Clim INVEST

October 2020

Floods and physical climate risk

This fact sheet introduces the basics about floods, describes the sectors that are most affected by this hazard with examples from different locations across the world. It also explains the relevant indicators that investors can use to evaluate and anticipate their exposure to physical climate risks from floods.

Foto: Tech. Sgt. Rachelle Blake/U.S. Air Force

What is a flood?

According to the IPCC, a flood is defined as the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods (precipitation), sewer floods, coastal floods, and glacial lake outburst floods (IPCC, 2012).

This definition highlights **the variety of flood types, each caused by different meteorological or climate events**. For example:

- Pluvial flooding is linked directly to precipitation whereas fluvial flooding is caused by an overflow of the river systems that can be caused by continuous rainfall over weeks or snow melt (therefore linked to temperature).
- Flash floods are due to extreme precipitation over a short period of time (usually a few hours) and are especially impactful in urban areas, where the drainage systems can overflow and fail to evacuate the water that cannot be absorbed by non-porous surfaces.
- Coastal events are not limited to precipitation but also driven by storm surge, sea level rise, tides and wind.

Key considerations

Floods are a category of hazards, not a single hazard. They are caused by a variety of meteorological, hydrological and human factors. Meteorological factors include precipitation, cyclones, snowmelt, and temperature. Hydrological factors include soil moisture and density; groundwater levels; presence of impervious cover such as snow and ice, and runoff systems. Finally, human factors include land-use activities and land-use change, restriction of waterways, and waste and wastewater management. For more information:

https://www.floodmanagement.info/publications/tools/APFM_Tool_07.pdf

A combination of flood events can happen simultaneously. The occurrence of a combination of different flood events can strongly affect the economy across supply chains.

Floods are a result of atmospheric processes (precipitation) and specific ground conditions (e.g. topography, soil typology, urbanization, land and catchment management). Atmospheric process and the asset location inform the asset's exposure to flooding; the specific ground conditions determine vulnerability. Flood prediction is therefore linked to both climatic and hydrological conditions. Land-use changes in the catchment area and floodplains also affect natural frequency, intensity and general characteristics of flooding.

Floods are site-specific. Flood hazards are usually defined by the increased level of water (in feet or meters) above a local reference, and are largely determined by local contextual factors such as elevation, soil type, building materials, etc. that climate models do not capture. As such, flood projections combine climate models and local flood models. The accuracy of flood models highly depends on the quality of the local hydrological information, at the watershed level. This is a challenge as climate projections are typically calculated over large grid cells. Estimates based on global or regional relationships that do not consider the local context (building specificities, ground information) will present a high level of uncertainty.

A 1-in-100 year flood event is not always caused by a 1-in-100 year rainfall; it can be caused by a less intense rainfall in a flood-prone area. Flood thresholds and return periods (e.g. the shape of the area flooded by a 1-in-100-year event) are often used for insurance and protection purposes. However, flood return periods are not directly linked with rainfall return periods. As ground conditions evolve (e.g. urbanization) so can the link between rainfall and floods change in the future, so past relationships might no longer be valid. Furthermore, 1-in-100 year flood and rainfall calculations have been based on historical data; given the increased frequency of extreme events in the past ten years, these metrics and approaches need to be reevaluated.

The impacts of floods are related to either too much water or the violent displacement of water. Too much water leads to damages on buildings, agricultural land, and transport infrastructure, and can overwhelm wastewater management systems causing sanitation problems. In some cases, extreme precipitation following long periods of drought in deforested areas can result in landslides. The violence of the displacement of water – coupled with winds – can cause sediments, debris and large waves to impact and damage structures.

Coastal areas could be particularly exposed to flooding events in the future due to global warming and sea level rise. In addition, in some tropical regions, tropical cyclones tend to move poleward and slower than before. This means that regions with low adaptive capacity might be impacted strongly as slow-moving tropical cyclones tend to release more water.

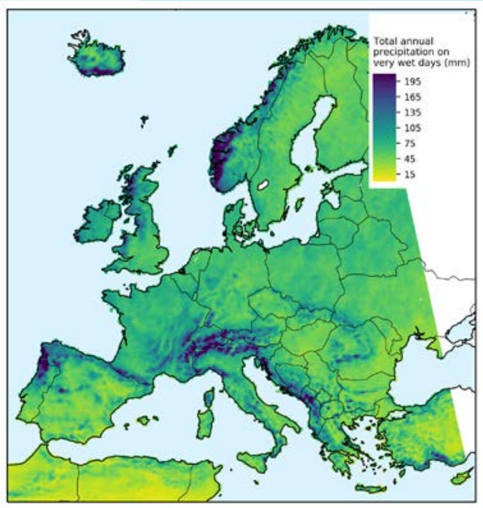
Calculating asset exposure to flooding: relevant hazard indicators

Climate hazard indicators like the ones below, drawn from climate models (see Calculating Climate Risk and Climate Modeling 101 for more information), can be used to develop maps. These maps provide a user-friendly way to interact with the hundreds of available indicators used to describe the factors that contribute to flooding conditions. They can also be used to understand specific asset exposure to each indicator if asset location data is available to overlay on the map.

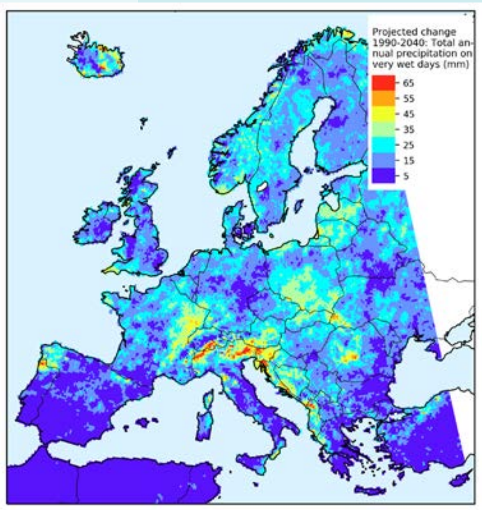
Note that these maps are only part of the climate risk assessment equation; they can demonstrate an asset's exposure to potential flooding conditions but do not show an asset or portfolio's vulnerability to the hazard (determined by specific ground conditions and asset specification), nor do they definitely describe the probability that an area will flood (as determined by land use, in particular deforestation, urbanization and agricultural practices, elevation and other factors). They are most useful as indicators of trends rather than probability calculations because they depend on specific choices such as scenarios selected, models included, grid resolution, etc.

Below, we showcase five climate-related hazard indicators that can be used to describe the frequency or intensity of precipitation conditions potentially leading to flood events in Europe. The maps assume an RCP 8.5 scenario which correlates to around 4°C warming in global average temperatures by the end of the century. This scenario was used to illustrate what more extreme climate hazards might look like and emphasize the direction of future trends, but should not be used as a predictive tool. See our **Climate modeling 101 factsheet** for more information about scenarios and uncertainties.

Climate indicator	**Definition**
Rainfall in the 99th percentile (r99p)	Millimeters of rainfall accumulated during days with very heavy rainfall, that is as much or more rain than on 99 percent of the days in the reference period from 1981-2010. This indicator is used to help describe chronic flooding patterns or recurring flashfloods. Large amounts could suggest more accumulated rainwater in sewer systems and valleys, waterlogged fields, overflowing rivers. e.g. heavy rainfall on extremely wet days may have negative implications for agriculturally intense regions where extreme rainfall can wash away topsoil needed for crop growth.

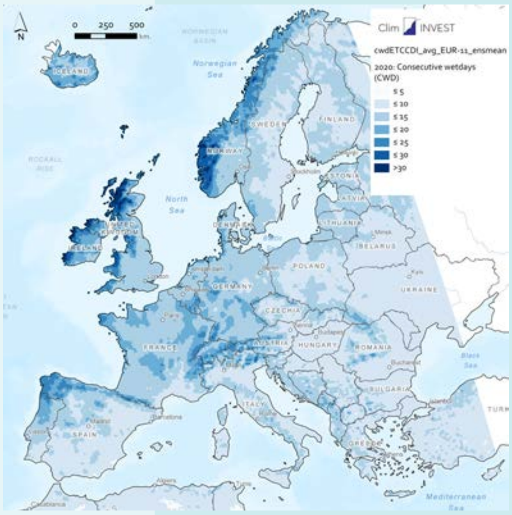


Total yearly rainfall on days with as much or more rain on 99 percent of days in the reference period (1981-2010) Frequency of extremely wet days per year around 2020 (obtained by using an average of model values in the period 2011-2030), i.e. rainfall over 22mm per day. Light yellow is less than 25 mm per year, darkest purple is over 225 mm per year.

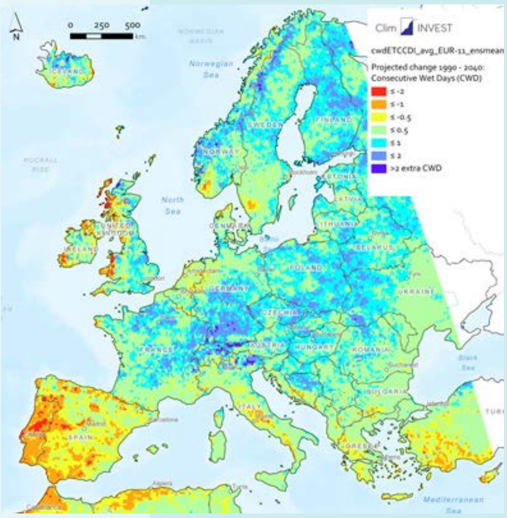


Projected change in total yearly rainfall on extremely wet days per year (days with as much or more rain than 99 percent of days in the reference period 1981-2010) from 1990 to 2040. Indigo is less than 1 mm per year, red is over 75 mm per year. The map below shows that the expected increase in rainfall on the wettest days seems to be highest where the rainfall on the wettest days is already high. The 1990 value was obtained as the average value for historical model runs from 1981-2000, whereas the 2040 projection is the average of projections for 2031-2050.

Climate indicator	Definition
Consecutive number of extremely wet days	Indicates the greatest number of consecutive days with intense daily rainfall, over 20mm per year. This indicator, unlike the above, can help describe a specific event instead of a general trend. Increased consecutive wet days (CWD) means multi-day precipitation spells are getting longer. *e.g. high concentration of CWD in low lying urban areas may contribute to flash floods and fluvial/pluvial flooding.*



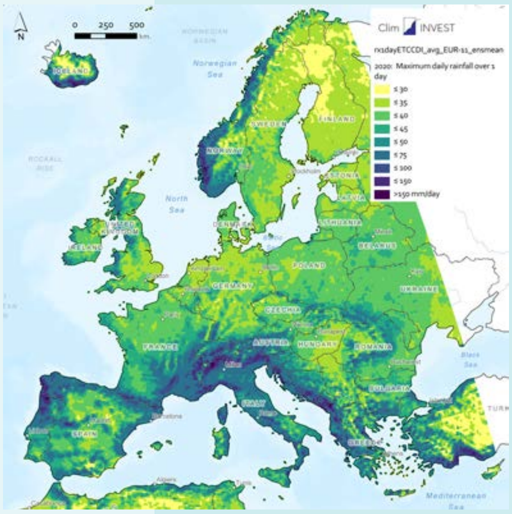
Consecutive wet days for Europe around 2020 (obtained by using an average of model values in the period 2011-2030) where white is fewer than 5 days of consecutive wet days and darkest blue is over 30 days of consecutive wet days.



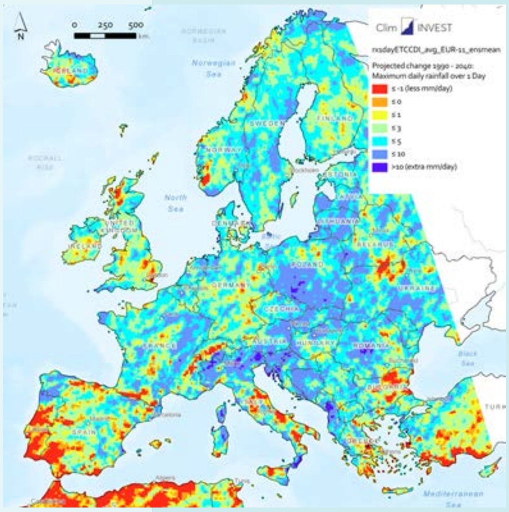
Projected change in consecutive wet days for Europe from 1990 to 2040, where red is 2 or more fewer days of rain and indigo is 2 or more extra days of consecutive rain. The 1990 value was obtained as the average value for historical model runs from 1981-2000, whereas the 2040 projection is the average of projections for 2031-2050.

Flooding in Dresden
Photo: Stefan Malsch

Climate indicator	Definition
Maximum daily rainfall (RX1day)	Describes the maximum intensity of daily rainfall to help spot short-term intensive rainfall (i.e. the highest amount of rain in a day), for instance caused by thunderstorms in the summer that can lead to pluvial flooding or flash floods. This indicator could be used to assess thresholds for sewage system carrying capacity and to inform flood zones.



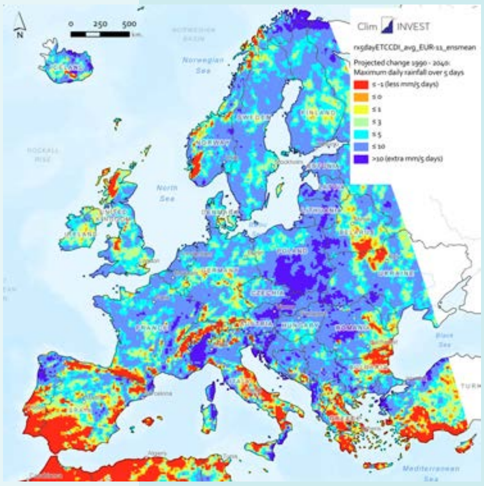
Map of projected maximum daily rainfall in Europe around 2020 over one day (obtained by using an average yearly maximum of model values in the period 2011-2030). Yellow is under 30mm per day and darkest purple is over 150 mm per day.



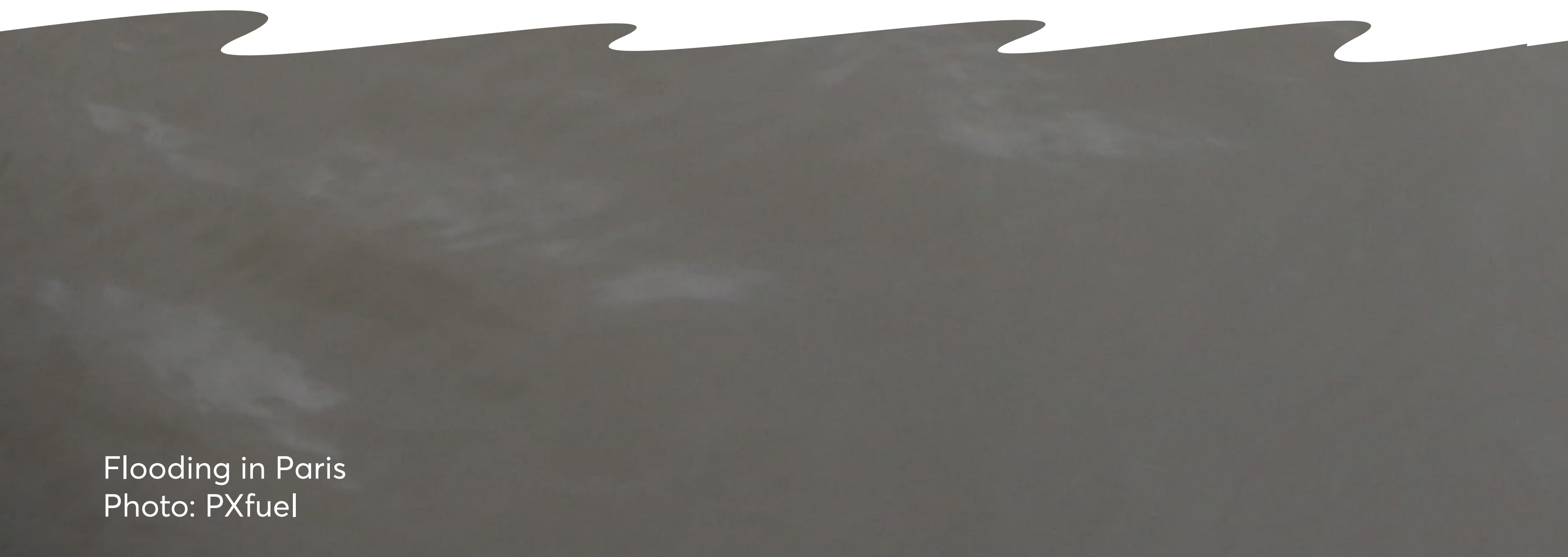
Projected change in maximum daily rainfall over 1 day in Europe between 1990 and 2040, where red indicates a decrease in maximum daily rainfall, and deep purple is over 10 extra mm of rain per day. The 1990 value was obtained as the average value for historical model runs from 1981-2000, whereas the 2040 projection is the average of projections for 2031-2050.

Climate indicator	Definition
Maximum daily rainfall over 5 consecutive days (RX5day)	The maximum amount of rain found in any five day period during a year.Prolonged heavy rainfall can for instance lead to fluvial flooding.

Maximum yearly rainfall over the course of 5 consecutive days in Europe around 2020 (obtained by using an average yearly maximum of model values in the period 2011-2030). Yellow is under 50 mm per 5 days and deep purple is over 300 mm over 5 days.



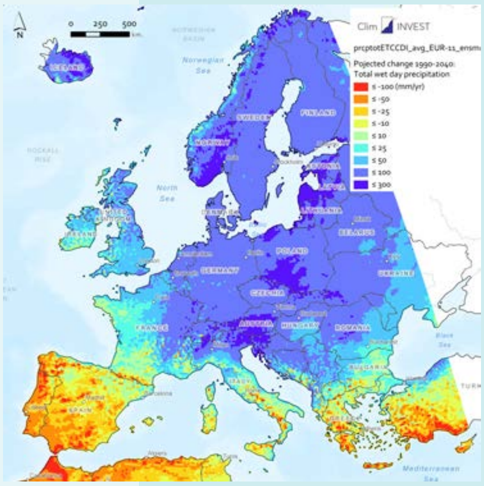
Projected change in maximum daily rainfall over 5 days in Europe from 1990 to 2040, where red is 1 fewer mms per 5 days and deep purple is over 10 extra mm per 5 days. The 1990 value was obtained as the average value for historical model runs from 1981-2000, whereas the 2040 projection is the average of projections for 2031-2050.



Flooding in Paris
Photo: PXfuel

Climate indicator	Definition
Total annual precipitation (PRCPTOT)	Shows total precipitation (rainfall + snowfall) per year in mm. Shows what areas receive the most or least rain but doesn't show in what season and how intensely precipitation is accumulated over the year, e.g. light rain every day or intense rainfall in a few weeks per year. This can generally inform land use planning and flood management, but must be put into local context. *E.g. general trends towards increased rainfall suggest ideal conditions for reservoirs and hydropower dams, especially in regions dependent on glacier melt.*

Projected total rainfall per year in mm around 2020 (obtained by using an average of model values in the period 2011-2030). Yellow is under 500 mm per year and deep purple is over 3000 mm per year.



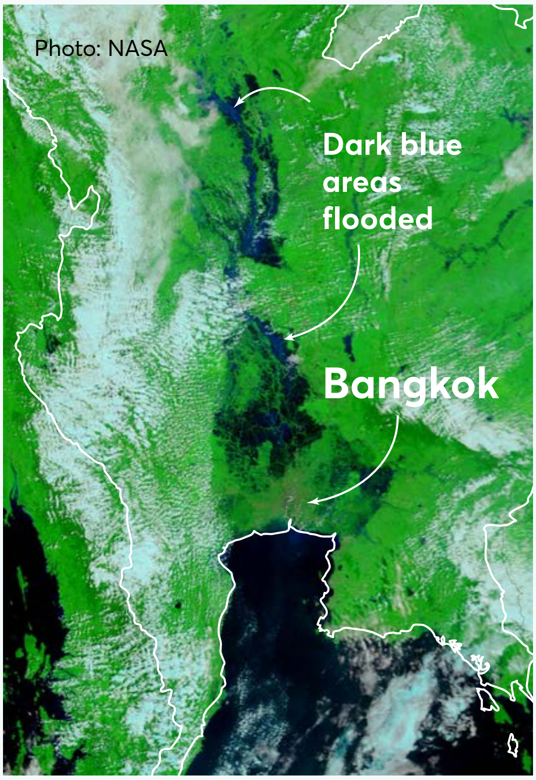
Projected change in total yearly rainfall in Europe from 1990 to 2040, where red is 100 mm less per year and deep purple is over 300 more mm per year. The 1990 value was obtained as the average value for historical model runs from 1981-2000, whereas the 2040 projection is the average of projections for 2031-2050.

The number of European airports expected to face risk of inundation is expected to increase 60 percent between 2030 and 2080. 64% of all European seaports are expected to be inundated by 2100.

- Adaptation of Infrastructure Systems: Background Paper for the Global Commission on Adaptation

The 2011 floods in Thailand

The 2011 Thailand floods provide a dramatic example of widespread flooding caused by a tropical storm and exacerbated by high seasonal precipitation.



The floods began in July 2011 with landfall of Tropical Storm Nock-ten and persisted during the whole monsoon season, reaching their peak in October and inundating the capital Bangkok as well as a large part of the country along the Mekong and Chao Phraya river basins.

Flooding persisted in some areas until mid-January 2012, killing 815 people and affecting 13.6 million. 65 of Thailand's 76 provinces were declared flood disaster zones and over 7,700 square miles of farmland was damaged.

The floods and resulting damage represented significant setbacks for major Thai economic sectors, including tourism and manufacturing, and had international implications.

At the time, Thailand was the world's second-largest producer of hard-disk drives with clients including leading actors such as Western Digital. When the water barrier protecting the industrial complex housing most of these plants collapsed, equipment and buildings were flooded and production had to stop for months.

Companies that sourced their hard-disk drives from Thailand, such as the Japanese automobile industry, could not complete production orders or had to scramble to find last minute, alternate sources for parts which almost doubled the price of electric devices around the world in the following months.

SUMMARY:

- **Exposure**:
  Thailand's manufacturing sector was highly exposed to intense rainfall over time combined with storm surges.
- **Vulnerability factors:**
  Insufficient flood protection of manufacturing equipment, urbanization.
- **Adaptive interventions:**
  Reinforcing seawalls, improving drainage systems, diversifying supply chains.

Consequences of the flooding

Car industry

6000 Cars not produced each day in Thai car factories.

67m$ The cost incurrend by Nissan to restore its production line.

50% Decrease in production of Honda's factories in the US and Canada.

Electronics industry

45% Share of hard disks in the world produced in Thailand 2011.

235m$ The loss for the industrial company Western Digital

x2 The increase in hard disk prices following the floods

Vulnerability: sector sensitivity & adaptive capacity

The sector sensitivity table outlines potential physical impacts of flooding on key economic sectors and resulting financial impacts. Sector sensitivity is part of an asset's vulnerability, but must be combined with adaptive capacity factors to fully understand a sector's vulnerability. Sectors with higher potential physical and financial impacts are considered more sensitive to flooding, but are not necessarily more vulnerable.

Factors that contribute to an asset's vulnerability include the following:

- **Construction materials and design.** Older infrastructure may have been built to lower standards without taking climate change into account.
- **Land use around the asset.** Urbanization and associated non-porous surfaces can create or exacerbate flood conditions; deforestation contributes to soil erosion over time and – in particular – during extreme rainfall.
- **The age of the asset.** Aging infrastructure built using outdated construction materials with lower technology may begin to break down over time, particularly if maintenance is lacking. For example, the natural gas distribution system in the Northeast of the United States was originally laid using cast iron pipes that have begun corroding and leaking over time.
- **The connectivity of the asset.** Assets in the energy, water, financial services, transportation and ICT sectors are highly interconnected. For example, a physical impact at a power station or along a major transmission line can affect an entire power network. A water treatment plant with reduced capacity may have health implications for an entire community, and reduced access to cellular or internet services can severely impact emergency response or general economic activity. The number of people or assets in a network could be a useful indicator to inform project prioritization.
- **Dependency on the asset.** This is particularly relevant for infrastructure such as ports, train lines and roads. Areas with alternative routes available are less vulnerable, whereas areas with fewer transportation options can see significant setbacks in the case of flooding. High income countries tend to have more roads, ports and trainlines and so may be more exposed. However, high income countries are more likely to have alternative routes available, which reduces vulnerability. The amount of money flowing through a port or trainline could be a useful indicator to inform project prioritization.
- **Time horizons of the asset.** Different sectors have different time horizons. Agriculture operates on a seasonal basis, whereas construction and energy work on 20-40 year time horizons. The impacts of climate hazards may therefore have differing levels of relevance or immediacy for each sector.

"…in 2050 […] approximately 450 million flood-prone people and 430 thousand km² of flood-prone cropland [c]ould be exposed to a doubling of flood frequency"

Arnell and Gosling, 2014

Sector sensitivity

Sectors	Impacts	
Real estate	Physical	Direct. Damages to structures and properties, corrosion of IT networks Interruption of work due to inundated building sites, damaged materials.
	Financial	Revenues. Lost revenue from delays or reduced operation. Operation costs. Cost of cleanup and repairs, higher flood insurance premiums. Asset value: devalued property in vulnerable areas or loss of property, Financing costs increase with increased risk.
Transportation	Physical	Direct. Inundation of roads, runways, railway tracks or other related infrastructure. Resulting obstructed travel, potential damages to infrastructure. Changing water levels disrupt transport on inland waterways.
	Financial	Revenue. Lost revenue from delays or reduced operation. Operation costs. Cost of new infrastructure and/or improvement of drainage systems Financing costs increase with increased risk.
Agriculture	Physical	Direct. Water-logged or submerged fields can impede crop growth, extreme rainfall can wash away topsoil. Extreme storms and rising sea levels in coastal regions or river basins can subject crops to salinization.
	Financial	Revenue. Partial or whole crop loss reduces income. Operation costs. Costs of drainage, repair and replanting. Potentially higher insurance premiums. Financing costs increase with increased risk.
Energy	Physical	Direct. Damages to plant structures and power lines, transmission and distribution networks, including due to sediments and debris (hydropower). Severe flooding can rupture flow lines and storage tanks, "shut in" wells (i.e. stop production), and overflow of contaminated water from fracking.
	Financial	Revenue. Lost revenue due to low production capacity and high demand Operation costs. High repair costs and potentially higher insurance premiums. Financing costs may increase with increased risk
Water	Physical	Direct. Extreme precipitation in combined sewer and stormwater systems can cause contamination of potable water sources and pollution of connected waterways. Storms can cause damage to structures such as buildings and pipes. Indirect. Implications for health and hygiene of local population, potential for spread of infectious diseases.
	Financial	Revenue. Lost revenue due to interrupted service delivery. Operation costs. Costs of repair. Liability insurance premiums may increase.

Adaptive capacity

Adaptive capacity is determined by such elements as land use, construction materials, and water management systems. There are hard measures (e.g. investments in infrastructure) and soft measures (e.g. policy or pricing signals) that can be taken to reduce an asset's vulnerability to extreme or sustained drought, explored below.

Sectors	Adaptive capacity interventions: Soft measures / Hard measures
Real estate (Soft measures)	Adjustments in zoning, more frequent and de-politized flood mapping assuming higher intensity and frequency rainfall as appropriate to the region. Price signals in the form of flood insurance premiums can signal flood risk to investors or buyers and dissuade investment in areas with high exposure and vulnerability. Regulations and mandatory standards that require developers to build rainwater management systems, bioswales or green roofs into building specifications can be set in place
Real estate (Hard measures)	Invest in grey and green (nature-based solutions) flood resilience infrastructure such as rain gardens, bioswales, mangroves and salt marshes, dikes, levees, seawalls, green roofs, or upgraded gutter systems. Move HVAC, backup generators, and other key equipment off bottom three floors of buildings. Invest in solar or other distributed renewable energy to protect access to energy.
Transportation (Soft measures)	Set industry standards or regulations requiring new heights, zoning, or protective walls. In the case of private transportation companies (toll road construction, trains, airports), set up tax credits for climate resilient construction.
Transportation (Hard measures)	Raise roads, runways and tracks to levels comfortably past new projections for 1-in-100 year storms, or build walls or riparian buffers to suit the new levels. Nature-based and grey infrastructure solutions include bioswales, marshes, dikes and seawalls.
Agriculture (Soft measures)	Develop early warning systems for agricultural sector, upgrade flood zoning maps more often, provide price or tax incentives for investment flood resistant crops or flood insurance. Direct payment insurance payouts can reduce impact.
Agriculture (Hard measures)	Invest in flood resistant crops and/or rainwater management or drainage systems that can channel rainwater effectively. Plant cover crops to manage soil erosion, minimize tillage, set up wind breaks, use perennial crops in erosion susceptible areas. Reforestation or forest conservation can reduce rates of erosion.
Energy (Soft measures)	Review proximity of well pads, compressor stations and flow lines to rivers and flood zones in the environmental review and risk assessments to help drill around flood plains. Develop an emergency response plan to prevent release of oil and gas into water supply. Design plants with alternative water sources like grey water and sea water. Improve hurricane and winter storm forecasting. Enhance design to withstand higher winds and ice loading.
Energy (Hard measures)	Reinforce power line networks, flow lines, and well casings; seal "produced water" tanks and storage tanks. If possible, run powerlines underground to avoid tampering and damage. Develop upstream sediment control facilities, install variable speed turbines for a wider range of discharge. Replace wooden utility poles with steel. Improve vegetation management around lines. Waterproof pipelines and substations, seal manhole covers, incorporate submergible transformers, switches and pumps.
Water (Soft measures)	Develop emergency response plans to extreme storms, enhance public messaging around health risks in extreme cases, upgrade flood zoning maps and provide financial incentives to invest in nature-based solutions for flood management in urban areas.
Water (Hard measures)	Increase pumping station capacity, upgrade and extend pipes, build additional storm tanks, upgrade drainage. Build flood protection for water treatment plants and pumping stations, and permeable urban surfaces. Relocate assets to areas not in flood plains, waterproof treatment plants, incorporate submergible transformers, switches and pumps.

Real estate prices, flooding and climate gentrification in Miami

Miami is ground zero for a phenomenon that has been coined "climate gentrification" thanks to more frequent pluvial and coastal flooding in concentrated, low lying urban areas as well as increased frequency and intensity of tropical cyclones.

Average global coastal flood losses in the 136 largest coastal cities in the world have been estimated to be approximatively US$6 billion per year (Lumbroso, 2017). There is an increasing awareness that flood risk is potentially reflected in real estate prices: a report by First Street Foundation found that between 2005 and 2017, property values on the eastern coast of the US lost nearly US$16 billion. This shift in consumer preferences for real estate properties with potentially lower exposure to climate risks is being called "climate gentrification." Miami-Dade County provides a vivid example of this new concept at work.

Historically, wealth has clustered along the beachfront communities in Miami while the higher ground has been occupied by low-income communities of color in neighborhoods like Liberty City, Little Havana and Little Haiti. In the past ten years, waterfront properties have faced more frequent flooding as storms push sea levels past traditional coastlines and into the streets. This is expected to get worse over time: low-lying Miami faces anywhere from 14 to 36 inches of sea rise by 2060. About 2,500 people live on land less than a foot above sea level, according to data from Climate Central.

Many low-income communities at higher elevations now find themselves under increasing pressure to sell their property to real estate developers hoping to build high-end projects for high profits. Little Haiti – often pointed to as the poster child for this phenomena – has seen a 1,121% increase in owner-occupied units between 2000 and 2014.

Some, including Harvard professor Jesse Keenan, argue that this is evidence of climate gentrification and shifting buyer preferences towards properties with lower exposure to flooding. In his 2018 case study, his team reviewed sales of over 100,000 homes in Miami-Dade County from 1971 to 2017 and found that lower elevation houses have gained value more slowly than higher elevation homes. That gap has accelerated after 2000, a trend that seems to support the "climate gentrification" hypothesis.

It should be noted that the converse is not necessarily true: according to the Miami Association of Realtors, properties in expensive, low-elevation neighborhoods like Edgewater and Brickell have not seen a corresponding drop in value and are seeing increased investment and development as well.

Clim INVEST

Tailored climate risk information for financial decision makers

ClimINVEST brings climate scientists and investors together to provide transparency on methodologies for physical climate risk assessment, and develop guidance tools that inform investors' risk management processes. Learn more at www.cicero.oslo.no/en/climinvest

Project ClimINVEST is part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by RCN (NO), ANR (FR), NWO (NL) with co-funding by the European Union (Grant 690462)

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