Climate Impacts in Portugal

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About Climate Analytics

Climate Analytics is a non-profit climate science and policy institute based in Berlin, Germany with offices in New York, USA, Lomé, Togo and Perth, Australia, which brings together interdisciplinary expertise in the scientific and policy aspects of climate change. Our mission is to synthesise and advance scientific knowledge in the area of climate change and on this basis provide support and capacity building to stakeholders. By linking scientific and policy analysis, we provide state-of-the-art solutions to global and national climate change policy challenges.

Climate Analytics was founded in 2008 in Potsdam, Germany by Dr. (h.c) Bill Hare, Dr. Malte Meinshausen and Dr. Michiel Schaeffer to bring vanguard climate science and policy analysis to bear on one of the most pressing global problems of our time: human induced climate change. We are motivated by the desire to empower those most vulnerable – small island states and least developed countries – to use the best science and analysis available in their efforts to secure a global agreement to limit global warming to levels that don't threaten their very survival.

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PORTUGAL

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1. Summary

This report provides scientific evidence on observed and future impacts of climate change in Portugal. Portugal is already experiencing increasing climate change today – with global warming currently at approximately 1°C above pre-industrial levels – which manifests itself in a range of impacts for humans and ecosystems.

Portugal's vulnerability to climate impacts is increasingly recognized in policy circles. During the European Council meeting in December 2019, President von der Leyen stated that "Portugal is one of the countries most affected by climate change". The Intergovernmental Panel on Climate Change (IPCC) has reported that southern Europe has experienced increases in temperature and decreases in precipitation as a result of climate change. In addition, in the Mediterranean region, increases in drought frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C of global warming. Sea level rise exacerbates risks in coastal areas and stresses on land aggravate existing risks to livelihoods, biodiversity, human and ecosystem health, infrastructure and food systems.

In Portugal, mean and extreme temperatures have increased in the past decades and are projected to continue to do so. Under a scenario where global warming reaches about 4.3°C by 2100 (RCP8.5), maximum summer and autumn temperatures in Portugal increase by up to 8°C and maximum spring and winter temperatures increase between 2°C and 4°C. Annual precipitation has decreased and climate models project that this decrease will continue: under a scenario where global warming reaches about 3°C by 2100 (RCP6.0), precipitation will decrease by about 30% in the southern part and by about 15% in the northern part of the country.

Portugal is projected to be exposed to a more than 0.4m projected change in relative sea level in the period 2081-2100 compared with 1986-2005 under a scenario where global warming reaches about 2.5°C by 2100 (RCP4.5). This will result in flooding and coastal erosion. Severe heatwaves, storms and droughts have already affected Portugal and will continue to do so, with increasing frequency and intensity. Increases in extreme precipitation are expected mainly over north-eastern Portugal in winter and spring. Wildfires are, furthermore, occurring more frequently and on a greater scale than originally expected. Relative to other Mediterranean countries, Portugal is the country which has suffered by far the most from forest fires: during the last 30 years, 35% of the region's fire incidents and 39% of the area affected each year were located in Portugal.

These impacts will have sectoral consequences. In the agricultural sector, drought stress is largely responsible for yield gaps. A reduction in crop productivity together with increasing water demand for irrigation are projected. Forest ecosystems will move towards higher altitudes and latitudes and will be exposed to higher fire risks. The Portuguese economy will also be affected as flows in tourism shift and climate-related hazards increase. The Portuguese wine industry is and will continue to be affected by climate change and olive trees are also at great risk. Negative economic impacts from climate change will also be felt in the fishing sector. Labour productivity will also be affected by heat stress as many work hours are lost due to rising temperatures. Under a scenario where global warming increases by about 4.3°C by 2100 (RCP8.5), southern Europe, including Portugal, will experience a widespread loss of working hours by at least 15% by the end of the century. Southern Europe's Gross Domestic Product (GDP) is also predicted to decrease by about 2.78% if global warming rises to 3°C. Under a scenario where global warming increases by about 4.3°C by 2100 the GDP per capita of Portugal is projected to decrease by up to 7.75%.

Climate change impacts also affect human health and lead to fatal illnesses: increasing temperatures cause heat stress and increasing death rates from respiratory diseases. Young children and ageing populations are particularly vulnerable to heat waves and the mortality rates from these extremes will likely increase. Climate change also has a detrimental impact on air quality which in turn has consequences for human health. Long-term exposure to reduced air quality increases premature mortality rates by causing greater instances of illnesses such as lung cancer and cardiopulmonary disease. Ozone (O_3) is a harmful air pollutant which is sensitive to changes in weather conditions such as those caused by climate change; climate change will lead to an increase in human exposure to ozone. Climate change also increase the risk of spread of vector-borne diseases, which have decreased over recent decades. For example, climate change stands to significantly increase the number of days in Portugal with temperatures suitable for the survival of malaria vectors. Globally 88% of the existing burden of diseases caused by climate change is, furthermore, carried by children under the age of five.

Table 1 shows some projected impacts of climate change in key sectors in Portugal.

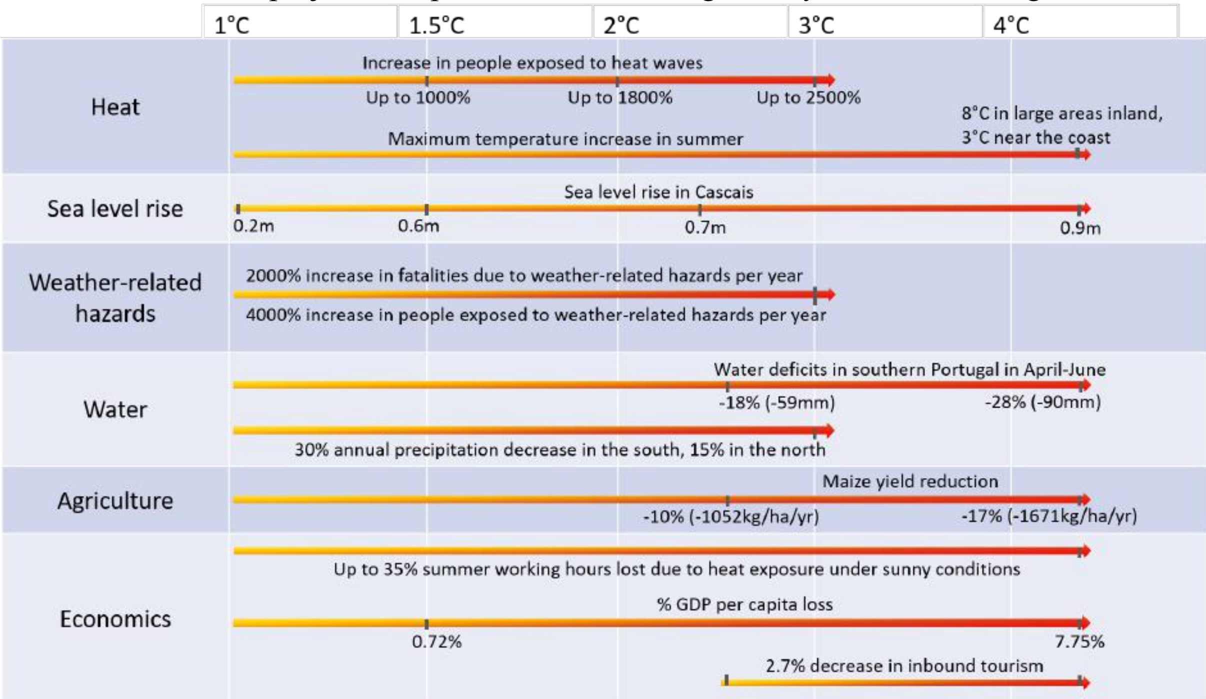


Table 1: Projected impacts of climate change in key sectors in Portugal. The data refers to the impacts which are projected to materialize under various global warming scenarios by the end of the century (for example, sea level rise in Cascais will reach 0.9m under a scenario where global warming reaches about 4.3°C by 2100), except for the data on water deficits in southern Portugal in April-June and on the annual maize yield reduction rate, which refers to impacts projected to materialize during the period 2061-2080 (under a scenario where warming reaches about 2.5°C in 2100 (RCP4.5), the maize yield will reduce by 10% in the period 2061-2080 compared to the baseline period of 1986-2005). All the data and sources can be found in this report.

Under current emission trajectories, Portuguese children will spend more than half their lives in a world warmer than 1.5°C above pre-industrial levels.

2. IPCC summary on climate impacts in Portugal

The Fifth Assessment Report (AR5) of the IPCC (2014) states that projected increases in temperature throughout Europe and decreasing precipitation in southern Europe are to be expected with increasing global warming. Climate projections show a marked increase in high temperature extremes (*high confidence*), meteorological droughts (*medium confidence*), and heavy precipitation events (*high confidence*). Climate change is very likely to increase the frequency and intensity of heat waves, particularly in southern Europe (*high confidence*). This region is particularly vulnerable to climate change (*high confidence*), as multiple sectors will be adversely affected (tourism, agriculture, forestry, infrastructure, energy, population health) (*high confidence*). Climate change and sea level rise may damage European cultural heritage, including buildings, local industries, landscapes, archaeological sites, and iconic places (*medium confidence*), and some cultural landscapes may be lost forever (*low confidence*). Climate change has affected both human health (from increased heat waves) (*medium confidence*) and animal health (changes in infectious diseases) (*high confidence*). Climate change will increase the likelihood of systemic failures across European countries caused by extreme climate events affecting multiple sectors (*medium confidence*). Climate change is expected to impede economic activity in southern Europe more than in other sub-regions (*medium confidence*).

The IPCC special report on the impacts of global warming of 1.5°C (Ove Hoegh-Guldberg et al., 2018) emphasizes that limiting global warming to 1.5°C is expected to substantially reduce the probability of extreme drought, precipitation deficits, and risks associated with water availability (i.e. water stress) in some regions (*medium confidence*). In particular, risks associated with increases in drought frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C in the Mediterranean region (including southern Europe, northern Africa and the Middle East) and southern Africa (*medium confidence*).

In its special report on the ocean and cryosphere in a changing climate (IPCC, 2019a), the IPCC states that global mean sea level is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (*very high confidence*), as well as continued glacier mass loss and ocean thermal expansion. Sea level continues to rise at an increasing rate (*very high confidence*), exacerbating risks in coastal areas. It also finds that since about 1950, many marine species have undergone shifts in geographical range and seasonal activities *(high confidence)*, and that warming-induced species range expansions have led to altered ecosystem structure and functioning such as in the North Atlantic, Northeast Pacific and Arctic (*medium confidence*). A decrease in global biomass of marine animal communities, their production, and fisheries catch potential, and a shift in species composition are projected over the 21st century in ocean ecosystems from the surface to the deep seafloor under all emission scenarios (*medium confidence).*

The IPCC's special report on climate change and land (IPCC, 2019b) explains that climate change creates additional stresses on land, exacerbating existing risks to livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems (*high confidence*). In addition, with increasing warming, the frequency, intensity and duration of heat-related events including heatwaves are projected to continue to increase throughout the 21st century (*high confidence*). Frequency and intensity of droughts has increased in some regions including the Mediterranean (*medium confidence*) and there has been an increase in the intensity of heavy precipitation events at a global scale (*medium confidence*), impacting food security and terrestrial ecosystems as well as contributing to desertification and land degradation (*high confidence*). Furthermore, the Mediterranean, among other regions, may be increasingly affected by wildfire *(very high confidence).*

3. Technical note: Representative Concentration Pathways, climate impacts analysis and projected temperature warming

Representative Concentration Pathways

A scenario is a plausible description of how the future may develop, based on assumptions about key forces which drive climate change and the relationships between them (IPCC, 2014b). A Representative Concentration Pathway (RCP) is a suite of scenarios based on possible future emissions trajectories and concentrations of greenhouse gases, aerosols and land use (Moss et al., 2008).

The IPCC and the climate modelling community use four different RCPs (RCP 2.6, 4.5, 6.0, 8.5) (Moss et al., 2010), including when assessing the likely impacts of climate change under different scenarios. An approximation of the range of increases in the global average temperature by 2100 (in comparison to pre-industrial times) is associated with each of these RCPs. These ranges reflect the considerable uncertainty surrounding the response of the climate system to anthropogenic greenhouse gas emissions (which in turn stems from uncertainties relating to feedback processes in the earth system). The IPCC AR5 report estimates the transient climate response to cumulative CO_2 emissions to be between 0.2-0.7°C per 1000 Gt CO_2.

Table 2 shows (in square brackets) the “likely” range of temperature increases associated with each RCP, as assessed in the IPCC AR5. This means that, for each RCP, there is a 66% probability of warming falling within the range associated with that RCP. This leaves a non-negligible 17% chance of warming exceeding that range. The median (best estimate) projected temperature increase associated with each RCP, again as assessed in the IPCC’s AR5, is also provided in Table 2.

Name	**Expected temperature increase over the 2081-2100 period (median and [66% range])**
RCP2.6	1.6°C [0.9-2.3°C]
RCP4.5	2.4°C [1.7-3.2°C]
RCP6.0	2.8°C [2.0-3.7°C]
RCP8.5	4.3°C [3.2-5.6°C]

Table 2: Warming under different Representative Concentration Pathways scenarios. The expected temperature increases given for the period 2081-2100 assumes that 0.61°C of warming has occurred between 1986–2005. Source: (Stocker et al., 2013)

Climate change impacts analysis and RCPs

Substantial effort is required to provide climate and climate impact simulations. For this reason, not all of the above RCPs are relied upon in equal measure in the scientific studies which seek to generate different types of climate impact simulations. Many studies in climate research use a subset of the RCPs (deploying either RCP8.5, RCP4.5 or RCP2.6 or several scenarios) and hence do not provide estimates of impacts under all warming levels. The analysis which follows draws on the available studies which analyse the impacts anticipated to result from climate change in Portugal under various RCPs. The relevant RCPs will be referred to by reference to the expected median temperature increase by 2100 associated with them (for example, RCP8.5 will be referred to as "a global warming scenario of about 4.3°C by 2100 (RCP8.5)"). For high emission scenarios either RCP8.5 and RCP6.0 are used, while RCP2.6 is consistently used for a low emission scenario.

Climate Action Tracker projections

The Climate Action Tracker provides best estimates of the emissions pathways and associated warming trajectories throughout the 21st century which will result from both countries' combined Nationally Determined Contributions under the Paris Agreement and their national climate change mitigation policies if the same level of ambition was displayed over the course of the 21st century. These are shown in Figure 1 below. In the case of "Pledges & Targets" which have been adopted by governments to date, the temperature range provided reflects the climate response uncertainty referred to above. In the case of "Current Policies," the temperature range provided reflects both climate response uncertainty as well as uncertainty related to emissions pathways associated with government policies. Specifically, the Climate Action Tracker evaluates two current policy pathways, high and low, to account for uncertainties relating to the quantification of emissions reductions associated with current government policies. For each of these high and low pathways, the climate response uncertainty is reflected in the 66% likely temperature range which it produces, from which a median figure is then derived. The median figure of 3.0°C provided for "Current Policies" is therefore the average of the median temperatures of both the high and low current policy pathways. The higher (4.1°C) and lower (2.3°C) end figures listed in relation to current policies range from the 17% probability percentile of the lower pathway to the 83% probability percentile of the high current policy pathway.

As Figure 1 makes clear, current policies are projected to lead to a median warming of about 3°C by 2100, while warming of 4°C by the end of the century is within the uncertainty range under current policy projections. Furthermore, there is a non-negligible 17% probability of warming exceeding 4.1°C by the end of the century under emissions projections derived from current policies (high estimate). There is therefore a significant overlap between the warming range projected to result from current policies and the warming range of 3.2-5.6°C associated with the RCP8.5 scenario. Accordingly, based on current mitigation policies globally, climate impacts occurring under a RCP8.5 scenario cannot be excluded as a distinct possibility. It is important to note in this context that recent studies which indicate a refined range of warming estimates with lower probabilities for extreme warming outcomes (Sherwood et al., 2020) do not fundamentally affect this assessment.

Finally, following the best estimate of the future temperature trajectory based on the Climate Action Tracker, the global mean temperature will exceed 1.5°C around the year 2035 (model median) and 2°C around the year 2055; by 2100 it will have exceeded 3°C in 2100 (Climate Action Tracker, 2018). Today's average Portuguese 14-year old is expected to live until the age of 91 and has a 99% probability of being alive in 2035, 98% in 2055 and 16% in 2100 (World Data Lab, 2019).

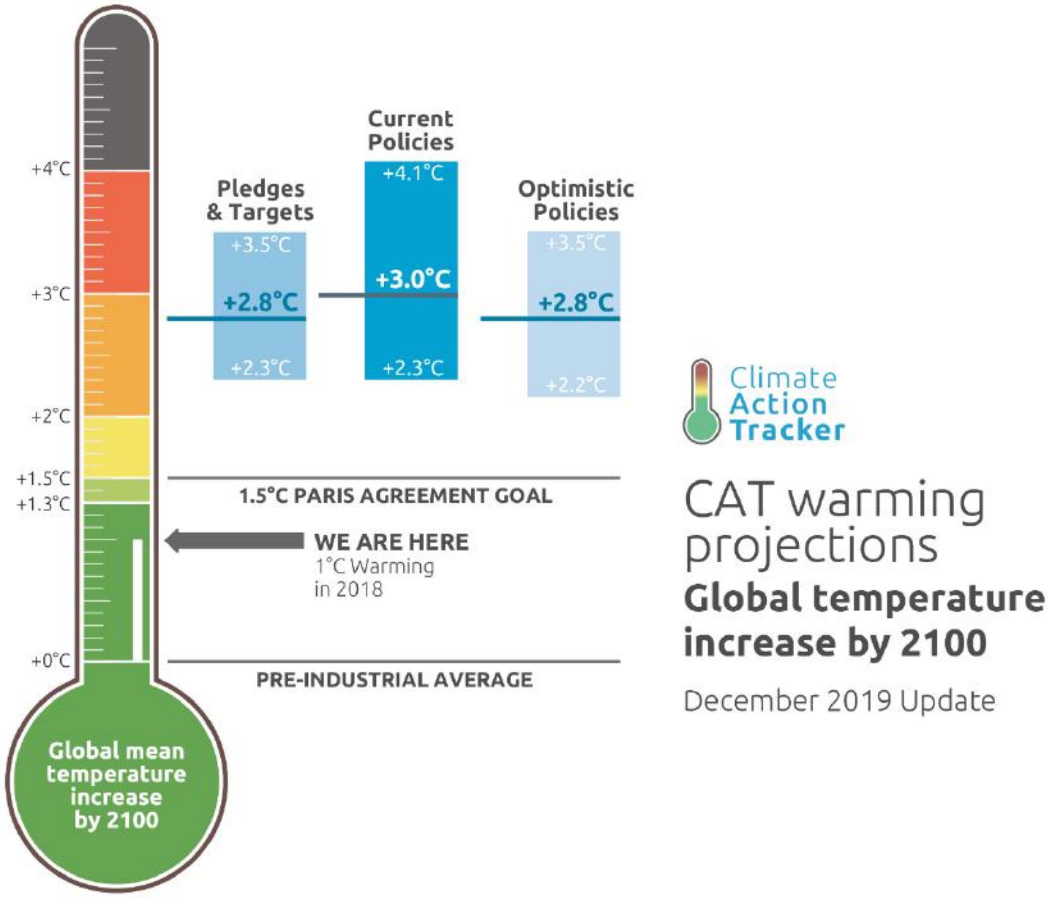


Figure 1: Climate Action Tracker warming projections. Warming is shown for three different assumptions about future warming differentiating between targets of countries and actual policies in place to meet those targets. Source: (Climate Action Tracker , 2019)

4. Temperature increase

Portugal has a Mediterranean climate characterized by warm and dry summers and cool and wet winters (Carvalho et al., 2014). The vulnerability of Portugal to present day climate variability is well established (Gomes et al., 2018). Portugal has experienced a rise in mean temperatures accompanied by intensifying extremely high temperatures (Cardoso et al., 2019). Furthermore, eight of Portugal's 10 warmest years on record have been recorded in the last 20 years (Carvalho et al., 2014). Figure 2 shows the historical mean annual temperature for Portugal between 1971-2000.

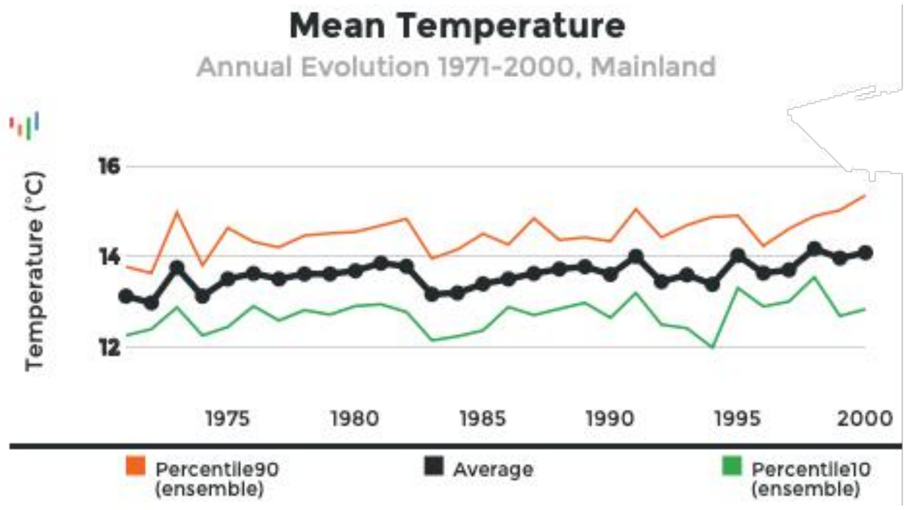


Figure 2: Modelled historical mean annual temperature for mainland Portugal (1971-2000) (derived from: http://portaldoclima.pt/en/)

Multi-model ensembles project a "significant increase of the maximum and minimum temperatures in all seasons and scenarios" (Cardoso et al., 2019). Under a global warming scenario of 4.3°C by 2100 (RCP8.5), maximum summer and autumn temperatures in Portugal increase by up to 8°C and maximum spring and winter temperatures increase between 2°C and 4°C (Cardoso et al., 2019). The same scenario projects that the mean daily maximum temperature increase by up to 4.5°C in some inland regions, and between 3 and 4°C near the coasts (Cardoso et al., 2019). For summer specifically, the mean daily maximum temperatures could increase by 3°C near the coast and by up to more than 8°C in large areas inland. Moreover, half of the extended summer months (May, June, July, August, September) will experience maximum temperatures exceeding the historical 90th percentile. These months are also projected to experience 60 tropical nights per year in contrast with the 7 tropical nights per year which would have been typical in the historical period (Cardoso et al., 2019). In general, under a global warming scenario of about 4.3°C by 2100 (RCP8.5), temperatures in Portugal will almost never drop below 2°C, whereas temperatures above 40°C will be much more common (Cardoso et al., 2019).

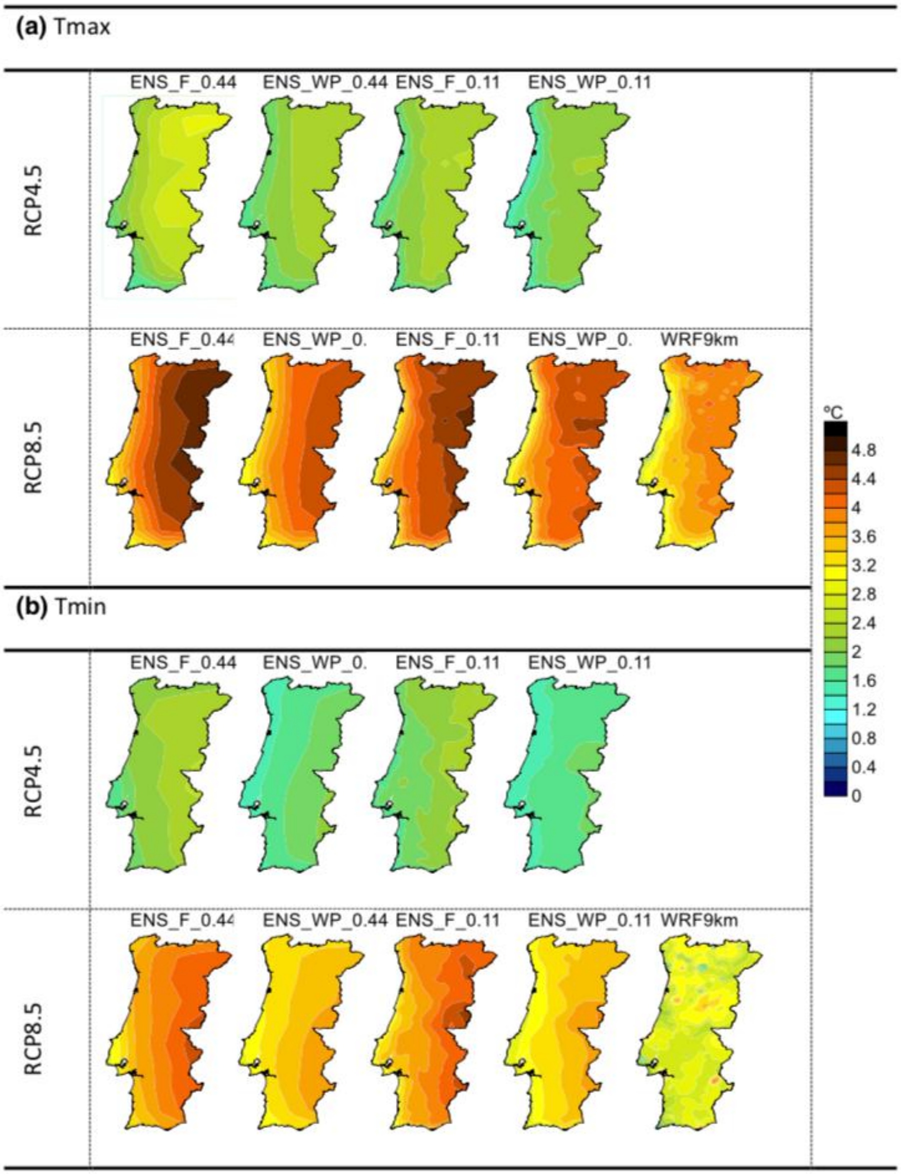


Figure 3: Climate change signal for daily temperatures (a) maximum, and (b) minimum, (2071-2100 minus 1971-2000) for a global warming scenario of 2.5°C (RCP4.5) and 4.3°C by 2100 (RCP8.5) (Cardoso et al., 2019).

5. Precipitation

Portugal is one of the countries with the largest spatial precipitation gradients, from the north-western region, which is directly affected by the passage of Atlantic storms, to the drier southern regions (Soares et al., 2015). Migratory storms are responsible for most of the annual precipitation between November and April. According to Carvalho et al., “In the period 1902–2010, the region has experienced 10 of the 12 driest winter seasons in the last 20 years“ (Carvalho et al., 2014). In total, annual precipitation has decreased by 90mm per decade in Portugal (Füssel et al., 2017).

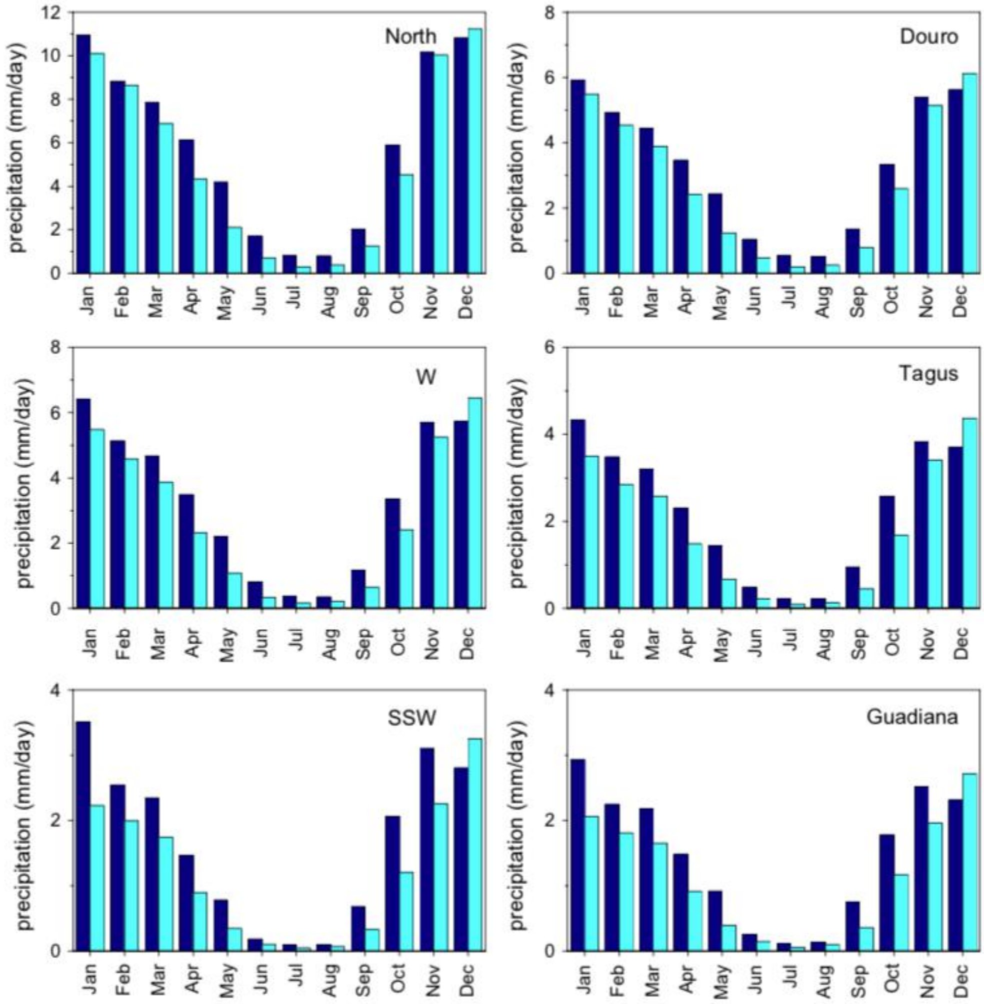
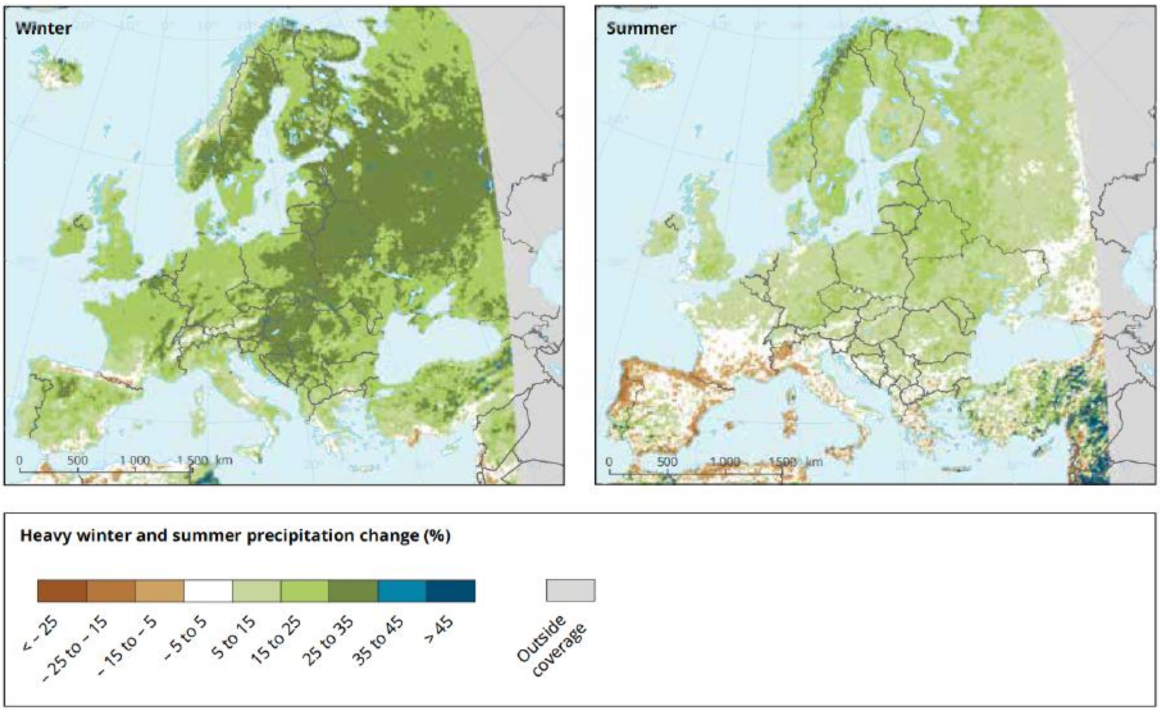


Figure 4: Present (blue) and future (light blue) monthly mean precipitation for the six basins of Portugal (Ensemble of 5 regional climate models for a A1B-scenario (RCP6.0 – global warming of 2.8°C by 2100)) (Soares et al., 2015).

A future global warming scenario of 2.8°C by 2100 (RCP6.0), would lead to an annual precipitation decrease of 15% in the northern part of the country, and 30% in the south (Soares et al., 2015). These precipitation decreases have a sharp seasonal dependency, as values above 50% occur in some places in summer, while they are only at 20-30% in autumn and spring and there is only a very small decrease or even a slight increase in winter (Soares et al., 2015). Expected precipitation changes for 6 water basins in Portugal can be seen in more detail in Figure 4, where the light blue bars indicate the future monthly mean precipitation under a global warming scenario of 2.8°C (RCP6.0).

In general, southern Europe is expected to experience an overall decrease in total precipitation, an increase in heavy precipitation events and a significant increase in the length of dry spells (Hov et al., 2013). The projected increase in heavy precipitation in winter over Portugal and Europe is illustrated in Figure 5. The decrease in overall precipitation leads to a reduction in soil moisture; this leads to greater availability of sensible heat flux which in turn heats the atmosphere (Cardoso et al., 2019).



Note: This map shows projected changes in heavy daily precipitation (%) in winter and summer for 2071–2100, compared with the baseline period 1971–2000, for the RCP8.5 scenario based on the ensemble mean of different RCMs nested in different GCMs.

Source: EURO-CORDEX (Jacob et al., 2014).

Figure 5: Projected changes in heavy precipitation in winter and summer (Füssel et al., 2017).

6. Sea level rise

Mean and extreme sea levels have increased globally and along most coasts in Europe (Füssel et al., 2017). Currently, the global mean sea level is about 20 cm higher than at the beginning of the 20th century (European Environment Agency, 2017). In Portugal, estuaries and coastal lagoons will be the coastal areas most affected by sea-level rise (Ferreira et al., 2008). Amongst these, the Sado and Tagus estuaries, and the Ria de Aveiro and the Ria Formosa coastal lagoons are the ones where socio-economic impacts resulting from sea-level rise will likely be greater (Ferreira et al., 2008).

Figure 6 shows the projected change in relative sea level in Europe.

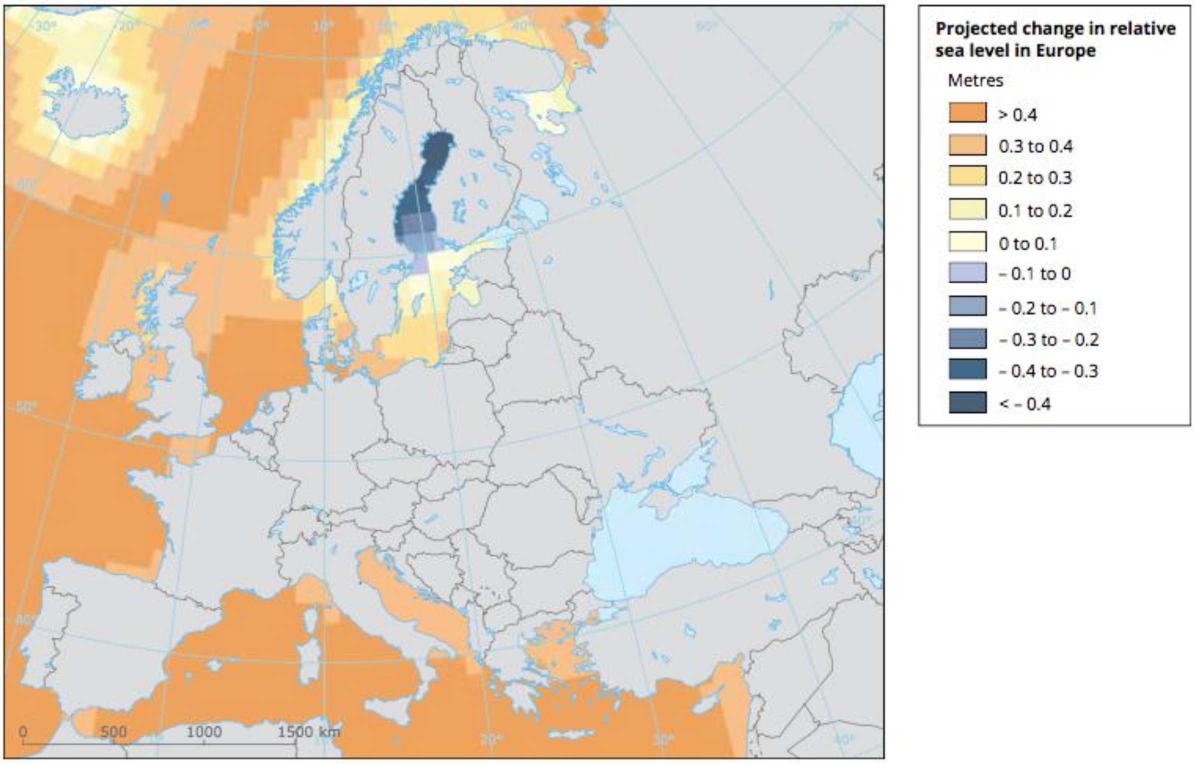


Figure 6: Projected change in relative sea level in Europe in the period 2081-2100 compared with 1986-2005 for a scenario of 2.5°C expected temperature rise by 2100 (RCP4.5) from (Füssel et al., 2017)

Figure 7 shows the projections for the tide gauge station of Cascais, around 40 kms west of Lisbon.

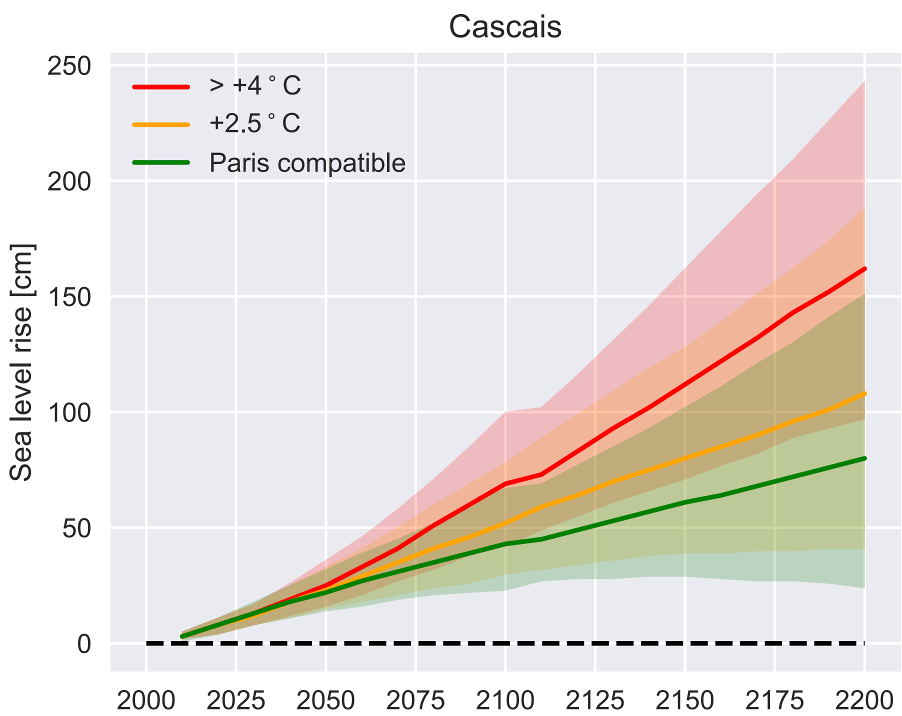


Figure 7: Local sea level projections for Cascais (located in south central Portugal close to Lisbon) for a scenario compatible with the Paris Agreement (green), a scenario leading to +2.5°C global mean temperature (orange) and a scenario exceeding +4°C (red). The solid lines represent multi-model medians, the shaded areas include 66% of the models (retrieved from http://localslr.climateanalytics.org/location/Cascais)

A recent study by Mengel et al. (2018) analyses the relationship between near term emissions reduction compatible with the Paris Agreement and sea level rise. As illustrated in Figure 8, the timing of mitigation actions matters for long-term sea level rise. Every 5 year delay in peaking global CO_2 emissions will lead to an additional 20 cm sea level rise by 2300, about as much as observed sea level rise since the pre-industrial times. This represents a long-term commitment that cannot be reversed.

Future generations well beyond today's children will therefore be affected by short-term actions and decisions taken today (Mengel et al. 2018). For higher emission scenarios, reaching 2°C, 3°C or even >4°C, much higher levels of sea level rise, up to many meters, can be expected over the coming centuries. The emissions implied by the current combined Nationally Determined Contributions of States under the Paris Agreement are projected to lead a long-term sea-level rise of well above 5m within this millennium (Clark et al., 2018)

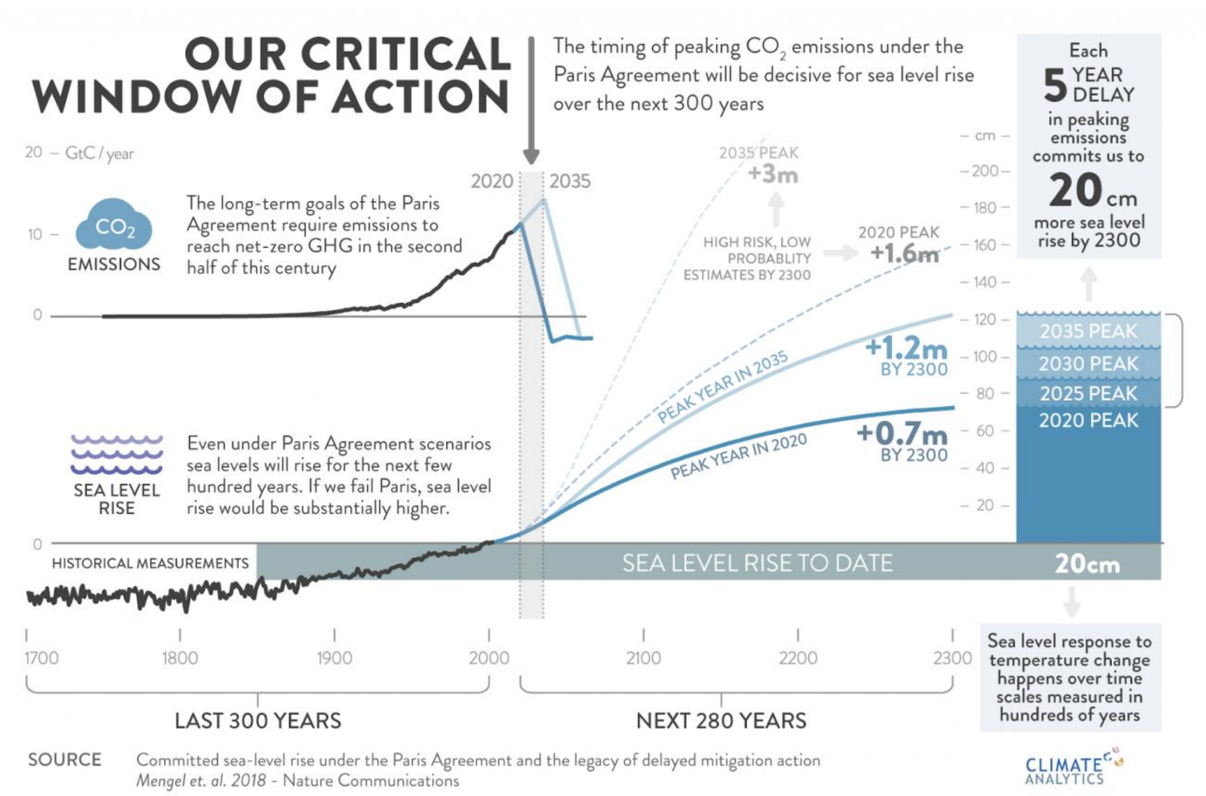


Figure 8: Critical window of action for sea level rise over the next 300 years

In addition to sea level rise, coastal conditions are already endangered by flooding and erosion, both of which are likely to increase as a result of climate change (Coelho et al., 2009; Hov et al., 2013). The increase in the occurrence of extreme weather events, the weakening of river-sediment supplies and the acceleration of sea level rise aggravate coastal erosion (Coelho et al., 2009). This puts the Portuguese continental coast (where erosion is already significant along about 67% of its length) at greater risk of inundation and land loss due to sea level rise (Carvalho et al., 2014). Currently, the shoreline of Portugal is retreating at an annual average of 9 meters in some locations as a result of weakening river sediment supplies because of dams and embankments (Hov et al., 2013). Based on the current state of coastal erosion along the northwest Portuguese coast, the anticipated sea level rise resulting from climate change should have a significant effect in 2050-2100 on the already high sedimentary deficit (Silva et al., 2007).

7. Extreme weather events

The observations show a tendency towards more frequent and intense extreme weather events, in particular heat waves, droughts and extreme precipitation (Carvalho et al., 2014). The Mediterranean region, and specifically Portugal, is regarded as a climate hotspot, which is, among other impacts, projected to experience the greatest drying among 26 regions across the globe (Carvalho et al., 2014).

7.1 Heat waves

Portugal and the wider Mediterranean region have experienced an increase in the frequency of heatwaves (Hov et al., 2013). Between 1981-2010 a total of 130 heat waves occurred in the mainland of Portugal during the dryer and hotter periods (between May and October) (Parente et al., 2018). 60% of the total number of these heat waves occurred in July and August (Parente et al., 2018). The areas with the most heatwaves were the north-east quarter and the southernmost region of Portugal (Parente et al., 2018). Also affected, but to a lesser extent and magnitude, were the central western coastal region and the metropolitan areas of Porto and Lisbon (Parente et al., 2018).

A study from 2011 on Portugal shows that there has been a significant positive trend in heat waves, tropical nights, summer days, warm spells and warm nights and days since 1976 (Ramos et al., 2011). This study observed a simultaneous negative trend in cold extremes, particularly in winter (Ramos et al., 2011). In 2017, a European heat wave and heat stress led to extreme forest fires across Europe including Portugal leading to the evacuation of thousands of people (Vitolo et al., 2019). During the following summer of 2018, all-time records were broken in Portugal, where unprecedented absolute temperatures were recorded. In August 2018, western Iberia (including Portugal) reached values beyond 45°C (Sousa et al., 2019). Figure 9 displays the temperatures during the summer of 2018, the new all-time temperature records and the difference between the observed maximum temperatures and the previous all-time temperature records. For example, in the area of Lisbon, it can be observed that the previous record of 42°C (established during August 2003) was surpassed by 2°C, setting a new absolute value of 44°C (Sousa et al., 2019). This heat event was followed by another major heat wave in June 2019, where in regions of eastern Iberia (including Spain and parts of Portugal) absolute temperature records were broken again (Sousa et al., 2019). These increasing trends are directly attributable to general mean warming trends (Parente et al., 2018)

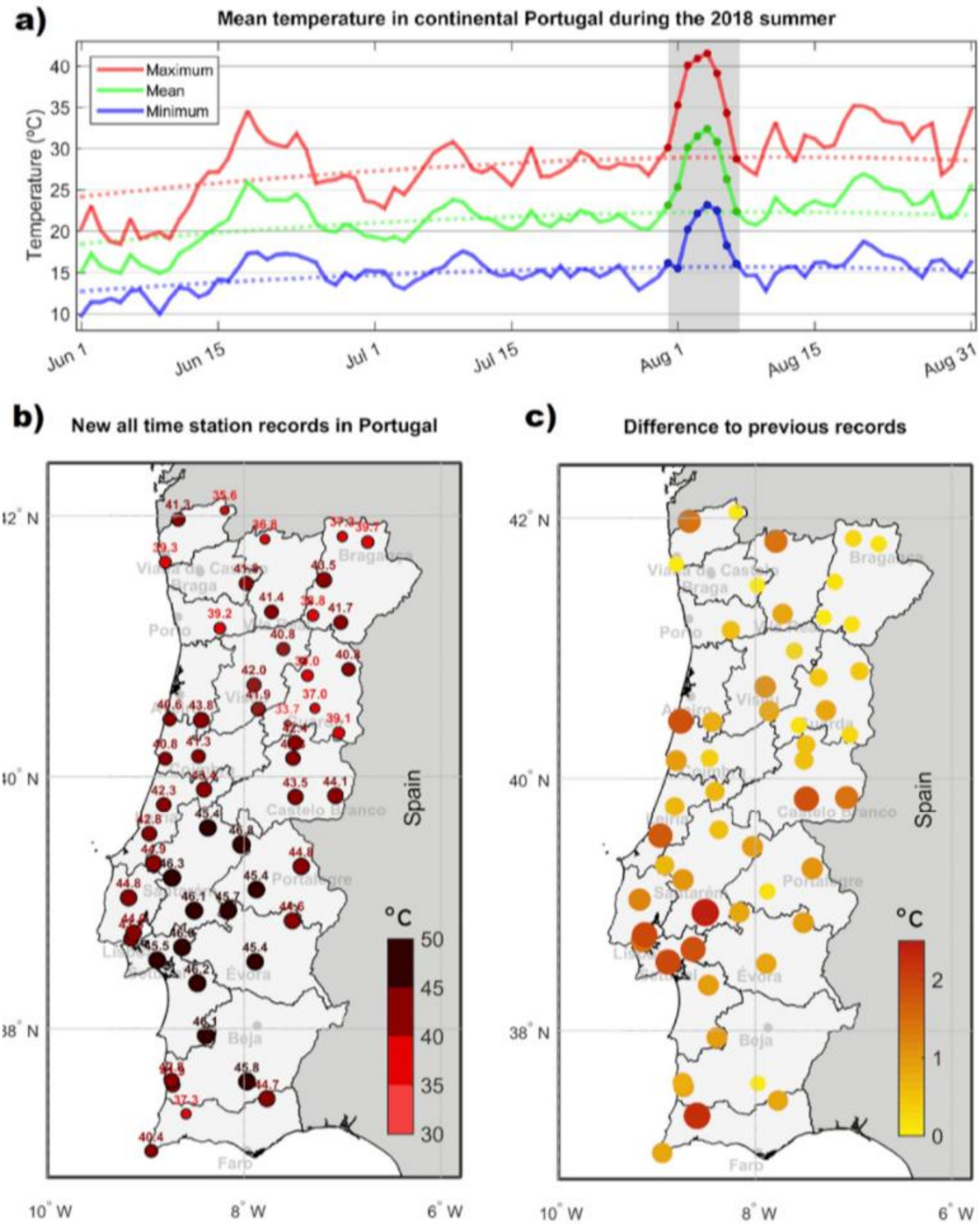


Figure 9: (a) Evolution of mean temperature in Portugal throughout the 2018 summer (thick lines), compared with the climatological mean (stippled lines), (b) New all-time temperature records established during early August 2018, (c) Difference between the observed maximum temperatures during the event and the previous all-time records (Sousa et al., 2019).

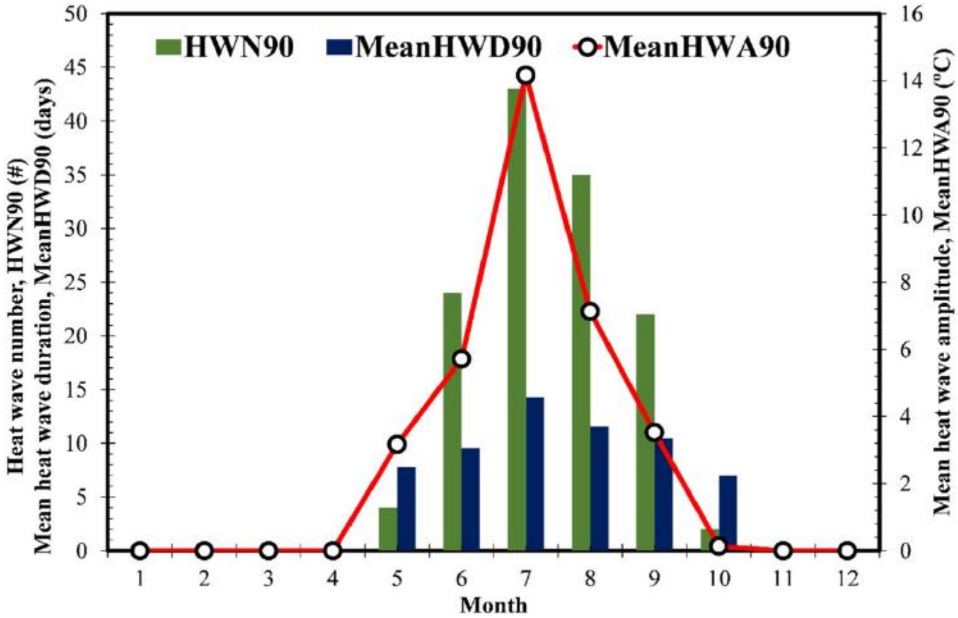


Figure 10: Monthly distribution of heat wave number (HWN90) and mean heat wave amplitude (MeanHWA90) for control period (1981-2010) (Parente et al., 2018).

The two-week heat wave event in August 2003 counts as the warmest August on record for the country in terms of mean air temperature (Sousa et al., 2019). Moreover, it is counted as one of the 10 costliest natural catastrophes in Europe between 1980 and 2010 (Hov et al., 2013). During this event, a total of 12,300 million Euro was lost and 70,000 fatalities were recorded (Hov et al., 2013).

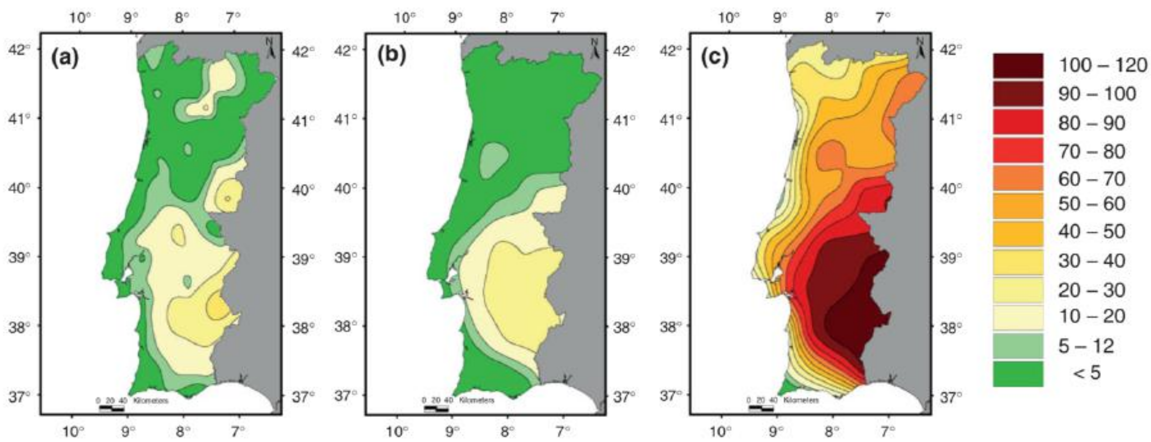


Figure 11: Number of hot days per year with maximum temperature above 35°C (summer days) for the (a) 1961-1990 climatology; (b) HadRM2 control simulations (model simulations aiming to reproduce the climatology of 1961-1990. A control run shows how well a model performs and how reliable the information is for future projections); (c) HadRM2 simulation (2081-2100) (Carvalho et al., 2014).

The frequency and severity of heat waves will progressively increase with global warming, accompanied by a gradual decline in the intensity and frequency of extreme cold spells. Multi-model ensembles project that the yearly average number of heat waves increases by 7 to 9-fold by 2100 under a global warming scenario of 4.3°C (RCP8.5) (Cardoso et al., 2019). Under the same scenario, the average length of such heat waves increases from 5 to 22 days throughout the 21st century, with 5% of the longest events being more than 30 days in duration; it is also projected that in the time period 2071-2100, heat waves will cover the entire country at least 3 times per year (Cardoso et al., 2019). According to another study, in a 3°C warmer climate compared to pre-industrial times, a current 1-in-50-year heatwave may occur almost annually in parts of Portugal. On the other hand, the strongest absolute reductions in exposure to cold extremes are projected for southern and northern European countries, including Portugal, which is projected to experience the fourth largest reduction in Europe (-93% of exposure) under a 3°C warming (Naumann et al., 2020)

This increase in heat will lead to dangerous conditions which are more conducive to the outbreak of wild fires, as outlined in the following section.

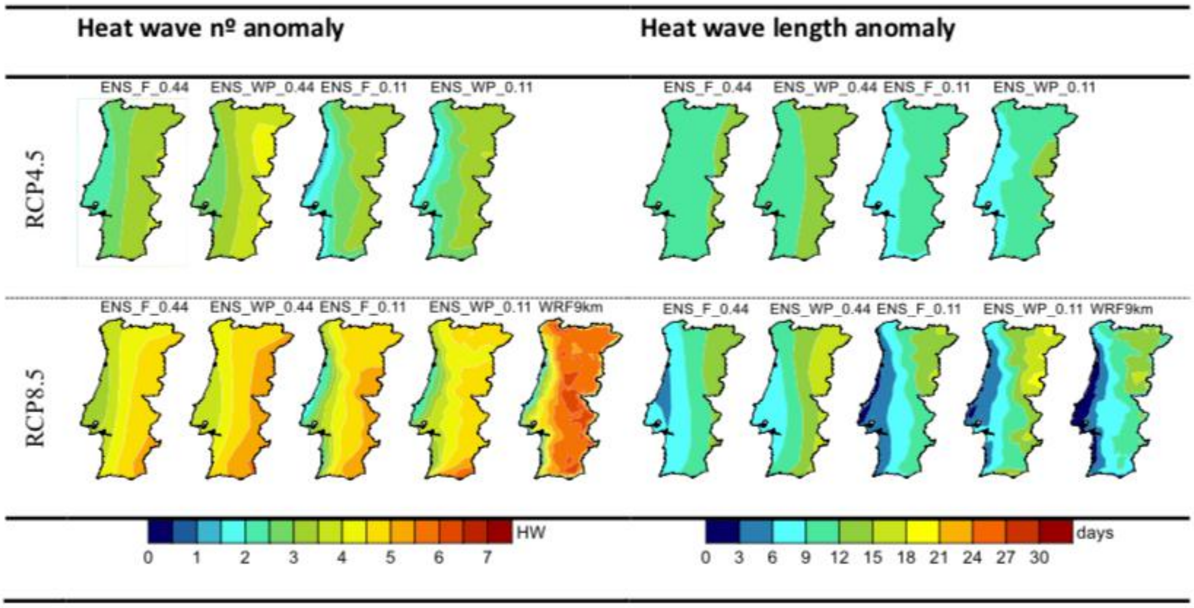


Figure 12: Projected (a) average number of heat waves and (b) average length of heat waves for end of the 21st century under a global warming scenarios of 2.5°C (RCP4.5) and 4.3°C (RCP8.5) (Cardoso et al., 2019).

7.2 Wild fires

Extensive forest fires have already taken a very high toll in Portugal (European Commission, 2019). Between 1966 and 2017 around 160 major wildfires and heat waves occurred in Europe, which together caused 140,000 deaths (Vitolo et al., 2019). Wildfires are also extremely financially costly. The 6 largest wildfires in Europe (Spain, Portugal, Croatia and Montenegro) resulted in damage costing up to 732 Million US Dollars (Vitolo et al., 2019). Portugal is the Mediterranean country which has suffered by far the most from forest fires: during the last 30 years, 35% of the region's fire incidents and 39% of the area affected each year were located in Portugal. On average, 3% of Portugal's forests burn annually (Hernández, 2019).

The factors that favour the occurrence of heat waves, namely, reduced precipitation, drought and intense hot spells, are also the main drivers of wildfires (Parente et al., 2018). The regions which have experienced the most heatwaves in Portugal in modern times, namely the southwest and northeast, are precisely those regions where most of the wildfires have occurred (Parente et al., 2018). It has been shown that all of the wildfires which occurred in these regions did so during (96.8%) or immediately after (3.2%) long heatwaves (Parente et al., 2018). During the heat wave in 2003, about 390,000 hectares of forests in Portugal were destroyed by fire, which amounts to 60% of the total area burnt throughout Europe during that heatwave (Parente et al., 2018).

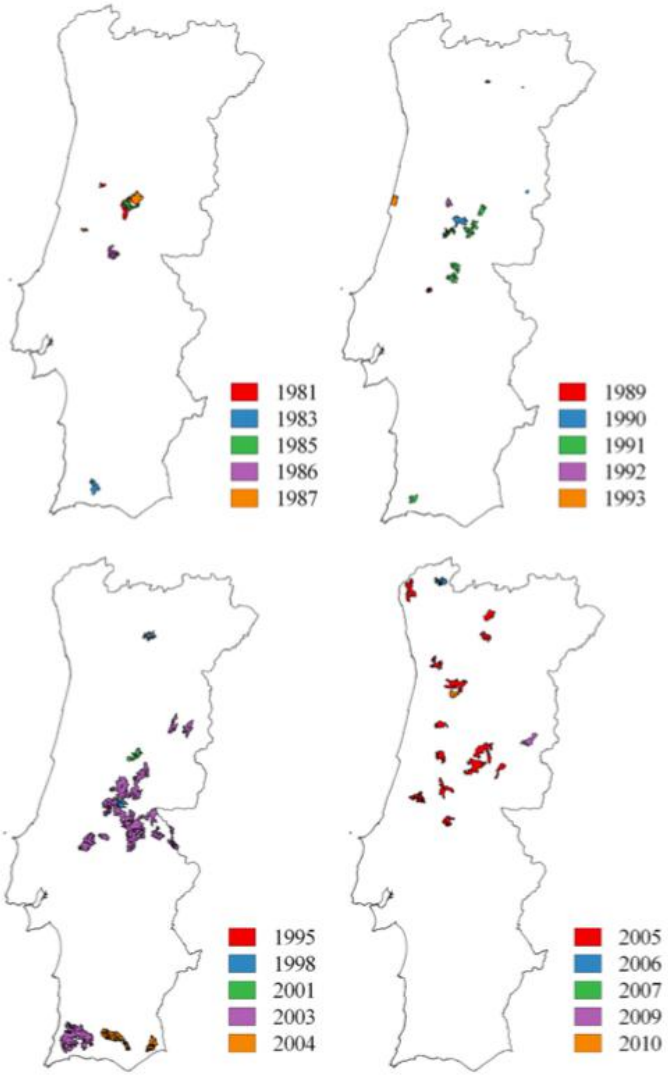


Figure 13: Spatial and temporal distribution of extreme wildfires (burnt area > 5,000 ha) between 1981 and 2010 (Parente et al., 2018).

During the extreme wildfires of 2017, a record 500,000 hectares were burned in Portugal and 120 human lives were lost (Turco et al., 2019). The prior heat wave event was started by an intrusion of warm air, resulting from the subtropical ridge, of a kind which had never previously been seen as early as June (Turco et al., 2019). The circumstances of anomalous high temperatures and relatively low humidity strengthened the local fires (Turco et al., 2019). The fires that happened later that year in October, however, were exacerbated by strong and persistent southerly winds caused by hurricane Ophelia moving northward. These winds, together with the dry soil and vegetation resulting from extremely high temperatures in 2017, exacerbated the extreme fires (Turco et al., 2019).

The total area affected by forest fires has decreased in recent years in almost all Mediterranean countries due to a general increase in the effectiveness of firefighting mechanisms and a reduction in the total number of incidents. The opposite is true in Portugal, however, where the burnt area has continued to grow, as Figure 14 demonstrates (Hernández, 2019).

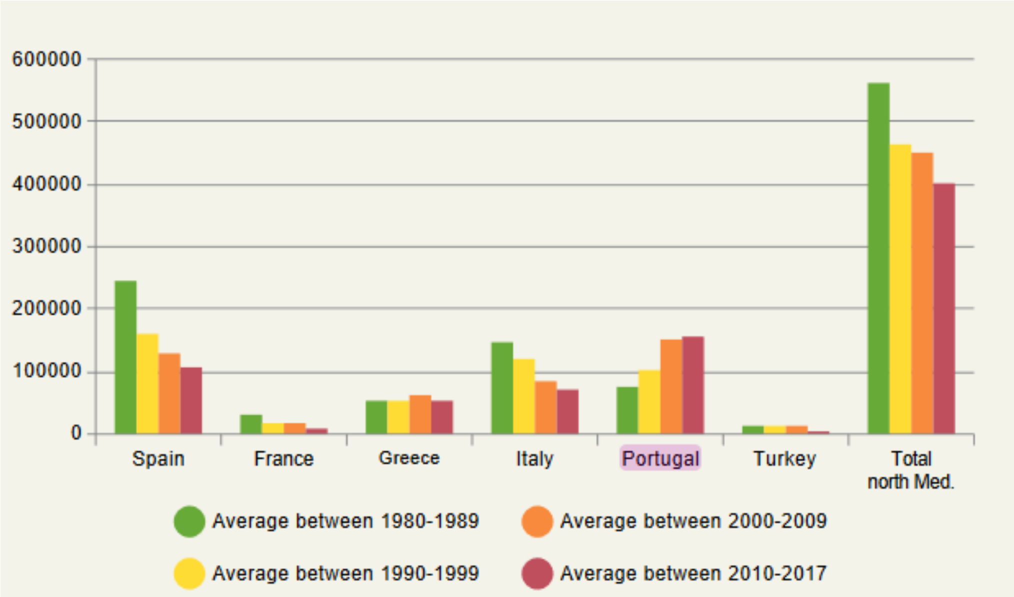


Figure 14: Trends in the total area affected (ha) per decade and per country (Hernández, 2019).

Increasing temperatures and reduced precipitation leads to a significant decrease in the amount of soil moisture (Nunes et al., 2019), causing an increased fire risk (Turco et al., 2019). Future warming will therefore increase the number, duration and amplitude of heat waves and thus wildfires (especially in the north-east region) (Parente et al., 2018). Indeed, according to a World Wildlife Fund report on Mediterranean fires, climate change is accelerating and intensifying the occurrence of large fires at a faster pace than originally expected (Hernández, 2019). The IPCC's special report on climate change and land further indicates that the risk of wildfires in future is expected to increase significantly in some regions including Southern Europe (Jia et al., 2019). Figure 15, which is drawn from that report, demonstrates how Portugal is projected to remain a particularly fire prone region under both of the scenarios on which that figure is based.

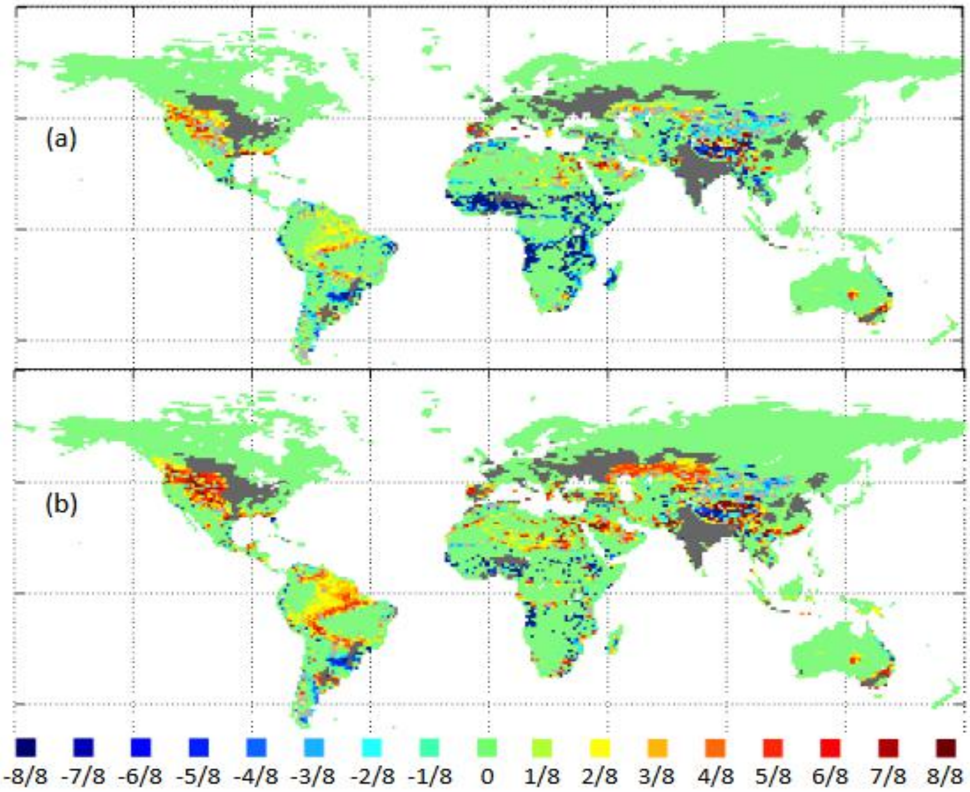


Figure 15: The probability of low-fire regions becoming fire prone (positive values), or of fire-prone areas changing to a low fire state (negative values) between 1971-2000 and 2071-2100. The data is based on eight-Earth system model ensembles, two Shared Socio-economic Pathways (SSPs) and two Representative Concentration Pathways (RCPs). Light grey: area where at least one ensemble simulation predicts a positive and one negative change (lack of agreement). Dark grey: area with >50% past or future cropland. Fire-prone areas are defined as having a fire frequency of >0.01 yr-1, (a) RCP4.5 emissions with SSP3 demographics, and (b) RCP8.5 emissions with SSP5 demographics. (Jia et al., 2019)

Figures 16, 17 and 18 illustrate the projected rise, over the period 2071-2100, in the number of days on which there will be an extreme risk of wildfire in the Lisbon metropolitan area, the Centro region and the Alentejo region, under a global warming scenario of 4.3°C by 2100 (RCP8.5). The mean number of such days rises to 50 per year by 2100 in the Lisbon metropolitan area, up from 20 in 2000.

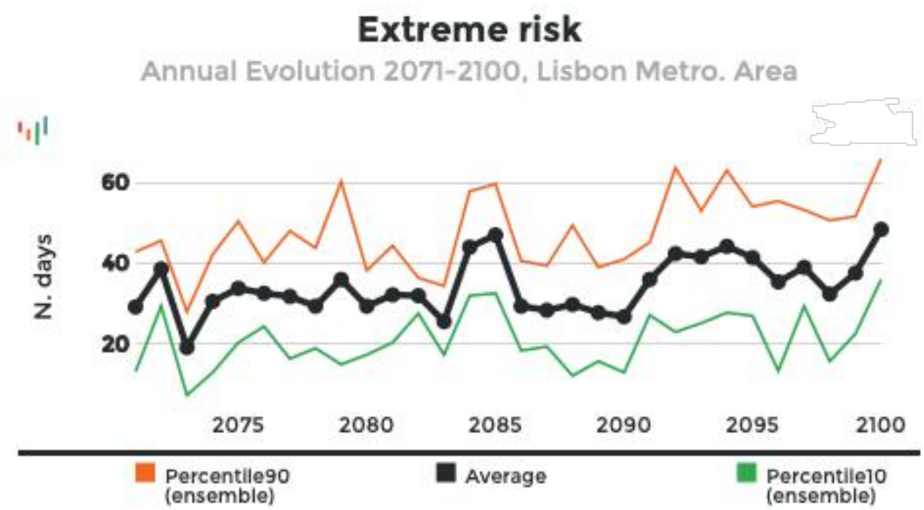


Figure 16: Annual evolution of extreme risk to wildfires in the metropolitan area of Lisbon for a global warming scenario of 4.3°C by 2100 (RCP8.5) for 2071-2100 (derived from http://portaxldoclima.pt/en/).

In the Centro region, that number rises to nearly 40 days per year by 2100 up from 6 in 2000.

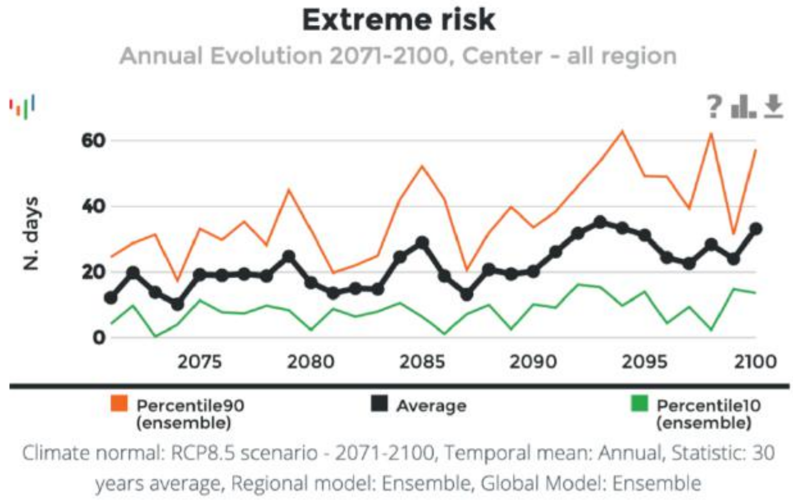


Figure 17: Extreme fire risk projections for the Centro region of Portugal for scenarios of 4.3°C of expected temperature increase by 2100 (RCP8.5) (retrieved from: http://portaldoclima.pt/en/)

For the Alentejo region, the mean number of days on which there is an extreme risk of wildfire will rise to 80 days per year in 2100 compared to 20 days per year in 2000.

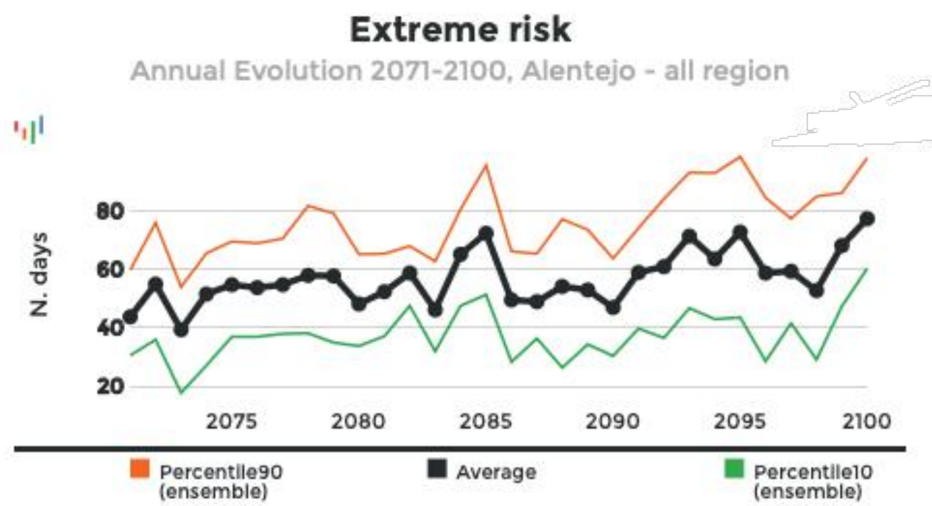


Figure 18: Annual evolution of extreme risk to wildfires in the area of Alentejo for a global warming scenario of 4.3°C by 2100 (RCP8.5) for 2071-2100 (derived from http://portaldoclima.pt/en/).

Figure19 further demonstrates that in the part of the Alentejo region which is closest to the Spanish border, the number of such days rises to 90 days per year (compared to 22 days in 2000), again under a global warming scenario of 4.3°C by 2100 (RCP8.5).

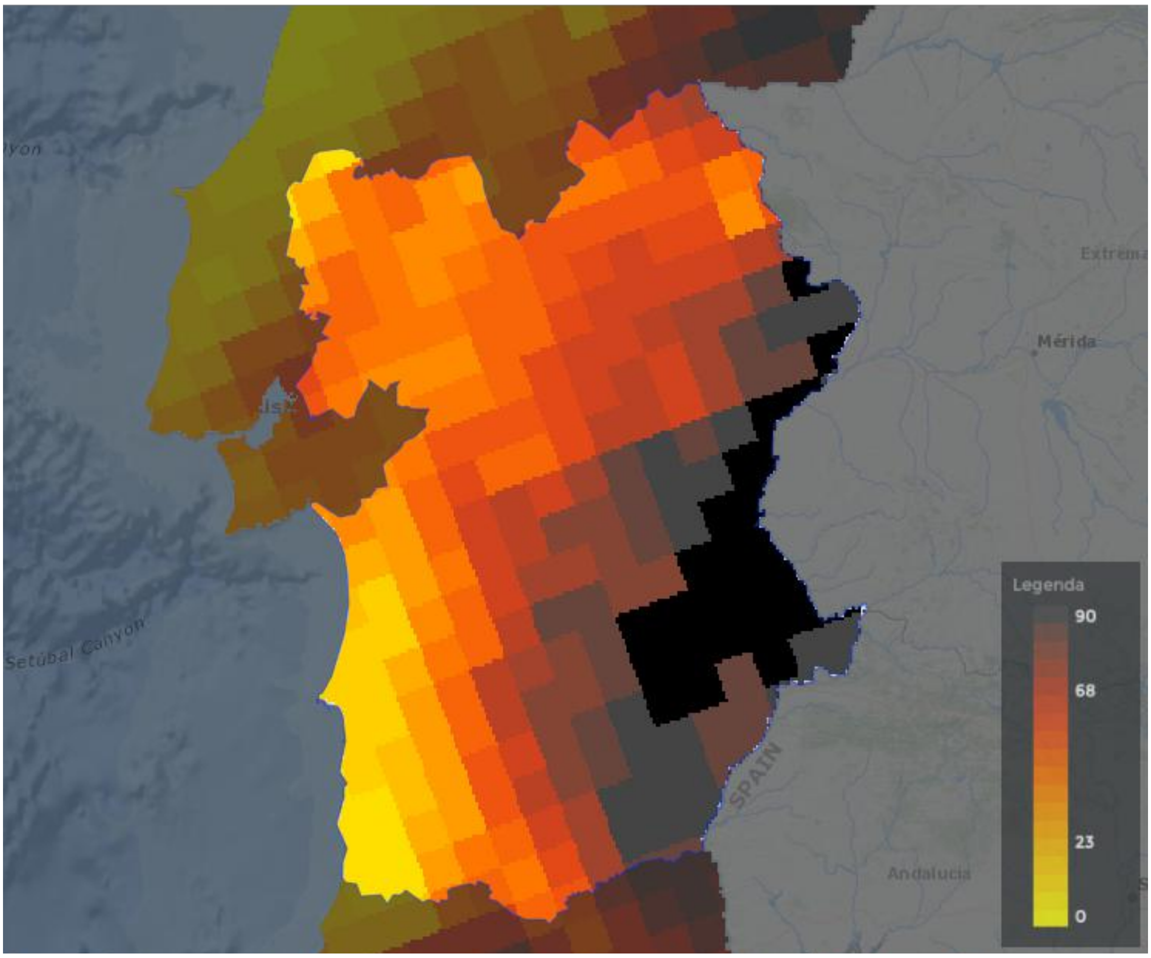


Figure 19: Days (0-90) of extreme risk to wildfires per year in the area of Alentejo for a global warming scenario of 4.3°C by 2100 (RCP8.5) as a mean for the time period 2071-2100 (derived from http://portaldoclima.pt/en/).

7.3 Droughts

The south of Portugal, in particular, is prone to the occurrence of regular drought episodes (Dias et al., 2018).

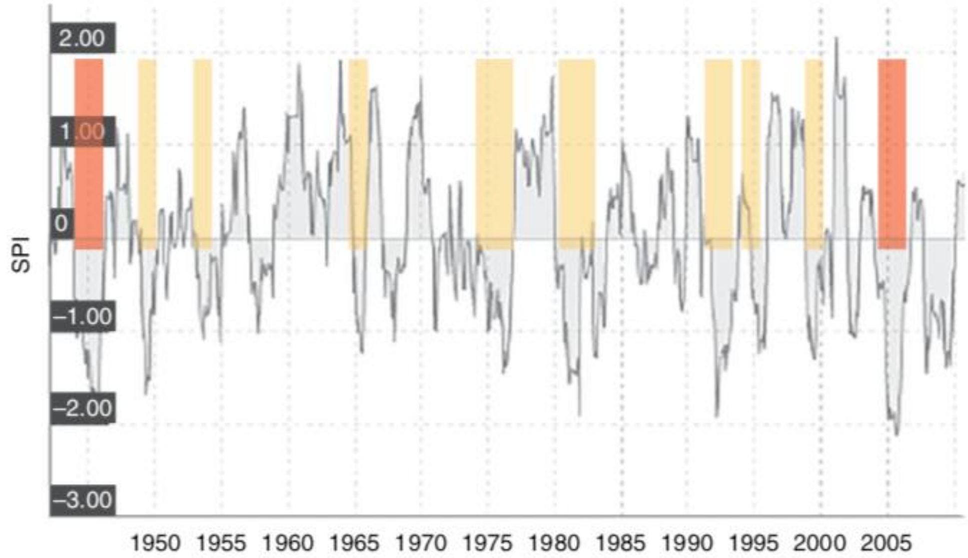


Figure 20: Six decades of annual precipitation anomalies estimated by the standardised precipitation index (SPI) for mainland Portugal, regarding the reference period of 1970-2000. Major drought events are highlighted: red – extreme; yellow – moderate or severe (Dias et al., 2018).

The mainland of Portugal has experienced severe droughts over the past 30 years – especially in the years 2004-2005, 2011-2012 and 2017-2019 (Carvalho et al., 2014; Sousa et al., 2019). 2005 was the driest year in the last 78 years, followed by 2007 and 2004 (Carvalho et al., 2014). The 2005 droughts affected 100% of mainland Portugal, and had strong impacts on different socioeconomic and environmental sectors (Dias et al., 2018). By the end of the hydrological year of 2005, 97% of Portugal was still in severe or extreme drought (Dias et al., 2018). Already 36% of the Portuguese continental territory is affected by desertification (Carvalho et al., 2014).

As climate change models predict a drier climate in Portugal with longer summers and shorter rainy seasons, increasing temperatures and decreasing precipitation, droughts will be a more common problem (Dias et al., 2018). Moreover, drought can lead to seawater intrusion in the south due to lower recharge (Dias et al., 2018).

7.4 Storms

The Atlantic coast of Portugal is exposed to very energetic waves generated along the north Atlantic, which also constitute the dominant coastal hazard component (Vousdoukas et al., 2016). Extreme short-term events like coastal storms have become more intense and frequent and constitute a threat for coastal environments in Portugal, mostly during winter periods (Gomes et al., 2018).

During such storms, wave heights reach up to 9 metres and these conditions persist for as long as five days (Carmo, 2017). Significant storms include Rafael in 2012, Hercules and Stephanie in 2014, and Joaquin in 2015. Due to the increasing urbanization in coastal areas, there has been considerable degradation of natural protection systems (Carmo, 2017). Figure 21 shows a significant increase in the number of storms since 1930 and a linear growth starting in the mid-1990s (Carmo, 2017).

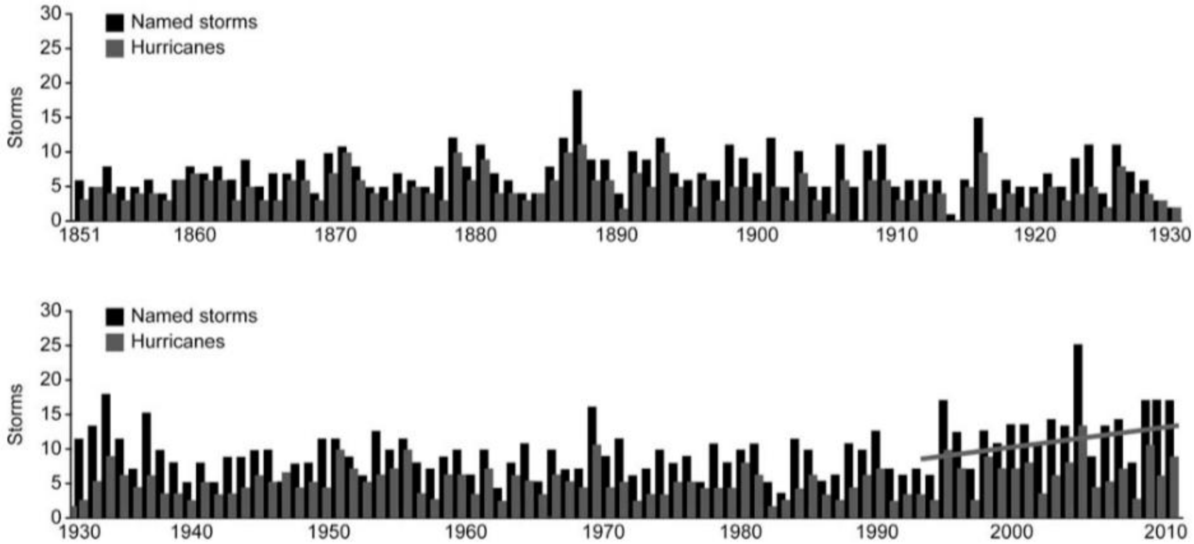


Figure 21: Number of named storms and hurricanes in the Atlantic Ocean per year between 1851 and 2010 (Carmo, 2017).

On the north-western coast of Portugal, the Minho, Lima, Cávado, and Douro estuaries are vulnerable to the impacts of climate change, such as coastal storms and sea level rise (Gomes et al., 2018). Very low-lying coastal areas, where river deltas and estuaries coincide are among the most vulnerable areas. Other coastal locations are also vulnerable to extreme weather events and in particular coastal storms which can induce significant storm surges that lead to coastal erosion (Gomes et al., 2018). During winter months, the coast is affected by heavy swells approximately 30% of the time (Gomes et al., 2018). As the temperatures of the sea surface are projected to increase, the frequency of severe winds and a shift in the projected season of storm occurrences could be observed (Gomes et al., 2018).

7.5 Heavy precipitation

The projected reduction in mean annual precipitation that was described in section 5 is accompanied by a significant increase in precipitation extremes (Soares et al., 2015). Extreme precipitation is one of the main triggers of natural disasters, such as urban inundations, soil erosion, crop destruction and flash floods (Santos et al., 2019). Figure 22 shows an index of extreme precipitation susceptibility (EPSI) over Portugal (susceptibility refers to the probability of any given region being affected by a precipitation-driven disaster given a set of conditions). For the current time span it is clear that more than 60% of Portuguese municipalities have a very high or high EPSI ranking (Santos et al., 2019).

Increases in extreme precipitation are expected mainly over north-eastern Portugal in winter and spring (Santos et al., 2019). For the time period 2046-2065 there is a projected increase in susceptibility for 29% of the municipalities – meaning that 74% of them are classified with high or very high extreme precipitation susceptibility under a global warming scenario of 4.3°C by 2100 (RCP8.5).

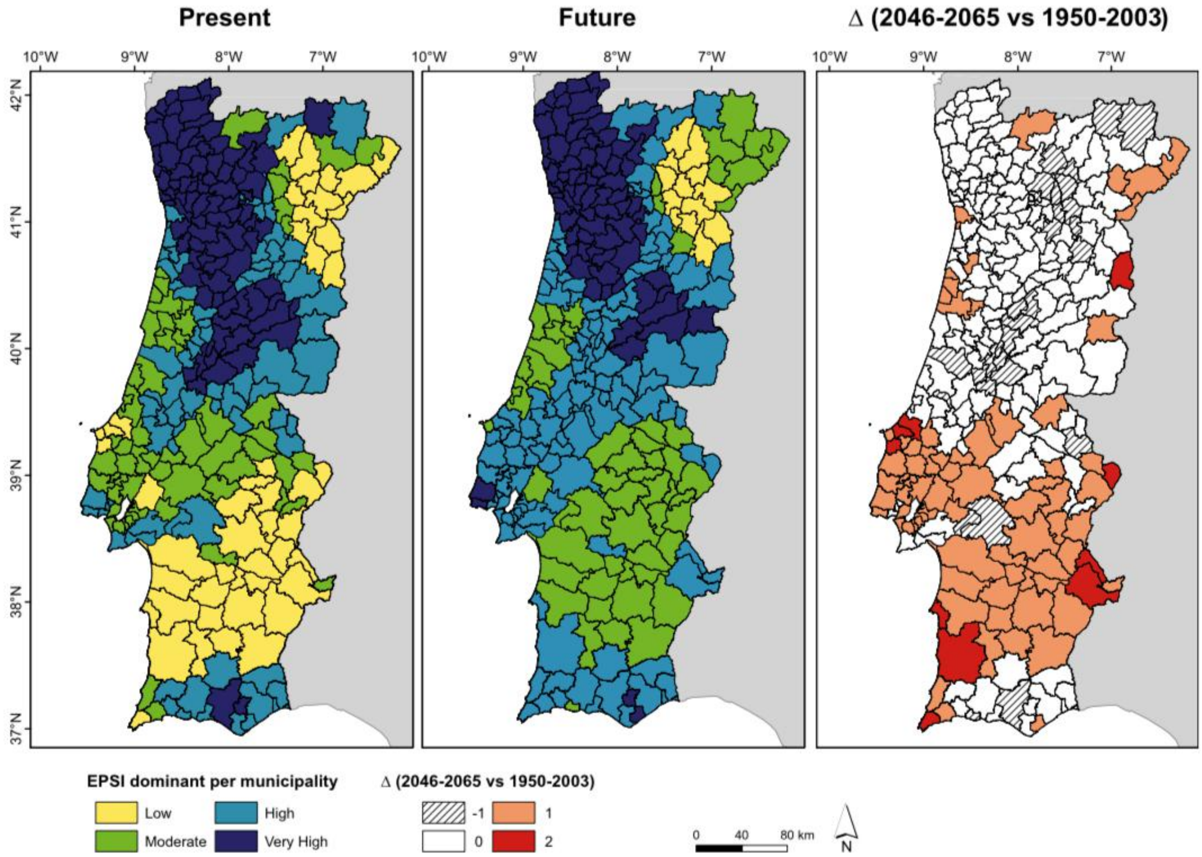


Figure 22: Present (1950-2003), future (2046-2065) and the difference between the two time periods of the dominant extreme susceptibility index (EPSI) in mainland Portugal, aggregated by municipality. The corresponding climate change signal (seven-member ensemble mean for 2046-2065 minus 1950-2003) is measured by the difference in the class rank (under a global warming scenario of 4.3°C by 2100 (RCP8.5)) (Santos et al., 2019).

7.6 Floods

Between 1865 and 2010, floods in Portugal caused 1012 deaths, 478 injuries, the displacement of 13,372 people and rendered 40,283 people homeless (Santos et al., 2017). 65% of these fatalities were caused by flash floods, which for example occurred in 2012 on the Madeira island or in 1967 in Lisbon (Santos et al., 2017). In Portugal, the cyclonic circulation weather type is the weather type which is most like to give rise to flood occurrences, owing to the transport of Atlantic air masses over the country. Floods are one of the major natural hazards caused by climate change, that have implications over a broad range of socio-economic activities.

Between 1900 and 2008, 82% of the hydro-geomorphological events were floods and 75.6% of total flood cases took place between November and February (Cunha et al., 2017). "According to the social consequences of floods, during the same period, from 1900 to 2008, the Tagus hydrographic region registered 60% of the total of people made homeless or displaced by flash floods in the Lisbon region" (Cunha et al., 2017). Douro, Mondego and Bouga river regions are also affected by these consequences (Cunha et al., 2017). Figure 23 indicates the flood risk areas and occurrences in mainland Portugal. An increase in the frequency and severity of extreme precipitation could lead to increased flood risks, leading to monetary damages from flooding. As described in section 7.5, heavy precipitation over the winter months is expected to increase. The growing number of flood events worldwide have been considered by the IPCC as a likely manifestation of climate change (Santos et al., 2017).

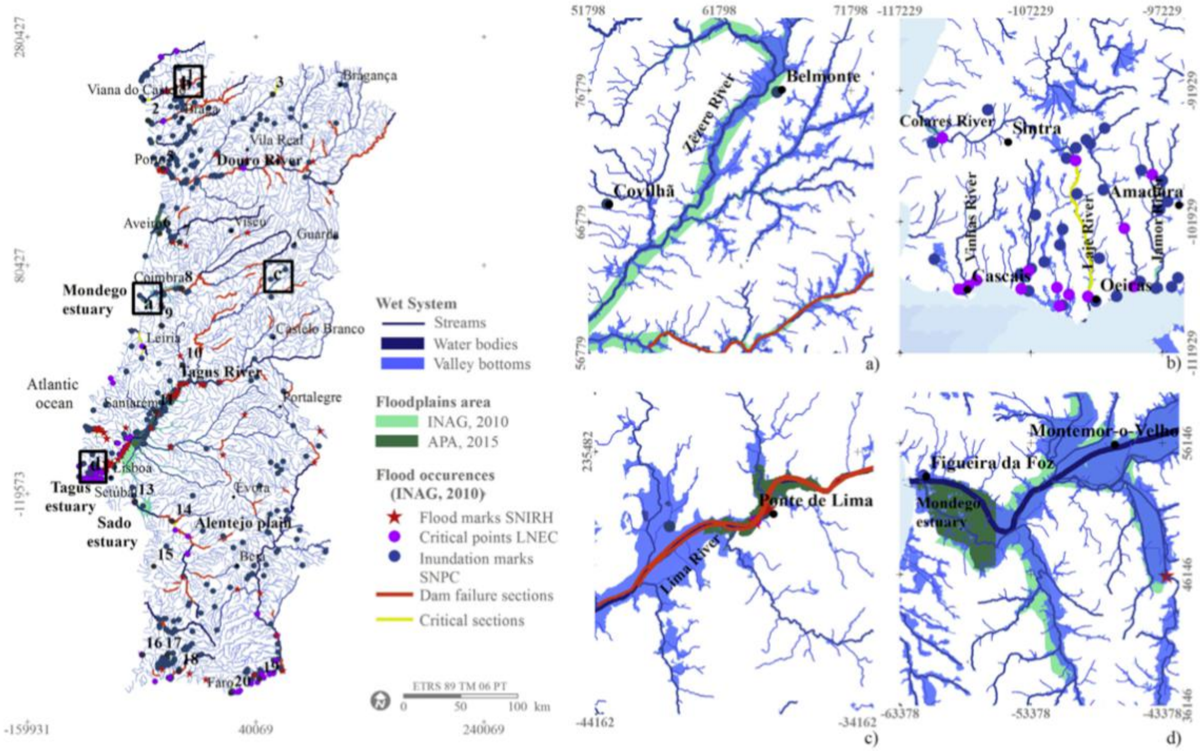


Figure 23: Flood risk areas and occurrences in mainland Portugal. A) Zezere River; b) Colares, Vinhas, Lage and Jamor rivers in the north of Lisbon metropolitan area; c) Ponte de Lima urban area; d) Mondego Estuary (Cunha et al., 2017).

Apart from river flooding, coastal ecosystems are also among the most threatened by marine hazards. Two-thirds of the population is still living in coastal floodplains with an increasing trend, as 50% of the new urbanized areas are located within 20km of the coast (Cunha et al., 2017). These regions are even more vulnerable to damages from flooding and storms, aggravated by climate-induced sea level rise. A study by Roudier et al. (2015) showed that Portugal will be one of the few European countries which will be most affected by extreme coastal floods under a 2°C global warming scenario (Roudier et al., 2016).

Due to its coastal location at the mouth of the river Tagus, Lisbon is particularly vulnerable to the impacts of climate change (Silva and Costa, 2017). Having land morphology which is strongly impacted by the Tagus estuary dynamics (tides, storm surges, winds and undulation) and fragile drainage infrastructure, Lisbon is often impacted by flooding (Silva and Costa, 2017). Such flooding is exacerbated by the increase in the average sea level, increased precipitation as well as variations in atmospheric pressure and the consequent increase of storm surge magnitudes (Silva and Costa, 2017). The increase in storm surges which Portugal is projected to experience will threaten the Lisbon metropolitan area (Silva and Costa, 2017). There is, furthermore, a high degree of confidence that flooding will increase and bring stronger impacts and more severe damage to Lisbon by 2100 (Silva and Costa, 2017).

8. Sectoral impacts

Projections show that the increasing average temperature, the more frequent heat waves and the very likely decrease in mean annual precipitation and intensification of droughts will have significant adverse effects in various socioeconomic sectors in Portugal, such as water resources, agriculture, forests, biodiversity, health, and tourism in Portugal (Carvalho et al., 2014).

8.1 Agriculture

Climate change is projected to reduce crop productivity in large parts of southern Europe (Füssel et al., 2017). Recent heat waves, droughts and floods have greatly reduced the yield of some crops and the projected increase in the occurrence and intensity of such events will be detrimental for crop production in southern Europe, especially, typical Mediterranean crops, e.g. grapevine, durum wheat and olive; animals will also be exposed to increased heat stress during summer (Füssel et al., 2017).

The changing climate condition over Portugal may reduce food production which would increase pressure on water resources and cause food security risk (Rolim et al., 2017). There will be increasing water demand for irrigation to maintain crop yield levels and several studies indicate that water resources will become less available in southern Portugal (Rolim et al., 2017). For example, the predicted maize yields show a continuous decrease from 10,081.3 kg ha^{-1} in the baseline to 9,029.9 kg ha^{-1} (−10%, for scenario of 2.5°C expected temperature increase by 2100, RCP4.5, annual reduction rate of -20kg/ha/yr) and 8,410.6 kg ha^{-1} (−17%, for scenario of 4.3°C expected temperature increase by 2100, RCP8.5, annual reduction rate of -28.9kg/ha/yr) for 2061–2080 (Yang et al., 2017). With regards to wheat, projected climate change is likely to have an overall negative impact in Portugal on mean wheat yield (−27% to −14%), primarily driven by intensified drought and heat stresses during anthesis and grain-filling periods (Yang et al., 2019).

According to the IPCC’s special report on climate change and land, “Europe is increasingly affected by desertification leading to significant consequences on land use, particularly in Portugal, Spain, Italy, Greece, Malta, Cyprus, Bulgaria and Romania” (Mirzabaev et al., 2019, p. 264).

A recent study by Yang et al. conducted in the Alentejo region found that drought stress is the main limiting factor for potentially attainable wheat yields, representing a major source of yield gaps in the region, i.e. 40–70% mean potential yield losses covering most of the area for all sowing dates (Figure 24) (Yang et al., 2020). Several studies confirm that in southern Portugal, water stress can occur with varying degrees of severity throughout the growing season (Rocha et al., 2020; Yang et al., 2020, 2019). In April–June, in southern Portugal, water deficits are projected to increase by 38mm (for scenarios of 2.5°C expected temperature increase by 2100, RCP4.5) or 51mm (for scenarios of 4.3°C expected temperature increase by 2100, RCP8.5) for 2021–2050 and by 59mm (RCP4.5) or 90mm (RCP8.5) for 2051–2080, in addition to the mean baseline climatic water deficit of 324 mm for April–June (Yang et al., 2019). Moreover, central littoral and western coastal areas of Portugal are currently suffering particular pressure on green freshwater resources. This is partly due to the decrease of evapotranspiration, which leads to less green water available for land use (Quinteiro et al., 2019).

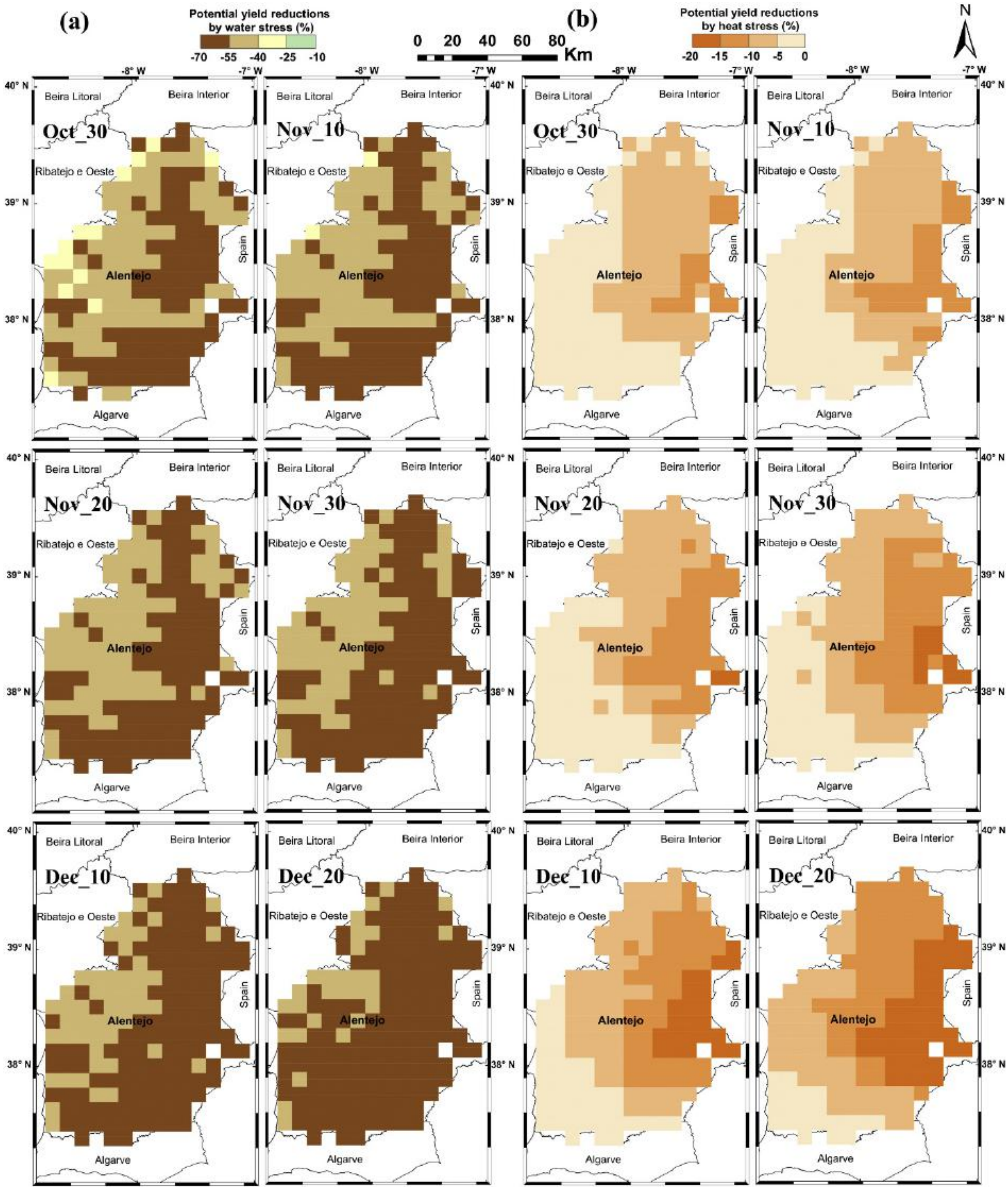


*Figure 24: Quantified and isolated impacts of main abiotic (drought and heat) stresses on potentially attainable yields over 1986—2015 in Alentejo region without adaptations (simulations are performed under different sowing dates: _10 means from the first to the tenth, _20 means from the eleventh to the twentieth, _30 means from the twenty-first to the thirtieth). Quantified mean potential yield losses (%) for individual grids are the average of yearly values over 1986—2015, resulting from either (**a**) seasonal water stress only (**b**) or solely from extreme high temperature (≥38 °C) during grain-filling phase (Yang et al., 2020)*

The Portuguese wine industry is and will continue to be affected by climate change, since grapes are one of the most sensitive crops to small changes in climatic conditions. The proliferation of microorganisms, the high pH and low acidity, the proliferation of new mycotoxins and increase in biogenic amines content are some of the consequences of climate change that have a high impact on wine development and fruit composition. Thus, some European regions, including

Portugal, will be required to adjust current approaches to terroir relating to cultivation selection and winemaking technology (Ubeda et al., 2020).

Furthermore, olive trees, one of the oldest permanent crops grown in the Mediterranean basin, are also subject to a great risk from temperature increase due to climate change (European Environment Agency, 2019), mostly because higher water demand and lower water availability will enhance the water stress for olive trees in the future (Fraga et al., 2020). As can be seen in Figure 25 below, olive yields are expected to decrease in some parts of Portugal down to -30% (Fraga et al., 2020).

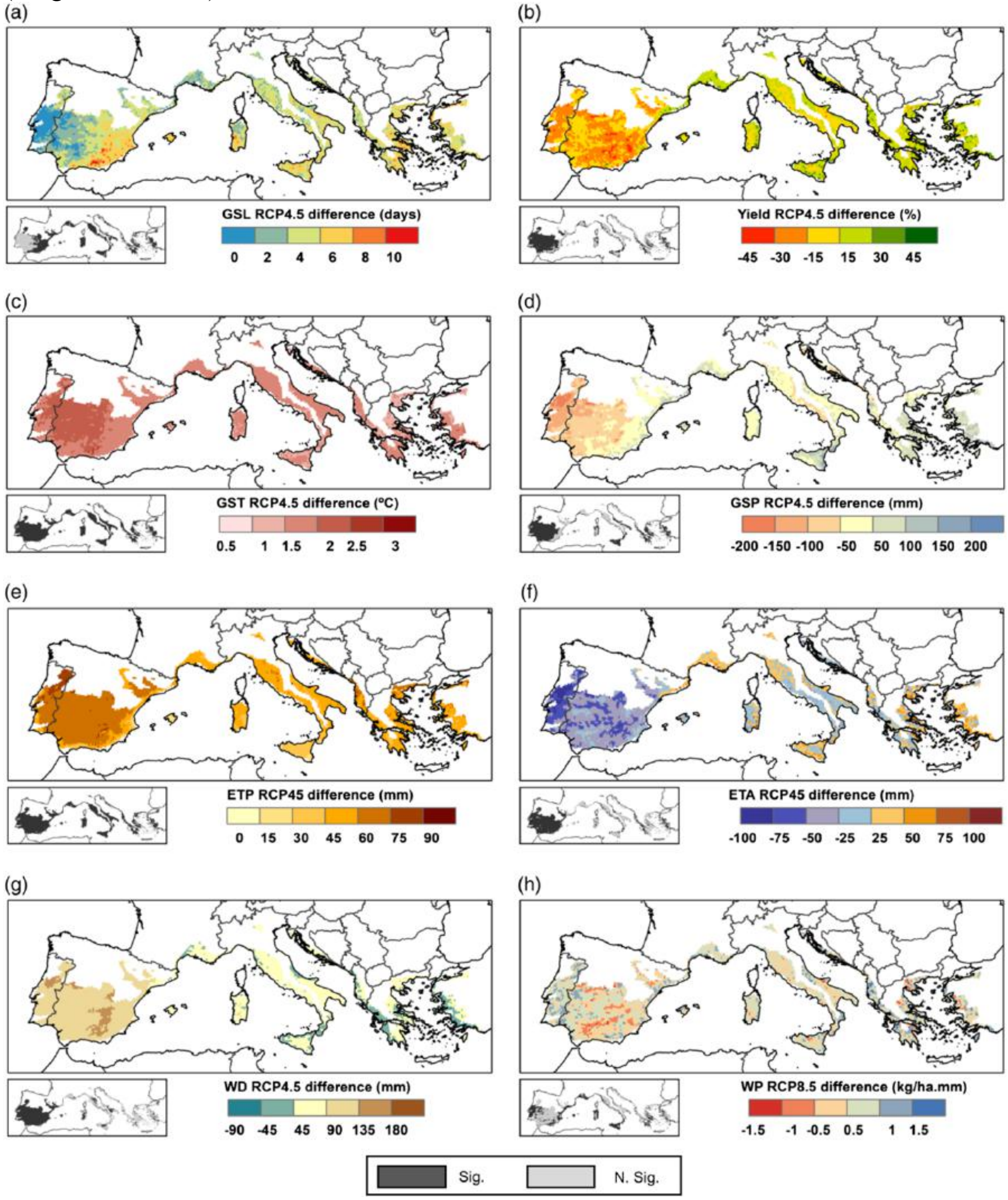


Figure 25: Patterns for Olives for the differences between global warming of 2.5°C in 2100 and recent past (1989-2005) for the variables: (a) growing season length (days), (b) yield (kg ha^{-1}), (c) growing season mean temperature (°C), (d) growing season precipitation sum (mm), (e) potential evapotranspiration in the growing season (mm), (f) actual evapotranspiration in the growing season (mm), (g) water deficit (ETP minus ETA; mm) in the growing season, (h) water productivity (kg ha^{-1} mm; yield divided by ETA) in the growing season (Fraga et al., 2020)

8.2 Economic impacts

Climate change is expected to shift the major flows of tourism in Europe (Füssel et al., 2017) (Pintassilgo et al., 2016). The suitability of southern Europe for tourism will decline during the summer but will improve in other seasons (Füssel et al., 2017). The projected damage costs from climate change are distributed very heterogeneously across Europe, with notably higher impacts in southern Europe (Füssel et al., 2017). In Portugal, the projected temperature increases will lead to a decrease of inbound tourism between 2.5% and 5.2%, which is expected to reduce the Portuguese GDP between 0.19% and 0.40% (by using scenarios of 2.4°C-4.3°C expected temperature increase by 2100) (RCP 4.5-RCP8.5) (Pintassilgo et al., 2016).

Climate extremes in Portugal are also causing economic losses. For the period 1980-2013, Portugal lost 6,783 million EUR from climate-related hazards, representing 0.14% of its GDP (Füssel et al., 2017).

In addition, farms in southern Europe, including Portugal, could also suffer from the economic impacts of climate change on agriculture. According to the projections presented in Figure 26, the farmland value in regions in Portugal is projected to decrease by more than 80 % by 2100 (European Environment Agency, 2019).

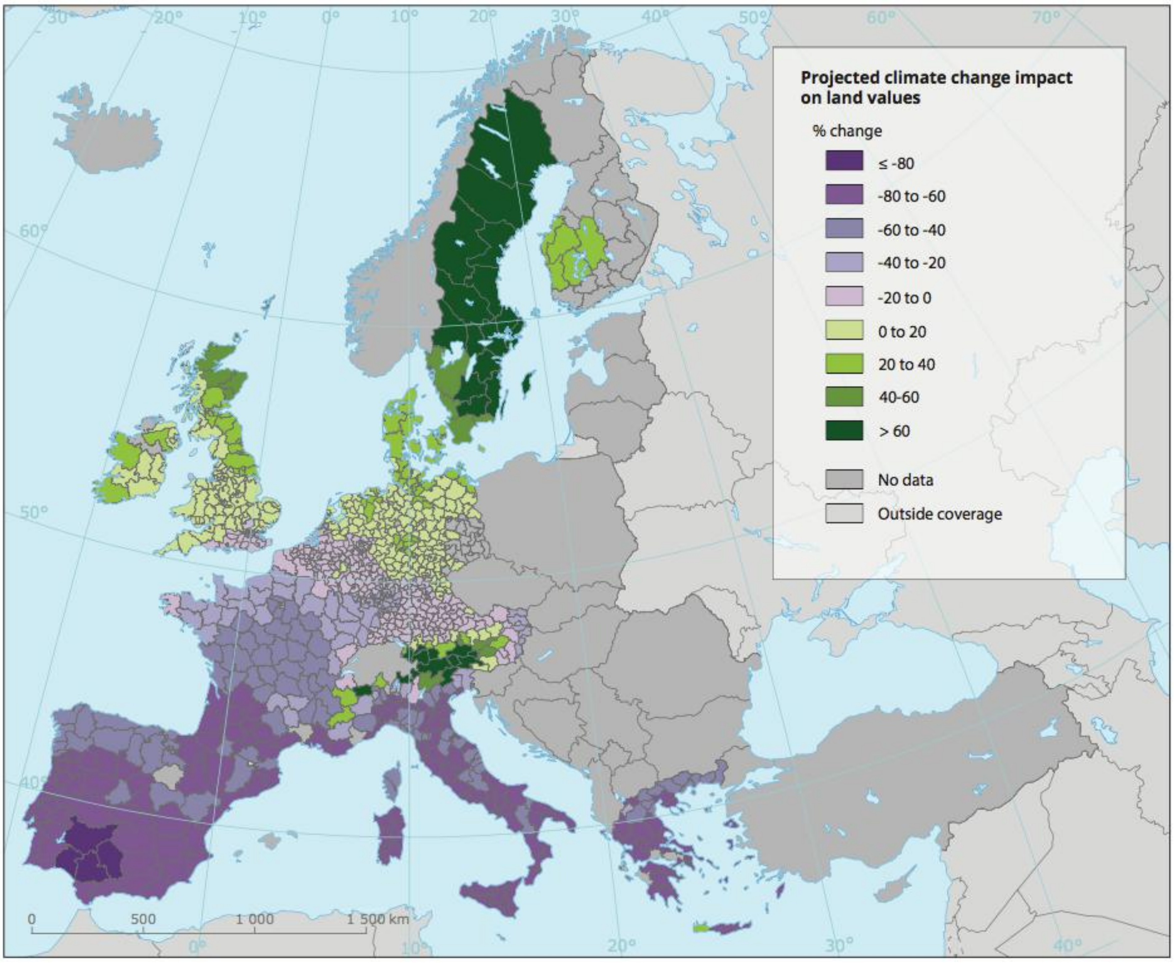


Figure 26: Percentage change in farmland values projected for the period 2071-2100 compared to 1961-1990 based on scenarios of 4.3°C expected temperature increase by 2100 (RCP8.5) from (European Environment Agency, 2019)

Climate change also has negative economic impacts on the fishing sector in Portugal. There are around 15,000 people in Portugal working in the fishing industry (Eurostat, 2019). Figure 27 shows the employment in the EU fisheries industry and fisheries production in 2017.

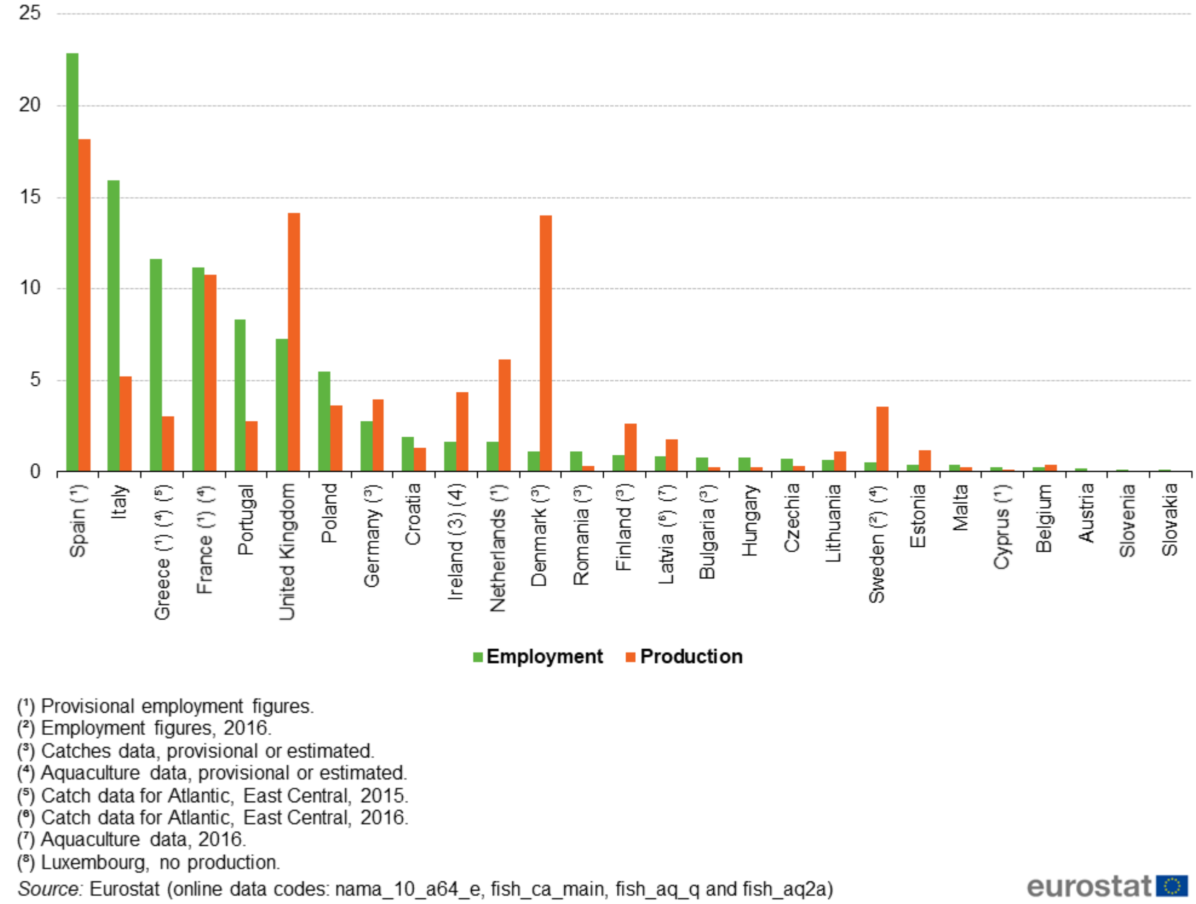


Figure 27: Employment in the EU fisheries industry and fisheries production, 2017. (% share of EU-28 totals). (Eurostat, 2019)

According to the IPCC's Special Report: *The Ocean and Cryosphere in a Changing Climate*, the Atlantic Meridional Overturning Circulation (AMOC), the main current system in the South and North Atlantic Oceans, has weakened relative to 1850-1900, and "any substantial weakening of the AMOC is projected to cause a decrease in marine productivity in the North Atlantic." Furthermore, "shifts in species distributions and abundance has challenged international and national ocean and fisheries governance, including in the Arctic, North Atlantic and Pacific, in terms of regulating fishing to secure ecosystem integrity and sharing of resources between fishing entities (high confidence)." (IPCC, 2019, p. 16). Figure 28 summarizes the impacts from changes in the ocean and the cryosphere by region:

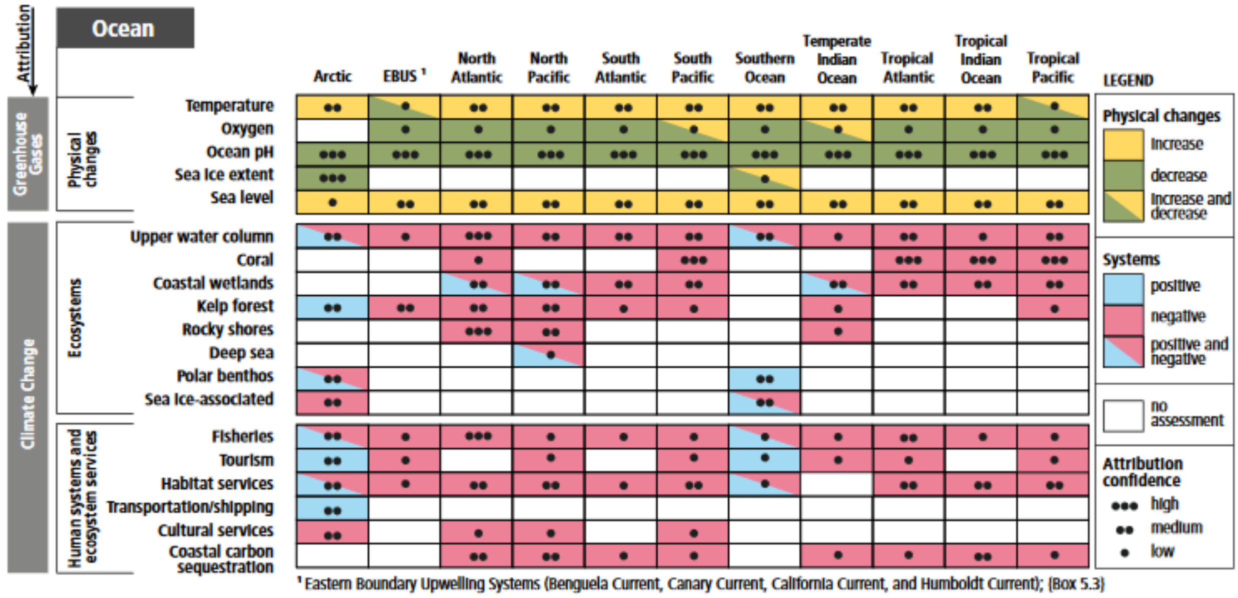


Figure 28: Observed regional impacts from changes in the ocean and cryosphere. Portugal is concerned by the North Atlantic column. (IPCC, 2019)

Submergence and flooding of coastal areas have a high economic impact in Europe: “EAD [Expected Annual Damage] are expected to rise from 1.25 billion EUR today to 93–960 billion EUR by the end of the century” (Oppenheimer et al., 2019, p. 376).

The PESETA IV report (Szewczyk et al., 2020) assesses the welfare loss of selected climate impacts in % of GDP for the EU-27 and UK for three levels of global warming (Portugal belongs to southern Europe):

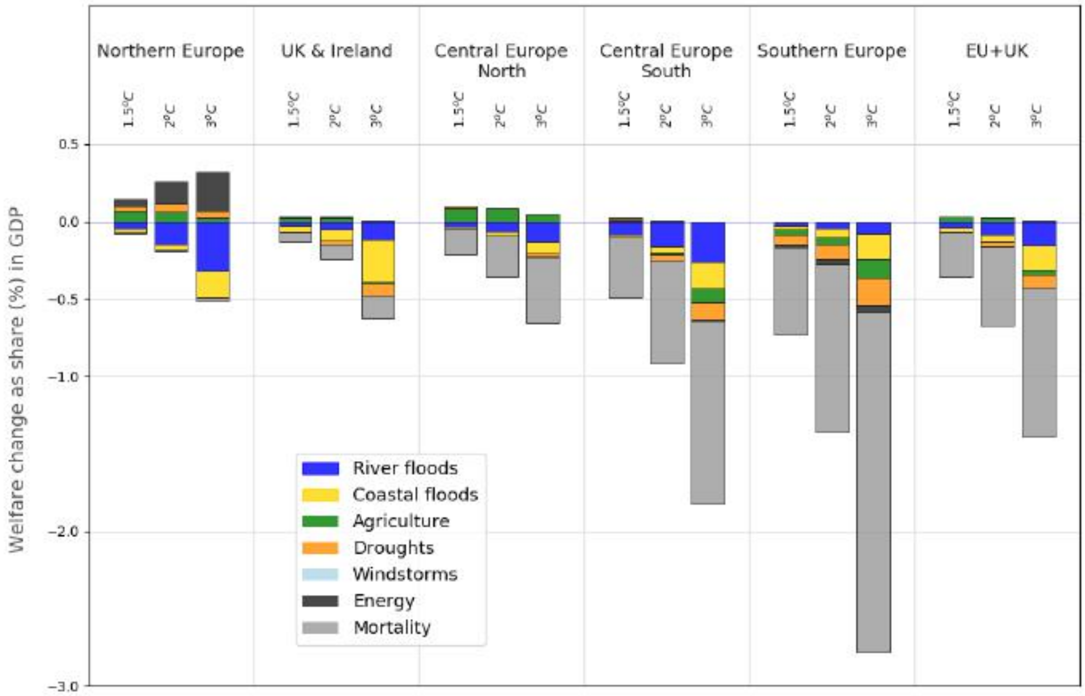


Figure 29: Welfare change from selected climate impacts (% of GDP) for the EU-27 and UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy (Szewczyk et al., 2020)

The following table summarizes the data for southern Europe:

Sector	Welfare change, bn € (additional to base)			Welfare change as share in GDP (%)		
	1.5°C	2°C	3°C	1.5°C	2°C	3°C
Inland floods	-0.9	-1.5	-2.5	-0.03	-0.05	-0.08
Coastal floods	-0.9	-1.8	-5.2	-0.03	-0.06	-0.16
Agriculture	-1.0	-1.4	-3.7	-0.03	-0.04	-0.12
Droughts	-1.8	-3.0	-5.6	-0.06	-0.09	-0.18
Energy	-0.7	-1.0	-1.4	-0.02	-0.03	-0.04
Mortality	-17.6	-34.1	-68.9	-0.56	-1.09	-2.20
Sum of the sectors	-23.0	-42.7	-87.3	-0.73	-1.36	-2.78

Table 3: Welfare change from selected climate impacts (bn € and % of GDP) in Southern Europe, for three levels of global warming. The results represent change with respect to current economy. Data source: (Szewczyk et al., 2020)

Economic impacts are particularly influenced by the increase in human mortality (Figure 29). There is a clear North-South divide in the regional distribution of welfare losses, illustrated for example by changes in the frequency and severity of droughts, which lead to a small increase in welfare in Northern Europe, but become a major source of welfare reduction in the southern EU regions (Szewczyk et al., 2020).

A study from Kahn et al. assessed the macroeconomic effects of climate change and found that in 2100, under RCP2.6, Portugal's GDP per capita will decrease by 0.72% compared to the beginning of the century's value. This number considerably increases under RCP8.5, reaching 7.75% (Kahn et al., 2019).

9. Health

Direct and indirect impacts of climate change affect human health by a combination of processes. Direct impacts include the abrupt increase or decrease in temperatures, whereas changes in air pollution levels are an example of an indirect impact of climate change.

In western Europe, an increase in people exposed to and fatalities due to weather-related hazards is expected with increasing climate change. Forzieri et al. (2017) observed 50,503 people (per 1 million inhabitants) exposed to weather-related hazards in 1981-2010. They expect this number to increase to 451,542 people (per 1 million inhabitants) in western Europe by 2071-2100 – which would be an increase of nearly 800% (Forzieri et al., 2017). Similar numbers count for the number of deaths (per 1 million inhabitants) due to weather-related hazards in western Europe. These are projected to increase from 38 in 1981-2010 to 1029 in

2070-2100 – a percentage increase of around 2600% (Forzieri et al., 2017). These quantifications are based on a future global warming scenario of 2.8°C by 2100 (RCP6.0). Figure 30 displays these projected increases on a European scale.

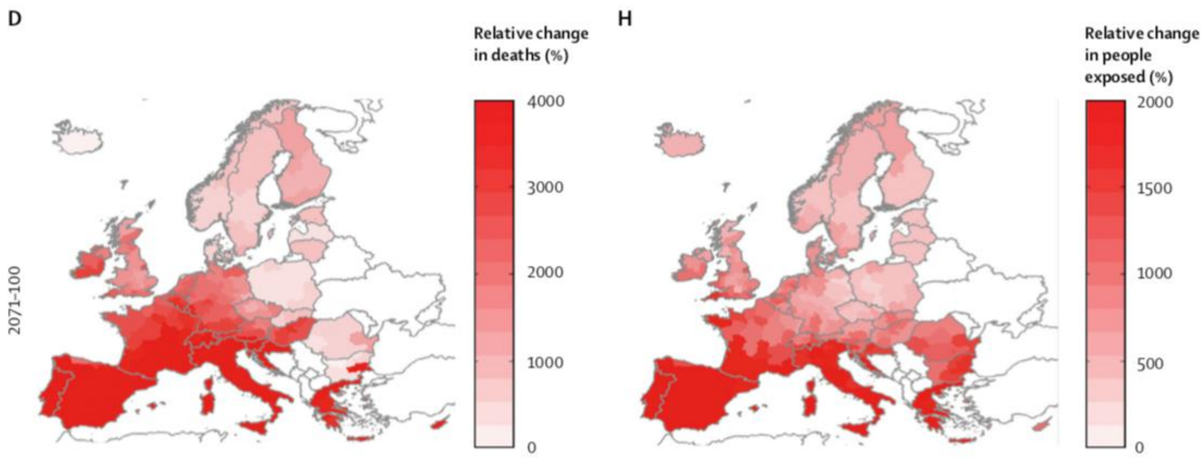


Figure 30: Relative change in deaths (%) and relative change in people exposed to weather related hazards per year in 2071-2100 compared to the reference period (1981-2010) for a global warming scenario of 2.8°C by 2100 (RCP6.0) (Forzieri et al., 2017)

9.1 Heat

Abrupt increases or decreases in temperature have already been found to have caused fatal illnesses, such as heat stress or hypothermia, in Portugal, as well as to have increased death rates from respiratory diseases (Dias et al., 2012). One study shows that mean apparent temperature exposure in Portugal leads to increased mortality, even when adjusting for air pollution (Almeida et al., 2010). Monteiro et al. (2013) observed that for a 1°C increase in mean apparent temperature there would be a 2.7% increase in mortality (all causes), a 1.7% increase in respiratory morbidity, a 2.2% increase in respiratory morbidity in women, a 5.4% increase in chronic obstructive pulmonary, and a 7.5% increase in chronic obstructive pulmonary morbidity in women, for the entire population (Monteiro et al., 2013)
An increase in the number and intensity of extreme heat events will have a massive impact on human health in Portugal (Cardoso et al., 2019). Areas like Lisbon in particular, where many densely populated urban centres are located, will face more severe health risks (Füssel et al., 2017). A recent study demonstrates that there has been a definite modification in seasonal mortality in Lisbon over the past century and a half, which is illustrated in Figure 31 below (Alcoforado et al., 2015). The increase mortality in Lisbon is attributable to a positive trend of increasing monthly maximum temperature and heat waves (Alcoforado et al., 2015).

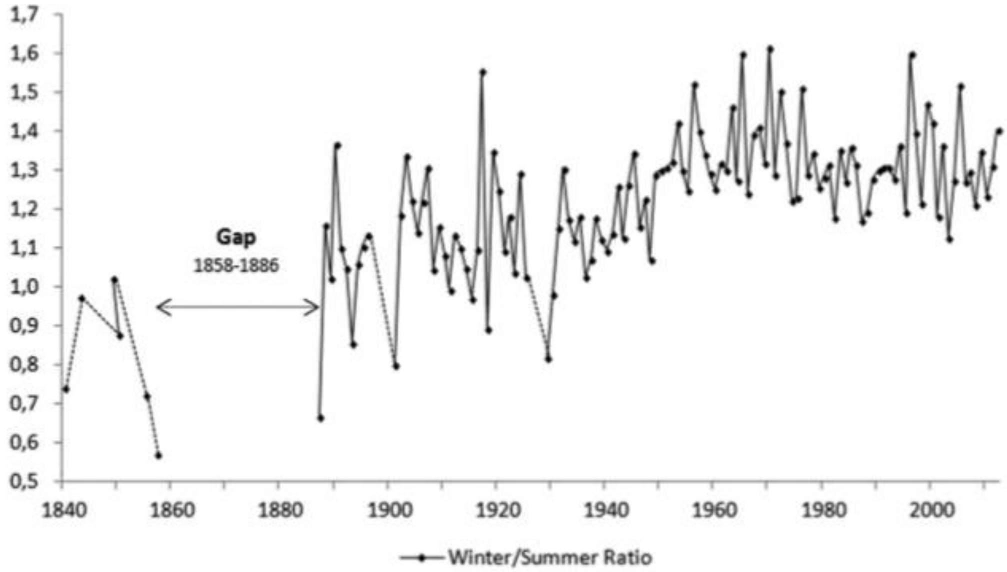


Figure 31: Winter-Summer ratio of mortality in Lisbon (1840-2012) (solid line: no gaps; dashed line: gaps between yearly data) (Alcoforado et al., 2015).

The 2003 heat wave referred to in section 7.1 was responsible for a total of 2,399 excessive deaths. This represents a 58% increase in the expected number of deaths in Portugal (D. Dias, Tchepel, Carvalho, Miranda, & Borrego, 2012). The heat waves projected to be experienced by Portugal as a result of climate change, as described in section 7.1, will be stronger than the heat wave from 2003. The annual heat mortality rate is projected to increase in Portugal to between 16.2-29.5 deaths per 100,000 by 2050 under all climate change scenarios – assuming no additional adaptation – compared to 5.4-6 deaths per 100,000 in 1980-1998 (Casimiro et al., 2006). Forzieri et al. (2017) expect the number of deaths in western Europe per 10 million inhabitants due to heatwaves to increase from 34 (1981-2010) to 1,023 by 2071-2100 under a global warming scenario of 2.8°C warming in 2100 (RCP6.0) – a percentage increase of around 3000% (Forzieri et al., 2017).

According to a 2019 Lancet report, Europe remains highly vulnerable to heat exposure. This is due to its ageing population, its high rates of urbanisation, but also its high prevalence of cardiovascular and respiratory diseases and diabetes (Watts et al., 2019). In the European Union, the share of people older than 65 years is projected to increase from 19% to 30% by the end of the century, with the highest shares in some southern European countries including Portugal. Since populations aged 65 years and older are particularly vulnerable to heat extremes, the mortality rates from heat extremes will likely increase in European populations (Naumann et al., 2020; Watts et al., 2019). Compared to other health impacts, and because the population in Portugal is getting older, heat-related mortality has been found to be the highest public health concern associated with climate change (Casimiro et al., 2006).

It is not just older populations who are vulnerable to heatwaves, however. Studies have also shown that children younger than one year are particularly vulnerable to heatwaves. Infants and small children are unable or lack agency to regulate their body temperature and control their surrounding environment, which is why they are more likely to die or suffer from heat stroke. They are also vulnerable to dehydration caused by heat stress (UNICEF, 2015).

Figure 32 shows the current and projected number of people in Europe annually exposed to what is at present a 1-in-50-year heatwave and cold wave:

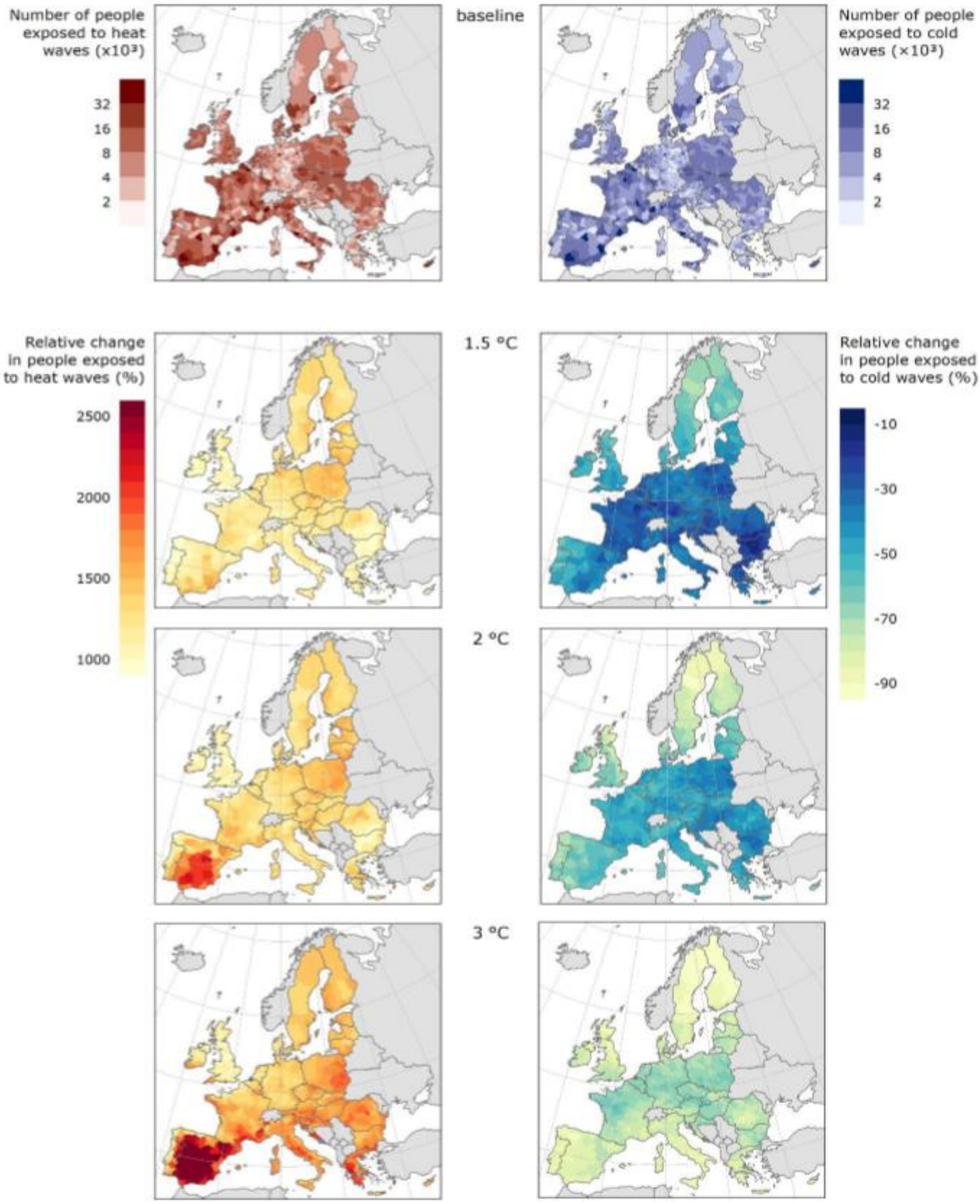


Figure 32: Number of people annually exposed to a present 1-in-50-year heatwave and cold wave (top row) and projected changes in human exposure to these events for 1.5°C, 2.0°C, and 3.0°C levels of global warming. (Naumann et al., 2020)

Heat stress also reduces labour productivity. A decrease in labour productivity is one of the first symptoms of the health effects of heat, and if not addressed, can lead to more severe health effects, such as heat exhaustion and heat stroke (Watts et al., 2019). Due to rising temperatures, in 2018, 45 billion additional potential work hours were lost globally due to rising temperatures, compared with in the year 2000. (Watts et al., 2019)

Figure 33 shows the potential full-time annual work lost in 2018 in the shade (A) or in the sun (B) based on the percentage of people working in agriculture (400 Watts), industry (300 Watts) and services (200 Watts). The number of watts refers to the average metabolic rate that characterizes the mean workload for a given occupation. On average, agriculture requires more energy per minute than industry, which in turn requires more energy per minute than services (1 kcal/min=69.78 W) (Watts et al., 2019). In Portugal, most of the loss can be found in the south-west.

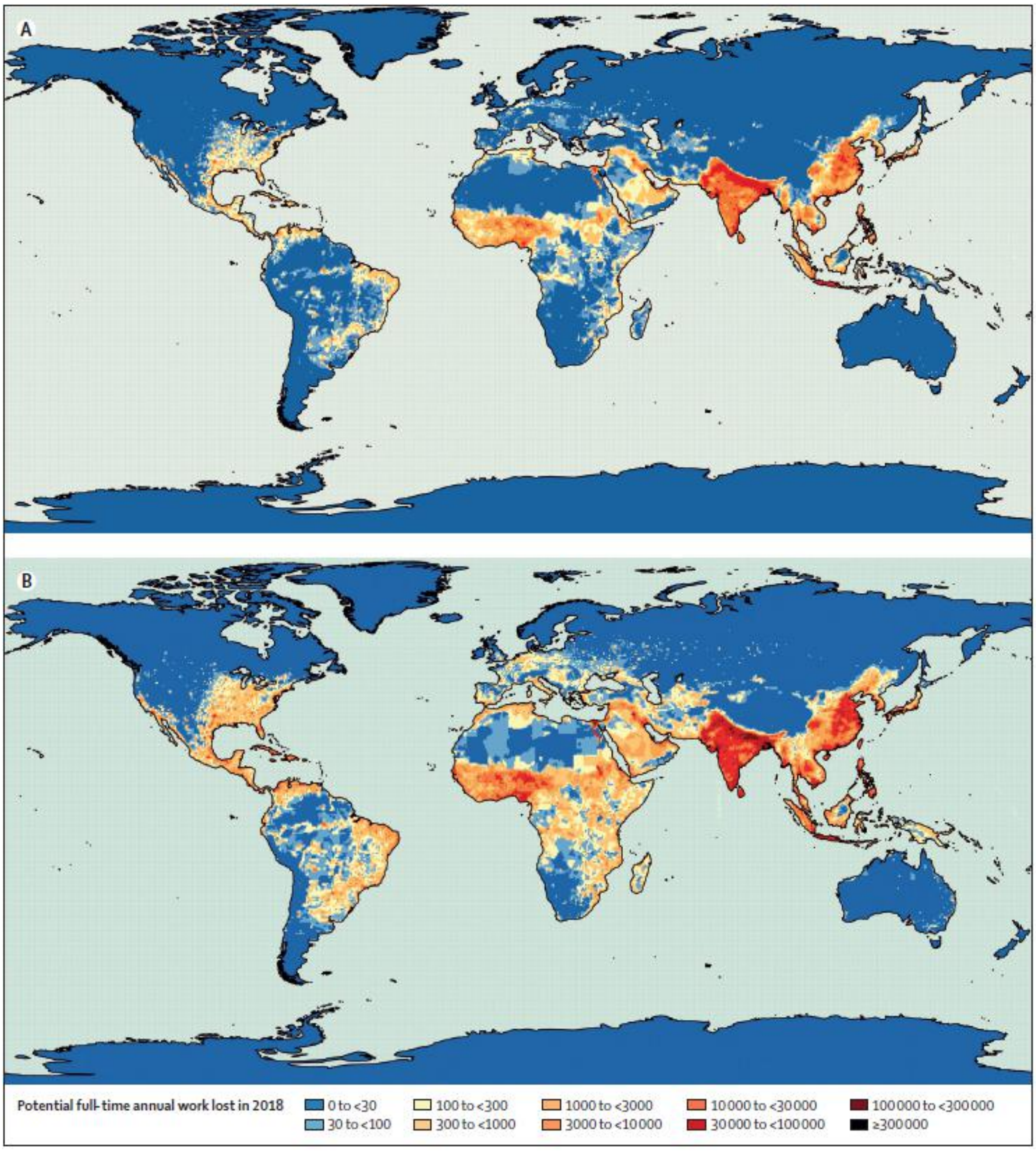


Figure 33: Potential full-time annual work lost in 2018 in the shade (A) or in the sun (B) based on the percentage of people working in agriculture (400 Watts), industry (300 Watts) and services (200 Watts). The values are given for each 0.5x0.5 degree grid cell in the map. (Watts et al., 2019)

According to a recent study by Casanueva et al., under a global warming scenario of 4.3°C by 2100 (RCP8.5), Southern Europe, including Portugal, will experience a widespread loss of working hours by at least 15% by the end of the century. Even if stronger global mitigation actions are implemented (i.e. under a global warming scenario of 1.6°C by 2100 (RCP2.6)), high heat risk is found for large parts of Southern Europe during the twenty-first century (Casanueva et al., 2020). Figure 34 shows the observed and projected percentage of summer working hours lost due to heat exposure under sunny conditions for a scenario where warming rises to about 4.3°C by 2100 (RCP8.5):

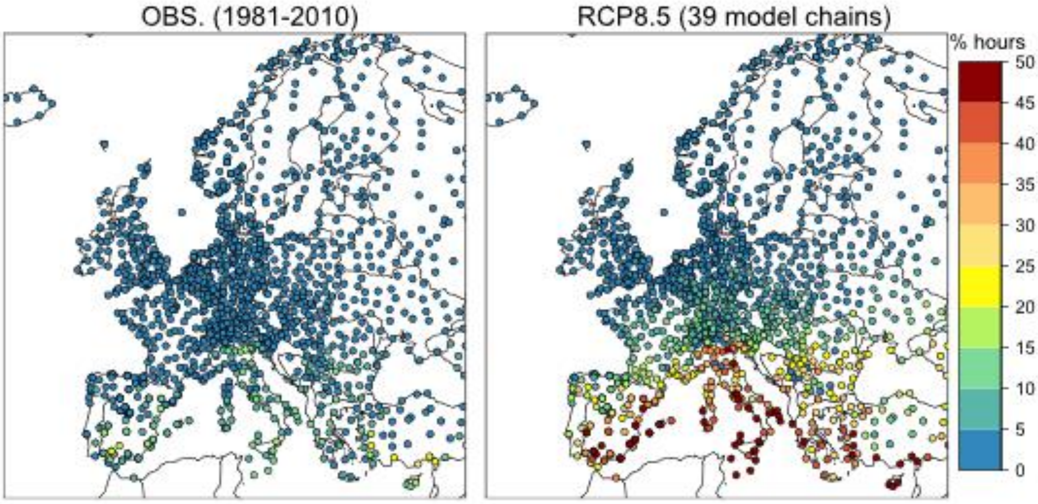


Figure 34: Productivity loss due to environmental heat exposure. Observed (left) and projected (right) percentage of summer working hours lost due to heat exposure under sunny conditions. Projections show a median of several models (over 39 model chains) for a scenario where warming rises to about 4.3°C by 2100(RCP8.5) and the period 2070-2099. (Casanueva et al., 2020)

9.2 Air quality and respiratory diseases

An increasing range of adverse health effects have been linked to two major air pollutants: ozone (O_3) and particulate matter (PM) (Monteiro et al., 2016). The number of deaths attributable to ozone in Portugal has been constantly increasing in recent decades, as Figure 35 shows:

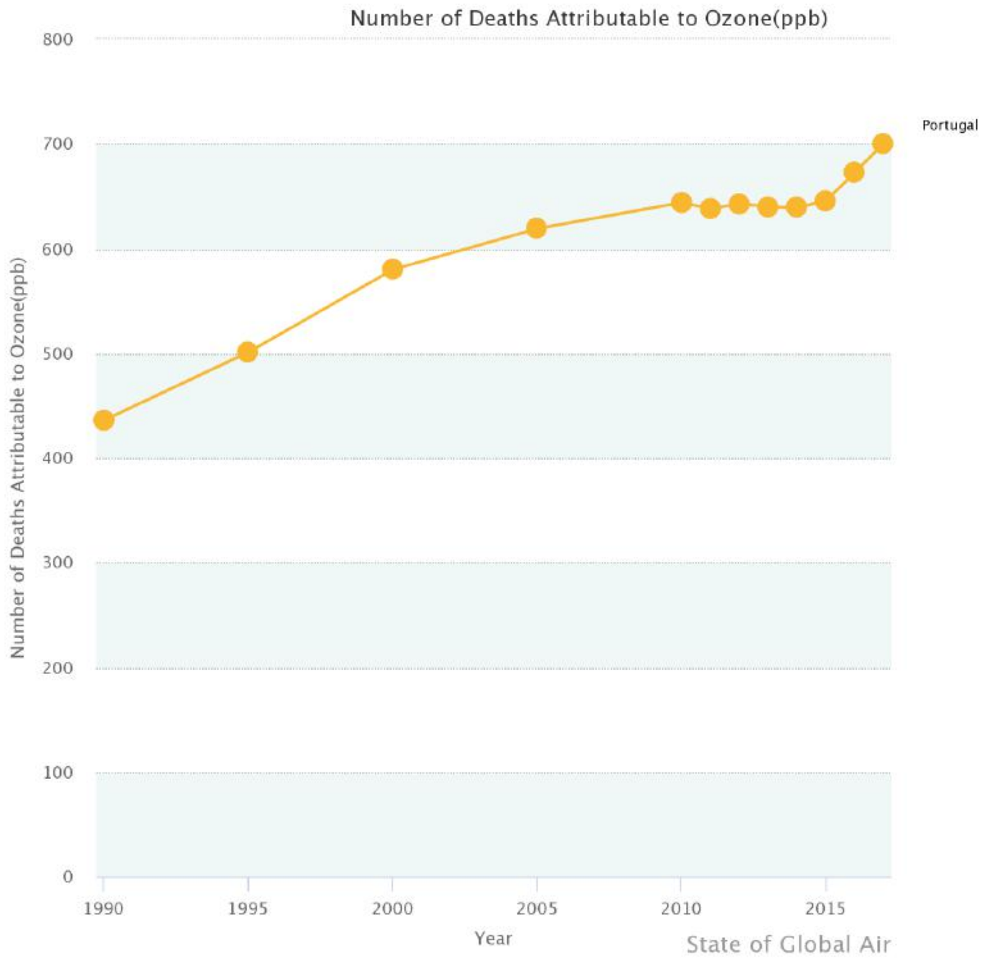


Figure 35: Number of deaths attributable to ambient ozone pollution (1990-2017) in Portugal (Heath Effects Institute, 2019).

While, the health effects caused by air pollution are broad, it mostly impacts the respiratory and cardiovascular systems (Monteiro et al., 2016). According to The State of Global Air 2019 report, tropospheric ozone pollution exposure increases the likelihood of dying from respiratory diseases, specifically chronic obstructive pulmonary diseases, and is therefore responsible for many premature deaths around the world (Health Effect Institute, 2019).

Both ozone and PM are very sensitive to changes in weather conditions (Monteiro et al., 2016). It has been noted that, "changes in temperature, humidity, wind and precipitation that may accompany future climate change can deeply impact air quality because of induced changes in the transport, dispersion, and transformation of air pollutants at multiple scales" (Dias et al., 2012). Figure 36 shows the expected increase in summertime ozone concentration over Europe. The modelled data shows an expected increase of more than 6% for most of Portugal for the end of the century (2071-2100) in comparison to present levels (1960-2010).

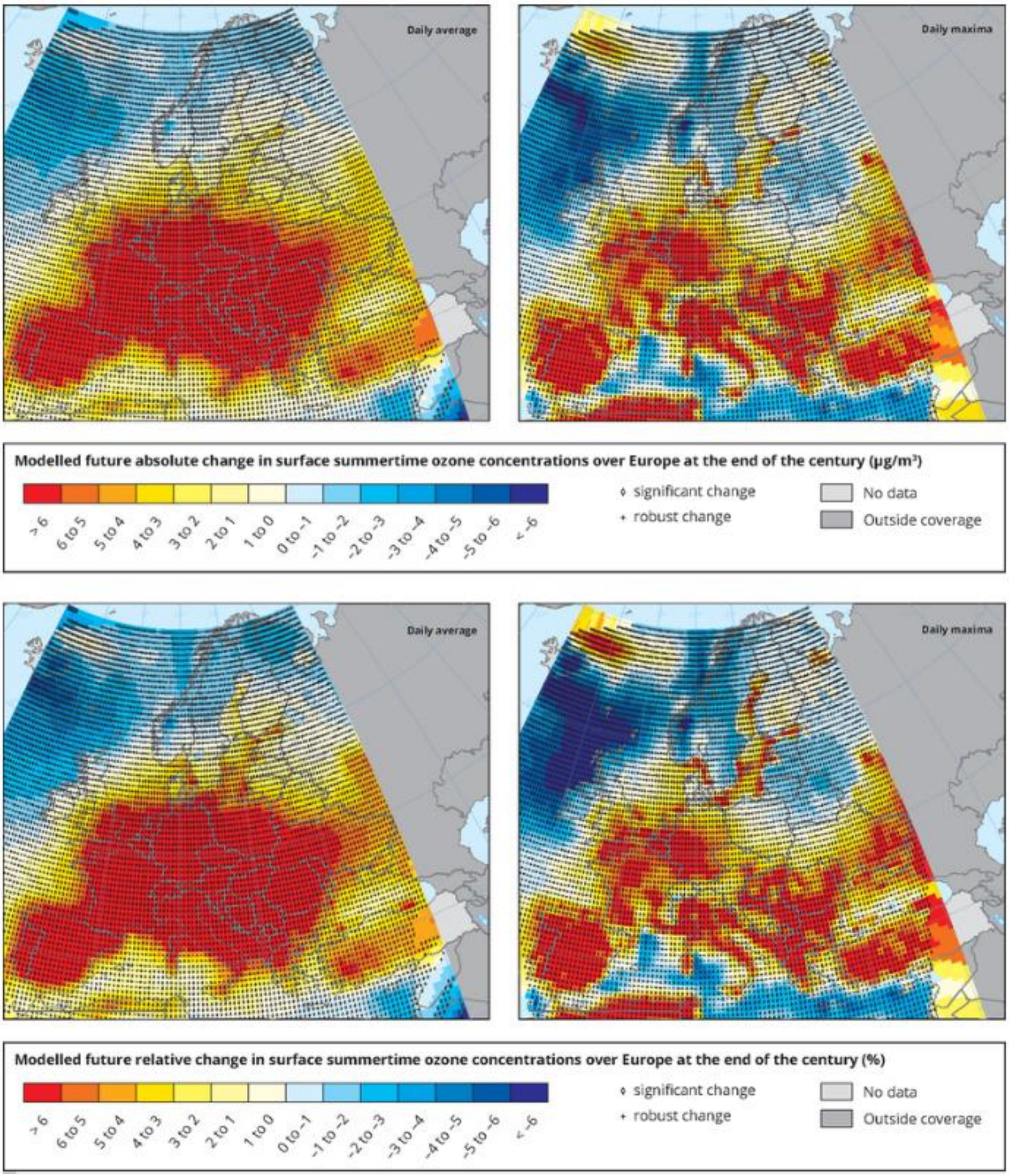


Figure 36: Modelled future change (absolute and relative) in surface summertime ozone concentrations (left: daily average, right: daily maxima) over Europe at the end of the century. Absolute and relative difference between future (2071-2100) and present (1960-2010) summertime average daily and maxima ozone levels in a 3 model ensemble. The modelled changes shown are only due to climate variability and climate change. A diamond sign is plotted where the change is significant, and a plus sign is added where the change is robust across two-third of modelled years. The period 2071-2100 is taken as representative of the end of the 21st century (2100), Source: (European Environment Agency, 2015)

In a future global warming scenario of 4.3°C by 2100 (RCP8.5), annual mean PM levels over Portugal are expected to increase by 30% in the north and by more than 40% in the south (Monteiro et al., 2016). Moreover, between 50% (for PM10) and 80% (for PM2.5)[1] of the days

[1] PM10 and PM2.5 refers to different types of PM according to size (the numbers refer to the diameter of the respective types of PM particles in micrometers).

per year are expected to exceed the WHO Air Quality Guidelines for PM (Monteiro et al., 2016). These results indicate that, as a result of climate change, populations in Portugal will be exposed to high levels of pollution which have a risk to health, including lung cancer mortality, cardiopulmonary disease and premature mortality due to long-term exposure (Monteiro et al., 2016).

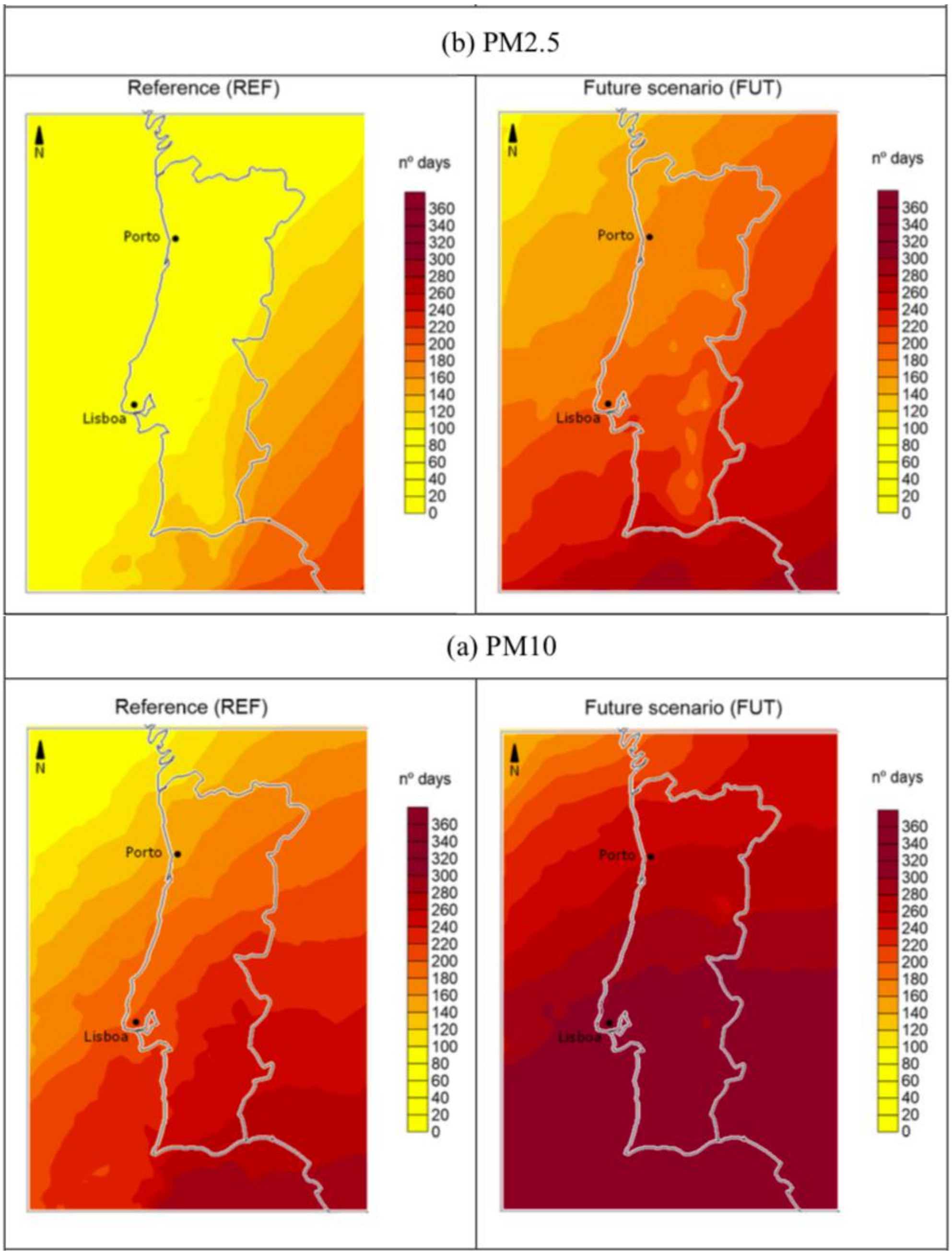


Figure 37: Number of days with exceedance of the daily limit value of (a) PM10 and (b) PM2.5 for reference period and future scenario under a global warming scenario of 4.3°C by 2100 (RCP8.5) (A. Monteiro et al., 2016).

Climate change also has the potential to increase ambient air levels of aeroallergens such as pollen (in addition to pollutants such as tropospheric ozone) in Portugal, thereby exacerbating respiratory diseases such as asthma (Amelung et al., 2007).

Finally, insofar as Portugal will experience increasing forest fires as a result of climate change, it is of note that the emissions from wildfires can increase the effects of heat stress, especially on the cardiovascular and respiratory systems (Vitolo et al., 2019).

9.3 Vector-borne diseases

Risks from vector-borne diseases are projected to increase with warming from 1.5°C to 2°C (high confidence) (Ove Hoegh-Guldberg et al., 2018). According to Casimiro et al.'s Portugal-specific study,

> "climate change may increase the risk levels of zoonoses, such as leishmaniasis, Lyme disease, and MSF [Mediterranean spotted fever], which currently pose the greatest risk to public health. Diseases that currently have lower transmission risk levels such as malaria and schistosomiasis are more sensitive to the introduction of infected vectors than to local temperature changes. The current risk of (local) introduction of a new population of infected vectors was not assessed but is influenced by factors ranging from global trade and population movements from countries where the disease is endemic, to alterations in the geographic range of infected vectors due to ecologic changes or vector control management practices. In general, climate change has the potential to change most of these factors to favor an increase (global) risk of infected vector introduction as well as imported (human) disease cases" (Casimiro et al., 2006).

Until 1950, mosquito-borne diseases such as malaria were a major public health concern in Portugal but in recent decades human cases of vector-borne diseases have generally decreased (Casimiro et al., 2006). There are, however, still many competent vectors present in Portugal and climate change is projected to cause a significant increase in the number of days with temperatures suitable for the survival of malaria vectors (Casimiro et al., 2006).

In general, 88% of the existing burden of diseases as a result of climate change is carried by children under the age of five (Ahdoot and Pacheco, 2015). Children are highly vulnerable to vector-borne diseases such as dengue fever and malaria (UNICEF, 2015). Two thirds of the deaths by malaria happened to children, of which two thirds are below the age of five (UNICEF, 2015).

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