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Climate risk and response: Physical hazards and socioeconomic impacts

A Mediterranean basin without a Mediterranean climate?

Case study
May 2020

McKinsey Global Institute

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Introduction to case studies

In January 2020, the McKinsey Global Institute published *Climate risk and response: Physical hazards and socioeconomic impacts*. In that report, we measured the impact of climate change by the extent to which it could affect human beings, human-made physical assets, and the natural world. We explored risks today and over the next three decades and examined specific cases to understand the mechanisms through which climate change leads to increased socioeconomic risk. This is one of our case studies, focused on the Mediterranean.

We investigated cases that cover a range of sectors and geographies and provide the basis of a "micro-to-macro" approach that is a characteristic of McKinsey Global Institute research. To inform our selection of cases, we considered over 30 potential combinations of climate hazards, sectors, and geographies based on a review of the literature and expert interviews on the potential direct impacts of physical climate hazards. We found these hazards affect five different key socioeconomic systems: livability and workability, food systems, physical assets, infrastructure services, and natural capital.

We ultimately chose nine cases to reflect these systems and based on their exposure to the extremes of climate change and their proximity today to key physiological, human-made, and ecological thresholds (Exhibit 1). As such, these cases represent leading-edge examples of climate change risk. Each case is specific to a geography and an exposed system, and thus is not representative of an "average" environment or level of risk across the world. Our cases show that the direct risk from climate hazards is determined by the severity of the hazard and its likelihood, the exposure of various "stocks" of capital (people, physical capital, and natural capital) to these hazards, and the resilience of these stocks to the hazards (for example, the ability of physical assets to withstand flooding). We typically define the climate state today as the average conditions between 1998 and 2017, in 2030 as the average between 2021 and 2040, and in 2050 between 2041 and 2060. Through our case studies, we also assess the knock-on effects that could occur, for example to downstream sectors or consumers. We primarily rely on past examples and empirical estimates for this assessment of knock-on effects, which is likely not exhaustive given the complexities associated with socioeconomic systems. Through this "micro" approach, we offer decision makers a methodology by which to assess direct physical climate risk, its characteristics, and its potential knock-on impacts.

Climate science makes extensive use of scenarios ranging from lower (Representative Concentration Pathway 2.6) to higher (RCP 8.5) CO_2 concentrations. We have chosen to focus on RCP 8.5, because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. Such an "inherent risk" assessment allows us to understand the magnitude of the challenge and highlight the case for action. (We also choose a sea level rise scenario for one of our cases that is consistent with the RCP 8.5 trajectory). Our case studies cover each of the five systems we assess to be directly affected by physical climate risk, across geographies and sectors. While climate change will have an economic impact across many sectors, our cases highlight the impact on construction, agriculture, finance, fishing, tourism, manufacturing, real estate, and a range of infrastructure-based sectors. The cases include the following:

— For livability and workability, we look at the risk of exposure to extreme heat and humidity in India and what that could mean for that country's urban population and outdoor-based sectors, as well as at the changing Mediterranean climate and how that could affect sectors such as wine and tourism.

— For food systems, we focus on the likelihood of a multiple-breadbasket failure affecting wheat, corn, rice, and soy, as well as, specifically in Africa, the impact on wheat and coffee production in Ethiopia and cotton and corn production in Mozambique.

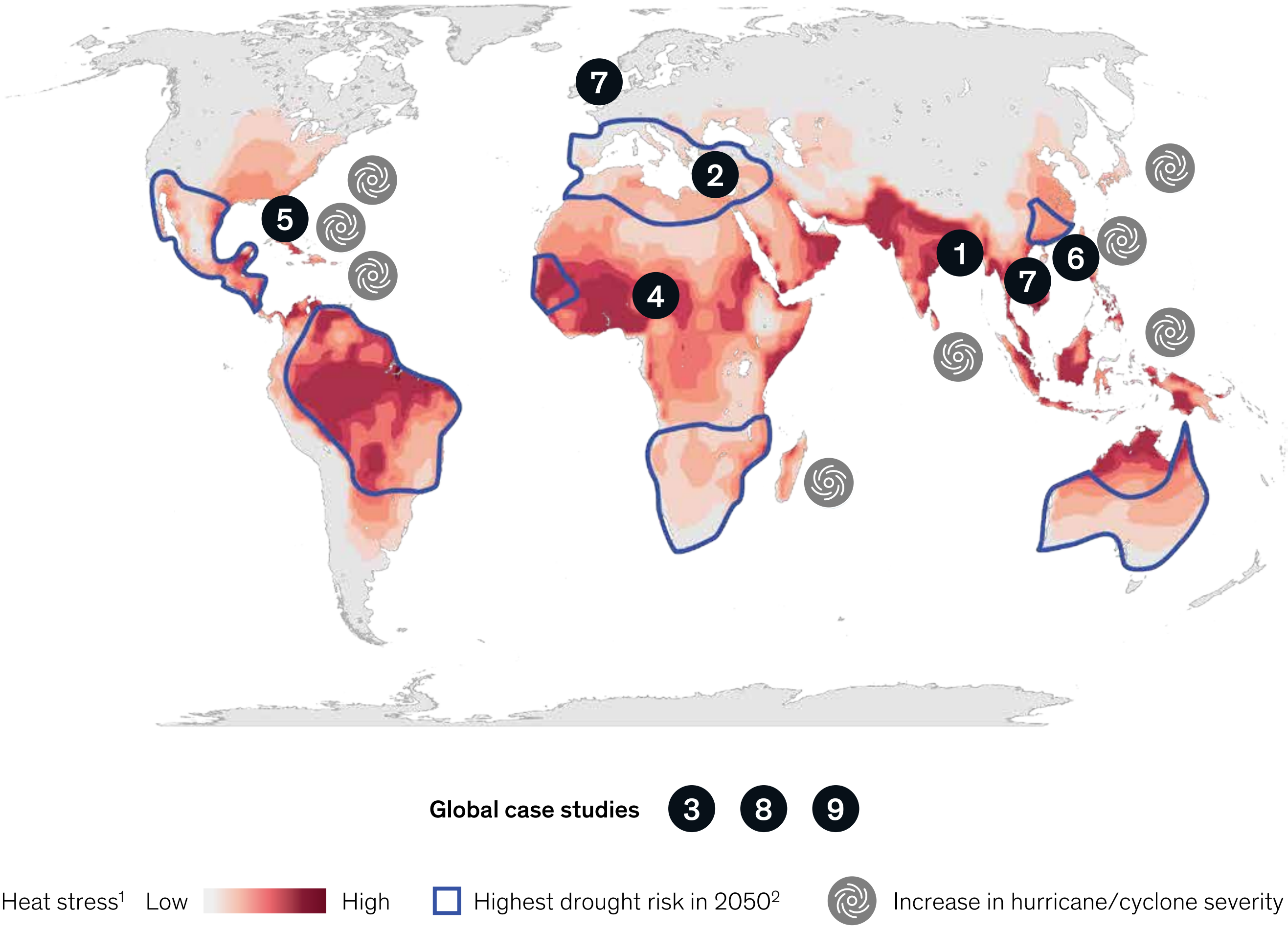
— For physical assets, we look at the potential impact of storm surge and tidal flooding on Florida real estate and the extent to which global supply chains, including for semiconductors and rare earths, could be vulnerable to the changing climate.

— For infrastructure services, we examine 17 types of infrastructure assets, including the potential impact on coastal cities such as Bristol in England and Ho Chi Minh City in Vietnam.

— Finally, for natural capital, we examine the potential impacts of glacial melt and runoff in the Hindu Kush region of the Himalayas; what ocean warming and acidification could mean for global fishing and the people whose livelihoods depend on it; as well as potential disturbance to forests, which cover nearly one-third of the world's land and are key to the way of life for 2.4 billion people.

Exhibit 1

We have selected nine case studies of leading-edge climate change impacts across all major geographies, sectors, and affected systems.



Livability and workability	1	Will India get too hot to work?
	2	A Mediterranean basin without a Mediterranean climate?
Food systems	3	Will the world's breadbaskets become less reliable?
	4	How will African farmers adjust to changing patterns of precipitation?
Physical assets	5	Will mortgages and markets stay afloat in Florida?
	6	Could climate become the weak link in your supply chain?
Infrastructure services	7	Can coastal cities turn the tide on rising flood risk?
	8	Will infrastructure bend or break under climate stress?
Natural capital	9	Reduced dividends on natural capital?

1. Heat stress measured in wet-bulb temperatures.
2. Drought risk defined based on time in drought according to Palmer Drought Severity index (PDSI).

Source: Woods Hole Research Center; McKinsey Global Institute analysis

Rising flood waters in Venice.

Mediterranean

A Mediterranean basin without a Mediterranean climate?

The Mediterranean basin is often perceived as the ultimate in climate, comfort, and culture. Year-round, millions of visitors from all over the world flock to enjoy the mild climate, wine and food, and stunning scenery. However, climate change may harshen the Mediterranean climate and disrupt vital industries such as tourism and agriculture. The mean temperature in the Mediterranean basin has increased 1.4 degrees Celsius since the late 19th century, compared with the global average of 1.1 degrees—and absent targeted decarbonization, temperatures are projected to increase by an additional 1.5 degrees by 2050.[1] Rising temperatures are expected to raise hydrological variability, increasing the risk of drought, water stress, wildfires, and floods.

In this case study, we examine the consequences of a changing climate for Mediterranean communities and economies. We focus on heat- and precipitation-related aspects of climate change, though coastal flooding will also have an impact (see Box 1, "Coastal flooding"). Climate projections indicate that the annual number of days with a maximum temperature above 37 degrees will increase everywhere in the Mediterranean region, with a doubling in North Africa, southern Spain, and Turkey from 30 to 60 by 2050. Many areas could see a decline in water supplies of between 10 and 25 percent between 2030 and 2050.[2] Heat and drought conditions further increase the risk of wildfires and disease. In the Iberian Peninsula, for example, the expected annual area burned by wildfire is projected to double by 2050.[3]

We then explore the economic impacts of climate change in tourism and farming. We find physical climate change is likely to increase spatial inequality across countries and regions within Europe. We expect that an increase in the number of "too hot" days in a given region could discourage tourism in peak season, which today accounts for approximately 15 percent of the GDP of Mediterranean countries while other northern countries may benefit from a warmer climate. We find that agriculture will likely be impacted. Farmers in many places have already seen their crop yields diminish and become less predictable, a trend that is likely to continue.[4] Areas known for the quality of their wine grapes, for example, risk losing prominence on the viticulture map while nontraditional growing regions could gain advantage.

Economic impacts are by no means the only effects of a hotter, drier climate. Past European heat waves have resulted in deaths. In France, an August 2003 heat wave caused 15,000 more deaths than expected for the three-week period.[5] In the EU in total, up to 35,000 deaths were attributed to the heat wave.[6] Absent a mitigation response, EU researchers estimate that heat-related mortality could double by 2080.[7]

1 Wolfgang Cramer et al., "Climate change and interconnected risks to sustainable development in the Mediterranean," *Nature Climate Change,* November 2018, Volume 8, Number 11; CORDEX via KNMI Climate Explorer.

2 If not indicated differently, we follow standard practice and define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060. Also, if not indicated differently, the climatological analyses in this case use RCP 8.5 to represent the changes in atmospheric greenhouse gas concentrations that could occur absent a mitigation response. Please see technical appendix of the full report for details.

3 Marco Turco et al., "Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models," *Nature Communications,* 2018, Volume 9.

4 Insert footnote: Deepak K. Ray et al., "Climate change has likely already affected global food production," *PLoS ONE*, May 2019, Volume 14, Issue 5.

5 Stéphanie Vandentorren et al., "August 2003 Heat wave in France: Risk factors for death of elderly people living at home," *European Journal of Public Health,* December 2006, Volume 16, Number 6.

6 Shaoni Bhattacharya, "The 2003 Europe heat wave caused 35,000 deaths," *New Scientist,* October 10, 2003.

7 Juan Carlos Ciscar et al., *Climate impacts in Europe: Final report of the JRC PESETA III project,* European Commission, 2018; "Peseta II," European Commission.

Policy makers and companies in the Mediterranean can take action to lessen the impact of climate change. Farmers, for example, might gain access to public funds, training, and supplies to cultivate crops that do not belong to traditional rotations. Tourist destinations may adjust their high seasons and provide incentives to attract travelers, and governments may invest in reducing wildfire risk through enhanced forest management. But choices will need to be made. For example, coastal areas at risk from flooding will face a decision between protecting existing properties and infrastructure, and reducing exposure to this risk through managed retreat.

Mediterranean countries are already increasing their efforts to counter the effects of climate change. In France, climate-change-related financing for farmers has averaged more than $200 million per year since 2015, up from an average of $70 million per year from 2007 to 2014. About half of the support took the form of disaster compensation, while the remainder consists of subsidies for insurance programs.[8] Issuing payments to compensate farmers and others for financial damages resulting from climate change is only one form of adaptation. In many cases it will be more economical for Mediterranean governments to protect and build resilience against the effects of climate change than to adhere to habits that climate change will render more impractical and costly.

Box 1.

Coastal flooding

Between 1993 and 2015, the Mediterranean Sea rose by two to three millimeters per year.[1] The rising of the sea is projected to accelerate, resulting in a further increase of about 25 centimeters from its current level by 2050.[2] The higher mean sea level, combined with tidal forces and storms, will result in more frequent and/or severe coastal flooding.[3]

This could lead to significant costs. Researchers have estimated that the continued development of the northern Mediterranean's already-populous shorelines, along with the flooding that is expected to stem from climate change, will likely expose 300,000 to 400,000 people to coastal flooding each year and result in annual damage of $7 billion to $22 billion per year by 2050.[4] France is projected to bear more than half of those impacts, while Italy shoulders roughly one-fifth.

To adapt, EU researchers have estimated that the total average required expenditure for the continent on dikes and beach nourishment could be roughly $2.2 billion annually starting in 2020.[5] However, spending in individual countries suggests that the costs could be much greater. The Netherlands, for example, spends some $1.4 billion each year on the protection of its coastline.[6] Furthermore, sea levels will continue to rise after 2050—even if net-zero emissions have been reached—further increasing the related protection costs.

1 Marta Marcos, Gabriel Jorda, and Gonéri Le Cozannet, "Sea level rise and its impacts on the Mediterranean," in *The Mediterranean Region under Climate Change: A Scientific Update,* Jean-Paul Moatti and Stéphane Thiébault, eds., Marseille, France: IRD Éditions, 2016.

2 Michalis I. Vousdoukas et al., "Extreme sea levels on the rise along Europe's coasts," *Earth's Future,* March 2017, Volume 5, Number 3.

3 Michalis I. Vousdoukas et al., "Climatic and socioeconomic controls of future coastal flood risk in Europe," *Nature Climate Change,* 2018, Volume 8, Number 9.

4 Michalis I. Vousdoukas et al., "Climatic and socioeconomic controls of future coastal flood risk in Europe," *Nature Climate Change,* 2018, Volume 8, Number 9. Combined annual damage for all European countries bordering the Mediterranean Sea.

5 Juan Carlos Ciscar et al., *Climate impacts in Europe: Final report of the JRC PESETA III project,* European Commission, 2018; "Peseta II," European Commission.

6 Government of the Netherlands, *Delta Programme,* government.nl/topics/delta-programme/organisation-of-the-delta-programme.

8 French Ministry for Agriculture and Food, "Agreste—Statistique agricole annuelle (SAA)," data.gouv.fr/en/datasets/agreste-statistique-agricole-annuelle-saa

As the Mediterranean becomes hotter and drier, the risk of water stress, wildfires, and coastal flooding increases

The Mediterranean climate could change in multiple ways as temperatures rise, water stress increases, and precipitation becomes more volatile, in turn creating multiple knock-on effects from wildfires to the spread of disease.

— **Heat.** With warm, dry summers and mild winters, the Mediterranean climate has long been suited to tourism and the cultivation of valuable crops, notably wine grapes. However, rising temperatures may disrupt established industries and norms. The temperature in the Mediterranean basin has climbed 1.4 degrees, and the increase is projected to continue to exceed global rates, rising approximately 0.5 degree by 2030 and 1.5 degrees by 2050.[9] Climate projections indicate that the number of days with a maximum temperature above 37 degrees will increase everywhere in the Mediterranean region, with especially large rises in northern Africa, the Middle East, southern Spain, and Turkey (Mediterranean-1).[10]

— **Drought.** In Italy, Portugal, Spain, and parts of Greece and Turkey, rainfall during the warm, dry season of April through September is projected to decrease by as much as 10 percent by 2030 and as much as 20 percent by 2050.[11] By 2050, drought conditions could prevail for at least six months out of every year in these areas (Mediterranean-2).[12] These changing temperature and precipitation patterns will noticeably transform the Mediterranean climate. Scientists have projected that even under the RCP 4.5 scenario, in Spain, Madrid's climate in 2050 will be more like Marrakech's in Morocco today, while in France Marseille's climate will resemble that of Algier in Algeria.[13]

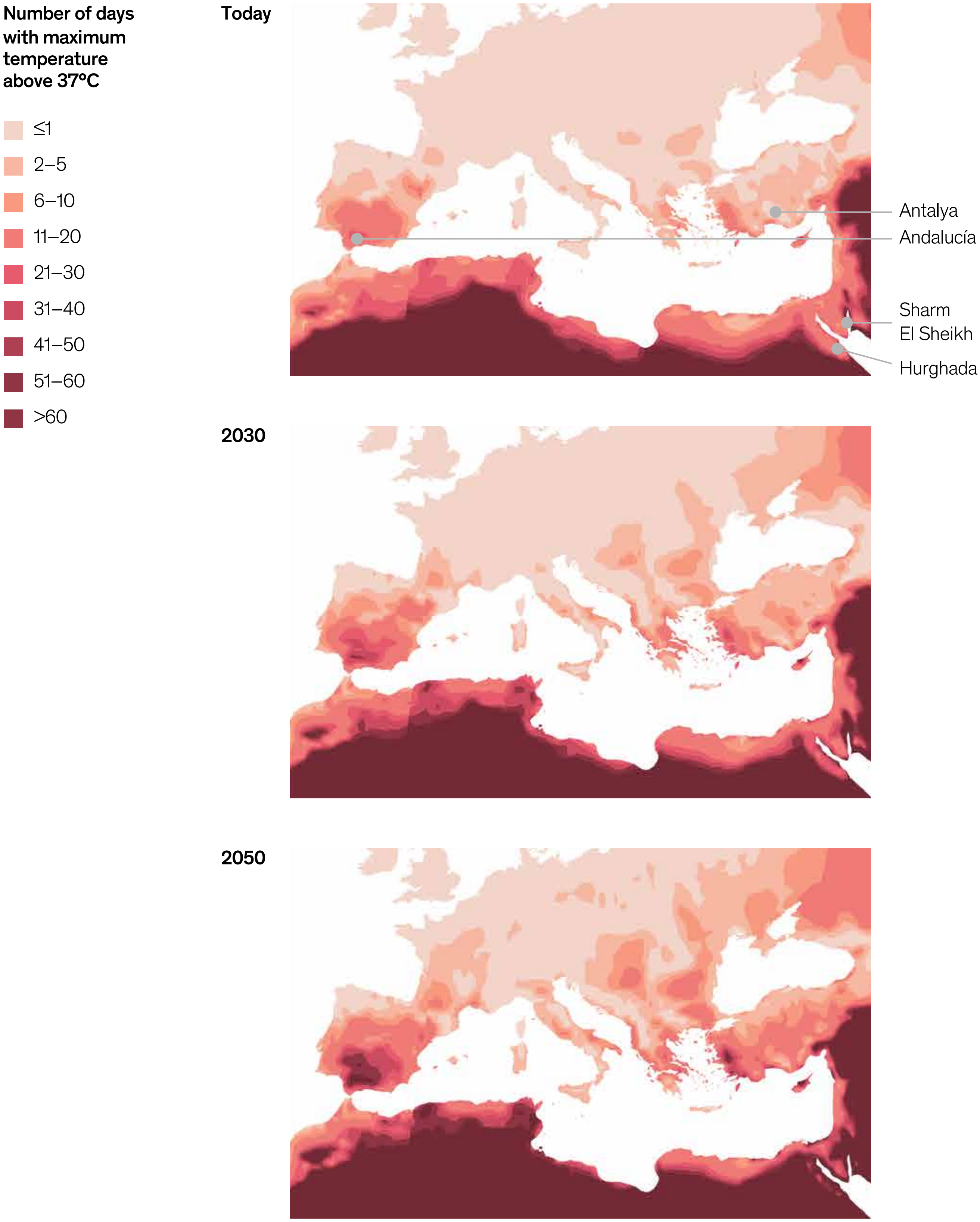
— **Water stress.** Changing rates of annual precipitation and increasing evaporation are projected to impact the Mediterranean region's supply of fresh water. Many basins could see a decline of approximately 10 percent in water supplies by 2030 and of up to 25 percent by 2050 (Mediterranean-3). Water stress is already high in most countries in the Mediterranean and extremely high in Morocco and Libya.[14] The decline in supply is projected to heighten water stress in all Mediterranean countries between now and 2050, with the greatest increases in Greece, Morocco, and Spain.[15]

  Dwindling supplies may increase competition for water between different sectors. The agriculture sector will be a key contestant in this competition. It accounts for about 80 percent of water withdrawals in North Africa and about 60 percent in southern Europe.[16] Its demand may grow even further. Areas that are now irrigated could require more irrigation, and those that are now rainfed might need to be irrigated.[17]

9 Wolfgang Cramer et al., "Climate change and interconnected risks to sustainable development in the Mediterranean," *Nature Climate Change,* November 2018, Volume 8, Number 11; CORDEX via KNMI Climate Explorer.
10 EURO-CORDEX regional climate model (RCM) ensemble.
11 CORDEX via KNMI Climate Explorer.
12 Based on Palmer Drought Severity Index of –2 (moderate drought) or lower. NOAA characterizes moderate drought by: some damage to crops and pastures; high fire risk; low streams, reservoirs, or wells; some water shortages developing or imminent; and voluntary water use restrictions requested. In general, drought means dry relative to what is normal for a given location and time of year.
13 Jean-Francois et al., "Understanding climate change from a global analysis of city analogues," *PLOS ONE,* July 2019, Volume 14, Number 7.
14 High water stress is defined by a water demand over supply ratio of 0.4–0.8, extremely high water stress by a ratio higher than 0.8.
15 Population growth, urbanization, and other developments will likely increase demand for water and worsen water stress.
16 FAO Aquastat, fao.org/nr/water/aquastat/tables/WorldData-Withdrawal_eng.pdf; for comparison, the rest of Europe uses approximately 10 percent of water withdrawals for agriculture.
17 Samuel Levis et al., "CLMcrop yields and water requirements: Avoided impacts by choosing RCP 4.5 over 8.5," *Climatic Change,* February 2018, Volume 146, Number 3–4.

The number of days above 37°C in southern Spain, Turkey, and Egypt is expected to double by 2050, from about 30 to 60.

Based on RCP 8.5



Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multimodel ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.
Source: EURO-CORDEX RCM ensemble; Woods Hole Research Center

Drought is expected to become prevalent in the Mediterranean region by 2030 and further increase by 2050.

Based on RCP 8.5

Share of decade spent in drought
%

- 0–10
- 11–20
- 21–40
- 41–60
- 61–80
- 81–90
- >90

Measured using a 3-month rolling average. Drought is defined as a rolling 3-month period with Average Palmer Drought Severity Index (PDSI) <-2. PDSI is a temperature- and precipitation-based drought index calculated based on deviation from historical mean. Values range from +4 (extremely wet) to -4 (extremely dry).

Today

2030

2050

Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.
Source: Woods Hole Research Center

Case study Mediterranean-3

More parts of the Mediterranean are projected to experience shifts in water supply and increasing water stress.

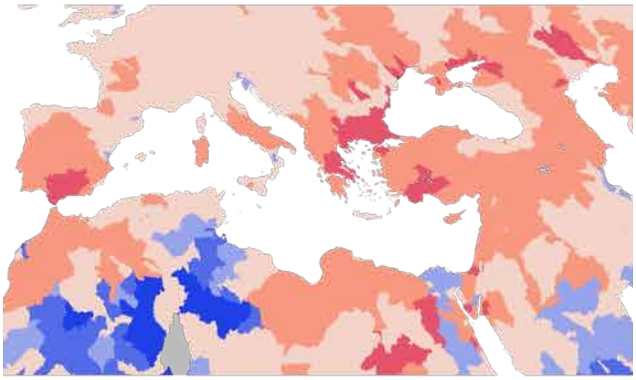
Based on RCP 8.5

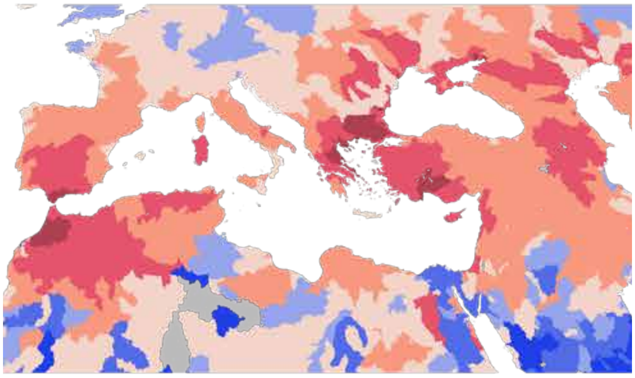
2030[1]	2050[1]

Water supply change relative to today,[2]
%

Significant decrease — Significant increase

< -15 | -6 to -15 | -1 to -5 | 0 | 1–5 | 6–15 | >15

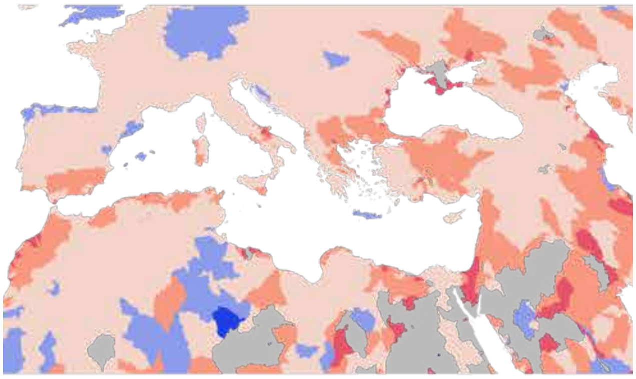


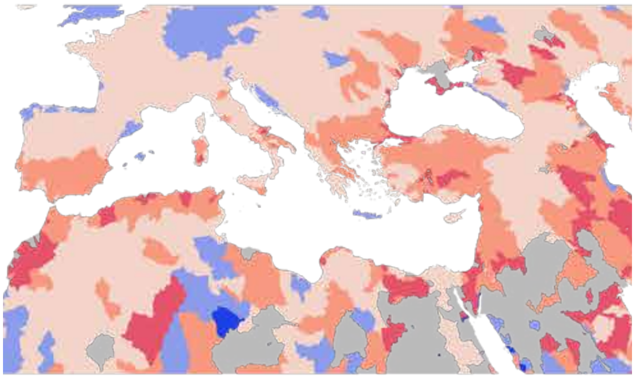


Water stress change relative to today,[3]
%

Significant decrease — Significant increase

< -0.8 | -0.1 to -0.8 | 0–0.2 | 0.3–0.8 | >0.8





1. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.
2. Average annual renewable water supply from precipitation.
3. Water stress is defined as the ratio of water demand to water supply. Water demand is assumed to remain constant at today's levels.

Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multimodel ensemble. Heat data bias corrected.

Source: World Resources Institute; McKinsey Global Institute analysis

— **Wildfires.** Given that temperature and drought conditions are the most important factors determining the variability of wildfire activity in southern Europe, increased levels of heat and dryness are also projected to cause larger areas—up to double the current areas on the Iberian Peninsula—to burn from wildfires.[18]

The Mediterranean basin has been beset by major wildfires in recent years. In 2017, fire destroyed more than 500,000 hectares of forest in Portugal, over 5 percent of the country's area. The largest fire, in and around the town of Pedrógão Grande, killed 66 people.[19] Each year between 1998 and 2017, wildfires destroyed an average of 150,000 hectares in Portugal and 120,000 hectares in Spain.[20] By 2030, wildfires are expected to burn 50 percent more of those countries' forestland each year, and by 2050 the burned area is projected to double (Mediterranean-4).[21] With the burned area doubling, the additional economic damage could reach more than $1.5 billion per year in Portugal and Spain alone.[22]

— **Disease.** High summer temperatures have also been linked with the increasing incidence of West Nile fever in Europe.[23] Researchers have already projected that the West Nile virus is likely to spread by 2025 and to spread further by 2050.[24] For example, the Balkans and parts of Turkey are projected to be affected (Mediterranean-5). The summer of 2019 saw the first reported case of West Nile virus infection as far north as Germany.[25]

These climate hazards and risks are likely to impose socioeconomic costs on the Mediterranean. The region's agriculture and tourism industries, which depend on a favorable climate, could suffer, with the largest impacts (on local employment, for example) in areas with undiversified economies. We explore these effects in the sections that follow.

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18 Marco Turco et al., "Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models," *Nature Communications,* October 2018, Volume 9.

19 M. Turco et al., "Climate drivers of the 2017 devastating fires in Portugal," *Scientific Reports 2019,* Volume 9.

20 EFFIS annual fire reports, https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports/

21 Marco Turco et al., "Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models," *Nature Communications,* October 2018, Volume 9. The 100 percent increase in Spain and Portugal occurs at global temperature increase of two degrees above preindustrial level, which will be reached by approximately 2050 in a representative concentration pathway (RCP) 8.5 scenario.

22 European Commission, *Forest fires: Sparking firesmart policies in the EU,* November 2018. Total economic losses in the EU were estimated more than $3 billion per year from 2000 to 2017; Portugal and Spain accounted for almost half of the burned area.

23 Annelise Tran et al., "Environmental predictors of West Nile fever risk in Europe," *International Journal of Health Geographics,* July 2014, Volume 13. While approximately 20 percent of people infected with West Nile virus will experience flulike symptoms, less than 1 percent develop severe neurological illness. In such cases, the probability of not surviving is 4 to 14 percent; Dutch National Institute for Public Health and the Environment (RIVM).

24 Jan C. Semenza et al., "Climate change projections of West Nile virus infections in Europe: Implications for blood safety practices," *Environmental Health,* 2016, Volume 15.

25 Robert-Koch-Institut, "First West Nile virus disease transmitted by mosquitoes in humans in Germany," https://www.rki.de/DE/Content/Service/Presse/Pressemitteilungen/2019/09_2019.html.

Case study Mediterranean-4

By 2050, the area in Spain and Portugal burned by wildfires is projected to double.

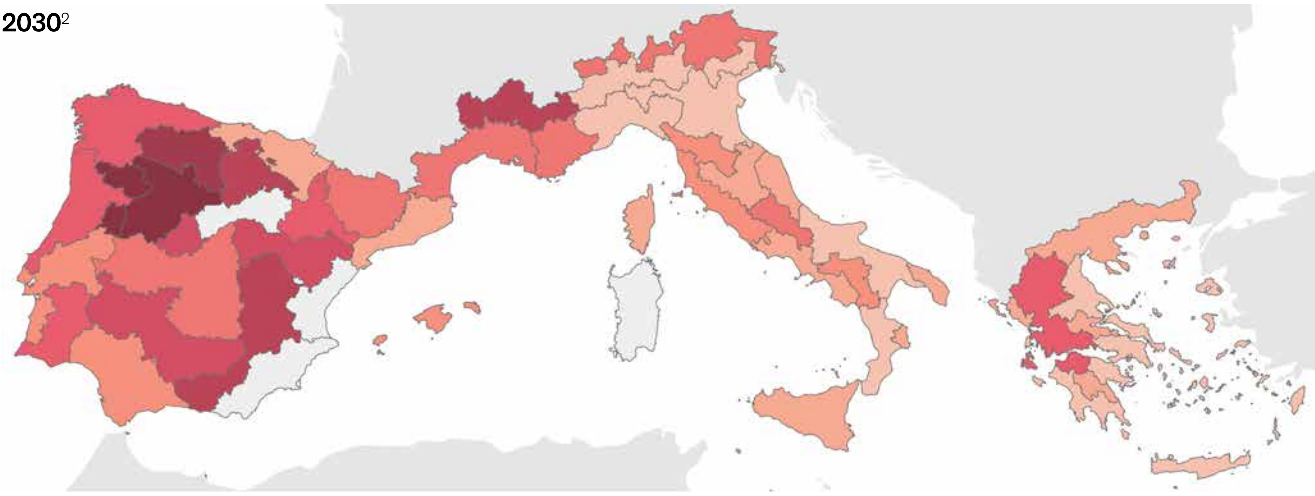
Based on RCP 8.5

Increase in burned area, by eco-region (compared with 1871–2000)[1]

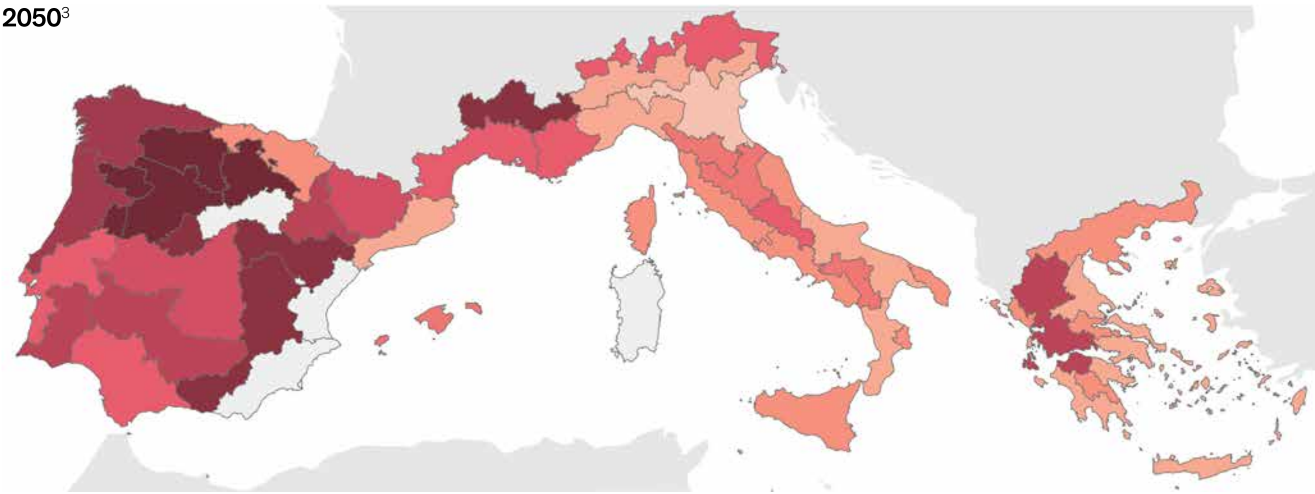
%

No model | ≤10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80 | 81–90 | 91–100 | >100

2030[2]



2050[3]



1. Ecoregion is a statistical stratification based on environmental variables such as temperature, precipitation, altitude, etc. Regions have relatively similar climatic properties.
2. Based on regional climate projections at 1.5°C of mean global warming, which is projected to be reached in approximately 2030 under RCP 8.5.
3. Based on regional climate projections at 2.0°C of mean global warming, which is projected to be reached in approximately 2050 under RCP 8.5.

Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multimodel ensemble. Heat data bias corrected.

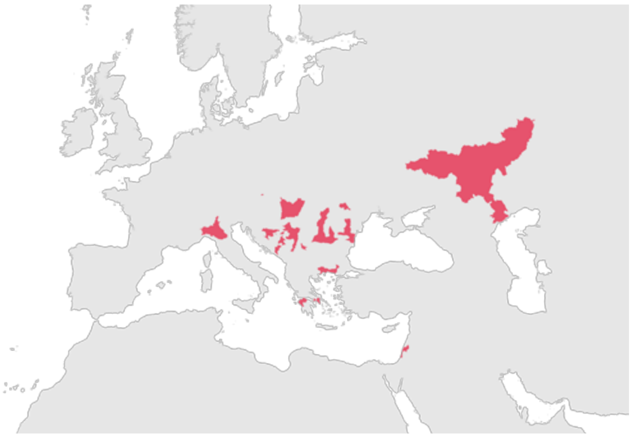
Source: Adapted from Turco et al., 2018

As temperatures rise, the potential transmission area of West Nile virus is projected to expand in the Mediterranean region.

Districts with probable and confirmed cases of West Nile virus infections[1]

Areas reporting cases in 2014

No reported cases



Modeled probability of having one or more West Nile virus infections per year, by district[2]

%

>50

≤50

2014

2025

2050

1. As of November 20, 2014. An affected area is defined as an area with one or more autochthonous human West Nile virus cases (neuroinvasive and non-neuroinvasive), meeting laboratory criteria per EU case definition (Directive 2008/426/EC). A probable case is any person meeting the clinical criteria and with an epidemiological link or a laboratory test for a probable case.
2. Based on temperature projections under A1B scenario. In that scenario, by 2050 A1B is between RCP 4.5 and 8.5.

Source: Adapted from Semenza et al., 2016

Climate change hazards may increase economic inequality within and across Europe

The spatial nature of physical climate change means that Mediterranean countries will face varying risks and associated costs relative to the European continent. The greatest costs are likely to fall on regions that largely rely on economic output from agriculture or tourism. Those areas could see significant decreases in income and employment and could experience knock-on effects when, for example, holiday real estate markets weaken. Local unemployment may also result in people moving to larger cities in search of jobs. However, whereas southern Europe is likely to see negative effects on agriculture and tourism, in northern Europe these sectors could benefit. This divergence could increase inequality across the continent. Impacts will be uneven not only between countries but also within countries. One example is France, where considerable climatic difference exists between the north and the south. An economic slowdown, to which climate change impacts could contribute, in southern Europe would increase the north-south gap on various indicators, such as unemployment. That could lead to increased tensions within the European Union and to more people moving in search of jobs, both within countries and potentially across borders.

Agricultural production

Nearly half of the Mediterranean region's agricultural production value comes from four crops: grapes (14 percent), wheat, tomatoes, and olives (9 percent each) (Mediterranean-6). Of the last three, Mediterranean countries produce about 90 percent of the total global supply.[26] (See Box 2, "How climate change could affect the production of wheat and tomatoes.") We focus on how climate change is likely to alter the production of grapes and wine in the period to 2050, and how those effects could cascade through the Mediterranean economy.

The wine industry in France, Italy, and Spain is important to regional economies. These three countries produce about half of the world's wine and 80 percent of the wine made in the European Union.[27] In France, nearly $2 billion of value-added tax revenues derive from wine production. In addition, the wine industry directly employs some two million people, mostly in rural areas, and supports several other sectors, such as tourism (ten million people visit French vineyards, tasting rooms, and wine museums each year, spending more than $5 billion), manufacturing (equipment and materials), construction, distribution, and retail.[28]

Production from traditional winemaking regions could diminish as the Mediterranean climate changes, since grapevines are highly sensitive to fluctuations in temperature and precipitation. In the past decade, annual wine production volumes in France have ranged between 36 million hectoliters in 2017 and 51 million hectoliters in 2011.[29] The quality of grapes and wine, too, depends on the weather. Researchers estimate that 10 to 60 percent of vintage ratings can be explained by temperature variations during the growing season.[30] Higher temperatures usually reduce grape quality by increasing sugar levels and decreasing acidity.

Increasing temperatures are not the only potential threat to grapes. Increasing water stress causes problems for growers, too. While mild water stress enhances grape quality for red wines, severe water stress will reduce yields.[31] Production can also be lost due to severe hailstorms, and climate change may contribute to their increasing incidence.[32] Researchers project that hailstorms in France will bring larger hailstones, resulting in a hail kinetic energy increase of 40 percent between 2000 and 2040.[33]

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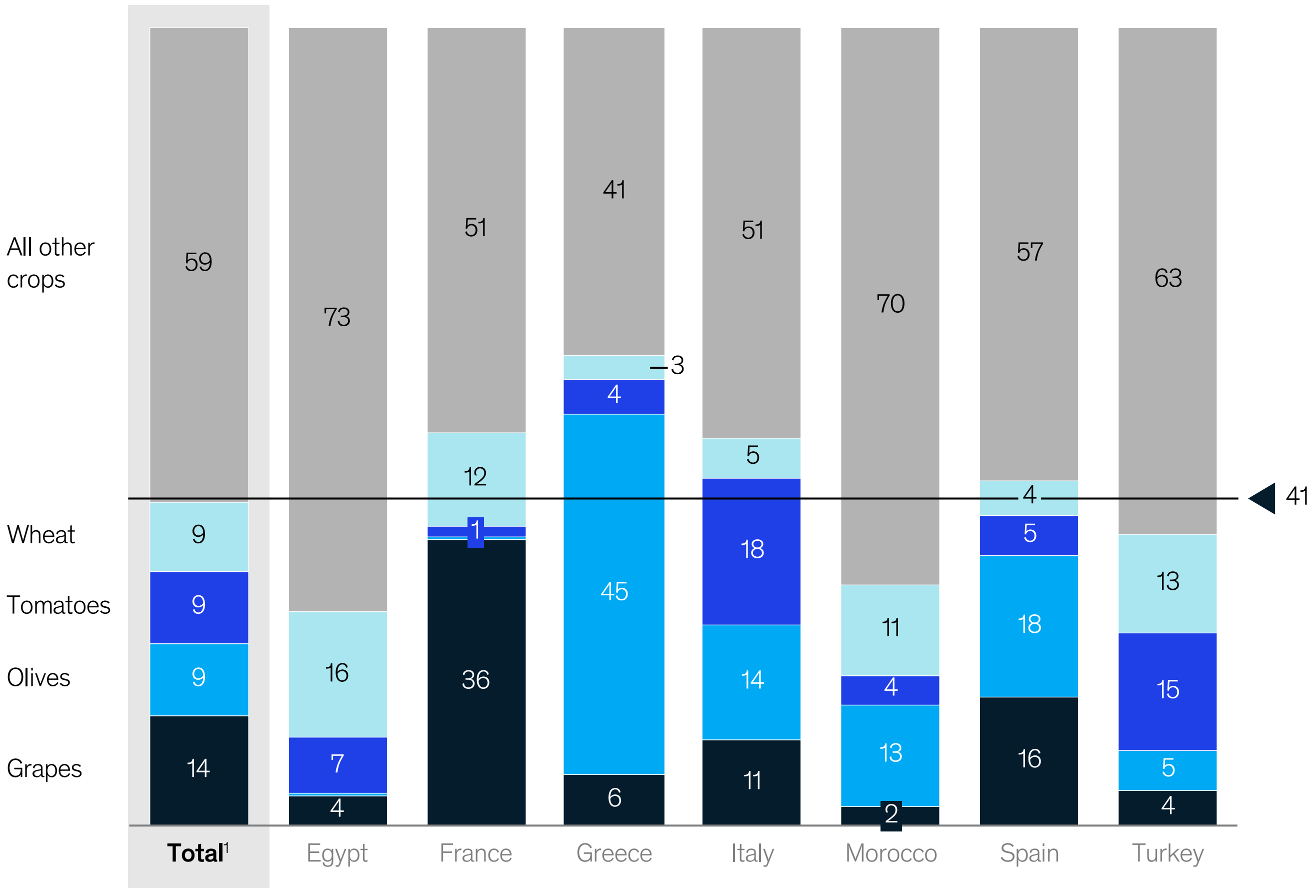
26 Food and Agriculture Organization of the United Nations, FAOSTAT; based on 2017 production value.
27 Comité Européen des Entreprises Vins, "European Wine: A solid pillar of the European Union economy," 2016, ceev.eu/images/documents/press_releases/2016/Brochure_CEEV_-_High_resolution.pdf
28 Ibid.; Atout France, L'Œnotourisme en France en 2016, http://www.atout-france.fr/download/4097; Vin et Société, *Les chiffres clés de la filière vin,* vinetsociete.fr/chiffres-cles-de-la-filiere-vin
29 French Ministry for Agriculture and Food, "Agreste—Statistique agricole annuelle (SAA)," data.gouv.fr/en/datasets/agreste-statistique-agricole-annuelle-saa.
30 Gregory V. Jones et al., "Climate change and global wine quality," *Climate Change,* December 2005, Volume 73, Number 3.
31 Cornelis van Leeuwen et al., "Vine water status is a key factor in grape ripening and vintage quality for red Bordeaux wine. How can it be assessed for vineyard management purposes?," *OENO One,* 2009, Volume 43, Number 3.
32 Eberhard Faust and Anja Rädler, "Hail—An underestimated and growing risk," Munich Re, 2018.
33 Jean Dessens, Claude Berthet, and J. L. Sanchez, "Change in hailstone size distributions with an increase in the melting level height," *Atmospheric Research,* May 2015, Volume 158–159.

About 40 percent of the Mediterranean region's agricultural production value comes from just four crops: wheat, tomatoes, olives, and grapes.

Crop production value in the Mediterranean region, 2016

% of total gross production value



1. Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Malta, Morocco, Portugal, Slovenia, Spain, Tunisia, Turkey.

Note: Figures may not sum to 100% because of rounding.

Source: FAO; McKinsey Global Institute analysis

Researchers have forecast a wide range of possible effects of climate change on grape yields. Some studies project that the Mediterranean area suitable for viticulture could fall by up to 70 percent at the high end of their range, though considerable debate surrounds these predictions, as others do not see negative impacts at all.[34] As the Mediterranean region becomes warmer, it is also likely that specific grape varieties will no longer grow where they do now (for example, Merlot in Bordeaux), while at the same time the opportunity to plant new varieties may rise.[35] Certain growing areas in Italy, Portugal, and Spain could experience large declines in production or even collapse.[36]

[34] Lee Hannah et al., "Climate change, wine, and conservation," *Proceedings of the National Academy of Sciences,* April 2013, Volume 110, Number 17; Cornelis van Leeuwen et al., "Why climate change will not dramatically decrease viticultural suitability in main wine-producing areas by 2050," *Proceedings of the National Academy of Sciences,* August 2013, Volume 110, Number 33.

[35] Elizabeth M. Wolkovich et al., "From Pinot to Xinomavro in the world's future wine-growing regions," *Nature Climate Change,* 2018, Volume 8, Number 1.

[36] Helder Fraga et al., "Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe," *Global Change Biology,* November 2016, Volume 22, Number 11.

Some researchers anticipate that the warming projected to occur throughout Europe could make it possible to grow wine grapes in regions farther to the north. In effect, Europe's grape-growing belt would shift. But the characteristics of Mediterranean vineyards and wineries cannot be replicated instantaneously. Indeed, they might never be matched, because gaining similar levels of experience in new winemaking regions may take generations.[37]

Box 2.

How climate change could affect the production of wheat and tomatoes

Researchers estimate that between 1989 and 2009, average wheat yields in Europe were 3 percent lower than they would have been without climate change. Some individual countries have endured steeper declines: 8 percent in Greece, 15 percent in Italy.[1] Climate change can also trigger more dramatic and acute variations in yield, for example due to the increased frequency of droughts; a drought in 2016 lowered France's wheat yield by 30 percent.[2] In recent years, wheat production has also been threatened by the deadly stem rust disease, the occurrence of which could increase due to climate change.[3]

In Egypt, wheat production relies exclusively on irrigation, and the country's future water supply available for irrigation is uncertain. Nearly all fresh water is drawn from the Nile River.[4] If the upstream countries extract more water from the river or constrain the Nile's flow in other ways, the country's ability to grow wheat (which supplies 30 percent of the calories in the average Egyptian diet) will be affected.[5]

Tomatoes can survive in a relatively wide temperature range, 10 to 35 degrees. As cold stress in northern Europe decreases, the region becomes more suitable to grow tomatoes, and Mediterranean growers may see increased competition.[6]

1 Frances C. Moore and David B. Lobell, "The fingerprint of climate trends on European crop yields," *Proceedings of the National Academy of Sciences,* March 2015, Volume 112, Number 95. Note that this is the isolated impact of climate change and not the absolute change historically observed. Observed yields of wheat have plateaued during this period but could have increased without climate change (thanks to technological improvements, for example).

2 Tamara Ben-Ari et al., "Causes and implications of the unforeseen 2016 extreme yield loss in the breadbasket of France," *Nature Communications,* April 2018, Volume 9, Article 1627.

3 Shaoni Bhattacharya, "Deadly new wheat disease threatens Europe's crops," *Nature,* February 2017, Volume 542, Number 7640; Peter Juroszek and Andreas Tiedemann, "Climate change and potential future risks through wheat diseases: A review," *European Journal of Plant Pathology,* May 2013, Volume 136, Number 1.

4 Senthold Asseng et al., "Can Egypt become self-sufficient in wheat?," *Environmental Research Letters,* September 2018, Volume 13, Number 9; FAO Aquastat, fao.org/nr/water/aquastat/countries_regions/EGY/index.stm

5 FAO, *Egypt: Wheat sector review,* 2015.

6 R. S. Silva et al., "Assessing the impact of global warming on worldwide open field tomato cultivation through CSIRO-Mk3·0 global climate model," *The Journal of Agricultural Science,* April 2017, Volume 155, Number 3.

37 K. A. Nicholas and W. H. Durham, "Farm-scale adaptation and vulnerability to environmental stresses: Insights from wine-growing in northern California," Global *Environmental Change Human Policy Dimensions,* 2012, Volume 22.

Travel and tourism

Travel and tourism, including indirect and induced impacts, generate about 15 percent of the GDP of Mediterranean countries on average.[38] In certain areas, the local economy depends much more on tourism. (We look at examples below.) While climate change has not yet caused structural shifts in Mediterranean tourism flows, anecdotal examples show tourists reacting to the changing climate. For example, northern European destinations such as Denmark have become more popular with Belgian and Dutch tourists, who may avoid the hot summers in southern Europe and take advantage of warmer summers in northern Europe.[39] In southern Europe, heat waves can keep tourists from the beach. This happened in Portugal during the summer of 2018, when temperatures in Lisbon exceeded 40 degrees and news articles reported beach temperatures of 30 degrees at 8 a.m.[40]

One way to estimate the effects of climate change on tourism is to look at the number of days during the summer months—high vacation season—when the temperature might become too hot for tourist comfort. Heat tolerance varies from person to person, but surveys suggest that most northern Europeans consider 37 degrees unacceptably hot, even for a warm-weather vacation.[41] This is also supported by tourism behavior in warmer areas of the world. For example, the summer months in Dubai, when average daily high temperatures exceed 37 degrees, are off-season for tourists. If many tourists consider 37 degrees too hot for summer vacations, tourist spending could decrease in correspondence with the rising number of days above 37 degrees.

Three cities whose economies depend on tourism illustrate what might be at risk from an increase in extremely hot days. Antalya, a beach and resort city of two million people on Turkey's southern coast, attracts more than ten million visitors each year, some 30 percent of all tourists who visit the country. The city is projected to experience a significant increase in the number of summer (June to August) days above 37 degrees: about 15 days each summer by 2030, and approximately 30 days (10 days per month) in 2050. These months are crucial to the tourism industry. They generate 40 percent of each year's visits and account for tourist spending of some $4.5 billion, as well as about 20 percent of Antalya's GDP and about 2 percent of Turkey's. Similarly, Sharm El Sheikh and Hurghada, important beach resorts in Egypt, are projected to have 30 days per year above 37 degrees by 2030 and 50 days by 2050, up from about 15 today. About half of the visitors to the country fly to one of these cities.[42]

Mediterranean destinations could adapt to climate change in a number of ways. Tourist destinations could extend their shoulder seasons as the Mediterranean climate changes. However, this may not be as simple as offering discounts. Large discounts already give tourists an incentive to travel outside the summer months, yet the summer tourist visit peaks have remained stable over the past ten years. One reason for this is that many tourists are restricted to traveling during school or work holiday periods. Tourist destinations may also offer year-round activities to increase the flow of tourists during the months now considered shoulder or off-season or target different markets such as those convening for meetings and conferences.

38 World Travel & Tourism Council, October 2019.
39 Ulrik Kongsgaard et al., "More tourists go to Denmark: 'The South is too hot'," https://www.dr.dk/nyheder/indland/flere-turister-tager-til-danmark-syden-er-alt-varm.
40 Linda Givetash, "Record temperatures in Portugal mean even beaches are unusually empty," NBC News, August 4, 2018.
41 Michelle Rutty and Daniel Scott, "Will the Mediterranean become 'too hot' for tourism? A reassessment," *Tourism and Hospitality Planning & Development,* 2010, Volume 7, Number 3.
42 "Egypt's traffic up 35 percent in three years," February 23, 2010, https://www.anna.aero/2010/02/23/egypts-traffic-up-35pc-in-three-years/

Climate change is expected to raise adaptation costs

Physical climate change will also require increased levels of investment to adapt to increased level of wildfires, coastal flooding, and potentially health risk. These costs will likely need to be borne across the continent but will be particularly intense in the Mediterranean basin.

Increase transparency of climate risks

Greater awareness of the risks of a changing climate can reduce exposure and impacts. The majority of wildfires are caused by human ignition, often through negligence or accidents. One possible countermeasure could therefore be to prohibit forest entrance in the case of high-risk levels. Early-stage detection and suppression can avoid widespread fires that are much more difficult to control. It is therefore critical to monitor wildfire risk (and the spreading of eventual wildfires) in real time, as the EU is doing in its EFFIS program. Likewise, adaptation regarding tropical diseases can focus on monitoring and prevention through more effective public health programs.

Invest in adaptation

Most regions in the Mediterranean will need to invest in adaptation. Forests can be made more resilient to wildfire risk, for example by planting fire-resistant trees, reducing the amount of easily burning fuel available (such as leaf litter and brush), and even prescribed and controlled burning. Annual spending on wildfire prevention in Portugal, for example, was about $25 million between 2011 and 2016, compared with approximately $80 million per year on suppression.

Wine growers already take measures to manage variations in production quantity and quality; these actions include cultivating grape varieties that ripen more slowly or require less water. Various hardening measures can help them cope with increased heat and drought. These include:

— Harvesting earlier. In Burgundy, wine growers have harvested 13 days earlier in the past 30 years, on average, compared with the preceding six centuries.[43]

— Reducing sunlight on grapes (for instance, by setting up canopies).

— Irrigating vineyards. Controlled, efficient irrigation (drip irrigation, for example) can lessen pressure on water reserves.

Hardening measures might not be enough to help growers in all parts of Europe, or even to protect all types of wine grapes. Wine growers can increase their resilience by planting different crops or moving to new locations, including higher altitudes and slopes other than the conventional south-facing ones.[44] This requires longer-term planning, because new plants will need at least a few years before their grapes are of sufficient quality for wine production (and even longer for high-quality wines). Wine growers can collaborate to better understand the properties and resilience of alternative grapes, for example via industry-organized experimentation with different grape types. Locating new vineyards in nontraditional grape-growing areas will also require time and experimentation, because the suitability of a vineyard is determined not only by the regional climate but also by other factors, such as the altitude and microclimate.

43 Thomas Labbé et al., "The longest homogeneous series of grape harvest dates, Beaune 1354–2018, and its significance for the understanding of past and present climate," *Climate of the Past,* 2019, Volume 15, Number 4.
44 Eric Asimov, "How climate change impacts wine," *New York Times,* October 14, 2019.

To help growers and winemakers adapt, European lawmakers might also consider changes to the Protected Designation of Origin labeling system, which is meant to safeguard the integrity of wines and other regional agricultural products. French law, for example, requires that grapes be grown, made into wine, and bottled in a given geographical region, or "appellation," in order for a wine to be labeled as a product of that region. If agricultural activity shifts to new areas but PDO requirements remain the same, regional growers and producers could lose the advantage of PDO labeling (PDO-labeled wines sell for higher prices, on average, than other wines).[45]

Mobilize finance to support vulnerable communities

Not every region will be able to afford the investments needed to adapt to physical climate change. For these areas financial mobilization will be key, for example, through crop insurance or disaster compensation. In France, climate-change-related financing for farmers has averaged more than $200 million per year since 2015, up from an average of $70 million per year from 2007 to 2014. About half of the support took the form of disaster compensation, while the remainder consists of subsidies for insurance programs.

45 Tanguy Chever et al., "Value of production of agricultural products and foodstuffs, wines, aromatised wines and spirits protected by a geographical indication (GI): Executive summary," European Commission, October 2012.

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