Climate change impact on the built environment in coastal regions

SPAIN

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May, 2021

Co-funded by the
Erasmus+ Programme
of the European Union

Contents

1 Introduction

In the year 2005 the report entitled "Preliminary Assessment of the Impacts in Spain from Climate Change" was published. The results from this report provided the basis for the development of the first National Climate Change Adaptation Plan for Adaptation to Climate Change (PNACC-1), adopted by the Council of Ministers in 2006. In the year 2020, the second PNACC (PNACC-2) covering the period 2021-2030, was launched. This new National Adaptation Plan, which is part of the Strategic Framework of the Government for Energy and Climate in Spain, brings together a set of instruments, like the Climate Change and Energy Transition Law (recently approved, May 2021), the Long-Term Strategy for a Modern, Competitive and Climate-Neutral Economy by 2050, the Integrated National Energy and Climate Plan 2021-2030 and the Just Transition Strategy. The PNACC-2 was approved by the Council of Ministers on 22 September 2020 and aims to meet the growing needs for adaptation to climate change in Spain, as well as our international commitments in this field (Agenda 2030, the Paris Agreement and various European regulations), laying the groundwork to promote a model of development that is more resilient to climate change over the next decade. Thus, the government places adaptation at the centre of its public policies to make the country safer and better prepared for the risks of a changing climate. It aims to give a boost to adaptation, expanding the issues addressed to date, the actors involved the ambition of its objectives, and the inclusion of social and territorial components in the diagnoses and solutions. Always based on the conviction that promoting adaptation is sustainable and avoids significant socio-economic costs and losses. The preparation of PNACC-2 had as its starting point an in-depth evaluation of the work carried out since 2006 with the first Plan, and has had the support of the LIFE SHARA project, whose general objective is to improve the governance of adaptation to climate change and increase resilience in Spain and Portugal (Sanz et al, 2020).

This report summarizes the main impacts of climate change on built environment in Spanish coastal regions, as identified in the PNACC- 2 and in the following official documents:

- National Climate Change Adaptation Plan for Adaptation to Climate Change - PNACC-2. (Title in Spanish: *Plan Nacional de Adaptación al Cambio Climático 2021-2030*. Reference: MITECO, 2020);
- Climate Changes Impacts and Risks in Spain (Title in Spanish: *Impactos y riesgos derivados del cambio climático en España*. Reference: Sanz et al, 2020);
- 7th National Communication, United Nations Framework Convention on Climate Change (UNFCCC) (Title in Spanish: *Séptima Comunicación Nacional de España*. Reference: MAPAMA 2017);
- Strategy for Climate Change Adaptation in Spanish Coastal Areas (Title in Spanish: *Estrategia de adaptación al cambio climático de la costa española*. Reference: MAPAMA, 2016);
- Climate change on the Spanish coast (Title in Spanish: Cambio climático en a costa Española. Reference: MAPAMA, 2014).

This report is structured into the following sections:

1. Introduction: includes background, objective and the content of the report.
2. Background: provides an overview of the country situation of the climate change impact in coastal regions.

3. Climate changes evidences in Spain: includes observed data, trends and projections of climate variables.
4. Disaster Risk and Climate Change: describes how climate change has affected disaster under the main topics of hazard and exposure in Spain.
5. Climate change impacts in coastal regions: compiles the identified impacts on Spanish coastal areas.
6. Climate Change Impacts on built environment in coastal regions: compiles the identified impacts on Spanish cities.
7. Conclusion.

2 Background

Spain is a predominantly a coastal country, with almost 8,000 km of coastline. The Spanish coast, both on the Mediterranean and Atlantic sides, is considered a strategic area given the many zones of great ecological, cultural, social and economic value. Spain's coastal heritage is highly precious and recent management attention has focused on conservation of these landscapes (Ministry of Environment, 2004). Some of the main socio-economic activities are tourism, fisheries and aquaculture, ports, maritime transport, and energy, all of which depend on adequate conservation of coastal systems and waters.
In Spain there are 10 Autonomous Communities (CCAA) with part of their territory located on the coast: 8 on the Spanish mainland (País Vasco, Cantabria, Asturias, Galicia, Andalucía, Murcia, Valencia and Cataluña), plus the Balearic and Canary archipelagos, and the cities of Ceuta and Melilla. These communities comprise 24 provinces and 487 coastal municipalities.

Table 1. Some figures on the Spanish coastline, Source: Barragán 2004 (extracted from MAPAMA, 2014).

CCAA	Coastal length (km)
Galicia	1,720
Canarias	1,545
Baleares	1,342
Andalucía	917
Cataluña	597
Asturias	497
Valencia	474
Cantabria	283
País Vasco	256
Murcia	252
ESPAÑA	7,883

As shown in the following figure, there are many coastal cities along the Spanish coastaline, as San Sebastián, Santander, Gijon or A Coruña on the Atlantic coast, or Málaga, Valencia and Barcelona at the Mediterranean Sea, Palma de Mallorca in the Balearic Islands or Tenerige in Canary Islands (among others).

Figure 1. Map of Spain with main coastal cities.

According to Abadie et al (2020) Iberian coastal cities are subject to significant risks in the next decades due to climate change-induced sea-level rise. These risks are quite uncertain depending on several factors. It is analyzed the expected accumulated damage costs if no adaptation actions take place and comparation is being made with investment cost of implementation of some adaptation strategies. The results show that some adaptation strategies are less costly than the potential damage under inaction. In other words, it is economically rational to invest in adaptation even in a context of high uncertainty.

A number of threats arising from the effects of climate change on natural processes and dynamics, such as coastal flooding, increased extreme events, erosion, drought, desertification and fires, as described throughout the document, are affecting coastal areas and coastal built environments in Spain.

Figure 2. Storm surge in Santander, Spain.

3 Climate change evidence in coastal regions

According to the National Plan for Climate Change Adaptation 2021-2030 (MITECO, 2020), climate change is an unequivocal reality in Spain, validated through a wide set of observations. The observed changes include:

- Temperature increase.
- Decrease in precipitation.
- Sea level rise (SLR).
- Increased sea temperature.
- Ocean acidification.
- Longer Summers.
- Increased number of nights over 25ºC.
- Increased number of hot days.
- Loss of glaciers.
- Reduced river flows.
- Expansion of the semi-arid climate.

This section presents climate change evidences in Spanish coastal regions, grouped as follows:

1. Temperature variations.
2. Precipitation changes.
3. SLR.
4. Wave climate.
5. Other changes affecting coastal areas.

For each group, observed changes and trends, and projections for 21st century are briefly described based on the information presented in the PNACC-2 (MITECO, 2020), the 7th National Communication (MAPAMA, 2017) and the Spanish Meteorological Agency (AEMET).

3.1 Temperature variations

Spain's rugged terrain and geographic location produce substantial climate variability. Differences in annual average temperatures of over 18 ºC are recorded at separate sites on the mainland.

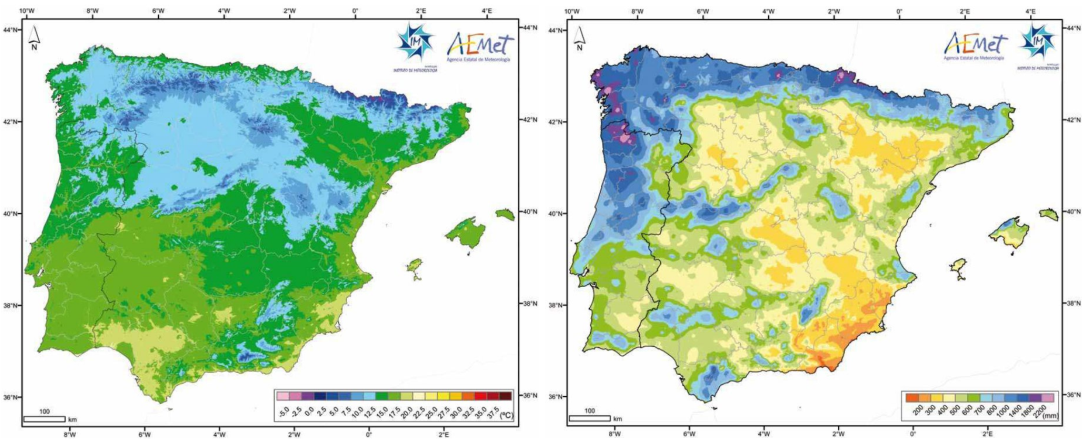

Figure 3. Left: annual average temperature. Right: annual average precipitation. Source: Atlas Climático de la Península Ibérica (http://www.aemet.es/documentos/es/conocermas/publicaciones/Atlas-climatologico/Atlas.pdf), extracted from MAPAMA (2017).

Temperature trend analysis in the Iberian Peninsula confirms that there has been a widespread rise in annual average temperature, around 1.5 ºC in the last 50 years, being warming more apparent in summer. Maximum temperatures have risen more than minimum temperatures (MAPAMA, 2017).

According to Sanz et al, 2020, the latest climate change scenarios prepared for Spain by AEMET project increases in the annual scale of maximum temperatures of between 2 °C and 6.4 °C towards the end of the century (depending on the RCP used), more pronounced in summer, with greater increases in the interior and smaller increases in the north and northwest of the peninsula. An increase with the same trend is expected for minimum temperatures, although less pronounced than for maximum temperatures, and a decrease in the annual number of frost days. Near the coast the frequency of frost days has decreased (−0.6 days/decade), especially from 1965 onwards. An increase in the number of warm days is also expected and heat waves are expected to lengthen. From 1980 onwards the frequency of summer tropical nights has increased in the southeast of Spain (+3.8 days/decadegre), and the frequency of summer days has increased in Southern Spain (+2.3 days/decade) (Fernández-Montes and Rodrigo, 2012). As an example, according to Barriopedro et al. (2020), the August 2018 heat wave in Portugal and Spain was the warmest since that of 2003. Recent climate change has exacerbated this event making it at least 1°C warmer than similar events since 1950.
Finally, it is remarkable that the average temperature has risen slightly more in Spain than in Europe or globally. The average temperature rise in the previous century was between 1.2-1.5 ºC in Spain whereas the increase was 0,74 ºC globally and 1 ºC in Europe, in te same period (Comisión de Coordinación de Políticas de Cambio Climático, 2007).

Regional projections for annual, monthly and daily temperature over Spain obtained by different statistical and dynamic methods are available at the AEMET website: http://www.aemet.es/en/serviciosclimaticos/cambio_climat.

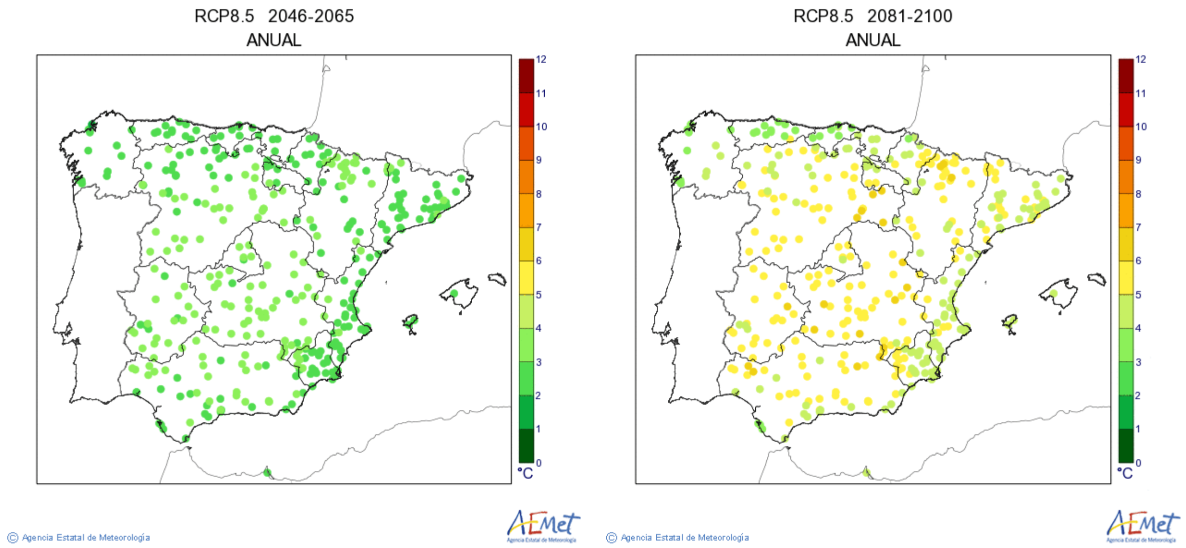

Figure 4. Projected changes in annual maximum temperature under RCP 8.5 (statistical regionalization/analogous). Right: period 2046 - 2065. Left: period 2081-2100. Source: AEMET: http://www.aemet.es/es/serviciosclimaticos/cambio_climat/result_graficos?w=0&opc1=Espan&opc2=Tx&opc3=Anual&opc4=1&opc6=0.

3.2 Precipitation changes

Average annual precipitation ranges from barely 300 mm in southeaster areas to over 2,000 mm in the Pyrenees and Galicia. Rainfall has a notable seasonality, more pronounced in the southern half of the peninsula and lower in the northeast, with a clear decrease in precipitation in summer. The frequency of intense rainfall is higher in some areas of northern Spain (as west of Galicia) with more than 20 days per year with precipitation over 30 mm. In some flat interior areas of Spain there is less that 1 day per year with this precipitation values.

In the last 50 years, there has been a slight decrease of annual precipitation in Atlantic basins but there are no significant **trends** in Mediterranean basins and Balearic islands. It is also remarkable the decrease of precipitation during February and March in central and southwest, as well as a decrease in the interannual variability of precipitation in the Mediterranean coast (MAPAMA, 2017).

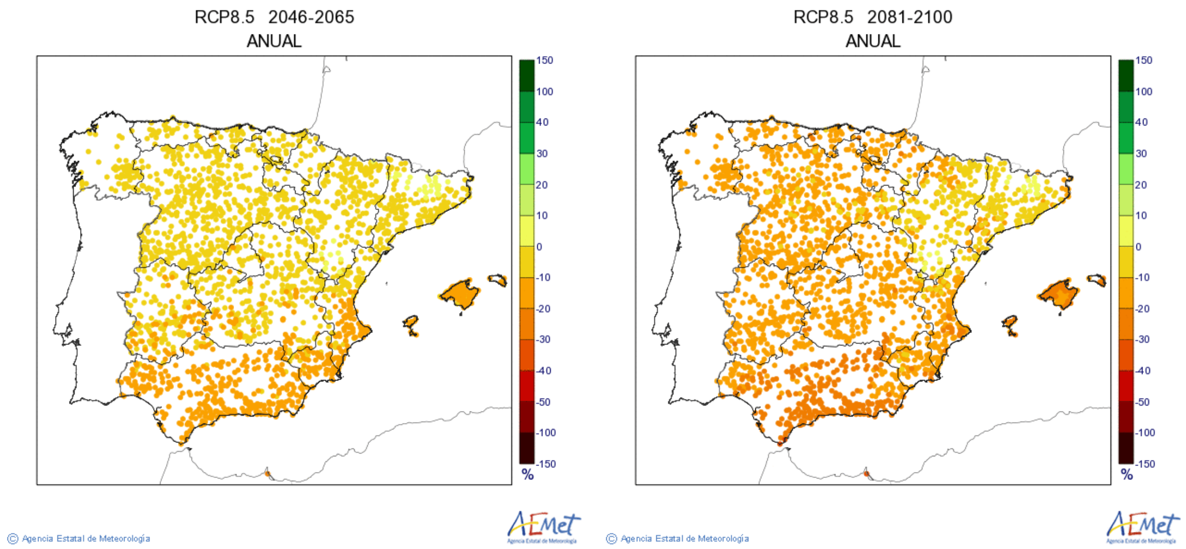

Figure 5. Projected changes in annual precipitation under RCP 8.5 (statistical regionalization/analogous). Right: period 2046 - 2065. Left: period 2081-2100. Source: AEMET: http://www.aemet.es/en/serviciosclimaticos/cambio_climat/result_graficos?w=0&opc1=Espan&opc2=P&opc3=Anual&opc4=1&opc6=0.

3.3 Sea Level rise

In the previous century, sea level has risen 2-3 mm/year along the Spanish coast, with variations in the Mediterranean due to regional effects. In the Atlantic coast, sea level raised between 1.5 and 1.9 mm/year from 1900 to 2010 and between 2.8 and 3.6 mm/year from 1993 to 2010 (MAPAMA, 2016). From 1993, SLR has been higher in the Strait of Gibraltar, Canary Islands and the Atlantic coast (MITECO, 2020). The following table presents **SLR trends** at some Spanish coastal cities.

Table 2. Conclusions from SLR studies. Source: MAPAMA, 2016.

SERIE - CITY	TREND (RISE - CM/YEAR)	PERIOD
Bilbao	0.259	1992-2013
Santander	0.159	1922-2013
Gijón	0.061	1996-2013
A Coruña	0.293	1992-2013
Vilagarcía	0.429	1997-2013
Vigo	0.205	1993-2013
Huelva	0.333	1997-2013
Sevilla – Bonanza	0.497	1992-2013
Motril	0.129	2005-2013
Málaga	0.342	1992-2013
Valencia	0.550	1993-2013
Eivissa	0.448	2003-2013
Barcelona	0.631	1993-2013
Santa Cruz de Tenerife	0.568	1991-2013
Las Palmas	0.494	1992-2013
Puerto del Rosario (Fuerteventura)	0.432	2004-2013
La Estaca (El Hierro)	0.691	2004-2013

Slangen et al. (2014), presented regional **sea-level projections** and associated uncertainty estimates for the end of the 21st century, including regional projections of sea-level change resulting from changing ocean circulation, increased heat uptake and atmospheric pressure in CMIP5 climate models. A moderate and a warmer climate change scenarios were considered, yielding a global mean sea-level rise of 0.54±0.19 m and 0.71±0.28 m respectively (mean±1σ). Regionally however, changes reach up to 30 % higher in coastal regions along the North Atlantic Ocean and along the Antarctic Circumpolar Current, and up to 20 % higher in the subtropical and equatorial regions, confirming patterns found in previous studies.

To estimate the rise in local sea level on the Spanish coasts, it is necessary to also consider subsidence effects, which are of special relevance in the Ebro Delta and the mouth of Guadalquivir River. Following figure shows the local SLR projections along the Spanish coast.

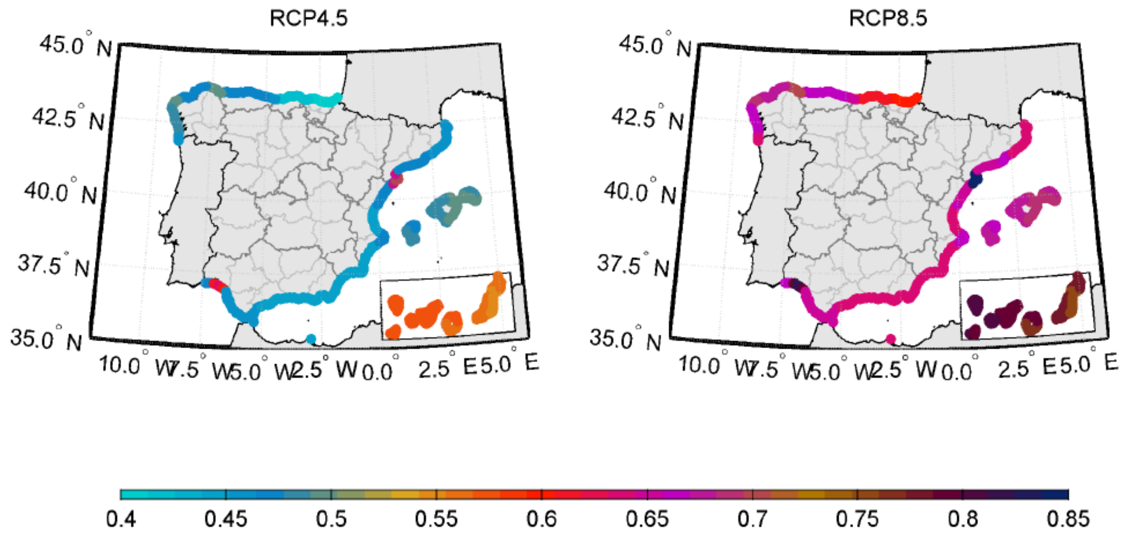

Figure 6. Local SLR projections (m) for the period 2081-2100 (relative to period 1986-2005) under RCP4.5 (left) and RCP8.5 (right) scenarios, considering natural subsidence in Ebro delta and the mouth of Guadalquivir river. Source: IHCantabria.

According to the PNACC-2, in the short term (2026-2045) the models estimate, in their upper band, more or less uniform values of SLR for the entire Spanish coast, between 17 and 25 cm depending on the scenario. However, for the period 2081-2100 the differences between scenarios widen:

- RCP4.5 scenario: models calculate in their upper band increases in mean sea level between 55 cm and 70 cm, relative to period 1985-2005. Highest values correspond to Canary and Balearic Islands and the western Cantabrian coast.
- RCP8.5 scenario: models project in their upper band a notable increase of SLR, with values over 75 cm along the Spanish coast, being especially high in Galicia, the Balearic Islands (> 80 cm) and in the Canary Islands (≈ 1 m).

The most updated results provided by the last special report of the IPCC (IPCC, 2019) entitled Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) indicate that SLR projections are worsen than the projections presented in previous IPCC reports.

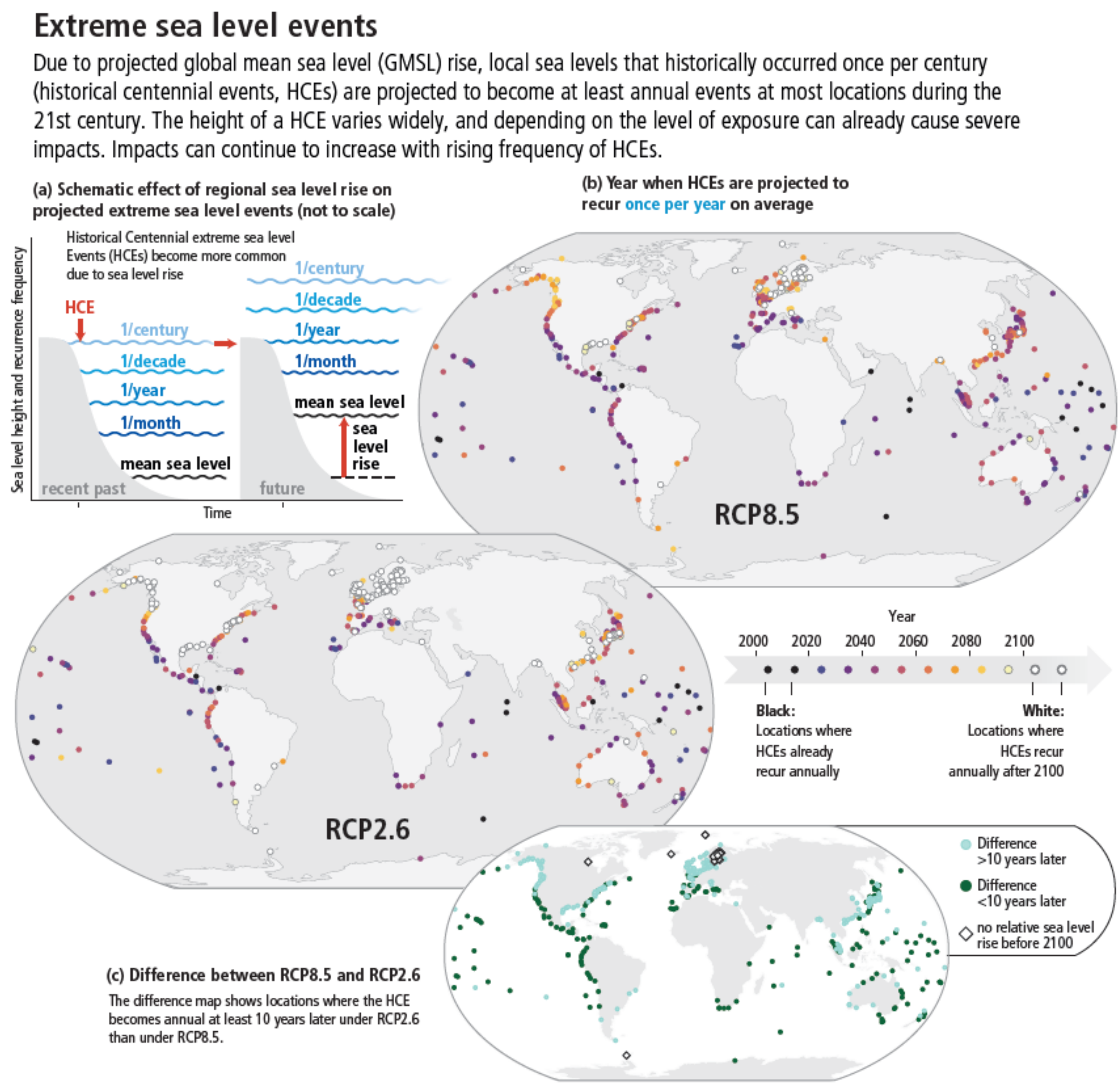

Figure 7. The effect of regional sea-level rise on extreme sea level events at coastal locations. a) Schematic illustration of extreme sea level events and their average recurrence in the recent past (1986–2005) and the future. As a consequence of mean sea level rise, local sea levels that historically occurred once per century (historical centennial events, HCEs) are projected to recur more frequently in the future. b) The year in which HCEs are expected to recur once per year on average under RCP8.5 and RCP2.6, at the 439 individual coastal locations where the observational record is sufficient. The absence of a circle indicates an inability to perform an assessment due to a lack of data but does not indicate absence of exposure and risk. The darker the circle, the earlier this transition is expected. The likely range is ±10 years for locations where this transition is expected before 2100. White circles (33% of locations under RCP2.6 and 10% under RCP8.5) indicate that HCEs are not expected to recur once per year before 2100. c) An indication at which locations this transition of HCEs to annual events is projected to occur more than 10 years later under RCP2.6 compared to RCP8.5. Source: SROCC – Summary for Policy Makers (IPCC, 2019).

3.4 Wave climate

Changes in wave parameters affect coastal processes, as sediment transportation. In the last six decades, important changes have been observed in both intensity and direction of waves. In the Cantabrian Sea, a significant increase of up to 0.8 cm/year has been observed in the highest waves (95th percentile of significant wave height) and a decrease in the Mediterranean and the Canary Islands. Also, there have been significant changes in the direction of the mean flow of mean energy.

Regarding wind intensity, it is remarkable that observations show an increase in the Cantabrian coast (over 0.6 $W/m^2/year$) and a slight decrease in the Mediterranean and Canary Islands (between 0.2 and 0.4 $W/ m^2/year$) (MAPAMA, 2016).

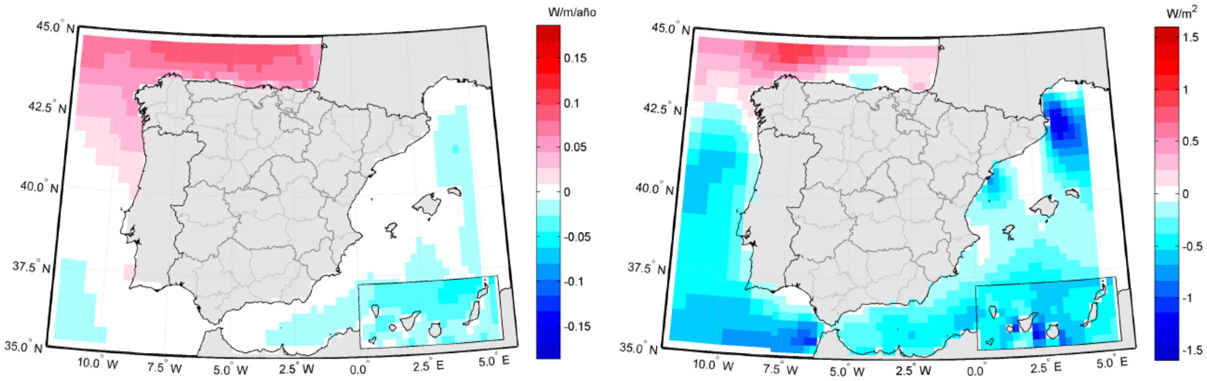

Figure 8.Changes in mean wave energy flux (left) and wind power (right) in the last 60 years. Source: IHCantabria, extracted from MAPAMA, 2016.

Once the swell reaches the coast, it is necessary to characterize it, since that information is crucial for infrastructure design and shoreline management. Mean annual significant wave height is an indicator of how the marine climate evolves under average conditions, influencing port and coastal activities. The significant wave height only exceeded 12 hours per year, H_{s12}, is closely related to the depth of closure of the beach profile (Birkemeier, 1985 – MAPAMA, 2016) and, therefore, with potential erosion, as well as the mean energy flow, which is related to the transport of sediments and the shape of pocket beaches (González and Medina, 2001 – MAPAMA, 2016). On the Cantabrian coast, where the highest values of H_{s12} are recorded, an increase in H_{s12} has been observed with values around 1.4 cm/year in the last 60 years, whereas in the Mediterranean, a negative trend has been observed, with values between -0.6 and -0.4 cm/year.

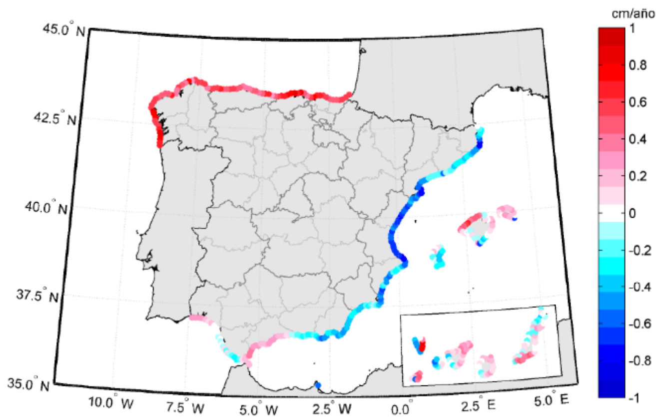

Figure 9. Observed changes in Hs12 in the last 60 years. Source: IHCantabria, extracted from MAPAMA, 2016.

Projections of average wave height show a very slight decrease in most of the Spanish coastline, except on the southeast face of the Canary Islands, where wave height would increase. Regarding the mean energy flux, projections indicate a decrease under all scenarios and horizon years.

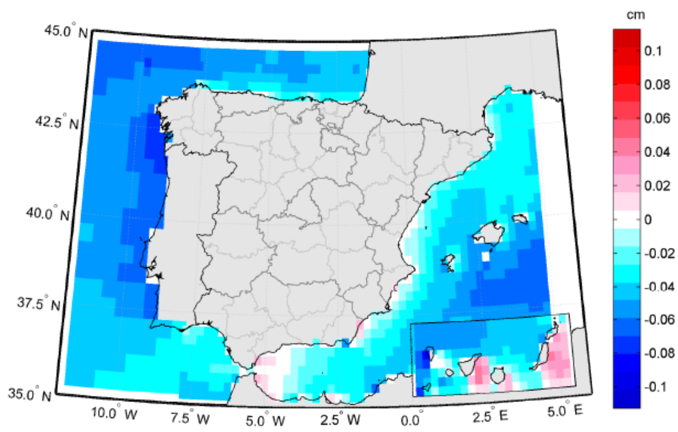

Figure 10. Projected changes in mean wave height under A1B scenario for the period 2070-2100. Source: IHCantabria, extracted from MAPAMA, 2016.

3.5 Other changes affecting coastal areas

In addition to the sea level and wave climate, other variables contribute to shape coastal regions, as river flows, sea surface temperature (SST) or seawater pH. Changes in these variables produce changes in coastal processes and therefore in the use and activities of coastal areas. Table 3 briefly presents trends and projections of these variables, based on the information provided by PNACC-2 (2020).

Table 3. Trends and projections in river flow, SST and pH, extracted from the PNACC (MITECO, 2020).

	RIVER FLOW	SST	PH
TRENDS	Period 1966-2005: -1.45%/year in river mean flux (rivers with semi-natural regime). Flow reductions are more significant in spring and summer.	Increased over the entire coast. In the Mediterranean Sea, ΔSST= 0.34°C/10 years, between 1982 and 2019.	Acidification: Decrease of pH about 0.1 during last century.
PROJECTIONS	Decrease of river flow in most of Spanish basins, especially in Andalucia and Canary and Balearic Islands.	Increased, especially in Balearic Islands, with an increase in mean temperature of 4 °C for the period 2081-2100 relative to period 1985-2005.	No data.

4 Disaster Risk and climate change

As stated in the summary of the diagnosis of the Strategy for Climate Change Adaptation in Spanish Coastal Areas (MAPAMA, 2016), should the trend in population growth, activities and location of assets on the Spanish coast continue, coastal exposure and vulnerability will increase. Accordingly, the risks and consequences on the socio-economic system due to extreme flood events that have already been experienced will continue, and will be aggravated by the effects of the climate change, especially due to the sea level rise. As mentioned above, the latest IPCC-SROCC report (2019) indicates that projections of sea level rise and extreme events will be higher than indicated in previous reports, presumably also leading to increased risk in coastal areas.

According to the SROCC report (IPCC, 2019), the higher the sea levels rise, the more challenging is coastal protection, mainly due to economic, financial and social barriers rather than due to technical limits (*high confidence*). In the coming decades, reducing local drivers of exposure and vulnerability such as coastal urbanization and human-induced subsidence constitute effective responses (*high confidence*). Where space is limited, and the value of exposed assets is high (e.g., in cities), hard protection (e.g., dikes) is *likely* to be a cost-efficient response option during the 21st century taking into account the specifics of the context (*high confidence*), but resource-limited areas may not be able to afford such investments. Where space is available, ecosystem-based adaptation can reduce coastal risk and provide multiple other benefits such as carbon storage, improved water quality, biodiversity conservation and livelihood support (*medium confidence*). Financial, technological, institutional and other barriers exist for implementing responses to current and projected negative impacts of climate-related changes in the ocean and cryosphere, impeding resilience building and risk reduction measures (*high confidence*). Whether such barriers reduce adaptation effectiveness or correspond to adaptation limits depends on context specific circumstances, the rate and scale of climate changes and on the ability of societies to turn their adaptive capacity into effective adaptation responses.

4.1 Hazard

Expected changes in environmental variables (including met-ocean) as increased soil dryness, increased air temperatures, SLR, etc. increase the following hazards in Spanish coastal areas:

- Increased coastal flooding (in relative terms on the Mediterranean coast. In absolute terms, an increase on the Atlantic coast and Canary Islands). SLR will exacerbate intensity and frequency of extreme flooding events.
- Increased extreme events.
- Continued erosion hazard, especially due to SLR.
- Increase drought and desertification risk.
- Increased fire hazard.

4.2 Exposure and vulnerability

Spain, as stated in MAPAMA (2014) and MAPAMA (2016), is a predominatly coastal country (24 provinces and 487 municipalities) with a very long and rich coastline (about 8,000), with numerous ecosystems and stunning landscapes. Furthermore, the Spanish livelihoods and economy depends to a large extent on the coast and its seas (beaches occupy 24% of the Spanish coastline and account for around 1,900 km of coastline), since many activities are carried out there, from very traditional ones such as traditional fishing, to others such as sun and beach tourism, services, maritime transport, aquaculture, the use of wave, wind and tidal energy, water desalination, etc. In 2006, over 75% of the Spanish coastal area was already urbanized (MAPAMA, 2016).
The socio economic development model and the extensive exploitation of resources pose a threat to the coast, which has increased its exposure and vulnerability in many areas due to urban pressure and environmental degradation. In addition to these pressures related to the exploitation of resources, there are also those resulting from the effects of climate change on the coast (MAPAMA, 2016).

In terms of **population**, around 60 % of the Spanish population live in coastal regions, as compared with the EU-28 average of 42 % (Eurostat, 2015[1]). It is expected that the trend of population growth in coastal areas will continue, and as outlined in the IPCC AR5 report, the population and assets threatened by coastal risks, as well as human-induced pressures on coastal ecosystems, will increase significantly in the coming decades due to population growth, economic development and urbanisation (high confidence).
Considering SLR trends in the North Atlantic coast, the population affected in 2040 by permanent flooding will be around 2-3% of the total population of the provinces of Coruña, Cantabria and

[1] Only territories within the European continent are included. EUROSTAT list of coastal regions (COAS_NUTS3.xlsx), received on 15.09.2016, combined with EUROSTAT population data for NUTS-3 regions [demo_r_pjanaggr3], last updated on 07.09.2016 (souorce of this information at https://coastal-management.eu/governance/spain).

Guipúzcoa (referring to the 2008 census population). For an increase of 50 cm of mean sea level, the number of people per province affected in 2100 along the North Atlantic coast varies between 1% and 4% of the population in 2008 (these projections have been estimated without considering adaptation options).

Regarding land use and goods exposed, **infrastructures** are the main asset exposed in all the provinces studied. In Galicia, in 2100, more than 10% of the land corresponding to infrastructures could be affected in the Galician provinces by 85 cm of sea level rise (close to the worst IPCC scenario).

Figure 11. Evolution of urbanization in La Manga del Mar Menor in the 60´s(left) and today (right).

5 Climate change Impact in coastal regions

Climate change represents a major threat to the coasts of Spain, although it is one of the best-studied sectors and has its own adaptation strategy. Among the most important factors of change are the rise in sea level, extreme events, such as meteorological tides, changes in the waves and changes in water temperature, but also various anthropogenic factors, such as the occupation of the coast, which increase exposure to climatic risks. Climate change is already aggravating many of these processes and will continue to do so in the future. Therefore, and in the absence of adaptation policies, coastal flooding and erosion are expected to increase, affecting both natural and human systems, as well as the associated material, ecological and economic damage (Sanz et al, 2020).

This section presents the major impacts on climate change on the Spanish coast, identified in the report Climate Changes Impacts and Risks in Spain (Sanz et al, 2020) the PNACC-2 (MITECO, 2020) and the Strategy for Climate Change Adaptation in Spanish Coastal Areas (MAPAMA, 2016).

5.1 Physical impacts

The physical impacts of climate change on Spanish coastal areas are:

- **Increased coastal flooding:** intensity and frequency of extreme flooding events due to SLR. According to Sanz et al (2020), extracted from Losada (2014), for 2040 inundation level could increase:
    - 8% in Atlantic coast and Alboran Sea;
    - 6% in Canary Islands, and

   - 3% along the Mediterranean coast.

  As for extreme events, their frequency and intensity are expected to increase in the future. For example, in Bilbao the intensity (measured as change in flood height) could increase from 3.85 m in 2010 to 4 m in 2040, and its frequency will increase from once every 50 years (2010) to once every 15 years in 2040. In Barcelona, however, no changes in intensity are expected and the increase in frequency is also less (the return period goes from 50 to 40 years).

- **Coastal retreat/loss of beaches:** considering only regular regime (not extreme events) and a 6 cm SLR, coastal retreat in the Atlantic coast and northern Canary Islands will be at least 3 m in 2040, 2 m in Cadiz Gulf and between 1 and 2 m in other coastal areas in Spain.
- **Decrease in water resources:** quantity and quality of available water resources, with implications for agriculture and livestock, urban supply, hydroelectric production and ecosystems, particularly affected, in the latter case, to ecological processes, species and habitats linked to aquatic ecosystems.
- **Loss of coastal resources:** SLR and increased coastal storms produce various impacts on the coastline, as coastal retreat and changes in sediment transportation, with effects on coastal ecosystems, such as sandbanks, deltas and estuaries.
- **Saltwater intrusion,** especially in the Ebro delta due to the combination of SLR and river flow decrease.

5.2 Environmental Impacts

The main environmental impacts of climate change identified on Spanish coastal areas are:

- **Reduction of beach and dune area**. In Asturias, at the end of the century beach retreat is estimated around 31, 56 m +/- 11.64 m. In Cataluña, considering 4.5 and 8.5 RCP scenarios, beach retreat is about 47 and 65 m respectively (Sanz et al, 2020).
- **Reduction of marshes and wetlands**.
- **Loss of *Posidonia* meadows** in the Mediterranean Sea. An average increase of 3,4±1,3º C, density of *Posidonia* meadows could decrease 90% in about 30 years.
- **Changes in demography, phenology and behaviour of species.**
- **Expansion of invasive species.**
- **Habitat degradation and loss of ecosystem services:** as regulation services (pollination, weather regulation, water availability, flood protection, etc.), goods (as food, energy, row materials, etc.) and cultural and recreational services (as learning, relaxing, etc.)

5.3 Economic Impacts

- By the end of the century permanent **flood damage** in the Cantabrian Sea could **reach EUR 1 billion and 8 billion**, between 0.05% and 0.6% of GDP (2008) for each province. Damage could double if extreme weather events are considered and the provinces most affected would be Bizkaia and Gipuzkoa, although Cantabria would be so in relative terms.

- In terms of land use, **infrastructure** would be the asset most affected by coastal flooding, followed by industrial activities. On the Atlantic coast (A Coruña and Pontevedra) between 15% and 20% of the infrastructure area is at risk.
- **Impacts on tourism**, including impacts on key coastal resources as beaches and dunes, impacts of coastal infrastructures as promenades, and impacts on tourism demand due to heat wave or increased temperatures.
- **Loss of recreational value of beaches.** In Asturias, the results show that in 2100 a return period event of 50 years could generate losses of more than EUR 670 million (Toimil et al, 2018).
- **Impacts on fisheries and aquaculture**.
- **Port operation downtimes**: due to SLR, there will be a decrease in the time adequate for port operation in all Spanish harbours. Considering changes observed in wave climate, it is expected port operation downtimes in ports in the Atlantic coast, southeast Canary Islands and north Mallorca if no adaptation measures are implemented. In the Mediterranean, port operation could be increased due to wave climate changes.
- **Decreased reliability of coastal structures** along the Spanish coast, except in some areas of the Mediterranean façade due to wave climate trends.
- **Changes in energy production and consumption**: changes in production due to changes in wind, water flow, transportation and storing of energy. Changes in consumption: decrease in heating but increased use of air conditioned.

5.4 Social Impacts

- Projections for 2040 estimate that **population exposed to permanent flooding** on the Cantabrian coast could reach 2% -3% in Cantabria, Gipuzkoa or A Coruña. If extreme events are also considered, in Cantabria 9% of the population would be exposed, followed by Bizkaia and A Coruña, with around 4% of the population.
- **Impacts on human health**: through the direct effects of climate change -as heat waves and other extreme events, such as floods and droughts– but also through indirect effects as increase in air pollution and aeroallergens, change in the distribution of disease-transmitting vectors, loss of water or food quality). In the Canary Islands, the possible eastward movement of the Azores anticyclone would favor the arrival of African winds with Saharan dust.
- **Social changes**: including: 1) direct impacts and 2) the consequences of the adaptation measures applied to deal with them. These impacts are related to aspects such as the economy and employment, culture, heritage and identity values, governance, population distribution in the territory, social cohesion, conflict associated with the use of natural resources, social inequality, including gender inequality, etc.
- **Impacts on cultural heritage**: some of the effects of climate change on cultural heritage are already visible, as many cultural and historical complexes affected by rising sea levels, changes in the water table, or atmospheric pollution. In addition, there are climate change impacts on cultural landscapes, in practices and knowledge related to agricultural activities and traditional ways of life caused by the increase in population. desertification, floods, and extreme events.

6 Climate change impact on built environment in coastal regions

The Spanish Urban Agenda (Ministerio de Fomento, 2018) identify climate impacts that currently affect **Spanish cities** and points out that the inclusion of climate and risk forecasts into territorial and urban planning is essential to prevent climate related risks, increase the resilience of urban environments and increase the capacity to anticipate and reduce uncertainties. Specifically, the Spanish Urban Agenda identifies as main impacts on the built environment:

- the increase in urbanization and the reduction of soil permeability, which increases the probability of flooding in urban systems,
- changes in the rainfall regime and the drought that affect cities and can create dysfunctions,
- heat waves and the increase in temperatures that affect urban areas so much due to their urban characteristics, together with the heat island effect, which means an increase in mortality and morbidity, and
- increased temperatures that can cause disease transmission through food and water (translated from Sanz, 2020).

Specific impacts on urban environments and their causes are presented in Table 4.

Table 4. Impacts of climate change on urban areas identified by the Spanish Network of Cities for Climate (RECC, 2015), extracted from Sanz, 2020.

IMPACTS ON URBAN ECOSYSTEMS	CAUSES
Increased heat island effect in urban centres Increased need of shadow in summer and irrigation in urban parks Impacts on health Increased evapotranspiration in lagoons, ponds and pools Increased periods of temperature inversion	Increase in temperature
Coastal flooding Loss of beaches	SLR
Flooding Exceed capacity of sanitation Changes in run-off and water availability Landslides near urban roads	Heavy rains
Electrical shortcuts Food supply issues Erosion risk Changes in run-off and water availability Landslides near urban roads	Drought
Increased presence of some parasites	Changes and extinction of species
Fire risk near urban areas	Fires

The identification of impacts on the **built environment in the coastal zone** has been based on the report entitled Climate Change Impacts and Risks in Spain (Sanz et al, 2020) which was based on existing climate change adaptation plans/strategies of different coastal cities, available at June 2019 (see Table 5). Other urban adaptation plans at regional or local level currently being developed are not included in this review (for instance, the climate change adaptation plan for Murcia or Cantabria).

Table 5. Coastal cities (including climate category) with climate change adaptation plans. Source: adapted from Sanz, 2020.

CITY	CLIMATE	NAME OF THE ADAPTATION PLAN	REFERENCE
Donostia - San Sebastian	COASTAL OCEAN CLIMATE (COC)	Plan de Adaptación al cambio climático de Donostia-San Sebastián. Entregable 1: Diagnóstico y Entregable 2: Plan de Adaptación 2017-2030	2017, Donostiako Udala / Ayuntamiento de San Sebastián
Barcelona	Mediterranean Coastal Climate (CMC) (This category also include Girona, that is 30km from the coastline)	Plan Clima 2018-2030	2018, Ayuntamiento de Barcelona
Valencia		Plan de Adaptación al Cambio Climático de Valencia 2017-2050	2017, Factor CO2, 2017)

In that report, cities are classified according to their climate, to further conduct an analysis of the observed climate impacts on the built environment in coastal areas, presented in Table 6.

Table 6. Observed climate change impacts on COC and CTC cities. Source: translated from Sanz, 2020.

HAZARD	SECTOR	CLIMATE CHANGE IMPACT	COC (SAN SEBASTIAN)	CMC (BARCELONA, VALENCIA, GIRONA)
SLR	Built up	Flooding of buildings, urban infrastructure networks (mainly sanitation and transport) and other construction elements.	X	X
		Damage to port infrastructure and increased risk of failure of coastal protection structures.	X	X
	Ecosystem	Erosion		X
		Coastline retreat	X	X
Extreme wave climate	Built up	Flooding of buildings, urban infrastructure networks (mainly sanitation and transport) and other construction elements.	X	X
		Damage to port infrastructure and increased risk of failure of coastal protection structures.	X	X
	Ecosystem	Erosion	X	X

		Coastline retreat	X	X
Heavy rains	Built up	River flooding	X	X
		Flooding related to drainage systems	X	X
		Flooding of urban network infrastructure and other constructions	X	X
		Damages and reduced habitability of buildings in poor condition affected by floods	X	X
		Effects on infrastructure and buildings due to landslides and erosion		X
		Loss of recreational, landscape, aesthetic values; and changes in patterns of spatial and temporal use due to flooding	X	
	Ecosystems	Increased landslides, erosion, sedimentation and loss of soil		X
		Phenological changes and effects on terrestrial and aquatic ecosystems due to flooding and contamination derived from the collapse of sanitation systems		X
	Health	Personal injury as drowning, hypothermia, physical injury, traffic accidents, post-event physiological effects, etc.		X
		Increase in diseases due to contamination of water sources for human consumption		X
	Water resources	Pollution/water quality due to run-off or problems in sanitation network		X
		Increased need of investment in preliminary water treatment		X
	Economic activities	Delays, operation downtime and increased cost of transportation due to overflows or extreme events		X
	Energy	Impacts on electrical supply facilities and networks related to erosion and landslides		X
Decreased precipitation	Ecosystems	Phenological changes in fauna and flora, and loss of biodiversity		X
		Water stress, weakening of the forest mass and increased spread of diseases / pests.		X
		Activation of forest fires		X

		Changes in landscapes landscapes (terrestrial and aquatic)		X
	Health	Increase in mortality and morbidity during droughts related to extreme temperatures, especially in elderly citizens, children, or with diseases.		X
		Increase in infectious diseases due to drought and less dilution of pollutants in water		X
		Reproduction of certain infectious vectors such as mosquitoes due to the increase in the volume of stagnant water and in temperature		X
	Water resources	Water scarcity and increased water restrictions		X
		Reduction of superficial channels and longer duration of the dry water of rivers and streams.		X
		Contamination of water reserves and disturbances in the ecological balance of rivers		X
		Saltwater intrusion		X
		Decrease in groundwater level and impact on the efficiency of groundwater sanitation operations		X
		Increased water demand for irrigation of green urban areas		X
	Agriculture, farming and aquaculture	Loss of arable lands due to lack of humidity, salinization and desertification		X
		Decreased crop yields		X
		Decreased photosynthetic activity, weakness of crops and increased diseases due to water stress		X
		Activation of fires		X
	Economic activities	Conflicts among stakeholders to obtain hydraulic resources		X
	Energy	Power plants operation downtimes due to water stress		X
	Society	Increased price of food and water		X
Increased temperatures	Built up	Decreased comfort in housing		X
		Decreased thermal comfort in public space	X	

		Impact on transportation infrastructure (railways, etc.)		X
	Ecosystems	Decreased biodiversity	X	X
		Appearance of pests and invasive species and increased spread of diseases in vegetation due to the weakening of forest species.		X
		Activation of fires	X	X
		Decreased air quality	X	
	Health	Impacts on health, especially in vulnerable people		X
		Worsening of cardiovascular and respiratory diseases.		X
		Increase in zoonotic / vector diseases transmitted by mosquitoes (dengue, yellow fever, Nile fever, chicungunya and Zica fever).		X
		Increased duration and severity of allergic diseases such as asthma, rhinitis, allergic conjunctivitis or some dermatitis		X
		Damages to health derived from the increase of pathogens in water or food (legionella, salmonellosis, etc.).		X
	Water resources	Eutrophication and / or deterioration of water quality due to the increase in pathogens derived from the increase in water temperature		X
		Increase in the cost of treating contaminated water due to the increase in temperature		X
	Agriculture, farming and aquaculture	Affections to the cultivation cycles and modification / reduction in production as a consequence of the variation of the seasonality of the horticultural activity		X
		Increase in irrigation times in irrigated agriculture and associated expenses		X
		Changes in forestry, livestock and fish production		X
	Economic activities	Impact on the industrial and commercial sector due to the increase in energy consumption in production (processes, circuits, refrigerated areas ...) and other factors	X	

		Reduction of soil moisture, increased water needs of agriculture and other sectors, creating potential competition over this		X
	Energy	Increase in energy consumption or modification of demand dynamics (peaks and averages)		X
Heat waves	Built up	Decreased comfort in housing	X	
	Ecosystems	Water stress of the vegetation and lower growth and survival of arboreal vegetation due to the lower availability of nutrients in the soil	X	X
		Activation of fires	X	X
	Health	Health effects related to heat stress (increased mortality and morbidity), especially in elderly citizens, children, or those with illnesses		X
		Worsening of cardiovascular and respiratory diseases.		X
	Agriculture, farming and aquaculture	Water stress / weakening of crop species and increased spread of diseases, fungi and pests		X
		Effects on the cultivation cycles and modification / reduction in production as a consequence of the variation in the seasonality of the horticultural activity		X
		Activation of fires on agricultural productions		X
	Energy	Increased energy consumption		X
		Risk of overloading power plants and distribution networks, and risk of supply interruption due to increased electricity demand for cooling		X
Winds	Built up	Impacts to the electricity and gas supply networks		X
		Disturbances in the supply of fuels due to the closure of ports and competition over the use of resources Disturbances in the supply of fuels due to the closure of ports and competition over the use of resources		X
	Society	Increase in insurance hazard premiums and contractual restrictions on the coverage contracted		X

In terms of economic impact, by the end of the century the damage caused by permanent flooding in the Cantabrian coast could reach EUR 1 billion and EUR 8 billion, between 0.05% and 0.6% of the GDP (2008) of each province. Damages could double if extreme weather events are considered and the most affected provinces would be Bizkaia and Gipuzkoa, although Cantabria would be the most affected in relative terms. In terms of affected land uses, infrastructures would be the most affected by coastal flooding, followed by land for industrial activities. It is striking that on the Atlantic coast (A Coruña and Pontevedra) between 15% and 20% of the infrastructure surface area is located in areas at risk from coastal flooding (Losada 2014; Sanz, 2020).

Figure 12 shows the economic damages (in million EUR) in the ten Spanish coastal cities with the highest coastal flood risk due to SLR (RCP4.5, year 2050).

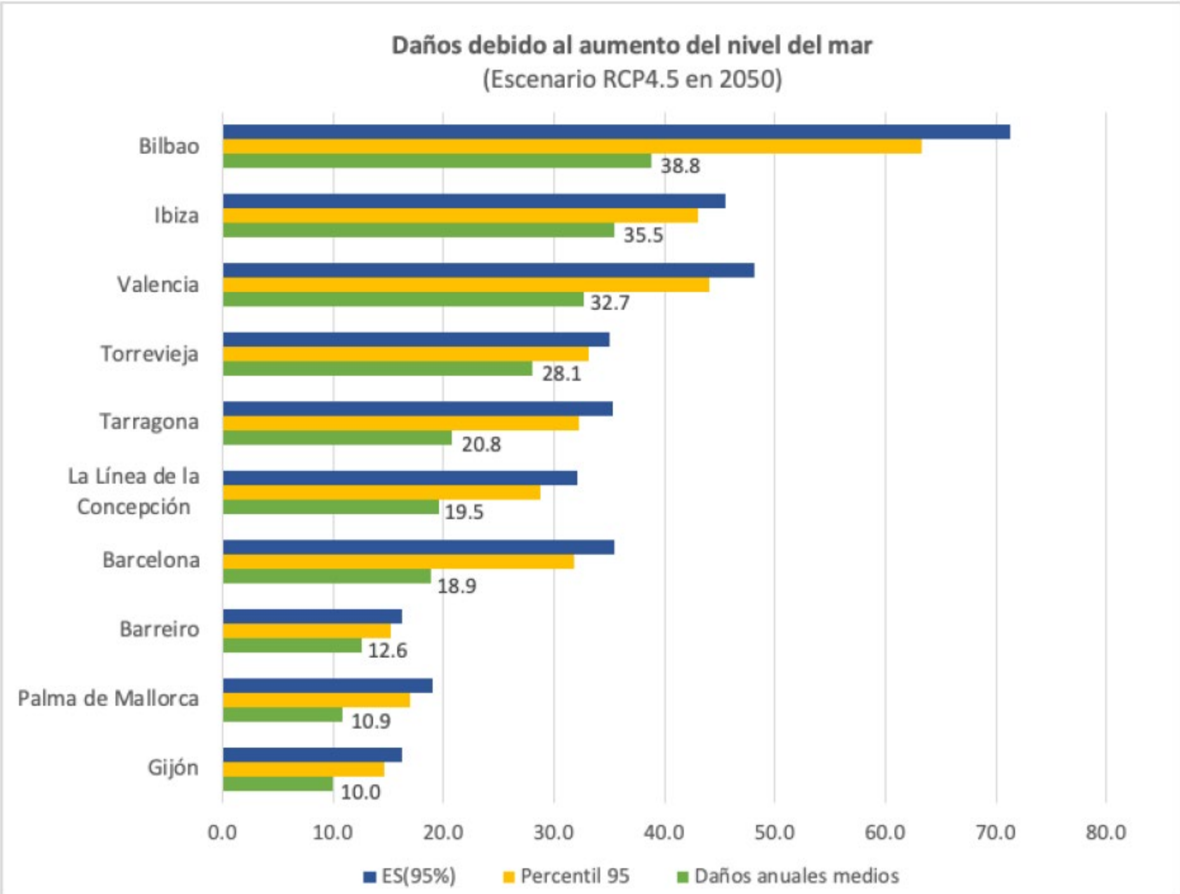

Figure 12. Economic damages. Green bars represent average annual damages, yellow bars represent 95 percentile; blue bars represent the average of 5% worst cases (ES95%). Source: Sanz et al, 2020.

7 Conclusion

The challenges that cities face in the context of climate change are many and diverse. Urban areas concentrate population and critical infrastructure, as well as knowledge and social and cultural assets. Cities are also highly exposed and prone to impacts due to their intrinsic characteristics (such as ground impermeabilization caused by paving), or their location in the territory (for example, in the coastal area). All these reasons make them particularly vulnerable to climate change.
In the urban plans for adaptation to climate change in Spain, 7 risk axes are identified: sea level rise, extreme waves, intense precipitation, decrease in rainfall, increase in temperatures, heat waves and gales, as well as various affected sectors (urban, ecosystems, health, economic sectors, etc.). Currently, the level of development and detail in risk and vulnerability assessments in cities is low. Spain must continue to work to generate qualitative and quantitative knowledge about the impacts of climate change in urban areas, both in terms of its magnitude and its temporality and probability of occurrence. Special attention should be paid to the most vulnerable groups and to the areas within the city that are either most exposed or least prepared. It is important to bear in mind that climate change will exacerbate many of the current problems in cities, since certain social groups will be especially affected due to their reduced capacity to prepare, respond and recover from impacts. This information is essential when planning efficiently and effectively investments in adaptation, taking into account the most likely climate risks, but without forgetting the uncertainty, particularly those events that are less likely but that may generate more damage (Sanz et al, 2020).

The Strategy for Climate Change Adaptation in Spanish Coastal Areas (MAPAMA, 2016) calls for the integration of urban planning and climate change projections. Urban planning should take climate change projections into account when allocating land uses, especially in areas that are or may be affected in the future by SLR and extreme weather events. To avoid or minimize damage to people and property, constructions near the Maritime-Terrestrial Public Domain (DPM-T) should be avoided, especially living places (both permanent and seasonal). The problems of saline intrusion in rivers and aquifers, as well as the rise in the water table that could affect the operation of underground networks and services, as well as the quality of the land and the sanitary conditions of the environment, must also be taken into account.

On the other hand, when assessing the costs and benefits of urban adaptation, it is also necessary to identify and consider the positive effects that some climate change impacts may have on urban management, ecosystems and resources, planning and infrastructure, economic activities or the population at large (MITECO 2020).

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