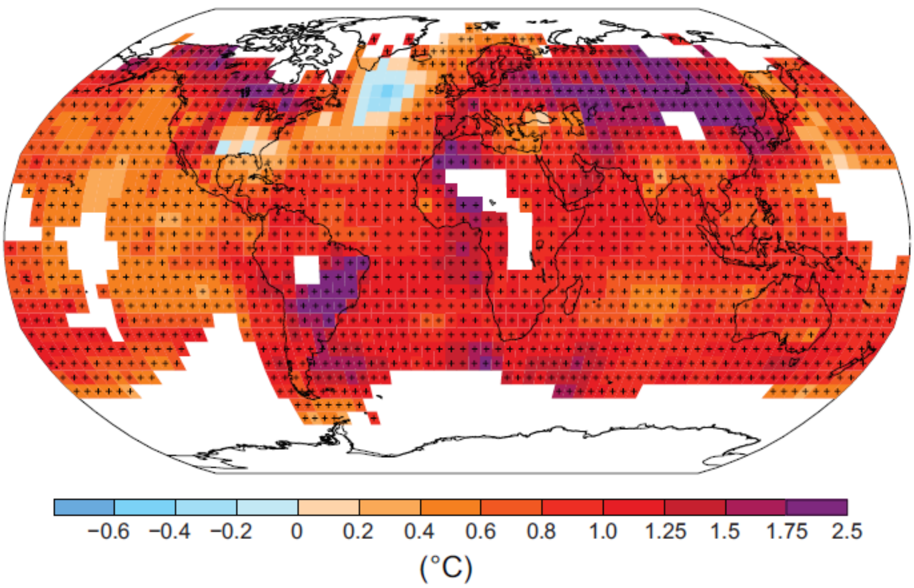
Figure 5: Global surface temperature increase over time



Source: NASA GISS (Goddard Institute for Space Studies)

However, not all areas of the world are warming equally. Warming is more pronounced over land than over water and towards the poles with the Arctic warming 2.8 times faster than the rest of the Northern Hemisphere (Box et al 2019). In fact, over a quarter of the global population already lives in regions that have already experienced more than 1.5^0C of warming in at least one season (Figure 6).

Figure 6: Observed change in surface temperature 1901-2012



Source: IPCC AR5, WG1, Figure SPM.1

In the face of ongoing global warming, the Greenland and Antarctic *ice sheets* have been losing mass. The Arctic *sea ice extent* has declined by about 10 percent and the average winter ice thickness has thinned by approximately 1.8 m over the 1979-2012 period (IPCC AR5, WG1, SPM-9; Box et al 2019). However, while melting ice in the Arctic is a result of global warming, melting ice is also a cause of further warming, since open-ocean absorbs more of the sun's energy than ice, a phenomenon known as reduced albedo. Moreover, as the Arctic is warming, frozen soils (*permafrost*) in parts of Northern Alaska and the Russian European North have started to thaw, often for the first time in thousands of years, releasing greenhouse gases into the atmosphere, further accelerating global warming (Turetsky et al 2019; Box et al 2019). Moreover, soils in the permafrost region hold twice as much carbon as the atmosphere does — almost 1,600 billion tonnes (Schuur et al 2015).

Warming temperatures also lead to the melting and shrinking of *glaciers*. Glaciers are shrinking five times faster now than they were in the 1960s. The glaciers shrinking fastest are in central Europe, the Caucasus region, western Canada, the U.S. Lower 48 states, New Zealand and near the tropics. Glaciers in these places on average are losing more than 1 percent of their mass each year (Zemp et al 2019). While Greenland's peripheral glaciers and ice caps crossed an irreversible tipping point around 1997, and will continue to melt (Noël et al 2017), the fate of each glacier will depend on both its specific characteristics, e.g., size, slope, and elevation range, and future climate conditions .

The temperature of the oceans has also risen. The greatest *ocean warming* has taken place close to the surface, with the upper 75 m of the ocean warming by an average of 0.11^{0}C each decade between the years 1971-2010 (IPCC AR5, WG1, SPM-8). However, it seems that ocean warming has been accelerating since the 1990s, setting a new record in 2018 ($19.67 \pm 0.83 \times 10^{22}$) surpassing 2017 ($18.76 \pm 0.80 \times 10^{22}$) and 2015 ($17.99 \pm 0.70 \times 10^{22}$), which were the previous warmest years ever recorded (Cheng et al. 2019). The ocean warming is not uniform over time and space and can vary at any given location with the seasons due to variations in ocean currents and the exchange of heat between ocean and atmosphere. The Southern Ocean (south of 30◦S) and Pacific Ocean show more warming than the Atlantic Ocean and Indian Ocean (Cheng et al 2019). Given the ocean's large mass and high heat capacity that allow it to store huge amounts of energy, even if greenhouse gas concentrations could be held at present levels into the future, sea levels would continue to rise for centuries to millennia.

Moreover, the chemistry of the oceans is changing due to higher CO_2 concentrations in the atmosphere. Oceans absorb about 30% of the carbon dioxide humans produce every year- in fact, oceans are the largest single carbon sink in the world. However, when carbon dioxide dissolves in the oceans, carbonic acid is formed. This leads to higher acidity (IPCC AR5, WG1, SPM-8). *Acidification* makes it harder for certain marine organisms—including coral, as well as shellfish and certain types of plankton—to build the hard outer shells they need to survive (Eyre et al 2018). This in turn can have a wide range of consequences for marine ecosystems as well as humans who depend on the ocean for food and survival.

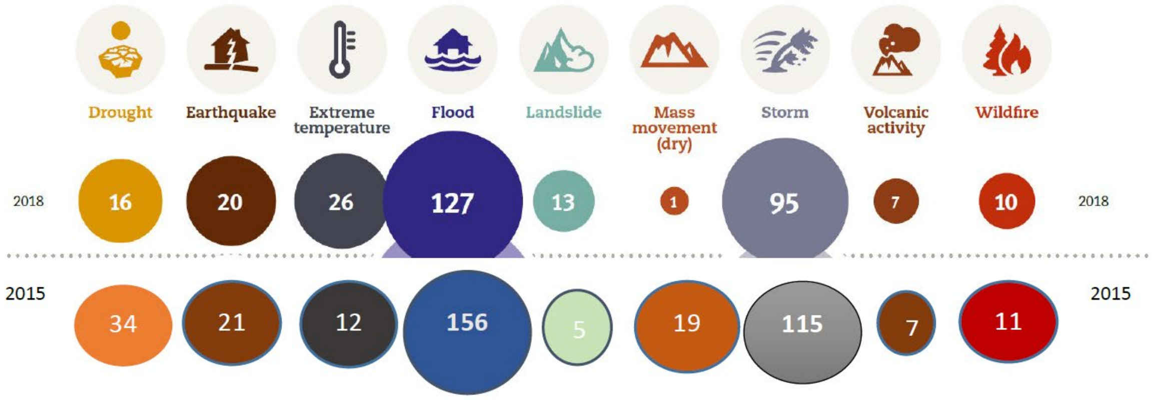
Warming temperatures also lead to rising *sea levels*. Sea-level rise is attributed to the melting ice sheets and glaciers and to the fact that water expands when it is heated (Mengel at al 2016). Melting of the Greenland ice sheet and its peripheral glaciers and ice caps contributes about 43% to contemporary sea level rise (Noël et al 2017). Between 1900 and 2016, the sea level rose by 16–21 cm (Sweet et al 2017). More precise data gathered from satellite radar measurements reveal an accelerating rise of 7.5 cm from 1993 to 2017 (WCRP 2018), which is a trend of roughly 30 cm per century. Higher see level rise then can be detrimental to heavily populated, coastal and island regions, where even a small increase in sea level can inundate large land areas. Coastal areas lacking capacity for flood protection are (and will) be particularly vulnerable to higher sea level rise.

Changes in many *extreme weather* and *climate events* have been observed since about 1950 (IPCC AR5, WG1, SPM-5). Although, in absolute terms an extreme climate event varies from place to place, for instance a hot day in the tropics may be a different temperature to a hot day in the mid-latitudes- more, severe and harmful extreme weather events are being seen around the world. In most regions of the globe, *warm days and nights* have increased and *cold days and nights* have decreased; a few exceptions being daytime temprtaures in central and eastern North America, and southern South America. *Heat waves* have become more frequent since the middle of the 20th century and are lasting longer with some parts of Europe, Asia and Australia experiencing a dispropotionate number of extreme heat waves in recent decades. The extent of regions affected by *drought*s has increased as precipitation over land has marginally decreased while evaporation has increased due to warmer conditions. Drought prevalence is mostly increasing in large parts of Africa, the Mediterranean region, parts of North- and South America and Southeastern Asia. *Wildfires* are connected to temperature and precipitation. Thus, whenever extreme temperatures, heat waves, and drought are becoming more likely, the risk of wildfires also increases. Warming is also causing more *frequent and intense rainfall* events but results vary strongly between regions and seasons. For example, while some regions such as Europe, North and Central America have experienced increases in heavy precipitation, others such as southern Australia and western Asia have seen decreases in precipitation. Generally, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere. The occurrence of tropical storms, and especially of hurricanes and cyclones with their huge destructive power, is connected to climatic factors. While the frequency of those events varies considerably from year to year, evidence suggests that storm activity has increased in the North Antlantic region since the 1970s and that storm severity (wind speed, rainfall rates, etc.) has also increased, although the reasons for this are still being debated.

The Centre for Research on the Epidemiology of Disasters (CRED) reports that in climate related disasters[3], that is climatological (e.g., drought and wildfire), meteorological (e.g., storm and extreme temperature), and hydrological (e.g., flood and landslide) events, occurred at higher numbers relative to geophysical (e.g., earthquake and volcanic activity) accounting for over 90% of all disasters occuring in 2015 and 2018 (Figure 7). In the year 2018 there were fewer climate-related disasters compared to 2015, 274 and 347 respectively. In both years, floods were the most frequent type of disaster followed by storms.

Figure 7: Number of disasters by major category 2015 and 2018

[3] A disaster event, in EM-DAT database, has to fulfill at least one of the following criteria: (i) at least 10 deaths (persons confirmed as dead and persons missing and presumed dead), (ii) 100 affected individuals (people that have been injured, left homeless, or requiring immediate assistance during a period of emergency, that is, requiring basic survival needs, such as food, water, shelter, sanitation, and immediate medical assistance after a disaster), or (iii) request for national or international assistance. The database includes both natural and technological disasters. Natural disasters are further classified into geophysical, meteorological, hydrological, climatological, biological, and extraterrestrial with altogether 17 additional subcategories, such as floods, storms, landslides, or earthquakes).



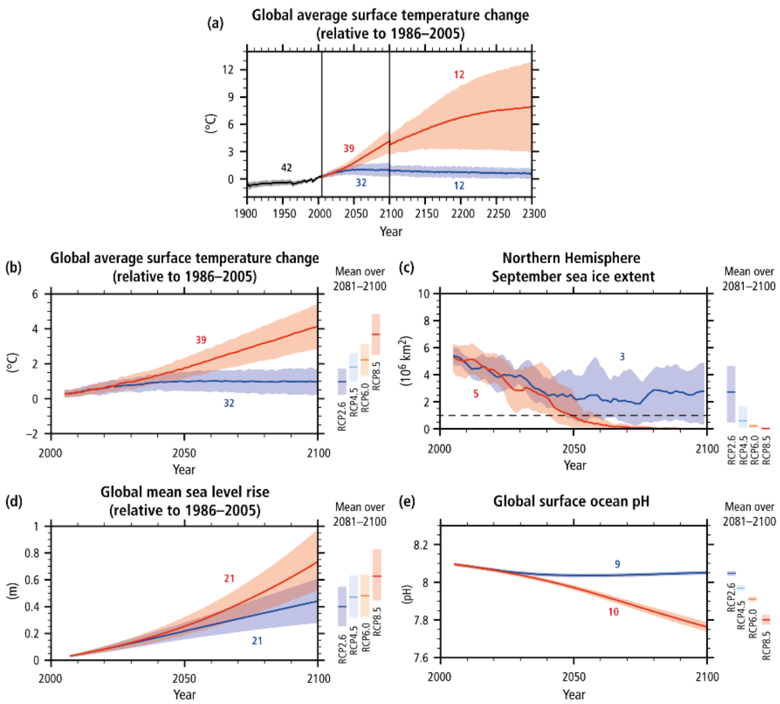
Source: CRED 2015, 2018

Global Warming Projections

Future projections of climate change depend on the path of future emissions. However, even if all emissions of greenhouse gases ended today, the world would continue warming for many decades, and effects such as sea-level rise would continue for centuries, because the environmental effects of emissions are not realized immediately (IPCC AR5 WGI, SPM-27).

In 2014, the IPCC in its AR5, based on a range models with different assumptions about future emissions estimated that during the 21st century global average temperatures will rise within a range most likely to be between 1.5^{0}C and 4.8^{0}C above pre-industrial levels (Figure 8b), with the possibility to exceed 12^{0}C in the longer term (Fig. 8a), unless drastic policy action to reduce emissions occurs (IPCC AR5, SPM-4, 15, 21). Figure 8 also shows that global mean sea level will continue to rise during the 21st century in the ranges of 0.26 to 0.98m depending on the applied emissions' scenario, due to increase ocean warming and increased loss of mass from glaciers and ice-sheets (Fig. 8d). In addition, a decrease in sea ice extent and volume is projected for Antarctica and in particular the Arctic, with the Arctic Ocean being ice-free in the summer by mid-century (Fig.8c), and in surface ocean pH (i.e., increase in ocean acidification) (Fig.8e). However, the magnitude of actual warming and other effects will depend upon the level at which atmospheric concentrations of CO_2 and other greenhouse gases are ultimately stabilized.

Figure 8: Future temperature changes and impacts

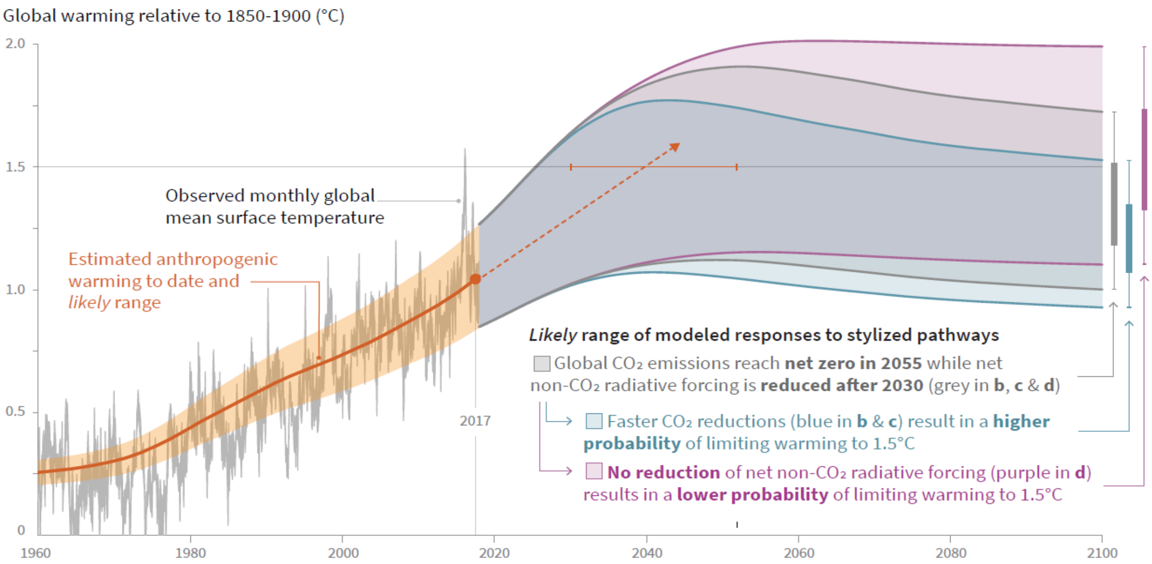


Source: IPCC AR5, WGI

And for many years, at least since the Conference of the Parties (CoP) in Cancun, Mexico in 2010, limiting global warming to no more than 2^{0}C above pre-industrial levels was the de-facto target for global policymakers. In December 2015, 195 countries endorsed the Paris Agreement, which backed a long-term goal to limit global temperature rise to "well below 2C" (relative to pre-industrial climate, meaning a future warming of less than 1.4 °C because temperature had already increased by 0.6 °C by the end of the twentieth century) and to "pursue efforts towards 1.5C". As part of the text of the agreement, the UN Convention on Climate Change (UNFCCC) "invited" the IPCC "to provide a special report in 2018 on the impacts of global warming of 1.5^{0}C above pre-industrial levels and related global greenhouse gas emission pathways".

The 2018 IPCC Special Report on Global Warming of 1.5^{0}C notes that human induced warming reached approximately 1^{0}C above pre-industrial levels in 2017 and ***is likely to reach 1.5^{0}C between 2030 and 2052 if it continues to increase at current rate*** (IPCC, Special Report on Global Warming of 1.5^{0}C (SR1.5, SPM: 4) (Figure 9). Hence, what appeared five years ago as a future threat for generations to come, in the late twenty-first century and beyond, global warming is now understood as an immediate and urgent issue.

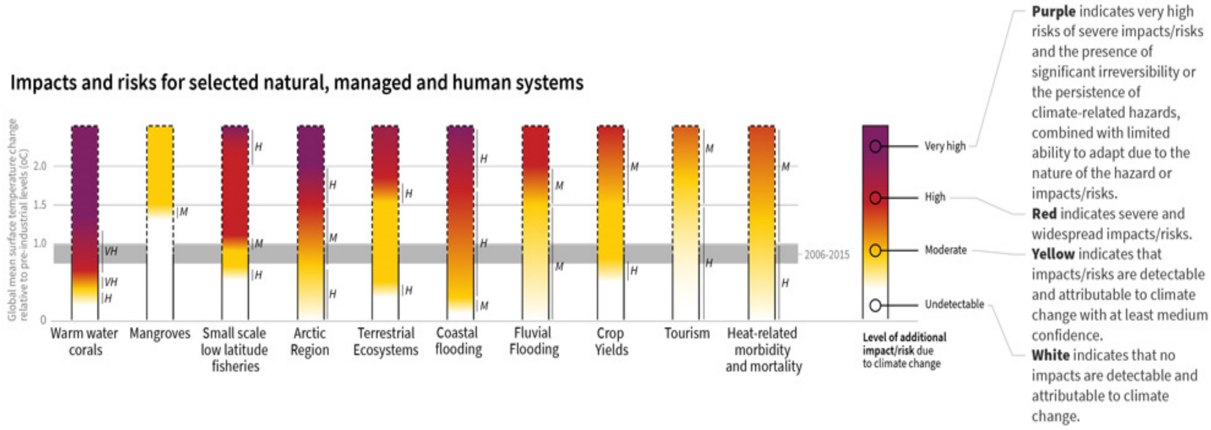
Figure 9: Global temperatures relative to pre-industrial levels and idealized potential pathways to meeting 1.5C limit in 2100



Source: IPCC SR1.5 Figure SPM.1

In general, and perhaps unsurprisingly, the report states that the potential impacts of global warming for natural and human systems are higher for global warming of 1.5^{0}C than at present, but lower than 2^{0}C. The risks are also greater if global warming exceeds 1.5^{0}C and comes back down rather than if warming 'gradually stabilizes at 1.5^{0}C' (IPCC SR1.5: SPM-8). Given that there are a lot of impacts to consider, the report includes as an illustration a 'reason for concern' figure that shows how the risks of severe impacts varies with warming levels (Figure 10). Warm water corals and the Arctic are particularly at risk from rising temperatures, moving into the 'very high' category with 1.5^{0}C and 2^{0}C of warming, respectively, followed by coastal flooding, small scale low latitude fisheries, and crop yields.

Figure 10: Impacts and risks for selected natural, managed and human systems



Confidence level transition: *L*=Low, *M*=Medium, *H*=High, and *VH*=Very high

Source: IPCC SR1.5 Figure SPM.2

In particular, coral reefs already under high risk are projected to decline by a further 70-90% at 1.5^{0}C with larger losses (>99%) at 2^{0}C. (IPCC SR 1.5 SPM-10). Recent studies using different approaches project that the Arctic Ocean will become ice-free in the summer under 2^{0}C warming, whereas if warming is limited to 1.5◦C then ice will persist through the summer in most years (Jahn 2018). This has obviously important implications for humans and species such as polar bears, which are dependent on sea ice for their survival. Limiting warming to 1.5^{0}C would also reduce the positive temperature feedback that would come from changing albedo associated with reduced ice extent. Limiting warming to 1.5^{0}C would also avoid the melting of an estimated 2 million km2 of permafrost, relative to 2^{0}C (Chadburn et al 2017). This would significantly reduce damages to Arctic ecosystems, buildings, and infrastructure, as well as avoid significant releases of carbon to the atmosphere, which would further accelerate warming (Turetsky et al 2019; Box et al 2019). Similarly, the risk of triggering irreversible melting of the Greenland or Antarctic ice sheets is lower under 1.5^{0}C warming than 2^{0}C. Reducing these risks would lower the rate of sea level rise in both the near term and the future. Sea level rise in 2100 is projected to be approximately 0.1 m less if warming is constrained to 1.5^{0}C compared with 2^{0}C (Nicholls et al 2018 ; Rasmussen et al 2018), with a corresponding reduction in the global area of land lost to inundation. In turn, this is estimated to reduce the number of people exposed to coastal flooding by 5 million annually by 2050 [including 40,000 fewer in SIDS] (Rasmussen et al 2018), to decrease the frequency of coastal floods in the Eastern United States and in Europe (Rasmussen et al 2018), and to lower flood risk in the vulnerable Ganges-Brahmaputra-Meghna delta (Brown et al 2018).

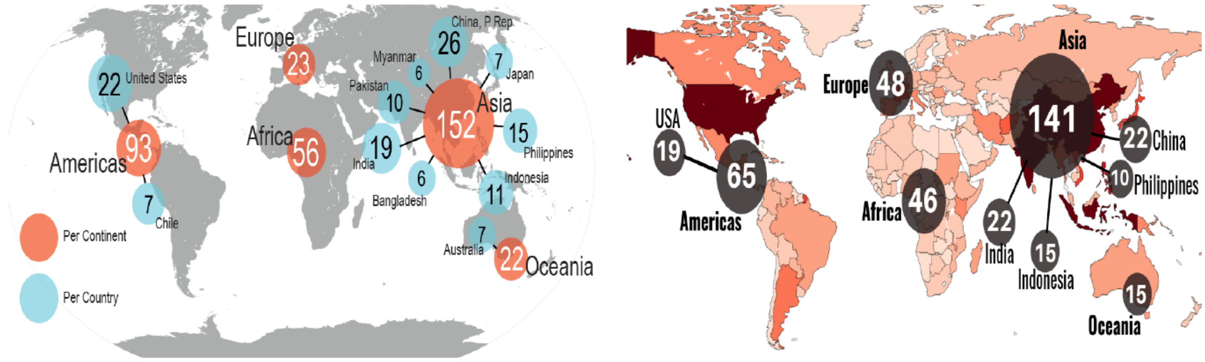
Risks to low-latitude fisheries due to climate change are already significant, and it is estimated that the potential global marine fishery catch will decline by more than 1.5 million tonnes at 1.5^{0}C compared to a loss of more than 3 million tonnes at 2^{0}C of global warming (Cheung et al 2016). In addition, climatic changes are already affecting crop yields, with more negative impacts than positive ones, and with the positive impacts being predominantly at high latitudes (Tol 2018). As the climate warms to 1.5^{0}C and 2^{0}C, the number of negative impacts is expected to rise, and to become large in most world regions, although positive effects could still be seen in some regions if CO2 fertilization occurs (Tol 2018). The negative impacts are projected to be greatest in tropical regions, where crops are grown closer to their thermal limits. In particular, limiting warming to 1.5^{0}C compared to 2^{0}C is projected to lower the risks to crop production in sub-Saharan Africa, West Africa, Southeast Asia, and North, Central, and South America (Schleussner et al 2018), including low-income countries at low latitudes (Iizumi et al 2017). Several studies quantify climate impacts on water resources under 1.5^{0}C warming and find significant benefits relative to 2^{0}C. For instance, under 1.5^{0}C warming, 80–274 million fewer people will be exposed to an increase in water scarcity (Arnell and Lloyd-Hughes 2014) and there will be a 25% reduction in freshwater stress in SIDS (Karnauskas et al 2018). In addition, by the end of the century, drought exposure is also projected to be reduced by about 40% globally (Arnell et al 2017), with the greatest benefits reapped in the Mediterranean, Southern Africa, and Northeast Brazil (Liu et al 2018; Gudmundsson and Seneviratne 2016). Finally, the loss and damage caused by natural disasters are expected to rise further in future largely due to climate change and the increased disaster exposure and vulnerability of our modern societies (IPCC 2018, SR 1.5).

The observed and projected climatic changes have affected and will affect human life on Earth in numerous ways. In the following sections, I highlight some of the most important of these effects on humans, namely, the economy, migration, and conflict, all of which endanger the successful implementation of the Sustainable Development Goals (SDGs).

2. Climate change and the economy

While in 2015 and 2018, there were 346 and 315 natural disasters events recorded respectively in the EM-DAT (International Disaster Database), yet the burden was not shared equally as Asia suffered the highest impact and accounted for 45% of disaster events followed by Latin America and Africa (Figure 11). Weighted by land area and population, small island states are exposed to more frequent natural disasters (Laframboise and Acevedo 2014).

Figure 11: Number of Disaster Events By Continent/Country: 2015, 2018



Source: CRED 2015, 2018

In relation to 2015, in 2018, there were fewer number of people affected (figure 12a) and fewer deaths (Figure 12b) caused by climate-related disasters. Asia accounts again for the majority of affected people and disaster victims followed by Africa. 2018 was a standout year for wildfires occurring in developed countries. The Attica fires in Greece killed an estimated 100 people, making it the deadliest wildfire recorded in Europe and in the United States, the California wildfire season was the deadliest on record, with Camp Fire killing 88 people.

Figure 12a : Number of affected (million) by disaster type: 2018, 2015

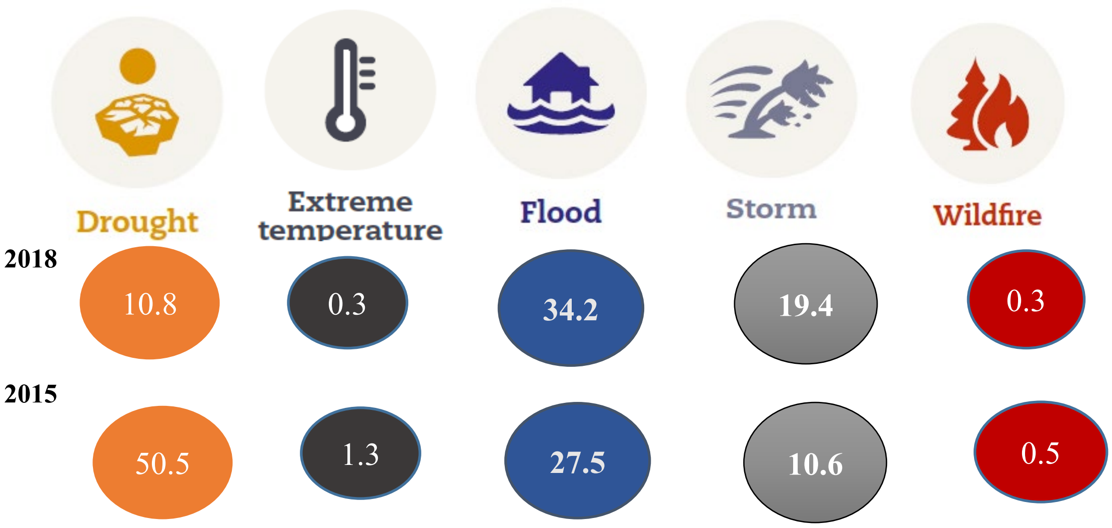
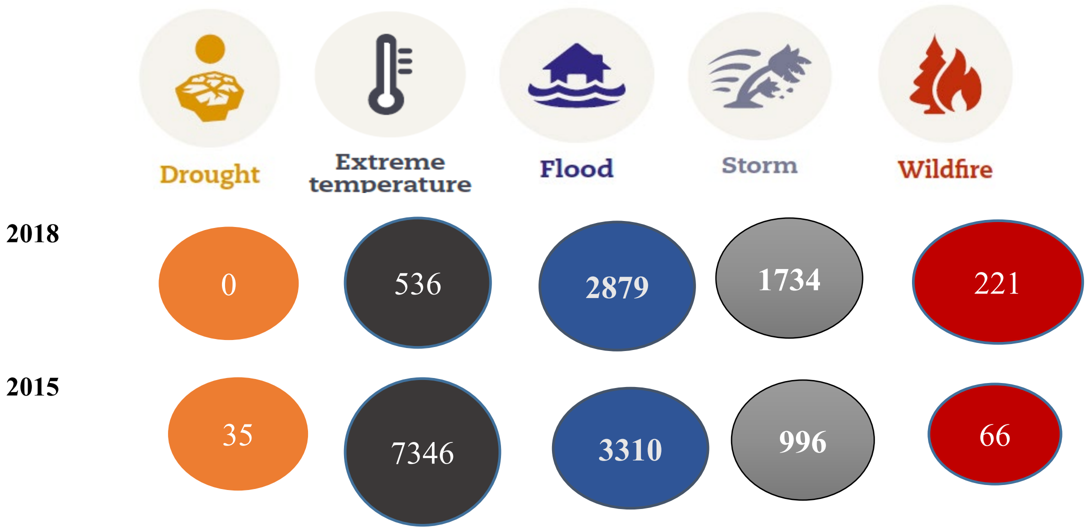


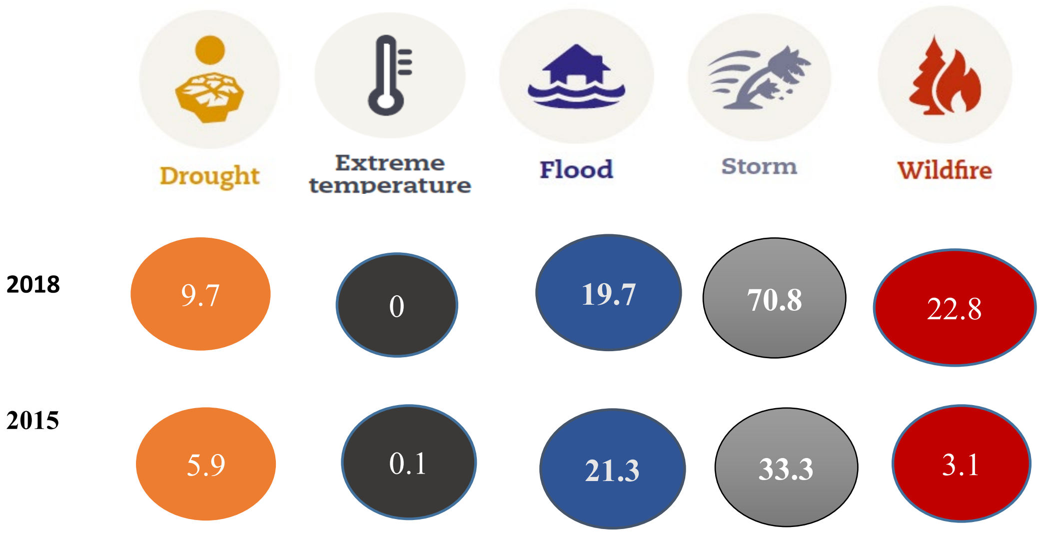
Figure 12b: Number of deaths by disaster type: 2018, 2015



Source: CRED 2015, 2018

Aside from people affected and lives lost, estimated total economic damages from climate-related disasters are staggering. Overall, economic losses due to extreme weather events rose by 100% from 2015 to 2018, 63.6 and 122 US$ billion respectively (Figure 13). While storms and floods seem to cause most economic losses, yet droughts often inflict significantly greater losses on national economies than other types of disasters, with some cases causing damage equal to or greater than 0.5% of the GDP of the affected countries (Guha-Sapir et al 2013). Economic damages are not homogeneous distribute across the globe: low and lower-middle income countries carried a disproportionate burden.

Figure 13: Economic losses (billion US$) by disaster type: 2018, 2015



Source: CRED 2015, 2018

In terms of total damages caused by climate-related disasters, advanced economies are the hardest hit, mainly due to the higher cost of physical capital and infrastructure, followed by developing Asia. For instance, the National Oceanic and Atmospheric Administration (NOAA) (2019) reports that in 2018, there were 14 different natural disasters, ranging from hurricanes to wildfires to winter storms across the United States, with a total cost of $91 billion. Eighty percent, or $73 billion, of the total loss was attributable to just three events: Hurricane Michael in Florida, Hurricane Florence in the Carolinas, and wildfires in the West, including California. While natural disasters affect rich and poor countries alike, they cause more severe destruction of life and property in the developing world. Thus, poverty and climatic stress interact to create severe outcomes not experienced in areas with better resources for crisis management. Assistance of wealthy donor states is often necessary to improve local adaptive capacity and to facilitate the training of local service providers in developing countries.

Climate-related disasters do not only cause direct losses of assets that have a market value, e.g., property and infrastructure, as well as losses of assets that do not have a market value, e.g., loss of life and damage to natural and cultural assets. They also produce indirect losses, including the lost output resulting from reduced productive capital and the output that is lost as capital when it is redirected towards reconstruction of assets that were destroyed, away from more productive uses, for example investment in human capital, thereby affecting the country's GDP in the long term.[4] Numerous studies have tried to estimate the direct and indirect impacts of climate-related disasters on economic growth and often distinguish between the short-to-medium (up to 5 years) and the long-term (10 years and beyond) terms.

Short-to-medium economic effects

Most of the current research that uses large data sets[5] finds the impact of disasters on short-term economic growth to be negative (Panwar and Sen 2019; Lopez et al 2016; Felbermayer and Gröschl 2014; Bertinelli and Strobl 2013; Strobl 2012**;** on aggregate welfare see Strulik and Trimborn 2019).[6] For instance, Bertinelli and Strobl (2013) examines the economic impact

[4] Two main approaches have been used to estimate the impacts of climate change on GDP and growth: a) statistical analyses of the economic impacts of past climatic fluctuations, e.g, temperature or specific climate-related disasters; and b) simulation modelling approaches, e.g., Integrated Assessment Models (IAMs) and Computable General Equilibrium (CGE) models. While both approaches can provide useful economic estimations of climate change impacts, still they have also important weaknesses. The modelling approaches are based on disputed or uncertain damage costs assumptions, do not include all impacts on GDP growth, and provide assessment of total costs rather than impacts on GDP. Statistical approaches, on the other hand, rely on historical data and they are hence limited in scope, and cannot provide reliable estimates of future projections since the link between climate and economy in the future may be fundamentally different to those that have prevailed in the recent past.

[5] A few studies focus on investigating the economic impacts of natural hazards from a regional perspective, analyzing specific events and using more disaggregate data. For example, Elliott et al (2015) examine the impact of typhoons on local economic activity in coastal China (1992-2010), while Lima and Barbosa (2019) study the effect of a flash flood that occurred in the Brazilian state of Santa Catarina in 2008. While both studies find that disasters cause substantial economic losses in the year they occur, growth rebounds back to the pre-disaster levels shortly thereafter in all sectors but the agricultural sector in the Brazilian case.

[6] A limited number of studies show that disasters have neither negative nor positive effect on economic growth (e.g., Hochrainer-Stigler 2015), while others find a positive effect. For instance, Cunado and Ferreira (2014) employ a dataset on large flood events in 135 countries between 1985 and 2008 and

of hurricane strikes in the Caribbean and report that on average hurricane strikes reduce income growth by around 1.5% at the local level, with no effect beyond the year of the strike. The negative impacts of relatively severe natural disasters are observed to be even stronger since large-scale destruction and damage caused by such events are more likely to decelerate economic growth or even trap the economy at a lower equilibrium level (Panwar and Sen 2019; Klomp 2016; Felbermayer and Gröschl 2014; Hsiang and Narita 2012). Hsiang and Narita (2012) examine the effect of tropical cyclones across 233 countries from 1950-2008 and report that stronger cyclones cause substantially high economic losses. In addition, developing countries are found to be more sensitive to the economic shocks caused by disasters than developed ones largely due to their limited capacity to cope with the economic and financial consequences of such events (Panwar and Sen 2019; Klomp 2016; Felbermayer and Gröschl 2014; Fomby et al 2013). Klomp and Valckx (2014) perform a meta-analysis, using more than 750 natural disasters estimates from 22 quantitative studies. After controlling for a large number of differences among the studies and estimates, related to disaster characteristics, sample composition and estimation method, they confirm that disasters have a negative short run effect on economic growth (see also van Bergeijk and Lazzaroni 2015). They also note that a large part of the statistical significant effect can be attributed to a so-called publication bias where significant results are more easily published. In addition, countries with higher levels of per capita income, better institutional frameworks, higher literacy rates, greater trade openness and more effective ex ante disaster risk financing mechanisms find it easier to absorb the economic shocks of disasters (Klomp 2016; Hochrainer-Stigler 2015; Klomp and Valckx 2014; Felbermayer and Gröschl 2014).

Several studies have also shown that higher temperatures also hamper economic growth in less developed countries. For instance, Dell et al. (2012), using a sample of 125 countries for the period 1950 to 2003, report that higher temperatures reduce not only the economic growth, but also the level of output in poor countries. They estimate that a 1^0C temperature increase in each year reduces economic growth by about 1.1 percentage points in poor countries (see also Dell et al 2014). Burke et al. (2015), however, using a global dataset of 166 countries over the period 1960-2010, find that temperature appears to affect output (the growth rate and the level of GDP) in both and rich countries alike. In addition, they report that temperature has a non-linear effect on both overall and agricultural GDP in all countries, meaning that the association between growth and temperature is positive up to a certain point (i.e., 13^0C), before becoming negative.

Long-term effects

Turning now to the long-term economic effects of disasters the existing literature is scarcer and its results less clear-cut than for short-run effects., The reason might be due to the fact that existing growth theories do not provide robust inferences on the possible growth effects of natural disasters and to the difficulty of constructing the appropriate counterfactual. Most of the empirical studies in the focus on four hypotheses (Hsiang and Jina 2014). Firstly, the

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report that flood shocks tend to have a positive and significant average impact on per capita GDP growth. However, this effect is limited to developing countries and to moderate floods and the positive impact of floods is larger and more significant in the agricultural sector.

Schumpeterian 'creative destruction' hypothesis postulates that there may be positive effects of disasters on economic growth, as the physical destruction caused by these disasters may trigger greater investment in the reconstruction and/or upgradation of existing physical capital. Secondly, the "building back better" hypothesis proposes that the economic growth may slow down initially due to human and physical capital losses, but the gradual replacement of lost assets with modern unities may produce net positive effects on economic growth in the long-run. Thirdly, the "recovery to trend" hypothesis postulates that the destruction of human and physical capital may increase the marginal product of these two inputs, which stimulates individuals and wealth flow to a devastating area until output recovers its pre-disaster trend. Lastly, "no recovery hypothesis" states that an economy may have a growing path in the long-run, but permanently below the pre-disaster path.

As already mentioned above, the empirical relationship between natural disasters and long-run economic growth has largely remained inconclusive with existing studies reporting negative, positive, and even no effects. For instance, Hsiang and Jina (2014) using meteorological data on all countries experiencing tropical cyclones during the period 1950-2008, find robust evidence that tropical cyclone strikes lead to a small suppression in annual growth rates and that this persists for almost two decades, leading to more substantial cumulative impacts. They estimate that the world GDP growth would have been 1.4% higher per year, had no cyclones occurred. Moreover, both rich and poor countries experience GDP losses, with losses magnified in countries with less historical cyclone experience, a finding that suggests some effective adaptation in the presence of repeated events. Similarly, Berlemann and Wenzel (2016) based on a panel of 153 countries over the period of 1960 to 2002 report significantly negative long-term growth effects of droughts in both highly and less developed countries. Contrary to these studies, Cavallo et al (2013) employ a synthetic control methodology and examine the impact of natural disasters from the EM-DAT on GDP per capita in a dataset of 196 countries covering the period 1970 to 2008, and do not find any significant effect of natural disasters on subsequent economic growth. In addition, they find that political instability following the disaster is the main driving factor in both cases in which natural disasters caused reduction in economic growth. Moreover, Guo et al (2015) analyze panel data of 577 recorded disasters from the EM-DAT in 30 provinces of China from 1985–2011, and find that climate-related disasters promote economic growth possibly due to government's great emphasis on the post-disaster construction of infrastructures, raising public awareness of disaster prevention and reduction, and improving human capital investment.

In conclusion, the existing literature discussed here seems to agree that there are short-term negative effects of climate change and in particular of natural disasters on economic growth. However, the long-term evidence is more mixed, with some studies supporting a 'creative effect' of disasters, while a large number finds the opposite results of a permanent GDP loss. Moreover, it appears that the channels, i.e., consumption, investment, or trade through which natural disasters affect GDP as well as their impact on different sectors of the economy, e.g., agriculture, manufacturing or services have not been fully examined. These issues should constitute venues for future research

Estimates of the future economic impacts of climate change and SDGs

While global economic effects of future climatic changes will be significant, yet there exists a lot of uncertainty about their magnitudes due to uncertainties in projecting the impact of climate change on the environment (e.g., large-scale singular events) and subsequently mapping them into economic effects, and in accounting for future adaptation strategies and technological innovation in mitigating those effects. Having said that, there exist a few studies estimating the effect of future climatic changes (mostly temperature) on economic growth (e.g., Burke et al 2015; Burke et al 2018; Tol 2018a, b) as well as the benefits of constraining global warming to 1.5°C compared to 2°C (e.g., Burke et al 2018; Pretis et al 2018; Yohe 2017).

The IPCC AR5 (2014) reported that additional temperature increases of around 2^0C are likely to lead to losses equivalent to 0.2%-2% of global GDP. Recent research shows that while the impacts of 1.5C warming on yearly global average growth rates are “near indistinguishable” from current climate conditions, yet the negative economic growth is projected for countries around the Equator and the Southern Hemisphere. In addition, a 2°C warming will lower annual economic growth by up to 2% for a large set of countries around the globe (Pretis et al 2018). Similarly, Burke et al (2015) based on a statistical analysis using a historic dataset of national temperatures and economic outcomes estimate that if future adaptation to temperature increase mimic historic adaptation, climate change could reduce average global GDP per capita by 23% by 2100, lowering thus the global annual growth rate by 0.28 percentage points on average, with most reductions concentrated in poor countries (see also Burke et al 2018; Carleton and Hsiang 2016). Ahmed and Suphachalasai (2014) report similar results from an analysis based on an IAM of six South Asia developing countries, namely Bangladesh, India, Nepal, Bhutan, the Maldives, and Sri Lanka. Their modelling suggests that Bangladesh, India and Nepal could all experience annual damages equivalent to roughly 2% of the GDP in 2015 (2%, 1.8%, and 2.2% respectively). These damages are likely to reflect lower bounds, given that the model used excludes some categories and impacts. Overall, the aggregate economic damage for the whole group of these countries could increase significantly to around 8% by 2100.

Studies also estimate that the net present value of global economic damage caused by climate change (including costs associated with climate change-induced market and non-market impacts, impacts due to sea level rise, and impacts associated with large-scale discontinuities) to be $54 trillion and $69 trillion at 1.5^0C and 2^0C warming respectively, relative to 1961- 1990 (Pretis et al 2018). In addition, they show that developing countries especially in Africa, Southeast Asia, and Latin America are more likely to disproportionately experience these negative economic effects (Burke et al 2018; Pretis et al 2018; Yohe 2017). However, even rich countries are at risk in suffering substantial economic losses as the recent Fourth US National Climate Assessment report (2018) reveals. The report states that the US economy could lose hundreds of billions of dollars – or, in the worst-case scenario, more than 10% of its GDP – by the end of the century if global warming continues apace (see also Hsiang et al 2017; Yohe 2017).

Moreover, not only poor countries are more vulnerable than rich ones to future climatic changes but also poor people are more vulnerable than rich to future global warming. It is estimated that by 2030 (roughly approximating the 1.5°C warming predicted by the IPCC SP1.5), 122 million additional people could experience extreme poverty, based on a ‘poverty scenario’ of limited socio-economic progress, comparable to the Shared Socio-Economic Pathway (SSP) 4 (inequality), mainly due to higher food prices and declining health (Hallegatte and Rozenberg 2017). This finding implies that future climate change will increase inequality across countries.

Hence, climate change threatens not only economic growth (SDG 8) but it will also act as a poverty multiplier by increasing the number of poor people and by making poor people even poorer (SDG 1), as well as inequality (SDG 10).

Climate and Food Production

Warming has increased crop yield in some high-latitude areas (Daliakopoulos et al 2017) because higher concentration of carbon dioxide in the atmosphere acts as a fertilizer allowing plants to manage their water more efficiently. Recent studies, however, show that climatic changes have already affected crop suitability in many areas, resulting in changes in the production levels of the main agricultural crops in many areas around the world. In particular temperature and precipitation trends have reduced crop production and yields, with the most negative impacts being on wheat and maize (Frieler et al 2017), while the effects on rice and soybean yields are uncertain and may be positive or negative (van Oort and Zwart 2018). Temperature, precipitation and extreme weather events are projected to substantially reduce future crop yields. The impacts are projected to be greatest in tropical regions, where crops are grown closer to their thermal limits. In particular, limiting warming to 1.5°C compared with 2°C is projected to lower the risks to crop production in Sub-Saharan Africa, West Africa, Southeast Asia, and North, Central, and South America, including low-income countries at low latitudes (Schleussner et al. 2018).

Climate change affects also livestock production directly via yield quantity and quality (Notenbaert et al 2017), as well as indirectly by affecting the livestock sector through feed quality changes and spread of pests and diseases (Kipling et al. 2016). Climate extremes can cause changes in physiological processes in livestock (i.e., thermal distress, sweating and high respiratory rates), negatively affecting their growth rates and reproduction (Collier and Gebremedhin 2015; De Rensis et al 2015). Climate change impacts on livestock are expected to increase. Boone et al (2018) estimate that globally, a decline in livestock of 7–10% is expected at about 2°C of warming, with associated economic losses between $9.7 and $12.6 billion.

Fisheries and aquaculture contribute to food security and to the livelihoods of millions of people, and many countries depend on these sectors for their social, economic and nutritional benefits. Specifically, an estimated 3.2 billion people globally get almost 20% of their average per capita intake of animal protein from the sea (FAO 2018a). In 2016, marine fisheries provided 79.3 million tonnes and marine aquaculture provided 28.7 million tonnes (FAO 2018a). At the same time, fisheries and aquaculture (both marine and inland) also provide livelihoods for an estimated 10-12% of the world's population (Barange et al. 2018), with an estimated 14% of fishers and aquaculture workers to be women (FAO, 2018a). Temperature increases and ocean acidification pose a risk to fisheries and aquaculture at mid-latitudes (Clements et al 2017) and sea level rise and storm intensification threaten hatcheries and other infrastructure (Weatherdon et al 2016). Projections of changes in national catch potential in exclusive economic zones (EEZs) are likely to decrease between 2.8-5.3% and 7.0-12.1% by 2050 relative to 2000 under RCP2.6 and RCP8.5 climate 19 scenarios respectively, and are projected to increase to 16.2-25.2% under RCP8.5 by 2100 (Cheung et al 2018). While at the global scale this average is not particularly large, the impacts are much greater at regional scale, because projected changes in catch potential vary substantially between regions. Although estimates are subject to significant variability, the biggest decreases can be expected in the tropics, mostly in the South Pacific regions. For the high latitude regions, catch potential is projected to increase, or show less of a decrease than in the tropics (Barange et al

2018). It is important to note that these projections only reflect changes in the capacity of the oceans to produce fish, and do not consider the management decisions that may or may not be taken in response to this productive capacity. This implies that interactions between ocean changes and management responses are thus crucial to determine future directions of fish catch change.

Climate, food production and SDGs

Climate change and extreme events by reducing crop yields, livestock, fisheries and aquaculture threaten food availability and hence food security both at the global and regional levels, especially in low-latitude areas. In 2017, **821 million people were undernourished (up from 777 million in 2015),** implying that 11% of the world's population experienced food insecurity, with higher percentages in Sub-Saharan Africa (23.2%), southern Asia (14.8%), and the Caribbean (16.8%). Northern America and Europe account for less than 2.5% (FAO 2018b). These figures imply that hunger is significantly worse in countries with agricultural systems that are highly sensitive to climatic conditions and where the livelihood of a high proportion of the population depends on agriculture. It is not surprising, then that climate variability and extremes are considered to have being a key driver behind the recent rises in global hunger and one of the leading causes of severe food crises (FAO 2018b). Overall, food security is expected to be reduced at 2°C of global warming compared to 1.5°C due to reduced agricultural production. This implies that there is a heightened risk of falling far short of achieving the SDG target of hunger eradication by 2030 (SDG 2), and of reversing the progress already made. Agriculture and food security are also critical to achieving other SDGs, including poverty eradication (SDG 1), health and well-being (SDG 3), clean water (SDG 6), decent work (SDG 8), climate action (SDG 13) the protection of ecosystems on land (SDG 14) and in water (SDG 15), and peace (SDG 16) (IPCC SR 1.5; Perez-Escamilla 2017). Achieving the SDGs, then, will require responses that integrate efforts directed toward providing food and feed production while minimizing resource use and waste, improving land-use management, decarbonizing the food systems and reducing ecosystem degradation.[7] Depending on the current state of the social-ecological systems, responses that enable long-term provisioning of food, feed, fibre and other ecosystem products will range from incremental to transformative and will need to address local to regional as well as global considerations.

3. Climate change and migration

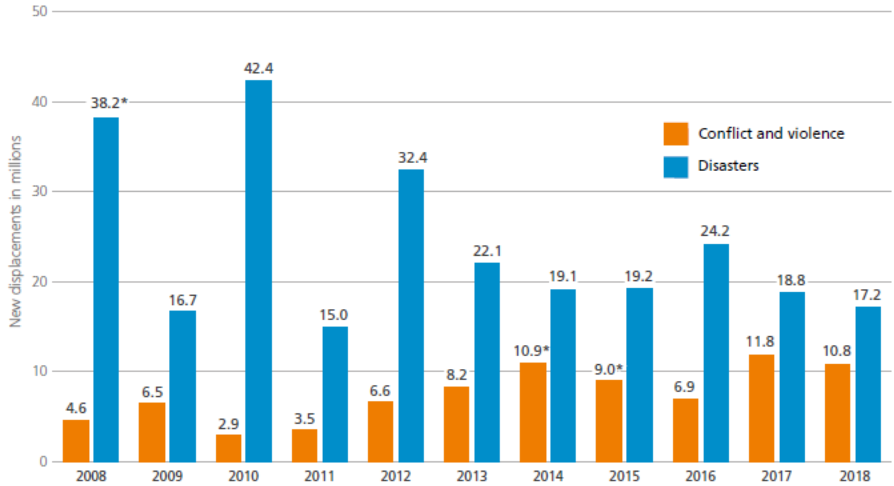
Environmental migration trends

Climatic changes and disasters have always driven people to leave their homes. According to the Internal Displacement Monitoring Centre (IDMC), between 2008 and 2018, about 265 million people worldwide were internally displaced as a response to disasters, which is more than three times the number of people who were displaced by conflict (81 million) (Figure 13).

[7] Biofuels have emerged as an interesting alternative to mitigate climate change by replacing greenhouse gas emissions from fossil fuels. Although there can be positive environmental outcomes, and biofuels can represent an additional source of livelihood in low income countries (Renzaho et al 2017), several studies show that the use of food crops to produce biofuels can have negative consequences for food security. The rise in food prices can be associated to the increasing use of food crops for biofuels in countries, like the United States, Brazil, the European Union (Souza et al 2017).

In 2018, the number of people displaced by disasters (17.2 million) was lower by 2 million relatively to the people displaced in 2015 (19.2 million). Moreover, in 2018, as it is often the case most people were displaced by storms (9.3 million) followed by floods (5.4 million). While small developing island states (SIDS) continued to be disproportionately affected by natural hazards, South and East Asia, as well as the sub-Saharan Africa were the most affected regions (IDMC 2019). In addition, 75 percent of the new displacements, roughly 13 million, were triggered by only ten events[8].

Figure 13: New displacements associated with conflict, violence and disasters (2008-2018)



Source: IDMC, 2019

Those who are forced to move often lose property, crops, and other resources. However, this kind of movement tends to be temporary. For example, storms and floods (e.g., hurricane Katrina in USA in 2005 and the floods in Pakistan in 2010) displaced large number of people, however, most of them returned within a year or so (Fussell et al 2010; Brickle and Thomas 2014). For some though, the displacement will be permanent, as in the case of desertification and sea level rise, which will ultimately force people to move to avoid severe deterioration in habitat and resources and potential risks to human lives. This unfortunate scenario is most likely going to be the fate of some SIDS and river deltas where land will be lost along the coasts and livelihood will be affected by salinization and coastal erosion. While the majority of migration in the context of environmental and climate change more generally, including disaster displacement, occurs within the countries' own borders, some individuals are forced to relocate across borders (Kumari Rigaud et al. 2018; Afifi et al. 2016).

Why do people move when they experience natural disasters?

The need to understand the role of climate and environment on migration decisions, particularly in relation to when, why, how, and where individuals migrate, has increasingly become central to current political and public debates. Earlier studies on environmental migration draw on the neo-Malthusian approach, which focuses on *pull-push* factors and

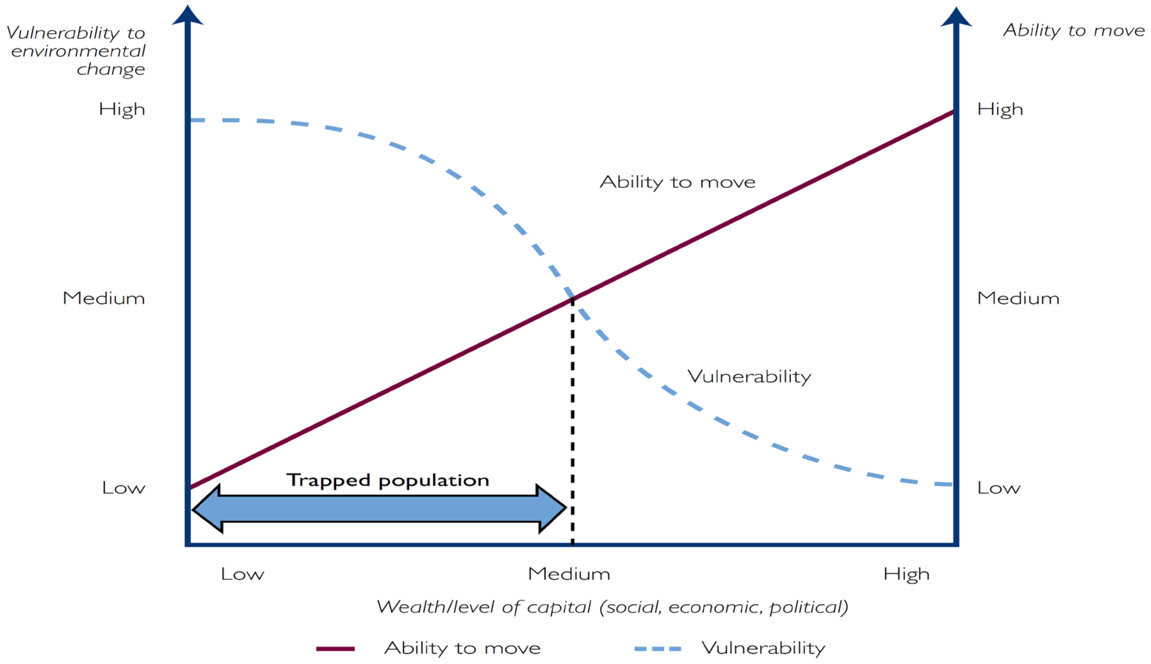
[8] This figure includes all forms of displacement, from people pre-emptively evacuated in anticipation of a disaster to those fleeing their homes in response to a hazard's impacts.

identifies a direct and unidirectional relationship between environmental change and migration, creating the notion of environmental migrants[9]. Recent research, however, adopts an 'augmented gravity model', which emphasizes a more complex pattern of causality, in which environmental, demographic, economic, political, and social factors are interrelated. Understanding these interrelationships facilitates the disentanglement of environmental factors role in population movements (Adger et al. 2015; Hunter et al. 2015; McLeman 2014; Black et al 2011a, b; Piguet et al. 2011).

Across disciplines, environmental factors are regarded as either "stressors" or "locational characteristics" that influence the likelihood of migration (Adger et al. 2015; Hunter et al. 2015; Lilleør and Van den Broeck 2011; Speare 1974; Wolpert 1966). That is, climate change by exacerbating socio-economic factors of migration, such as poverty, food insecurity, lack of employment opportunities, limited access to social protection, and the depletion of natural resources induces migration. Environmental stress should be more important in areas prone to natural disasters and/or where people are more directly dependent on the natural environment for their livelihood such as farming. Under environmental stress, individuals might consider migration to places with better environmental attributes. Nevertheless, migration is not the "default" response to environmental/climate change. Migration is costly, both financial (i.e., individuals need to possess at least some form of human, social, or material capital) and sociological/psychological (i.e., individuals tend to develop strong personal bonds with their home location over the course of their life) terms (Adams 2016; Adams and Adger 2013). Consequently, an individual will consider migration only when (1) environmental change has a *major impact* on personal well-being and (2) the individual's efforts to adapt to and/or mitigate this impact have failed or are likely to fail in the future (see also Penning-Rowsell et al. 2013). If environmental/climate change has a major impact and adaptation is unlikely to succeed, the costs of migration are lower than the costs of staying in a given place and, hence, migration becomes another adaptation strategy to environmental change (Adger et al. 2015, 2009; Black et al 2011c). Consequently, *vulnerability* to environmental factors as well as the *capacity to adapt* determine whether migration takes place in the occurrence of climatic changes (Black et al. 2013; Foresight 2011; De Sherbinin et al. 2008).

Figure 14: Relationship between vulnerability to environmental change and mobility

[9] There are many terms and definitions seeking to delineate the relation between migration and the environment such as 'environmental refugees' (El Hinnawi 1985), which has been heavily criticized by scholars (e.g., Black 2011). I use the term "climate and environmental migration" as relating to persons who are displaced primarily for climatic or environmental reasons (Foresight 2011).



Source: Foresight 2011: 14

Figure 14 illustrates that vulnerability to environmental change and the ability to move depend strongly on an individual's wealth. Richer, educated, and socially connected individuals are typically less vulnerable and are more capable to relocate. Conversely, poor, uneducated, and socially isolated individuals are less mobile and hence belong to the so-called "trapped population" (Foresight 2011). While there are several theoretical accounts on this issue (e.g., Black and Collyer 2014; Black et al. 2013; Foresight 2011), we still lack explicit empirical analyses on the existence of such trapped populations.[10] Moreover, political (e.g., institutions and government quality), economic (e.g., economic development), social (e.g., social networks), and household (e.g., family size) factors affect vulnerability and resilience to climatic hazards and hence they condition migration decisions. For instance, disaster risk reduction and climate change adaption policies can build/improve the resilience and adaptive capacity of individuals and communities and help them to prepare for and prevent displacement due to climate extremes. Therefore, policies aimed at reducing disaster risk can limit displacement.[11] Consequently, to fully understand the linkages between climate change and migration, empirical research is of paramount importance.

What do we know?

During the last decade, a surge in data availability and improvements in tools and techniques, e.g., survey and econometric methodologies, have contributed to a steady rise in empirical

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[10] Two recent studies provide empirical evidence of trapped populations. Nawrotzki and DeWaard (2018) show that in Zambia, the association between adverse climate conditions and migration is positive only for wealthy migrant-sending districts. Koubi et al (2017) based on a study comprising 5 developing countries find that older, poorer, and unskilled individuals are less likely to move even in the presence of natural disasters (sudden-onset events).

[11] Disaster risk reduction policies commonly include structural measures to protect people and assets (such as dykes and sea walls) and land-use planning and relocation policies to limit exposure to hazards.

studies on climatic changes and migration. A large body of literature examines the impacts of climatic changes on internal and international migration using macro-level (e.g., Call et al. 2017; Lu et al. 2016; Beine and Parsons 2015) or micro-level (e.g., Bohra-Mishra et al. 2017; Koubi et al. 2016a,b; Thiede et al. 2016; Mastrorillo et al. 2016) data, as well as a diverse range of approaches, including quantitative methods and qualitative research. However, our empirical knowledge in the field remains varied and desultory (IPCC SR 1.5 2018; Adger et al. 2015; Hunter et al. 2015; IPCC 2014). There is simply no conclusive evidence on the direction and magnitude of the influence of climate (or environment in general) on migration. It may range from limited (Beine and Parson 2017, 2015) and indirect, through changing agricultural yields and livelihood sources, (Bohra-Mishra et al 2017; Cai et al 2016) to significant impacts (Baez et al 2017a,b; Backhaus et al 2015). This empirical ambiguity may be due to: a) lack of theoretical work that guides the empirical analysis; b) lack of common standards in data measurement (operationalization of climate and migration); and c) failure to account for climatic changes' different impacts on migration given individual and/or household characteristics as well as local institutional conditions (see also Adger et al. 2015; Hunter et al. 2015, McLeman 2014; Black et al. 2011a,b). Consequently, only an adequate understanding and quantification of the multiple interconnected components that contribute to livelihood and migration decision-making, at appropriate spatial and temporal resolutions, will allow us to construct relevant models reflecting the reality and its potential future.

Having said that, results from the existing literature identify the effects of climate on migration as multidimensional and heterogeneous. Migration varies according to the type of climatic event (sudden-onset vs and gradual events) the nature of damage caused to property, infrastructure, and livelihoods. The size of migration that ensues is further moderated by the capacity of individuals, households, communities, governments, and humanitarian organizations to provide assistance. Very recent research suggests that climate has most likely a significantly positive impact on migration mainly via its effects on agriculture.

The following section summarizes the main findings from the quantitative literature on climatic conditions and international and internal migration on which the above mentioned conclusion derives.

International migration

Temperature and precipitation

Using bilateral migration flows[12] between a large number of origin and destination countries, a number of articles examine the 'direct' effect of climatic factors[13], mainly temperature and

[12] The International Migration Database (IMD) from the OECD and the Global Bilateral Migration Database (GBMD) provided by the World Bank are the most frequently used data sets in the macro-level literature on climate, natural disasters, and international migration.

[13] Temperature and precipitation are the most often used climate indicators. However, they have been operationalized in quite different ways; for instance, in absolute terms (averaged over certain time-period) year-to-year variation, or standardized anomalies (the difference of actual temperature/precipitation and their respective means, normalized by their standard deviation). The data usually come from the National Oceanic and Atmospheric Administration (MLOST dataset), Climate Research Unit of the University of East Anglia (HadCRUT and CRU TS datasets), or the Goddard Space Flight Center of the NASA (GPCP dataset). The Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) have been also used extensively as measures of drought.

precipitation on international migration with inconclusive evidence. A few studies show that increases in both temperature and precipitation are associated with increases in migration flows to destination countries (Backhaus et al 2015); excessive rainfall as well as severe decreases in temperature during rainy season are associated with large outmigration in less developed countries and towards developed countries in particular Europe (Coniglio and Pesce 2015); and rainfall deficits increase migration from Mexico to the USA (Leyk et al 2017; Nawrotzki and DeWaard 2016). Others, however, do not find a direct effect of temperature and precipitation anomalies on emigration (Beine and Parsons 2015; Drabo and Mbaye 2015) and when they find one, it is conditional upon the economic development of the affected country. In particular, these studies show that rainfall and temperature anomalies deter emigration from middle- (Beine and Parsons 2017) and poor-income (Cattaneo and Peri 2016) countries, presumably due to the existence of severe liquidity constraints which prevent people from emigrating.

In recent time, the linkages between climate change (and its variability) and migration that operates through the agriculture channel (the 'indirect effect') have received increased attention. The idea here is that climatic changes destabilize livelihoods by negatively affecting agricultural income, employment opportunities, or food production for sustenance. When the *in-situ* (in place) adaptation strategies, e.g., changing farming practices, borrowing money from relatives/friends, selling assets, and accessing public assistance programs are exhausted or insufficient, individuals and households may resort to migration to improve their livelihood security. A number of studies show consistent evidence that higher temperatures in agriculture-dependent countries tend to induce outmigration (Cai et al 2016; Cattaneo and Peri 2016; Coniglio and Pesce 2015; Marchiori et al 2012; Feng et al 2010). For instance, Cai et al (2016) use bilateral migration flows between 163 origin countries and 42 destination countries, mainly from the OECD, during the period 1980-2010. They find that temperature increases significantly induce outmigration in agriculture-dependent countries only and that climate-induced migration reinforces flows in already established migration routes, potentially presenting challenges to major migrant-receiving countries, mostly industrialized.

Natural disasters

The literature on natural disasters and international migration has produced similarly inconclusive evidence for a 'direct' effect. While several studies report statistically significant linkages between natural disasters, e.g., floods and storms/typhoons/hurricanes and international migration especially for less developing countries (Loebach2016; Coniglio and Pesce 2015; Drabo and Mbaye 2015), others do not find evidence for such an effect (*Gröschl* and Steinwachs 2017; Cattaneo and Peri 2016; Beine and Parson 2015). And yet, others find that international migration varies considerably from one climate event to another. Nawrotzki and Bakhtsivarava (2017) show that excessive precipitation increases international migration from Senegal, while heat waves decrease international mobility in Burkina Faso. Past hurricanes in Central America seem to have generated international migration within the region, typically along pre-existing social networks (Loebach 2016).

However, interesting patters are discerned when this relationship is conditioned upon country characteristics or when the agricultural channel is considered. For instance, Beine and Parson (2015) focus on the dyadic characteristics between origin and sending countries, and find that while, on aggregate, natural disasters decrease migration in both poor and middle-income countries, they spur emigration to former colonies and countries which share a common border. Gröschl and Steinwachs (2017) consider the economic development of the origin countries and find that natural hazards have positive push and negative pull effects in middle-income countries which are neither financially constrained (like low income countries), nor do they show high insurance penetration rates (as in high-income countries). Finally, Nawrotzki and Bakhtsivarava (2017) find that climate change effects show a clear seasonal pattern, with the strongest effects appearing when heat waves overlap with the growing season and when excessive precipitation occurs prior to the growing season.

Internal migration

Temperature and precipitation

Most of the empirical research explores the effects of climate on internal migration in countries with relatively low levels of development, predominantly located in either Africa, South Asia, or South America due to the exposure and vulnerability of these regions to extreme climatic conditions. Studies employ both precipitation and temperature anomalies to measure climate. While both climatic measures deliver inconsistent results (e.g., Dallmann and Millock 2017; Baez et al 2017 a,b; Koubi et al 2016a,b; Thiede et al 2016; Mastrorillo et al 2016), recent findings again suggest that temperature anomalies have a consistent positive effect on migration via the agricultural channel (e.g., Gray and Wise 2016; Kubik and Maurel, 2016; Bohra-Mishra et al. 2014, 2017; Mueller et al. 2014).

Overall, precipitation shows weak and inconsistent 'direct' relationships with migration across countries (Bohra-Mishra et al. 2017; Thiede and Gray 2017). Both low and excessive levels of precipitation decrease inter-provincial migration in eight South American countries (Thiede et al 2016), foster outmigration at the inter-district level in South Africa, especially for poor Black affected populations (Mastrorillo et al 2016), and do not seem to affect out-of-village migration in any systematic way in Pakistan (Mueller et al 2014). In addition, Dallmann and Millock (2017) find that while precipitation deficits systematically increase outmigration, excess precipitation lowers outmigration in India.

Similarly, inconsistent results are obtained regarding temperature anomalies. In South America, for instance, both positive and negative temperature shocks increase youth inter-state migration (Thiede et al 2016). Migration tends to increase with temperature anomalies in Uganda, to decrease with temperature anomalies in Kenya and Burkina Faso, and shows no consistent relationship with temperature in Nigeria and Senegal (Gray and Wise 2016). Temperature has a nonlinear effect on migration in Indonesia, in that whenever average annual temperature exceeds 25.3^0C, it leads to an increase in outmigration and the other way around (Bohra-Mishra et al 2014). Droughts increase outmigration in Pakistan (Mueller et al 2014), Indonesia (Thiede and Gray 2017), and northern Ethiopia (Hermans and Garbe 2019), as well as rural-to urban migration in Northern Latin America and the Caribbean (Baez et al 2017a) and in Central America (Baez et al 2017b) mostly for young females and young uneducated males. Drought, however, is also found to have an insignificant effect in South America (Thiede et al 2016) and to decrease the likelihood of migration in Vietnam, Peru, Uganda, Vietnam, and Cambodia (Koubi et al 2016a, b).

Recent studies provide systematic evidence that temperature and precipitation anomalies increase migration via a reduction in agricultural yields in Philippines (Bohra-Misha et al 2017), India (Viswanathan and Kumar 2015), and Pakistan (Mueller et al 2014) as well as income in India (Dallmann and Millock 2017) and Tanzania (Kubik and Maurel 2016). In particular, Bohra-Misha et al (2017) study inter-provincial migration within the Philippines and find that higher temperatures have significant negative effects on rice yields generating more outmigration from provinces that are more agriculturally dependent and have a larger share of rural population. Mueller et al (2014) find that drought during the wheat season increases migration especially for males in Pakistan. Similarly, Kubik and Maurel (2016) find that in Tanzania, a 1 per cent reduction in agricultural income induced by weather shock increases the probability of migration by 13 percentage points on average within the following year but only for households whose income is highly dependent on agriculture, and those who are in the middle of the wealth distribution respond to the weather shock by spatially diversifying their income sources.

Natural disasters

The effect of natural disasters on internal migration depends on the type and the severity of the disaster. Overall, sudden-onset natural disasters tend to have a great likelihood of inducing migration (Koubi et al 2016) - 'People flee to save their lives' (Warner 2010: 405). However, while the short-term migration consequences of natural disasters are to be expected, it is more interesting to know whether affected individuals and households migrate permanently. A number of studies have thus focused on specific disasters and examined their effects producing inconclusive results once more. Starting with floods, while several studies find that floods increase the likelihood of migration in Vietnam, Cambodia, Uganda, Nicaragua, and Peru (Koubi et al (2016) as well as in Costa Rica (Robalino et al 2015), others report either a no effect in Ghana (Goldbach 2017), Bangladesh (Chen and Mueller 2018), and Indonesia (Goldbach 2017; Bohra-Mishra et al 2014) or a significant negative one in Bangladesh (Chen et al 2017; Mueller et al 2014). The latter result may imply that individuals are either trapped or that broader benefits from extreme flooding outweigh the short-term costs, as flooding can improve overall soil quality and yields in subsequent crop cycles potentially increasing the opportunity cost of migration.

Extreme storms, tropical cyclones, typhoons and hurricanes can also have considerable potential to stimulate displacement, with the potential for subsequent migration. Bohra-Misha et al (2017) show that in Philippines typhoons generate more outmigration from agriculturally dependent provinces and males, younger individuals, and those with higher levels of education are more likely to migrate. Similarly, cyclones in Bangladesh often force households to migrate from the affected area when they fail to derive a secure income in the aftermath of the disaster (Saha 2016). It is worth noting, however, that a recent study by Lu et al. (2016), which tracked population movements around the time Cyclone Mahasen stroke Bangladesh in 2013 using mobile phone network data, finds that population flows were largely unchanged by this event implying that no substantial migration took place. Hurricanes tend to increase migration in Northern Latin America and the Caribbean (Baez et al 2017a). In the United States, coastal counties often experience increased outmigration after hurricanes by people who are on average wealthier than out-migrants at other times (Ouattara and Strobl 2014). This migration often flows along existing social networks to predictable destinations, with post-disaster reconstruction employment opportunities potentially attracting new migrants to the affected areas (Curtis et al 2015; DeWaard et al 2016).

Later this century, sea level rise (SLR) is expected to have widespread impacts on populations living in low elevation coastal zones and atolls (IPCC SR 1.5C). The key physical risks to settlements include increased rates of inland penetration of storm surges and groundwater contamination by salt water, and eventual inundation and submergence (McLeman 2018). SLR could thus force people to migrate and, in the extreme case, the resettlement of small coastal settlements around the world, particularly from small pacific islands such as Tuvalu, may be required. So far, the evidence suggests that these vulnerable communities resist migration due to cultural and social ties to that specific place. In fear these places may be lost, individuals prefer in-situ adaptation, as is the case with residents in Maldives (Stojanov et al 2017) and small-island communities in the Philippines (Jamero et al 2017). Moreover, residents in Maldives rarely identify the potential of future climate impacts as influencing their migration decisions, which are mostly motived by better job opportunities and standard of living via improved services (Kelman et al 2019). People in Funafuti and Tuvalu are more concerned about economic issues, food, water, and overcrowding than climate change (McCubbin et al 2015). In coastal Louisiana, USA, communities tend to resist leaving exposed settlements until a neighborhood community loses at least 50% of its land area (Hauer et al 2019). Lastly, salinity also induces migration in Bangladesh but mobility is restricted to certain locations mostly close to the affected areas (Chen and Mueller 2018).

Estimates of future climate migration flows

The Intergovernmental Panel on Climate Change Reports in 2014 and 2018 postulate that climate change is very likely to create mass-population displacements, particularly in developing countries with low income (IPCC AR5 2014: 4-6 and SR 1.5 2018: SPM-11). While the evidence on the links between climate variability and migration show that climatic changes influence migration, there is high uncertainty about how this will play out in the future as using the past to understand the present and future may be problematic due to the dynamic nature of climate and society's adaptive capacity (Lutz and Muttarak 2017). Projections of future migration flows due to climatic changes have largely been focused on the number of people who will migrate or become displaced. Estimates have gone from coarse studies based on the number of people living in vulnerable areas (i.e. exposure mapping) (Laczko and Aghazarm 2009; Myers 2002) to more complex models including different RCPs and SSPs (Rigaud et al 2018).

The most encompassing forecasting project to date has been the World Bank's *Groundswell* project, which developed gravity models of potential internal population displacements by 2050 in sub-Saharan Africa, South Asia, and Latin America under various standardized greenhouse gas emissions and development scenarios (Kumari Rigaud 2018). The authors report that in a high-emissions/low development scenario, slow-onset climate hazards (e.g., droughts) could internally displace approximately 140 million people. Alternative estimates, combining climate and statistical models, show that in sub-Saharan Africa 11.8 million would been displaced between 2000 and 2100 (Marchiori et al 2012), and that that climate change by exerting more stress on vulnerable populations around the world increase asylum applications to the European Union between 98000 (RCP4.5) and 660000 (RCP8.5) by 2100 (Missirian and Schlenker 2017). However, the evidence they provide is weak, because they do not account for different levels of vulnerability to climatic change and potential adaptation strategies, which, to a great extent, depend on the economic and political conditions of countries in which affected populations reside (Koubi 2019; Adger et al. 2015; Hunter et al. 2015). That said, it remains challenging to detect and assess the effect of climatic changes on migration with any degree of confidence since the social, economic, political, and environmental factors underlying migration are quite complex and varied (Cramer et al. 2014). It is not then surprising that the IPCC Reports stress that there is low confidence in quantitative projections of future migration flows, although the likelihood of migration is currently high.

In addition, while large-scale models seeking to project future migration patterns due to climate change are becoming more complex, they are still not able to answer detailed questions about what migration will look like in the future. There is thus limited evidence on the future impacts of climate change and natural disasters on migration patterns, but studies agree that migration will increase in the future. More research is needed on more detailed projections of future migration patterns in the context of climate change and disasters. Research needs to provide a better understanding of the differences between countries and sub-national regions in terms of future migration patterns, as well as projections regarding trapped populations and people using other adaptation strategies than migration. Projections of future migration patterns also need to incorporate an understanding how adaptive capacities might change in the future. There is also a great need for better migration data. The fact that a climate migrant is not legally recognized has hindered the collection of official data on the number of people that have moved from their homes due to climate change directly or indirectly due to socio-economic and/or political changes (including conflict) triggered or exacerbated by climate change, especially when it comes to international migration.

It is worth noting that climate migration and displacement were not explicitly mentioned in any SDG. Other SDGs, specifically SDGs 8, 10 and 17, point to the need for facilitated, planned and well-managed migration policies – but do not make the connection with climate change. Therefore, the ways in which migration may be altered by climate change and the challenges this poses for policy and planning are not directly addressed in the SDGs. Nor are the broader challenges that human mobility presents to meeting goals on mitigating and adapting to the impacts of climate change. Migration will affect progress on SDG13, yet, given the uncertainty surrounding migration projections as well as the destination(s) of future climate migrants, it is hard to anticipate the precise impact of migration on achieving these targets. Nevertheless, one could safely say that climate migration could make the implementation of some SDGs difficult. To start, (rural) migrants tend to move to urban[14] settings and are particularly vulnerable to climate change impacts due to low levels of social support and greater exposure to typically urban hazards such as flooding (Waters and Adger 2017). They may also come from other environmental, social and cultural settings and therefore, the may be unfamiliar with how to respond to the unfamiliar climate extremes, e.g., heat waves. Similarly, those left behind in places where emigration is high may become even more vulnerable to climate change, especially women and children since they are less able to manage the farming activities and deal with floods and other extreme weather events. Consequently, climate change could compromise SDGs 1-8, 10-11, and 13.

A final observation of the framing of climate migration since it has been show that there are important linkages between the framing of climate and migration and the nature of subsequent policy discussions and recommendations. For example, the government of Kiribati has advocated for a 'migration-with-dignity' approach, which sees freer labor migration between vulnerable countries and developed nations as a means of harnessing skills and remittances earned abroad for building adaptive capacity at home, while at the same time enhancing skills and expertise of young people and improving development prospects in general (McNamara 2015). By contrast, the "threat multiplier" interpretation was invoked frequently in media and policy discussions following anecdotal, poorly documented reports that drought-related migration caused the civil conflict in Syria, and may have influenced

[14] That climate migrants and environmental migrants move to cities from rural areas is a conjecture and not a fact corroborated by rigorous scientific evidence.

European policy responses to the 2015-16 refugee crisis (Selby et al 2017). It is consequently important that future policymaking discussions regarding climate and displacement mandated under the Paris Agreement, and on how best to address climate-migration challenges within the context of meeting SDGs, be framed in such a way that they reflect empirical data and not contested political narratives.

4. Climate Change and Conflict

In 2007, the IPCC 4th Assessment Report stated that climate change could become a major contributing factor to conflicts by exacerbating the scarcity of important natural resources, such as freshwater, and triggering mass population dislocations (migration) due to extreme weather events. Subsequently, governmental agencies (CNA 2007) and high-ranking policy-makers such as President Obama and the UN Secretary General Ban Ki-Moon have issued statements linking climate change to conflict on many occasions. With the acceleration of climate change and the focus on climate change as a security threat, the academic literature on climate change and conflict saw exponential growth. During the last decade, numerous academic studies have sought to explore whether a climate change-conflict link exists and how climate change is – or could be – linked to conflict.

How is climate change linked to conflict?

There exist two potential *channels* linking climate to conflict:

The first one views climate as affecting the likelihood of *interpersonal* conflict, i.e., violence among individuals such as murder, assault, rape, and robbery, via *physiological and/or psychological* factors. That is, warmer (colder) temperatures by elevating levels of discomfort and aggressiveness increase hostility and violence (Anderson and Bushman 2002).

The second channel postulates that climate leads to *intergroup* conflict[15] i.e., conflict among groups such as civil war, civil conflict, protest, or riots, via *resource scarcity*. Consequently, most of the existing literature theorizes that the effect of climate on conflict operates through economic conditions such as reduced economic output and crop yields as well as increased food prices and increased migration flows.

There also exist several possible theoretical explanations (*mechanisms*) on why climate depressed economic conditions could lead to conflict.

Economic channel: lower income and limited future economic opportunities (Hsiang and Meng 2015; Burke et al. 2015; Dell et al. 2012) can lead to conflict by decreasing the opportunity cost of rebellion (the *low opportunity cost of rebellion argument*). That is, since individuals expect lower returns from peaceful employment (e.g., farming), they are more likely to be attracted to selective benefits of rebel leaders and hence they are more likely to join insurgent groups (Chassang and Padro-i-Miguel 2009). Furthermore, climatic variability by reducing crop production decreases crop supply, which in turn increases food prices. Temporary food price increases are likely to amplify the opportunity cost of rebellion mechanism, since they likely reduce the short-term opportunity cost of more fighting (Chassang and Padró i Miquel 2009). Climate-driven economic downturns are also likely to exacerbate actual or perceived

[15] Intrastate (domestic) conflict measures range from violence against the government (civil wars (1,000 deaths) and civil conflict (25 deaths)) to low intensity conflict (e.g., protests and riots), and inter-communal violence (conflict occurring between competing groups within a state).

economic and political *inequalities* in a society, which increase the likelihood of conflict by motivating individuals/groups to attempt to redistribute wealth and political power (the *grievances argument*) (Cederman et al. 2013). Moreover, Climatic changes by decreasing economic output also reduce resources available to the government (e.g., reduced tax revenue). In turn, this curtails government's strength and ability to provide good and services to people, making it easier for opponents to organize political resistance**,** e.g., a coup or a revolution to remove the leader from office (the *weak state capacity argument*) (Bueno de Mesquita and Smith 2017).

Migration channel: climate-induced migration might lead to conflict in the receiving areas due to *competition* for jobs, public goods and services, and *ethno-political concerns* that arise when migrants and residents belong to different ethnic groups and the arrival of newcomers upsets an unstable ethnic balance (Reuveny 2007).

Context matters: Whether climate ultimately leads to conflict, however, depends on socio-economic and political factors that would condition or intensify (weaken) the effect of climate on conflict. For instance, high levels of poverty and high dependence on renewable resources, e.g., agriculture, increase the likelihood that weather shocks produce detrimental economic conditions for large sections of the population (Ide et al. 2014). Climate induced migration, especially in underdeveloped countries, might exacerbate the likelihood of conflict since these countries find it typically more difficult to absorb and manage an influx of migrants in (urban) receiving areas (Reuveny 2007). In addition, political institutions and government capacity at multiple levels are important in addressing acute resource shortages and resolving these in a peaceful manner (Linke et al. 2017).

What do we know?

Interpersonal violence

Numerous empirical studies report a positive relationship between temperature and different forms of *interpersonal* violence, e.g., murder (Ranson (2014), assault (Anderson et al 1997), homicide (Mares and Moffetti (2016), domestic violence within households (Card and Dahl 2011), the use of force during police training (Vrij et al 1994), inter-player violence during sporting events (Larrick et al 2011), and horn-honking while driving (Kenrick and Mcfarlane 1986) for different time periods and geographical regions. For example, Mares and Moffetti (2016) find that homicide rates increase as temperatures rise in a sample of 57 countries for the period 1995-2012. They also claim that this positive relation will continue as global warming raises average temperatures around the world and predict that each degree Celsius increase in global temperature will increase homicide rates by 6%. Ranson (2014) examines the impact of temperature on the prevalence of criminal activity in 2,997 US counties for a period of 30 years and reports that temperature has a strong positive effect on violent crime, such as murder but a non-linear effect on property crime, with property crime increasing up until about 70^0F. Overall, these studies suggest that temperature has an immediate effect upon criminal activity, especially violent crime, even though the exact physiological mechanisms linking temperature to aggression are not yet known. While the physiological mechanism has not been observed in intergroup conflict, Hsiang et al (2013: 4) note that since aggression at high temperature increases the probability that intergroup conflicts escalate in some contexts (e.g., in football stadiums) and also the probability that police officers use force (e.g., during training), it is possible that this mechanism could affect the occurrence of larger scale group-level conflicts.

***Intergroup violence, the direct channel*[16]**

Turning to intergroup conflict, empirical studies a) focus mostly on Africa and regions/countries within it and, to a lesser extent, on Asia, since these continents are highly dependent on agriculture for income and food generation and already suffer from climatic changes; and b) rely almost exclusively on simple meteorological indicators, such as temperature and/or rainfall, as well as natural disasters (e.g., floods, storms, or droughts), as possible correlates of intergroup conflict. Most of this research, although it accounted for some contextual factors, such as economic development and differing political systems, provides little evidence for a strong direct link between climate variability and/or natural disasters and conflict (Koubi 2019; Buhaug 2015). For instance, some studies report either a positive effect of temperature and precipitation or natural disasters on civil conflict/war (e.g., O' Loughlin et al 2014; Hendrix and Salehyan 2014), as well as on communal conflict (Maystadt et al. 2015; Ember et al 2014). Other studies find no effect (e.g., Detges 2014; Wischnath and Buhaug 2014a; Böhmelt et al. 2014).[17] However, there is some evidence that natural disasters lengthen civil conflict (Eastin 2016) and the outbreak of armed conflict is more likely to follow disasters in non-democratic (Koubi et al 2012) and ethnically fractionalized countries (Schleussner et al 2016). Nevertheless, research also suggests that disasters may precipitate peace rather than conflict (Tubi and Feitelson 2016; Nardulli 2015).

Climate variability, e.g., less precipitation by reducing the supply of water in transboundary river basins, can threaten the well-being and national security of the riparian states, thus increasing the probability of interstate conflict. Research largely indicates that while river sharing does not increase conflict over and beyond the increase in conflict due to proximity, i.e., sharing a border (Brochmann and Gleditsch 2012), water scarcity increases the risk of conflict in river sharing dyads relative to other pairs of countries (Gleditsch et al. 2006) and the risk of conflict is more pronounced in upstream/downstream configurations (Brochmann and Gleditsch 2012). The most recent study on this topic (Devlin and Hendrix 2014), however, finds that joint precipitation scarcity, i.e., when both members of a dyad experience drier than average conditions, reduces the likelihood of an interstate militarized dispute (MID). Other studies report that water scarcity enhances the incentives of riparians to cooperate (Dinar et al. 2011), and that the existence of transboundary treaties (Tir and Stinnett 2012), the specific design of international water agreements (Dinar et al. 2015), and effective international frameworks for water allocation and prevention of climate-induced geo-hazards in shared river basins can mitigate the risk of conflict (Bernauer and Siegfried 2012). Link et al. (2016),

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[16] Climate change affects the likelihood of *intragroup* violence via the *scarcity* of renewable resources such as freshwater, arable land, forests, and fisheries. Following a neo-Malthusian line of argument, it is assumed that adverse climatic conditions, e.g., high temperatures or low rainfall coupled with overpopulation reduce the resources needed to sustain human livelihood. Reduced resources increase competition, which leads to conflict (Homer-Dixon 2001). At the national level, for instance, less rainfall or high temperatures could lead to conflict among consumers of water, e.g., farmers and herders, urban unrest, insurrections, and other forms of civil violence, especially in the developing world. This line of argumentation has been criticized as being overly deterministic since it removes violent conflict from its local, social and political contexts (Raleigh et al. 2014), and dismissive of the fact that substitution, technological innovation, investment, and international trade can overcome resource scarcity.

[17] Lower rainfall, however, increases the duration of civil conflict: as rainfall declines, there is a reduction in resources available to both the government and the rebel group, leading to a stalemate in fighting (Keels 2017).

however, note that successful management of shared river basins in times of climatic changes should not be based on only water allocation schemes but also consider other socioeconomic and political factors affecting water availability such as adaptive capacity and construction of dams, and hence conflict (see also Feitelson and Tubi 2017 and De Stefano et al. 2017).[18]

Admittedly, the inconclusiveness of the empirical results might be due to the differences in: a) datasets regarding the operationalization of both conflict (e.g., civil war, civil conflict, intergroup conflict, and protests)[19] and climate (e.g., temperature, precipitation and precipitation anomalies, droughts, floods) variables; b) temporal (e.g., month, quarter, and year) and spatial (e.g., grid, national, and global levels) domains; c) model specification (e.g., fixed effects, and inclusion of control variables); and d) heterogeneity that can play an important role. That is, studies examining the direct effect of climate on conflict assume that the effect is the same within a country and across different types of countries or regions. However, given that neither climatic shocks nor conflict risk affect a state's entire territory in the same way it seems unlikely that a given climatic shock would have the same effect across different countries and socio-economic and political contexts: climatic shocks usually do not lead to conflicts in wealthy and politically stable countries. Consequently, criticism has arisen that these direct connections between climate and civil conflict are a type of environmental determinism (Raleigh et al. 2014). Several scholars indeed note that other factors, e.g., population pressure, political regime, low economic development, and ethno-political exclusion, are likely to either condition this relationship (Buhaug 2015; Ide et al 2014) or to have a stronger impact on conflict risk than adverse climatic conditions (O'Loughlin et al 2014; Böhmelt et al. 2014).

Nevertheless, seeking to examine the climate-conflict relationship, Hsiang et al. (2013) systematically conduct a meta-analysis based on 60 studies whose empirical analysis could be specified as fixed-effect panel regressions of a reduced form equation, i.e., regress climatic variables on conflict. They conclude that deviations from mild temperatures and normal precipitation systematically increase conflict risk, often substantially and estimate that on average, a one standard deviation change in weather variables increases intergroup conflict by 14% (see also Hsiang and Burke (2014) for another meta-analysis of 50 studies). Buhaug et al. (2014), however, criticize this study with respect to sample selection, selection of indicators and interpretation of results and point out that the conclusion is misleading and at odds with recent empirical evidence (Buhaug et al. 2014, 3). The UN Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), however, supports Buhaug et al.'s assessment stating that 'collectively the research does not conclude there is a strong positive relationship between warming and armed conflict' (Ref 3, p. 16). The report also affirms that climatic changes can indirectly increase the risk of conflict by amplifying well-documented drivers of conflict such as poverty and economic shocks.

[18] Climate change could contribute to abundances that could contribute to interstate conflict. For instance, higher temperatures by causing the melting of the polar ice cap in the Arctic will improve accessibility to Arctic ports, reduce costs of oil and mineral exploration and exploitation, and open up new shipping lanes. Under these circumstances, however, competition and conflict could become the Arctic reality if cooperative mechanisms cannot keep pace with developments or otherwise prove inadequate to settle international disputes in the region. Future research could examine whether climate change could act as a "threat multiplier" also for interstate conflict in the Arctic (Koubi 2019).

[19] Most research rely on data from the Uppsala Conflict Data Program Dataset (UCDP/PRIO), the Social Conflict Analysis Database (SCAD), and the Armed Conflict Location and Event Data (ACLED).

Intergroup violence, the indirect effect

While climatic changes *per se* are unlikely to cause conflict, they still could act as a "threat multiplier" (CAN 2007) since they have the potential to exacerbate a wide range of existing and often interacting conflict drivers such as high population growth, resource scarcity, poverty, poor governance, and unmanaged migration. Hence, a new wave of empirical research examines the climate-conflict nexus in a multiple-stage fashion considering conditional effects such as political institutions and migration and indirect links such as economic growth and agricultural production.

Climate, national income, economic growth, and conflict

There are only a few quantitative studies, which explicitly examine the causal pathway linking climate to violent conflict via national economic conditions. Building on an influential study by Miguel et al. (2004), these studies use mainly rainfall and/or temperature as instrument for economic conditions under the assumption that climate influences conflict *only* through the national economy. Miguel et al. (2004) study 41 African countries in 1981-1999 and report that lower rainfall growth reduce economic growth, which in turn increase civil conflict onset and incidence (see also Hodler and Raschky 2014). Ciccone (2011), however, disagrees. Extending the time period to 2009, he re-evaluates Miguel et al.'s result using rainfall levels instead of rainfall growth rates, due to the mean-reverting nature of rainfall, and reports that conflict is unrelated to rainfall. Miguel and Satyanath (2011) attribute the contradictory results to the difference of the temporal domains of the two studies rather than to the measurement of the rainfall arguing that the relationship between rainfall shocks and civil conflict appears to be weaker in Africa after 1999 mainly due to Africa's unprecedented economic growth in non-agricultural sectors and perhaps to the spread of democratization. Koubi et al. (2012) using a global dataset as well as an African sub-sample for the 1980-2004 period also do not find evidence that climatic variability, measured as deviations in temperature and precipitation from their 30years long- run past levels (a 30 years moving average), increases the risk of civil conflict via their negative effect on economic growth (Van Weezel 2015, Wischnath and Buhaug 2014a; see Bergholt and Lujala (2012) on natural disasters). They also find than non-democratic countries are more likely to experience civil conflict when economic conditions deteriorate thus providing evidence that the effect of climate-driven economic downturns on conflict is conditional on the type of political system. Overall, there is no evidence for a strong relationship between climate (temperature, precipitation or extreme weather events), deteriorating economic conditions, and conflict.

Climate, agriculture production and income, and conflict

Given the natural relationship between weather and agricultural production, agriculture has been the focus of much of the recent literature on climate and conflict. Several studies provide evidence for a climate-induced adverse agricultural production and conflict relationship across many centuries. However, they disagree on which particular type of climatic change is the most influential one. Two studies based on data stretching back 1,000 years show that cooler temperatures caused conflict in the northern hemisphere (Zhang et al 2011) and increased the frequency of conflict in Eastern China by reducing agricultural production (Zhang et al 2007). Similarly, Anderson et al (2015) employ panel data from 1100 to 1800 and show that colder growing seasons led to greater expulsion of the Jewish population from European cities during the fourteenth to sixteenth centuries, and that the effect was stronger in societies with lower state capacity. Jia (2014), however, using panel analysis for the period 1470 and 1900, shows that drought triggered peasant rebellions in China, and that technological innovation in the form of the introduction of drought-resistant sweet potatoes mitigated the drought's effect on rebellion.

Studies using recent data focus on areas where agriculture represents a large share of the national income and with predominantly rain-fed crops such as sub-Saharan Africa and Asia. With the exception of Buhaug et al. (2015), these report that adverse climatic conditions via their negative effect on agricultural production and incomes affect various types and characteristics of conflict. In particular, Gawande et al. (2017) find that rainfall shocks increase the intensity of conflict, measured as number of killings, in the Maoist belt in India by reducing agricultural production. Similarly, Eastin (2018) shows that excess rainfall, typhoons, and declines in agricultural productivity increase violence in armed intrastate conflict in the Philippines. Drought increases the incidence of most crimes, including burglary, banditry, rape, riots, and murder in India (Blakeslee and Fishman 2017) and property crimes in South and South East Asia (Papaioannou 2017). Rainfall extremes increase the number of Hindu-Muslims riots in India (Sarsons 2015). Drought increases the likelihood of riots in sub-Saharan Africa (Almer et al. 2017).

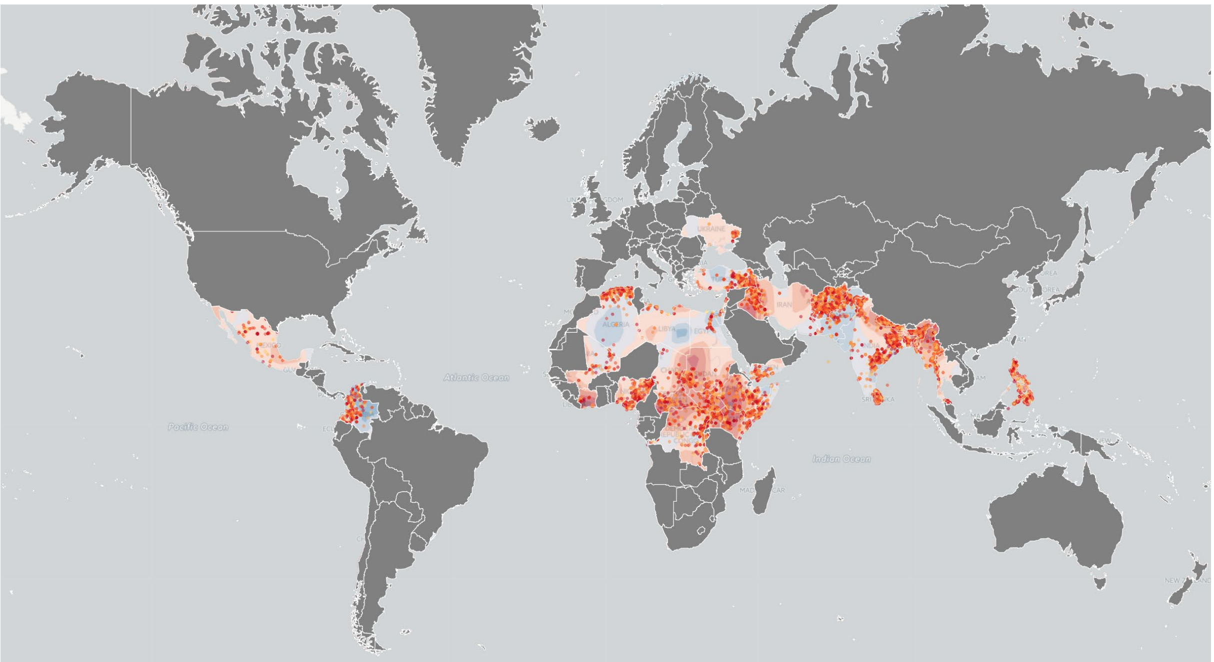
Furthermore, a few studies seeking to construct a better measure of agricultural production exploit within-year variation in the timing of climate shocks, which occur during the growing season of the main crop(s) cultivated in an area (country or grid) (e.g., Harari and La Ferrara 2018; Jun 2017; Caruso et al. 2016). These studies find that lower or higher temperatures during the core month of the rice-growing season in Indonesia (Caruso et al. 2016) or the maize-growing season in sub-Saharan Africa (Jun 2017) reduce the crops' yield, which in turn increase the incidence of civil conflict. Similarly, Harari and La Ferrara (2018) show that weather shocks such as above-average temperatures or below-average rainfall during the growing season of several types of crops in 39 African countries have a larger impact on conflict-related incidents than weather shocks outside of the growing season. Finally, Crost et al (2018) show that abnormally heavy rainfall during the wet season in Philippines growth leads to an increase in violent events, mainly in agricultural provinces one year later, by harming crop. This violence occurs predominantly among rebel groups that take advantage of the chaos created by a bad harvest season.

In addition to fostering income shocks for agricultural producers, adverse climate can also affect consumers by increasing the prices of the affected crops, and hence food prices. Higher food prices lead to various forms of social unrest, such as demonstrations, riots, and government crises, e.g., the so called 'food riots'. For instance, it is often stated that rising *food prices* played a role in fomenting the Arab Spring unrest across North Africa and the Middle East in 2011 (Johnstone and Mazo 2011). It is worth noting, that higher food prices might not necessarily be the result of reduced crop availability at the local level: hiked global food prices may be the results of failed harvest further away from home, as in the case of waves and wildfires in Russia, China, and other food-growing countries in the summer of 2010 that hiked global food prices in the following months. Several studies report a positive relationship between higher food prices caused by adverse climatic conditions and the outbreak of urban unrest in African countries (Smith 2014), civil conflict in Africa (Fjelde 2015; Raleigh et al. 2015), and the incidence of social unrest globally (Bellemare 2015). It is worth noting, that reduced crop availability may not only have local effects.

Context matters

As mentioned above, the effects of climate on conflict are likely to vary with national and local economic development as well as the political institutions and administrative capacity of national and local governments. Recent studies interact and/or combine climatic variables with socioeconomic and political factors to examine when and where conflict occurs (see Ide 2015 for an opposing view). Overall, these studies reveal (and figure 15 illustrates) that *'context matters'* since adverse climatic conditions are more likely to increase the likelihood of sustained violence in regions, which are already hot with agriculturally dependent and politically excluded groups (Bagozzi et al. 2017; Von Uexkull et al. 2016; Schleussner et al. 2016; Bretthauer 2015), institutions are ineffective (Linke et al. 2015; Linke et al. 2017), and essential public services are difficult to obtain (Detges 2016; Jones et al. 2017). For instance, Schleussner et al (2016) report that the initiation of civil conflict follows drought more often than is to be statistically expected in cases in which there is a high degree of ethnic fractionalization within a country. Furthermore, von Uexkuell et al (2016) find a significant statistical correlation between drought and conflict in areas where minority groups are excluded from political participation while being dependent on agriculture for income. In addition, this relationship seems to be more pronounced for civil conflict intensity than for conflict onset, which implies that climatic magnifies the consequences of conflict.
Figure 15 displays these relationships: drought and conflict coexist in countries or regions that already suffer from adverse climatic changes, are highly dependent on agriculture for income and food generation, have few capabilities to cope with these changes, and are characterized by pre-existing tensions and conflict. In turn, conflicts contribute to environmental degradation and undermine the ability to adapt to climate change, thus creating a vicious circle of increasing vulnerability. The Lake Chad basin exemplifies this vicious circle scenario: it is vulnerable to climatic changes and at the same time is characterized by low socio-economic development, high levels of poverty, low levels of national integration, historical government neglect, perceived and actual marginalization, and political violence.

Figure 15: Drought Trends and Civil Conflict (1989-2014)



Data: NOAA PDSI and UCDP GEO v17.1. Conflict incidents occurring during the 2005-2014 period are shaded darker than conflicts occurring during the 1989-2004 period.

Source: Koubi 2019

The migration channel

The migration channel through which changes in the climate could significantly increase the probability of conflict has been rarely explored systematically (Burke et al 2015a). Qualitative work, on the one hand, provides some evidence that mass population movements induced by climatic shocks could destabilize (fragile) countries and result in conflict, an example of this is Syria (Kelley et al. 2015). However, in this case, these connections have not been established conclusively. Several scholars have vigorously contested the links between drought, migration, and conflict (Selby et al 2017; Frohlich 2016; Chatel 2014). On the other hand, existent empirical evidence based on large-*N* studies is mostly inconclusive regarding the onset of new conflicts (e.g., Brzoska and Fröhlich 2015; Bernauer et al. 2012). Several studies, however, find that climatic conditions could lead to low levels of political violence and prolong conflict. For instance, Bhavnani and Lacina (2015) show that greater rates of internal migration due to irregular rainfall are associated with a higher risk of riots in migrant–sending Indian states. Ghimire et al. (2015) report that displacement caused by catastrophic floods is likely to lengthen the duration of an existing civil conflict but it does not affect the risk of new conflict outbreaks. Finally, De Juan (2015) finds that in Darfur, conflict was more prevalent in areas that experienced higher water availability and more vegetation, and showed higher levels of immigration.

The lack of conclusive evidence linking climatic changes with migration and conflict is largely due to the difficulties in isolating the effect of climatic change from the many other determinants of conflict and to inability of the existing research to model adequately the complexity of this relationship. For instance, most of the existing literature assumes that all types of climatic change, i.e., floods or droughts, lead to conflict and that all environmental migrants are equally prone to conflictive behavior, yet neither is accurate. For example, migration due to a sudden/short-term climatic event, e.g., flood, is less likely to cause conflict compared to migration after a long-term climatic event such as a drought. This is because the migrants of sudden-onset climatic events are welcomed as they do not have any other option than to flee but they also are expected to leave as soon as the impact of the climatic event fades out. Moreover, the distribution of humanitarian aid is likely to alleviate immediate scarcities. Koubi et al. (2018) focus on the individual and argue that migrants who experience gradual/long-term climatic events such as droughts or desertification in their place of origin relative to the ones who experience sudden/short-term climatic events such as floods and storms, are more likely to have developed grievances that lead to heightened conflict perceptions in their new location. Relying on individual-level survey data from five developing countries, they find that migrants of long-term climatic changes show significantly higher levels of perceived conflict in their new location. This indicates that climate migration could only lead to conflict under specific climatic conditions. Consequently, it is crucial to understand the exact causes of why migrants leave their homes and how residents in the host locations perceive them in order to be able to prevent potential conflict at the receiving areas. This is one of the most important priorities for future research on the security implications of climate change.

Projections of future 'climate conflicts' and the SDGs

There exists an extremely small number of studies making projections on future climate conflicts. On the one hand, Burke et al (2009) predict that if future conflicts in sub-Saharan Africa are on average as deadly as present conflicts, and assuming linear increases in temperature to 2030, this warming will increase armed conflict incidence by roughly 54%, or an additional 393,000 battle deaths by 2030. On the other hand, based on a statistical model of the historical effect of key socioeconomic variables on country-specific conflict incidence for the period 1960–2013, Hegre et al (2015) forecast the annual incidence of conflict for the 2014–2100 period along the five shared socioeconomic pathways (SSPs). They show that broader socioeconomic development, expressed by higher growth in education and poverty alleviation, could help in offsetting most of the conflict risk in developing countries associated with reduced economic growth due to implementation of policies to curb GHG emissions. However, predictions based on historical models provide a weak foundation for projecting future conflict risk under future climate scenarios since we do not know how conflict patterns will evolve over time under anthropogenic climate change. Research needs to simulate future conflict risk along alternative configurations of representative concentration pathways and shared socioeconomic pathways, while at the same time accounting for feedbacks from conflict onto economic activity.

Although climatic conditions seem to affect the characteristics of conflict, in particular duration and intensity, rather than its onset, they can still endanger the successful implementation not only of SDG 13 but almost all SDGs. Conflict is development in reverse: conflict does not only undermine the capacity of governments (and non-governmental actors) to reduce greenhouse emissions and to provide adequate protection from natural disasters, but it is also a major driver of climatic/environmental vulnerability via its negative effects on economic growth, education, food security, and environmental destruction. Hence, ending violent conflict may be one of the most efficient and cost-effective ways to improve social resilience to natural disasters and climate change in general.

5. Policy Recommendations

In an attempt to meet the Sustainable Development Goals, it becomes imperative to recognize that climate change, the economy, migration, and conflict are interconnected and are a function of larger global challenges. Moreover, it appears that agriculture is the main mechanism behind this interconnection. This implies that effective policies aiming at reducing the vulnerability and strengthen the resilience of agricultural communities could substantially increase the likelihood that the Sustainable Development Goals would be met by 2030. The need for new (or the redesigned old) policies and programs that foster sustainable agriculture will require creative responses that are international in scope yet tailored to unique local and regional situations. Thus, reaching the SDG targets will simply not be possible without a strong and sustainable agricultural sector.

My recommendations focus primarily on what can be done to adopt sustainable agriculture and, to a lesser extent, on what specific policies should be implemented to deal with migration, the presence of climatic changes. In particular, promoting sustainable agriculture should be central to responses to climate, economic growth, migration, and conflict challenges, as it fosters the adaptation and mitigation of climate change and also reduces other root causes of migration and conflict such as rural poverty, food insecurity, and inequality. Sustainable agriculture should have targets that focus on both domestic and international efforts. The following is a list of such targets:

- Increase agriculture production in developing countries through sustainable agricultural practices such as rotating crops and embracing diversity, reducing or eliminating tillage, integrating livestock and crops, and adopting agroforestry practices.

- Ensure access by small farmers to land and security of land tenure, particularly women, indigenous peoples and people living in vulnerable areas/situations and to credit, markets, and marketing facilities.

- Improve social safety nets to enable farmers and the rural poor to cope with external shocks, such as climate-related disasters. This includes implementing a range of policies that support the economic viability of smallholder and subsistence agriculture and reduce their vulnerability.

- Develop and transition to ecological farming through national agriculture policy frameworks that, in particular, increase emphasis on the conservation and use of agricultural biodiversity, fostering healthy soils, and developing and sharing water harvesting and other water management techniques

- Implement a research and knowledge-sharing agenda towards sustainable agriculture. Research and development efforts must be refocused towards sustainable agriculture, while at the same time strengthening existing farmer knowledge and innovation.

- Stimulate rural development by adopting or enhancing comprehensive plans and activities, including raising the living conditions, infrastructure, and work opportunities and incomes of rural communities in especially developing countries.

All of the above require that national leaders look at the role of agriculture, forestry, and fisheries in such fashion that situates these sectors in a more prominent and adequate place in the national development trajectory. Furthermore, in order to achieve said targets, the means of implementation and a genuine global partnership for development are prerequisites. This would include the provision of finance, e.g., via the Green Climate Fund, transfer of appropriate technology and capacity building for the adoption of sustainable agriculture practices.

Integrating 'climate migration' into national climate change adaptation, disaster risk reduction policies and plans, and sustainable development is vital in order to effectively manage its challenges. For national policymakers, this implies that adaptation policies should include awareness raising, capacity building and education on climate change to ensure that people are aware of the risks they face as well as the impacts their behavior might have on the environment, wherever they live.

Proactive investment in adaptive capacity building in high-risk natural disaster areas to protect the wellbeing of exposed populations reduces the potential for large-scale distress migration and of having to relocate people at tremendous expense afterwards, which is also likely to be more efficient than reactive (and often unsuccessful) border enforcement. Understanding affected populations' subjective experience of place is also crucial to ensuring that the right solutions (protection, assistance with resettlement, or facilitating migration) are implemented. In the short run, relevant international organizations should improve coordination of humanitarian assistance following catastrophic events, anticipating a higher frequency and severity of these events in the future.

Climate-related migration is seen as a successful adaptation strategy. Yet, this depends on whether residents in receiving areas see the presence of migrants as a threat or a benefit. Tied up with the wider securitization of migration discourse, currently, climate-migrants are largely framed as a security threat. Solutions to climate change migration, therefore, lie within the promotion of alternative, positive discourses of migrants that can pave a way for more open border regimes. Given, however that the majority of climate migrants will move within their own countries or to countries with shared borders, countries vary in the degree to which their borders are open and migrants and refugees are securitized, solutions lie in supporting climate migrants, their host communities, and/or countries in the Global South.

Further delays in sharply reducing GHG emissions will inflict large economic damage on future generations, both in rich and poor countries, and are likely to increase social conflict and violence particularly in parts of the Global South that already suffer from such problems today. Nonetheless, by unevenly imposing higher opportunity costs on certain sectors, individuals, or geographic areas, drastic cuts in GHG emissions have strong distributional effects within countries. Moreover, they also require painful trade-offs between reduced economic growth in the short or even medium term and avoid large economic damage from climate change in the long-term, which may cause severe social conflict and migration and even worse social conflict accordingly. Such distributional problems and trade-offs are very difficult to deal with even in rich countries, as the recent “Gilet Jaune” unrest in France demonstrates, and are probably even more challenging in poorer countries, making these problems a top priority both in climate and in development policy. Scientific research should then contribute to such policy efforts by advancing quantitative assessments of the net effects of different GHG mitigation strategies both on economic welfare and social conflict.

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