TRANSFORMATIVE RESPONSES TO THE CRISIS

# CLIMATE IMPACT INDUCED CRISIS IN EUROPE: AN EXPLORATION OF SCENARIOS

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# An exploration of scenarios

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## Preface

by Jörg Haas, Head of International Politics Division, Heinrich Böll Foundation

The Covid-19 crisis painfully reminds us of our society's vulnerability and unpreparedness in many different ways. Our health systems, for example, are designed to function so 'efficiently' that they leave no room for the challenges of a global pandemic and reach their limits of capacity in a very short time. However, the pandemic was less of a black swan than one would think. Experts have repeatedly warned us of the increased danger of global pandemics and called for minimizing the risk or at least preparing for potential consequences. For example, by investing in or at least maintaining additional capacities of public health care systems.

The same is true for climate-induced crises. It may not be easy to predict what exactly might trigger such crisis, but it is obvious that the likelihood of such an event rises with every new temperature record and every missed climate target.

The project "Transformative responses to the crisis" aims at developing policy proposals to increase our systems resilience by addressing the socio-economic and ecological challenges. In order to prepare and adapt, or in the best case prevent, it is crucial to understand what the future might bring. This is the aim of this report: to generate orientation regarding potential future developments by examining six scenarios of climate impacts that can trigger social, political, economic or financial crises in Europe in the next decade.

These scenarios are not predictions about what is likely going to happen. Each scenario is initially rather unlikely but becomes more probable each year. Therefore, low probability high impact scenarios should not be dismissed. Imagine what great length's we go through as a society to prevent airplanes from crashing, even if the actual probability of a plane crash is minuscule. Nobody would consider boarding a plane if he had a 1% probability of a fatal crash. We specifically asked the authors to look at scenarios of low probability, but high impact of a scale that could trigger a political, economic or financial crisis within Europe.

The authors identify six scenarios: 1. Major river flooding in central Europe or coastal defence failure during a major storm surge in western Europe, causing hundreds of billions in damages. 2. Prolonged drought in southern Europe leads to crop loss, decreased tourist arrivals, and conflict between water users. Social unrest exacerbates the economic impacts leading to economic crisis. 3. Power supply failure due to an extreme weather event (e.g. storm, flooding) or a demand peak, during cooling water shortages due to drought and high temperatures. 4. Flooding induces a rapid drop in US coastal real estate prices inducing a global financial crisis.

5. Extreme weather events in key producing regions and transportation hubs disrupting agricultural trade flows. 6. Armed conflict in Sahel leading to large-scale migration to Europe.

This report was initiated before the Covid-19 pandemic erupted. In some cases, this has led to the description of possible future effects that could be induced by climate-related events, but were triggered by Covid-19 already. The dramatic losses in the Southern European tourist sector are an example.

The climate-risk scenarios of this report stay highly relevant after Covid-19. Especially in light of the Post-Corona economic recovery that will likely be unsteady. It can plausibly be assumed that economic recovery will be marked by upswings in some sectors and downswings in others, by bright outlooks in some world regions and dire ones in others. Therefore, climate-induced crises could hit an already destabilized European economy potentially worsening their effects.

The overheating of our climate is clearly a risk to political, economic and financial stability within Europe and worldwide. 'Building back better' in a way that advances the radical transformation of the European economy to a zero-emissions society is therefore imperative. It is a paradox, to say the least, that the primary European institution tasked with fighting economic and financial crises, the ECB, could actually undermine future stability with its carbon-heavy bond buying programme[1].

This report is deliberately written in a sober, technical language that avoids alarmist connotations. However, make no mistake: Aligning all levers of economic policy, fiscal and monetary alike, with the overarching need for a rapid transition to a zero emissions society while strengthening resilience is the conclusion that this study clearly demands. While progress can be seen in the rhetoric of some leading European policy makers, it is the actual delivery on the rhetoric that civil society and parliaments will have to watch closely.

1 See Jourdan, S. & Kalinowski, W. (2020): Aligning Monetary Policy with the EU's Climate Targets. Veblen Institute and Positive Money Europe. https://www.veblen-institute.org/IMG/pdf/aligning_monetary_policy_with_eu_s_climate_targets.pdf and Greenpeace (2020): Bankrolling the Climate Crisis. European Central Bank injects over €7 billion into fossil fuels since COVID-19 crisis https://storage.googleapis.com/planet4-eu-unit-stateless/2020/06/20200603-Report-ECB-coronavirus-bond-purchasing-bankrolls-fossil-fuels.pdf

# 1. Introduction

## 1.1 Context

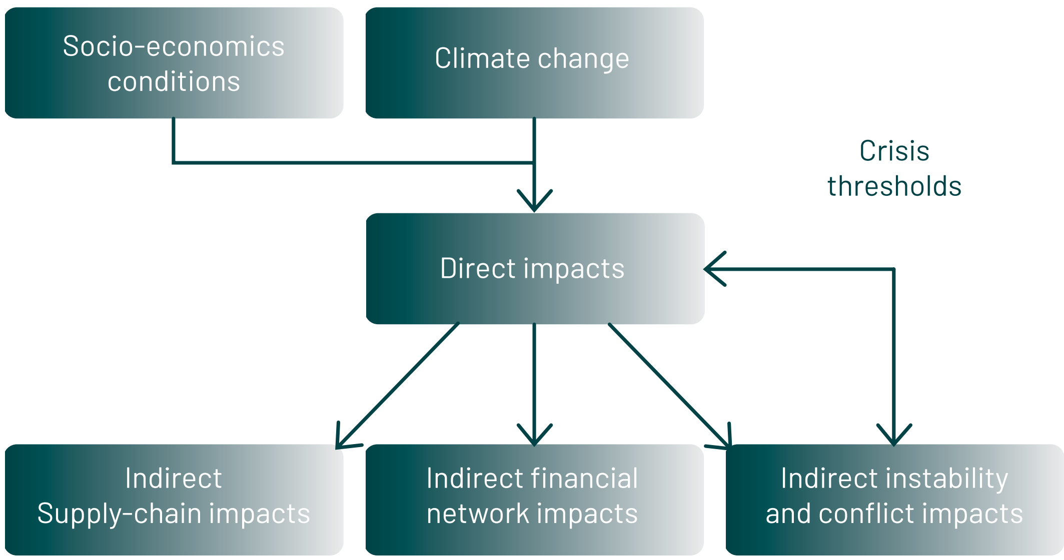
Climate change is causing impacts around the world, threatening exposed populations and assets. A key emerging issue is the extent to which climate impacts can lead to crisis. This is particularly important for governments and societies in Europe, which generally have the capacity to adapt to incremental increases in risks and associated costs brought on by climate change, but may be less aware of, and well-prepared for, residual risks of high-impact, low-likelihood climate impacts that can lead to crisis.

Generally, crises are situations in which the former way of doing things is no longer seen as adequate, and thus spark a search for new solutions, or coping mechanisms, to deal with the situation. It is important to note here that crises thus imply a threshold – i.e. the point where the status quo is no longer adequate – and that this threshold is subjective – i.e. it is perceived, e.g. by stakeholders. Further, for societies, crises may be social, political, economic or financial in nature. A recent example of a social and political crisis in Europe is the migration crisis of 2015-2016. An example of an economic crisis is the sovereign debt crisis of the early 2010s. At the time of writing, Europe and indeed the world is in the midst of the crisis induced by the COVID-19 pandemic. In each case, the perceived crisis led to a search for a new solution by decision-makers (i.e. the open-door immigration liberal policy letting refugees in, and subsequent 'wir schaffen das' response of the Merkel government in Germany, and the quantitative easing and 'whatever it takes' response of ECB head Mario Draghi in 2012, and the current social distancing efforts, for example, in Germany aimed slowing the rise and then reducing overall infection rates).

Here, we are interested in climate impacts that can trigger social, political, economic or financial crises in Europe. Indeed, the financial sector has begun to take an interest in how the climate, either through physical risks or transition risks, may induce such crises through so-called 'green swan' events (Bolton et al. 2020). Green swan events, based on the 'black swan' concept (Taleb 2007), are unexpected or rare; wide ranging in their impacts; and can only be explained after the fact. As can be observed from the examples above, crises may be triggered by an initial event, or sequence of events, that is outside the range of normal experience leading to impacts that are propagated (and amplified) through different channels. To take the European sovereign debt crisis, falling housing prices in the US lead to insolvencies of US financial institutions, which was then propagated through financial contagion to governments in the EU triggering a sovereign debt crisis in several European countries.

Climate-impact induced crises in Europe may thus be triggered by climate impacts occurring either within or beyond Europe that are beyond the range of typical experience. Climate impacts can be distinguished in 2 categories (see figure 1). Direct impacts refer to physical impacts on people (e.g. deaths, injuries, reduced life expectancy, etc.) or physical assets (e.g. damage to buildings or land, crop loss, etc.). Indirect impacts refer to all impacts that are not direct physical impacts and can be categorised as supply chain interdependencies (e.g. business interruption from lack of transport, supply-chain interruption, lack of labor, etc.) and financial system interdependencies (e.g. post-disaster insolvencies of investors, insurers, banks). Generally, crises can be triggered by each of these types of impacts.

**Figure 1. Conceptual framework of climate induced crisis in Europe**




Source: own illustration

## 1.1 Structure of the report

This report presents six scenarios of climate-induced crisis in Europe that may plausibly occur by 2030. The scenarios have been identified through literature review and interviews (n=5) with domain experts. We first discuss three crisis scenarios triggered by physical impacts within Europe, followed by crisis scenarios triggered physical impacts outside of Europe. Each scenario first discusses the relevant context, in order to scope out the order of magnitude of the hazards and impacts in question. We then discuss relevant trends in exposure, and the contribution of climate change.

Finally, we identify critical thresholds of direct and indirect impacts that would be sufficient to induce a crisis, in order to estimate the severity of the different crisis scenarios (see Figure 1). We note that across the different scenarios there is a great deal of variance in how precisely these thresholds can be estimated. For instance, the direct impacts of flooding have relatively well-developed methods for estimating the magnitude of impacts in ‚ tail risk' events (see Chapter 2), whereas identifying critical thresholds for a financial crisis triggered by herd behavior in real estate markets (see Chapter 5) does not have similar methods. Further, estimating the magnitude of impacts from climate hazards, such as droughts, tropical storms etc., is subject to uncertainty regarding how relevant climate variables, e.g. wind speed, precipitation, storm duration etc., will evolve in the future. For some hazards, e.g. sea-level rise induced coastal flooding, there is agreement among models, and thus future flood risk under climate change can be explored through scenario analysis. For other hazards, e.g. tropical storms, there is less agreement about how the frequency and magnitude of these extreme events will evolve in the future. For these hazards, past observations inform risk assessment, however, it is important to acknowledge that, under a changing climate, the distribution of these events may also change. Given the very high stakes involved in 'tail risk' events, under such uncertainty, a precautionary approach is warranted, which takes account of the possibility that extreme events, e.g. a 1-in-250 year drought, becomes more severe in the future than would be expected based solely on past observation. This is because it is these 'worse than before' outcomes that are far more important for societal decision-making in avoiding climate-induced crises. In the last chapter of this report, we discuss the implications of the different scenarios, and the need for responses that ensure minimizing the risk that such crisis scenarios will recur in the future.

Table 1 shows scenarios of climate-induced crises from impacts occurring within Europe, described in terms of the contribution of climate change to their likely occurrence, exposure and critical thresholds in terms of other direct impacts, or indirect impacts that could trigger a crisis. Table 2 shows the same for impacts occurring outside of Europe. As noted, for some scenarios, it is possible to provide rough quantitative estimates of critical thresholds, while for others, this is not possible. In such cases, we provide a qualitative description of the processes that could lead a threshold to be crossed.

### Table 1. Scenarios of climate impacts within Europe inducing crisis

| Scenario | Climate change contribution | Exposure | Critical threshold |
|---|---|---|---|
| 1. Major river flooding in central Europe or coastal defence failure during a major storm surge in western Europe, causing hundreds of billions in damages. | Sea-level rise of 4cm/decade sea-level rise; and increases in precipitation intensity | Assets and population in coastal and river floodplains; e.g. €130 billion in physical assets in Germany alone. | *Direct impacts*: Impacts greater than 1% EU GDP attained for 1-in-250 year flood in Germany, Austria, Czech (€198 billion in damages)<br><br>*Indirect impacts*: Overwhelmed disaster risk financing mechanisms lead to slow recovery and depression |
| 2. Prolonged drought in southern Europe leads to crop loss, decreased tourist arrivals, and conflict between water users. Social unrest exacerbates the economic impacts leading to economic crisis. | Increasing temperature and decreasing precipitation in southern Europe likely across even low emission scenarios | Farmers and tourism operators in southern Europe: e.g. tourism contributes more than 10% of GDP in Mediterranean countries, and agricultural is large employer. | *Direct impacts*: Agriculture production loss and tourism losses (€30 billion); decreased household water consumption<br><br>*Indirect impacts*: Conflicts and unrest lead exacerbate slowdown leading to economic crisis (€110 billion) |
| 3. Power supply failure due to an extreme weather event (e.g. storm, flooding) or a demand peak, during cooling water shortages due to drought and high temperatures | Increases temperature and droughts, reducing cooling water availability for energy sector | Regions with water scarcity, high cooling water needs and electricity demands peaks e.g. for air conditioning | *Direct impacts*: Relatively small direct impact threshold, if it triggers failure of interregional transmission during period of low production capacity<br><br>*Indirect impacts*: Blackouts longer than a few days, as critical infrastructure breaks down, can trigger crisis |

## Table 2. Scenarios of climate impacts beyond Europe inducing crisis

| Scenario | Climate change contribution | Exposure | Critical threshold |
|---|---|---|---|
| 4. Flooding induces a rapid drop in US coastal real estate prices inducing a global financial crisis | Global mean sea-level rise of 4cm/decade sea-level rise, possibly accelerating beyond 2050 | US coastal real estate in the 1-in-100 year coastal flood plain ($1.4 trillion); and system-relevant investors exposed to these risks, e.g. as owners or lenders | *Direct impacts*: Modest flood events (e.g. Superstorm Sandy, $65 billion in damages) may trigger a major correction across several regional real estate markets<br><br>*Indirect impacts*: Difficult to quantify financial crisis inducing thresholds in advance; depends on exposure of European financial institutions |
| 5. Extreme weather events in key producing regions and transportation hubs disrupting agricultural trade flows | Increase in frequency and intensity of extreme weather events affecting production and transportation networks (e.g. ports) | Small, open industrialised economies, of which Europe has many, highly dependent on agricultural imports | *Direct impacts*: Crop losses (greater than $1 billion in value) in multiple world regions due to extreme weather<br><br>*Indirect impacts*: Concurrent with transportation hub disruption, e.g. storm damage and flooding of key ports, leading to food price spikes, and protectionist policy responses |
| 3. Power supply failure due to an extreme weather event (e.g. storm, flooding) or a demand peak, during cooling water shortages due to drought and high temperatures | Increases temperature and droughts, reducing cooling water availability for energy sector | Regions with water scarcity, high cooling water needs and electricity demands peaks e.g. for air conditioning | *Direct impacts*: Crop-loss (ca. 8-10% GDP damages) leading to internal migration<br><br>*Indirect impacts*: Greater than 2 million arrivals and €40 billion for integration expenditures is plausible, and could lead to social cohesion ‚ backlash' and radicalisation of political discourse |

# PART I: Climate events within Europe

## 2. Crisis Scenario 1: Major Flooding in central and western Europe

### Short description

Major concurrent coastal and river flooding in Europe resulting in widespread destruction of property. Business and insurer insolvencies ensue due to overwhelming of risk finance instruments. Financial crisis results as insolvencies leading to slow response and recovery, and economic depression.

### Overview:

- Flood exposure is increasing due to build up of assets in floodplains, driven by attractiveness of waterfront development, myopic short-term bias, and sense of "over-security" behind flood defenses
- Climate change is also increasing coastal flood risk; this is less clear for river flood risk
- A crisis flooding scenario would require ‚ tail event' flooding to occur, i.e. 1-in-250 year river flooding or major coastal protection failure
- Such an event would easily overwhelm disaster risk finance instruments in place, leading to a protracted recovery, risking economic recession or depression

## 2.1 Context

Flooding is the most damaging of natural hazards. In Europe, the last 150 years has seen an increase in area flooded and absolute flood losses, though losses have decreased as a share of GDP (Paprotny et al., 2018). Historically, Europe has experienced catastrophic floods from both rivers and at the coast. Recent major flooding of the Elbe (2002) caused over €15 billion of damage in Germany and Czech Republic, and while in 2013 flooding in the Elbe and Danube basins affecting 9 countries also caused around €15 billion of damage (Jongman, 2018). Major coastal flooding occurred longer ago, with North Sea flooding causing major destruction and fatalities in the UK and Netherlands in 1953, and in Germany in 1962. The countries that experienced these floods responded by increasing protection levels significantly, and thus Europe has some of the highest levels of built coastal flood protection in the world. Yet catastrophic flooding could trigger a Europe crisis, particularly as high protection levels can lead to a sense of 'over-security' and increase development in the flood plain (Ciullo et al., 2017).

A climate-induced crisis from flooding in Europe has greatest potential regarding the densely developed coastal flood plains of North-Western Europe, e.g. in the Netherlands, or in the central and western Europe river basins. Coastal flood hazard in Europe is greatest with regard to the large coastal storm surges in North-western Europe. In southern Europe, coastal flood risk is more limited due to smaller range of coastal hazards in the Mediterranean. For river flooding, the major central and northern Europe river basins of the Rhine or Elbe rivers present the most significant crisis risks because of the population and value of assets in the flood plain.

## 2.2 Exposure

Floodplain development is leading to increasing exposure of assets and population in the floodplains in Europe, and these trends are projected to continue. A recent study finds that total urban area in Europe exposed to flooding has increased by a factor of 20 over the last 100 years (Paprotny et al. 2018). Generally, the attractiveness of waterfront locations makes it highly likely that risks will continue to accumulate, as the behavioral change required for private actors to willingly and collectively refrain from waterfront development conflicts with short-term incentives.

Similarly, it is difficult for governments to enact laws or regulations that reduce such coastal development, as there is high public desire for the immediate benefits of floodplain development. Myopic bias in decision-making of both individuals and public actors discount the future benefits of avoided damage of catastrophic flooding (Meyer and Kunreuther, 2017).
In Europe, flood protection measures are in place. For coastal flooding, as noted, Europe, particularly the north-western region, has some of the highest protection levels in the world. The Netherlands protects large extents of the coast against a 1-in-10,000 year event. Even outside of the highest protected regions, e.g. the Netherlands, London, most urban areas have high protection levels. Yet while protection levels are high, and thus substantially reduce expected flood damages, they can increase risk of catastrophic flood, as development tends to increase in areas perceived as well protected. 'Tail events', e.g. events that are less frequent than 1-in-200 years, may lead to disproportionally high impacts, if they overwhelm protection measures, and the capacity of recovery measures, such as, risk financing instruments. Thus, some commentators see a trend towards less frequent, but more damaging, flood events in the 21st century (Nicholls et al., 2019).

## 2.3 Climate change contribution

The contribution of climate change to flood risk in Europe differs with respect to coastal and river flood hazards. For coastal flood risk, climate change drives sea-level rise (SLR), and thus increases flood risk, all else being equal. Local coastal processes, including both subsidence and uplift, influence relative SLR at specific location, yet for many highly populated coastal areas in Europe relative sea-level is increasing. For riverine flooding, the literature is more ambiguous, and while some authors identify an increasing trend in precipitation and run-off, there is less confidence associated to this (Wong et al. 2014). For either hazard, other difficulties arising in attributing flood risk to climate change in a setting with substantial flood protection. This means that flood damages will be zero when extreme water levels remain below the protection level. Damages however immediately and substantially increase once water levels exceed protection heights, leading to, for example, dike failure. One approach to event attribution in this context is that the fraction of damages from the event is attributed to climate change in proportion to the contribution of SLR to overall storm surge height. For example, if SLR contributed 20cm to a flood event caused by a 2.2m storm surge, this would mean that climate change is responsible for 9.1% of the damages (0.20m SLR/ 2.2m storm surge height).

## 2.4 Impacts

### 2.4.1 Crisis threshold

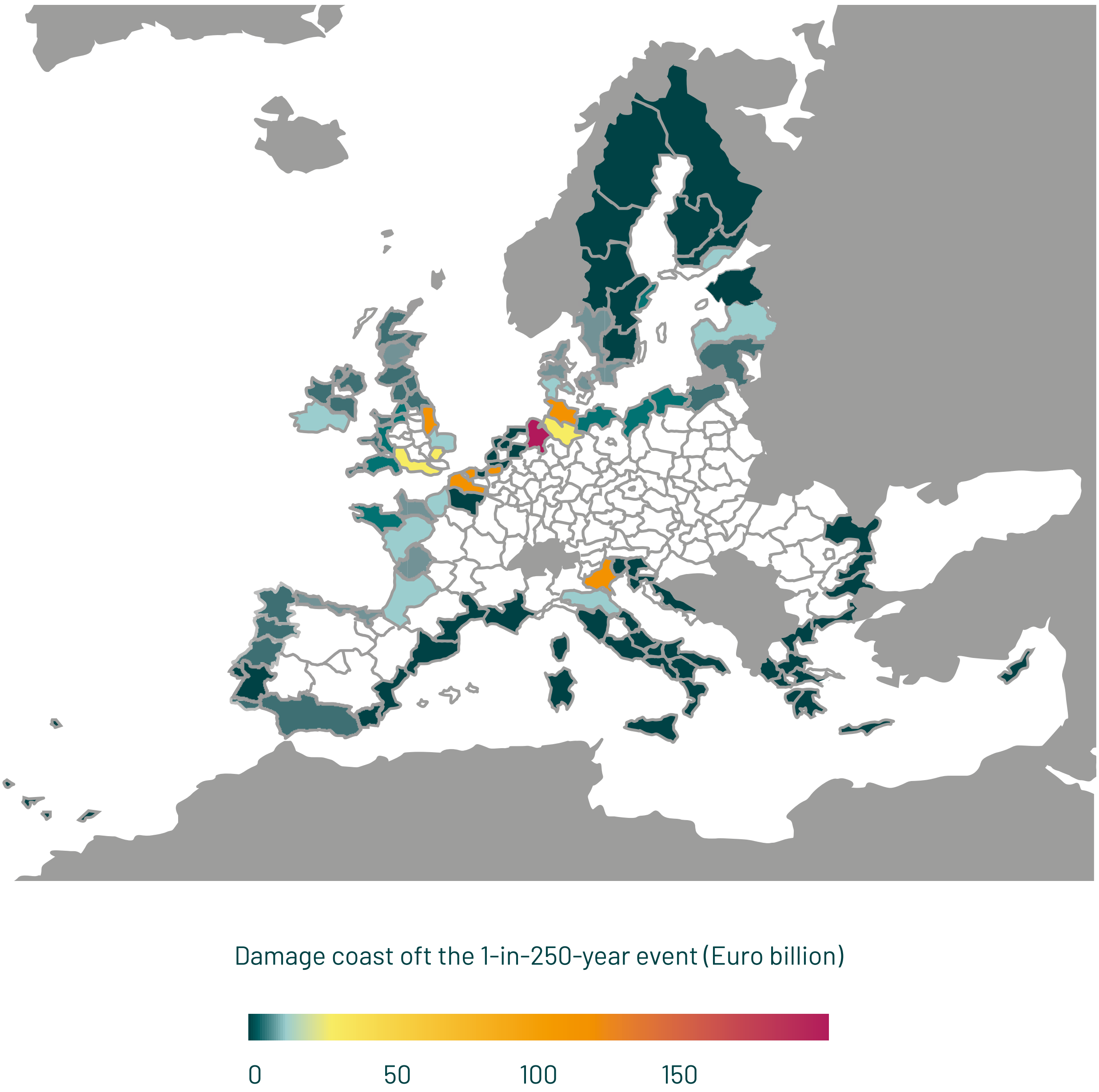
As noted, Europe is highly exposed to both river and coastal flood hazard and has both protection measures and recovery instruments in place to manage these risks. Thus, critical thresholds are only likely to be reached for very high levels of direct damages (see Figure 2, which illustrates that because of protection expected damages of even a 1-in-250 year event are relatively low). As a first order approximation, direct flood damages of around 1% of European GDP (around €180 billion (2018)) is a plausible estimate for direct damages that could trigger a crisis – slightly less than the 1.5% of GDP country level threshold for individual country eligibility for European Solidarity Fund grants (Jongman et al. 2014). The direct damages thus required are an order of magnitude greater than even the major river floods that have occurred in recent decades in the central Europe. For coastal flooding, recent damages have been even smaller due to the significant protection measures in place. Damages exceeding 1% of GDP for many European countries in the same year also would easily overwhelm the disaster risk financing mechanisms in place at the European level. At the country level, such damages would also be highly likely to exceed disaster risk financing mechanism in place as well, leading to more protracted and difficult recovery.

### 2.4.2 Direct impacts

Based on a survey of the flood risk literature, only low-probability 'tail' events have the potential to cause large enough damages to trigger a crisis. For instance, Mandel et al. (2020) construct flood risk curves for coastal and river flooding at the country level in Europe based on historical flood data. Generally, to cross a critical threshold of 1% of EU GDP flood events with return periods of 1-in-250 years or greater would need to occur. For instance, for river flood risk in the European countries most significantly affected in the 2013 floods, Germany, Austria and Czech Republic, they estimate that 1-in-250 year event would cause €198 billion of direct damages. This is consistent with Jongman et al. (2014) who examine riverine flood risk in Europe finding that the 1-in-200 year level of damages in Europe increase from €116 billion in 2013 to € 236 billion in 2050. For coastal flooding, risk may be smaller due to the high levels of protection in place in major urban areas. However, the residual risk, e.g. of a defense failure, is still present and could lead to a crisis. Though such residual risks are by their nature difficult to quantify.

Mandel et al. (2020) calculate that without protection (i.e. with dike failure), the Netherlands alone would experience €55 billion in damages from a 1-in-250 year storm surge. However, the fact that damages would require dike failure in conjunction with storm surge makes them even more unlikely.

### Figure 2. Expected flood damages in Europe from the 1-in-250 coastal flood event, including coastal protection




Source: Linkce et al. 2018

### 2.4.3 Indirect impacts

Major flooding of the order magnitude discussed would, as noted, overwhelm disaster risk finance mechanisms in Europe. This is particularly important due to the fact that present insurance penetration for flood losses in Europe is relatively low at 30%. At the European level, the main disaster risk finance instrument, the EU Solidarity Fund (ESF) of €1 billion would be easily overwhelmed. For individual countries, most disaster risk finance instruments would also be overwhelmed. For example, Austria has a disaster loss fund currently capitalised at €260 million, approximately covering current expected annual losses from disasters (Schinko et al. 2017). Such a Disaster Fund will be overwhelmed by a ‚tail risk' flood disaster. The lack of sufficient disaster risk finance for such a 'tail risk' event would lead to a slow recovery in the absence of available capital to avoid major supply-chain and business interruptions, and recession or even depression.

## 3. Crisis Scenario 2: Drought in southern Europe

### Short description

Prolonged severe drought in southern Europe leads to additional water scarcity, which in turn leads to competition between different water users (agriculture, energy production, industries, tourism or cities). Major restrictions on irrigated agriculture leads to crop failure, while water restrictions in the tourism sector lead to shutdowns and urban household water use restrictions lead to social unrest. Conflicts between stakeholders over water use further slow-down economic activity leading to economic crisis.

### Overview:

- Several southern European countries are highly dependent on water intensive sectors such as agriculture and tourism, which will be severely impacted by prolonged droughts
- Climate change is increasing the likelihood and severity of such prolonged droughts particularly in southern Europe
- A prolonged drought would cause crop failure or strongly reduced yields in irrigated agriculture, disruptions to tourist facilities, while water restrictions could lead to conflicts between different stakeholders
- Thus, a large scale prolonged drought, an order of magnitude or greater than the 2003 drought, could lead to an economic crisis especially through tourism impacts.
- Indirect impacts of such conflicts, like social unrest, could further exacerbate economic impacts increasing the risk of crisis

### 3.1 Context

The economic consequences of decreasing water availability are considered the most critical of potential climate impacts in the Mediterranean region, and concerns about droughts and water scarcity have grown steadily (EEA, 2017b). Indeed, economic impacts of droughts in the EU have increased over time. The average annual impact doubled between the periods 1976-1990 and 1991-2006, reaching an average of €6.2 billion annually (EC, 2007). By the late 1990s, droughts in Spain and other Mediterranean countries, depleted water reservoirs were causing the shut-down of many irrigation dependent agricultural systems (Iglesias et al., 2007).

These trends have continued, as more recently, between 2006 and 2010, droughts affected an annual average of 15 % land area and 17 % population within the EU, with significant droughts also occurring in 2010, 2011 and 2015 (EEA, 2017a). The 2011-2012 drought was especially severe, the worst in a century, affecting many countries, particularly in southern, western and northern Europe. In winter of 2011-2012, the Iberian Peninsula, as well as Mediterranean regions of southern France and northern Italy, experienced extremely low rainfall, 20% below the long-term mean (baseline period 1951-2000). This significantly reduced water availability and led to water use restrictions in large parts of the EU (Bissolli et al., 2012 & EC, 2012).

Droughts have severe consequences for many economic sectors, including agriculture, tourism, energy production, industry and public water supply, as well as for private households (Iglesias et al., 2007; Blauhut et.al, 2015). This poses crisis potential, first, because these are each critical sectors individually and their shutdown can have widespread socio-economic consequences. Second, water scarcity gives rise to potential conflicts between stakeholders in each of these sectors. When such conflicts grow into social unrest, they can significantly exacerbate already damaging direct physical impacts of droughts.

### 3.2 Exposure

Water scarcity is common in southern Europe, with around 130 million people (around 27% of the total European population) affected by water scarcity (EC, 2007). Water scarcity issues are particularly pronounced in summer because of lower supply and higher abstraction rates from agriculture and tourism (EEA, 2019a).

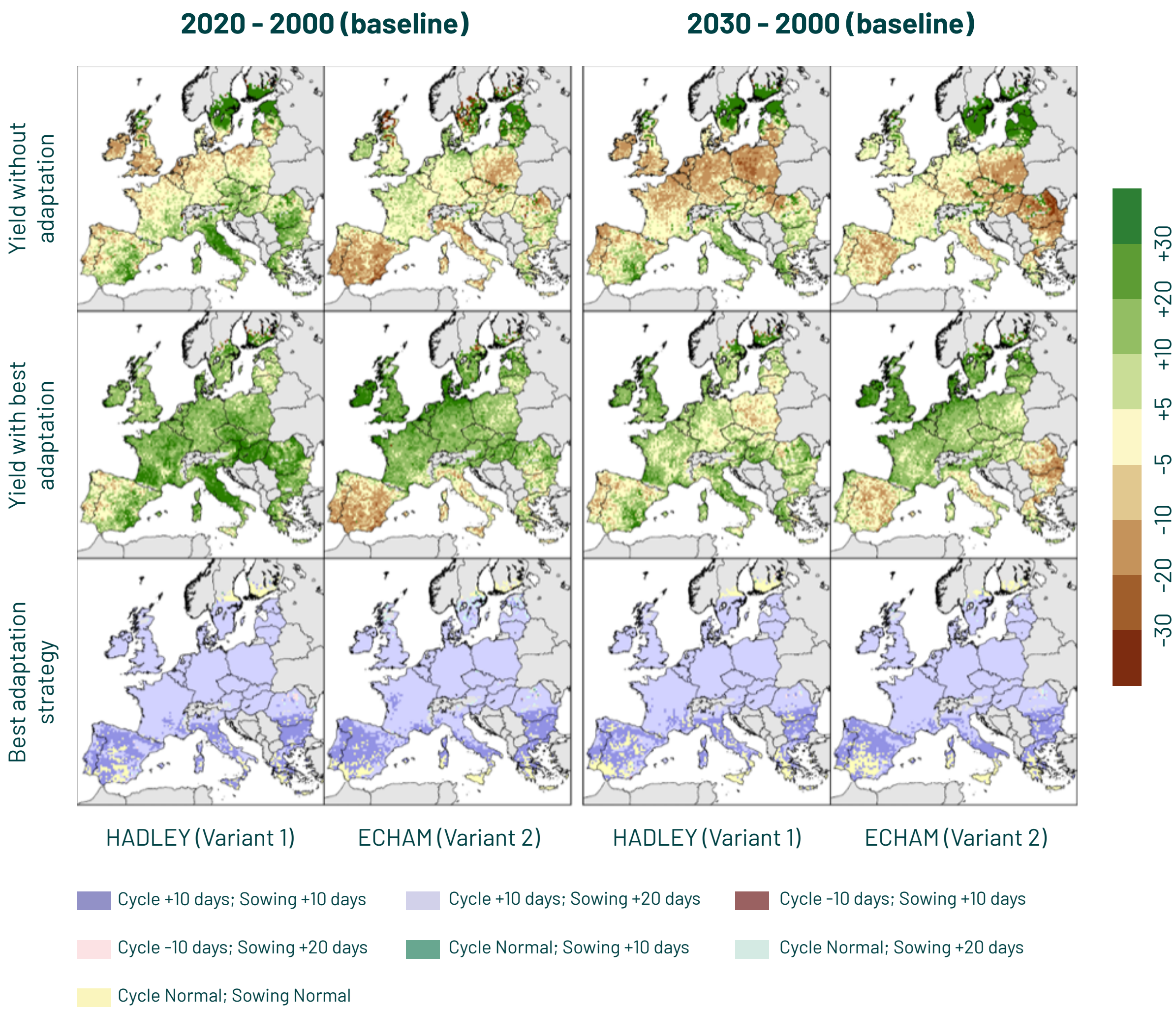
Agriculture is a significant user of renewable freshwater resources, being responsible for up to 50% of water use in most Mediterranean countries, and of national significance in Portugal, Spain, Italy and Greece. In Spain, agricultural uses as much as 75% of total water uses (Iglesias et al. 2011; Chico and Garrido, 2012). Irrigation needs are particularly acute during growing periods between April and August, when precipitation typically decreases and evapotranspiration increases (EEA, 2019a). One reason that agriculture consumes such a high share of water in southern Europe is that farmers in these countries are often dependent on income from water intensive crops (Iglesias et al., 2011). For example, strawberry production is a major source of employment in Doñana, Spain where about 80.000 people earn a living in the sector, among them many smallholders (Morillo et al., 2015). Another water intensive crop that has increased in economic importance in southern Europe is avocadoes. In 2018, Spain exported 97.000 tons of avocadoes, increasing stress on water resources (Deutsche Welle, 2020). Other important crops in Spain include cereals (38%) and olive trees (20%), which account for the largest share of water used for agricultural production, due to their large share cultivated area and high per unit water consumption. While these crops traditionally rely mainly on rainfed production, irrigation has become an increasingly important supplement (Chico and Garrido, 2012).

Tourism also puts pressure on water supply, and as tourism is highly seasonal, this pressure is also greatest in summer. In Mediterranean countries, international tourism contributes on average around 10 % of GDP (Magnan et al., 2013), and up to a quarter of GDP in popular tourist regions in Greece, Spain, France, Italy and Portugal (EC, 2012). Tourist water consumption is about three times more than local consumption. Further, while seasonal, tourism can also increase year-round water demand because of the fixed requirements of tourist facilities, e.g. hotel complexes and waterparks (Iglesias et al., 2007). Rising water demand from tourism has led to water extraction from surrounding areas, and thus directly competing with agriculture water needs. To cope with increasing water demand from both agriculture and tourism, intensive extraction of groundwater has been undertaken in most Mediterranean countries, which can deplete aquifers over the long-term (Iglesias et al., 2007; Iglesias et al. 2011).

### 3.3 Climate Change Contribution

Climate change is projected to lead to higher temperatures and lower precipitation levels in southern Europe (EEA, 2017b). Related to this, climate change is expected to reduce water availability and increase irrigation withdrawals in Mediterranean river basins (EC 2007 & Iglesias et al., 2007). Even under a moderate emission scenario (RCP4.5), droughts are projected to become more frequent and severe in the Mediterranean area, especially in southern Europe. Also, seasonally, drought frequency is projected to increase everywhere in Europe in spring and summer, especially over southern Europe (Spinoni et al., 2018). Extended and more frequent droughts will decrease water availability and exacerbate the risk of conflict between sectors over water uses, and thus the potential that such conflicts lead to crisis.

**Figure 3. Change (%) in simulated water-limited yield with and without adaptation measures for winter wheat in 2020 and 2030 with respect to 2000**




Source: Ciscar et. al., 2014

## 3.4 Impacts

### 3.4.1 Crisis threshold

Negative economic drought impacts arise when water demand can no longer be met by water supply and are likely to emerge when prolonged droughts over consecutive years (or months) deplete water reservoirs. While there have been significant direct drought impacts, causing economic losses in agricultural and tourism sectors of many European countries, particularly in southern Europe, historical direct impacts have not led to a crisis. Yet a large-scale prolonged drought in southern Europe would cause significant losses in irrigated agriculture, shutdowns of tourist facilities and household water restrictions. If such impacts were larger than historical events, or occurred in consecutive years, there is a potential that tourism losses could be sufficient to trigger an economic crisis.

Additionally, it is likely that direct impacts and responses, e.g. water restrictions, lead to conflicts among different stakeholders over water restrictions and appropriate water use, which leads to social unrest. Such conflicts would further exacerbate already occurring economic impacts through further tourism losses as arrivals would be suppressed in such conditions, as well as reductions of other economic consumption activities in a situation of social unrest.

### 3.4.2 Direct impacts

Droughts can negatively impact both agriculture and tourism, key economic activities in southern Europe. For agriculture, the major drought in 2003 caused an estimated €10 billion of losses in France, Italy, Spain and Portugal (COPA-COGECA 2003). For tourism, droughts can also reduce revenues by reducing arrivals. Climate change could decrease tourism revenues by 0.31% to 0.45% of GDP per year in southern Europe due to decreased arrivals (Watkiss et al., 2019). This number represents only an annual expected loss. Much higher losses could occur during 'tail event' extreme drought conditions. Moreover, such losses, when incident on the tourism and hospitality sector are large enough to induce widespread bankruptcies, particular if they occur in consecutive years.

Observing recent past droughts, it is thus unlikely that drought impacts on agriculture alone would trigger a European crisis. However, there is a small probability that before 2030, a drought much larger than in 2003 could seriously impact tourism enough to trigger an economic crisis. Taking Spain as an example, with 12% of GDP from tourism (OECD, 2020a), it is plausible that a major drought leading to water restrictions could lead to a 1.5% GDP reduction (around €30 billion in damages) (OECD, 2020b). While these estimates are highly uncertain, there is recent evidence that drought strongly impacts tourist arrivals. For example, the 2017-2018 Cape Town drought saw a 20% drop in tourist arrivals (Hyman, 2018).

### 3.4.3 indirect impacts

Indirect impacts that amplify the direct economic losses increase the likelihood of a European crisis from extended drought. Generally, droughts can lead to income loss and unemployment in agricultural as well as in non-agricultural sectors, increasing societal tension and the potential for social conflicts (ILO, 2013). Further, social conflicts between different stakeholders emerge over water usage and restrictions, and could lead to social unrest, and business interruptions furthering economic impacts. During the 2017-2018 Cape Town drought, water restrictions lead to a reduction in crop production of 20% and agricultural losses valued at $415 million. Further, the anticipation of the reduced harvest size led to the unemployment of seasonal farm workers, with over 30,000 jobs lost during the drought, increasing social unrest in agricultural areas (Parks et al., 2019). Even though agriculture in Spain makes up only around 3% of GDP (EC, 2020), it is a major employer, and farmers are well organised, and may resist major water restrictions, e.g. through organized protests, or other actions increasing the likelihood of social unrest.

Indeed, the emergence of such social conflicts are a considerable risk for a European level crisis emerging from prolonged drought. As social conflicts could erupt between different social groups, for example, leading to street protests or riots, economic activity, including tourism, would be further negatively affected. The Barcelona riots of November 2019 are an example in which tourism revenue and the service sector more broadly were immediately and severely affected. The situation in a prolonged drought would potentially be much worse because of the prospect of continuing conflicts as the drought conditions persisted over several months, endangering a much greater proportion of the significant tourism revenue. While quantifying such indirect impacts is highly uncertain, if around half of tourism GDP in Spain was put in jeopardy (around €110 billion) (OECD, 2020), the impacts would reach the scale of a potential European crisis. Indeed, without fiscal support through EU financing instruments, Spain would, under the weight of such drought impacts, risk economic collapse, potentially triggering a sovereign debt crisis.

## 4. Crisis Scenario 3: European electricity grid vulnerability

### Short description

Power supply failure, i.e. blackout, due to an extreme weather event (e.g. storm, flooding) or a demand peak (e.g. for air conditioning) during a period of reduced electricity production because of cooling water shortages. Such cooling water shortages are caused by drought and high temperatures in summer, which are more likely due to climate change. Power blackouts lead to a crisis due to collapse of critical infrastructure (e.g. transport, communication systems, water distribution etc.).

### Overview:

- High summer temperatures and reduced run-off in Europe reduces cooling water availability, and could thus constrain the capacity of conventional coal, nuclear and hydro power stations that need cooling water for safe operation
- Climate change will decrease cooling water availability due to both reduced run-off during summer months, and increased temperature decreasing the heat storage capacity of water
- Extreme events, e.g. flood or storms, occurring during such a period of reduced electricity production could lead to regional blackouts, as they can damage transmission lines, and reduce interregional electricity transmission
- Major blackouts that exceed 24 hours would have far reaching consequences for critical infrastructure like transport, health services or water supply, and with unaltered condition over several days increasing risk of fires, deaths and disruption of social order.

## 4.1 Context

Water availability is critical for power generation from conventional sources. Hydropower requires large water volumes to drive turbines, while thermoelectric fossil-fuel and nuclear power plants also require large water volumes for cooling. In Europe, increased summer temperatures and droughts reduce water availability both for driving turbines, due to low river flows, and for cooling, due to low flows and increased water temperatures. Reduced water availability requires reducing electricity production from these conventional sources. Yet summer temperatures can also increase demand for air conditioning (van Vliet, Vögele and Rübbelke, 2013; EEA, 2020). Reduced electricity production coupled with spikes in demand can lead to partial or total blackouts, when demand is not met (Förster and Lilliestam, 2010).

During recent European heat waves (e.g. 2003, 2006 and 2009) numerous thermoelectric power plants in France and Spain were powered down or temporarily shut to prevent river temperature exceedances (Paskal, 2009; Förster and Lilliestam, 2010; Rübbelke and Vögele, 2011). In France, large-scale blackouts were avoided during this period of reduced supply, through trade in the European electricity market. The reduction of power generation capacity in one region or plant was replaced by an increase in generation capacity in another location.

Such solutions however depend on transmission capacity between locations and regions. If transmission capacity is insufficient to compensate for power generation decreases in a given region, partial or total blackouts in the region can result (Förster and Lilliestam 2010). Blackout risk can thus be enhanced by transmission disturbances, such as, line tripping by tree contact due to storms. Such incidents can trigger a series of cascading events e.g. overloading of generators and transmission lines, which, if not well managed, lead to a blackout (Haes Alhelou et al. 2019). Indeed, an analysis of approximately 40 major blackouts worldwide over the past 40 years found that extreme weather was the most important primary cause. A recent analysis within Europe found that 65% of power outages in Croatia, Slovenia, Portugal and Belgium were due to weather shocks (Hallegatte et al., 2019).

Climate change is likely to reduce cooling water availability in Europe, thus increasing the vulnerability of energy systems with a mix that is highly dependent on electricity production with cooling water, or water flow needs. Climate change will also change the frequency and distribution of extreme weather events that are likely to disrupt transmission lines, and potentially trigger a blackout, particularly in regions that already have reduced production capacity due to low cooling water availability (Rübbelke and Vögele, 2011). A major, continuing blackout would lead to disruptions of critical infrastructure, such as, communication systems, water distribution or transport, leading quickly crisis, involved social unrest and the collapse of the social order (Petermann et al. 2011).

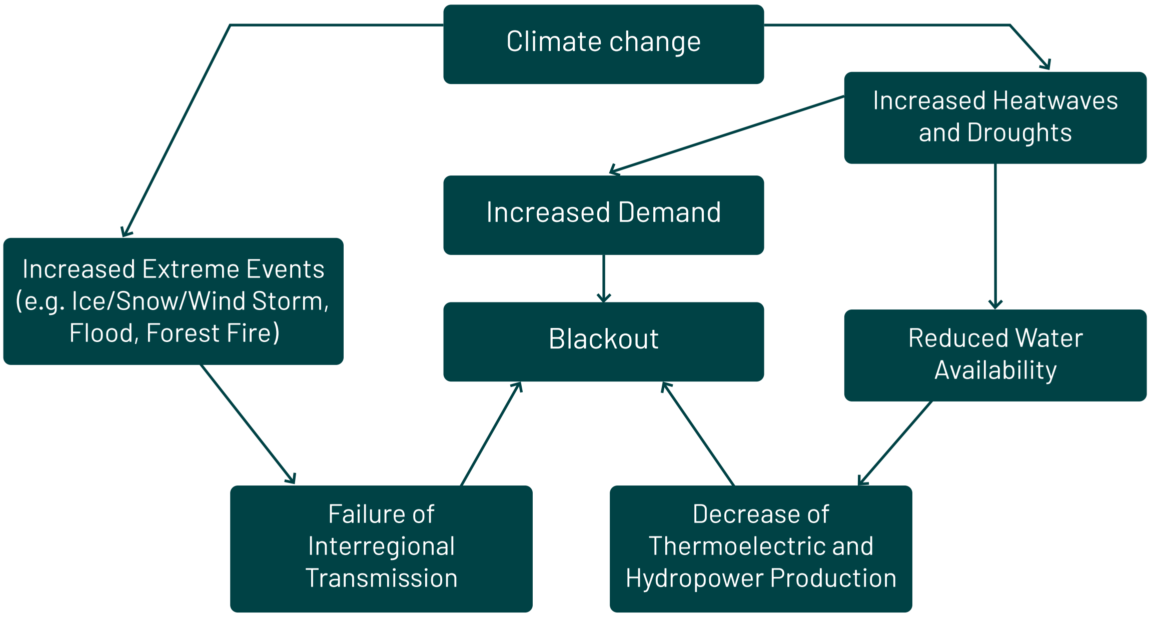
### 4.2 Exposure

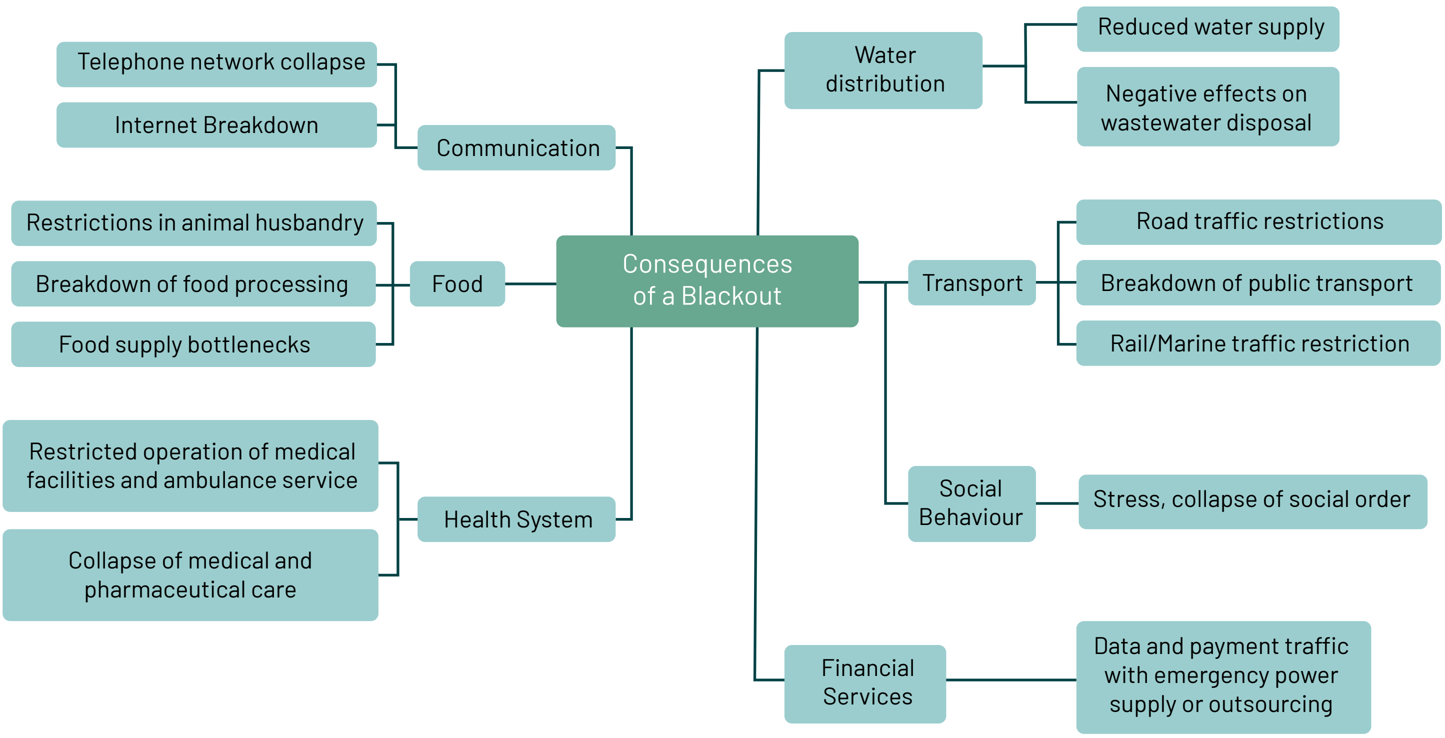
A number of major blackouts have occurred in Europe in the last decade. A blackout in Italy in 2003 affected 57 million people and left some provinces without power for 18 hours. In Sweden and Denmark in 2003, a blackout left 4 million people without electricity for 6 hours, and cost an estimated €145 to €160 million. In 2005, 250.000 people in Germany were left without power for up to 7 days due to sudden ice rain which induced costs of up to €130 million (Petermann et al. 2011).
Electricity production and transmission are vulnerable to climate change or extreme weather events. As noted, climate-related electricity blackout risks are greatest when a number of factors are present at the same time. First, risks are increased in energy systems with a high share of power sources requiring cooling water. For instance, France has a relative high share of nuclear power generation (71% in 2018) and hydropower (10%) both vulnerable to low water availability (IHA, 2020). Other regions around Europe, for instance, in the German Rhine Valley, also have significant cooling water needs for energy production. Second, risks increase in such systems when heat waves and droughts decrease cooling water availability and river flows. Such hazards are greatest in southern Europe (van Vliet et al., 2012; EEA, 2019c). Third, risks are increased, when in conjunction with the other two aspects, peaks in electricity demand, for example, from air conditioning occur (EEA, 2019c). The largest increases in daily peak demand for air conditioning have been projected for Italy (average increase of 40 GW h), Spain and France (Damm et al., 2017). Finally, other extreme weather events, such as, severe storms, heavy winds, snowstorms or ice rain can damage transmission lines putting distributional grids at risk (Haes Alhelou et al., 2019). Reducing inter-regional transmission capacity from a storm can mean that a regional energy system, already under stress due to reduced production capacity during a drought, is no longer able to meet demand, leading to a partial or total blackout.

## 4.3 Climate Change Contribution

Climate change can increase blackout risk by decreasing cool water availability, as well as, through increasing the frequency or intensity of weather extremes that are likely to damage transmission lines, and thus restrict transmission capacity (see Figure 2). In Europe, climate change is expected to increase average temperatures, as well as heatwave and drought frequency (Kovats et al. 2014) . Water availability for energy production is expected to decline, while water temperatures are expected to increase, reducing cooling water availability for thermoelectric power generation as well as its hydropower potential (Förster and Lilliestam, 2009; Rübbelke and Vögele, 2011). Dry periods and reduced water availability is especially expected in southern Europe (EEA, 2019c), while at the same time, demand peaks for electricity for air conditioning accelerate in regions with higher temperatures (Damm et al., 2017). Further, climate-related extreme events that can negatively affect transmission capacity are also expected to increase. Forest fires are expected to increase in southern Europe, while windstorm are expected to increase in frequency and intensity in both northern and central Europe (EEA, 2019c).

**Figure 4. Causes and Consequences of Large-Scale Power Blackouts**




Source: Adapted from Behnert & Bruckner, 2018 and Petermann et al., 2011

Note: This illustration does not claim to be exhaustive, but rather shows schematically the connection between climate risk and power failure shows as well as individual exemplary events that occur shortly after a power failure.

## 4.4 Impacts

### 4.4.1 Crisis threshold

Blackouts are the consequence of a long chain of cascading failures of individual components of the energy system triggered by a variety of events such as natural disasters, equipment failure, mistakes in operations, and so on (Haes Alhelou et al., 2019; Sun et al., 2019). Weather events are thus one link in a chain of events, either triggering the disruption (e.g. falling trees) or increasing the vulnerability of the operating systems (e.g. shutdown of power plant due to water scarcity). It is thus difficult to define a critical threshold for major blackout, as this risk manifests in a conjunction of conditions and triggering events.
One set of conditions that can destabilize electricity networks dependent on thermoelectric power generation are present during heat waves: reduced cooling water availability and increased electricity demand from air conditioning (EEA, 2019c). For cooling water availability, shutdowns can occur even if the amount of streamflow is still sufficient for cooling purposes. For instance, regulations in the Rhine river basin require plants to cease discharges when river water temperature exceeds 23°C (van Vliet et al., 2013; EEA, 2019c). For electricity demand, the probability of line tripping i.e. an interruption in power supply increases exponentially if more than 160% of nominal capacity of line load is passed (Woetzel et al. 2020). Such partial shutdowns within a region increase electricity system vulnerability to failure, as other events such as storms and heavy winds can reduce transmission capacity, and thus a regional system may no longer be able to meet demand, and a blackout can result (Behnert & Bruckner, 2018; Haes Alhelou et al., 2019).

Most blackouts do not last longer than a few hours, and thus the direct impacts of such short-lived blackouts will generally not lead to a crisis. However, blackouts due to natural shocks generally last longer (532 minutes) than power outages due to other causes (137 minutes) (Hallegatte et al., 2019). Further, blackouts that last longer than a couple of days can quickly induce crisis, as critical infrastructure can only be run on back up supply (i.e. local generators) for a limited time. In an extended blackout, transportation infrastructure, critical health services, water, and food refrigeration and distribution infrastructure would potentially no longer be operational. On local and regional level, this could lead to massive functional and supply disturbances, economic damage and considerable threat to public safety and order within a few days (Petermann et al., 2011). In the case of an extended blackout in a major economic region, with associated interruptions of major business and manufacturing processes, indirect impacts could induce a crisis on European level.

### 4.4.2 Direct Impacts

Major blackouts in Europe occur in low-probability scenarios, due to the interconnectedness of power plants, electricity grid and European electricity market. The direct impacts of such blackouts alone, e.g. cost of damage to electricity transmission infrastructure, or reduced production capacity due to lack of cooling water, is not sufficient to induce a crisis. For instance, a recent study of the German energy system finds that each kWh of electricity lost causes costs €8 to €16 of economic losses (Bothe and Riechmann 2008). Transferred to a one-hour power failure throughout Germany on a working day in winter, this would result in an economic loss of between €0.6 and €1.3 billion, which is significant but not crisis inducing on a European or even national scale. Further, in France, the reduction in generation capacity during the heat wave in 2003 forced state-owned Électricité de France to buy power on the open market at close to ten times the cost it was charging clients. The inability to generate its own power in a heatwave cost the utility an estimated €300 million (Paskal, 2009). Major European energy utilities have been able to withstand such losses, provided that they have been relatively infrequent.

Other direct impacts arise from damage from climate extremes on critical infrastructure in Europe, including 10 types of energy infrastructure, as a result of climate change. The multi-hazard damage for infrastructure in the energy sector is projected to rise up to 15-fold, from a baseline EAD of €0.5 billion per year to one of €1.8 billion in the 2020s (Forzieri et al., 2018). While the increase is significant, it is not crisis-inducing. Indeed, it is prolonged blackouts, that could occur with the conjunction of climate events, in a cooling water dependent system, that have more significant potential to induce a crisis.

### 4.4.3 Indirect Impacts

Indirect impacts of a prolonged blackout are likely to be much higher than the direct climate impacts because damage to critical energy infrastructure can result in failures and cascading effects on related and dependent infrastructures like communication, water systems, food distribution or the health system (see Figure 2). Given strong dependence of almost all critical infrastructure on an uninterrupted power supply, a large-scale power failure of duration long enough to overwhelm temporary generators, can have far reaching economic and social consequences. Scenario analyses, for example, of blackouts affecting critical infrastructure in Germany find the population may no longer be supplied with essential goods and services after a blackout of only a few days (Petermann et al. 2011).

This analysis projects that almost immediately following blackout onset, abrupt and massive disruptions in traffic and public transportation occur leading to a spike in traffic jams and accidents with injured and death victims. Fire-fighting or ambulance services are considerably hindered. Fuel for vehicles will quickly run short, as filling stations are not operational, posing a threat to food or medical supplies.

In such a scenario, health care system capacity will be severely constrained following the first 24 hours (Petermann et al. 2011). Emergency power generation will allow hospitals to run albeit at limited capability, while doctors' offices and pharmacies will be without power in a full blackout and thus closed. Within the first week, medical and pharmaceutical supplies can no longer be provided leading to serious health damages and deaths. Further, food supply will be considerably hindered after few days. In particular, the livestock sector will encounter difficulties in providing a critical supply of food, water and air within stables.  As the duration of the failure progresses, the risk of fires and diseases spreading increases (Petermann et al., 2011; Behnert & Bruckner 2018). Other disruptions of daily life add further psychological stress, increasing the potential for breakdowns in social order. Freshwater supply would be endangered after a few hours of blackout leading a comprehensive impact on domestic life, as habitual personal hygiene would no longer be feasible and the preparation of food and drinks would constrained.
The consequences of a blackout would lead to critical thresholds being crossed already within the first week without electricity. As the power outage continues these effects are likely to reinforce each other, leading to a collapse of social order and catastrophic conditions.

# PART II: Climate events beyond Europe

## 5. Crisis Scenario 4: US coastal real estate market collapse

### Short description

Sea-level rise and coastal development increase flood risk exposure of real estate, particularly in the eastern United States. While sea-level rise is a gradually increasing risk, a triggering event, such as a damaging storm or a policy change leading investors to exit en masse, could lead to a sudden drop in coastal real estate prices. Such a precipitous drop could trigger a financial crisis, though impacting the balance sheets of major financial institutions in a financial contagion similar to the 2008 sub-prime crisis.

### Overview:

- SLR is a slow onset risk that objectively increases coastal flood risk, but which subjectively may not be perceived by market actors
- This mismatch gives rise to the risk of financial crisis, as a sudden awareness of the objective risk could lead to rapid drops in coastal asset prices
- Such sudden , awareness' could be triggered by physical events or policy changes
- Barriers to objectively pricing coastal risk in real estate include "sophistication" of investors, experiences of past events, beliefs about SLR. The presence of such barriers could amplify real estate market volatility
- The potential for a sudden drop is coastal real estate prices to trigger a financial crisis is difficult to assess, but we provide an indicator for the links of coastal real estate in the US to the global financial system

## 5.1 Context

The 2008 financial crisis showed that Europe can be critically affected by events beyond its borders. Beginning in 2007 concurrent housing price declines in many US regional markets led to a wave of defaults of ‚ sub-prime' mortgages, exacerbating housing price declines in a vicious cycle leading to further defaults. As these subprime mortgages had been bundled by issuing banks and sold onto large investors, housing sector liabilities were further passed on through the financial system causing a rapid deterioration of balance sheets of major financial institutions. A financial crisis ensued, for example, with the bankruptcy of Lehman Brothers in September 2008, and massive bailouts to a number of other large investors and insurers. The repercussions were unprecedented for the European Union. The global recession that followed led to worsening debt-to-GDP ratios for many EU governments, and concurrently real estate bubbles burst in several countries, e.g. Spain and Ireland, sparking the EU sovereign debt crisis.

Climate-related impacts on the US real estate market could induce just such a destabilization of financial markets. Indeed, landfall of major hurricanes in the US over recent decades include Hurricane Katrina ($125 billion damages) and Superstorm Sandy ($12 billion in direct damages). While in 1992, Hurricane Andrew caused around $25 billion of damage in Florida. Yet even such large direct damages are unlikely to have critical impact in Europe on their own. Rather, the more significant risk to Europe is that such events could trigger a sudden and precipitous drop in US coastal real estate prices leading to a global financial crisis similar to 2007-2008. Moreover, due to the slow onset risk of SLR, a sudden mass exit of the coastal real estate market, i.e. herd behavior, could be triggered by either a physical or policy event, e.g. insurance premium reforms or a mortgage refusal, leading other actors to re-consider their assessments of coastal risks under SLR.

## 5.2 Exposure

The value of assets in the US in the 1-in-100 year coastal flood zone has been estimated at $1.4 trillion (Ward et al. 2019). Further, coastal development is proceeding rapidly, and many locations are under-protected, as it is difficult to mobilize funding for public protection measures. Indeed, in the 2017 Houston flooding during Hurricane Harvey, lack of sufficient drainage capacity was a significant driver of the approximately $125 billion in damages (NHC 2019).

Yet in terms of crisis potential in Europe, direct damages to US coastal real estate are only part of the story. More central is how physical assets exposed to coastal risk are linked to the broader financial system, and in particular, whether this links can lead to financial system instability.
Climate risks to financial stability is however an emerging field and few empirical studies address this particularly for the coastal US, thus it is difficult to estimate exposure. Existing studies are largely conceptual, showing that slow onset risks, such as SLR, lead to macro-economic impacts through channels accounted for a standard growth model (Batten 2018). One study that does attempt to link climate impacts to the financial system is Lamperti et al. (2019), who show in an agent-based macro-economic model linked to climate impact functions that climate change may increase the likelihood and frequency of banking crises, through impacts on the capital stock, leading to financial instability through weakening the balance sheets of banks. They project that banking crisis will increase in frequency by 26-248% and bailing out insolvent banks will add an additional 5-15% of GDP of fiscal burden per year. While not address coastal risks in particular, this demonstrates the potential of climate to impact the global financial system.

## 5.3 Climate change contribution

Climate change driven sea-level rise (SLR) contributes to increasing coastal flood risk. Global mean sea-levels have risen at 3.6cm per decade over the last twenty years (IPCC SROCC 2019) and will accelerate over the coming decades.[1] Storm intensity (e.g. wind speed, duration) may also increasing with climate change (IPCC 2019). SLR is thus a slow onset hazard that presents a challenge for coastal communities and property owners. In the absence of large-scale adaptation measures, the main challenge is to navigate "smooth transition" of the coastal real estate market, reducing exposure of coastal properties, gradually, while avoiding rapid price corrections. SLR makes this challenging because, while coastal properties experience objectively increasing flood risk from SLR, as the frequency and distribution of extreme water levels is shifted with rising mean sea-levels, this risk may not reflect in real estate prices. Indeed, whether coastal flood risk is reflected in real estate prices is influenced by a number of factors including risk awareness, beliefs regarding SLR, policies on risk assessment, etc.

1 Regional SLR, i.e. at specific location, is influenced by local coastal processes, and thus can differ from the global mean. Subsidence, often induced by groundwater or oil extraction, is an important driver of relative SLR, increasing SLR rates.

Recent research from the US finds evidence that real estate markets are beginning to account for SLR, discounting residential property prices exposed to SLR by 7% compared to non-exposed properties (Bernstein et al., 2019). However, it is not clear whether this is sufficient to ensure a , smooth transition' in coastal real estate markets. Interestingly, this discount generally applies only to markets segments involving , sophisticated' (i.e. non-owner-occupant owners) investors, and the discount is more prevalent when market liquidity is low. Moreover, non-sophisticated owners are shown to be more greatly influenced by their beliefs in their real estate decisions, as believers in SLR risks more readily exit the coastal real estate market. These results point to risks of a sudden rather than gradual and smooth transition in coastal real estate markets in areas where more owner-occupiers and less sophisticated investors are present.

## 5.4 Impacts

### 5.4.1 Crisis threshold

In contrast to the crisis scenario for flooding in Europe, where the scale of direct damages must be very large to trigger a crisis (e.g. 1% of EU GDP), here a critical threshold could be reached for much smaller direct impacts. A storm could be limited in extent but still trigger a re-appraisal of coastal risks by asset holders. Similarly, flood insurance policy makers could decide to raise premiums in response to rising risks leading to a similar re-appraisal leading to a rapid drop in real estate prices triggering a crisis.

For direct damages, relevant thresholds are the magnitude of physical damages, or policy change, needed to trigger a major drop in coastal real estate prices. Such thresholds are difficult to quantify because they are related to the subjective perceptions of coastal real estate investors. Here, we can only review qualitative insights regarding what can social science tell us about under which conditions (i.e. objective risk, past events, political preferences, etc.) herd behavior is likely to triggered.

For indirect damages, a relevant threshold is the amount of decrease in coastal real estate asset values that could induce a financial crisis. We note however that such thresholds are also by their very nature difficult to predict in advance. For instance, while the Lehman Brothers bankruptcy in 2008 is in hindsight seen as a major contributor to the global financial crisis, it was difficult to predict that this would be the case at the time.

Had Lehman's insolvency been understood as a critical threshold, the US Federal Reserve would have surely bailed it out, as this would have been much less costly to the US economy than the financial crisis that followed. To our knowledge, the only existing empirical study linking coastal risk to the financial system is that of Mandel et al. (2020), who develop an indicator of the ‚amplification' of coastal risk to the global financial system, by tracing the ownership of liabilities in the coastal flood plain across countries. This is reviewed below.

### 5.4.2 Direct impacts

Personal experience of a hazardous event heightens awareness of the risks. Coastal flooding is no different, as a major storm can make those who experienced it, and those in the immediate vicinity more aware, and thus take account of SLR in their decision-making. Indeed, analysing real estate transactions in New York City following Superstorm Sandy, Ortega and Taspınar (2018) find that both prices of damaged and undamaged houses in flood risk zones declined post-Sandy, compared to prices in non-flood risk areas, which can be explained by a heightened risk awareness post-disaster. Even with the significant damages caused by the storm, the price decline was not significant enough to cause financial system instabilities, and indeed must be put into context of an otherwise strong real estate market in NYC. But a similar scenario in a real estate market that is less robust than NYC would have greater crisis potential. In particular, a storm path that impact several different regions causing declines in several regional markets could pose a significant crisis risk.

In addition to the absence of recent historical flood events, several other factors also contribute to low SLR risk awareness. Bernstein et al. (2019) find that beliefs about SLR affect the level of housing price discount among owner-occupant transactions, but not for non-owner-occupant transactions. This influence of such beliefs can amplify crisis risks, as shown by research in the US exploring the effects of heterogeneous beliefs about flooding likelihood on the coastal housing market (Bakkensen and Barrage, 2017). The authors find that accounting for changing beliefs, e.g. increased risk perception after experiencing a flood event, leads to a 4 fold increase in expected housing market declines and increased volatility in the market. Thus, real estate markets with high owner-occupancy rates and low belief in climate change may be more vulnerable to sudden market corrections.

### 5.4.3 Indirect impacts

The concern of a ‚ sub-prime' like crisis triggered by coastal flooding arises from both asset ownership and associated instruments, i.e. mortgages, that are then passed on through the financial system through complex financial instruments, e.g. collateralised debt obligations. One of the first studies of physical climate change risks to financial system stability is carried out by Mandel et al. (2020) for coastal and riverine flooding.  They assess the "amplification ratio", for different climate change and adaptation scenarios, of coastal flooding by comparing direct damages of a flooding event to indirect effects on the global economy due to losses transmitted through the financial system.  They find that countries such as Iraq and Russia have very high amplification ratios, which is likely due to the high centrality of high-value assets, i.e. oil and related infrastructure, in the global financial system. For Europe and the USA, the amplification ratio is currently low, both for coastal and riverine flooding, however the measurements are at a global level, this may hide the exposure of European investors to US coastal real estate. Further, these measures are aggregate thus do not provide insight on the exposure of particular investors that may be critical to the stable functioning of the financial system.  This is an area of much needed future research.

## 6. Crisis Scenario 5: Global agricultural supply chain collapse

### Short description

Extreme weather events outside of Europe in key agricultural producing regions lead to disruptions of agricultural trade flows. Resulting volatile prices, and fragmented political responses, magnify the impacts of food production shocks, causing a cascade of economic, social and political impacts, leading to destabilisation and social unrest in Europe.

### Overview:

- The EU is a major agricultural importer. It contains many small, open and industrialised economies, which have high exposure to global agricultural supply chains.
- Extreme weather events around the world can lead to crop failures, and disrupt transportation networks, thus disrupting European food supply;
- Such extreme weather events are changing in frequency and intensity with climate change; potentially increasing the volatility of global food prices.
- Several concurrent low probability high-impact events, e.g. tropical storm at a major global transportation hub, combined with crop failures on different continents, could lead to a food security crisis in Europe; the impacts of such a crisis could be exacerbated by fragmented, individual country responses

## 6.1 Context

The globalisation of modern food networks is increasing complexity in the global food system, which can bring productivity benefits, yet also introduce supply-chain risks (Maynard, 2015). Indeed, globalized agricultural supply chains mean that climate impacts outside of Europe can be transmitted to Europe via the global agricultural market, through changes in production, disruption of transport infrastructure and volatility in food prices. Further, climate change will shift the frequency and intensity of extreme weather events, and this can significantly impact agricultural production and transportation networks worldwide (Gadhge 2019).

Europe is exposed to these risks, as agricultural product imports play a major role in the European economy, and trade in agricultural commodities is significant in the value chains of European products (EEA, 2017a; Benzie et al. 2017; EC, 2019). Several recent examples illustrate how climate impacts on agricultural production outside Europe have affected global markets and international supply chains, impacting Europe. For instance, the severe summer heatwave of 2010 in Russia destroyed 13.3 million hectares of crops, equivalent to about 30 % of Russia's grain harvest. This led to an export ban on wheat by the Russian government that contributed to an increase of 60–80 % in global wheat prices (Coghlan et al. 2014). Another example is the 2008 collapse of Australia's rice production after six consecutive years of drought. This was one of several factors contributing to a doubling of the world market price of rice (Stephan and Schenker 2012), in turn affecting European markets and consumers (EEA 2017a). In 2012, drought in the United States increased US agricultural prices by 12.7 % in the third quarter of 2012, primarily as a result of increases in the price of soybeans (up 28.5 %), corn (29.8 %), and wheat (29.6 %) (BLS, 2012).

Given the complexity and interconnectedness of the global food system, even a single extreme weather event in a remote part of the world may cause a chain of reactions that eventually lead to consequences in Europe through the disruption of global supply chains (EEA 2017a). While none of these single events is likely to lead to a crisis on its own, the conjunction of multiple crop failures, along with disruptions of major transportation hubs could have more far reaching effects. Further, when global scale disruptions of agricultural trade occur, exporting countries may respond with export restrictions, while wealthier or more powerful countries may seek to capture existing supply, putting additional pressure on the global market (Benzie et al. 2017). Under such circumstances, small, open economics of Europe, and particularly poor countries in the European neighbourhood would experience a major food security crisis.

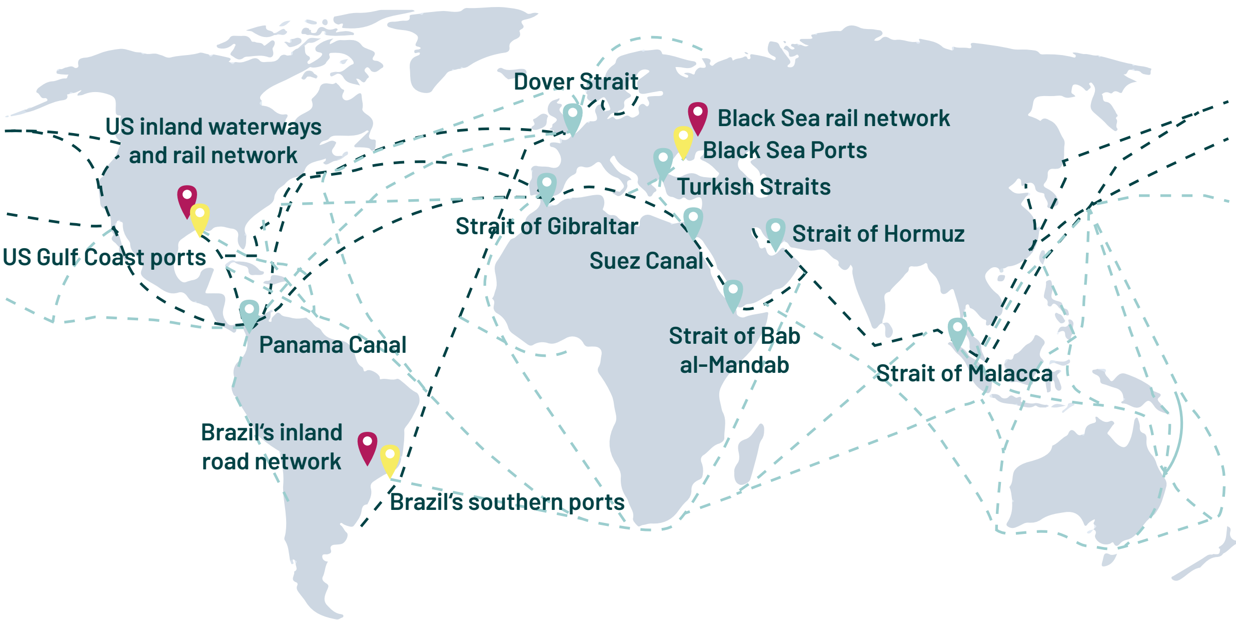
### 6.2 Exposure

Europe is a major importer of agricultural commodities and products, and thus exposed to agricultural supply chains and markets. In 2018, the EU became the world's second larger agri-food products importer with €116 billion worth of imports (EC, 2019). The EU mainly imports three types of products: those hardly or not at all produced in the EU, e.g. tropical fruit or coffee (23.4% of imports in 2018); those destined for animal feed (10.8% of imports); and those used as ingredients in further food processing, e.g. palm oil (EC, 2019). Key trading partners are the United States, China, Brazil, Japan and Russia.

Small, industrialised, and highly globalised countries, of which there are many in Europe, are particularly vulnerable to disruptions in global agricultural supply chains and cascading effects because they are generally highly dependent on agricultural imports, often with little domestic production capacity. For example, in terms of trade openness and the dependency on cereal import, countries like Malta (highest cereal imports in Europe as %GDP), Belgium (imports are 61% of GDP) or the Netherlands (imports are 53% of GDP) are highly exposed to climate-related shocks via international agricultural supply chains (Benzie et al., 2016). Moreover, across all countries of Europe, low-income populations are likely to be disproportionally more affected by food price volatilities (Porter et al., 2014).

Exposure of European agricultural supply chains is further conditioned by extreme weather events reducing crop yields in significant producing regions, or disrupting major global transportation hubs. As noted, droughts have reduced crop yields in the recent past in the US as well as Russia lead to increased agricultural commodity prices in Europe, while other key producing regions, such as Brazil are highly vulnerable to climate change (Peter et al. 2019). Exposure to major transport hub disruptions is also significant for agricultural commodities, as trade in this sector depends on critical transport hubs through which exceptional volumes of trade pass (see figure 5). Two of the three most important hubs lie in the US and Brazil, through which 53% of global exports of wheat, rice, maize and soybean pass. These major hubs are exposed to disruptions hazards from flood, drought or storms, as there have been at least three disruptions since 2002 (Bailey and Wellesley, 2017).

## Figure 5. Critical maritime, inland and coastal transportation hubs and shipping routes




**Type:** Maritime Coastal Inland

**Major shipping routes:** Core route Secondary route

Source: Bailey and Wellesley, 2017

### 6.3 Climate Change Contribution

Climate change may increase European vulnerability to global agricultural supply chains impacts. Under climate change, agricultural production is expected to become more variable, with higher risks of crop failures due to droughts, floods and/or extreme heat (Porter et al. 2014). Indeed, many regions throughout the world are projected to experience climate change-induced reductions in crop yield (Rosenzweig et al. 2013). One reason for this is that climate change is likely to change the spatial and temporal distribution and proliferation of agricultural pests, i.e. insects, weeds, and pathogens. Further, the El Niño-Southern Oscillation (ENSO) phenomenon also affects climate patterns that directly influence crop growth around the world (Rosenzweig et al., 2001). In the 21st century, El Niño and La Niña events are likely to become stronger and more frequent (Collins et al., 2019).

Strong El Niño events are associated with increased intensity extreme weather events, which can potentially cause large crop losses in a single year, and are thus more likely to have global impacts (Rosenzweig et al., 2001; Iizumi et al. 2014). Europe may be impacted by strong El Niño, as countries it imports from are sensitive to changes in ENSO. For example, the US, a major exporter to Europe, is vulnerable to extreme weather events through this mechanism (Iizumi et al. 2014). Climate change is also likely to influence the frequency and intensity of extreme weather events that pose a risk to transportation hubs, potentially disrupting agricultural supply chains. For example, climate change-induced sea-level rise increases the likelihood of major floods disrupting transport networks through impacts on ports (Bailey and Wellesley, 2017).

## 6.4 Impacts

### 6.4.1 Crisis threshold

Extreme weather events may cause direct damages in terms of crop failures or disruptions to transportation hubs in one location. Yet the scale of direct climate impacts that would need to occur outside of Europe to trigger a crisis are much greater than what has been seen in the recent past.  Past events that impacted world food prices, e.g. the noted crop failure in Russia in 2010, had a significant impact on the global market, but relatively small effects in Europe. Further, while such direct damages may lead to indirect impacts through supply chain disruptions, for the agricultural sector, it is unlikely that these indirect impacts from a single event would be large enough to induce a crisis in Europe. This is because supply-chains in agriculture and transportation networks are resilient and offer many different routes to conduct global trade. In this sense, agricultural supply chain can be contrasted to industrial supply-chains, which often consist of assembly plants in the supply-chain that are more difficult to substitute in the event of a disruption.

Thus, generally, impacts to agricultural supply chains significant enough to induce a crisis in Europe are likely to require that several events occur in a short time span in different world regions, and include both crop production and transportation disruptions. The recent global events surveyed demonstrate that at least an order of magnitude greater compared to direct impacts of recent events, e.g. Russian droughts in 2010, or indirect supply-chain impacts would be needed globally to have large-scale impact in Europe.

Yet we note that identifying even rough thresholds regarding crisis-inducing impacts is highly uncertain. This is partly due to the fact that government policies and responses can exacerbate an event or conjunction of events, and thus shape whether it leads to a food security crisis, and these policies and responses are inherently difficult to predict. For instance, the global food price crisis of 2007–08, which witnessed an 84% increase of global food prices between 2005 and 2008, resulted from complex interactions of multiple factors, including a decline in agricultural production, partly caused by adverse weather conditions and higher energy prices. However, government policy played a key role, as biofuels quotas in many developed countries drove an increasing share of cropland devoted to biofuels. Further, in addition to changing food demand patterns, protectionist governments trade policy responses during the food price rises further exacerbated the crisis (Mittal, 2009; Benzie et al. 2015).

### 6.4.2 Direct Impact

In order for a crisis in Europe to emerge from agricultural supply chains, low probability high-impact climate events would need to occur at several different places concurrently. Recent weather extremes have seen direct impacts of agricultural losses excess of $1 billion. For instance, the 2011 flooding in Thailand caused $1.3 billion in direct damages from agricultural losses (AON BENFIELD 2012). Further, the 1998-99 drought in the U.S. resulted in and estimated $1.35 billion in total losses, approximately 3 percent of 1999 U.S. net farm income (Rosenzweig et al., 2001). Any of such single events would however be unlikely to cause significant impacts in Europe on their own. However, if in the same season major concurrent crop failures of similar or greater magnitude to those mentioned above occurred in, for example, the US, Russia and Brazil, direct impacts would potentially have a significant impact in Europe. Moreover, the conjunction of extreme weather events causing such crop failures in different world regions may be influenced by the El-Niño-Southern Oscillation (Iizumi et al., 2014; Maynard 2015). However, direct agricultural impacts remain unlikely to be large enough to induce a crisis in Europe in the period up to 2030.

### 6.4.3 Indirect Impacts

Major disruptions of global agricultural supply chains, i.e. crop production losses as well as disruptions to transportation hubs, could reduce global food supply and trigger spikes in food prices, and potentially even food shortages (Maynard, 2015). While the EU is unlikely to experience food scarcity due to crop production losses because its wealth allows Member States to procure food on global markets even at very high prices, a food security crisis risk is present under extreme scenarios that include fragmented national policy responses.

An extreme scenarios leading to crisis in Europe and the European neighborhood would be triggered by droughts and floods in separate agricultural production regions around the world, combined with extreme shocks due to pathogens or insects, potentially leading to a broad range of negative socio-economic impacts (Maynard 2015) In such a scenario, plausible under a warm phase of El Niño-Southern Oscillation (ENSO), global crop yields could decline 10% for maize, 11% for soy, 7% for wheat and 7% for rice (Lunt et al. 2016). This could lead to a quadrupling of commodity prices and thus food affordability problems both within Europe and worldwide. Food affordability pressures can then be exacerbated by protectionist government policies (Gledhill et al., 2013). For instance, for some countries, rice trade and distribution are controlled by national policy-makers, who may wish to avoid domestic shortages for political reasons, even at high economic cost. National policies in these countries, e.g. to ban exports, can lead to ever increasing prices, and shortages in countries unable to pay very high import prices.

Within Europe, there is a risk that, despite the EU common market, under such a global agricultural supply chain collapse, national rivalries would come to the fore, leading to tensions among EU member states, as well as, between EU member states and non-members. Relatively poor non-EU member states could be particularly affected, not only by the collapse of agricultural supply chains, but in the response of other richer European nations to this collapse, as EU Member states, and other rich European nation, would be likely to secure their own national supply at higher global prices, thus exacerbating shortages in neighbouring poorer countries. Such a sequence of events could lead, particularly in smaller, open economies of the EU, and European neighborhood, to political instability, civil unrest, and significant negative humanitarian consequences.

## 7. Crisis Scenario 6: Large-scale migration due to conflicts in Africa

### Short description

Temperature rises, and prolonged droughts in Africa, and particularly the Sahel region, leads to decreasing agricultural production, which in turn leads to the outbreak of armed conflicts and state collapse. Large-scale migration ensues resulting in a migration crisis in Europe.

### Overview:

- The literature on climate-induced migration is contentious, but there is evidence that under certain social, economic and political circumstances, climate extremes (temperature and water) increase risk of violent conflict and migration
- It is highly likely that climate change will increase temperatures in the Sahel, which could negatively impact agriculture
- Large populations of Sahelian countries, high agricultural dependence and political fragmentation presents a risk of climate-induced conflict and large-scale migration to the EU
- Rough population estimates show that the scale of the crisis could equal or exceed recent migration influxes to Europe

## 7.1 Context

Migration has been a salient issue in Europe in recent years. The Syrian refugee crisis of 2015-2016, which saw more than 1 million asylum seekers in Germany, brought the issue to the fore, straining state capacity to absorb the sheer numbers of new arrivals, and leading to political conflicts and radicalization of segments of political discourse across several EU member states. Large-scale migration, e.g resulting from civil conflict and resulting human security failures, represent salient near-term crisis potential in Europe. Moreover, there is evidence, albeit contested, that climate change can increase the risk of violent conflict that can often lead to such large-scale migrations.

Generally, the interplay between migration, political conflict and climate change are highly complex. While some research on the environment-migration-conflict nexus relies on a simply causal model, which states that climate change will lead to resource scarcities, which will in turn engender violent conflict and migration (Brzoska and Fröhlich, 2016), in practice, it is difficult to disentangle these complex and intertwined processes. Violent conflict is clearly a significant push factor in forced migration (Moore and Shellman, 2004), yet evidence is more ambiguous regarding the influence of climate on the likelihood of conflict. Several authors posit climate as a cause, or at least, a 'risk multiplier' of violent conflict (Gleick, 2014; Kelley et al., 2015), while others refute these claims (Selby et al., 2017; Theisen et al., 2012). It is thus important to distinguish between the strong causal claims in the media that climate "sparked conflict" or was "the primary causal factor", which are not substantiated in the scientific literature, and the softer claims that climate was "a significant contributory factor", which can be supported or are, at least, difficult to dismiss (Selby et al. 2017). Indeed, the literature is clear that in conjunction with other conditions, such as, low state capacity, or the presence of excluded ethno-political groups (Fjelde and von Uexkull, 2012), climate can indeed raise the likelihood of crisis.

## 7.2 Exposure

At a global level, in 2016, there were 11.6 million refugees in protracted crises and this increased to 13.4 million in 2017, with 6.5 million of these having been displaced for more than 10 years (Brück and d'Errico, 2019). It is well established that migration flows are strongly influenced by network effects, economic factors (e.g. employment rates) and physical proximity (Brück et al., 2018). Thus, salient risks for large-scale migration to Europe are posed by countries and regions from which asylum seekers are likely to migrate to Europe, i.e. relatively closely situated countries, with low levels of economic opportunity. From this perspective, sub-Saharan Africa, and particularly the Sahel region, appears to pose a salient risk, as it includes countries with high rates of population growth, including Sudan (pop. 43 million), Mali (pop. 19 million), Niger (pop. 22 million), and the northern part of Nigeria (pop. 195 million), all with low GDP per capita (Nigeria having the highest at approx. US$2000). Moreover, while global climate model projections for precipitation in the Sahel are highly uncertain, and many do not even agree in the direction of futures changes, (Barros and Field, 2014), for temperature there is greater uniformity, projecting 2-2.5 C of warming until 2050 (Vizy et al., 2013). As populations in many these countries are largely dependent on agriculture, and thus will be affected by temperature increases that will reduce crop yields, risk of violent conflict may rise (Burke et al., 2009).

## 7.3 Climate Change Contribution

In the media, claims linking climate, conflict and migration are prominent. Yet few studies investigate the causal path from climate change to violent conflict and forced migration. A large literature explores the link between climate and violence, but not the subsequent decision to migrate. In this literature, the link between climate and armed or violent conflict is contentious. Studies of conflict in general (as opposed to armed conflict) find a link to climate, as a meta-analysis of both inter-personal and inter-group conflict since 1950 find that the frequency of interpersonal conflict rise 4% and intergroup conflict rises 14% for each one standard deviation (1 $\sigma$) change in climate toward warmer temperatures or more extreme rainfall (Hsiang et al., 2013). Moreover, other authors find a historical relationship between temperature increases and armed conflict, and based on this, project an increase in armed conflict in SSH Africa by 54% due to increased temperatures from climate change until 2030 (Burke et al. 2009).

Yet the IPCC 5th Assessment Report chapter on human security concluding that the literature does not establish a positive relationship between climate change and violent conflict, though individual studies do show the influence of climate change on known drivers of conflict (Gleditsch and Nordaas, 2014).

More recent studies aim to more explicitly address the link of climate and conflict to migration. Missirian and Schlenker (2017) analyze statistical relationships between climate variables (e.g. temperature anomalies) and migration (e.g. asylum seekers) finding that asylum applications increase non-linearly with increasing temperature, and project, all other conditions equal, an average increase of asylum applications in the EU of 188% annually by 2100. More explicitly modeling migration decisions through an agent-based modeling framework, Abel et al. (2019), analysing asylum seekers flows from over 150 countries to the EU for the period 2006-2015, find that climate influences asylum seeker flows by increasing drought severity and the likelihood of armed conflict. Further, they find that climate influence is however limited to periods of greater political instability, and in specific contexts, e.g. in the presence of excluded ethno-political groups. These findings are highly relevant to Sahelian states, which do exhibit such ‚political vulnerability' (Raleigh, 2010).

## 7.4 Impacts

### 7.4.1 Crisis threshold

Identifying critical thresholds is challenging with respect to large-scale migration induced by violent conflict because, as noted, multiple interacting causes are at play of which climate (or climate extremes) is just one. Further, as noted the literature does not come to a consensus on the mechanisms that lead to such large-scale migrations. Several ‚ resource scarcity' mechanisms can induce conflict, including water scarcity due to drought, food scarcity due to crop failure, or economic scarcity due to reduced labor productivity at higher temperatures. Sufficient theoretical or empirical basis to quantify these thresholds is however not available. We note that, generally, for Sahel countries until 2030, the most likely scenario is that temperature increases will continue and potentially lead to food shortages, thus triggering conflict and migration.

### 7.4.2 Direct Impacts

As noted, climate-induced triggering events are uncertain: because whether a large-scale conflict breaks out is not deterministic, and depends also on a number of other social, economic and political contextual factors. However, some aspects are noted in the literature as increasing conflict risk, for example, high dependence on agriculture pre-conflict, which is present in Sahelian countries (ca. 25% of GDP from agriculture in 2003). One mechanism for increasing conflict risk is that drought leading to agricultural failure can in turn lead to large-scale internal displacement from rural areas to urban centers (Kelley et al., 2015). Taking Sudan, for example, agriculture makes up ca. 30-35% of GDP and is a source of livelihood for 65% of the population. Thus, extreme temperatures leading to staple crop failures would affect more than half the population and plausibly lead to increased risk of conflict.

### 7.4.3 Indirect Impacts

Indirect impacts that could trigger a migration crisis in Europe would migrant arrivals exceeding those of the past decade, i.e. greater than 2 million arrivals over the course of a few years. A survey of demographics in Sahelian countries, and past experiences in regard to the proportion of migrants that flee conflict and civil war, shows that major conflict in Sahelian countries does have the potential to produce crisis in Europe. While acknowledging that the Syrian civil war cannot be linked to climate causes, we can observe the number of arrivals in Europe sparked by this conflict to get a rough estimate of the potential impacts in Europe of a major conflict in the Sahel. The population of Syria was ca. 21 million before the conflict in 2010, with up to 6 million refugees having fled the country from its outbreak, just under 30% of its population. More than a third of these reached Europe or its immediate borders, or around 10% of the total population of Syria prior to the civil war. If such proportions are applied to Sudan, but reduced by half to account to a more difficult journey from Sudan to Europe, and lower capacity to travel for the Sudanese population owing to lower levels of wealth, it is plausible that over 2 million Sudanese refugees arrive in Europe due to such a crisis. This at least matches the scale of the Syrian refugee crisis, which still continues today five years after its emergence. Moreover, the scale of investments in infrastructure and human and organisational capacity to deal with, and integrate, the arrival of such a large-scale number of migrants is significant.

For instance, Germany in 2016 spent €22 billion to handle all stages of asylum seeker arrivals, from initial processing, and accommodation, to expanding education system infrastructure and human resource capacity to ensure integration of refugees over the longer term. While there is disagreement over whether such expenditures represent a long-term cost or benefit to host countries, the upfront investment needs are substantial. Moreover, irrespective of economic aspects, the major crisis risk lies in the observation large-scale immigration can induce ‚ backlash' among groups within host populations, and radicalisation of political discourse and social life.

## 8. Discussion and conclusion

Our six climate-induced crisis scenarios until 2030 show that threats to Europe arise from a range of different hazards in different parts of the world, and that climate change is already increasing the likelihood of these events.

Climate-induced crisis remain however ‚ tail risk' events for Europe at least in the relatively near-term. These tail risks are of two different types. The first type is the ‚ tail risk' of an event or conjunction of events that can be quantified with some (low) probability. For example, in the case of both coastal and river flooding, probability distributions of extreme events are available and can be applied to assess current risks and project risks into the future. However, it should be noted that this assignment of probability should be treated with a great deal of caution due to short observational record. This type of tail risk includes: very low probability coastal or river flood events, i.e. high return period or dike failure, because of high protection measures (Chapter 2); it also includes low probability drought events leading to both crop losses, and more significantly for crisis risk, severe reductions in tourist arrivals and thus tourism revenues (Chapter 3). For such events, adaptation measures, or preparation measures, such as, disaster risk financing pools for flooding might be calculated quantitatively up to a level that would ensure that such "tail events" do not reach the scale of a larger crisis by having enough capital available to ensure a rapid recovery. Such measures are not currently in place, as current disaster risk financing arrangements in Europe, e.g. the Europe Solidarity Fund, would be overwhelmed by a 1-in-250 flood event spanning several central European countries. Given the present risks of crises resulting from such flooding or drought events, it appears worthwhile to consider what level and sources of disaster risk finance could be put in place to reduce these risks.

Further, as noted in the introduction, we emphasise that the precise magnitudes of expected damages for particular extreme events should be treated with caution. While for some hazards, namely, coastal flooding, we can project the evolution of risks into the future under different scenarios, and quantify the effect of sea-level rise on increasing coastal flooding magnitude, even this does not fully account for how flood risk may evolve under climate change, as storm intensities and frequencies change. Under such deep uncertainty a precautionary approach is warranted, which takes account of possibility that extreme events, e.g. a 1-in-250 year flood, becomes more severe than would be expected based solely on past observations, and sea-level rise projections. This is because it is these 'worse than before' outcomes that are far more important for societal decision-making on measures to avoid climate crises.

A second type of ‚ tail risk' events are those for which it is not possible to assign probabilities. These include: Blackouts in Europe due to failure of electricity grid during periods of low cooling water availability (Chapter 4); US coastal real estate correction leading to a global financial crisis (Chapter 5); outbreak of a large-scale armed conflict in the Sahel and subsequent migration (Chapter 7). Here, it is difficult to quantify the degree of risk involved, and consideration of measures to reduce these risks can be taken on a more ‚ precautionary principle' or ‚ no regrets' basis, aiming to adjust systems in such a way as to avoid that these risks materialise at all. For instance, in the case of coastal real estate, collective flood protection measures, such as, coastal protection or managed retreat, could avoid crises from real estate corrections, and ensure a 'smooth transition' to more sustainable, resilient and equitable coastal cities. Such measures require early and sustained stakeholder engagement across multiple levels, and from multiple sectors, including government, scientists, business and civil society. In the case of a migration crisis, avoiding future crises points to the need for Europe to support climate-resilient development international, as well as, also to the need to develop a sustainable and resilient domestic economy that can manage sustainable refugee integration to avoid such socio-political repercussions and reap the society and economy-wide benefits of successfully integrated new arrivals.

Another important observation is that for nearly all of the scenarios discussed above climate change interacts with one or several other socio-economic conditions in order to produce the scale of impacts needed to induce a crisis.

For example, the drought in southern Europe (Chapter 3) scenario shows that while drought puts pressure on different sectors potentially leading to conflicts, these conflicts are more likely to emerge when both agricultural and tourism sectors are significant in the economy, and have the capacity to organise action. Similarly, for the large-scale migration scenario (Chapter 7), while climate change increases the likelihood of crop losses, for this to translate into increased risk of armed conflict, particular social, economic and political conditions need to be present. Low state capacity, the presence of intergroup competition and ethno-political exclusion, are characteristics that in conjunction with climate can induce crisis, but which are exogenous to the climate. Further, for the "Flooding in Europe" (Chapter 2), as noted above, the risk of direct impacts turning into a larger crisis would be reduced by increased insurance or risk financing instruments. Disaster risk finance is a well-developed field, and there have been a number of analyses at both European and country levels that show that disaster risk finance is likely too low to prevent ‚ tail risk' flooding events from turning into protracted crisis.

The key role played by socio-economic conditions in crisis scenarios points to the need for responses to these crises that do not simply return to business-as-usual, but rather that improve resilience to such events in the future, or avoid their occurrence altogether, i.e. to ‚build back better'. Indeed, such recovery strategies must be informed by the need to deliver a more resilient, and more stable financial system. Indirect climate impacts on the financial system are the key aspect leading to several crises discussed here. Further, these crises scenarios also make a strong argument for building measures that reduce GHG emissions into all recovery strategies to avoid exacerbating climate change that is increasing the crisis risks discussed in this report. This is particularly important considering that, we have only examined risks till 2030, and the contribution of climate change to all of the hazards discussed here will accelerate further into the future.

Finally, we emphasise that a lack of considering long-term resilience in economic recoveries, would leave such recoveries prone to failure, laying the seeds for the next, even more catastrophic collapse.  For flooding, either within Europe or beyond, such crisis risks are evident as the dynamics of decisions around flood plain and coastal real estate development tend to reinforce short-term decision-making, and asset development in the floodplain. But these concerns are applicable to all of the crisis reviewed here, as food security, large-scale migration, and energy security will be put under increasing pressure by unabated climate change.

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