National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

REPORT

WP4 Sectoral Impacts Modelling

National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

Title: RNA2100 – Sectoral Impacts Modelling

Authors: Pedro Matos Soares (coord.), Daniela Lima, Luís Dias, Virgílio Bento, Gil Lemos, Carlos Antunes, Ivana Bosnic, Pedro Costa, Franciane Santos, Sílvia Carvalho, Miguel Rodrigues, João Pedro Nunes, Ana Russo, Filipe Duarte Santos.

February 2024

This report is a product of the National Roadmap for Adaptation 2100 project.

Through the Agreement on the European Economic Area (EEA), Iceland, Liechtenstein and Norway are partners in the internal market with the Member States of the European Union.

In order to promote a continuous and balanced strengthening of economic and trade relations, the parties to the EEA Agreement have established a and trade relations, the parties to the EEA Agreement established a multi-annual Financial Mechanism, known as the EEA. known as EEA Grants.

The EEA Grants aim to reduce social and economic disparities in Europe and to strengthen bilateral relations between these three countries and the beneficiary countries.

For the 2014-2021 period, a total contribution of 2.8 billion euros has been agreed for 15 beneficiary countries. for 15 beneficiary countries. Portugal will receive 102.7 million euros.

Funded by:

Promoter:

Partners:

Table of Contents

Executive Summary

The objective of this Working Package (WP) is to bridge knowledge gaps through modelling exercises in selected key sectors/vulnerabilities and also to update the state-of-the-art findings in the light of the input data from the climate (WP2) and socioeconomic scenarios (WP3). This WP includes the task of conversion of the physical impacts into the associated social and economic impacts with (WP5) and without adaptation measures.

Impacts will be detailed in key sectors, such as:

WP4.1 – Hydrological Balance

WP4.2 – Droughts

WP4.3 – Forest Fires

WP4.4 – Agroforestry

WP4.5 – Sea Level Rise

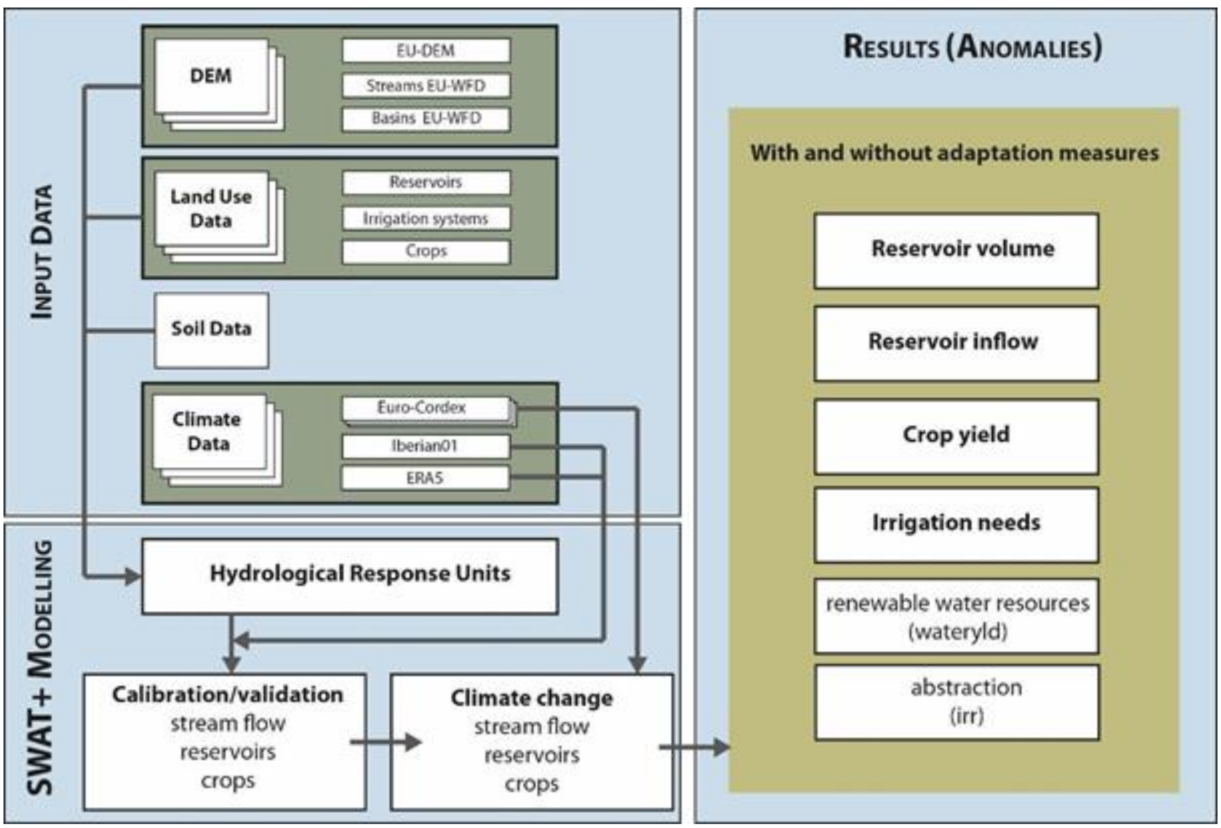
WP4.6 – Coastal Erosion and Storm Surges

This WP is divided into 4 individual reports: WP4.1 & WP4.4; WP4.2; WP4.3; and WP4.5 & WP4.6.

Hydrological Balance & Agroforestry

The impact of climate change on water resources in the Mediterranean region has emerged as a growing concern for policymakers and water resource managers. According to the latest report from the Intergovernmental Panel on Climate Change (IPCC), there is high confidence in the projection of rising temperatures across Europe and a decline in precipitation in the southern part of the continent. These changes are anticipated to result in reduced availability of river water and groundwater resources, along with an escalation of extreme events such as hydrological and agricultural droughts, as well as floods when excessive and unpredictable rainfall events occur.

This research involves the hydrological and crop modelling of main crops cultivated in mainland Portugal. The aim is to assess the effects of climate change on water availability, crop productivity, and irrigation requirements. The methodology employed to evaluate water resources in climate change scenarios for mainland Portugal is based on the updated version of the SWAT+ model.



Graphical summary of the assessment of climate change impacts on the hydrological balance and agroforestry productivity

The results related to the hydrological impacts include projections of water yield for each distinct river basin district. These encompass data on inflow and volume stored in multiple selected reservoirs (with a volume greater than 10000 m^3) with particular emphasis on reservoirs allocated to irrigation purposes whenever feasible. The projections indicate a maintenance of water yield under the RCP2.6 scenario and a decrease considering the remaining climate scenarios, with a more significant decline towards the end of the century for the RCP8.5.

Regarding the reservoirs, there is also a projected decrease in the inflow during the summer months, with a potential increase in some winter months due to more concentrated precipitation events. Nevertheless, the stored volume in the reservoirs is expected to have a decreasing trend throughout the century, mainly in reservoirs used for irrigation. This trend is prominent for the RCP4.5 scenario and even more pronounced considering the RCP8.5 scenario. This situation is a result of both the decrease in total inflow and the increase in irrigation needs, which will be particularly high for the main perennial crops, under the scenarios with the most significant climate impact (i.e., RCP4.5 and RCP8.5).

Concerning the agroforestry component, projected anomalies in the productivity are estimated for some rainfed crops, namely almond, grape, and olive grove, as well as the irrigation needs for apple, vineyard, and olive grove. There is evidence of a slight decline in productivity for rainfed almond and olive grove crops, whereas the losses are more substantial for vineyards, particularly in the southern regions.

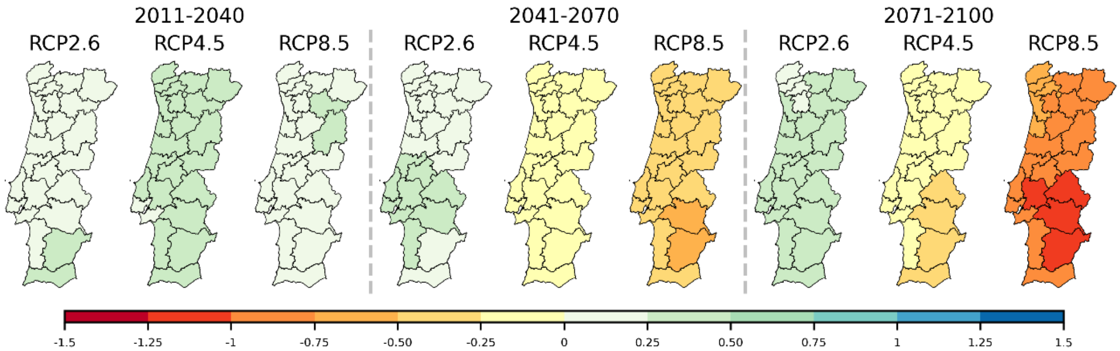
Finally, the analysis of the WEI+ suggests the increase of water stress conditions across almost all river basin districts by the end of the century. Only the country's Northern regions will likely remain with low or no water stress conditions. This reflects a combination of a drier climate, reduced flows, and increased abstractions for irrigated agriculture. Overall, these findings underscore the imperative need to implement adaptation measures to guarantee sustainable water availability and address the challenges posed by climate change.

Droughts

Amongst all natural hazards, droughts are one of the costliest, with cross-sectorial concurrent negative impacts, encompassing health, agriculture, vegetation activity/productivity, water resources, forest fires and energy production. Droughts manifest globally with either a rapid onset or a slow development, spreading across large areas, and with impacts that can linger long after the end of the event. As a result of warming and precipitation deficits and the increasing shortage of water resources, droughts have become one of the main drivers of desertification, land degradation and food insecurity, with direct impacts on ecosystems and society, especially in fragile communities. Iberia has been identified for decades as a climate change hotspot, especially due to its vulnerability to temperature extremes, precipitation reductions, and consequent associated droughts. Over Iberia, the occurrence of droughts varies in intensity and severity, making its assessment under present and future conditions an important tool for adaptation measures.

We present a comprehensive analysis of the different plausible evolutions of droughts throughout the 21st century over Iberia on a monthly basis, featuring three different emission scenarios (RCP2.6, RCP4.5, RCP8.5). A multi-variable, multi-model EURO-CORDEX weighted ensemble (explain in detail in WP2 Report) is used to assess future drought conditions using the SPI (Standardized Precipitation Index) and SPEI (Standardized Precipitation Evapotranspiration Index) at 1-, 3-, 6-, 12- and 24-month timescales. All indices were computed using, the 1971 to 2100 period as reference, i.e., the historical period from 1971 to 2000 was merged with the 2011 to 2100 from each RCP scenario.

The results clearly show that Iberia is highly vulnerable to climate change, indicating a significant increase in the intensity and severity of drought occurrences, even for the low-end RCP2.6 scenario. For the RCP4.5 and RCP8.5 scenarios, the increases are more pronounced and enhanced throughout the 21st century, from 3 up to 12 more severe droughts for the shorter timescales with increases in mean duration above 30 months for the longer accumulation periods. The use of all the RCPs data pooled together with a multi-variable weighted ensemble approach allows not only a more accurate and robust projection of future droughts but also ensures comparability among the projections from the three RCP scenarios.



Annual average of SPEI-12 over mainland Portugal for the future periods considering different GHG emission scenarios.

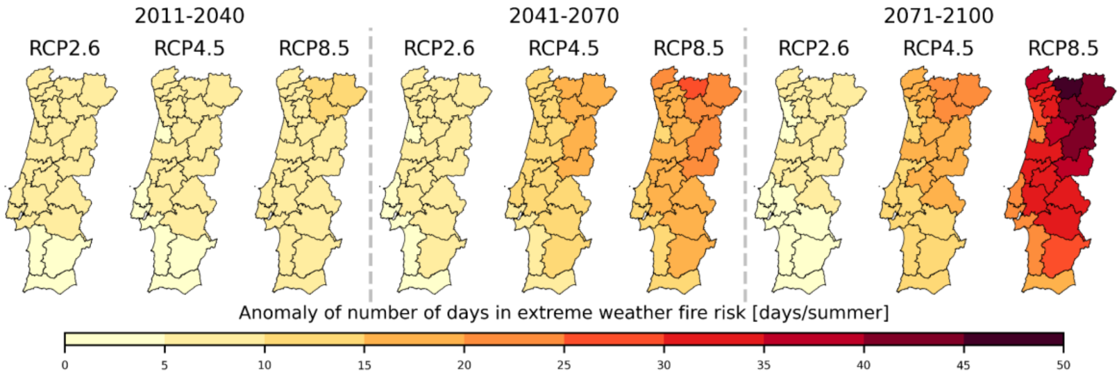
Forest Fires

This report delves into a comprehensive examination of the likely future meteorological fire danger in Portugal, with a primary focus on the potential impacts of climate change. As part of the overarching National Roadmap for Adaptation XXI, the study employs a sophisticated approach, leveraging a multi-model ensemble comprising 13 Regional Climate Models (RCMs). The assessment centres on two key indices, the widely used Fire Weather Index (FWI) and an enhanced version denoted as FWIe, with the implementation of information about atmospheric instability using the Haines index. This investigation serves as a critical component in the development of adaptation strategies for Portugal, contributing valuable insights to the ongoing discourse on climate change mitigation and resilience.

Key Findings and Insights:

- Geospatial Danger: Through meticulous analysis, the study pinpoints the north-eastern region of Portugal, as exhibiting the most significant increases in meteorological fire danger. This geographical specificity enables a nuanced understanding of the localised impact of climate change on fire danger.
- Scenario-dependent Dynamics: A noteworthy aspect of the research lies in its revelation of substantial disparities in meteorological fire danger projections among various emission scenarios. The study systematically contrasts the outcomes under different Representative Concentration Pathways (RCPs), emphasising the nuanced implications of strong mitigation efforts (RCP2.6) versus scenarios with limited or no mitigation (RCP4.5 and RCP8.5). This scenario-specific analysis underscores the importance of tailoring adaptation strategies to the projected climate trajectories.
- Temporal Shifts in Danger Periods: Beyond spatial considerations, the research illuminates temporal shifts in the meteorological danger periods. Projections suggest a noteworthy increase in extreme fire danger days during the summer season. Particularly noteworthy is the extension of the danger period into June and, to a lesser extent, September. This temporal dimension adds a layer of complexity to adaptation planning, urging a more nuanced and dynamic approach to danger assessment.
- Probability of Having Megafires: This study points to a larger probability of having megafires in the future, with fires with intensities larger than 1000 MW doubling or even occurring 3 to 3.5 more times than those of the historical period.
- Return Periods of Large Burned Areas: The study further investigates the projected return periods of large burned areas in Portugal and NUTS II regions, considering various emission scenarios and

future periods. Results, focusing on thresholds of 100,000 ha, 150,000 ha, and 200,000 ha, show a significant decrease in return periods for larger burnt areas, especially for RCP 8.5. For Portugal, return periods of 200,000 ha burnt areas decreased from 6-7 years to 1-2 years for RCP 8.5, a threshold particularly relevant as only three years since 1995 surpassed this value. NUTS II Norte and Centro exhibit similar patterns, with a steep increase in the probability of occurrence for large burnt areas. Return periods decrease, indicating a higher frequency of occurrences in RCP 2.6 and RCP 4.5.



Extended summer average anomaly of number of days with extreme weather fire risk over mainland Portugal for the future periods considering different GHG emission scenarios.

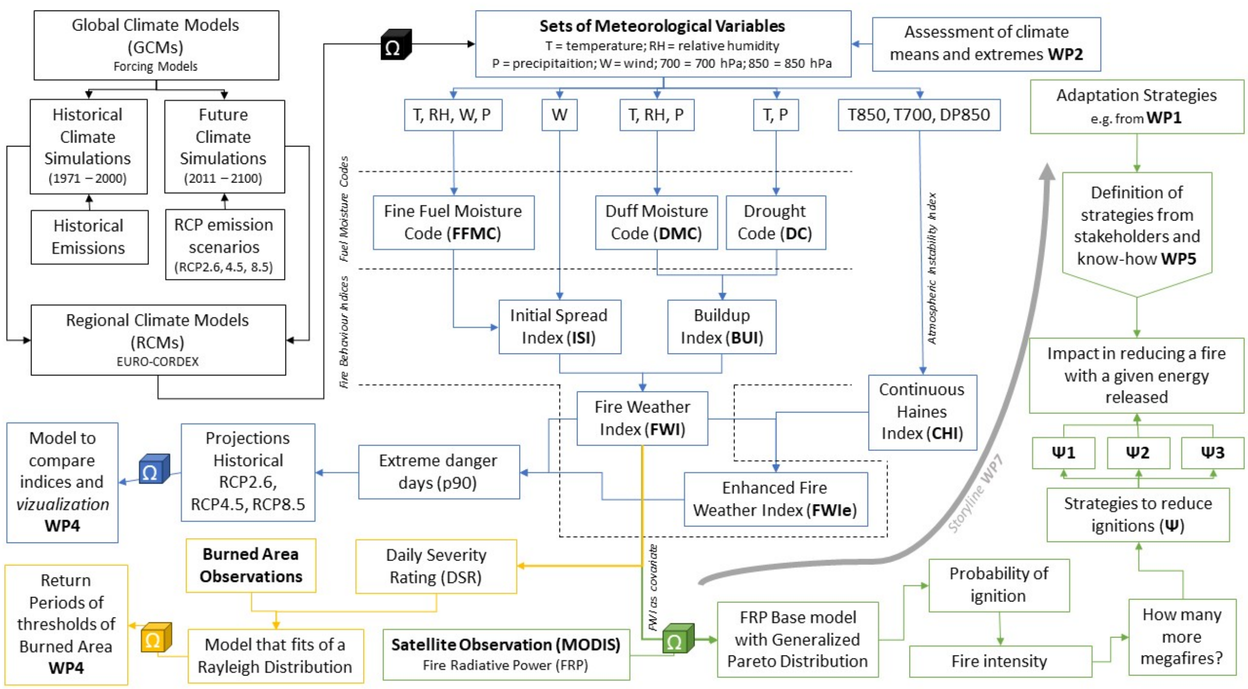
Practical Implications and Recommendations:

- Strategic Adaptation Planning: The study's findings hold profound implications for the formulation of strategic adaptation plans. The identification of regions with heightened danger serves as a crucial guide for directing resources and efforts toward areas where the impact of increased fire danger is anticipated to be most pronounced.
- Scenario-specific Adaptation: The scenario-specific nature of the findings underscores the importance of tailoring adaptation measures to the prevailing emission scenarios. While the heavily mitigated RCP2.6 exhibits relatively modest increases in fire danger, scenarios with less mitigation (RCP4.5 and RCP8.5) demand more robust and targeted adaptation efforts.
- Sensitivity Analysis for Precision: A recommended next step in the research agenda involves a sensitivity analysis, specifically focusing on forest management and understanding the danger of these ecosystems to wildfires. This granular approach aims to enhance the precision of adaptation strategies by accounting for ecosystem-specific dynamics.
- Vegetation Interaction Studies: Acknowledging the pivotal role of vegetation in influencing fire dynamics, future research endeavours should delve into the interaction between meteorological

indices (e.g., FWI and FWIe) and vegetation patterns. The incorporation of insights from the latest CMIP6 projections, which include dynamic vegetation components, promises to enrich our understanding of this complex interplay.

- Baseline for Storylines: Integrated into the broader RNA2100 project, this study not only contributes to the scientific discourse but also serves as a practical baseline for the timely preparation of adaptation measures. Its utility extends beyond academia, providing valuable storylines that can be articulated and integrated into the decision-making processes of stakeholders and policymakers.

In conclusion, this research contributes significantly to understanding the intricate dynamics of meteorological fire danger in Portugal. Its multifaceted approach equips stakeholders with actionable insights for effective climate change adaptation and resilience planning, considering both spatial and temporal dimensions, as well as the projected return periods of large burned areas.



Workflow diagram outlining the activities undertaken within the scope of WP4, illustrating its interconnections with WP5 and WP7.

Sea Level Rise & Coastal Erosion and Storm Surges

Some of the most disruptive effects of climate change are projected to be felt along the coastlines. From flooding to extreme coastal erosion, future changes in coastal dynamics are particularly feared, especially if combined with sea level rise, tides, storm surges and changes in wave climate. Coastal areas are amongst the most vulnerable regions to climate change, comprising important populational centres and economically relevant hubs. The portion of total population living in coastal areas has rapidly increased in the last decades, being estimated that at least 10% of the current world's population lives near the coast, less than 10 m above sea-level. In Portugal, data from the CENSOS2011 shows that 14% of the national population lives within 2 km of the sea, with the most recent update (CENSOS2021) pointing to increases in the Lisbon and Algarve regions, of 1.7% and 3.7%, respectively, in comparison with 2011.

Rising sea levels, together with the effects of tides, storm surges and extreme waves are considered key-drivers of coastal hazards, threatening coastal infrastructures, ecosystems, and communities. The increase in human pressure along the Portuguese coastlines calls for a reliable, long-term coastal vulnerability assessment, paramount for effective coastal management, sustainable development, adaptation, and impact mitigation strategies.

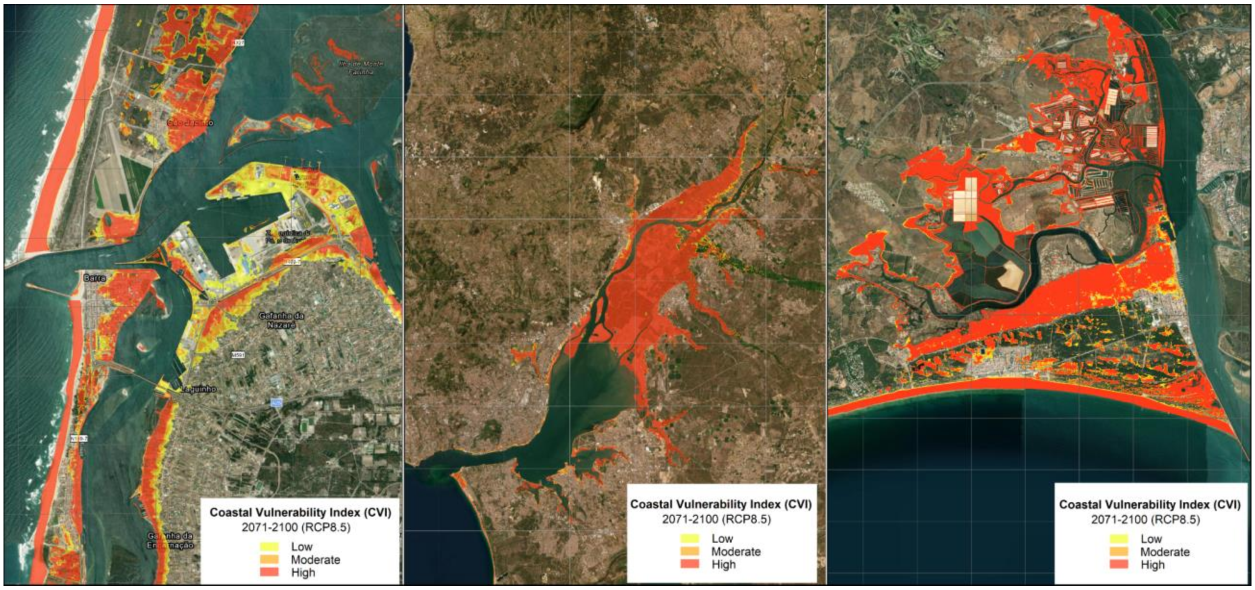
In the context of an increasing need for accurate physical and socioeconomic coastal vulnerability assessments, and incorporated in the National Roadmap for Adaptation XXI, we present a thorough and comprehensive assessment of future projected hydro-morpho-dynamical changes along the Portuguese coastlines. Future shoreline evolution and extreme coastal flooding projections are obtained, through high-resolution hydro- and morpho-dynamic modelling, for five coastal key-locations, selected due to their higher currently perceived vulnerability to climate change (based on historical records). Ensemble-based projections forced by Coupled Model Intercomparison Project phase 5 (CMIP5) Global Climate Models (GCMs), are used to drive an innovative methodology, focused on dealing with the multivariate challenges of an accurate coastal vulnerability assessment for Portugal, aiming to accurately assess the extension of future projected extreme coastal flooding. Two Representative Concentration Pathway scenarios are considered, namely the RCP4.5 and the RCP8.5. These baseline results are used to train a parametric approach designed for the complete, national-scale coastal vulnerability assessment, supported by a composed coastal vulnerability index.

At a local scale, our results indicate that future nearshore wave action, projected to become more northerly and less energetic, is expected to lead to northward beach rotations especially along the northern and central Portuguese coastal stretches. Nevertheless, the impact of SLR is shown to lead to consistent shoreline retreats throughout all analyzed key-locations. Such results are in agreement with several studies indicating that while wave action is projected to dominate morphological response until the mid-21st century, SLR should become the main driver of shoreline evolution beyond that time-frame. Final projected shoreline retreats are shown to locally reach 100 m (120 m) by 2100 under RCP4.5 (RCP8.5) at Ofir, 200 m (210 m) at Costa Nova, 140 m (150 m) at Cova Gala, 290 m (300 m) along Costa da Caparica, and 65 m (80 m) in Praia de Faro. The projected lost areas between the reference (2018) and future mean shorelines range between 0.088 km^2 and 0.184 km^2 (0.118 km^2 and 0.197 km^2) by 2100, under RCP4.5 (RCP8.5), the smallest (greatest) losses expected to take place at Faro and Cova Gala (Costa Nova). Throughout all key-locations (approximately 14 km of coastline), the cumulative amount of projected lost area from 2018 to 2100 ascends to 0.786 km^2 (2100 under RCP8.5), relevant when compared to the historical nationwide area lost to the sea between 1958 and 2021, which amounted to 13.5 km^2 for over 980 km of coastline.

The synchronized action of extreme total water levels, resulting essentially from SLR, but also from the joint occurrence of high spring tides or storm surge conditions, in the context of weaker natural protection structures due to erosion, is shown to lead to unprecedented coastal flooding in the future. Throughout the five key-locations, the future projected threatened area, expected to become flooded under extreme conditions, is projected to ascend to 0.657 km^2 (0.738 km^2) by 2070 under RCP4.5 (RCP8.5), and 0.841 km^2 (1.47 km^2) by 2100 under RCP4.5 (RCP8.5).

Based on the dynamical modelling at the five key-locations, a parametric approach is calibrated to characterize coastal retreat, flooding and the overall vulnerability along the entire Portuguese coastline. The coastal vulnerability index, divided into three levels (low, moderate and high), is inversely related to the projected flooding extent, so that areas under high CVI are the ones showing increased vulnerability to less extreme (more frequent) events, and vice-versa.

Finally, the ocean-facing areas under CVI along Mainland Portugal are projected to ascend to 41.7 km^2 (2070 under RCP4.5), 49.7 km^2 (2070 under RCP8.5), 54.7 km^2 (2100 under RCP4.5) and 55.9 km^2 (2100 under RCP8.5). These areas, related to episodically flooded territory, are projected to amount to 3.09, 3.68, 4.05 and 4.14 times the area observed to have been lost between 1958 and 2021 (13.5 km^2). However, when considering inland waters, an additional value between 514 km^2 and 548 km^2 (2070 under RCP4.5 and 2100 under RCP8.5, respectively) must be considered. Therefore, for all types of coastlines along Mainland Portugal, the future area under CVI is projected to ascend to 604 km^2 by 2100, under the RCP8.5 scenario.



Projected areas under CVI for Aveiro, Lisbon and Vila Real de Santo António regions, by the end of the 2071-2100 future period (2100), under the RCP8.5 scenario.

The combination of coastal retreat with high-frequency flooding could result in loss of coastal ecosystems and fertile soil for agriculture given the potential landward intrusion of saltwater, besides the imminent risks for human life. Our results call for the implementation of adequate coastal management and adaptation plans, strategically defined to withstand changes until 2100 and beyond.