Environment, Climate Change and Low Carbon Economy Program

'Environment Program'
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Final Report
07/09/2020 - 30/04/2024

PDP#2 - PRE-DEFINED PROJECT-2
NATIONAL ROADMAP FOR ADAPTATION XXI

In accordance with Articles 25, no. 2, paragraph j) and 29, no. 4 of the 'Guide for Applicants for Financing Environmental Projects, on Climate Change and Low Carbon Economy'

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i. Project description and main WP achievements

General information about the project

Start date: 07/09/2020
End date: 30/04/2024
Duration: 44 months
Promoter: Portuguese Environment Agency (APA)
Partners: Faculdade de Ciências da Universidade de Lisboa, Direção-Geral do Território, Banco de Portugal, Instituto Português do Mar e da Atmosfera, Norwegian Directorate for Civil Protection
Total Cost: 1.300.000,00€
Financing rate: 30,80%
Funding: 400.000,00€
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The Project begun in September 2020 and came to an end in the 30th of April 2024. All project working packages were completed successfully, and all deliverables were fully accomplished as shown in the following Tables. Briefly, the project spanned from building new climate change projections for the XXI century, to impact modelling of the physical consequences of climate change in Portugal focused on the main vulnerabilities (water resources/agroforestry, coastal areas and wildfires), and to the economic cost, including the inaction and adaptation costs due to climate change. The project also developed a macroeconomic integrated assessment model for the Portuguese economy and defined guidelines to mainstream climate change adaptation into Municipal Master Plans. The project also performed high resolution climate simulations for the Archipelagos of Madeira and Azores and integrated all the climate data on a new portal: http://rna2100.portaldoclima.pt/. Finally, noteworthy the project largely surpassed the number of international scientific publications initially envisaged of 10 papers to 17, most of them already published or in second round of revision.

Intervention areas	Activities	Status
WP1. Stakeholder engagement	Sectorial meetings (1/3)	**Concluded**[1]
	Preparation, implementation and report - workshop 1	**Concluded**[1]
	Sectorial meetings (2/3)	**Concluded**[1]
	Preparation, implementation and report - workshop 2	**Concluded**[1]
	Sectorial meetings (3/3)	**Concluded**[1]
	Preparation, implementation and report - workshop 3	**Concluded**[1]
WP2. Climate projections and indexes	Set of results of the climate projections and indexes	**Concluded**
	Project report chapters addressing this topic including uncertainty analysis	**Concluded**
	Synthetic summaries of climate scenarios for Portugal including for all sectors and at different geographic scales	**Concluded**
	Climate monitoring and scenarios for the Azores and Madeira	**Concluded**
WP3. Socioeconomic scenarios	Presentation of the results of socioeconomic scenarios to be considered in the determination and analysis of sectorial impacts including at macroeconomic level	**Concluded**
	Presentation of the adaptation measures and Project report chapter	**Concluded**
WP4. Sectorial impacts modelling	Hydrological balance	**Concluded**
	Forest fires	**Concluded**
	Agroforestry	**Concluded**
	Sea level rise	**Concluded**
	Coastal erosion and storm surges	**Concluded**
WP5. Adaptation needs	Review of adaptation measures	**Concluded**
	Definition of the adaptation measures	**Concluded**
	Articulation and integration of stakeholder's views	**Concluded**
	Costs and benefits in coherence to the results of WP4	**Concluded**
WP6. Macroeconomic impacts	Use of macroeconomic models to analyse the macro impacts of different climate change scenarios relative to a baseline scenario	**Concluded**
WP7.	Development of the adaptation storylines	**Concluded**
	Factsheet for each adaptation storyline	**Concluded**

[1] Due to delays with the Covid-19 pandemic, it was decided to hold the three workshops together on May 4, 2023, as documented in the report.

Intervention areas	Activities	Status
Development of the adaptation storylines	Project report chapter addressing this topic	**Concluded**
WP8. Communication and capacitation	Project website	**Concluded**
	Press releases	**Concluded**
	Regional seminars	**Concluded**
	Guidelines and project report chapter	**Concluded**
WP9. Coordination and project management	Management Committee meetings	**Concluded**

Follows a summarized description of all the working packages.

WP1. Stakeholder engagement

WP1 was devoted to stakeholders' engagement and therefore workshops were carried out. The workshops of the RNA2100 took place on May 4th, 2023, and aimed to disseminate, to the interested parties, the work carried out within the scope of the National Roadmap for Adaptation project, and to gather information about climate change adaptation measures that the stakeholders deemed most suitable to address climate projections until the end of the 21st century in Portugal. The goal was also for these contributions to be relevant to the process of constructing sector-based and NUTS II-based storylines for mainland Portugal. In this way, the gathered information was used in both WP 5 (Measures and Costs of Adaptation) and WP 7 (Development of the adaptation storylines).

The workshops were highly productive, making a significant contribution to the evaluation and proposal of adaptation measures within the impact modelling framework and the development of storylines. Among the proposed measures, it is worth noting that there were suggestions at the strategic level, which are more related to adaptation options than specific measures. Examples include the option of "Diversifying water sources / reducing demand / increasing efficiency" in the context of the Water resources & Agroforestry sectors, as well as the "Incremental and adjustable implementation of a variety of adaptation measures (i.e., from accommodation to relocation)", within the Sea level rise & Coastal erosion sectors.

WP2. Climate projections and indexes

WP2 collected all the regional climate information at high resolution available for mainland Portugal and developed new climate change projections for the XXI century, in agreement with the CMIP5 RCP concentration scenarios, following the new methods proposed in-house for multi-model/multi variable ensembles (Lima et al. 2023a,b). Continental Portugal (hereafter Portugal) is located in the western tip of the Mediterranean basin, in the transition zone between the arid to semiarid climates of subtropical regions and the humid climates typical of northern Europe.

This region has been identified as a climate change "hotspot", with observed and projected rates of climate change exceeding global trends for most variables (Giorgi 2006; Lionello and Scarascia 2018; Cramer et al. 2018). Humid mild winters and dry warm/hot summers are common features that characterise both the Portuguese and Mediterranean climates. Indeed, observational records between 1860 and 2005 show a general trend for warmer and drier mean atmospheric conditions over these areas (Giorgi and Lionello 2008; Trenberth 2011; Turco et al. 2018). According to the Fifth and Sixth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013, 2021), the observed increase in mean temperature over the western Mediterranean basin during the last decades has been particularly pronounced in summer months, and the warming and drying trends across the Mediterranean will continue throughout the twenty-first century (Lionello and Scarascia 2018; Tuel and Eltahir 2020).

The projected warming and drying trends over Portugal were shown to be stronger for high anthropogenic emission scenarios, confirming the importance of the human component on the overall climate change projections when compared to the natural variability of the climate system, even at the regional scale (Barcikowska et al. 2018; Cramer et al. 2018). The goal of the Paris Agreement is to limit the global temperature increase to 1.5 ºC relative to pre-industrial levels, while pursuing efforts to avoid the 2 ºC warming threshold. Nonetheless, even in a 2 ºC global warming scenario, a critical environmental situation will develop, related to the enhanced warming of land areas in summer and widespread reduction of precipitation, especially over the Mediterranean region. In this report, it is shown that, even under an optimistic scenario of strong mitigation (RCP2.6), Portugal is projected to experience an average warming between 1 ºC and 2 ºC, relative to the historical period. On the other hand, for the scenario without mitigation (RCP8.5), a generalized warming exceeding 6 ºC is projected until the end of the 21st century. Temperature is projected to increase through all seasons and regions in Portugal during the 21st century, with a greater warming during summer (Cardoso et al. 2019), enhancing the land-sea thermal contrast. In fact, the projected intensification of the Azores anticyclone and its expansion to northeast due to the northward expansion of the Hadley Cell (Miyasaka and Nakamura 2005; Kang and Lu 2012), together with the strengthening of the Iberian thermal low, forces more intense and frequent summer winds parallel to the coast ("Nortada"), especially in the northwestern Iberian Peninsula, especially impacting the northern and central areas of Portugal (Cardoso et al. 2016; Soares et al. 2017b, c). In general, projections of maximum temperature were shown to have slightly larger magnitudes than those of minimum temperature, consistent with a slender amplification of the daily temperature range.

The frequency and intensity of extreme hot events was also shown to be projected to change considerably through most of the territory, evident even already during the first future climatological time-slice (2011-2040), especially in the southern regions. In fact, the 100-year return levels during historical climate are generally exceeded by the projected 10-year return levels from 2041-2070 onwards. Moreover, the intensity of extreme heat event is also projected to increase for future events. The expansion of the Azores high and its enhanced persistency in higher latitudes during winter is projected to lead to a reduction of the weather regimes that produce large-scale precipitation events (Bengtsson et al. 2009), and the strengthening of pressure and temperatures gradients may increase the advection of warmer continental air. On the other hand, the increase of pressure gradient along the coast may intensify the across-shore winds limiting the advection of moist air inland, which may explain the reduction of precipitation projected for intermediate and summer seasons. Although summer precipitation does not have a significant contribution for the annual total due to its lower values, projected decreases below -40% are expected during 2071-2100. Warming and drying conditions may cause a decline in the relative humidity, and consequently an increase in potential evapotranspiration.

Along with the warming, reflected in maximum temperatures, summer days, hot days, and very hot days are projected to become more frequent and intense. A northwestern-southeastern gradient is generally observed, with the south-eastern interior regions depicting a more pronounced increase than the north-western coastal regions. Projected changes differ substantially among the emission scenarios, often duplicating in magnitude from RCP2.6 to RCP8.5. Under the worst-case scenario (RCP8.5), maximum temperatures above 25ºC are projected to be registered in more than half of the year (an increase of approximately 50% regarding the historical period), with up to 100 days above 35ºC. Conversely, for the strong mitigation scenario (RCP2.6), the projected increases for these variables are set at approximately 25%, and 50 days per year, respectively. The considerable projected increase in number of heat days may be detrimental to public health since it directly impacts the human thermoregulatory capacity (Kovats and Hajat 2008) which will be greatly aggravated if greenhouse gases are not considerably reduced (Kang and Lu 2012). Aligned with the projected increases in minimum temperature, tropical nights were shown to become more common, accompanied by an expected decrease in the number of cold and frost days. Since tropical nights are the main cause of thermal discomfort, such frequency increases may affect the thermal comfort conditions, and consequently human health (Karyono et al. 2020). Nocturnal thermal stress is projected to be further aggravated over cities by the urban heat island effect (Nogueira and Soares 2019; Nogueira et al. 2020), with significant implications to human health. Furthermore, in the north-eastern regions, a gradual shrinking of the area where the number of cold and frost days attain the maximum values during the historical period is projected to occur, throughout the 21st century. Aligned with the projections for cold days, results of the maximum number of consecutive cold days show a reduction throughout the 21st century (not shown). For all the emission scenarios and time periods, the frequency of cold waves is expected to decrease throughout the entire country. The steady decline in severity and frequency of cold waves over the last decades in the observations is a subject that has been recently discussed for high mid-latitudes of the northern hemisphere (Van Oldenborgh et al. 2019). In fact, the decline in cold and frost days may have a positive repercussion in the health system pressure during winter (Charlton-Perez et al. 2019).

Associated to the decrease in mean accumulated precipitation, the number of wet days is projected to decrease until the end of the 21st century, in line with Soares et al. (2017a). Consequently, the number of dry days is expected to increase, enhancing drying conditions. The magnitude of such projections is enhanced for the non-mitigated scenario when compared with the scenario with strong mitigation. After 2041, a decrease in the number of wet days is expected for RCP4.5 (RCP8.5), to less than 18 (24) days per year, worsened by the end of the 21st century, with a reduction of up 36 days under the RCP8.5. For the RCP2.6, the projected changes are negligible throughout the century, with a slight decrease up to 12 days over the northeastern region during the mid-21st century. In terms of moderate and heavy precipitation, clear projected reductions are visible, especially for the RCP4.5 and RCP8.5 scenarios, however, local increases are projected for the maximum 5-day accumulated values. These projections indicate that rainfall may become more concentrated into shorter time frames, implying an intensification of moderate/heavy precipitation independently of the scenario. Such results may be linked to the expected increase in the average percentage of annual precipitation originating from days with moderate to heavy rainfall. Especially during autumn and winter, the westerly flux driven by the seasonal displacement of the Azores high-pressure system towards lower latitudes favours the influence of low-pressure systems, leading to especially rainy conditions over the northern and central coastal areas. The topography north of the Tagus River prevents most of the precipitable water from reaching the regions near the Spanish border, leading to lower accumulations there.

The projected climatological poleward displacement of the storm tracks over the North Atlantic due to the northward expansion of the Hadley Cell is a well-known consequence of climate change, leading to consistent reductions in wind speeds and accumulated precipitation in Portugal (Bengtsson et al. 2006; Ulbrich et al. 2008; Kang and Lu 2012; Harvey et al. 2014). In fact, the largest reductions of 10-m wind speeds are found in winter and autumn seasons over elevated terrain in northern and central-eastern regions, and over the southwestern coastal regions for the end of the 21st century. Precipitation changes depend on the season, region, and the emission scenario. The highly-(non-)mitigated emission scenario projections were shown to point to a moister (drier) winter. Although an overall decrease in the accumulated precipitation is expected, an intensification of heavy, short-term precipitation events is projected, especially over the northern region, which agrees with Soares et al. (2017a). In fact, although a reduction of stormy weather across Portugal is an expected reality, the intensity of individual storms may increase, originating not only concentrated precipitation events, but also increases in the maximum wind gusts in several areas of the country (Bengtsson et al. 2009).

Throughout most of mainland Portugal, projections of 10-m wind speeds showed a general decrease, especially for intensities above 5.5 m/s, even on mountainous areas in northern and central Portugal. Implications from these results are especially evident for the renewable energy sector. In the first three months of 2022, 36.9% of the country's clean energy was generated through the wind, being the largest source at national scale (APREN 2022). Furthermore, 11 of the 16 wind energy production parks in Portugal are located in the northern and central regions, where the projected decreases in wind intensities tend to be greater. Adaptation of the renewable energy sector to climate change may require a revaluation of the geographical distribution of wind energy generation turbines. The sole location where a consistent projected increase in frequency of occurrence of 10-m wind speeds above 5.5 m/s was shown to be the Lisbon district, associated to the intensification of northerly winds ("Nortada"). Notice that these results are in agreement with Nogueira et al. (2019), which reported the largest projected reduction on wind energy production to occur during winter and autumn over northern Portugal, with a small increase during summer over Lisbon metropolitan area and Alentejo. In fact, it is important to point out that despite the small magnitude of the average 10-m wind speed projected changes, the impact on wind turbine energy production is substantial due to the logarithm wind profile combined with the cubic dependence of wind energy production on wind speed, and the high and low cut-off thresholds of wind turbines for energy production (Soares et al. 2017b, 2019; Lima et al. 2021).

WP3. Socioeconomic scenarios

This WP explored approaches for developing and analyzing socio-economic scenarios (narratives and trajectories) for Portugal. The approaches are based on information developed in multiple areas and scenario series at global to national and regional scales. The information sources comprise i) information from the socio-economic scenarios developed for the United Nations Intergovernmental Panel on Climate Change (IPCC) between the fifth and sixth assessment report on climate change (2013-2022), ii) other international scenario sources, and iii) information from national scenario sources, namely the National Statistics Institute (INE) and the Portuguese Roadmap for Carbon Neutrality 2050 (RNC2050). In this context, we compiled or developed projections of different socio-economic and land use variables for Portugal, seeking to justify the choice of a specific scenario that will be applied throughout the RNA2100 project (https://rna2100.apambiente.pt/). Thus, the WP3 report served to provide a critical analysis to build plausible narratives for a future Portugal. From this analysis a static scenario was assumed for population and land-use.

WP4. Sectorial impacts modelling

The objective of this WP was 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 included the task of conversion of the physical impacts into the associated social and economic impacts with (WP5) and without adaptation measures.

Impacts were detailed in key sectors, such as: WP4.1 – Hydrological Balance & Agroforestry; WP4.2 – Droughts; WP4.3 – Forest Fires; WP4.5 – Sea Level Rise and Coastal Erosion.

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.

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 presented 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.

Forest Fires

This task delved 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 employed 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.

<u>Key Findings and Insights:</u>

- 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.

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 contributed significantly to understand 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.

Sea Level Rise & Coastal Erosion

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 analysed 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.

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.

WP5. Measures and Costs of Adaptation

This WP aimed to moldel sectoral adaptation measures, for the most vulnerable sectors (aforementioned) in articulation with the results from the dynamic impact modelling (WP4) and estimate the associated costs and benefits. Stakeholder inputs (WP1) form the basis for this exercise, fostering a comprehensive approach to climate resilience, to inform effective adaptation strategies and promote a more resilient future for Portugal.

Hydrological Balance & Agroforestry

The water resource sector investigated the costs of inaction and the measures taken to adapt to climate change projections. Specifically, the costs of inaction are assessed in the water resources and agroforestry sector, considering factors such as the average cost of water and alterations in water availability and the productivity of the most representative crops across different river basin districts. Additionally, the study explores adaptation measures, with a focus on four strategies studied.

The initial adaptation measure centres on the selection of crops better suited to climate change projections, employing a strategic approach to ensure agricultural resilience and sustainability within evolving environmental conditions, such as temperature increases and the higher likelihood of extreme weather events.

In assessing the advantages of this adaptive measure, the study estimated improvements in water availability and productivity by replacing corn with sunflower crops. Notably, the transition to sunflower cultivation revealed a reduced water requirement over time, coupled with higher yields than corn.

To calculate the associated costs of implementing this measure, detailed information regarding the expenses related to sunflower and corn cultivation was acquired. The divergence in these costs in regions where corn is currently cultivated was then calculated. This comprehensive analysis enabled an estimation of the costs linked to the substitution of crops, revealing the economic viability of transitioning from corn to sunflower cultivation, particularly in the context of adapting to climate change.

The second adaptive measure, focusing on enhancing irrigation efficiency, aims to reduce water consumption in agriculture. Within this project, an examination of water availability results was conducted through the conversion of irrigation systems to drip irrigation, particularly in contexts where it is applicable, such as in corn and vegetable cultivation.

The results demonstrated that the transition from conventional irrigation systems to a more efficient system led to a reduction in water consumption by crops. This is attributed to the direct delivery of water to the plant roots, minimising wastage.

To assess the economic costs of implementing this measure, information on the average cost for the implementation of the drip irrigation system was obtained. The results of this analysis emphasised the viability and cost-effectiveness of replacing irrigation systems, particularly in terms of reducing water consumption.

The third measure implemented in this study involved Reducing system water loss and leakages. The SWAT+ model does not account for water losses and leaks in the water supply system. To address this, information from simulated historical modelling results was utilised to estimate the benefits of reducing losses in the agricultural water distribution network.

Specifically, the losses in the irrigation component, as derived from the simulated historical data, were incorporated, leading to the recalculation of the WEI+. Notably, the results indicated an increase in the water stress index upon the implementation of these losses. This underscores the significance of reducing losses as essential for enhancing water availability over time.

The final measure involves water recycling and reuse, promoting a more sustainable approach to water management across various purposes. In quantifying the advantages of water recycling and reuse, the analysis took into account the hydro-agricultural developments (AH) within each river basin district, along with the wastewater treatment plants situated in those regions. Approximately 80% of the municipal water supply, derived from available wastewater for recycling, resulted in a significant increase in the WEI+, thereby reflecting an augmentation in water availability in the respective regions.

In calculating the costs associated with Reducing system water loss and leakages and Water recycling and reuse, there were observed increases in water use for irrigation compared to the scenario without adaptation. This has the potential to contribute significantly to mitigating the impacts of climate change.

Finally, other measures were considered as a result of the workshops held and other interactions with institutions with decision-making power in agroforestry and water resources making a group of possibilities for adaptation in the context of climate change.

Forest Fires

This study underscores the significance of meteorological variables in developing effective wildfire adaptation measures. Focusing on Fire Radiative Power (FRP) as a key metric, three distinct fire prevention strategies are evaluated, employing varying degrees of randomness and stringency in reducing FRP values associated with Fire Weather Index (FWI) conditions. These strategies are rigorously assessed across historical simulations and future projections, revealing their impacts on mitigating the probability of extreme fire events.

Three key strategies are analysed:

- Strategy 1 – Awareness: Randomly reduces 50% of FRPs associated with FWI values exceeding the sample median. Shows promise in reducing fire occurrences in moderate conditions but demands substantial resources for widespread implementation.
- Strategy 2 – Awareness + Coercive: Varies reduction percentage based on FWI percentiles. Demonstrates a notable impact on reducing fires in regions facing extreme fire weather conditions.
- Strategy 3 – Coercive: Randomly reduces 95% of FRPs in very high FWI conditions. Effectively addresses extremely intense fires during critical fire weather, necessitating focused resources.
- Strategy 2 exhibits higher impacts, notably reducing the probability of exceeding log10(FRP) across various energy thresholds. Impact magnitudes increase, particularly for Strategy 2, under severe emission scenarios (RCP 4.5 and RCP 8.5). Strategy 3 proves most sensitive to mitigation scenarios, showcasing significant reductions in wildfires, particularly under high-emission scenarios.

Hence, the following recommendations for stakeholders are listed:

- Recognize Strategy 3 Effectiveness: Acknowledge the efficacy of Strategy 3 in addressing challenges posed by extreme fire weather events, offering a proactive and adaptive approach.
- Prioritise Long-Term Implementation (Strategy 1): Emphasise long-term efforts in implementing Strategy 1 measures, recognizing the challenges associated with changing population mentality and geography.

- Consider Complexities of Strategy 2: Acknowledge the potential complexities of Strategy 2 implementation, requiring a sophisticated infrastructure of warning systems and resources.

In conclusion, this study evaluates three fire prevention strategies, with Strategy 3 emerging as a promising approach for addressing challenges posed by extreme fire weather events. While Strategy 2 shows higher impacts, its implementation complexity may pose challenges. Recommendations provided aim to inform stakeholders and policymakers, offering valuable insights for decision-making in wildfire management and climate resilience. The study recognizes limitations, urging cautious interpretation of results, especially regarding assumptions about static vegetation in future projections. Additionally, adaptation measures linked to concrete strategies underscore the importance of informed, collaborative efforts in addressing evolving wildfire risks.

These strategies may have a positive impact on the losses caused by wildfires, with results pointing to halve the losses if Strategy 2 is implemented. This is particularly important in regions where losses from wildfires are large, such as the central and northern regions of Portugal.

Coastal Areas

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, strategically defined to withstand changes until 2100 and beyond. Approximately 30% of the Portuguese coastline has been altered by urban settling, harbour and industrial facilities, and tourism infrastructures, accommodating approximately 75% of the population. In Portugal, the coastal strip up to 50 m inland belongs to the State, and any private parcel within this domain has a public and administrative easement, according to Decree-Law nº 54/2005, modified by Decree-Law nº 78/2013 and Decree-Law nº 34/2014. Therefore, its management and protection policies are the responsibility of State coastal authorities.

In light of the WP4.5/6 dynamic modelling report and the WP1 stakeholder engagement report, the WP5 report on Measures and Costs of Adaptationfor the Portuguese coastal areas focuses on the translation of the physical projected impacts and the expert knowledge of technicians and decision-makers on coastal vulnerabilities to delve into the adaptation measures better suited to deal with the impacts of future climate change. The report is divided into three major sections: the first, focuses on the inaction costs (i.e., the total economic costs in a scenario of no action towards 2100), the second, provides a thorough description of adaptation strategies and measures currently in place and to be applied in the future along the Portuguese coastline, considering the modelling results and the stakeholders' views, and the third, revealing the economic costs associated to the adaptation measures proposed in the previous section (also establishing the cost-benefit between inaction and adaptation costs).

On a first approach, the inaction costs were estimated by crossing the Coastal Vulnerability Index (CVI) cartography (the reader is referred to the WP4.5/6 report) with the geographical distribution of patrimonial value related to the buildings and land projected to become vulnerable, using data from the CENSOS2021, the Portuguese Tax Authority ("Autoridade Tributária") and reference values from Ordinances and Decrees-Law. The sum of the vulnerable patrimonial values, at a national scale, under the three CVI levels, corresponds to the overall inaction costs, probabilistically estimated for the range of possible future extreme coastal flooding projections, with a direct relationship with the 100-year (low), 25-year (medium) and 4-year (high) total water level (plus extreme waves for the ocean-facing coastlines) return periods.

A thorough analysis of the current legislation and territorial management instruments in place in Portugal, regarding adaptation measures was undertaken, highlighting the fragilities of the current systems and proposing new measures to deal with the impacts of climate change. From expert knowledge and contact with stakeholders, ten adaptation measures were considered in the WP5 report for the coastal areas. These are (the first five are ordered considering the relative importance highlighted by the stakeholders):

- (1) Artificial beach nourishment;
- (2) Definition of safeguard zones and relocation;
- (3) Rehabilitation of dunes and use of nature-based solutions;
- (4) Cliffs stabilization;
- (5) Maintenance and construction of groins, breakwaters, barriers and dykes;
- Revision of legislation related to IGTs, along with its enforcement to safeguard the infrastructure, communities, and ecosystems in coastal areas;
- Accommodation of urban coastal areas and harbor infrastructure;
- Relocation/removal of structures exposed to risk;
- Incremental and adjustable implementation of a variety of adaptation measures (i.e., from accommodation to relocation);
- Declaration of the Portuguese littoral as a climate emergency zone.

Considering the five key locations in detail (Ofir, Costa Nova, Cova Gala, Costa de Caparica and Praia de Faro), specific adaptation measures were proposed, focusing on the particular characteristics of each area. At Ofir, the most relevant adaptation measures were considered to be artificial beach nourishment and the rehabilitation of dunes and the use of nature-based solutions. These were also considered crucial for Costa da Caparica. At Costa Nova and Gova Gala, artificial beach nourishment was considered a priority, above all the remaining measures. Finally, at Praia de Faro, relocation and removal of structures exposed to risk were considered crucial, along with the rehabilitation of dunes and the use of nature-based solutions. Regarding the existing adherent structures, such as seawalls, accommodation options should be considered along all key locations. The required heights for the coastal protection structures to withstand the future projected extreme coastal events (including a measure of uncertainty, also useful to deal with the statistical possibility of severer events) were shown to be set at 10.64 m (Ofir), 9.46 m (Costa Nova), 7.61 m (Cova Gala), 8.87 m (Costa da Caparica) and 7.77 m (Praia de Faro).

Finally, the adaptation costs were considered at a national level. These included the costs related to the maintenance of pre-existing structures along the Portuguese coastline, to new planned interventions (such as artificial beach nourishments, considering the projected changes in longshore sediment transport), and to the accommodation of harbor and adherent structures, to include new levels of protection. Finally, the comparison of the adaptation costs with the inaction ("no-action") ones allowed us to perform a cost-benefit evaluation of the considered strategies. The balance between inaction and adaptation costs allowed us to conclude that generally the cost-benefit ratio of adaptation is low at a national scale, and therefore, adaptation should be pursued. Nevertheless, in very densely urbanized coastal fronts, the adaptation costs related to the accommodation of pre-existing adherent structures or even the remaining infrastructures may saturate the cost-benefit ratio sooner than in the remaining coastal environments, and relocation is suggested in shorter timeframes, ideally to start within the next 20 to 30 years. Specific economic analyses, conducted locally, are recommended, since indirect costs from tourism and local economic activities (unconsidered in the present analysis) may contribute to different adaptation cost-benefit ratios.

WP6. Macroeconomic impacts

In the case of WP6, the goal is to give a broad-brush picture of possible macroeconomic consequences of different gradations of the atmospheric carbon concentration pathways. As in other work packages of the project, this analysis is conducted in reference to the Representative Concentration Pathways (RCPs) 2.6, 4.5 and 8.5, as characterised in the Fifth Assessment Report of the IPCC. For each of the scenarios, a global tax carbon policy is synthesised to be broadly consistent with its atmospheric carbon concentration trajectory.

Policy aimed at curbing carbon emissions only works if it is applied globally, since atmospheric carbon concentration is a global phenomenon. Policy must be global, but the effects of policy are local and highly heterogeneous. For this reason, the analysis zeroes in on the reality of Portugal, modelled as a small open economy subject to the global carbon tax policies and characterised by different values for selected parameters. In the context of this work, a small open economy is defined as one that has negligible impact on global output and carbon emissions, and with the same marginal productivity of capital as the rest of the world.

An integrated climate assessment model is developed featuring three regional economies (one oil-producing region, Portugal, and the rest of the world), different energy sources (coal, oil, gas, and clean sources), forestry, global carbon taxation policies capable of generating each of the RCP scenarios, and competitive markets for energy, capital, and goods. Long-term carbon sequestration subsidisation is assumed to be symmetrical to the global carbon tax. An additional feature of this analytical framework is the inclusion of adaptation at the local level, which is used to assess its importance in a transition subject to global carbon taxation. We assume that the revenue from the carbon tax, net of subsidies to forests and possible adaptation costs, is rebated lump sum to households. The fiscal neutrality of carbon taxation and subsidisation is particularly important in terms of wellbeing of the households, as it compensates them for the higher energy prices.

WP7. Development of the adaptation storylines

In this WP7, sectoral adaptation narratives were proposed, in articulation with the results from the WP4 "Sectoral Impacts and Modelling" and WP5 "Measures and Costs of Adaptation" reports, focusing on the identified risks related to climate change, namely water scarcity and stress on crops, coastal erosion and flooding, forest fires, and the associated economic losses. These are geographically organized by means of the 2013 Portuguese configuration of the NUTSII territorial division system, incorporating five regions, namely Norte, Centro, Área Metropolitana de Lisboa, Alentejo and Algarve. Each narrative identifies the present and future vulnerabilities for each region, in articulation with the impact modelling results from WP4. It highlights the adaptation measures identified for each sector, proposing structures for their territorial implementation, and focusing on the inaction and adaptation economic costs, from WP5. Moreover, a set of summary cards for each sector was developed as a synthesis of the impacts and adaptation costs.

Warming and drying future conditions may significantly affect human and natural environment in Portugal. The climate projections are found to be especially dramatic for the non-mitigated emission scenario (RCP8.5), while more manageable for the highly-mitigated scenario (RCP2.6). The results here revealed very distinct change magnitudes and patterns within the three RCPs, which will lead to substantially different socio-economic impacts and adaptation measures. Even under a strong mitigation scenario, substantial changes for sectoral climate indices are projected, which may strongly impact sectors like agriculture and water management.

Water resources and agroforestry in mainland Portugal are vulnerable to climate change. Projected changes in precipitation, temperature, humidity, solar radiation, and wind will affect water availability, demand, and crop productivity. By the century's end, impacts will vary depending on emissions trajectory. Southern regions, particularly beyond the Tagus River, will face more significant impacts, with the Water Exploitation Index plus (WEI+) potentially increasing by up to +99 percentage points in the Guadiana River Basin under RCP8.5, or around +22 points under RCP4.5. Without adaptation, economic losses could average €426 million annually under the moderate mitigation scenario and approach €670 million under the high emissions scenario. Even meeting Paris Agreement targets could still result in yearly losses of €172 million by 2100. As climate change worsens, adaptation becomes crucial, especially in the south, where the gap between water supply and demand will widen. In northern regions, solutions like reducing demand and enhancing irrigation efficiency can help, while southern areas will require more profound adaptation, such as selecting climate-resilient crops and investing on the reuse of wastewater for agricultural purposes.

The discourse on climate adaptation and wildfire management in the five NUTS II regions elucidates the imperative for multifaceted strategies in confronting the escalating threat of wildfires exacerbated by climate change. The results emphasize the pivotal role of meteorological factors, forest management practices, and societal engagement in shaping wildfire risk and resilience. It underscores the necessity of integrating awareness initiatives with coercive measures to effectively reduce ignitions and mitigate projected losses (saving from 290,000 euros/year in A.M.L. to 88 million euros/year in Centro). Moreover, the delineated adaptation pathways underscore the importance of a nuanced approach that evolves with changing climatic conditions, emphasizing the significance of continuous adaptation efforts to prevent catastrophic events (such as the 2013 Picões fire in Norte, the 2022 Serra da Estrela fire in Centro, the 2022 Palmela fire in A.M.L., the 2023 Odemira fire in Alentejo, or the 2018 Monchique fire in Algarve) from becoming the new norm. Ultimately, by fostering collaboration across disciplines and implementing proactive measures, the Algarve region can aspire towards a resilient and sustainable future, safeguarding its natural environment and communities against the ravages of wildfires in a changing climate landscape.

The Portuguese coastal areas were shown to be extensively vulnerable to the impacts of climate change, arising from sea level rise and changes in the combination of tides, storm surges and waves. By the end of the 21st century, projections reveal up to 587 km^2 (RCP4.5) and 604 km^2 (RCP8.5) of vulnerable coastlines, for both the ocean-facing (9.3%) and inland waters' (90.7%) environments. Adaptation is overall recommended at national scale, despite the different results yielded by the cost-benefit analysis, depending on the region. Total inaction costs (without adaptation) are projected to surpass 12000 million € (RCP4.5) and 14000 million € (RCP8.5) until 2100, in contrast with approximately 5000 million € (for both scenarios) of expected adaptation costs. While indirect contributions from economic activities, tourism, ecosystem services and non-structural adaptation measures were not considered in the estimated economic costs, they provide a baseline to highlight the potential losses related to inaction (or maladaptation), as well as the benefits of adapting the Portuguese coastlines to future climate change.

Additionally, spatial planning has a particular role to play in increasing resilience to extreme climate events by identifying vulnerable areas that are particularly exposed to events such as floods, coastal storm surges, heat waves or forest fires, and by enabling strategic planning of land use and infrastructure development to prevent impacts and increase the resilience of communities and ecosystems. In this context, spatial planning instruments can be used to address the specificities of each territory by proposing measures, rules and interventions that are adapted to each reality, and are an effective means of promoting adaptation to climate change.

Aiming to contribute to the promotion and integration of adaptation to climate change in planning and land use, and to build better responses to the projected climate impacts, the RNA2100 carried out a review of the current panorama of adaptation to climate change in spatial planning plans and programmes, and developed methodologies and criteria for integrating climate risks into spatial planning.

The report assessed the relationship between climate change adaptation and land use planning was contextualised in terms of policies and instruments, and the experience of implementing adaptation in land use planning instruments, namely the Municipal Master Plans (PDM).

WP8. Communication and capacitation

This WP shapes the project communication plan with focus both on communication and capacitation. It included the launch of the project website (https://rna2100.apambiente.pt/), the climate portal (http://rna2100.portaldoclima.pt/) where the climate projections are readily available, dissemination of project news including on sessions and discussion of results with relevant regional actors and sectoral authorities and stakeholders, as well as the production of Guidelines. Hence, together with the regional coordination and development committees (CCDR), five regional seminars were held to present and discuss the results of RNA 2100 in the different regions of the country. During the sessions, issues of enormous relevance in the context of the regional results obtained were debated that generate the greatest concern.

In addition to define the stage and documents of the plans and strategies at which full adaptation should take place, this WP includes the creation of Guidelines to establish key steps and reference practices for setting up adaptation in Portugal. The document produced is organised as a guide designed to facilitate the integration into Municipal Master Plans of adaptation measures for the hazards covered by the RNA 2100, namely droughts, water scarcity, rural fires, coastal erosion and overtopping and flooding in coastal areas.

The guide produced (WP8D – Guidelines and good practices for integrating adaptation into municipal master plans) follow-up phase to the previous work of reviewing the current panorama of adaptation to climate change in territorial plans and programmes (WP7B).

ii. Achieved Results

Due to the ambition, exploratory, and state of play character of the project and to the diverse challenges throughout its implementation, the project has faced a significant delay. This led to the extension of the project to April 2024 and respective review of its timeline. The revised timeline was properly followed ensuring the deliverance of the planned projects outputs, as listed in the following table.

Some of the challenges faced in the project was the need for a close articulation with the sectoral authorities to support and validate the modelling exercises. Also, there were major difficulties regarding the access and collection of data. These challenges were conveniently overcome and were well noted to be further addressed within the scope of the national adaptation strategy (ENAAC) in order not to limit future exercises.

Activity	Expected products		Finished products
WP1. Stakeholder engagement	WP1A	Reports for each of the workshops held, expressing the stakeholder's views on the WP subjects listed above	WP1A - Stakeholder´s Engagement Additional contributions from DSB: WP1B 1 - Emergency preparedness analysis - Forest fires WP1B 2 - Risk analysis at a societal level
WP2. Climate projections and indexes	WP2A	Set of results of the climate projections and indices, from mean climate to extremes and climate indices (publicly available)	WP2A - Climate Projections, Extremes, and Indices - Mainland Portugal WP2A - Climate Projections, Extremes, and Indices - Mainland Portugal - Anexos
	WP2B	Scientific papers on the extended modelling evaluation exercise and on new findings among climate projections;	WP2B 1- Cardoso, R. M., Lima, D. C., & Soares, P. M. (2023). How persistent and hazardous will extreme temperature events become in a warming Portugal? Weather and Climate Extremes, 41, 100600. DOI: https://doi.org/10.1016/j.wace.2023.100600 WP2B 2 - Lima, D. C., Lemos, G., Bento, V. A., Nogueira, M., & Soares, P. M. (2023). A multi-variable constrained ensemble of regional climate projections under multi-scenarios for Portugal – Part I: An overview of impacts on means and extremes. Climate Services, 30, 100351. DOI: https://doi.org/10.1016/j.cliser.2023.100351 WP2B 3 - Lima, D. C., Bento, V. A., Lemos, G., Nogueira, M., & Soares, P. M. (2023). A multi-variable constrained ensemble of regional climate projections

Activity	Expected products		Finished products
			under multi-scenarios for Portugal – Part II: Sectoral climate indices. Climate Services, 30, 100377. DOI: https://doi.org/10.1016/j.cliser.2023.100377 WP2B 4 - Soares, P. M., Lemos, G., & Lima, D. C. (2022). Critical analysis of CMIPs past climate model projections in a regional context: The Iberian climate. International Journal of Climatology, 43(5), 2250-2270. DOI: https://doi.org/10.1002/joc.7973 WP2B 5 - Soares, P. M., & Lima, D. C. (2022). Water scarcity down to earth surface in a Mediterranean climate: The extreme future of soil moisture in Portugal. Journal of Hydrology, 615, Part B, 128731. DOI: https://doi.org/10.1016/j.jhydrol.2022.128731
	WP2C	Project report chapters: - "Reframing the challenges of climate change" - Climate projections for Portugal: scenarios and uncertainties - Climate extremes in a changing climate in the Euro-Atlantic region Sectoral Climate Indices and identification of future vulnerabilities	Integrated in WP2A.
	WP2D	Synthesis of climate scenarios for Portugal, for all sectors and at different geographic scales (NUTS 1, NUTS 2 and NUTS 3 when relevant).	Integrated in WP2A and portal http://rna2100.portaldoclima.pt/pt/
	WP2E	Preparation of high-resolution climate monitoring for the Azores (9 islands) and Madeira (2 islands), based on the dynamical downscaling down to 3 km resolution and a set of climate scenarios.	WP2E - Climate Projections, Extremes, and Indices – Portugal Autonomous Regions Scenarios available at: http://rna2100.portaldoclima.pt/pt/
WP3. Socioeconomic scenarios	WP3A	Project report chapter "Emissions scenarios, narratives and socioeconomic trajectories".	WP3A 1 - Emissions scenarios, narratives, and socioeconomic trajectories WP3A 2 - Pedersen, J. T. S., van Vuuren, D., Gupta, J., Santos, F. D., Edmonds, J., & Swart, R. (2022). IPCC emission scenarios: How did critiques affect their quality and relevance 1990–2022? Global Environmental Change, 75, 102538. DOI: https://doi.org/10.1016/j.gloenvcha.2022.102538 WP3A 3 - Pedersen, J. S. T., Dias, L. F., Kok, K., van Vuuren, D., Soares, P. M., Santos, F. D., & Azevedo, J. C. (2024). Increased policy ambition is needed to avoid the effects of climate change and reach carbon removal targets in Portugal. Regional Environmental Change, 24(2), 1-17. DOI: https://doi.org/10.1007/s10113-024-02217-4 WP3A 4 - Pedersen J, Gomes C, Gupta J, Vuuren D, Santos FD, O'Rourke P, Swart R (2023) Policy-relevance of emission scenarios: Policymakers require simpler communicated scenarios, including national detail and actions. Under review. DOI: http://dx.doi.org/10.2139/ssrn.4073175
	WP3B	Scenarios tables with the indicator figures.	A static scenario was assumed, with the data integrated into the WP3A 1
WP4. Sectoral impacts modelling	WP4A	Scientific papers for each modelling exercise	WP4A 1 - Soares, P. M., Careto, J. A., Russo, A., & Lima, D. C. (2023). The future of Iberian droughts: a deeper analysis based on multi-scenario and a multi-model ensemble approach. Natural Hazards, 117(2), 2001-2028. https://doi.org/10.1007/s11069-023-05938-7

Activity	Expected products		Finished products
			WP4A 2 - Bento, V. A., Russo, A., Vieira, I., & Gouveia, C. M. (2023). Identification of forest vulnerability to droughts in the Iberian Peninsula. Theoretical and Applied Climatology, 152(1), 559-579. DOI: https://doi.org/10.1007/s00704-023-04427-y (WP4 & WP5) WP4A 3 - Santos, L. C., Lima, M. M., Bento, V. A., Nunes, S. A., DaCamara, C. C., Russo, A., ... & Trigo, R. M. (2023). An Evaluation of the Atmospheric Instability Effect on Wildfire Danger Using ERA5 over the Iberian Peninsula. Fire, 6(3), 120. DOI: https://doi.org/10.3390/fire6030120 WP4A 4 - Bento, V. A., Lima, D. C., Santos, L. C., Lima, M. M., Russo, A., Nunes, S. A., ... & Soares, P. M. (2023). The future of extreme meteorological fire danger under climate change scenarios for Iberia. Weather and Climate Extremes, 42, 100623. DOI: https://doi.org/10.1016/j.wace.2023.100623 WP4A 5 - van der Laan, E., Nunes, J. P., Dias, L. F., Carvalho, S., & Dos Santos, F. M. (2023). Assessing the climate change adaptability of sustainable land management practices regarding water availability and quality: A case study in the Sorraia catchment, Portugal. Science of the Total Environment, 897, 165438. DOI: https://doi.org/10.1016/j.scitotenv.2023.165438 (WP4 & WP5) WP4A 6 - Lemos, G., Bosnic, I., Antunes, C., Vousdoukas, M., Mentaschi, L., Soares, P. M. M. (2024a). The future of the Portuguese (SW Europe) most vulnerable coastal areas under climate change – Part I: performance evaluation and shoreline evolution from a downscaled bias corrected wave climate ensemble. Ocean Engineering, 117661. DOI: https://doi.org/10.1016/j.oceaneng.2024.117661 WP4A 7 - Lemos, G., Bosnic, I., Antunes, C., Vousdoukas, M., Mentaschi, L., Espírito Santo, M., Ferreira, V., Soares, P. M. M. (2024b). The future of the Portuguese (SW Europe) most vulnerable coastal areas under climate change – Part II: future extreme coastal flooding from downscaled bias corrected wave climate projections. Under review at Ocean Engineering.
	WP4B	Report of each modelling exercise results including cartography with open data;	Integrated in WP4C
	WP4C	Project report chapters addressing the topics of this WP	WP4C 1 - Sectoral Impacts Modelling Executive Summaries WP4C 2 - Sectoral impacts modelling WP4.1/4 - Hydrological Balance & Agroforestry WP4C 3 - Sectoral Impacts Modelling - Droughts WP4C 4 - Sectoral Impacts Modelling - Forest fires WP4C 5 - Sectoral Impacts Modelling - Coastal regions: from sea level rise to coastal erosion
WP5. Measures and Costs of Adaptation	WP5A	Project report chapter addressing this topic	WP5A - Measures and Costs of Adaptation

Activity	Expected products		Finished products
	WP5B	Scientific paper	WP5B 1 - DaCamara, C.C., Bento, V.A. Nunes, S.A., Lemos, G., Soares, P.M.M., Trigo, R.M.: Impacts of fire prevention strategies in a changing climate: an assessment for Portugal. Under review in Environmental Research: Climate. Some elements integrated in the WP4A scientific papers
WP6. Macroeconomic impacts	WP6A	Project report chapter addressing this topic	WP6A - Macroeconomic impacts of different climate scenarios: the case of Portugal
WP7. Development of the adaptation storylines	WP7A	Project report chapter addressing this topic	WP7A 1 - Regional Adaptation Storylines WP7A 2 - Araújo, J. R., Ramos, A. M., Soares, P. M., Melo, R., Oliveira, S. C., & Trigo, R. M. (2022). Impact of extreme rainfall events on landslide activity in Portugal under climate change scenarios. Landslides, 19(10), 2279-2293. DOI: https://doi.org/10.1007/s10346-022-01895-7 WP7A 3 - Ramos, A. M., Russo, A., DaCamara, C. C., Nunes, S., Sousa, P., Soares, P. M. M., ... & Trigo, R. M. (2022). The compound event that triggered the destructive fires of October 2017 in Portugal. IScience, 26(3). DOI: https://doi.org/10.1016/j.isci.2023.106141 WP7A 4 - Fernández-Nóvoa, D., González-Cao, J., Figueira, J. R., Catita, C., García-Feal, O., Gómez-Gesteira, M., & Trigo, R. M. (2023). Numerical simulation of the deadliest flood event of Portugal: Unravelling the causes of the disaster. Science of the total environment, 896, 165092. DOI: https://doi.org/10.1016/j.scitotenv.2023.165092 WP7A 5 - Fernández-Nóvoa D., Ramos A. M., González-Cao J., García-Feal O., Catita C., Gómez-Gesteira M., Trigo M. R. (2022) How to mitigate flood events similar tothe 1979 catastrophic floods in lower Tagus. Natural Hazards and Earth System Sciences. DOI: https://doi.org/10.5194/nhess-2022-243.
	WP7B	Review of the guidance on adaptation to climate changes on spatial planning plans and programs, including sub national strategies and plans	WP7B - Review of guidelines on adaptation to climate change in spatial plans and programmes (EN) WP7B – Revisão das orientações sobre a adaptação às alterações climáticas em planos e programas de ordenamento do território (PT)
	WP7C	Factsheet for each adaptation storyline	WP7C 1 – Summary Card - Hydrological Balance & Agroforestry WP7C 2 – Summary Card - Forest fires WP7C 3 – Summary Card - Coastal Areas: from sea level rise to coastal erosion
WP8. Communication and capacitation	WP8A	Project website	https://rna2100.apambiente.pt http://rna2100.portaldoclima.pt/pt/
	WP8B	Press releases: on the conclusion of each sectoral modelling exercise, and macroeconomic analysis, and also on the publication of the project report and adaptation storylines	Communication release at: https://apambiente.pt/index.php/destaque2/rna-2100-avaliacao-de-vulnerabilidades-do-territorio-portugues-alteracoes-climaticas-no Publication of news on the project website: https://rna2100.apambiente.pt/#noticias
	WP8C	5 regional seminars	Five Regional Seminars to present the project results took place in: • 04.08.2024: Algarve, Faro • 09.04.2024: AML, Lisboa

Activity	Expected products		Finished products
			• 12.04.2024: Centro, Coimbra • 12.04.2024: Norte, Espinho • 22.04.2024: Alentejo, Évora In addition, a closing seminar took place in 02.05.2024 in Lisbon that was streamed at https://www.youtube.com/watch?v=y6cN0UazxWI (664 views registered in 25.05.2024)
	WP8D	Guidelines and best practices on how adaptation is being integrated into the various spatial planning plans and programs	WP8D - Guidelines and best practices on how adaptation is being integrated into the various spatial planning plans and programs (EN) WP8D - Orientações e boas práticas para a integração da adaptação às alterações climáticas nos Planos Diretores Municipais (PT)
	WP8E	Guidelines developed under the task "*2. Capacity building and establishment of guidelines*"	Integrated in WP8D

iii. Costs and financial impact

The project expenses, including the final payment request, are summarized in the table below.

Project activity	Partner Expenses							Project Budget	*Financial execution rate*
	APA	BdP	DGT	DSB	FCUL	IPMA	TOTAL		
WP1. Stakeholder engagement				5 482 €	14 278 €		19 760 €	**33 119 €**	***60%***
WP2. Climate projections and indices					225 635 €	109 365 €	335 001 €	**324 038 €**	***103%***
WP3. Socioeconomic scenarios					51 028 €		51 028 €	**46 935 €**	***109%***
WP4. Sectoral impacts modelling	12 300 €				457 748 €		470 048 €	**508 246 €**	***92%***
WP5. Adaptation needs					86 544 €		86 544 €	**85 144 €**	***102%***
WP6. Macroeconomic impacts							- €	**- €**	-
WP7. Development of the adaptation storylines					57 822 €		57 822 €	**70 974 €**	***81%***
WP8. Communication and capacitation	6 150 €		46 898 €				53 048 €	**60 075 €**	***88%***
WP9. Coordination and project management	7 995 €						7 995 €	**35 808 €**	***22%***
Indirect Costs (exclusive for FCUL)					133 958 €		133 958 €	**135 660 €**	***99%***
TOTAL	**26 445 €**	**- €**	**46 898 €**	**5 482 €**	**1 027 014 €**	**109 365 €**	**1 215 204 €**	**1 300 000 €**	***93%***
Project Budget	**53 348 €**	**- €**	**50 000 €**	**50 000 €**	**1 040 060 €**	**106 592 €**	**1 300 000 €**		
Financial execution rate	*50%*	-	*94%*	*11%*	*99%*	*103%*	*93%*		

iv. Contribution of the Project to achieving the general objectives of the EEA Grants and the 'Environment Program'

The project only contributes directly to the indicator "Number of Portuguese territories/regions included in the updated assessment" through the development of the regional adaptation narratives, specific for each of the five NUTS 2 regions. The narratives were also presented in regional seminars. The information produced in this project will stand as a reference for adaptation strategies in Portugal, so it will contribute indirectly in the future for the "Number of people benefitting from the development of adaptation strategies".

Expected outcome	Indicator	Programme target[2]	Project contribution to date	Related activities
Outcome 3. Increase resilience and responsiveness to climate change in specific areas	Number of people benefitting from the development of adaptation strategies	**2 600 000**	NA	A02 e A05
	Number of people benefitting from the implementation of mitigation low-carbon measures	**13 000**	NA	
	Estimated annual CO2 emissions reductions (in tons)	**43 000**	NA	
	Number of jobs created (disaggregated by gender, age)	**10**	NA	
	Percentage of habitat areas, that were damaged by forest fires, recovered in the Rio Ceira River Basin	**30,0%**	NA	
	Number of acres with reduced susceptibility to desertification	**250**	NA	
Output 3.2 Vulnerability Assessment to Climate Change updated for territorial focus	Number of Portuguese territories/regions included in the updated assessment	2	5	A01, A02, A03, A04 e A05

The project also contributes to bilateral relations, with the presence of the Norwegian Directorate for Civil Protection and Emergency (DSB). This project partner shared his experience dealing with risks, including through the English translation of the following reports_ "Emergency preparedness analysis- Forest fires", and "Risk analysis at a societal level". On the other hand the project products were prepared in English and shared with DSB with the purpose of knowledge sharing.

[2] PS: The outcome targets relate to the Environment Programme as a whole and not the PDP#2 Project itself.

O Promotor do Projeto

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O Operador do Programa – Secretaria Geral do Ambiente

Nome	Marco Rebelo
Data e Assinatura	
Posição	Secretário-Geral

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- WP2A - Climate Projections, Extremes, and Indices - Mainland Portugal - Anexos
- WP2B 1- Cardoso, R. M., Lima, D. C., & Soares, P. M. (2023). How persistent and hazardous will extreme temperature events become in a warming Portugal? Weather and Climate Extremes, 41, 100600. DOI: https://doi.org/10.1016/j.wace.2023.100600
- WP2B 2 - Lima, D. C., Lemos, G., Bento, V. A., Nogueira, M., & Soares, P. M. (2023). A multi-variable constrained ensemble of regional climate projections under multi-scenarios for Portugal – Part I: An overview of impacts on means and extremes. Climate Services, 30, 100351. DOI: https://doi.org/10.1016/j.cliser.2023.100351
- WP2B 3 - Lima, D. C., Bento, V. A., Lemos, G., Nogueira, M., & Soares, P. M. (2023). A multi-variable constrained ensemble of regional climate projections under multi-scenarios for Portugal – Part II: Sectoral climate indices. Climate Services, 30, 100377. DOI: https://doi.org/10.1016/j.cliser.2023.100377
- WP2B 4 - Soares, P. M., Lemos, G., & Lima, D. C. (2022). Critical analysis of CMIPs past climate model projections in a regional context: The Iberian climate. International Journal of Climatology, 43(5), 2250-2270. DOI: https://doi.org/10.1002/joc.7973
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- WP2E - Climate Projections, Extremes, and Indices – Portugal Autonomous Regions

WP3.

- WP3A 1 - Emissions scenarios, narratives, and socioeconomic trajectories
- WP3A 2 - Pedersen, J. T. S., van Vuuren, D., Gupta, J., Santos, F. D., Edmonds, J., & Swart, R. (2022). IPCC emission scenarios: How did critiques affect their quality and relevance 1990–2022? Global Environmental Change, 75, 102538. DOI: https://doi.org/10.1016/j.gloenvcha.2022.102538
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- WP3A 4 - Pedersen J, Gomes C, Gupta J, Vuuren D, Santos FD, O'Rourke P, Swart R (2023) Policy-relevance of emission scenarios: Policymakers require simpler communicated scenarios, including national detail and actions. Under review. DOI: http://dx.doi.org/10.2139/ssrn.4073175.

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- WP4A 1 - Soares, P. M., Careto, J. A., Russo, A., & Lima, D. C. (2023). The future of Iberian droughts: a deeper analysis based on multi-scenario and a multi-model ensemble approach. Natural Hazards, 117(2), 2001-2028. https://doi.org/10.1007/s11069-023-05938-7
- WP4A 2 - Bento, V. A., Russo, A., Vieira, I., & Gouveia, C. M. (2023). Identification of forest vulnerability to droughts in the Iberian Peninsula. Theoretical and Applied Climatology, 152(1), 559-579. DOI: https://doi.org/10.1007/s00704-023-04427-y (WP4 & WP5)
- WP4A 3 - Santos, L. C., Lima, M. M., Bento, V. A., Nunes, S. A., DaCamara, C. C., Russo, A., ... & Trigo, R. M. (2023). An Evaluation of the Atmospheric Instability Effect on Wildfire Danger Using ERA5 over the Iberian Peninsula. Fire, 6(3), 120. DOI: https://doi.org/10.3390/fire6030120
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- WP4A 6 - Lemos, G., Bosnic, I., Antunes, C., Vousdoukas, M., Mentaschi, L., Soares, P. M. M. (2024a). The future of the Portuguese (SW Europe) most vulnerable coastal areas under climate change – Part I: performance evaluation and shoreline evolution from a downscaled bias corrected wave climate ensemble. Ocean Engineering, 117661. DOI: https://doi.org/10.1016/j.oceaneng.2024.117661.
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- WP5A - Measures and Costs of Adaptation
- WP5B 1 - DaCamara, C.C., Bento, V.A. Nunes, S.A., Lemos, G., Soares, P.M.M., Trigo, R.M.: Impacts of fire prevention strategies in a changing climate: an assessment for Portugal. Under review in Environmental Research: Climate.

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- WP7A 1 - Development of the Adaptation Storylines
- WP7A 2 - Araújo, J. R., Ramos, A. M., Soares, P. M., Melo, R., Oliveira, S. C., & Trigo, R. M. (2022). Impact of extreme rainfall events on landslide activity in Portugal under climate change scenarios. Landslides, 19(10), 2279-2293. DOI: https://doi.org/10.1007/s10346-022-01895-7
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