



SOCLIMPACT



**Downscaling climate impacts and decarbonisation pathways
in EU Islands, and enhancing socioeconomic and non-market
evaluation of Climate Change for Europe, for 2050 and beyond**



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Work Package 4:

Modelling Climate impacts in 11 EU islands' case studies for 2030- 2100

Deliverable 4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public

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1. Introduction

In 2016, an analysis of the elements that characterize the link between insularity and economic development still remarked that islands face significant economic disadvantages with respect to the mainland, which hinder their progress towards the goals of sustainable development set by the EU (Deidda, 2016). Following the definitions of EURISLES 2002, this study underlined that, far from being a mere geographical condition, insularity is a permanent phenomenon of economic and social peripheralization, whose consequences cannot be completely eliminated, but indeed mitigated through adequate policy interventions. On the other hand, while denouncing the current fragmentation and inadequacy of the economic literature on this theme, the survey also suggested that the traditional view of insularity as a mere disadvantage can indeed be overthrown in consideration of the abundance of natural resources which often characterizes islands, and already constitutes the basis of their attractiveness as touristic destinations. The availability of renewable energy resources and favourable environmental characteristics also represent additional potential assets, which would disclose valuable economic opportunities, in addition or in alternative to the often prevalent, yet seasonal, tourism industry. In the case of small islands, the social homogeneity and cohesion typical of insular communities, as well as their openness to explore new development trajectories, could also prove effective in inducing greater flexibility and decision-making efficiency, thus enhancing local coherence between natural resources protection, human capital endowment and the institutional context, and favouring the implementation of environmental-oriented policies that reduce both the exposure to external economic fluctuations and the vulnerability to climatic disasters and climate change (Gloersen et al., 2012; Deidda, 2016). From this perspective, traditional reactive strategies, usually aiming to design adequate compensations for islands' structural disadvantages (i.e. subsidization of transport costs), need to be progressively accompanied by novel proactive and sustainable initiatives, including economic diversification, technological and management innovation in traditional activities, and the development of new remunerative sectors, through mid- and long-term interventions that also prioritize the protection of the natural environment (ADE 2012, Deidda, 2016). In particular, the necessity is now undeferrable to permanently set climate-change-adaptation into the broader socioeconomic context and general policy framework, and to regard climate change as a permanent dimension of any sustainable policy, especially for highly vulnerable environments and less developed societies (Tol, 2018; Markkanen and Anger-Kraavi, 2019). The availability of analytic instruments that account for the specificities of insularity and identify the peculiar challenges and opportunities faced by islands is an ineludible step towards this goal, which would help quantify the cost-benefit ratios and the payback periods of the designed policies.

The main objective of the SOCLIMPACT project is to assess the potential impacts of climate change on specific blue economy sectors of European islands and archipelagos, and to estimate the projected consequences for the local economies, through the analysis of inter-sectorial relations. To this purpose, two different and complementary modeling pathways have been designed:

- in Work Package 4 (WP4), for each selected island and for each economic sector, climate change-induced risks are assessed through the evaluation of individual risk components (i.e. hazard, exposure and vulnerability), in order to allow the inter-comparison of islands as to the present and future climatic shocks they are liable to face, as to the dimension and importance of the exposed natural and socio-economic subsystems, and as to their preparedness to counteract adverse



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conditions, by implementing effective protection and adaptation measures, as well as by translating technological acquisitions and innovative business models into operational innovation for local industries;

- in WP5 and WP6, the economic value of climate-change-induced impacts on specific sectors of the blue economy is estimated for selected islands, together with its overall relevance for the island's economy, accounting for variations in both the supply and the demand parameters.

Despite the two approaches being largely independent, the first is anyway propaedeutic to the second, as it provides important points for reflection, and helps to correctly shape the problem when estimating the impacts of climate change on purely economic variables, such as the gross added value and the rate of employment.

Among the sectors of relevance to insular economies that are exposed to climate change, SOCLIMPACT selected Maritime Transport, Tourism, Energy and Aquaculture for its sector-specific analysis of climate-change-related impacts in EU islands, with the aim of helping to fill in some of the knowledge gaps that still hinder the design of custom-tailored adaptation options and the emergence of fast growth opportunities. To this end, this document presents the results of the risk assessment exercise conducted for the islands that participated in the project, as a preliminary step towards the subsequent evaluation of the economic implications of climate change for their economies.

1.1 Overview of the SOCLIMPACT blue economy sectors in European Islands

Maritime Transport

Maritime transport is defined as the carriage of goods and passengers by sea-going vessels, on voyages undertaken wholly or partly at sea. It is often considered as the backbone of the world economy, with 80% of the global trade volume passing through ports (Asariotis & Benamara, 2012). For islands, the transport of goods and passengers by ship is even more essential. At the same time, Maritime Transport contributes to climate change through its carbon emissions which are found to be near 3% of the global CO₂ equivalent emissions (Smith et al. 2015). Compared to land and air transport, it is the (economically and ecologically) most effective way of distributing goods globally. A changing climate will challenge Maritime Transport to adapt to future risks and lower its emissions.

The Maritime Transport is one of the key EU Blue Economy sectors, since Europe is amongst the leading maritime centers in the world with 329 key seaports along its coastline, and controlling around one-third of the world's merchant fleet¹. Ports are vital gateways, linking European transport corridors to the rest of the world. As 75% of European external trade transits through EU ports, the shipping sector plays a major role in connecting the European market with its trade partners. According to the European Union's Statistical Office (EUROSTAT) and other online resources, for Mediterranean countries including Cyprus, Greece and Malta there is a significant direct contribution (3-10%) of the Maritime Transport sector to the total Gross Value Added (GVA). The EU Maritime sector has a multiplier effect of 2.6. Hence, crudely speaking, for every Euro 1 spent in this industry there is the creation of another Euro 2.6. In addition, there is a very

¹ https://ec.europa.eu/transport/modes/maritime/maritime-transport_en



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strong linkage with other vital economic sectors such as services, tourism, energy, supply of goods, etc. (source: Oxford Economics). For every €1 million the EU shipping industry contributes to Gross Domestic Product (GDP) itself, it creates a further €1.6 million elsewhere in the European economy. According to EUROSTAT data, the sector directly employs nearly 250,000 persons (or 0.1% of the EU-27 workforce). About 20% of the total employment in the EU shipping industry are shore-based, while the rest 80% is based at sea. Besides the transport of goods within the EU territories and overseas, the Maritime sector is also important for the transportation of passengers and the connection between different countries or between remote islands and the mainland. There is therefore an important social dimension of the maritime services. Indicatively, according to EUROSTAT, only in the SOCLIMPACT case study islands each year are moving more than 40 million passengers, including tourists and permanent residents.

The whole range of potential impacts of climate change on ports operations and throughput is still under study and it remains a high degree of uncertainty about it². Various climate change stressors can affect both harbour infrastructure and ships on-route. For example, ports are vulnerable nodes of Maritime Transport as they are strongly affected by rising sea-levels, which in turn affect port facilities and increase the risk of flooding. Sea-level rise has accelerated in the last century and will rise by 0.43 to 0.84 m until 2100, depending on the emission scenario (Pörtner et al., 2019). Due to ocean dynamics and the Earth's gravity field, there will also be regional differences in sea-level rise in the order of 0.1 m (Asariotis & Benamara, 2012). The causes of sea-level rise are the thermal expansion of water and the melting of glaciers due to the increase in global mean temperature (Vermeer & Rahmstorf, 2009). Maritime transport can also be affected by climate change through the increase in the intensity of extreme weather events including tropical-like cyclones. According to climate projections, tropical cyclones are not expected to change significantly in frequency but in intensity due to rising sea-surface temperatures (Pörtner et al., 2019). The resulting extreme winds and waves can harm ships, but also cause damage and flooding of ports, especially in combination with sea-level rise (Hanson & Nicholls, 2012). Besides the risks for Maritime Transport due to climate change, a reduction of sea-ice extent in the Arctic offers the opportunity to open up a new shipping route, which, for example, shortens the sea route between Europe and East Asia by about 50% (Hong, 2011).

Climate hazards such as sea-level rise or extreme weather events of increased intensity (e.g. windstorms, floods) can impose direct biophysical impacts. These can include floods on ports, damage to storage capacity and ports' infrastructure or equipment, or increase the number of operational stops. Consequently, socio-economic impacts will likely be introduced. Such impacts can include the increased users' risk perception leading to lower rates of moorings and turnover, increased costs of maintenance in nautical installations and equipment, increased costs for new investment and insurance, carbon tax effects on fossil fuel prices, less turnover from Maritime Transport activities and disruption costs. Most of these impacts and their economic value will be discussed in SOCLIMPACT WPs 5 and 6.

Although most ports already adapted to climate change conditions, more investment from the public and private sectors is needed (Monios & Wilmsmeier, 2020). A case study from

² <https://soclimpact.net/blue-economy-sector/maritime-transport/>



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Monioudi et al. (2018) for Jamaica and Saint Lucia highlights the potential vulnerability of ports to a global temperature increase of 1.5 °C until 2030 and projects severe flooding by extreme events, which lead to operational disruptions and costs. Estimating the costs and effectiveness of adaptation measures depends on the location of the port and is often difficult to assess. In most cases, however, the most effective adaptation measure would be to improve the flood resistance of transport infrastructure and increase the height of the ports (Yang et al. 2018).

Tourism

Coastal and maritime tourism is the largest maritime activity in Europe and employs almost 3.2 million people, generating a total of €183 billion in gross value added. It represents over one third of the maritime economy. In islands, tourism is usually the main economic activity, not only in Europe but also around the world (Baldacchino, 2016). According to data from the World Bank, 9 of the 10 countries most dependent on tourism in terms of tourism income as a percentage of GDP are islands. From an economical point of view, tourism is a major economic sector in Europe, and EU Islands rely heavily on the foreign exchange from tourism to expand and develop their economies. According to the 5th assessment report of the IPCC3, climate change is expected to “reshape” the tourism industry and will impact the geographical and seasonal distribution of tourists in all Europe⁴ (Scott et al., 2008).

At the 1991 UNWTO Ottawa Conference on Travel and Tourism Statistics, tourism was defined as the activities of persons traveling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes. This demand side definition basically relies on the fact that tourism is what tourists do. The REGULATION (EU) No 692/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 July 2011 concerning European statistics on tourism, and repealing the Council Directive 95/57/EC also adopts a definition inspired in the Ottawa's one: “the activity of visitors taking a trip to a main destination outside their usual environment, for less than a year, for any main purpose, including business, leisure or other personal purpose, other than to be employed by a resident entity in the place visited.”

Finally, for SOCLIMPACT purposes, it is assumed that the whole tourism activity of the islands is assigned to the coastal and maritime tourism sector (hereafter referred as “tourism”). It is fully justified because the vast majority of the tourist activities in islands are based on the infrastructures and the natural attractions that are distributed throughout the coastal and littoral areas, and all tourists visiting inland areas enjoy their coastal environments during the visit (going to beaches, consuming coastal-based food and/or undertaking outdoor activities). It is relatively easy to demonstrate that in almost all cases, the iconography and tourism image of the islands are related to the sea and the coastal resources (Bramwell, 2004; Duke, 2016), and that the main tourist motivations pull factors to visit islands rely on sea-based assets (Cameron & Gatewood, 2008).

³ http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap29_FINAL.pdf

⁴ <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52013SC0133>



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Another reason is the simplification that this methodological decision implies for the economic valuation and modelling of climate shocks. A different assumption would imply first to estimate which part of the tourism activity would be affected by changes in environmental services; and then assess the effects of those changes on the total tourism industry. Under SOCLIMPACT, “Tourism as a demand-side phenomenon refers to the activities of visitors and their role in the acquisition of goods and services, usually related to coastal resources. It can also be viewed from the supply side, and Tourism will then be understood as the set of productive activities catered mainly to visitors during the stay.”

Changes in the multiplicity of variables that constitute the climate of the islands are the consequence of global warming, in its turn powered by human-induced emissions of GHG. These changes happen in each island depending of the complex interactions between air masses speed, temperature, and humidity; circulation, temperature and acidity of the oceans; and the location, topography and bathymetry, vegetal covered and types of soil characterizing the islands. In addition, tourism long-term sustainability depends on the preservation and enhancement of its environment. How and to what extent blue economy sectors are affected by changes in climatic parameters may be presented as alterations on the services that ecosystems provide to those sectors (Daily, 1997; Haynes-Young and Potschin, 2013)⁵.

All biophysical changes are directly and indirectly affecting tourism, especially in destinations where nature is a key attractor for tourists. Alteration of natural resources through changes in average conditions (water temperature and quality, biodiversity, etc.) or occurrence of extreme events (forest fires, droughts) may affect tourist practices in rural and coastal environment such as walking, riding, hiking, swimming. These impacts can damage ecosystems, biodiversity and landscapes, as well as infrastructure and human well-being. They can also increase difficulties in risk management of these areas in order to provide a safe environment and affect more broadly the tourism businesses in long-term when alteration is sustained (marketing, investments in those locations).

Energy

There are more than 2,200 inhabited islands in the EU. Lately, they have come into the focus of the EU, which addresses energy questions as part of the 'Clean energy for all Europeans' package. The Clean energy for EU islands initiative provides a long-term framework to help islands generate their own sustainable, low-cost energy. This is particularly interesting, because many islands have vast amounts of renewable energy sources but rely on fossil fuel imports yet. These are relevant challenges regarding the energy transition in the EU, whose aim of net zero greenhouse gas emissions in 2050 should determine the future energy plans of the islands. Islands could provide showcases for successful 100% renewable energy supply.

⁵ Daily (1997) defines ecosystem services as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. Haynes-Young and Potschin (2013) define ecosystems goods and services as the contributions that ecosystems make to human well-being, and arise from the interaction of biotic and abiotic processes. There are many other definitions but all are quite close each other.



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However, how can the islands' energy supply be robust against climate change? And how will energy demand change in a world with a changing climate? In brief, which are the risks, that climate change poses to the respective energy systems on European islands?

While the research project SOCLIMPACT focuses on the risk from climate change in the blue economy sectors, i.e. maritime transport, tourism, aquaculture and marine energy, the expert team on the energy sector decided early on to address the energy sector from a different perspective.

The National Hydropower Association (NHA) defines marine energy as electricity generation from marine kinetic energy, such as waves, tidal and ocean currents. Pisacane et al. (2018) add other marine energy sources like ocean thermal energy conversion (exploiting temperature differences between deep and surface ocean waters) and salinity gradient energy (harnessing the energy potential of differences in salt concentration in ocean and river waters). All these technologies are still in a development phase, and even if they reach the commercial phase in the future, it is not likely that they will generate a large share of the power. Therefore, the analysis in SOCLIMPACT focuses on the main renewable energy sources (RES), wind energy and solar photovoltaic (PV) energy, which are presently, and very likely in future, the backbone of the deployment of renewable energies, due to their technological maturity and low cost.

Nevertheless, we take into account not only onshore but also offshore wind energy, as a specific marine energy source which has distinct advantages like much higher productivity and less time variability than onshore wind energy, and does not require land space which is limited and costly in the islands. There are relevant obstacles for its deployment, like the deep bathymetry surrounding most of the islands, and the lower wind speeds over the Mediterranean in comparison to areas like the North Sea where offshore wind energy is being deployed rapidly. But recent technological advances in floating supports for the wind towers and cost reductions are opening this possibility, so that presently there are two commercial-scale projects respectively for Gran Canaria and Sicily.

Additionally, we consider also offshore PV energy. Despite some disadvantages that have to be overcome (corrosion problems due to salty water or the impact of waves), this application is receiving growing interest, as it offers an option for renewable energy development in countries and islands with limited space for the installation of solar panels, and can show increased performance due to the cooling effect of water and wind on PV cells (Golroodbary and Sark, 2020). The installation of offshore floating PV panels has been already tested for one of the islands of SOCLIMPACT (Malta; Grech et al., 2016), and one offshore PV farm is already operating near the coast of the Netherlands (Buitendijk, 2019), an area characterised by high waves. Offshore floating photovoltaics is being considered in future strategies and plans, like the recently published Roadmap for the Offshore Renewable Energy Strategy of the European Commission or the report of Monitor Deloitte and Endesa (2020) proposing a plan for the accelerated decarbonization of Canary and Balearic Islands.

Most RES depend on the climate, and therefore climate change can have an impact of the resource amount. Additionally, wind and solar PV energy are not dispatchable, and its variability represents a challenge for its integration in the power system. This is a challenge that can be addressed through storage or backup plants (which can be itself renewable



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energy plants), through demand management, but also taking advantage of complementarity of PV and wind energy and its very different variability characteristics. This approach is gaining attention from stakeholders in the islands, as demonstrated by the report by Monitor Deloitte and Endesa (2020), in which one of the key recommendations for achieving an accelerated zero carbon target in Balearic and Canary Islands by 2040 is the combination of solar PV and wind energy, with clearly higher shares of PV than of wind energy. Such a mix would reduce strongly the need for storage, due to the stability of solar PV production.

There are also challenges for the demand and transmission components of the energy systems of the islands due to climate change: changes in temperature leading to changing energy demand, changes in precipitation and evaporation creating risks for desalination, and extreme weather events (particularly extreme winds) challenging the distribution infrastructure. After intensive desk research, the latter was ruled out, due to the low number of past incidents found in the literature or news media and the future projections showing a reduction in wind extremes for most islands. As a consequence, we analyse the effects of climate change on the demand and supply sides of the energy system. From the demand side, we consider temperature and precipitation changes that can lead to increased energy consumption for cooling and desalination. From the supply side, we consider surface solar radiation and temperature changes affecting PV productivity and variability, as well as wind changes affecting wind energy productivity and variability.

Aquaculture

In recent decades, the amount of farmed fish consumed by the world's human population has been constantly growing, from 14 million tonnes per year in the 80s and early 90s to over 82 million tonnes in 2018 (FAO 2020). The contribution of aquaculture to fish production has grown from 25.7 percent in 2000 to 46 percent in 2018. However, in Europe, the share of aquaculture in fish production is only 17% and the EU is the largest importing market (FAO 2020). When looking at finfish production in 2018, only 13.44% was produced in marine and coastal environments, while inland aquaculture, mostly freshwater, accounted for the highest contribution to farmed fish production (FAO 2020). Of the total marine and coastal aquaculture production, 56.3% are molluscs, 23.9% finfish and 18.7% crustaceans (FAO 2020).

The growth in the aquaculture sector has been possible due to technological progress that allowed rapid species domestication, and the aquaculture industry now promises to abandon the current semi-intensive exploitation and move towards an increased control of production (Duarte et al. 2007; Asche et al. 2008). Sea-food demand is projected to outpace supply by 40 million metric tons by 2030 (FAO 2006), thus prompting a new industrial revolution in the sector to seek new means of production, the most promising options for marine aquaculture being land-based recirculating aquaculture systems or offshore farming in exposed oceanic locations (Buck and Langan, 2017).

In their dedicated technical paper "A global assessment of offshore mariculture potential from a spatial perspective" (McDaid Kapetsky et al., 2013), the Food and Agriculture Organization of the United Nations (FAO) highlighted that there is a growing need to transfer coastal aquaculture production systems further offshore. From the global perspective, this is due to the expected increase in human population and to the increasing problem of overfishing of wild-caught seafood, as well as to the competition for access to



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land, clean water and sea space that can limit the availability of fish and fishery products for human consumption from inshore farms. As a matter of fact, due to the divergent spatial, economic and political interests among the many coastal stakeholders competing for marine space (e.g. to be granted access to fishing grounds, shipping routes, marine environment protection, touristic development of coastal areas, seabed extraction rights, marine renewables deployment opportunities), further development of aquaculture can only be achieved after accurate combined mapping of the biological production potential and of the constraints deriving from existing ocean uses and limitations (Gentry et al., 2017; Oyinlola et al., 2018), highlighting the crucial role that economic planning and governance play in shaping growth trajectories, by harmonizing economic, environmental and social objectives.

In this context, offshore aquaculture represents a novel perspective as to governance issues, by shifting the competition for marine space from the historically well-rooted social networks with traditional use patterns, to a limited number of large, often international operating companies, with limited social networks and engagement with each other. This is also expected to imply a shift to a more innovative mentality, since the offshore industry is closely linked to sustained technological developments (Krause and Mikkelsen, 2017). Offshore aquaculture may also reduce the environmental impacts of nutrient release in correspondence of farms, and allow expansion of the operations to enable large-scale growth also in the connected sectors, provided suitable farming practices are adopted (Troell et al., 2009; Gentry et al., 2017).

For these reasons, the growing interest to move large scale aquaculture operations further out into the sea has transformed the sector into an innovative research field, which requires advanced solutions spanning a wide range of competences, both technical, social and managerial (Buck and Langan, 2017).

The definition of “offshore” aquaculture, was discussed in Lovatelli, Aguilar-Manjarrez and Soto, 2010, and agreed to depend on a variety of factors, both topographical (e.g. distance from shore and depth) and operational (e.g. accessibility of farms) (Table 1.1).

Table 1.1 – From Lovatelli et al., 2010

General criteria for coastal, off-the-coast and offshore aquaculture based on some environment and hydrographic characteristics

	Coastal	Off-the-coast	Offshore
Location/ hydrography	<ul style="list-style-type: none"> • < 500 m from the coast • ≤10 m depth at low tide • Within sight • Usually sheltered 	<ul style="list-style-type: none"> • 500 m–3 km from the coast • 10–50 m depth at low tide • Often within sight • Somewhat sheltered 	<ul style="list-style-type: none"> • > 2 km, generally within continental shelf zones, possibly open ocean • > 50 m depth
Environment	<ul style="list-style-type: none"> • Hs usually < 1 m • Short period winds • Localized coastal currents, possibly strong tidal streams 	<ul style="list-style-type: none"> • Hs < 3–4 m • Localized coastal currents, some tidal streams 	<ul style="list-style-type: none"> • Hs 5 m or more, regularly 2–3 m • Oceanic swells • Variable wind periods • Possibly less localized current effect
Access	<ul style="list-style-type: none"> • 100% accessible • Landing possible at all times 	<ul style="list-style-type: none"> • > 90% accessible on at least once daily basis • Landing usually possible 	<ul style="list-style-type: none"> • Usually > 80% accessible • Landing may be possible, periodic, e.g. every 3–10 days
Operation	<ul style="list-style-type: none"> • Regular, manual involvement, feeding, monitoring, and more 	<ul style="list-style-type: none"> • Some automated operations, e.g. feeding, monitoring, and more 	<ul style="list-style-type: none"> • Remote operations, automated feeding, distance monitoring, system function



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A simplified definition was proposed by Drumm (2010), who identified it as being exposed to wind and wave action, and requiring equipment and servicing vessels to survive and operate in severe sea conditions, while the distance from a shore base or a harbour is not always a distinctive factor. However, such classification criteria can only give a preliminary idea of the farming conditions, and specific individual situations should always be considered as to both prevailing local environmental conditions at the sites and administrative constraints. As regards this last aspect, offshore locations might in fact fall within internal waters in some countries with extensive archipelagos and in international waters for other countries.

The possibility of moving farms farther offshore clearly relies on: a) the recent design of more robust culture technologies based on substantial advances in numerical and physical modelling of cages and longlines and of their optimal arrangement (Goseberg et al., in Buck and Langan, 2017, Drimer, 2019), b) innovative strategies with respect to those adopted for inshore farming, such as Integrated Multi-Trophic Aquaculture⁶ - IMTA – systems (Buck et al., 2018), and c) the development of novel culture systems that can be submerged to avoid the winds and waves characteristic of offshore areas (Jeffs, in Lovatelli et al., 2010). A number of such technologies now exist at the commercial stage of development, consisting of either rigid or tensile structures, that remain at the surface in normal conditions but can be submerged upon early warning, before a storm reaches the farm site (Sturrock et al., 2008). Submersible systems offer the additional advantages of avoiding harmful oxygen-depleting algal blooms and of enabling the re-positioning of cages in correspondence of optimal currents and/or temperatures to improve fish farming conditions, optimize growth and avoid thermal stress, at the same time reducing the exposure to parasites and anthropogenic pollution (Buck and Langan, 2017). In addition, intelligent monitoring and control technologies for the optimization of operations at sea are constantly being developed, to increase yield and achieve high efficiency and safety of farming (Wei et al., 2020).

An additional opportunity for the development of offshore aquaculture is offered by the parallel development of marine renewables (e.g. offshore wind farms) (Abhinav et al., 2020, Jansen et al., 2016), which allows the co-location of plants, helping afford the increased costs of moving into more severe environments and at larger distances from shore, and reduce the combined footprint of offshore economic activities (Buck and Krause, 2012). In addition, innovative farming practices such as IMTA are expected to limit the negative environmental impacts from offshore aquaculture systems (i.e., nutrient release), which can be critical for aggregated farm units, by making use of waste products and transforming these into valuable co-products. It must be underlined, however, that further research is needed to improve both the impact assessment and the management of multi-trophic aquaculture, as to feeding regime, waste output and uptake by associated other species. (Buck et al., 2018). Aquaculture activities would also benefit from the limited shipping traffic in areas where energy farms are located and only operation and maintenance vessels

⁶“Integrated multi-trophic aquaculture (IMTA) is the co-cultivation of fed species (such as finfish or shrimp) together with extractive species, such as suspension-feeding (e.g., mussels and oysters) and deposit-feeding (e.g., sea-cucumbers and sea-urchins) invertebrates and macroalgae (e.g., kelps), which may feed on the organic and inorganic effluents generated by the fed species. By establishing such integrated cultivation systems, the sustainability of aquaculture may be increased, or adding value through accounting for the ecosystem services that extractive species provide. “[From: Buck et al., 2018]



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of the farms companies are allowed, which could also operate the aquaculture farms (Michler-Cieluch and Krause, 2008, Michler-Cieluch et al., 2009a,b).

Local communities would naturally act as nodes for farm operation and maintenance, thus benefiting from the potential creation of additional jobs, income protection through diversification, and access to new markets, with a consequent increase in the social acceptance of offshore development (Buck et al., 2018). Nevertheless, local and regional planning is crucial to correctly assess how such developments are liable to affect the inter-linked social and natural systems, and thus to avoid negative impacts (Krause et al., 2015). In view of the increasing complexity inherent in the development and management of different but spatially overlapping maritime activities, such assessment should account for the several potential secondary socio-economic effects that characterize the sector, well beyond the neoclassical economic input-output analysis (Buck et al., 2018).

Another alternative to marina aquaculture is the use of land-based Recirculating Aquaculture Systems (RAS). In RAS environmental parameters are fully controlled and monitored thus always providing an optimised environment for the species cultured. Another advantage of RAS is their resilience to climate change since it is a land-based system, not dependent on external factors and all environmental parameters (e.g. temperature) are controlled. It also has a reduced impact on the surrounding environment since over 95% of the water is reused and effluents can be treated before disposal. The disadvantage of RAS is the high energy demand, but this can be mitigated by using an energy efficient design. Sources of renewable energy such as solar or wind energy should be considered to provide the needed energy. However, in the framework of Soclimpact, looking only at mariculture, RAS can be considered as an adaptation strategy.

In summary, the feasibility of the aquaculture enterprise in both inshore and offshore farms depends on the development of suitable technological solutions, on biological feasibility, and on environmental and economic sustainability. Environmental conditions in specific sites will not be appropriate for all candidate species, and the early assessment of the ranges of key variables (e.g. water temperature, salinity, nutrients, currents) is therefore essential for a sound enterprise planning. Climate change adaptation represents an additional constraint on the future status and development of this sector, which will possibly imply additional costs for existing enterprises and determine the feasibility or the necessity of moving the activities in more suitable environmental conditions. A thorough assessment should obviously rely on detailed geographic information systems, detailed monitoring and mapping of the marine environment and high-resolution circulation models covering a wide range of scales and expanding from the open sea to the coast, as well as on spatial planning tools to support the ecosystem approach to aquaculture. That is to say, a complete and costly set of management tools should be developed and tuned to specific situations and needs, in order to support aquaculture planning at local levels (Macias et al., 2019).

As a first addition to the management toolkit, the SOCLIMPACT Project aims to provide an overall open-sea assessment of the expected climate change impact on aquaculture for a heterogeneous selection of European islands, setting a framework for further and more detailed analyses and easing the early elicitation of the trade-offs this sector is liable to deal with. This report therefore reviews the current development and state of the aquaculture sector in individual islands for which the relevant data were provided, and examines some



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of the environmental stresses farms are subject to under present climate and future scenarios. It provides a first evaluation of their degree of exposure and vulnerability, and a preliminary assessment of the local impacts, either negative or positive, of climate change on this industry.

The Mediterranean Basin

Following the global trend, in the Mediterranean countries, aquaculture has grown to become a crucial contributor to regional fish production, exploiting a wide variety of environments and farming technologies. Aquaculture production has in fact increased from 1 million tonnes in 1996 to around 2.65 million tonnes in 2016, and its economic value has correspondingly tripled, with an estimated figure of over 400 000 units for the generated direct and indirect jobs. For marine species, this trend is mainly due to an ever-increasing production of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*), from the 13 000 tonnes of 1991 to more than 371 000 tonnes in 2016. (FAO, 2018b, Macias et al., 2019). Such development benefited from the substantial improvements in floating cage technology, which allowed aquaculture to progressively move further into the open sea (FAO, 2017), thus minimizing conflicts of use in an over-exploited maritime space, and better meeting environmental constraints.

This positive trend is expected to consolidate in future years as a result of aquaculture development plans in the region, posing severe constraints on the management of maritime space and demanding accurate planning in order to mitigate the increasing pressure on coastal zones. Strategies must be designed to avoid that the availability of suitable areas for marine aquaculture turns into a bottleneck for any further development of the sector, given the harsh competition for sea space among a variety of well-established blue economy sectors and the extreme vulnerability of the Mediterranean area to environmental stresses (Macias et al., 2019).

A Google Earth-based study of the spatial distribution of fish cages among 16 Mediterranean countries showed that 80 percent of the installations were located within 1 km of the coast, with a maximum distance of about 7 km (Trujillo et al., 2012). Besides the obvious preference for sheltered coastal locations characterized by low hydrodynamic energy and by the proximity to supporting infrastructures, a strong reason for this renitence to move farther offshore lies in the rapid increase in depth with distance-from-shore that characterizes the basin, posing severe constraints on mooring systems (McDaid Kapetsky et al., 2013). On the other hand, the study of Trujillo et al. was not especially focused on Mediterranean islands, and in fact locates the vast majority of farms along the continental shoreline of Spain, France, Italy, Greece, Turkey, Tunisia, and along the jagged eastern coast of the Adriatic Sea, whose numerous islands are very close to the mainland. Nevertheless, among the considered installations, those that lie along the western coast of Sardinia and Corsica and around Malta can indeed be virtually considered as offshore, as they are anyway exposed to severe wind and sea conditions, in comparatively deep waters, and can represent effective case studies for future offshore installations.

Based on biological considerations only, the Mediterranean basin can be classified as a suitable area for offshore aquaculture development (Oyinlola et al., 2018), offering the advantages of sustained currents (10-100 cm/s) and temperature and chlorophyll-a threshold ranges that allow the farming of autochthonous species, as well as the



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opportunity of placing installations within cost-effective distance from the coastline (McDaid Kapetsky et al., 2013). However, the global race to design technologies for offshore aquaculture in much more extreme conditions than those represented by the comparatively mild Mediterranean climate, as well as the development of marine renewables in the region that would enable the co-location of multi-function platforms (Pisacane et al. 2018), now make the offshore option more appealing for the sustainable future development of the sector in the Mediterranean Sea, which is reported to be world's most overfished basin (FAO 2018).

In the future, resorting to offshore aquaculture might also help counteract the expected warming due to climate change, and allow better environmental conditions for fish farming, in colder waters and sustained currents. At present, it would help preserve the Mediterranean seagrass meadows which provide important marine ecosystem services and constitute an invaluable heritage as to both ecology and biodiversity. Seagrass regression may be due to natural processes, natural disturbances and/or anthropogenic pressures, including climate change. Human-induced losses of *Poseidonia oceanica* have been related to coastal development, pollution, trawling, fish farming, moorings, dredging, dumping and introduced species, although accurate data are generally very local and are lacking at basin scale (Boudoresque et al. 2009). However, the moving of aquaculture from coastal area above seagrass beds to the deeper waters around Cyprus, away from the meadows, constitutes a documented case of meadow recovery, all the more important as these areas are characterized by thermal conditions that are at the upper limits for the species (Kletou et al., 2018). The design of suitable mooring systems clearly represents a prerequisite for such option, in this as in other Mediterranean environments (Vassiliou et al., 2012).

From the administrative point of view, the Mediterranean basin is fully covered by contiguous Exclusive Economic Zones (EEZs), which provide a common understanding of where and at what pace offshore mariculture can develop both within and among the declaring countries. A sound legal framework for the development of the involved maritime economies therefore exists, under the protection afforded by the legal jurisdictions of each maritime nation that has agreed to an EEZ, which represents a prerequisite for any further agreement and dispute resolution. For instance, should free-floating or propelled mariculture structures be developed in the future for use on the high seas, which may pass from one EEZ to another, these cases will require specific legal treatment within this framework for international mariculture development. (McDaid Kapetsky et al., 2013).

In 2017, the General Fisheries Commission for the Mediterranean adopted the strategy for the sustainable development of Mediterranean and Black Sea aquaculture in the form of Resolution GFCM/41/2017/1, envisaging a future where production in this region will be globally competitive, sustainable, profitable and equitable. The Mediterranean and Black Sea coastal countries will be supported in formulating harmonized aquaculture activities and action plans, considering the environmental and socioeconomic priorities at all the relevant spatial scales, from the regional, to the national and local, in conformity with existing national and supranational strategies and legal requirements (GFCM, 2018).

The European Mediterranean islands need their touristic vocation to be harmonized with the development of sustained industrial activities, reconciling the competitive uses of



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marine space across the tourism industry, maritime transport infrastructures, the emerging opportunities offered by marine renewables, and the exploitation of fisheries and aquaculture. Offshore aquaculture can disclose significant opportunities for sustainable food production, for both the local and the continental markets, and for the development of insular communities, especially in small islands where the availability of nearshore space is limited.

The Caribbean Islands

A jump in the interest towards the development of aquaculture in the Caribbean was officially recorded in the early '80s of last century by the Gulf and Caribbean Fisheries Institute (GCFI), and measured by the number of aquaculture related papers published in the Proceedings the institute (Creswell, 2008). However, aquaculture in Latin America and the Caribbean had already begun in the 1940s, mainly for recreational and restocking purposes. In the 1960s and 1970s, it was then re-oriented towards the production of food for local consumption, also due to the necessity of diversifying rural and coastal activities. More recently, the adoption of advanced production systems and technologies have enabled a more efficient management of the sector, which now significantly contributes to food supply, to the stability of employment and to the collection of foreign hard currency through enhanced relations with target export markets. However, the aquaculture industry has so far relied for its development on government participation in small- and medium-scale enterprises, while global economic trends now oblige the sector to upscale and meet the standards and conditions of international trade, combining social equity, environmental sustainability and competitiveness through product diversification. (Hernandez-Rodríguez et al., 2001).

A new study recently demonstrated the Caribbean to have a large unexploited potential for deep-sea fish farming, which could produce over 34 million metric tons of seafood per year. Offshore mariculture was, in fact, indicated as a valuable option for the economic development of the region, increasing seafood production at the same time reducing the over-exploitation of wild fisheries and the pressure on coastal ecosystems (Thomas et al., 2019). Such a perspective had already been highlighted by several authors (McDaid Kapetsky et al., 2013; Benetti et al., 2003) who showed these islands to exhibit favourable environmental characteristics for the economically viable farming of selected species, despite the considerable depths of the surrounding ocean, which constituted a hurdle up to recent years. Technological development has now loosened this latter constraint, while the growing concern for marine habitat protection has progressively augmented the appeal of offshore farming, as it offers the opportunity of avoiding conflicts with other sea uses and helping preserve sensitive coastal habitats (coral reefs and seagrass meadows) in protected areas. However, a thorough integrated assessment of the ecological and economic sustainability of mariculture in the region is still lacking, besides the general recommendation of avoiding the introduction of non-indigenous species (Benetti et al., 2003). Thomas et al., 2019, indeed presented a first attempt to develop a spatial bioeconomic model in order to plan optimal siting, predict yield and estimate profit for offshore cobia (*Rachycentron canadum*) mariculture across 30 jurisdictions in the Caribbean, while a scoring system for the economic viability of species was developed by Van Wyk and Davis, 2006, which was used to rank nine species commonly considered as candidates for Caribbean aquaculture. The system was based on a mixture of technological, economic, and market-related factors, and species rated according to their commercial feasibility.



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Culture technologies and individual marketing opportunities were found to strongly affect the results, which however indicated cobia, sponge, shrimp, spiny lobster and queen conch as the top five species. On the other hand, the low nutrient concentration in the clear tropical waters, and the consequent low phytoplankton productivity, limit the cultivation of filter feeding bivalves, and of non-herbivorous mollusks (Creswell, 2008).

The Caribbean also share with the Mediterranean the positive condition of belonging to an Exclusive Economic Zone (McDaid Kapetsky et al., 2013). Nevertheless, any further development of the aquaculture industry will by necessity depend on the successful application of efficient technologies, innovation, modernization and reconversion processes, in order to increase the production of high-quality seafood and obtain an adequate return on investment.

The crucial role of research and administrators will be to guarantee the conservation of the local natural marine habitats, the constant improvement in farming technologies, and the sustained capacity of attracting foreign investments in the context of the global trends in marketing and economics, by fully assuming the required regulatory and monitoring responsibilities (Creswell, 2008; Benetti et al., 2003). To this end, the development of information systems and suitable mid- and long-term planning instruments in support of farmers and investors is recommended, including climate analyses aimed at characterizing the potential threats of warmer sea waters and increased frequency of occurrence of tropical cyclones (Hernández-Rodríguez et al., 2001).

Macaronesia

The Islands jointly referred to as Macaronesia (Azores, Madeira and Canaries) are oceanic islands that face diverse development challenges, mainly due to their distance from the mainland and limited land space, and where standardized mainland-based strategies cannot be directly implemented, as the complexity of the local context needs to be accounted for (Chapman, 2011). They usually experience more severe environmental constraints, exhibiting more variable and extreme climatic conditions and peculiar biogeographical attributes (e.g. higher waves, stronger currents, stronger winds, less nutrient input from rivers, narrow continental shelves, lower primary production). Moreover, their wild species often present distinctive evolutionary features, such as a high level of endemism and speciation, and unique biodiversity (Whittaker, et al., 2007; Whittaker et al., 2008).

As a result of the technological developments enabling high-sea farming, aquaculture can now offer a valuable opportunity for the socioeconomic development of such remote areas, helping avoid the over-exploitation of local fish stocks and allowing the diversification of products. Indeed, the first offshore fish farms installed in Madeira in the mid-1990s, as an initiative of the Madeira Fisheries Department, demonstrated the technical and commercial viability of aquaculture in the open and deep seas of the region, and served as a test case for other islands. The main economic constraint on the business proved to be that typical of small island industries far from the continent, namely the sustainability of the ratio between importation of production supplies (fingerlings, feeds, chemicals) and sales of end products. Production and maintenance costs evidently increase as a function of potential transport disruption, lock-down of farming operations, damages to cages and nets and loss of fish stock due to bad weather. Two additional costly logistical constraints are represented by the lack of local services (cranes, repairs, etc.) and of space for land bases near service piers. Some of the named obstacles had positive



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institutional responses, from the POSEI EU Programme for ultra-peripheral regions, to the development of extensive government services and R&D in support of farmers (Andrade and Gouveia, 2008).

The growth of the sector, however, must from now on also recognize as a priority the conservation of the natural patrimony, and align with effective marine protection plans. Any effective strategy to accelerate Blue Growth must necessarily preserve the significant ecosystem services offered by the several Marine Protected Areas (MPAs), as well as incentivate the sustainable management of the tourism fluxes attracted by the region's natural beauty (Isidro et al., 2008, Aguilar-Manjarrez et al., 2017).

The PLASMAR INTERREG Project (<http://www.plasmar.eu>) recently analyzed locations in the Macaronesia Region where the promotion of sustainable aquaculture can be grounded on sound scientific and technical bases and coniuigated with novel economic activities (Gouvello et al., 2017; Olivotto, 2011; Froehlich et al., 2017; Coen, 2011; Duarte et al., 2017; Pomeroy et al., 2006; Olivotto et al., 2017). The project identified sites where new maritime activities can take place and their possible conflicts with other sea uses are manageable, and where environmental pressures can be reduced by applying an ecosystem approach in multi-use areas inside MPAs. They used the International Union for Conservation of Nature (IUCN) management classification (Dudley et al., 2008), and developed a tool to reach a better understanding of the marine plan composition, allowing better allocation and use of resources. This clearly sets the path for further institutional intervention in promoting Marine Aquaculture Zoning in the region.

In the context of a high awareness of the environmental dimension on the part of the local administrators and academy (Andrade and Gouveia, 2008; Isidro et al., 2008; White, 2008), there is a growing concern for the potential impacts of climate change on the marine environment of Macaronesia, which might increase the vulnerability of marine habitats and further exacerbate both environmental pressures and the already tight constraints on economic development (Ferreira et al., 2019; Calado et. al, 2011, Riera et al., 2014).

2. Approaches to risk assessment: bridging the disaster risk reduction perspective and climate impact assessment

According to the UNDRR⁷ Report “Living with risk: a global review of disaster reduction initiatives” (2004), risk is defined as *the probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable/capable conditions.*

The possibility of understanding, assessing and counteracting risk is, therefore, intrinsically linked to our ability to project both future hazards (i.e. potentially damaging physical events, phenomena and/or human activities) and the physical, social, economic and environmental vulnerabilities that consistently contribute to determine the degree of susceptibility of the exposed elements, together with the positive capacity of communities to cope, endure and recover from adverse impacts.

⁷ United Nations Office for Disaster Risk Reduction



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However, contemporary risk research has often relied on a simplistic view of the relation between hazard, vulnerability and adaptive capacity, usually based on mechanistic notions of causation, in which hazards are seen as originating in the natural world, while exposure, vulnerability and preparedness are conceptualized as merely exacerbating/mitigating factors determined by human action (Jasanoff, 1999). In this framework, risk is bound to increase whenever our – possibly insufficient - knowledge of the hazard fails to translate into effective mitigation or adaptation, or into significant exposure reduction. In particular, such considerations apply when risk experts need to justify our enduring vulnerability to low-frequency yet high-impact events (Lane et al., 2012).

Such conceptual understanding finds its natural representation in the traditional pseudo-equation for risk, or in any of its variations: $\text{Risk} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Vulnerability}$, or $\text{Risk} = \text{Probability} \cdot \text{Consequence}$. This expression for risk clearly sets its assessment in a probabilistic framework, in which the concurring factors are basically treated as independent events, and the result is expressed as their joint probability of occurrence and/or relative magnitude. Nevertheless, while natural hazards can, in principle, be rigorously characterized in probabilistic, or anyway measurable, terms, each in its own scientific context, the same does not hold for any of the other components of risk, which are the object of extensive trans-disciplinary discussion among a variety of research fields, including social and political sciences, history, economics, engineering, and even of sophisticated theoretical debates as to the very nature of the concepts of *disaster* and *vulnerability* (Bankoff, 2004; Alexander, 2012). In its turn, the apparently straightforward characterization of hazard components in terms of measurable physical variables can also give rise to methodological issues, as the choice of the correct indicators largely depends on the scope of the risk assessment, on a clear definition of the impact to be quantified and managed, and on the specific knowledge available.

Recent research has therefore veered towards a more complex appreciation of the nature of risk, highlighting how, in observed disastrous events, the overall risk is mainly, if not acutely, determined by the coupling of systemic elements, rather than being simply determined by their accidental superposition (Lane et al., 2012).

Almost at the same time, in the context of climate studies, a different definition of vulnerability was being developed as the appropriate conceptual tool to better understand impacts as multifaceted processes, rather than as the mere consequences of natural physical phenomena impacting social communities and systems. Indeed, possibly thanks to the complex nature of the climate system and to the long timescales needed to characterize it, the 4th IPCC Assessment Report already referred to vulnerability as to the synthesis of multiple inter-connections and feedbacks between traditional risk components (IPCC et al., 2007). Later on, in 2014, the Vulnerability Sourcebook (Fritzsche et al., 2014) explicitly addressed vulnerability to climate in a way that was more congruent with the *disaster risk* definition than with the traditional vulnerability concept adopted by the Disaster Risk Reduction (DRR) community, while *exposure* actually coincided with *hazard*. For the sake of transparency and clarity, such terminology was then reviewed and harmonized in the Fifth IPCC Assessment Report (IPCC, 2014), where the term *vulnerability* was in fact replaced by the phrase *risk of climate change impacts*, borrowed from the DRR community. From the conceptual point of view, both communities had come to a common understanding of risk and risk components as processes in time, despite their having started from different perspectives, and had defined a common terminology accordingly. A supplement of the Vulnerability Sourcebook was then released in 2017, so as to bridge gaps between the evolving concepts, although reference is usually made to the 2014 issue.



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Consistently with the consequential view of risk assessment as an ongoing exercise, the Sourcebook mainly aims to set up a practical tool for the constant verification of adaptation measures in operational management, by adopting a holistic approach and indicating the detailed pathways to follow in order to achieve standardized results. The suggested method covers a broad range of sectors and topics, and different spatial levels and time horizons, and allows to account for both quantitative and qualitative factors. In operative projects, it enables the iterative evaluation of adaptation interventions, thus improving their effectiveness and optimizing cost-benefit trade-offs. To this end, the concept of the *Impact Chain* was developed, an analytical tool that, through sequential, logically ordered steps, guides the understanding, systematization and prioritization of the factors that jointly determine the nature and magnitude of risk.

2.1 The Impact chain method: a pragmatic and comprehensive approach that accounts for participative and qualitative elements

The SOCLIMPACT project has conducted a comparative climate risk analysis for selected Blue Economy sectors and European islands, based on the preliminary selection of implementable Impact Chains and through the use of different methodologies.

An Impact Chain is essentially a flexible algorithm for climate risk assessment and for the implementation of informed decision making. It can be represented in the form of a diagram, articulating the causal links between the different components of climate risks, each quantified via informative indicators, which in their turn result from accurate selection and data collection. Component indicators are normalised so as to enable their aggregation in the weighted average that measures the overall risk, whose magnitude is therefore expressed in a scale ranging from 0 to 1, aiming to obtain a standardised risk score that allows risk ranking according to highest likelihood or greatest consequence of occurrence. The resulting information is expected to shed light on the relative effectiveness of alternative adaptation pathways, and provide stakeholders and decision makers with better information for adequate resource allocation and prioritization and verification of interventions. The level of feasible intervention clearly depends on the spatial scale of the analysis, which is conditioned by data availability and by the very nature of the specific risk examined. A wide participation of the stakeholders and the general public is helpful for correctly framing the assessment problem, and for obtaining a more relevant outcome for the targeted beneficiaries. In particular, the broadest possible discussion helps identify potential collateral or secondary hazards deriving from the more appreciable primary ones, and evaluate the immaterial components that need to be objectively quantified. Among these, we need to reckon the social factors which concur to determine both vulnerability and coping capacity, and are often related to the level of well-being of individuals, communities and society, to the level of literacy and education, to the widespread availability of basic services, to the quality of local governance, to social equity, to the existence of open and flexible knowledge structures as opposed to the permanence of customs and ideological beliefs, and to the overall development of collective organizational systems.

The following steps were therefore implemented:

- selection of priority impacts by the Sector Modelling Teams – SMTs (D3.1);
- identification of risks by the SMTs and Islands Focal Points (IFPs), consolidated during the meeting in Corsica (May 2018);
- construction of theoretical impact chains (ICs), definition of components and identification of sub-components by SMTs and IFPs, for each specific IC (D3.2);



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- identification and selection of the indicators for each risk component and sub-component for the various impact chains by SMTs and IFPs (D3.3);
- selection of a sub-set of six implementable ICs, based on their relevance and actual feasibility of operationalization;
- selection of the islands to consider in the comparative analysis for each operationalized IC, according to the local economic relevance of the sector and to data availability;
- computation of normalized risk components and climate risk or, in cases where risk could not be objectively evaluated, ranking of islands with respect to risk, for the selected ICs and islands.

As mentioned above, the IC approach is intended for an iterative risk assessment, aiming not only to evaluate risk, but also to monitor how risk and risk components evolve with time and respond to human intervention. For this reason, the weights that determine each component (and sub-component) contribution, and, in fact, bear the responsibility of synthetically representing all the inter-dependencies and feedbacks occurring within the system under examination, cannot be expected to be constant in time. In the IC implementation presented here, however, weights are usually kept constant and are independent from the varying conditions, which, in their turn, are only determined by long-term climate change (i.e. the hazard component), due to a general lack of information as to future exposure and vulnerability. This is just the reverse of what happens when the method is applied in specific cases when environmental degradation is already observable, and focusing on current climate is explicitly recommended. In this case, weights are attributed to all components and sub-components based on the objective contemporary observation of the ongoing process (e.g. soil erosion), and possibly modified alongside with interventions, so as to verify their effectiveness. In the context of climate change over longer time scales, the improvement of current model projections is expected to affect the results through changes in the absolute estimate of the hazard component rather than in its weight, while a revision of the remaining factors and of their associated weights is still unforeseeable.

Reaching a compromise between data requirements and data availability was indeed the most challenging part of the IC operationalization, and in some applications difficulties could not be completely overcome, as reported in the sections dedicated to the specific sectors. This was partly expected, in view of the great variety in the geographical, climatological and socio-economic characteristics exhibited by the islands under study, which also determined the necessity to resort to different methods in different environments. However, the diversity of methodological choices presented in this deliverable can represent a resource for future research, and should be regarded as a prototypical database for the large-scale application of the IC approach in a broad context. Indeed, the specific methodology adopted in each case is not expected to significantly influence risk or island ranking, while the different applications anyway allow to draw up an overview of the current methodological plurality in comparative studies of the socioeconomic risks caused by climate change.



3. Key findings per sector and per island

3.1. Maritime transport

General considerations

For the Maritime Transport sector, three main climate change risks have been identified for the SOCLIMPACT project. These are: (a) risk of damages to ports' infrastructures and equipment due to floods and waves, (b) risk of damages to ships on-route (open water and near coast) due to extreme weather events, and (c) risk of isolation due to transport disruption. We selected to operationalize the third one (risk of isolation due to transport disruption) which in terms of hazards and impacts can be considered as a combination of the other two (see SOCLIMPACT report D3.3). The Impact Chain concept was adopted as described in Section 2, while the conceptualization framework of the operationalization is summarized in Figure 3.1.1. The SOCLIMPACT islands under investigation are Cyprus, Crete, Malta, Corsica, Canary Islands, and Balearics. The selection of islands was based on the importance and dependency on the Maritime Transport sector and on data availability. The hazard risk component indicators considered for the operationalization were slightly modified from the ones originally proposed from WP3 and include: extreme waves (SWHX98), extreme wind (WiX98) and mean sea-level rise (MSLAVE). The exposure indicators are: number of passengers (NPax), islands' total population (NTotP), value of transported goods expressed in freight (VGTStot) and number of ports per island or archipelago (NPo), while the sensitivity indicators include: the number of isolation days (NIID) and renovated infrastructure (NAgePo). Finally, for the component of adaptive capacity, the proposed indicators are: percentage of renewables (PEnRR), number of courses/trainings (NTrCoRM), early warning systems (NOcSta) and harbour alternatives (NApt). The raw and normalized data for all indicators and each island are presented in Tables 7.1.1-7.1.5 of Appendix 7.1. Unfortunately, due to the lack of reliable and consistent data we had to exclude the "number of isolation days" and "number of courses/trainings" indicators.

For assessing future risk, we considered projections or estimations for the indicators when these were available. This was mainly the case for the components of hazard (mean sea-level rise, extreme waves, and wind), exposure (population, number of passengers, value of goods), and the contribution of renewables. Two Representative Concentration Pathways (RCPs) were considered for meteorological hazards. One "high-emission" or "business-as-usual" pathway (RCP8.5) and a more optimistic one (RCP2.6) that is closer to the main targets of the Paris Accord to keep global warming to lower levels than 2 °C since pre-industrial times. Besides the historical reference period (1986-2005), we consider two 20-year future periods of analysis. One over the middle of the 21st century (2046-2065) and one covering the end of the 21st century (2081-2100). The normalization of indicators was performed across the different islands in order to facilitate and inter-island comparison and prioritize the islands of higher risk. A more detailed description of the raw indicator data and normalization methods is presented in Appendix 7.1.

Regarding the weighting of the different risk components, we have tested several weights, however, according to expert judgement and discussion with specialists on the Maritime sector, however, we found more appropriate to assign equal weights to all main components of risk (i.e. 0.33 for Hazard, 0.33 for Exposure and 0.33 for Vulnerability). For the sub-components of Exposure, we assigned a weight of 0.33 for Nature of Exposure and a weight of 0.66 for Level of Exposure since the latter one is believed to be of greatest importance. Similarly, for the vulnerability sub-components, we assigned a



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weight of 0.25 for the Factors of Sensitivity and a weight of 0.75 for the Factors of Adaptive Capacity. Risk for transport disruption is eventually categorized into five categories according to Table 3.1.1. The weighting and categorization of risk is a subjective decision, nevertheless, we consider our selection to be quite conservative and therefore we believe that a slightly different choice would not significantly affect the main conclusions drawn.

For the recent past/present conditions, the operationalization of the Maritime Transport Impact Chain indicates a low risk for all investigated islands (Table 3.1.2). In general, the Maritime Transport sector of the larger islands (e.g. Corsica, Cyprus and Crete) is found to be more resilient to the impacts of climate change. Up to a point, this is related to the large number of harbour alternatives in comparison with smaller islands. Our results for the future highlight the importance of adopting a low-emission pathway since this will keep the risk for Maritime Transport disruption similar as present conditions, while for some islands the risk is expected to slightly decline. In terms of island inter-comparison, Malta's maritime sector is found to be most vulnerable, nevertheless, future risk even under RCP8.5 is not expected to exceed medium risk values. On the contrary, Corsica is the island less susceptible to climate change impacts. Detailed results for each investigated SOCLIMPACT island are presented in the following sub-sections. Detailed tables of the Impact Chain operationalization (including all components) are presented in Tables 7.1.x of Appendix 7.1.

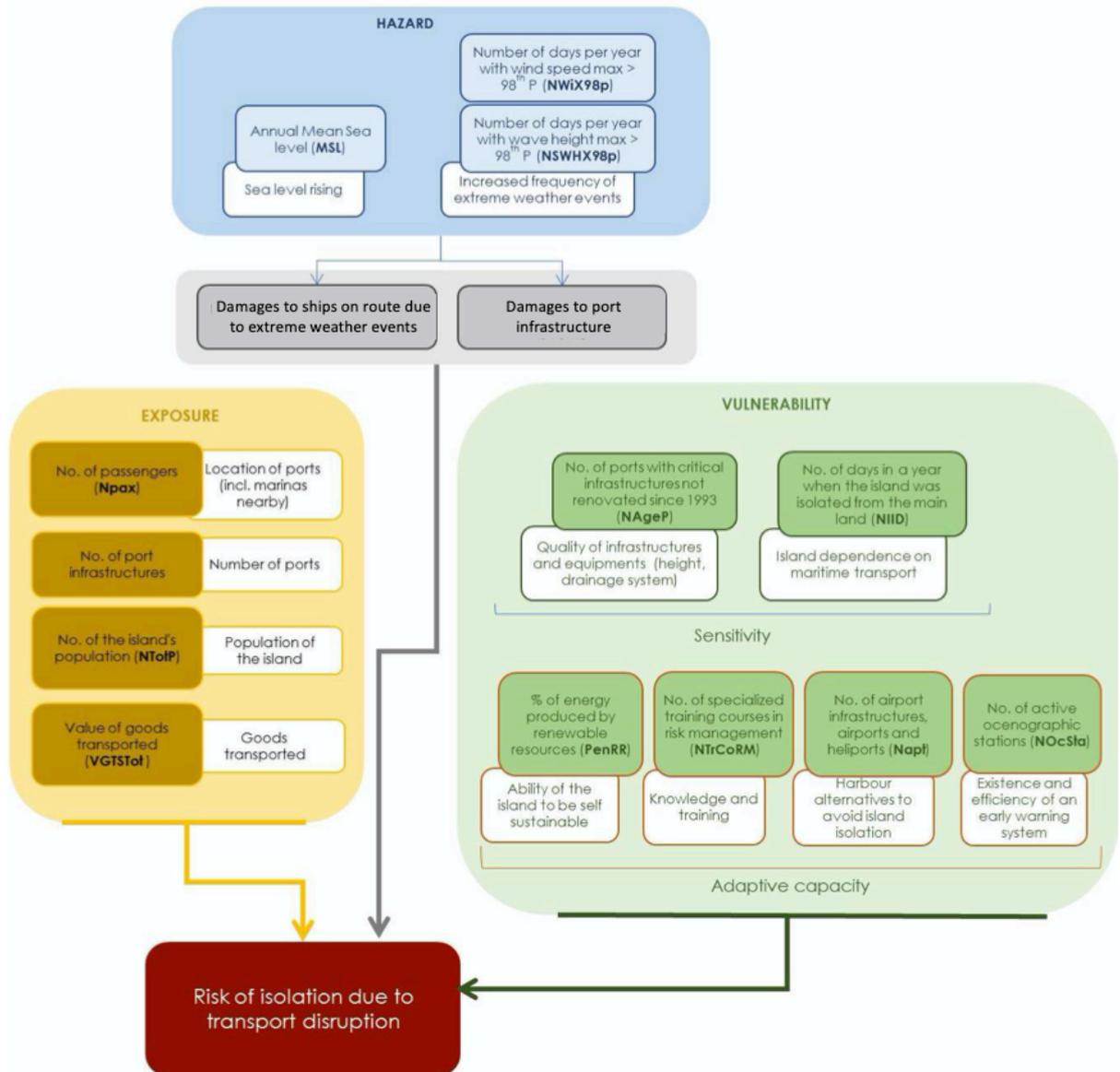


Figure 3.1.1. Conceptualization framework for the operationalization of the Maritime Transport Impact Chain: Risk of Transport Disruption.

Table 3.1.1. Categorization of the Risk of isolation due to Maritime Transport disruption based on the relative risk value.

0.00 – 0.20	0.20 – 0.40	0.40 – 0.60	0.60 – 0.80	0.80 – 1.00
Very low	Low	Medium	High	Very high



Table 3.1.2. Summary of present and future risk of isolation due to Maritime Transport disruption for each island and scenario based on the Impact Chain operationalization.

RISK VALUE PER ISLAND	Historical Reference	RCP2.6 MID	RCP2.6 END	RCP8.5 MID	RCP8.5 END
CYPRUS	0.241	0.210	0.218	0.258	0.292
CRETE	0.229	0.208	0.201	0.257	0.282
MALTA	0.376	0.347	0.335	0.395	0.414
CORSICA	0.220	0.194	0.194	0.243	0.273
CANARY ISLANDS	0.336	0.292	0.250	0.346	0.341
BALEARIC ISLANDS	0.326	0.281	0.264	0.331	0.344

Results per island

Cyprus

For the eastern Mediterranean island of Cyprus and the risk of isolation due to Maritime Transport disruption, our analysis indicated low risk values (0.241) during the historical reference period (Table 4.4.2). Greatest is the contribution that comes from the factors of adaptive capacity and nature of exposure. On the contrary, the hazard indicators related to the meteorological hazards had a much smaller contribution. For the mid of the 21st century, the risk for transport disruption remains low for both RCP2.6 and RCP8.5 (values of 0.21 and 0.258 respectively). The contribution of hazard indicators is becoming more significant since mean sea-level rise is increased compared to the default zero value of the historical reference period. Since the exposure indicators have the same values for both pathways, the differences in the risk values are for this period mainly driven by the factors of adaptive capacity (e.g. the contribution of renewables). This contribution is expected to be more important in an RCP2.6 future, and therefore the correspondent risk values are somewhat lower. For the end of the 21st century, the risk values do not change much for the optimistic RCP2.6. On the contrary, for RCP8.5 our analysis indicates an increase in the risk value (0.292), which is, however, still categorised in the low class.

Crete

For the largest Greek island, during the historical reference period, the Impact Chain operationalization indicates similar conclusions as in the case of Cyprus. The risk value is characterised as low (0.229), with a more important contribution arriving from the factors of adaptive capacity. This is due to the low contribution of renewables and the relatively low number of harbour alternatives (e.g. airports) in this particular island. For RCP2.6 the risk of transport disruption is projected to slightly decrease for the middle and remain stable for the end of the 21st century. This mainly due to a higher contribution of renewable energy. This higher contribution makes the island less dependent on imported fossil fuel for energy production and therefore increases its capacity to adapt and be self-sustained. For the business-as-usual RCP8.5, our analysis indicates an increase for the end of the current century (risk value of 0.28). This increase can be attributed to the projected augmentation of meteorological hazards (mainly extreme winds and mean sea-level rise). The fact that Crete is one of the islands where the level of exposure indicators (population, number of passengers and value of goods) is expected to strongly decrease, keeps future risk for transport disruption in relatively low levels.



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Malta

The Impact Chain operationalization for Malta highpoints a higher present relative risk for isolation due to Maritime Transport disruption compared to Cyprus and Crete (Risk value of 0.376). This is mostly related to the high values of *nature* and *level of exposure indicators* due to the combination of a small number of ports and the high value of goods. Two other contributors to the relatively higher risk value, related to increased vulnerability, is the small number of harbour alternatives (e.g. airports) and the small percentage of renewables in the total energy mix. For RCP2.6, the risk is expected to slightly decrease, mainly due to an expected increase of the renewable energy contribution, nevertheless Malta will be still classified as a low risk region. On the contrary, under the RCP8.5 pathway, the risk for transport disruption in the Maltese islands is projected to increase and marginally classified as low for the middle of the 21st century (risk value of 0.395). For the end of the current century, the risk is projected to increase into medium values (0.414). This is due to the lower contribution of renewables in this high-emission scenario and the increase of the hazard indicators (mainly extreme winds and mean sea-level rise). The mean sea-level in particular is expected to rise by 65 cm posing an additional threat to harbour infrastructure.

Corsica

The Maritime Transport sector in the island of Corsica is found to be less susceptible to climate change as our Impact Chain operationalization indicates the lowest risk values among all investigated islands (risk value of 0.22 for present conditions). This is related mostly to low exposure indicators. Under pathway RCP2.6, this value will be slightly reduced because the negative effect of increasing meteorological hazards is counterbalanced by an increase in the adaptive capacity as the percentage of renewables is expected to increase in this low-emission pathway. Under scenario RCP8.5, the risk is expected to slightly increase by the mid-21st century and reach a value of 0.273 by 2100.

Canary Islands

The Canary Islands is our only case study archipelago outside the Mediterranean. For the reference period, our analysis indicates low risk values of 0.336. It is, therefore, the second largest risk value after Malta. This result is clearly due to the contribution of exposure indicators. In particular, the total population, the number of passengers and the value of goods are the highest among all investigated islands. Under an RCP2.6 pathway, risk value is expected to decrease (risk values of 0.250-0.292). This is mainly due to the combination of decreased contribution from adaptive capacity and exposure indicators since the population of the archipelago was assumed to decrease following the mainland Spain trends. Under pathway RCP8.5, this reduction of the exposure and adaptive capacity indicators is counterbalanced with a significantly increased contribution of meteorological hazards due to climate change. As the Canaries are located in the Atlantic Ocean, the projected mean sea-level rise (0.74 cm) is the highest amongst all islands or archipelagos. As a result, the end of the century risk values (0.341) are not expected to exceed the low-level class.

Balearic Islands

The Balearic Islands, in the western part of the Mediterranean, are the final archipelago that was investigated for the impact of climate change in the Maritime Transport sector. For the historical reference period, the impact change operationalization resulted in a risk



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value of 0.326 (low risk). The greatest contribution to the overall risk comes from the low adaptive capacity because of the small number of harbour alternatives and the low percentage of renewables in the island. Since the contribution of renewables is expected to increase under RCP2.6 while the contribution of exposure and hazard indicators is more or less the same, for the middle of the current century the risk under this scenario is expected to decrease to a value of 0.281. By the end of the century, the risk for Maritime Transport disruption for the Balearics is expected to further decrease (0.264). For the “business-as-usual” RCP8.5, the risk is expected to slightly increase (values of 0.331-0.344), as a result of the meteorological hazards (mainly extreme winds and mean sea-level rise) and smaller contribution of renewable energy.

Visual representation of island inter-comparison

Hazard

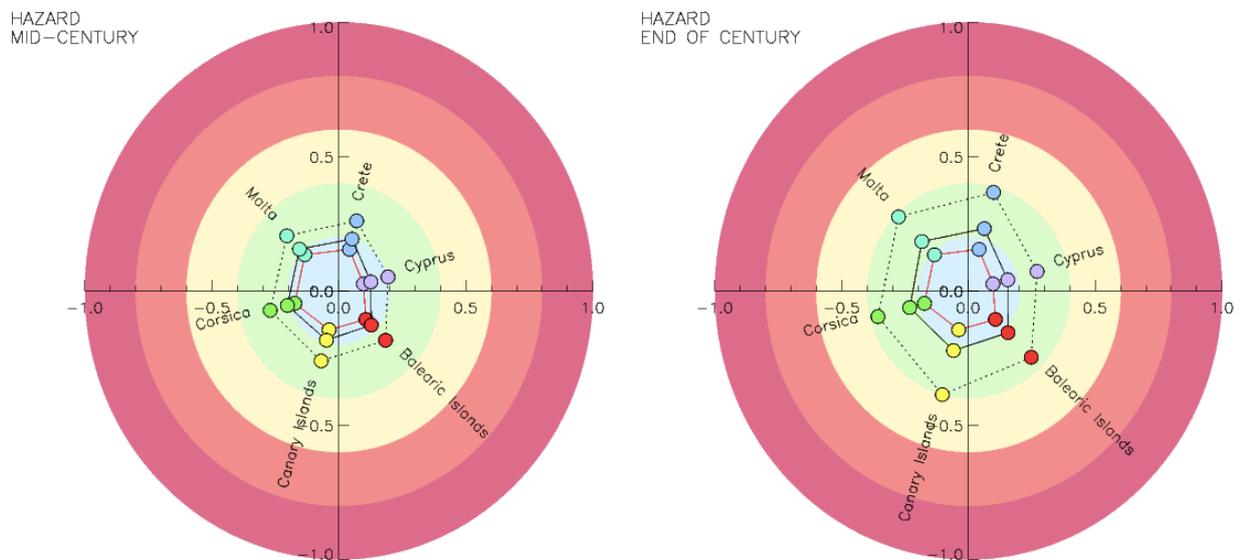


Figure 3.1.2. Hazard comparison across islands – Red: reference period; solid black: RCP2.6; Dotted black: RCP8.5



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Exposure

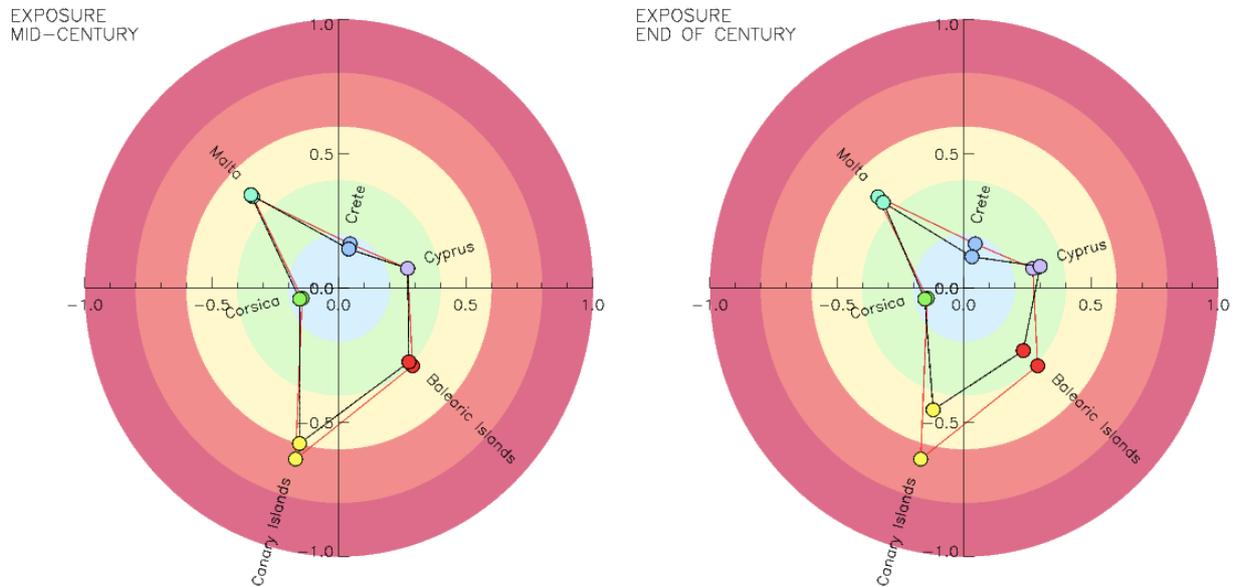


Figure 3.1.3. Exposure comparison across islands – Red: reference period; solid black: RCP2.6; Dotted black: RCP8.5

Vulnerability

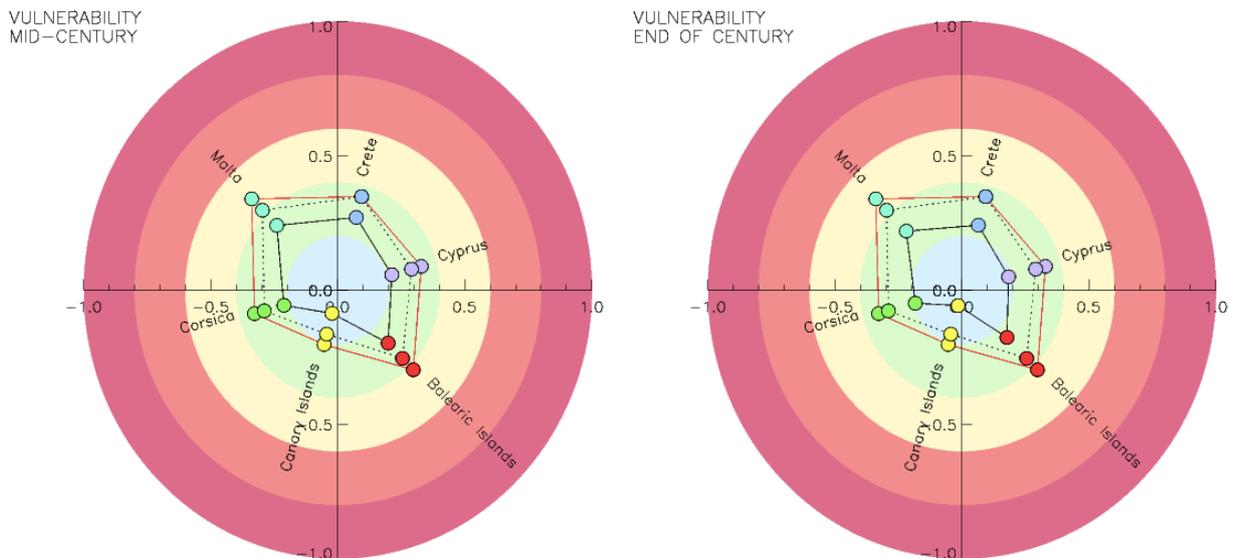


Figure 3.1.4. Vulnerability comparison across islands – Red: reference period; solid black: RCP2.6; Dotted black: RCP8.5



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Risk

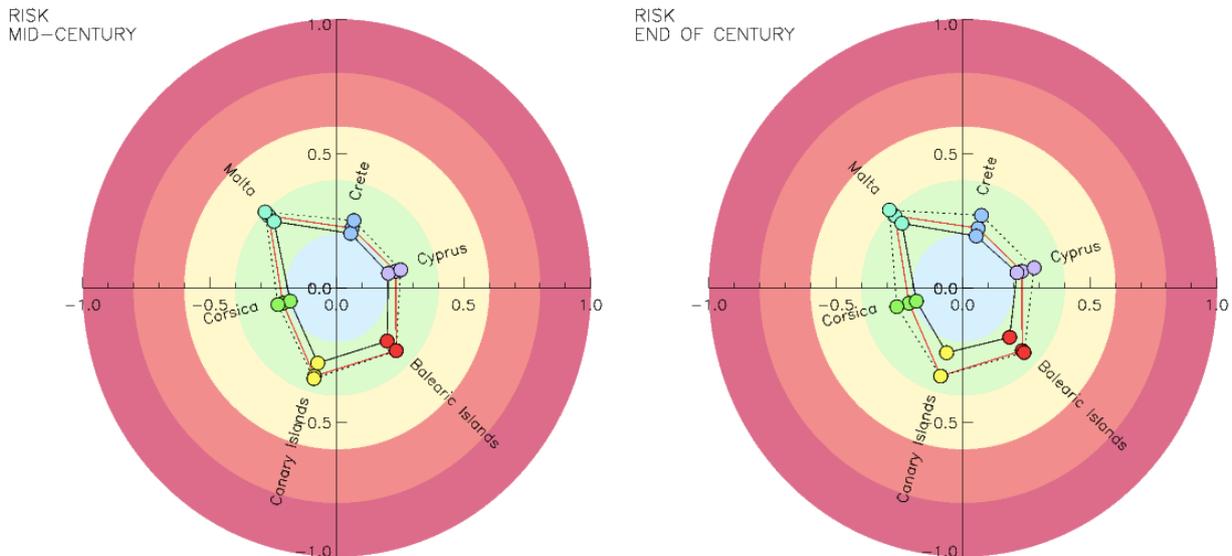


Figure 3.1.5. Risk comparison across islands – Red: reference period; solid black: RCP2.6; Dotted black: RCP8.5

3.2. Tourism

The impact chains to be operationalized in the tourism sector have been chosen according to their relevance, among all the impact chains defined in previous deliverables (D3.2). The relevance criteria considered have been: i) the importance of ecosystem services impacted by climate change for the value of the recreational experiences of visitors to the islands; ii) the potential to illustrate how differences in the destination profile also translate into the order in which islands become ranked regarding different climate threats; and iii) the availability of data to develop indicators to underpin the comparative analysis of the islands against the different components of the impact chain, so allowing for a balanced comparison amongst islands.

Firstly, coastal and marine tourism destinations concentrate a big part of their tourist product attributes on their marine and littoral ecosystems and habitats; thus the impact chain focusing on assessing the risk related to the loss of attractiveness due to the marine environment degradation was amongst the selected ones. Even if coastal destinations over the last decades have evolved towards offering a more diversified range of services, many of them related to inland resources, sea and coastal related resources still remain as the main attractors and the key bricks of the built image of destinations.

Secondly, in coherence with what was asserted above, land environment has gained protagonism in coastal destination visitors' experiences. Terrestrial ecosystems are increasingly perceived as relevant by tourists because they support attractive landscapes but also because endemic biodiversity has raised amongst the natural assets that citizenship are committed to protect the most, and islands treasure a big part of the European biodiversity. In parallel, the last decades have witnessed the increasing destructiveness of wild forest fires powered by social factors but also by changing climate conditions. Wild



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forest fires destroy natural habitats reducing the long-term conservation status of ecosystems, but additionally diminish the perception of safety and downgrade the image of the destination.

Thirdly, climate conditions are determinant is the destination choice, while thermal sensation is the singular weather dimension that influences the most the thermal comfort of tourists while visiting destinations. Over the last decades, heatwaves episodes have reached celebrity in the European context due to their increasing number and intensity, being the cause of a significant number of casualties and hospital admissions. In the European islands under study it is expected a substantial increase of the number of days per year under the effect of heatwaves, while the sensitivity of potential visitors to these expectations is also augmenting as information on the risk of extreme heat exposition is now widely accessible to the majorities.

Impact Chain 1: loss of attractiveness of touristic marine environment

Description of the Impact Chain and selection of the operationalization method

This sub-section describes the work carried out for the operationalization of the impact chain “*Loss of attractiveness of a destination due to the loss of services from marine ecosystems*”. It provides details on the method applied for the operationalization, the island data used, and the results obtained.

Taskforce

The task of operationalizing the impact chain was carried out by members of the Tourism sector modelling team (SMT). The team members participating in this task are listed in Table 3.2.1.

Table 3.2.1: Experts participating in the marine environment impact chain operationalization.

Participant Name	Partner
Dr. Matías Manuel González Hernández	TIDES-ULPGC
Dr. Carmen García Galindo	TIDES-ULPGC
Dr. Fernando Tuya Cortés	ECOQUA-ULPGC
Dr. Francisco José Otero Ferrer	ECOQUA-ULPGC

The team referred above took the responsibility of designing, developing and reporting the work required to obtain the comparative risk of the selected set of islands regarding the loss of competitiveness as a tourism destination due to the impacts of climate change on their respective marine habitats and the subsequent loss of ecosystem services that sustain tourism activity.

All the work was developed under the Covid-19 pandemic conditions, so about 20 multilateral and bilateral online meetings were conducted between February and July 2020 (6 months). During this period, other scholars were also consulted on the particular impacts of climate change hazards on phanerogam meadows surrounding the islands under study, as they are the foundation species structuring most of marine ecosystems around the islands.



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Published research results by Savva et al. (2018) and Rodríguez et al. (2020), and the research conducted by Gabriel Jordà in the Soclimpact framework for WP4, were essential to feed the experts' participation process and arrive to convergent assessments of the risks being faced by the studied islands.

Finally, experts have based their analysis on the best published research about the relationship between changes in seawater temperature and the conservation status of the phanerogam meadows surrounding the European Mediterranean and Atlantic islands. This research provides results based on lab experiments to fill the gap of field-based research and on simulation under seawater temperatures still not reached but expected for the future under some climate change scenarios.

Regarding this, recent research sheds light on the problem of overestimation of the impact on seagrass biology of seawater heating when lab results are taken as reference, and on the greater relevance of other human-related impacts, as sewage discharges (and seawater pollution) and coastal infrastructures. De los Santos et al. (2019) provide evidence of it in *Nature*. Seagrasses (in fact, all living organisms) develop adaptation capacities to changing environments that are not fully captured by lab experiments. Experts have taken all these issues into account to modulate their opinions when participating in the paired comparisons process.

Degradation of marine habitat due to changes in climate conditions

The impact chain initially defined as the *Loss of attractiveness of touristic marine environments due to climate change hazards* (described in subsection 4.1 in deliverable D3.2), presents a conceptual model on the effect that Climate Change would have on conditions that make marine environments attractive for tourists visiting coastal destinations. More in detail, climate hazards like the increase of mean and variability of seawater temperature and the increase of oceans acidification, mainly, are affecting marine habitats with touristic relevance through diminishing bio-productivity and attracting exotic species, some of them toxic, and because of that, reducing the attractiveness of marine landscapes and the presence of flagship species; increasing turbidity in bathing and diving sea waters affecting the quality of bathing, diving, snorkelling and bottom-glass boating experiences, at least; and increased frequency and intensity of episodes of seagrasses massive death that arrive to the beaches affecting the experience of lying and staying there.

The impact chain is shown in Figure 3.2.1. As can be seen in the figure, the impact of Climate Change on the touristic attractiveness of an island depends on a set of multi-dimensional factors, including:

1. Increase in the mean and variability of seawater temperature is the main driver of marine habitat degradation; seawater acidification also impacts marine life although it substantially varies depending of the marine organisms;
2. The risk of those marine habitat transformations for tourism critically depends on the nature exposed to it, the amount and proportion of tourists that feel marine habitat is a relevant motivation to visit the destination, and the resilience of the exposed natural assets and tourists to those changes in the marine environmental conditions;



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3. Finally, the preparedness to cope with the deterioration of its marine environment by developing substitutive attractions, is also a key aspect to assess the effective risk that those hazards pose on the tourism industry at the destination.

The complex relationship between climate change, marine habitats and tourism still exhibits important gaps of knowledge. For example, there is no evidence on the impact that the abovementioned hazards may have on the communities of cetaceans that live or pass through near the coasts of the islands under study. In some cases, this is a very important economic chapter within the tourism industry in the islands. Whether climate change is going to diminish or not the abundance or affect the distance of those cetacean communities from the island requires further research.

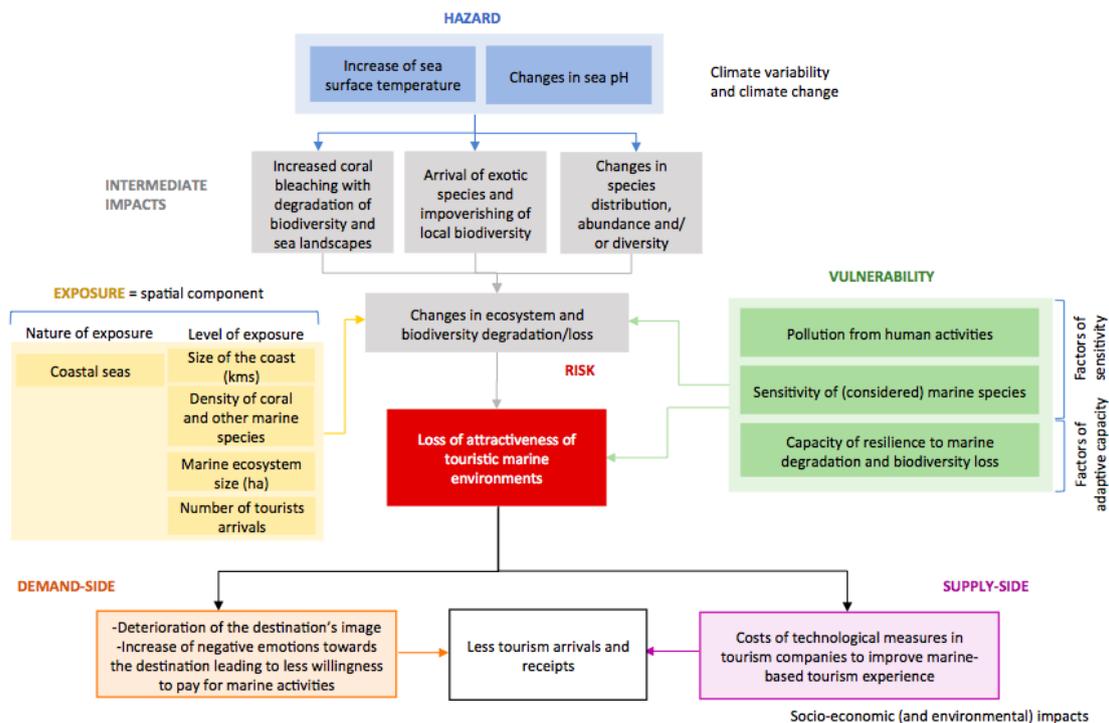


Figure 3.2.1. Loss of destination attractiveness due to marine environment degradation as a result of climate change hazards.

The selection of islands to be compared was conditioned by the relevance of the marine-based tourist activities in the islands, the availability of island data provided by partners and the limitations of the AHP-based multicriteria analysis to deal with a big number of alternatives (i.e., islands). The five islands selected for comparison are the Balearic Islands, the Canary Islands, Cyprus, Malta, and Sicily.

Selection of operationalization method

The Analytical Hierarchy Process (AHP) method was selected as the technique to operationalize the impact chain since it is a well-grounded tool that allows for the prioritization/ranking of alternatives using a weighting scheme that is established by expert judgement. Hence, for the purposes of the project, it was considered suitable as it would



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be able to reconcile the contribution of each risk factor (hazards, exposure, and vulnerability, which includes sensitivity and adaptive capacity) towards the risk based on expert opinion and, subsequently, order the islands in terms of which one is most at risk of losing attractiveness due to a decrease in thermal comfort. For a detailed description of the AHP method, see Section 7.3 of this report.

Application of the Analytical Hierarchy Process method

Hierarchy tree

The problem to be solved along through the expert decision process was comparing the risk of European islands of losing tourist attractiveness due to the deterioration of their marine habitats as consequence of climate change. The hierarchy tree for this decision problem was built underpinning on the impact chain elements presented in Figure 1. Thus, climate hazards that can affect the integrity of the marine habitat surrounding the islands were taken from the work delivered by WP3 researchers, together with the variables that express the tourism-related environmental and social systems exposure to those hazards, the sensitivity of the exposed systems to the referenced hazards and the social capacities to cope with the potential impacts of climate change by protecting nature and the society and/or making them more resilient.

Some modifications of the original impact chain were undertaken for the sake of feasibility, although experts were encouraged to have in mind all the factors they know can affect the impact of climate change on the marine habitat services for tourism. It means that the hierarchy tree is a simplified structure of the main factors explaining the complex relationship between climate change and the ecosystem services that support tourist use of marine environments, but other factors also known by experts must be taken into account at the time of comparing the components of the risk between islands. This is one of the most interesting strengths of the decision processes based on expert participation and, particularly, of the multicriteria analysis used in this case. Figure 3.2.2 shows the basic structure, or hierarchy tree, of the decision making process that was presented to the experts.

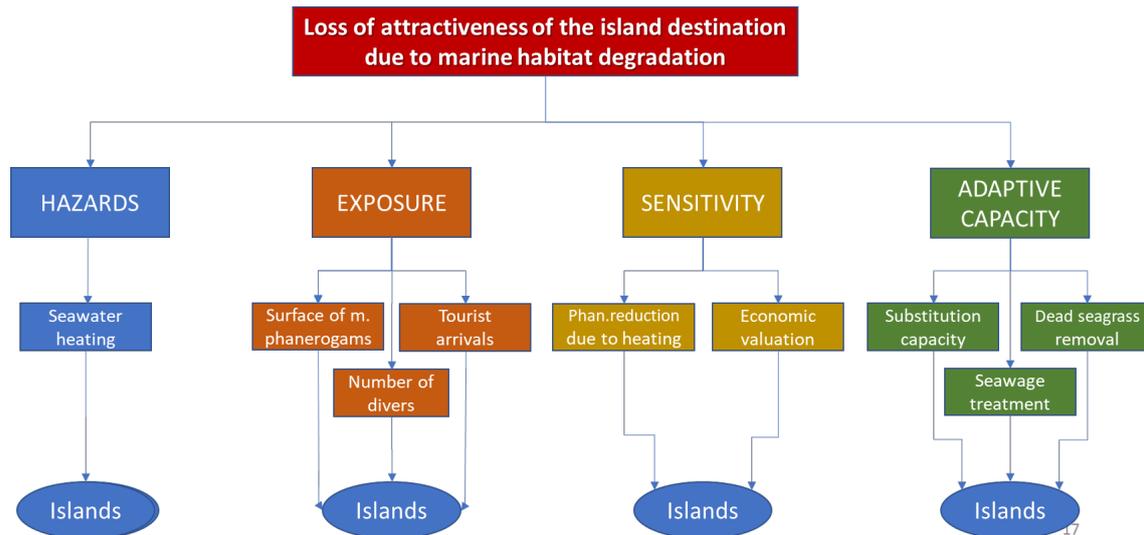


Figure 3.2.2. Hierarchy tree for marine habitat impact chain.

Hazards are the climate events that instigate the climate-associated risk. In our context, seawater heating was considered as the most relevant variable to assess changes in the conservation status of the marine habitats that provide services for coastal tourism activities. Other hazards initially considered, like acidification and storms, were finally discarded. The first one because its effects on living marine organism are still under study and the evidence is dispersed and not conclusive. The second one because in the Mediterranean Sea and the Atlantic Ocean that surrounds the islands under study, storms are considered not so frequent and intense to not giving time to marine ecosystems to recover their previous conservation status.

Regarding indicators, published research shows 25 and 26 Celsius degrees as the threshold temperatures over which seagrass meadows, the foundation species that mainly structure ecosystems in the marine habitats of reference, start to decline. The indicators used were the number of days per year with seawater temperature over 25 and 26 Celsius degrees. Sources of information and data were provided by the Soclimpact modellers.

Exposure denotes the range of ecological and social systems susceptible to be damaged by hazards. This criterion, the natural and social systems potentially damaged by the selected climate hazards, was decomposed into three sub-criteria, one referred to the marine environment, and the other two related to the use that tourists make of the services provided for the marine environments at the destination. These three sub-criteria were expressed through three respective indicators. One, referred to the surface of marine phanerogam that suffer from the climate stressors. Phanerogams, specially Posidonia in the Mediterranean and Cymodosea in the Atlantic, are the very foundation species organizing most of the coastal ecosystems. They provide food and shelter to many different species and keep seawater clear by absorbing sediments. Additionally, when become damaged, seagrasses meadows deliver dead individuals that go to lay on the beaches used by tourists.

The second sub-criterion is one about the different types of direct uses that tourists make of the ecosystem services. Diving was selected to represent these uses and the selected indicator was the number of divers per year. It was assumed that other sea watching



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activities like snorkelling and bottom-glass boating evolves similarly than diving. Experts were also invited to consider other sea environment users potentially affected by the lack of water transparency and dead seagrass suspended in seawater like surfers, windsurfers and other active users of the marine environment.

The third sub-criterion was related to the impact on most of tourists as bathers. Turbid water affects the quality of the bathing experience, which is an activity that most tourists do.

Sensitivity concerns the susceptibility of natural, cultural, and built resources to harm that is a direct or indirect result of Climate Change hazards. For the operationalization of this impact chain, sensitivity relates to the susceptibility of the phanerogam meadows to changes in seawater temperature and to the extent to which the impoverishing of seawater conditions and marine ecosystems may affect the welfare of tourists.

Regarding the effects of episodes of seawater heating on the integrity of seagrasses meadows, the variable selected was periods of overheating and the indicators were the number of days per year with seawater temperature over 25 and 26 Celsius degrees. As explained above, experts were invited to take into account their experience and their knowledge about the differences between the way seagrasses behave in the real world and in the laboratory when studying the impact of water heating.

With respect to the impact of the marine environmental degradation on the welfare of tourists, the indicator selected was tourists' willingness to pay for the preservation of marine ecosystems. It was delivered by Soclimpact researchers who are in charge of WP5. Thus, ecosystem and social susceptibility are both taken into account when comparing risks of marine environment degradation due to climate change between islands.

Adaptive capacity reveals the potential to face the hazards by reducing the level of exposure and/or increasing the resilience of the tourism system. This criterion was split into three sub-criteria, one referred to the substitution of marine-based activities by lesser marine habitat dependent ones, and two concerning with actions to heal the marine environment like removing dead seagrasses or reducing non-treated sewage discharges (and consequently, seawater pollution). In this case, island experts were consulted about the capacity of their reference destination to address these adaptation actions using a 1-4 scale, where 1 represented a very poor management capacity and 4 expressed a full capacity to deal with it.

The experts

Experts consultation had two phases. The first one consisted of gathering scientific information from researchers that published articles on the matter in journals of reference. Selected keywords were impact chain, climate change seawater heating, oceans acidification, , and phanerogams.

Several experts coming from different areas of expertise were consulted for the pairwise comparison. The experts are listed in Table 3.2.2 showing their background, field of expertise, and years of experience. Each expert was provided with the Fundamental Scale (Table 7.3.1) and they provided judgements on the importance of each criterion, sub-criterion and alternative. In the case of disagreeing scores, the values were averaged.



Table 3.2.2. List of experts consulted for pairwise comparisons.

Expert	Field of expertise
Dr Fernando Tuya Cortes	<p>Since 2000, Dr Tuya has published 134 papers in peer-reviewed international journals included in the JCR on different aspect of the ecology of marine communities; > 40 papers are within the first quartile (Q1) of the <i>Marine and Freshwater Biology</i> field, in addition to generalist scientific journals (e.g. Ecology Letters, PloS One, Nature Climate Change, Science) and broad ecological journals (Journal of Ecology, Oecologia, etc). Dr. Tuya is the first author in the ca. 35 % of published papers, while increasing last authorships (“senior” authorship) in the last years as the result of students’ supervision. This scientific production has received ca. 3,000 cites (h-index=28, ISI Web of Science) and ca. 5,000 cites (h-index = 36, Google Scholar).</p> <p>In the last 5 years, his research agenda has mostly focused on the effect of environmental stressors over 'ecosystems engineers', seagrasses and macroalgae in particular, for a total of 45 papers in peer reviewed journals. He has also communicated scientific information to society through dissemination of popular monographs, which can be freely downloaded from the Internet (www.fernandotuya.org).</p>
Dr Francisco José Otero Ferrer	<p>Dr. Otero-Ferrer has developed a wide research work on the marine environments in the Mediterranean Sea and the Canary Islands. He has published over 40 papers in peer-reviewed international journals included in the JCR. Amongst them:</p> <ul style="list-style-type: none"> ▪ Otero-Ferrer, F.; et al. (5/1). 2020. Effect of depth and seasonality on the functioning of rhodolith seabeds. <i>Estuarine, Coastal and Shelf Science</i>. Elsevier. ▪ Otero-Ferrer, F.; et al. (8/1). 2019. Early-faunal colonization patterns of discrete habitat units: A case study with rhodolith-associated vagile macrofauna <i>Estuarine, Coastal and Shelf Science</i>. Elsevier. 218, pp.9-22. ISSN 0272-7714 ▪ Espino, F; et al. (10/8). 2019. Geographical Range Extension of the Spotfin burrfish, <i>Chilomycterus reticulatus</i> (L. 1758), in the Canary Islands: A Response to Ocean Warming? <i>Biodiversity</i>. MDPI. ▪ Otero-Ferrer, F; et al. (6/1). 2015. First records of <i>Hippocampus algiricus</i> in the Canary Islands (north-east Atlantic Ocean) with an observation of hybridization with <i>Hippocampus hippocampus</i>. <i>Journal of Fish Biology</i>. Wiley. 87-4, pp.1080-1089. ISSN 0022-1112. ▪ Molina, L; Otero-Ferrer, F; Izquierdo, M. (3/2). 2006. Coral Reefs: Threats And Future Focusing In Over-fishing, Aquaculture, and educational Programs Management of Natural Resources, Sustainable Development and Ecological Hazards. Wit press. 99, pp.305-312. ISSN 1743-3541.
Dr Matías Manuel González Hernandez	<p>Dr González-Hernández has developed deep expertise in sustainable tourism planning through over more than 30 years of research and participation in dozens of projects of research and development. He has published over 20 papers in peer-reviewed international journals, amongst them <i>Ecological Economics</i>, <i>Tourism Economics</i>, <i>Current Issues in Tourism</i>, <i>Sustainability</i>, <i>Journal of Applied Economics</i>. He has performed as co-director of the UNESCO Chair on Tourism and Sustainable Development of the University of Las Palmas de Gran Canaria over the last 20 years.</p> <p>Dr González-Hernández also has headed several projects that have required undertaken economic valuation of marine resources threatened by human activities in different economic and geographical contexts. Over the last 10 years he has focus mainly in researching on the economic valuation of climate change impacts on tourism activities.</p>



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Experts were provided a *Guidelines* document presenting the aims of the task they were proposed to participate, summarizing the grounds of the AHP multicriteria analysis tool to be used for comparing the risk of climate change for marine habitats from the tourism industry perspective, a set of indicators expressive of the criteria and sub-criteria considered to carry out the risk comparison and a set of matrices to be used to carry out the pairwise comparisons.

Finally, results of the AHP method to compare the abovementioned risk were returned to experts to be reviewed and getting further comments from them, in order to guarantee the coherence between the risk scores obtained and the comments underpinning those scores.

Pairwise comparison

Pairwise comparisons, which are the very core of the AHP method, were undertaken by experts using the comparison scale developed by Saaty (1980). During the sessions devoted to this task, experts handed the above referred document of *Guidelines*, sent them previously. The ordering of the comparison process was, first, comparing criteria against the goal, that's to say, the ranking showing the differential risk the island faces due to climate change affecting marine services that support tourist attractiveness of island destinations; then sub-criteria were faced against their respective criteria; finally, the selected group of five island were compared regarding each of the sub-criteria.

- **Criteria against risk**

As said above, the four considered criteria coincide with the four main elements of the analysed impact chain, in turn coming from the conceptual framework developed by IPCC-AR5. The experts coincided in assessing adaptive capacity as the most relevant criteria to distinguish the intensity of the risk for marine habitats of the islands of experiencing a seawater heating over the 21st century. They argue that the most differential between islands the factual impact that seawater heating can pose on the tourism sectors of European islands is the one related to the governance (adaptive capacity) of such a complex issue. Then, the susceptibility of the natural and social systems to the climate change impacts (sensitivity) is considered very relevant. Finally, the intensity of hazards and the exposure are the following and equal in importance to explain the risk for tourism industry of the impacts of climate change on the marine environments and the subsequent response of the tourism sector. The source of the problem (hazards) and the exposure range both symmetrically. Regarding exposure, all destinations are coastal destinations and for all islands tourism is the most important economic activity in terms of jobs and income. So the size of the exposed systems is the lesser determinant when comparing the risk between islands.

Table 3.2.3. Comparison of criteria against the risk

	Hazards	Exposure	Sensitivity	Adaptive capacity	Weights	Rank
Hazards		1	1/2	1/4	0.125	3
Exposure	1/2		1/2	1/4	0.125	3
Sensitivity	2	2		1/2	0.250	2
Adap capacity	4	4	2		0.500	1
Consistency ratio: 0.000 < 10%					1	



- **Sub-criteria vs criteria**

The process of facing sub-criteria against criteria was carried out following the logical order presented in the impact chain under study, that is, hazards, exposure, sensitivity and adaptive capacity. The matrices containing the pairwise comparisons carried out by the experts are shown below. As just one variable was considered as the relevant hazard, none matrix was needed to weight sub-criteria against this criterion.

Table 3.2.4. Comparison of Exposure sub-criteria

	Phanerog surface	N° of divers	Tourists' arrivals	Weights (vs criteria)	Weights (vs risk)
Phanerog surface		4	2	0.571	0.071
N° of divers	1/4		1/2	0.143	0.018
Tourists' arrivals	1/2	2		0.286	0.036
Consistency ratio: 0.000 < 10%				1.000	0.125

Table 3.2.5. Comparison of Sensitivity sub-criteria

	Phanerog susceptibility	Economic Valuation	Weights (vs criteria)	Weights (vs risk)
Phanerog susceptibility		4	0.800	0.200
Economic Valuation	1/4		0.200	0.050
Consistency ratio: 0.000 < 10%			1.000	0.250

Table 3.2.6. Comparison of Adaptive Capacity sub-criteria

	Substitution	Seagrass removal	Sea water pollution	Weights (vs criteria)	Weights (vs risk)
Substitution		6	1	0.4615	0.231
Seagrass removal	1/6		1/6	0.077	0.038
Sea water pollution	1	6		0.4615	0.231
Consistency ratio: 0.000 < 10%				1.000	0.500

Regarding exposure, experts considered the physical magnitude of seagrass meadows as the most relevant sub-criterion because it determines the most the variation of the marine habitat conditions to host tourist activities. Then, experts gave more weight to the influence on the general tourists that enjoy marine habitat for bathing than to the reduced group of those that practice more specialised activities, like diving or snorkelling.

With respect to sensitivity, again experts gave more weight in a score between moderate and strong (4) to the response of seagrass meadows to seawater heating



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(phanerogams' susceptibility to heat) over the response that tourists gave, in monetary terms, to the deterioration of the conservation status of the marine habitat.

Adaptive capacities were given a clear different weight. Products substitution capacity and seawater pollution were highly evaluated against dead seagrass removal capacity, and equally assessed each other. Experts noted the high relevance that recent research is giving to seawater level of pollution in order to preserve the conservation status of the marine environments, and considered this sub-criterion as heavy as the destination capacity to provide visitors with alternative non-marine-based activities.

- ***Islands against sub-criteria***

Hazard

The only hazard finally considered, the seawater heating, or more precisely, a measure of seawater temperature variability relevant to influence the status of conservation of the seagrass meadows, was however analysed under four different scenarios by combining time-scaling and RCP emissions scenarios projections. The tables of expected episodes of seawater heating above the relevant thresholds were provided by WP4 Soclimpact researchers and combined with complementary information from specialised literature. They are presented in Appendix 7.4.3.

As a result, the matrices of pairwise comparison delivered by the expert deliberation were the following.

Table 3.2.7. Seawater heating under scenario RCP2.6 for the near future (2046-2065)

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		3	1/5	1/3	1/3
Canary	1/3		1/7	1/5	1/5
Cyprus	5	7		3	3
Malta	3	5	1/3		1
Sicily	3	5	1/3	1	
Consistency ratio: 0.0286 < 10%					

Table 3.2.8. Seawater heating under scenario RCP2.6 for the distant future (2081-2100)

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		3	1/5	1/3	1/3
Canary	1/3		1/7	1/5	1/5
Cyprus	5	7		3	3
Malta	3	5	1/3		1
Sicily	3	5	1/3	1	
Consistency ratio: 0.0286 < 10%					



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Table 3.2.9. Seawater heating under scenario RCP8.5 for the near future (2046-2065)

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		5	1/4	1/2	1/3
Canary	1/5		1/8	1/6	1/5
Cyprus	4	8		3	3
Malta	2	6	1/3		1
Sicily	3	5	1/3	1	
Consistency ratio: 0.0407 < 10%					

Table 3.2.10. Seawater heating under scenario RCP8.5 for the distant future (2081-2100)

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		6	1/3.5	1/1.5	1/1.5
Canary	1/6		1/9	1/7	1/7
Cyprus	3.5	9		2.5	2.5
Malta	1.5	7	1/2.5		1
Sicily	1.5	7	1/2.5	1	
Consistency ratio: 0.0159 < 10%					

○ A conjoint analysis of the four tables related to the RCP and time horizon scenarios regarding the heating of the sea surrounding the islands along through the 21 century reveals that experts mainly appreciate a faster worsening in the Balearic Islands. Even if seawaters in Cyprus are going to warm the most in absolute terms, followed by the islands of Malta and Sicily, in the scenario named RCP8.5 distant future, the indicator of number of days over 26 degrees in the seawaters of the Spanish archipelago practically reaches the same score than in those in Central Mediterranean waters. The relative advantage of the Canary Islands with respect to the remaining islands become consolidated as the 21 Century goes forward.

Exposure

Table 3.2.11. Seagrass meadows' surface

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		9	9	5	2
Canary	1/9		1/3	1/5	1/8
Cyprus	1/9	3		1/3	1/6
Malta	1/5	5	3		1/4
Sicily	1/2	8	6	4	
Consistency ratio: 0.0513 < 10%					

Table 3.2.12. Number of divers per year

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		3	8	5	7
Canary	1/3		6	3	5
Cyprus	1/8	1/6		1/3	1/2
Malta	1/5	1/3	3		1/2



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Sicily	1/7	1/5	2	2	
Consistency ratio: 0.0606 < 10%					

Table 3.2.13. Tourist arrivals

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		1	6	8	3
Canary	1		6	8	3
Cyprus	1/6	1/6		2	1/3
Malta	1/8	1/8	1/2		1/5
Sicily	1/3	1/3	3	5	
Consistency ratio: 0.0134 < 10%					

○ In this regard, phanerogams are the species that most determinate the maintenance of the marine habitat services that support a wide range of recreative and sportive tourist activities in coastal and marine tourism. They are responsible of sheltering and feeding a big part of the remaining species and keeping clear the seawater body by absorbing suspended organic matter and sediments. Diversification and increasing of added value of coastal and marine tourist activities critically depend on the conservational status of the phanerogam meadows.

○ Experts recognise that the Balearic and Sicily islands are the ones that present more of these natural resources exposed to the impacts of climate change, particularly to seawater heating, while the Canary Islands, Cyprus and Malta are the lesser exposed at this regard, respectively. The amount of tourism industry exposed to the marine habitat degradation because of the seawater heating exhibits a different ranking of importance. While the Balearic again leads the number of direct users of the islands' biodiversity across the set of the islands differently, the Canary Islands climb to the second position in this category, and to the first one, together with the Balearic, in the total number of users of the marine habitat services, mainly clear water for bathers.

○ Jointly, is it clear that the Balearic Islands outstand in the exposition of the relevant natural and human systems as a whole, while the islands lesser based in marine tourism are the least exposed to the hazard under study. Finally, regarding the Canary Islands, although their phanerogam meadows are not so large as those of some of the other islands, the magnitude of their tourist industry makes them globally quite exposed to the effects of seawater heating.

Sensitivity

Table 3.2.14. Phanerogam meadows' susceptibility to seawater heating

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		1	9	3	3
Canary	1		9	3	3
Cyprus	1/9	1/9		1/3	1/3
Malta	1/3	1/3	3		1



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Sicily	1/3	1/3	3	1	
Consistency ratio: 0.000 < 10%					

Table 3.2.15. Economic valuation: Tourists' willingness-to-pay (€/day) to implement policies aiming at avoiding marine habitats degradation.

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		1/7	1/2	1/3	1/4
Canary	7		6	5	4
Cyprus	2	1/6		1/2	1/3
Malta	3	1/5	2		1/2
Sicily	4	1/4	3	2	
Consistency ratio: 0.0273 < 10%					

○ The expert opinion compares two complementary aspects of the sensitivity of the tourist industry of the islands to the heating of the surrounding waters, the sensitivity of the phanerogam meadows to heating, that is, the rate of the surface reduction in response to changes in seawater temperature, and the sensitivity of tourism to those environmental changes. Together, these two sensitivities give account of the potential reaction of the whole tourism systems to climate change in this realm.

○ In this respect, scientific research is still lacking very concluding results. Paleo-studies show that the spreading of the phanerogams across the Mediterranean Sea and the Atlantic Ocean close to the Northwest African coasts, goes east to west. It means that the eastern meadows are more robust and genetically differentiated than the western ones so they can cope better with any impact, also those reacted to climate change. In addition, Mediterranean seawaters, particularly the eastern side of them, experience greater temperature variability than the Atlantic ones. Because of it, eastern phanerogam meadows are better endowed to support additional temperature variability as that powered by climate change. This issue displays very complex edges as even the same phanerogam specie shows different capabilities to face seawater temperature variability depending on its location, that is to say, of its past experience with the environmental pressure under study. Consequently, phanerogam meadows around Cyprus are more resilient to thermal stress, than those surrounding Malta and Sicilia and, finally, the seagrasses rooted on the sea grounds of the Balearic and the Canary Islands.

○ The other side of sensitivity, the one showed by tourists when facing the deterioration of the marine habitat of the island destinations and expressed in monetary terms, shows a very different hierarchy than the former one. Indeed, while the visitors of the Balearic Islands show a very low economic valuation for the loss of marine habitat tourist services, in terms of willingness to pay to act to prevent deterioration, the Canary Islands are located on the other extreme and their visitors display the highest inclination to pay for protecting the marine habitats. The other three islands play in the middle of the former two and very close to each other, in this regard.



Adaptive capacity

Table 3.2.16. Products Substitution Capacity

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		1	1/2	1/2	2
Canary	1		1/2	1/2	2
Cyprus	2	2		2	6
Malta	2	2	1/2		4
Sicily	1/2	1/2	1/6	1/4	
Consistency ratio: 0.0009 < 10%					

Table 3.2.17. Removal of dead seagrass from the beaches

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		7	4	4	6
Canary	1/7		1/3	1/3	1/2
Cyprus	1/4	3		1	3
Malta	1/4	3	1		3
Sicily	1/6	2	1/3	1/3	
Consistency ratio: 0.0256 < 10%					

Table 3.2.18. Seawater pollution

	Balearic	Canary	Cyprus	Malta	Sicily
Balearic		1	1/3	1/3	1/3
Canary	1		1/3	1/3	1/3
Cyprus	3	3		1	1
Malta	3	3	1		1
Sicily	3	3	1	1	
Consistency ratio: 0.000 < 10%					

○ As in many other cases, societies hold low capacities to prevent the direct effects of seawater heating on the marine habitats. To now, capabilities developed to reforest seagrasses are very low while seawater heating shows a strong inertia. Thus, adaptive capacities go along the ways of trying to reduce the dependence of the tourism industry on the marine habitat conservation status, even for the case of coastal destination, palliate the most immediate and perceptually negative effects and improve the management of other vectors of pressure that also affect the quality of the marine environment for tourism.

○ Three variables and their respective indicators were selected to represent the potential of the adaptive capacity that the studied islands hold to address the environmental problems associated to seawater heating; and according to the experts, islands show different capabilities related to those capacities. Regarding



the capacity to reduce the dependence of the tourist demand from the marine habitat services, experts consider Sicily the best positioned and Cyprus the worst one. Weighting the factors which influence the products substitution capacity is not an easy task as it takes into account not just the availability of non-coastal resources (cultural, urban, events, etc.) but also managerial, technological, financial and institutional resources. Considered jointly, the capacities of the the Canary Islands and Malta were assessed as similar although underpinning on different elements.

- The capacity of keeping the beaches free of dead seagrasses was critically evaluated by the experts. As said above, they had to make abstraction from the ecological recommendation of not removing these elements from the ecosystems for long term conservation purposes. So, they just considered the evidence about the presence of dead seagrasses and the frequency with which local authorities remove them from the populated beaches. The Balearic shows the worst and the Canary displays the best situation regarding this, considering the technical capacities, the priority in the decision-making process and the frequency and intensity of the dead seagrasses' arrival to beaches. Sicily was assessed very close to the Canary Islands addressing capacity while Malta and Cyprus occupied intermediate positions, in part because the natural episodes are not so intense and frequent as in the Balearic Islands.

- Assigning capacities in the realm of seawater pollution forced experts to distinguish between the technical capacities to sewage treatment and the self-depurative capacity of the seawater surrounding the islands, as explained above. For example, even if the technical capacities are similar in the Balearic and the Canary Islands, the seawater pollution is generally higher in the Mediterranean archipelago due to higher water column stratification. Having in mind both aspects, and also the experience collected from previous research in most of the islands under study, experts conferred to different levels being the best one that exhibited by both Spanish archipelagos, which were assessed moderately better than the level exhibited for the remaining set of islands (Malta, Sicily and Cyprus).

Result aggregation and island ranking

Based on the global weights of each sub-criterion and the corresponding comparison of the islands, the overall ranking of each island is computed. Although the general purpose is to compare the islands under each different emission scenario (RCP 2.6 and RCP 8.5) and time horizon (near and distant future), as the two RCP.2.6 and the near-future RCP 8.5 scenarios do not differ too much from the reference scenario (1986-2005), most of the analysis provided in this section is based on the results obtained under the distant future RCP 8.5 scenario⁸. The table below shows the global weights of the sub-criteria and the criteria and the global score of the risk for each island; thus islands can be compared not just globally but also across the set of the sub-criteria and the criteria being considered to estimate the aggregated risk.

⁸ Final scores and islands' ranking for all RCP scenarios and time horizons can be found in section 7.4 of this report.



Table 3.2.19. Final scores and islands' ranking (under RCP8.5 distant future).

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sicily
Hazards	Seawater heating RCP8.5 (2081-2100)	0.018 (8.0%)	0.004 (2.2%)	0.054 (23.6%)	0.025 (12.7%)	0.025 (14.7%)
Exposure	Surface of marine phanerogams	0.034	0.002	0.004	0.009	0.022
	Number of divers	0.009	0.005	0.001	0.002	0.002
	Tourist arrivals	0.013	0.013	0.002	0.001	0.006
	<i>Total</i>	0.056 (25.0%)	0.020 (11.0%)	0.007 (3.1%)	0.012 (6.1%)	0.029 (17.1%)
Sensitivity	Phanerogams' susceptibility to heat	0.072	0.072	0.008	0.024	0.024
	Economic valuation	0.003	0.027	0.004	0.006	0.010
	<i>Total</i>	0.075 (33.5%)	0.099 (54.7%)	0.012 (5.2%)	0.030 (15.2%)	0.034 (20.0%)
Adaptive capacity	Products substitution	0.034	0.034	0.086	0.060	0.016
	Seagrass removal	0.020	0.002	0.007	0.007	0.003
	Sea water pollution	0.021	0.021	0.063	0.063	0.063
	<i>Total</i>	0.079 (35.0%)	0.058 (32.0%)	0.155 (67.7%)	0.130 (66.0%)	0.082 (48.2%)
Total		0.224	0.181	0.229	0.197	0.170
Rank		2	4	1	3	5

Note: Total contribution of the criterion to the final score of the island in parenthesis.

The risk: from Eastern to Western and viceversa

The relative risk for marine habitat-based tourism demand due to the heating of seawaters surrounding European islands is determined by the combination of three different factors already reflected in the marine habitat impact chain: the intensity and lasting of periods of seawater heating, the susceptibility of the marine habitats and tourism activities based on it to the heating process and the changes in the habitat, respectively; and the capacities of the respective islands' societies to reinforce natural and social systems' resilience to seawater heating and its ecosystem impacts.

Based on the available indicators and on their own knowledge, the experts' evaluation of the complex relationships between seawater heating, habitats transformation and the response of the tourism system, depicts a big picture featured by the following results:



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- From the perspective of the intensity of the hazard, threats diminish from Eastern to Western. Effectively, episodes of water heating threatening the integrity of marine ecosystems will be much more relevant throughout the Eastern Mediterranean and will become softer as moving Western.
- From the perspective of the susceptibility of the marine foundation species to seawater heating, western Mediterranean hosts the most vulnerable phanerogam communities as genetically they are not ready to face increasing water temperature variability at the rhythm climate change is powering. As a result, this risk factor decays from Western to Eastern.
- Other relevant factors determining the relative risk faced by each island are related to the management capacity of other hazards, different than seawater heating, also degrading marine habitats (i.e. the current relevance of marine habitat-based tourism and the capacity of the local tourism system to provide competitive alternatives giving value to other, not marine-based natural and cultural tourist attractions). Those capacities are unevenly distributed across the islands, basically depending on the level of development of their respective environment management and tourism management subsystems.

Some characteristics of the risk ranking provided by experts, and consequently, the final scores, are:

- Cyprus leads the rank of risk due to, in addition to the greater seawater heating, its experiencing ecological disruptive processes related to its closeness to the Red Sea; strongly attracting exotic species with high capacity to destabilise the marine ecosystems.
- On the other extreme, Sicily is the island exhibiting a lesser risk mainly due to it holds a more balanced distribution of the indicators expressive of the range of factors determining the risk.
- The Canary Islands hold a relatively low risk mainly due to their expected low level of seawater heating; their higher weakness consists of the magnitude of the tourism system exposed to the potential risk.
- The Balearic Islands are the most exposed islands. In addition, RCP8.5 distant future shows a progress in heating relatively higher than other islands, meaning a strong threat for their relatively susceptible Posidonia meadows.
- Malta holds a relative low risk mainly due to its low exposition to the risk and the potential of alternative, non-marine-habitat-based, tourist products.

Below are presented some paragraphs devoted to go deeper into the complexity of the ecosystem dynamics that influence the holistic effect of climate change on the European islands' marine habitats; before presenting some lines highlighting the specificities of this impact chain for each island.

In the Eastern Mediterranean, the impact of seawater heating on the seagrass meadows (and on the marine habitat as a whole) not only depends on the physiological response of the plants concerned to heating, but also on the response of the system as a whole. On the Eastern shore of the Mediterranean, a strong increase in herbivorous species from the Red Sea has been observed that cross the Suez Canal and have settled near the continental and insular coastal areas. Posidonia meadows have been found to be part of their diet.



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The heating exacerbates the metabolic needs of these herbivorous species (*Siganus Luridus* and others) increasing their voracity and, consequently, leading to greater pressure on the phanerogams. Given that, on the other hand, the surface of these meadows in the environment of Cyprus is small, predation by these herbivores may threaten *Posidonia* with extinction, disappearing with it the conservation functions of the ecosystem that it currently carries out as protection against erosion, containment of water turbidity (assimilation of organic residues), shelter and food for fingerlings of fish and other marine organisms, etc.

Other factors such as the sewage treatment or the sedimentation of waste from coastal constructions interact with the seawater heating, exacerbating the degradation of marine habitats. Together, factors of global change other than seawater heating are expected to act more intensely in Cyprus, increasing the vulnerability of this island's marine habitat to climate change.

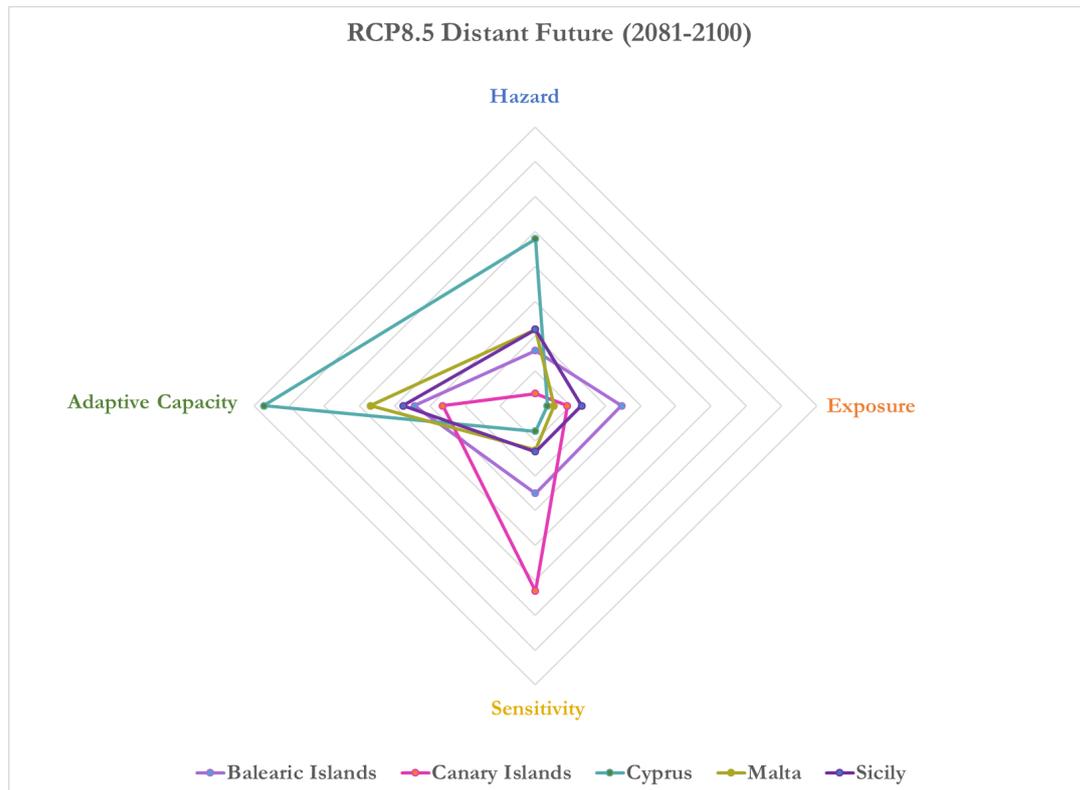


Figure 3.2.3. Comparison of criteria and islands for distant future under RCP8.5.

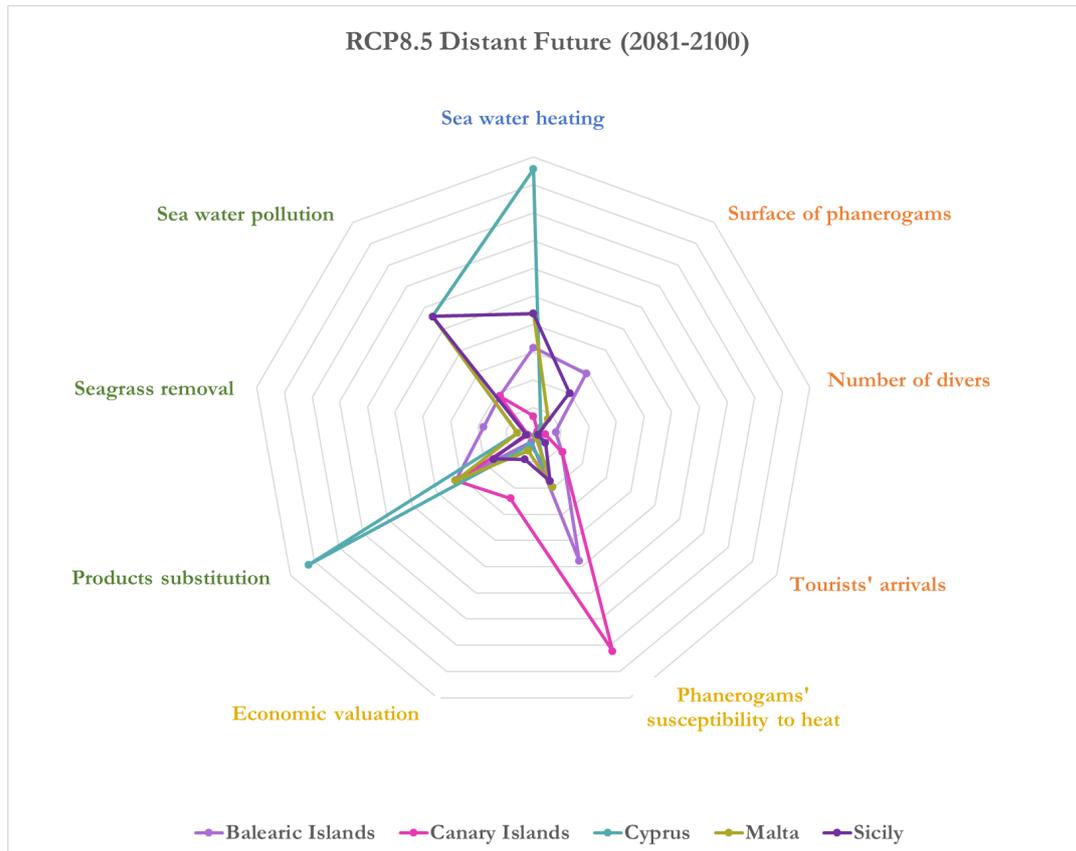


Figure 3.2.4. Comparison of sub-criteria and islands for distant future under RCP8.5.



Analysis per island

The results displayed above emphasise comparisons between islands as this is the main purpose of this analysis. However, results also allow to analyse the internal components of the risk exhibited by each island. This final sub-section aims at presenting a simple gaze of the components of the risk that each island face related to the impact of seawater heating on the marine habitat services that underpin its tourism industry. It comes simply from analysing with some more detail the percentages regarding the total score for the risk of the criteria and sub-criteria considered to obtain it. Graphical representation for each island can be found in section 7.4.

Balearic

Balearic's risk regarding seawater heating rests on the high natural exposure represented by the surface of their Posidonia meadows and the size of their marine habitat-based tourist activity, representing the 25% of the risk. Of course, as Posidonia surface must be preserved, and the flow of tourists maintained, resilience against this risk should be achieved through strengthening mainly the potential to successfully substitute marine based demand for demand for other tourist products, that need to be properly developed and commercialised. The Archipelago has a wide range of other natural and cultural resources and technical and financial capabilities to go forward this way and is already working on it. The eradication of other pressures on Posidonia meadows, as sewage and coastal infrastructures, is capital for keeping this risk under control, as it has been outlined by recent research.

Canaries

The Canary Islands hold the best natural conditions to face this risk as all consulted climatic models predict a very low probability of seawater heating to increase over the critical thresholds for the Cymodocea meadows surrounding their seaways. This and the tourists' perception of the marine attributes sensitivities explains more than 54% of the total risk that the Archipelago exhibits at this regard. This vulnerability is partially compensated by the fact that a great part of its marine biodiversity-based tourist activity depends on ecological processes different than those supported by seagrasses meadows, like cetaceans watching, but still showing high uncertainty about its relationship with this and other climate hazards. Like in the case of the Balearic, the Canary need to develop capacities for tourist diversification bringing other resources to the tourist value generation process. Fortunately, seawater mobility around the islands allows to hide the deficits of an insufficient and inefficiently managed sewage treatment system.

Cyprus

The position of Cyprus leading the ranking of the risk of its tourism industry to be negatively affected by seawater heating powered by climate change rests mostly on the two extremes of the impact chain under study. While the hazard explains the 23.6% of the risk the deficits of the adaptive capacity explain another 67.7%, both giving account for more than the 91.3% of the risk. Although the island holds many cultural resources to decouple the generating of tourist value added from the marine environment conditions, some technical, institutional and, even, historical factors prevent from going further this way so far. Reviewed information show some projects and policies that have been undertaken to explore pathways for a successful diversification but it seems that the translation of the potentialities into effective policies has failed due to obstacles related to governance.

Malta

The island shows starting surrounding conditions favourable to face the risk of seawater heating. Although the island scores the second worst in adaptive capacities to cope with the main vectors of the problem, there are two particular aspects that compensate that disadvantage. Firstly, the island does not hold attributes to attract classical massive tourism to its coasts, as large beaches and exuberant marine ecosystems. Conversely, Maltese tourism is attracted by cultural attributes and



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business. Secondly, its marine tourism industry heavily rests on activities that are not sensitive to the quality of the marine environment, as the motorised ones. Because of it, even if Malta shares with Sicily the lowest risk related to seawater heating, this island show lesser uncertainties than those showed by the Italian island.

Sicily

Sicily ranks the best position regarding the climate change risk under analysis. The island does not outstand in any component of the risk but neither shows critical pitfalls regarding it. With respect to the foundation specie, the island holds the second largest surface, but lesser susceptible to sweater heating. This island also presents the most balanced tourist demand, as it treasures a wide range of cultural, social, landscape, gastronomic and historic resources to underpin a tourism industry not very dependent on the marine environment. All these factors together, but none of them particularly, make Sicily the most resilient island to the risk of its tourism industry being affected by the seawater heating. The most salient weakness al tis respect seems to be the seawater pollution due to a deficient capacity to treat sewage. Related investments should be a priority for this island.

Table 3.2.20. Summary of scores and final ranking of islands for all four of the emissions scenarios.

Rank	Island	RCP2.6		RCP8.5	
		Near future (2046-2065)	Distant future (2081-2100)	Near future (2046-2065)	Distant future (2081-2100)
1 (most risk)	Cyprus	0.233	0.233	0.232	0.229
2	Balearic	0.218	0.218	0.221	0.224
3	Canary	0.197	0.197	0.196	0.197
4	Malta	0.182	0.182	0.181	0.181
5 (least risk)	Sicily	0.170	0.170	0.170	0.170

Conclusions

The operationalization of the impact chain for the “Loss of attractiveness of a destination due to the loss of services from marine ecosystems” was conducted using the AHP method. The method proved to be appropriate, firstly, for dealing with the hierarchical nature of the impact chain and, secondly, for using expert judgements to assess the comparative risk for the islands over a large number of indicators (sub-criteria).

Because the AHP method determines a ranking of the islands, it can provide decision makers with relative values but not with absolute values. Such values will be delivered by the modelling activities of other work packages and will give stakeholders a more complete picture of this specific risk in terms of social, economic, and environmental impacts, such as the increase in water demand, change in tourist seasonality, as well as increase in costs related to energy consumption and medical care.



Impact Chain 2: risk of forest fires and loss of attractiveness

Forest fires are considered as an important parameter for the attractiveness of tourist destinations, especially in the Mediterranean area. Severe episodes were met in Algarve (Portugal) and Greece (Athens area) in the recent period, threatening the tourist season.

This section focuses on the implementation and analysis of the selected Impact Chain “Risk of forest fires and consequences on tourism attractiveness of a destination”. Out of the 12 islands assessed in the SOCLIMPACT project, nine were included in the operationalisation: the three Atlantic Islands (Azores, Canary Islands and Madeira) and the Mediterranean ones (Balearic Islands, Crete, Corsica, Cyprus, Malta, Sardinia and Sicily). The other two (Baltic Island and French West Indies) do not have fire activity or show insufficient data availability.

In the framework of tourism sector, sector teams and IFPs identified as one of the main risks the “Loss of attractiveness due to increased danger of forest fire in touristic areas” and developed the theoretical IC as presented in Figure 3.2.5.

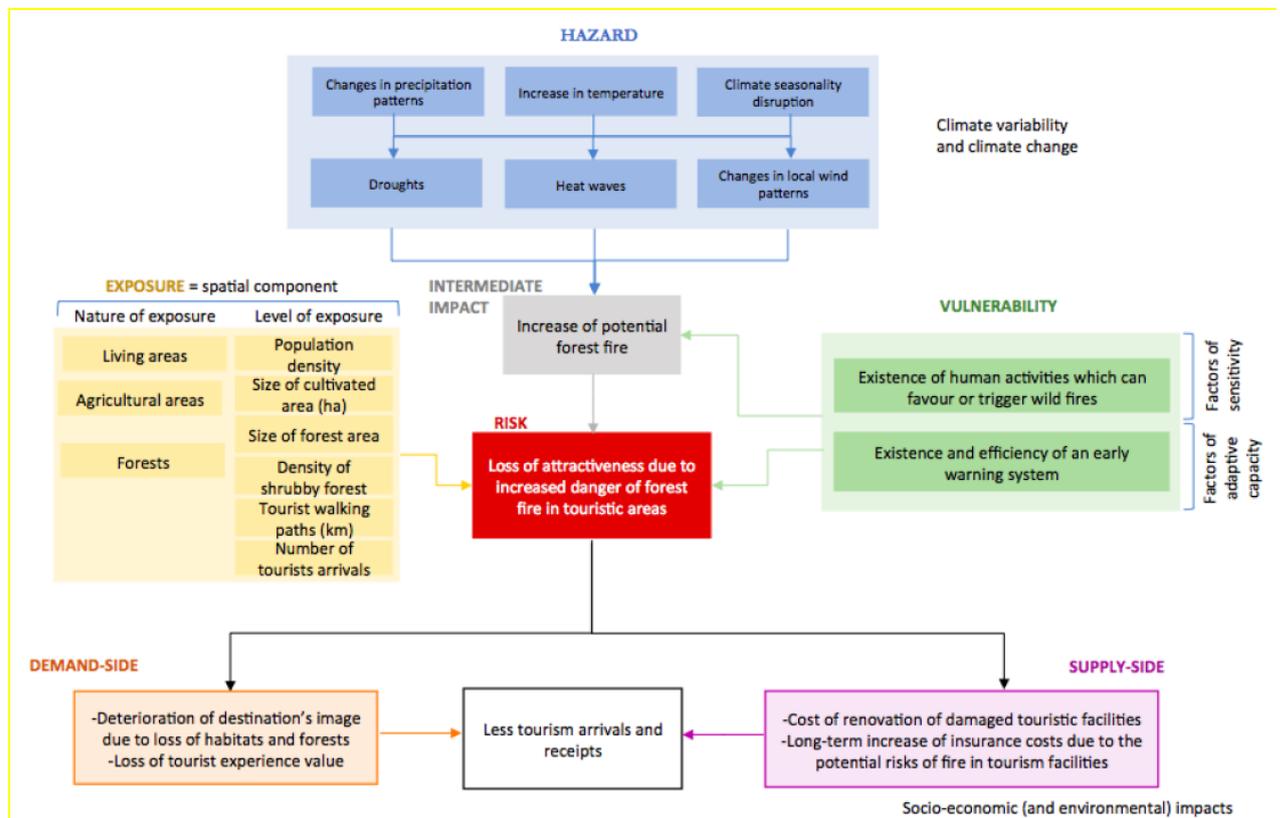


Figure 3.2.5. Loss of attractiveness due to increased danger of forest fire in touristic areas (source: D3.2).

With the aim to support the identification and selection of the indicators per factor in the impact chains developed in D.3.2, a template indicator factsheet has been prepared in the framework of D3.3 to record all potential indicators with a brief description, the unit of measurement, potential data sources, and a brief explanation outlining the reason for selecting it. Thus, the identified suitable indicators were associated to the identified factors of the impact chain and a new diagram tool has been proposed (Figure 3.2.6).

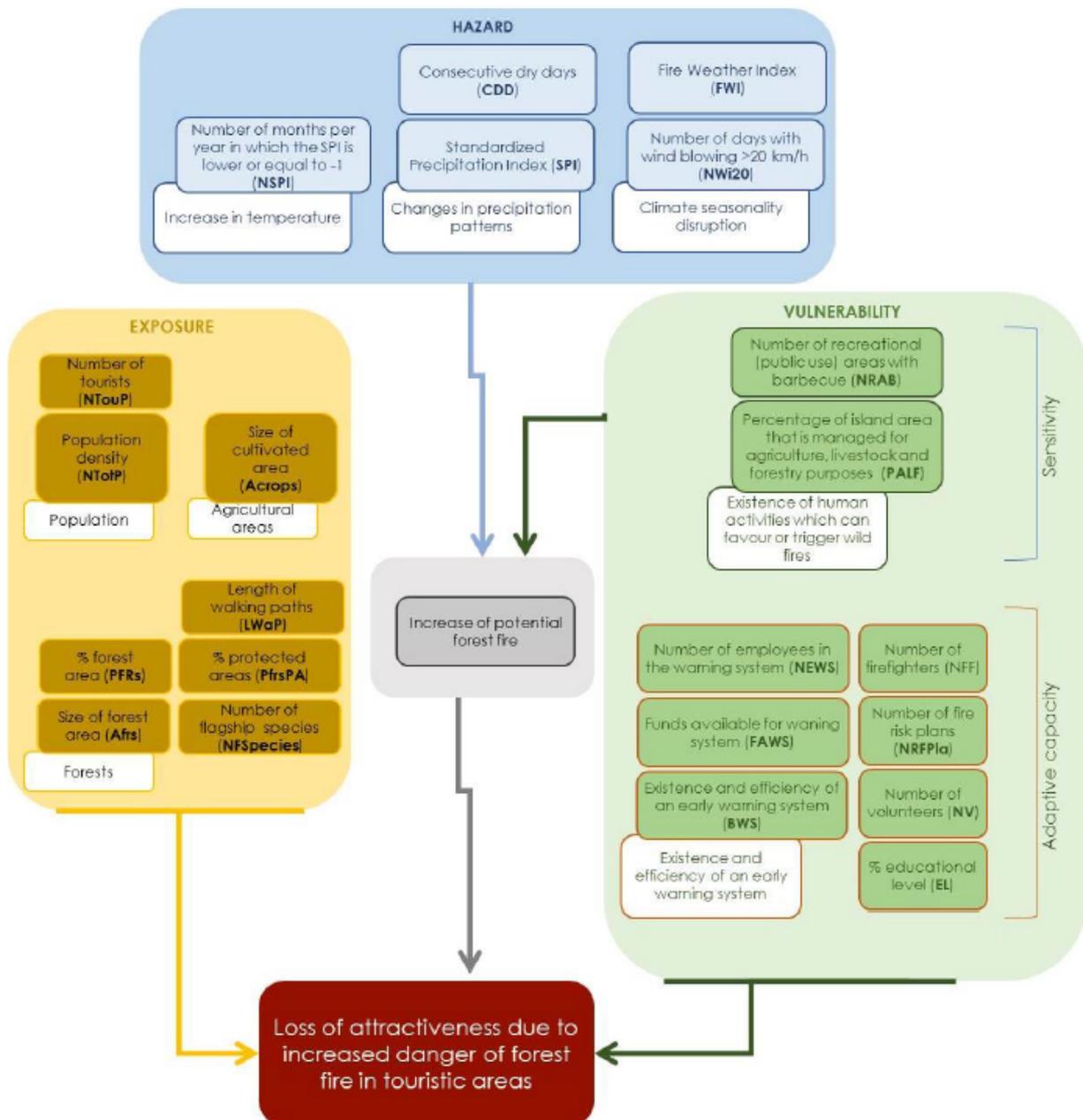


Figure 3.2.6. Loss of attractiveness due to increased danger of forest fire in touristic areas, from D3.3

We assessed whether selected indicators are sufficiently explicit or not. Indeed, many indicators were formulated in a very generic way, causing a few problems in identifying suitable data sets. Furthermore, the data were checked for explicit spatial coverage, resolution, temporal coverage and

time frame. Finally, we evaluated possible substitutes or alternatives for those indicators with no suitable data to substantiate them.

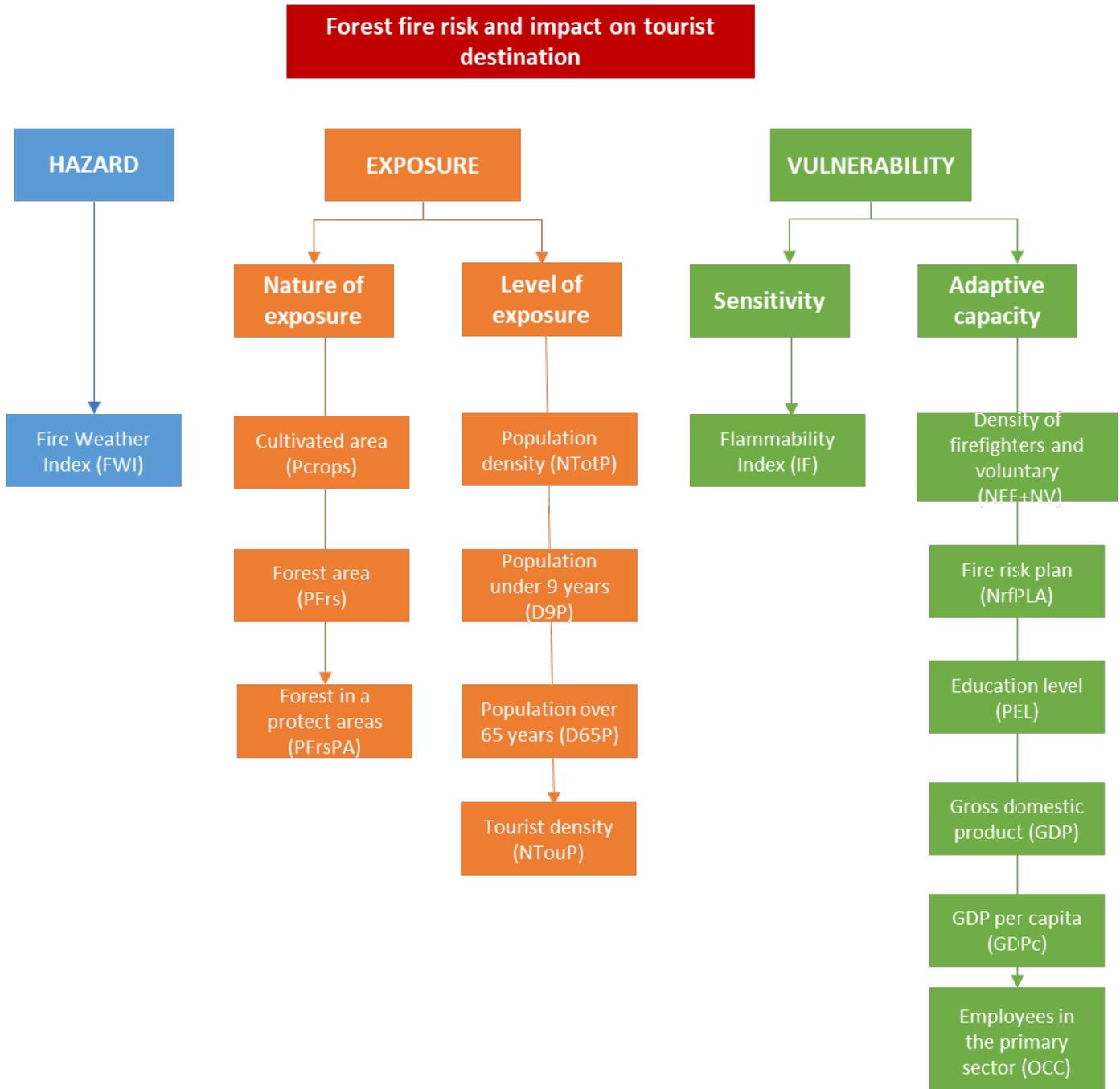


Figure 3.2.7. Final Impact Chain Model



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Comparative analysis

Hazard

The main findings are (from D4.3):

- Scores for fire danger (Figure 3.2.8, Figure 3.2.9 and Figure 3.2.10) increase as we move from West to East and from North to South, with the exception of Malta, which is much smaller and the selected grid cells are mostly influenced by maritime conditions.
- Under RCP2.6, it seems that the fire danger returns to the present conditions towards the end of the century (Figure 3.2.9) apart from Crete which score will increase from medium to high, even under this RCP.
- Under RCP8.5, the increase is much more prominent, ranging from 22% to 46%, with the highest values for Corsica, Sardinia and Sicily, which implies that under this scenario at the end of the Century, the western and central Mediterranean will be more affected (Figure 3.2.10).



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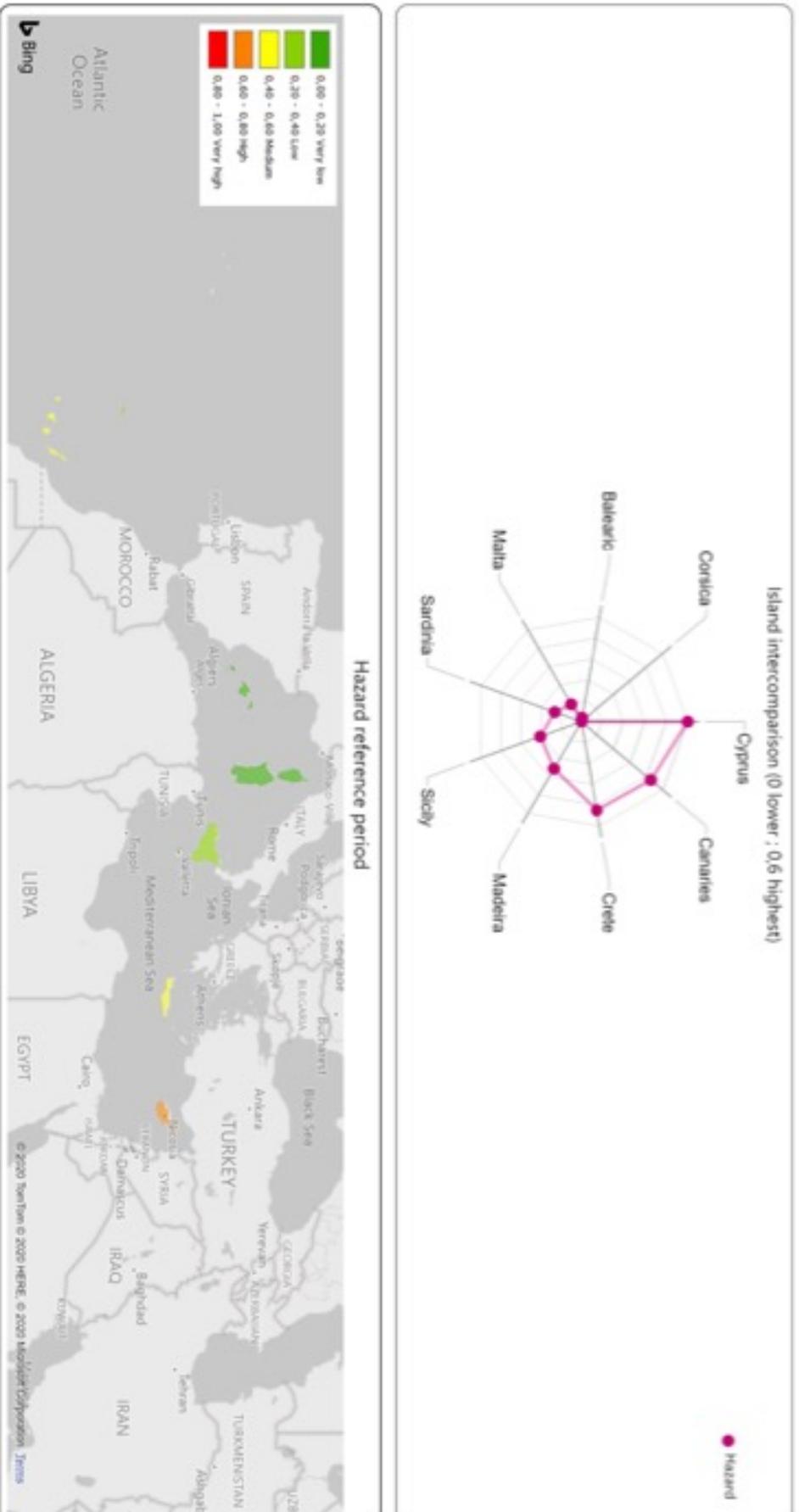


Figure 3.2.8. Hazard score (Fire Weather Index) per island for the reference period (1986-2005)



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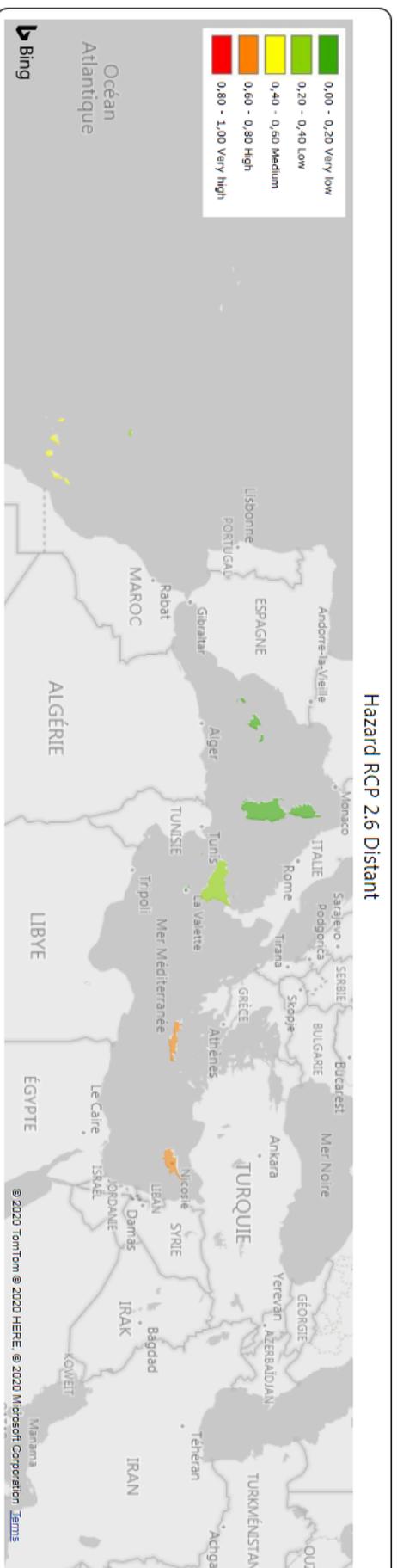
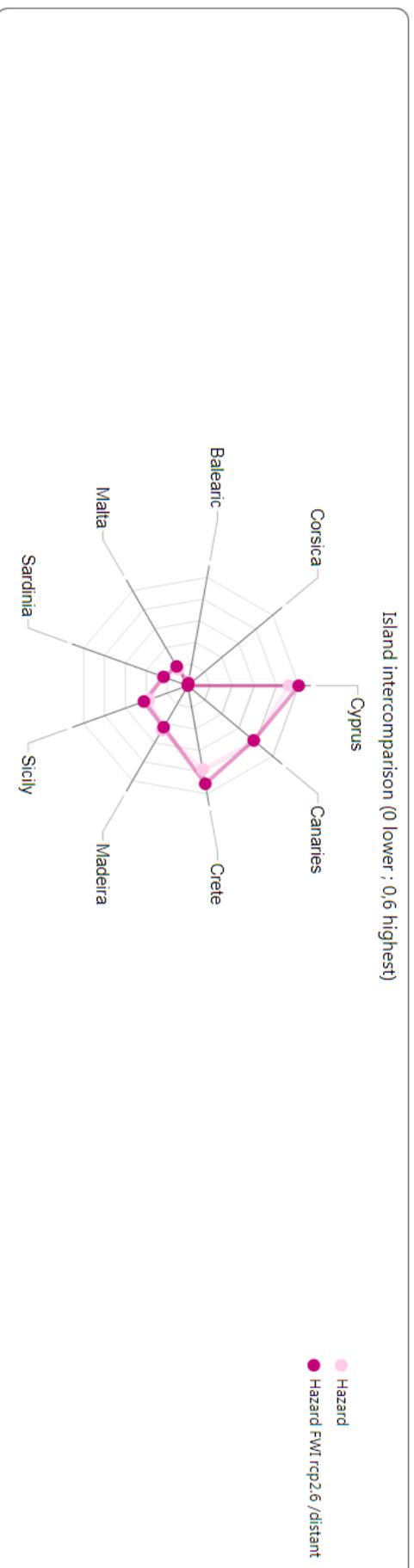


Figure 3.2.9. Hazard score (Fire Weather Index) per island at the end of the century (2081-2100) under RCP2.6 (Ambitious Mitigation Policies)



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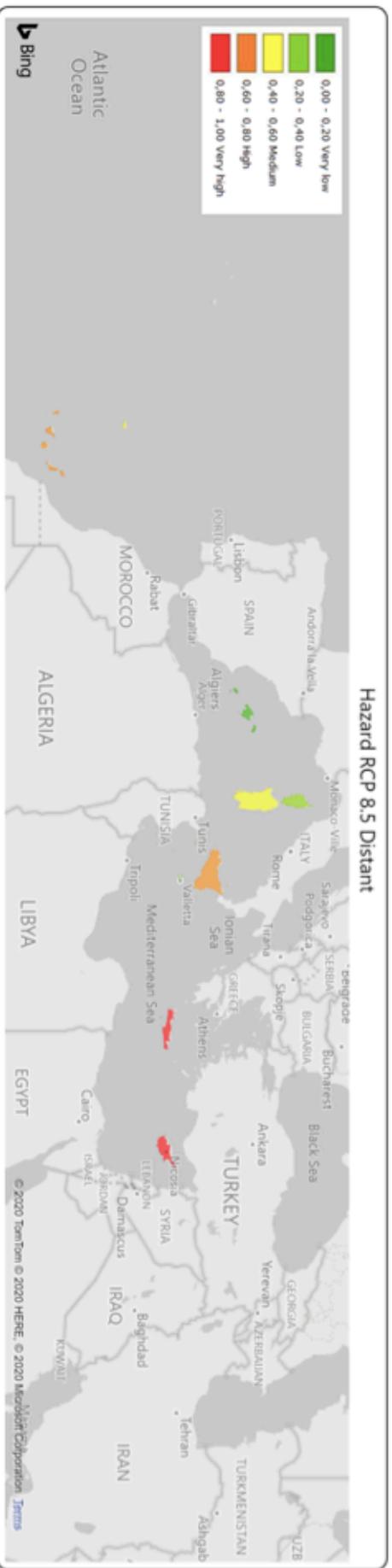
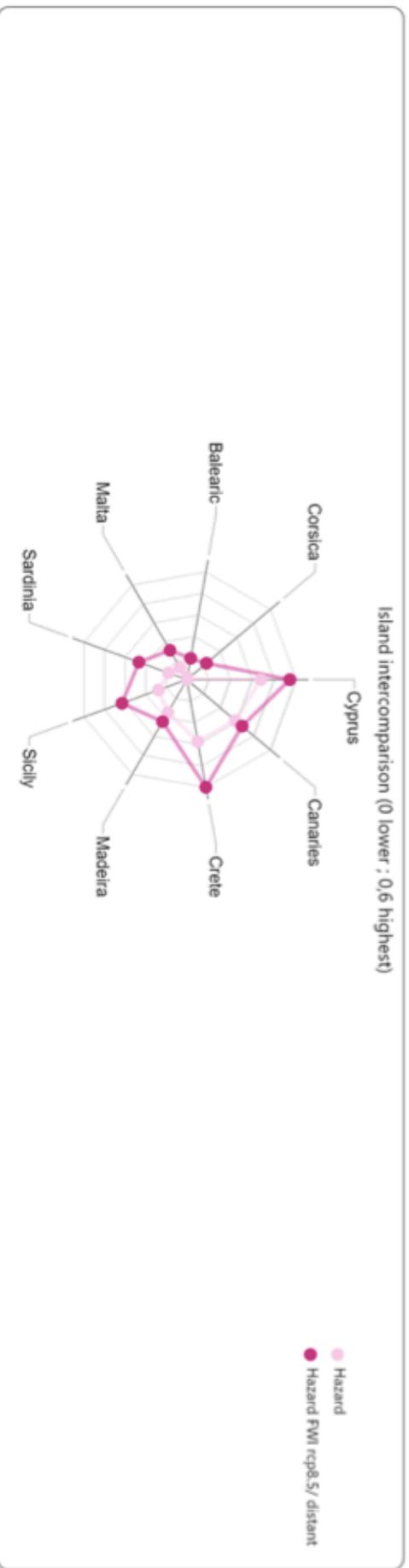


Figure 3.2.10. Hazard score (Fire Weather Index) at the end of the century (2081-2100) under RCP8.5 (Business as usual)



Exposure

The results show that:

- Atlantic Islands (Madeira and Canary Islands) are more exposed (high score, Figure 3.2.11) than Mediterranean Islands (from low to medium score). We can see an increase as we move from North to South in the Mediterranean area.
- Atlantic Islands higher scores (Figure 3.2.12) are mainly explained by the level of exposure rather than the nature of exposure, which is quite similar across islands, except for Malta which rate is very low.
- **The nature of exposure** varies across EU Islands despite of their homogeneous score: Corsica has the highest score for forest areas followed by Madeira, Canary Islands. These two last ones have the highest score of forest belonging to protected areas. We can find a significant proportion of cultivated areas in other Islands namely: Sicily, Sardinia, Balearic Islands, Crete and Cyprus.
- **The level of exposure** for Canary Islands and Madeira is particularly important because of the high scores for each of the 4 considered indicators: population density, population over 65 years, population under 9 years and tourist density (Figure 3.2.13).



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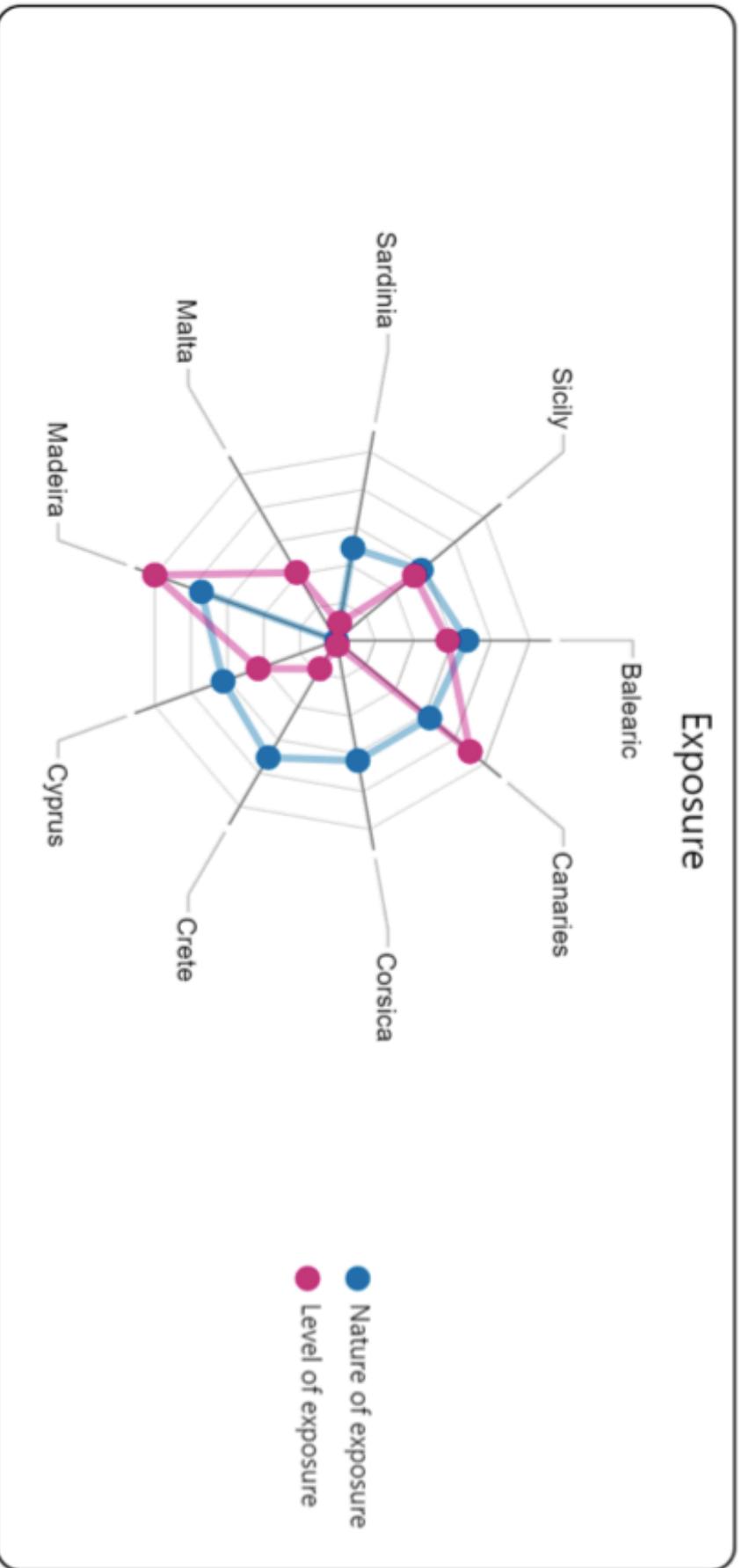


Figure 3.2.12. Subcomponents of exposure and related score (current period) per island



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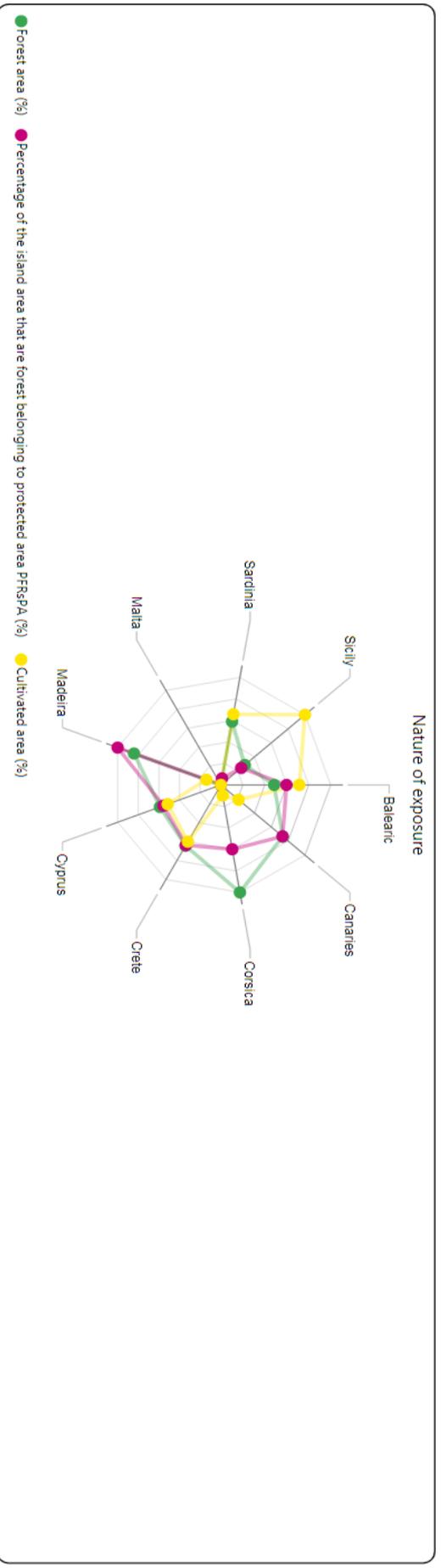
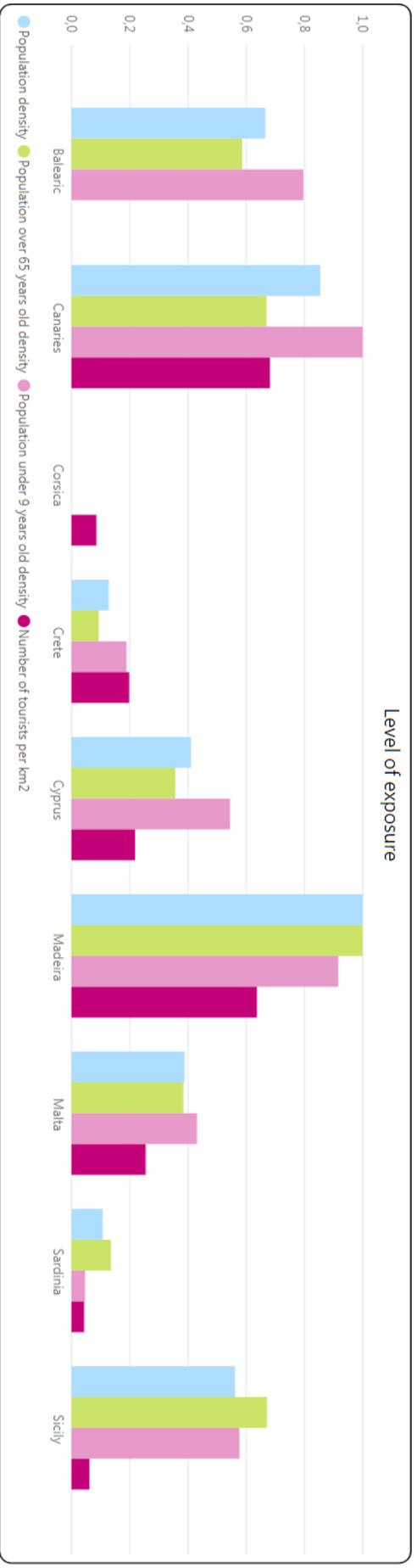


Figure 3.2.13. Breakdown by exposure subcomponent

Vulnerability

The main findings are:

- Results show large disparity across EU Islands in terms of vulnerability (Figure 3.2.14). The vulnerability score for Corsica is very high followed by Sardinia (high), Madeira, Balearic Islands, Cyprus and Crete. Malta, Canary Islands and Sicilia scores are low.
- Breakdown by component (Figure 3.2.15) highlights a quite homogeneous score for adaptative capacity whereas sensitivity score (Flammability Index) is very different from an island to another.
- Not surprisingly for the flammability index (Figure 3.2.16), Corsica and Sardinia have the highest score, Malta, Sicilia and Canary Islands, the lowest one.
- Looking at the adaptative capacity subcomponent (Figure 3.2.16), despite of the quite homogeneous scores, factors of influence are quite different among the islands:
 - high score for employees in the primary sector, apart from Sardinia and Sicily;
 - scores for density of firefighters and volunteers are important for all the islands except for Cyprus;
 - GDP per capita and level of education are the most heterogeneous factors of influence;
 - GDP per capita score is very high for Crete, very low for Corsica, Malta and Balearic Islands.
 - Scores for education level is important for Cyprus and low for Madeira, Malta and Corsica.



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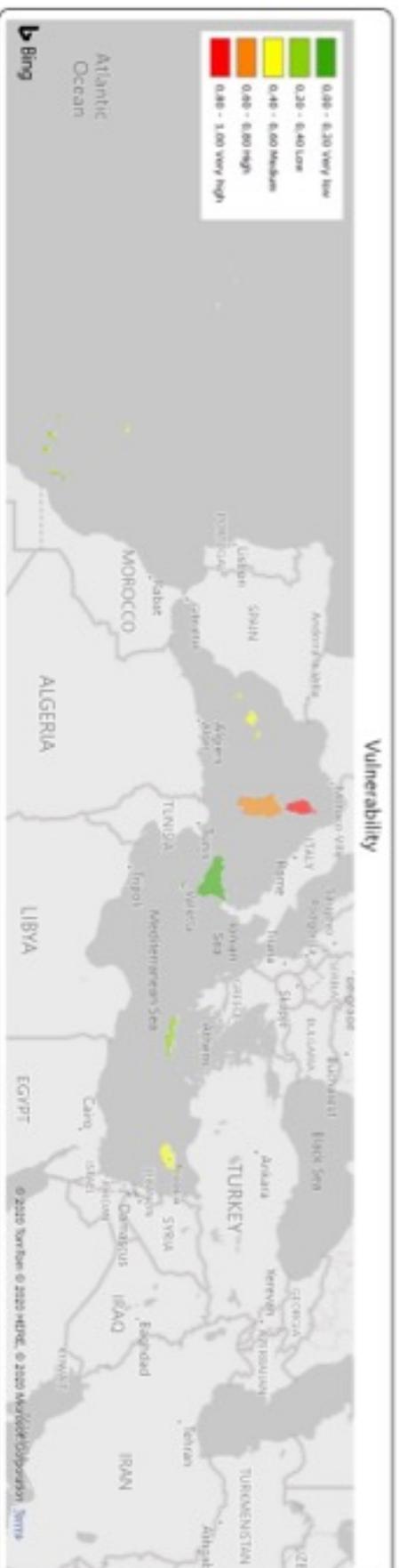
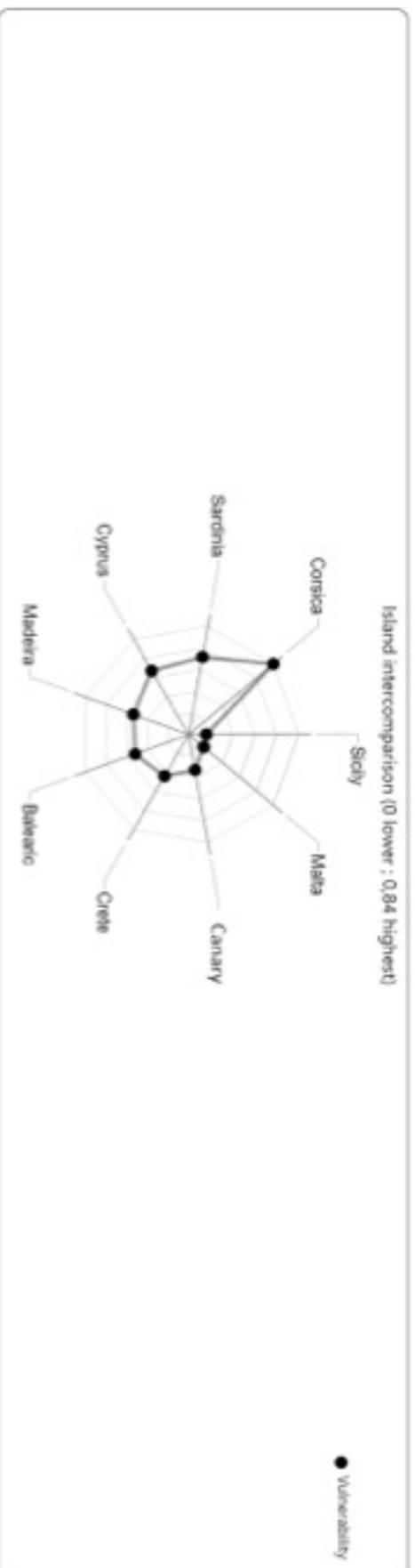


Figure 3.2.14. Vulnerability score per island



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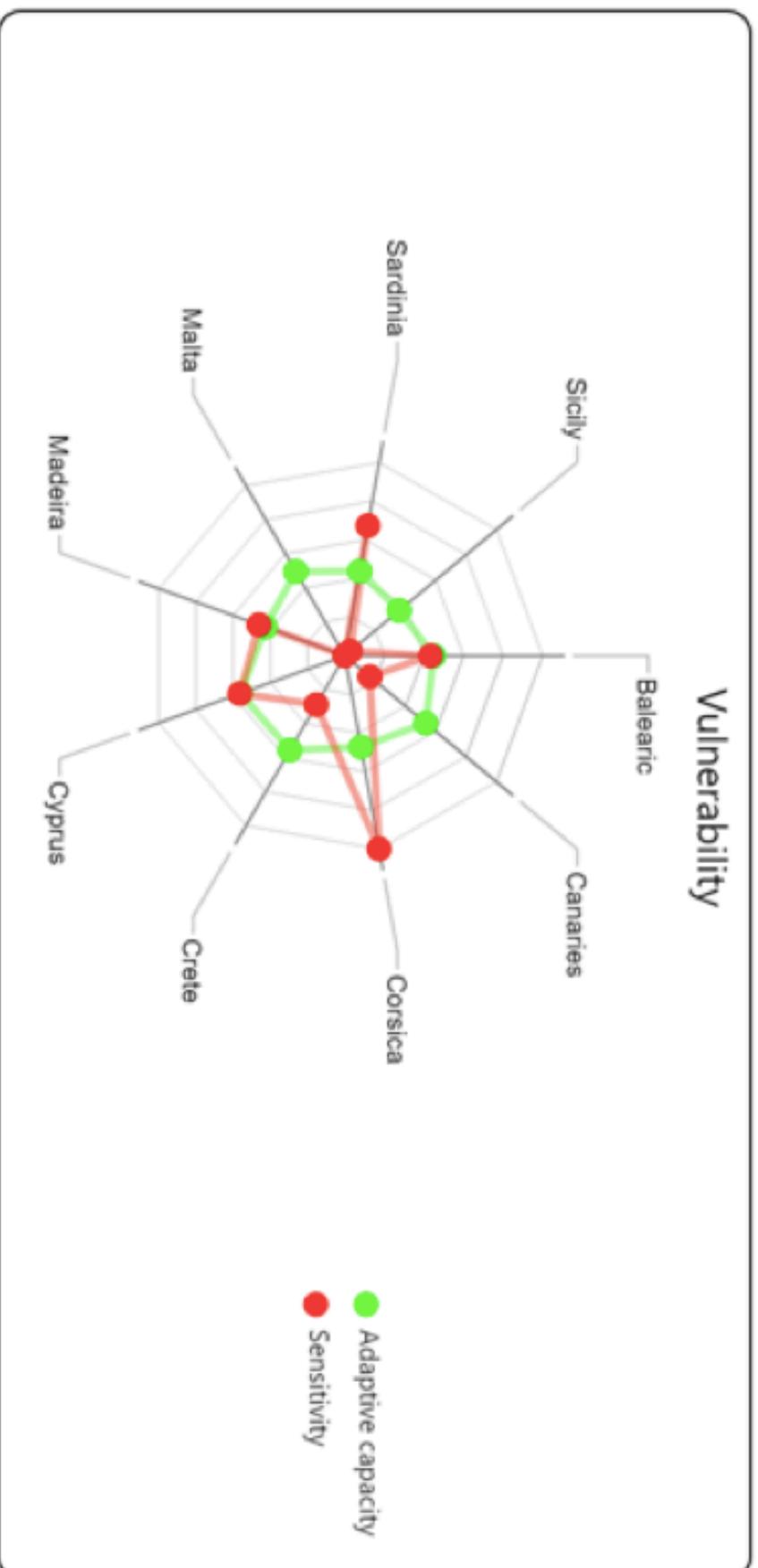


Figure 3.2.25. Subcomponents of vulnerability and related score (current period) per island



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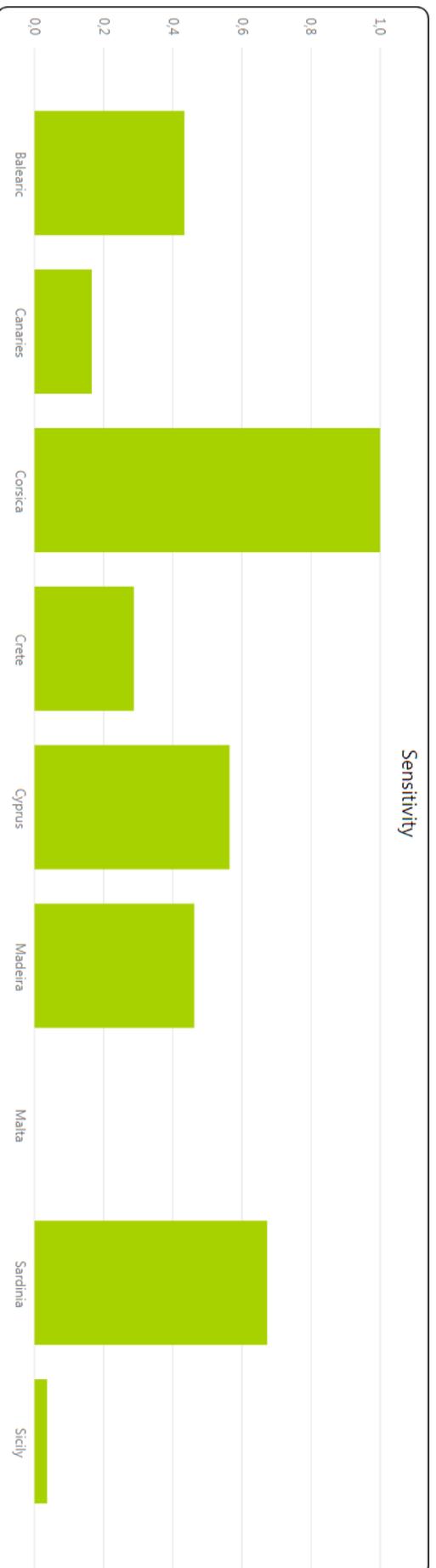
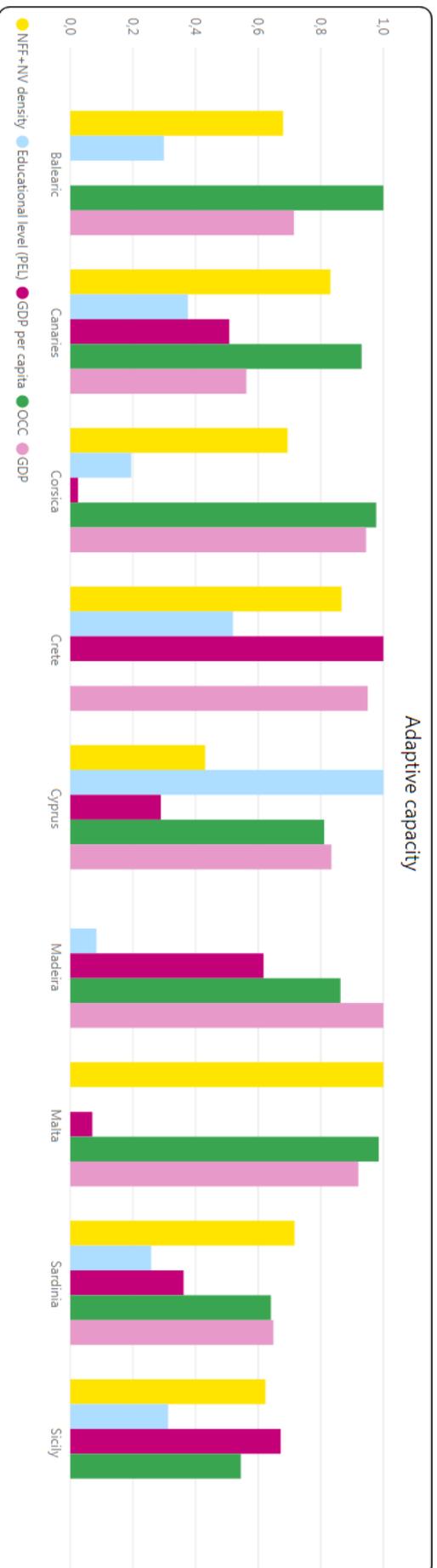


Figure 3.2.16. Detail and scores of the two subcomponents (adaptive capacity and sensitivity) per island

Risk

- For the reference period, the overall risk (Figure 3.2.17) is medium for Atlantic Islands (Madeira and Canary Islands) and Eastern Mediterranean Islands (Crete and Cyprus). Risk for other islands is low and very low for Malta.
- Looking at the breakdown of the risk (Figure 3.2.18), the structure is quite similar for 3 groups:
 - o Madeira, Canary Islands, Sicilia and Balearic Islands: Predominance of exposure component (around 50% of the score);
 - o Crete and Cyprus: Predominance of the hazard component (around 40% of the score);
 - o Corsica and Sardinia: Predominance of the vulnerability component (around 60-70%);
 - o Only Malta has a quite balanced distribution across the components.
- In this exercise, only the hazard component is changing in the future. In the near future (Figure 3.2.19 et Figure 3.2.21) whatever the considered RCP, the risk increases only for Cyprus from medium to high. While the risk remains stable with the RCP2.6 in the distant future (Figure 3.2.19) for all islands apart from Cyprus, there is an increase from very low to low for Malta and from low to medium for Balearic Islands, Corsica and Sardinia with RCP8.5 (distant future, Figure 3.2.20). Even under this RCP8.5 risk remains constant for Canary Islands and Madeira (Medium) and Sicily (Low)



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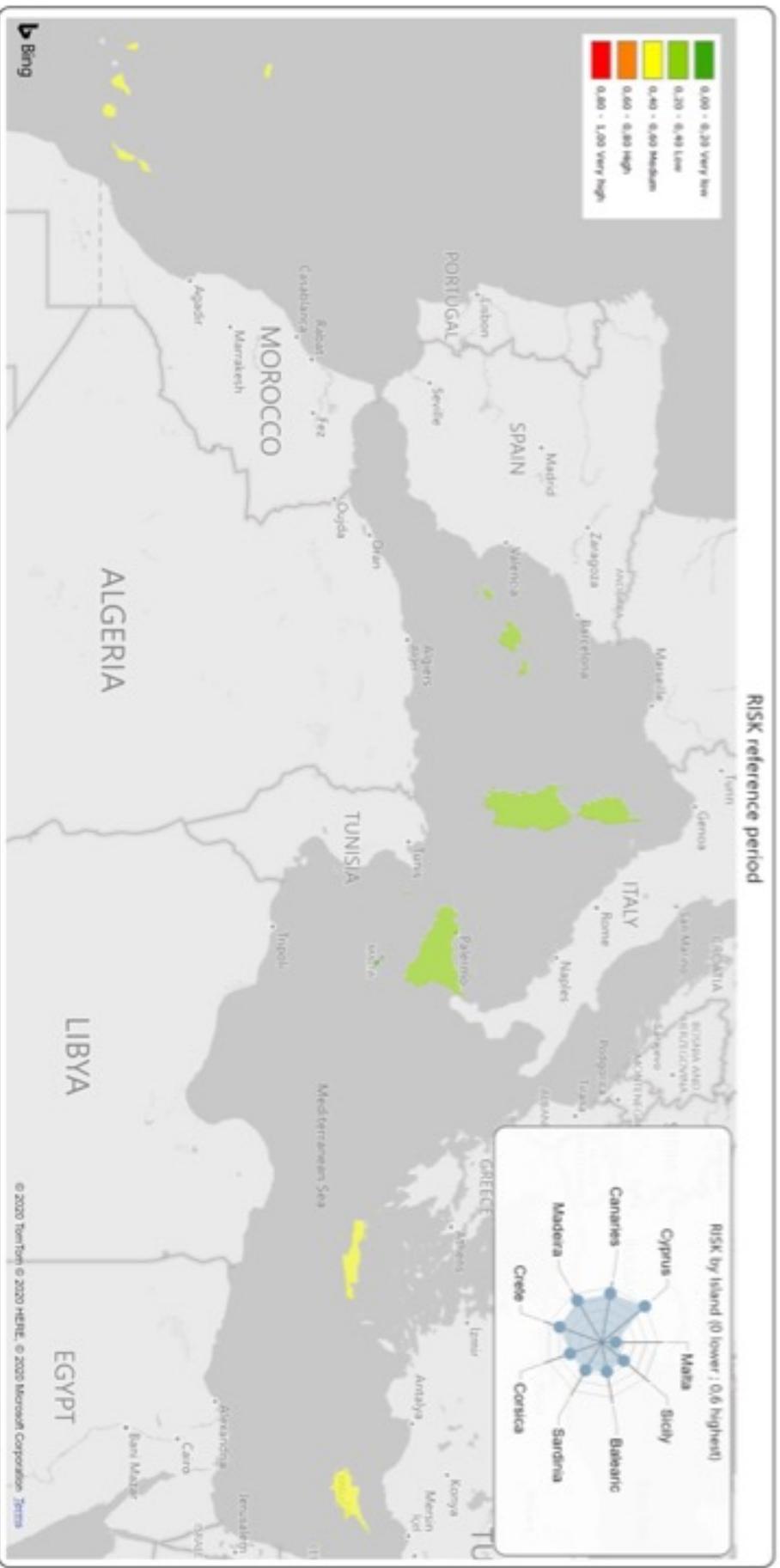


Figure 3.2.17. Risk score per island for the reference period (1986-2005)



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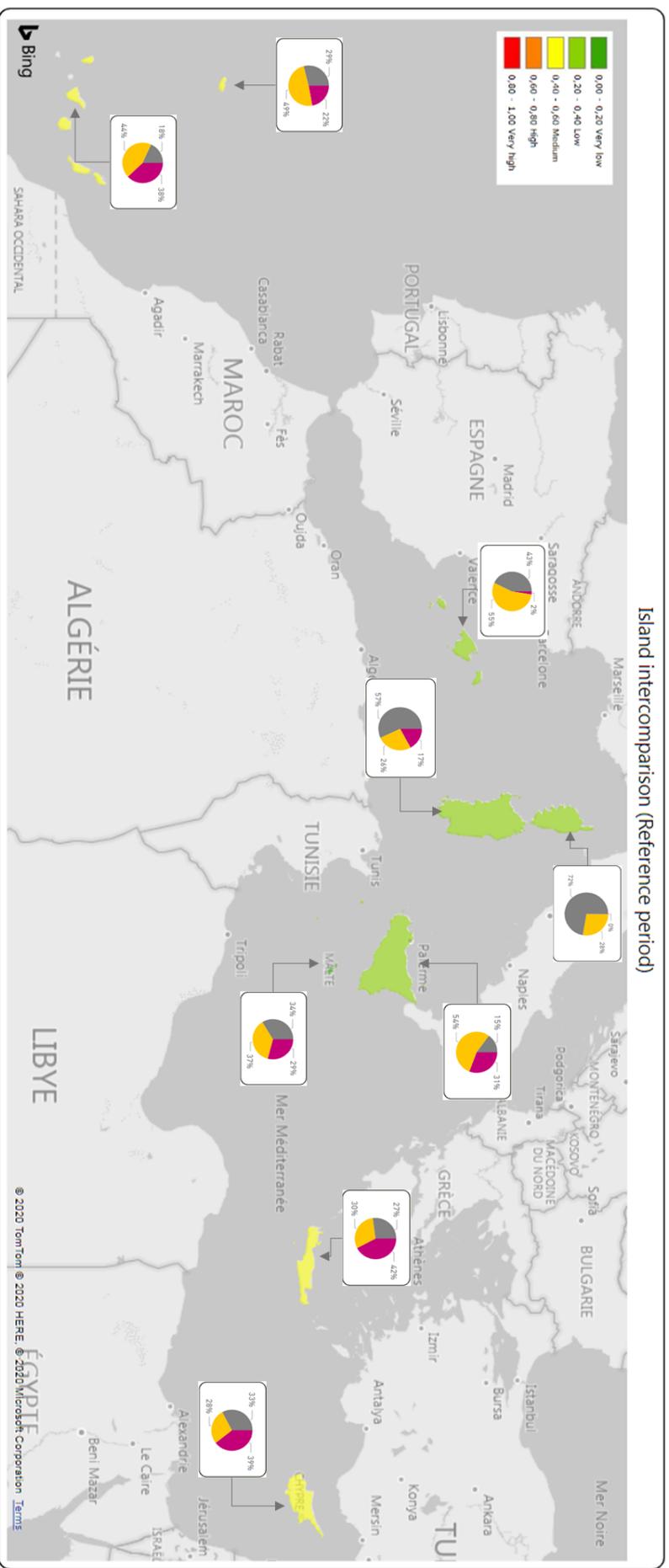


Figure 3.2.18. Risk breakdown by island for the reference period (1986-2005)



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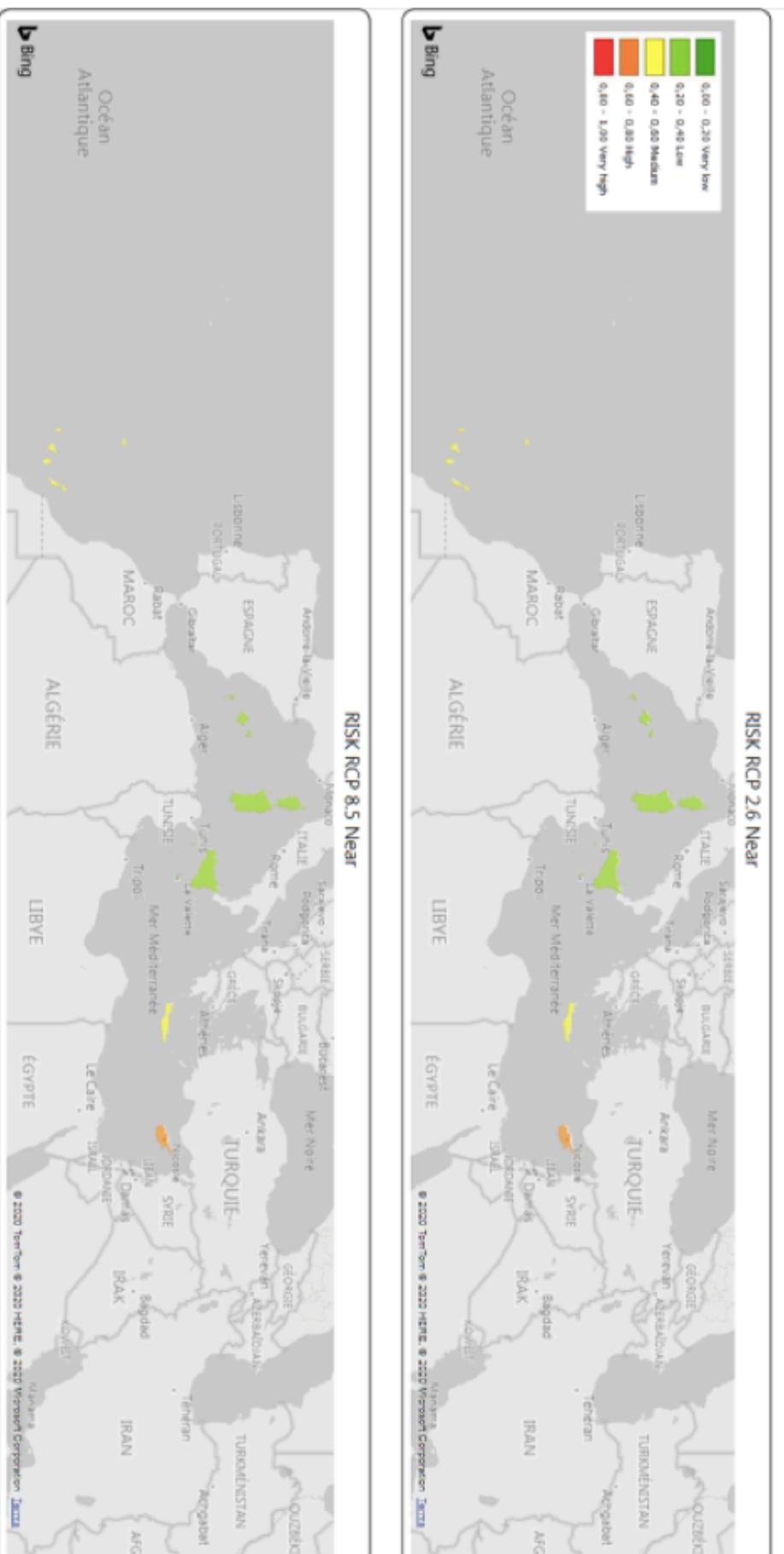


Figure 3.2.19. Risk score per island in the near future (2046-2065) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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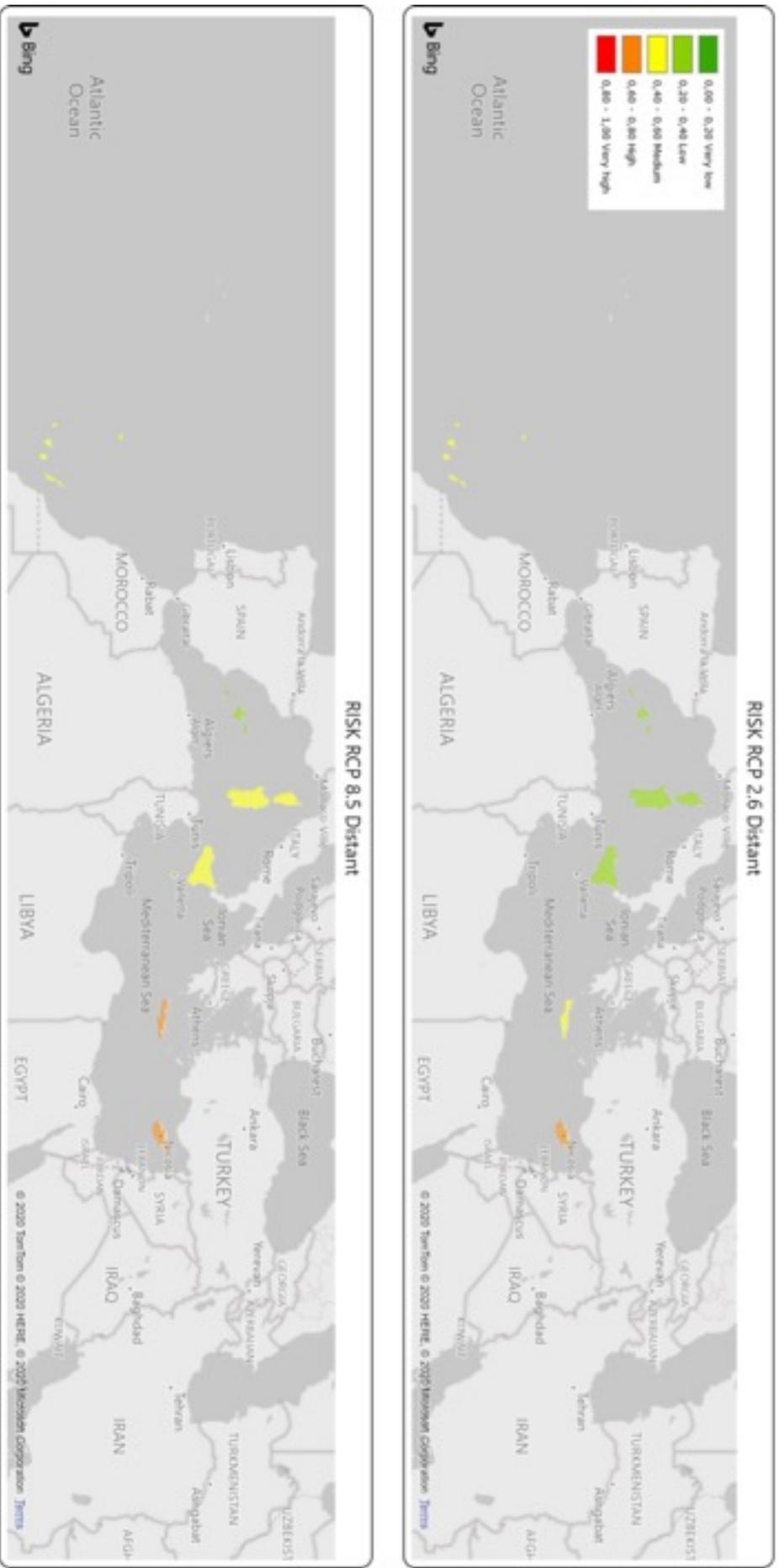


Figure 3.2.20. Risk score per island at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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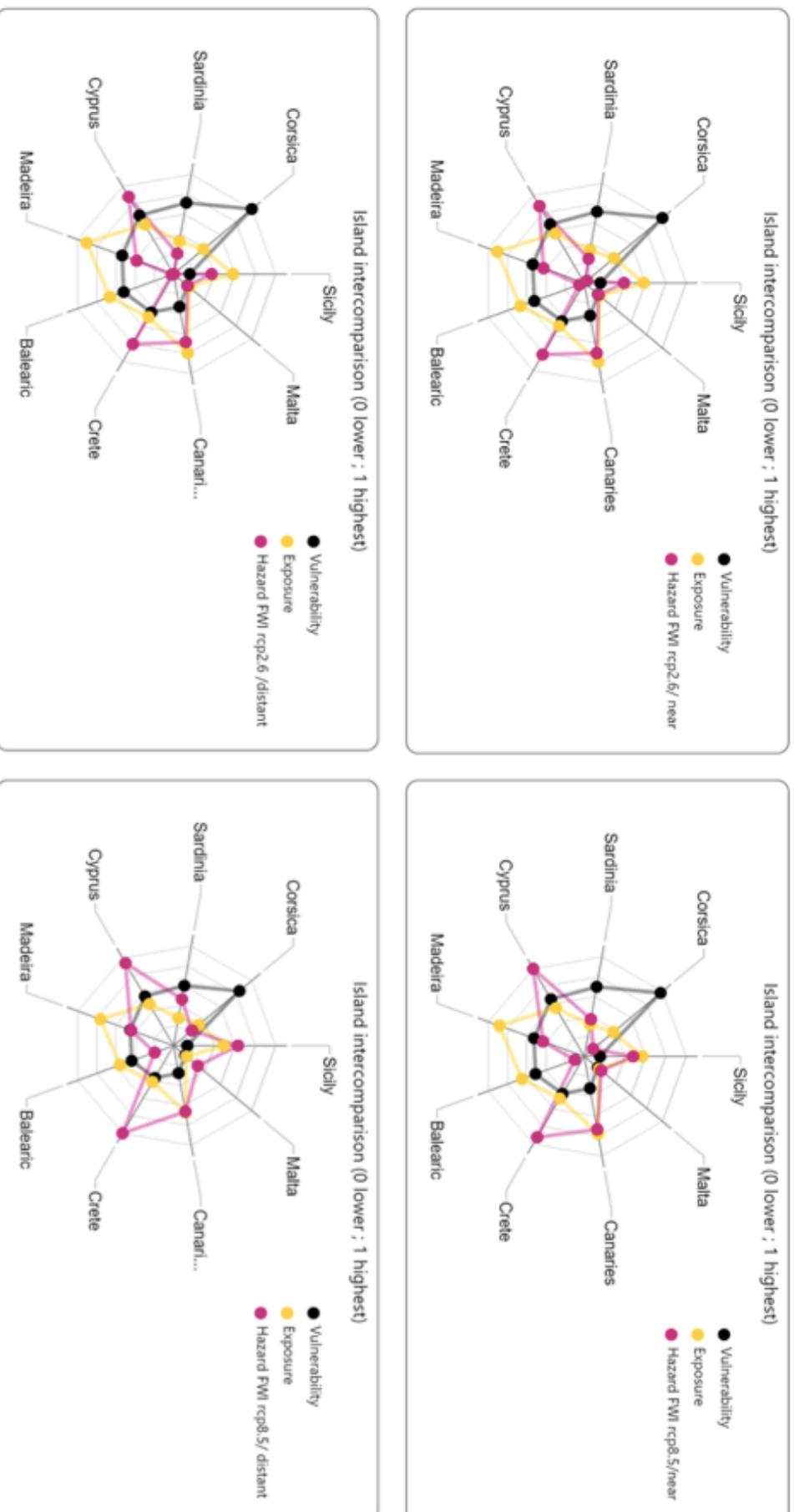


Figure 3.2.21. Score per component and per island in the near (2046-2065) and the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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Results per island

Azores

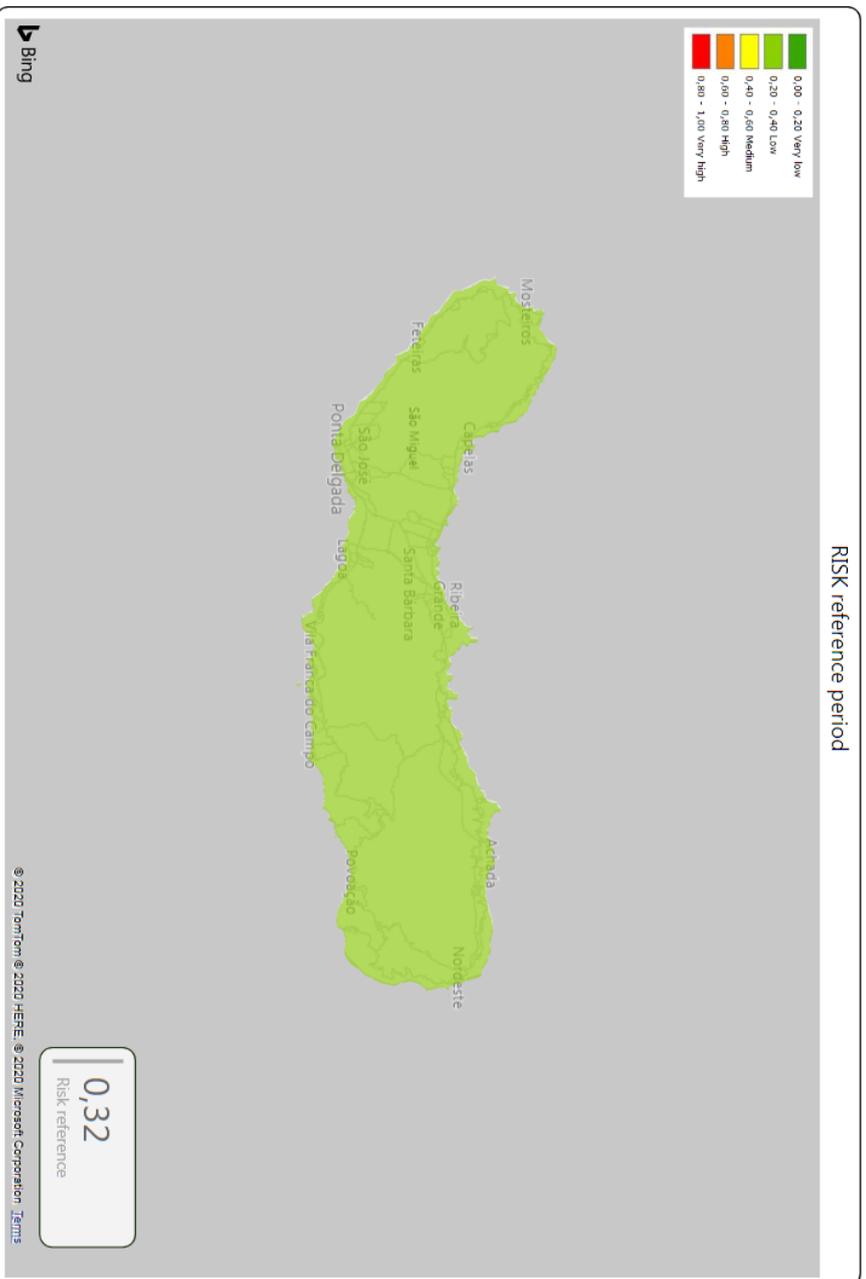


Figure 3.2.22. Risk score and components of the risk for the reference period



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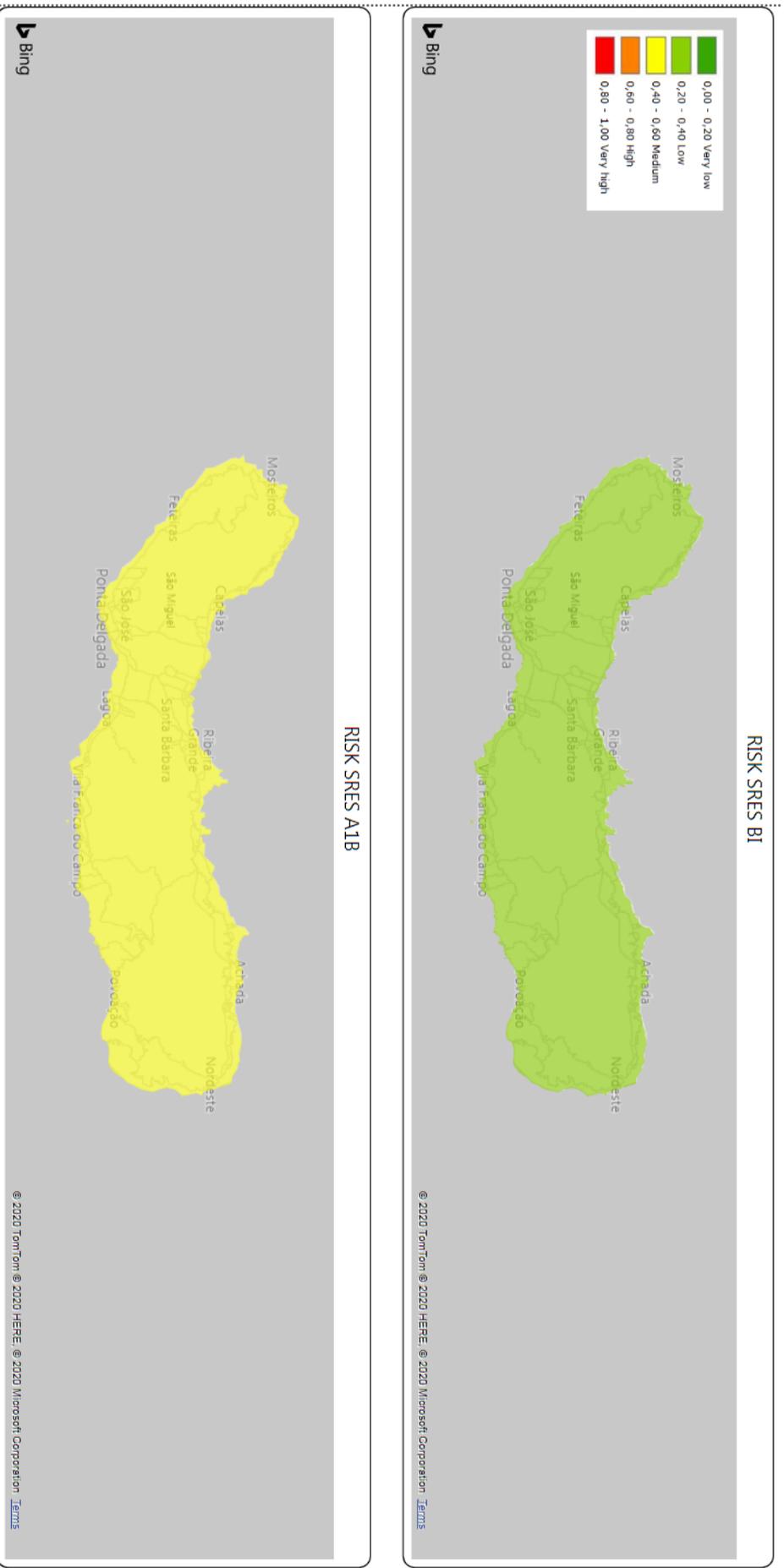


Figure 3.2.23. Risk score for scenarios for SRES B1 and A1B (near future).



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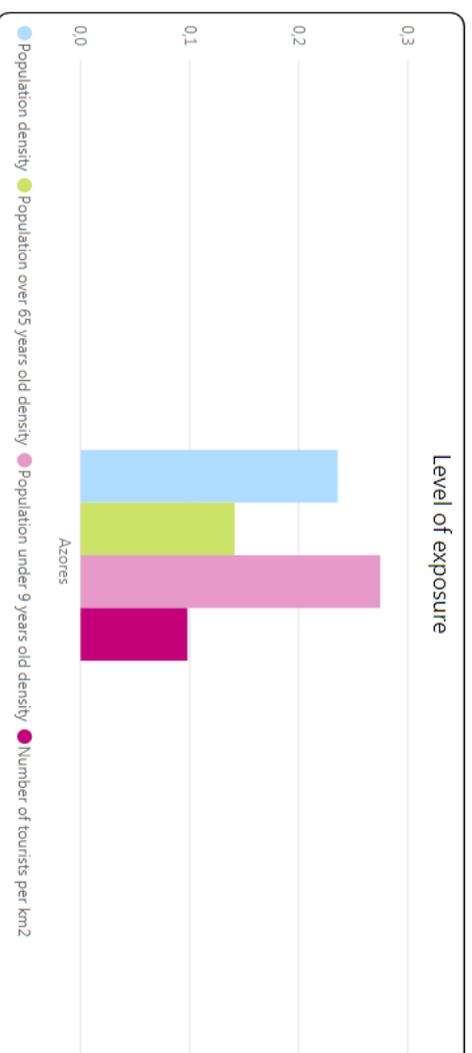
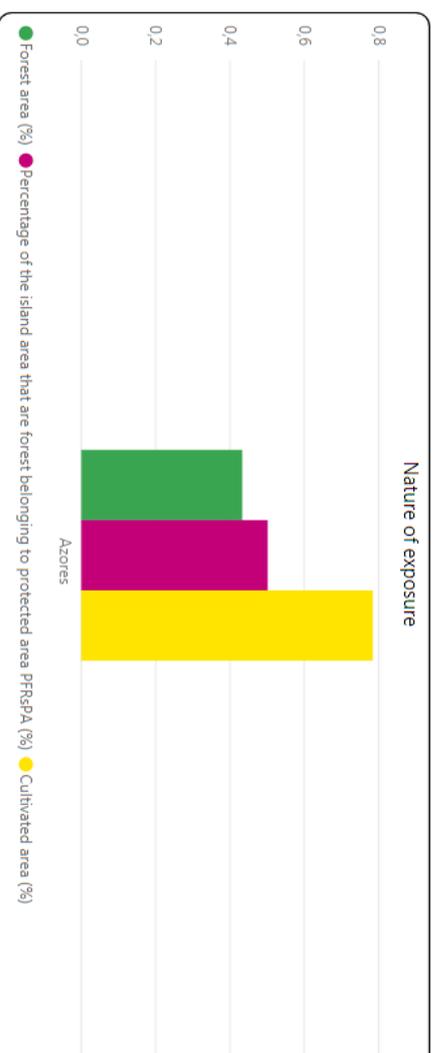
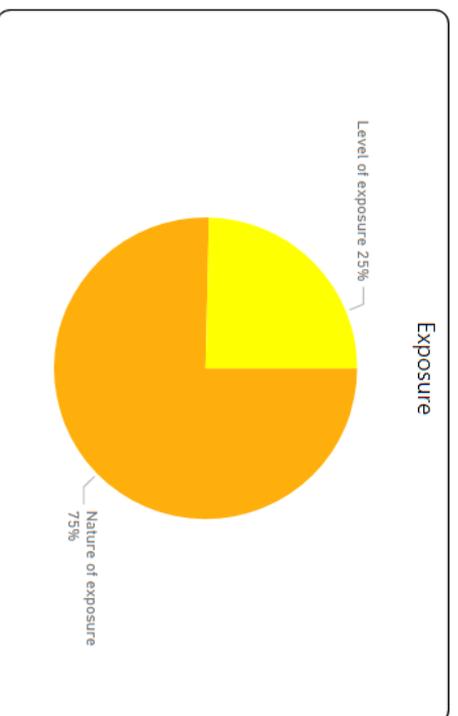


Figure 3.2.24. Detail and scores of the two subcomponents of exposure (nature and level of exposure)



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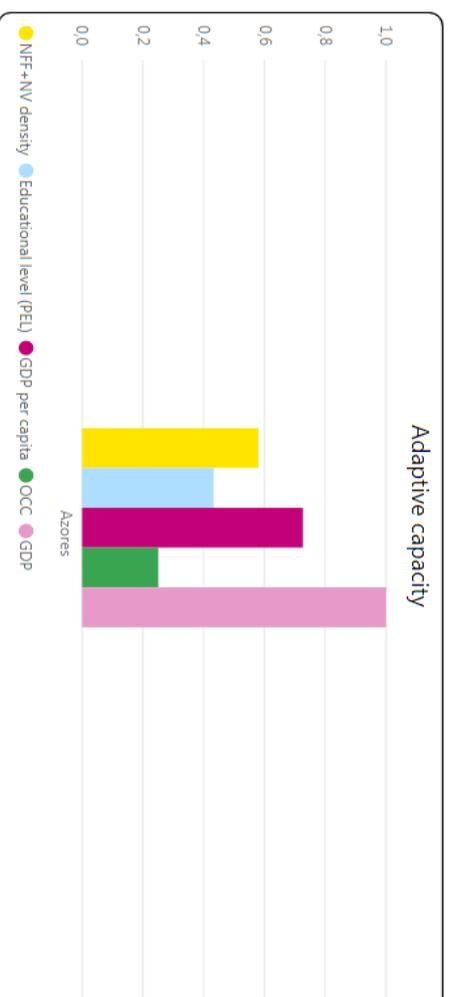
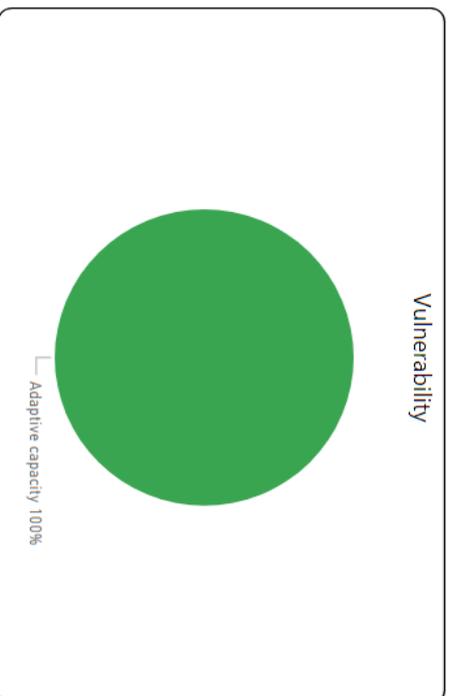


Figure 3.2.25. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Balearic Islands

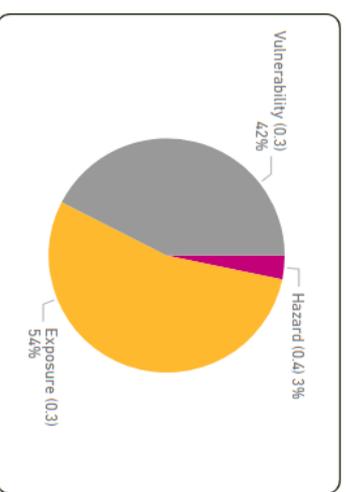


Figure 3.2.26. Risk score and components of the risk for the reference period



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Figure 3.2.27. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usua



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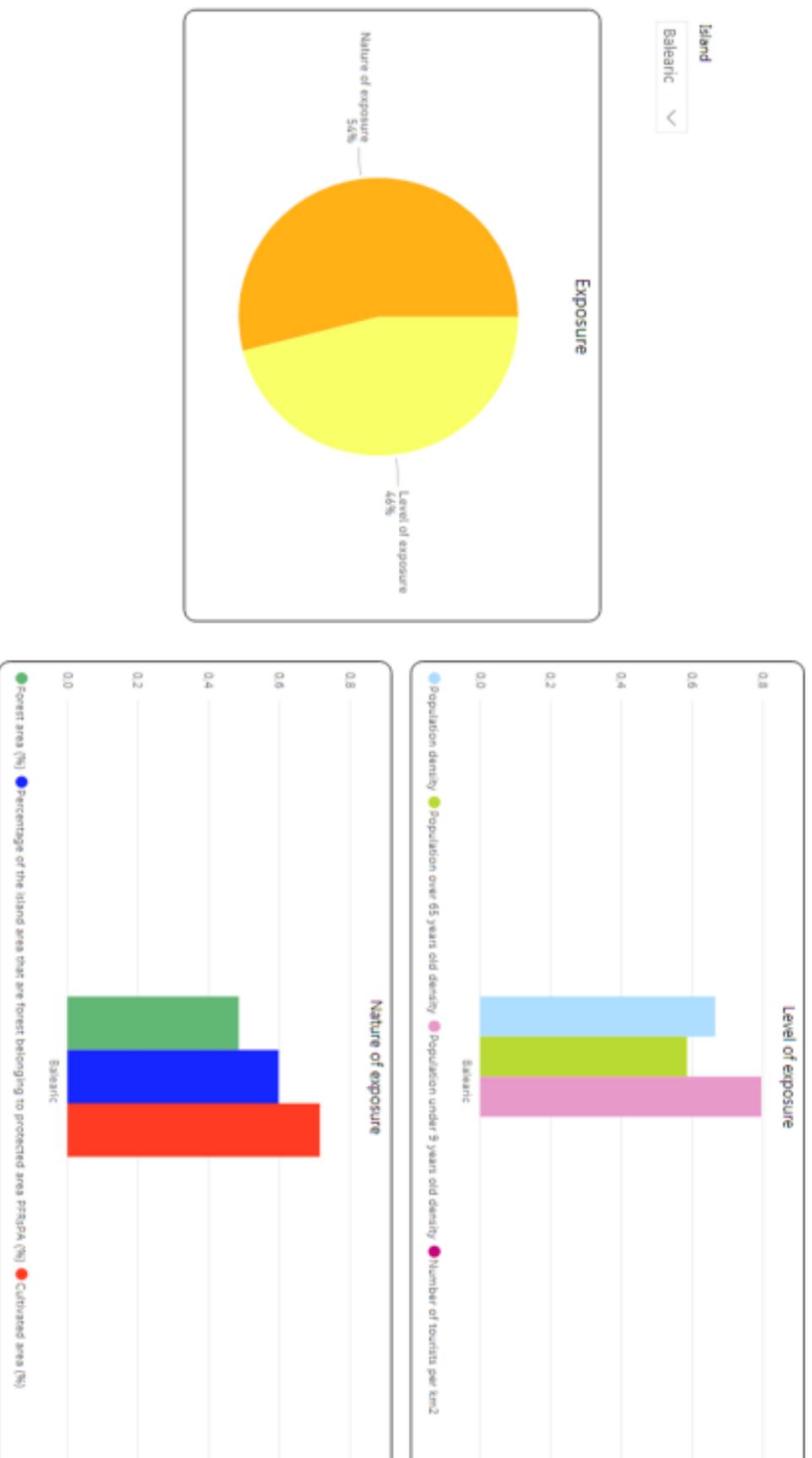


Figure 3.2.28. Detail and scores of the two subcomponents of exposure (nature and level of exposure)



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Figure 3.2.29. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Canary Islands

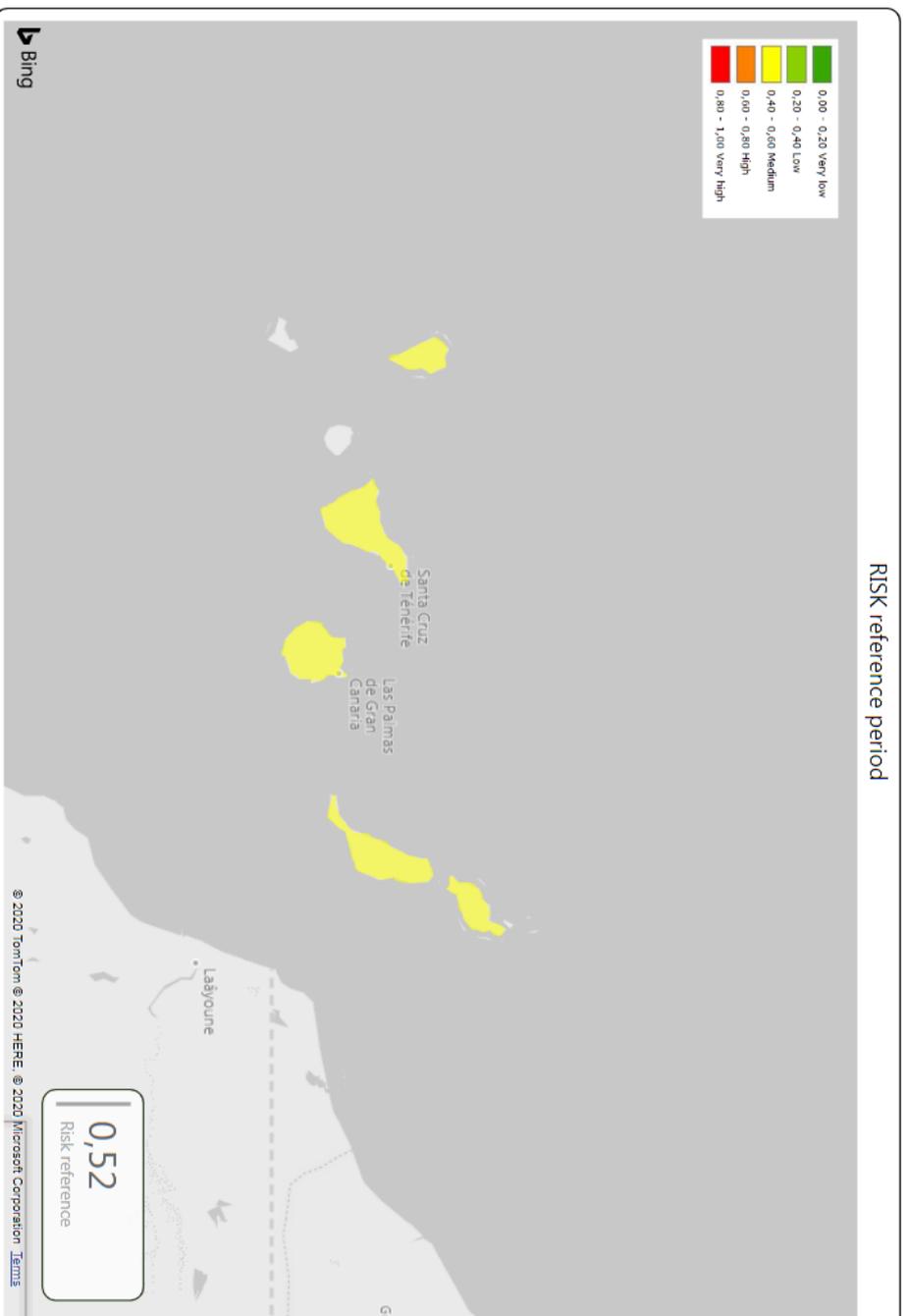


Figure 3.2.30. Risk score and components of the risk for the reference period



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RISK RCP 2.6 distant



RISK RCP 8.5 distant

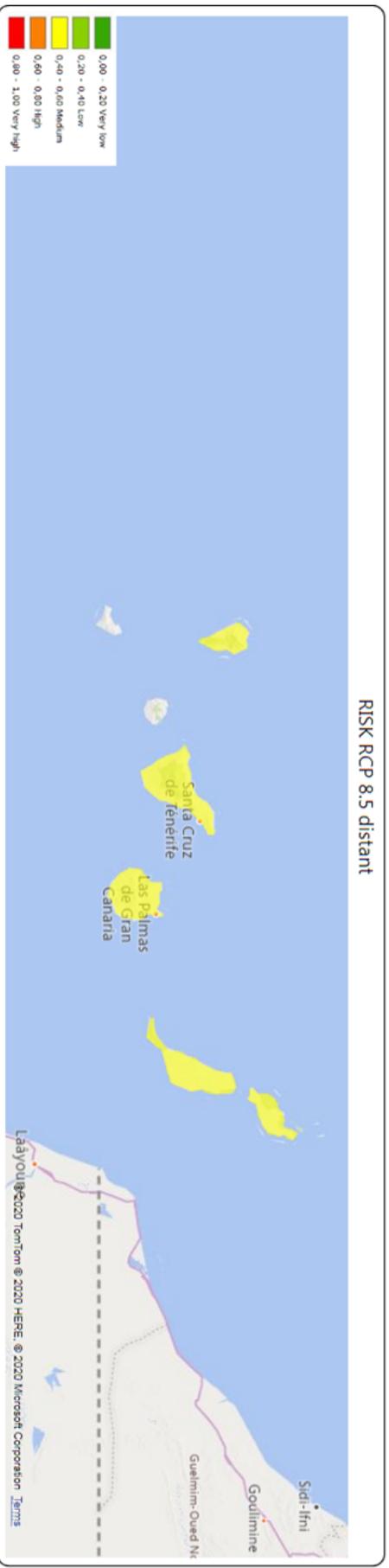


Figure 3.2.31. Risk score at the end in the distant future (2081 -2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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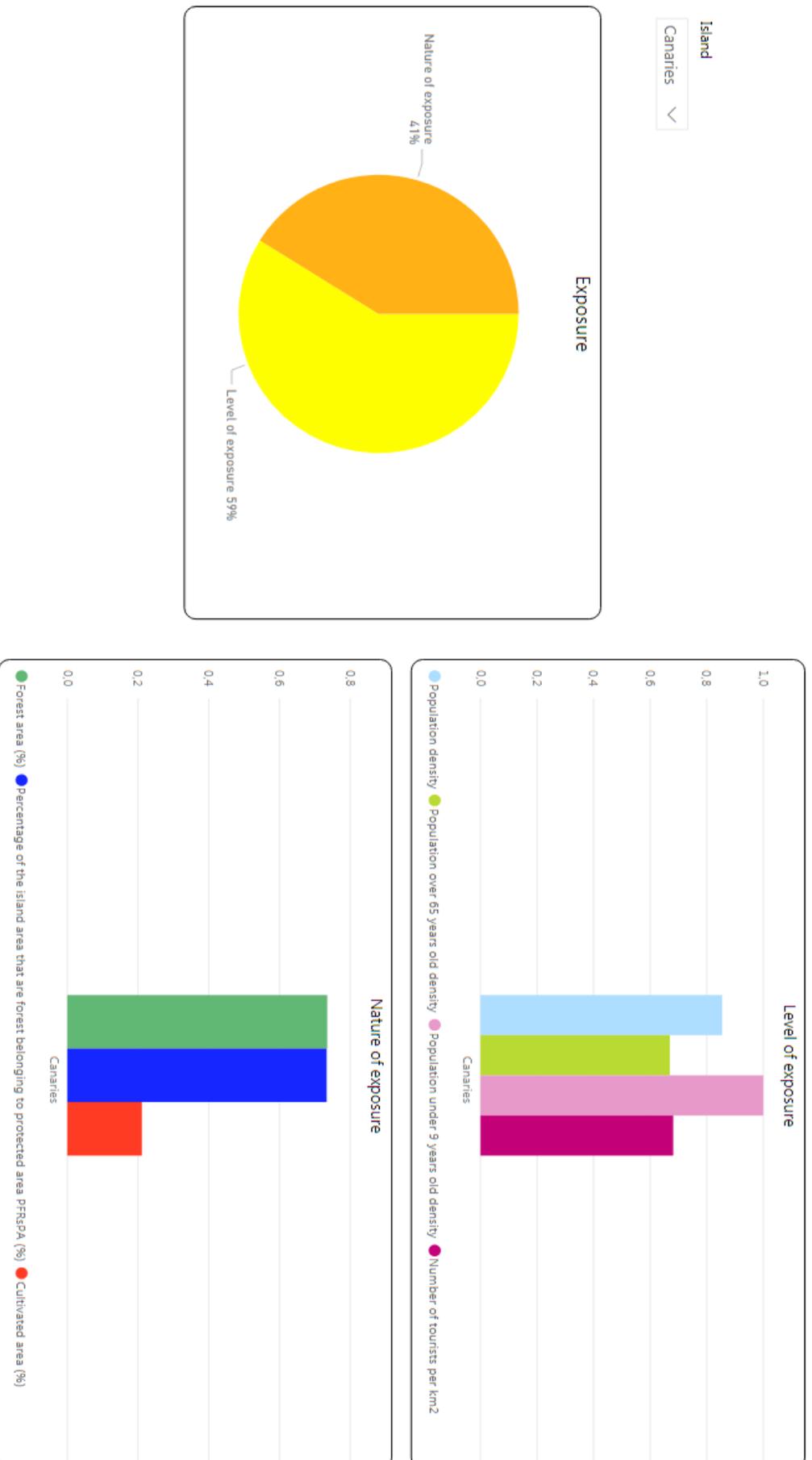


Figure 3.2.32. Detail and scores of the two subcomponents of exposure (nature and level of exposure) per island



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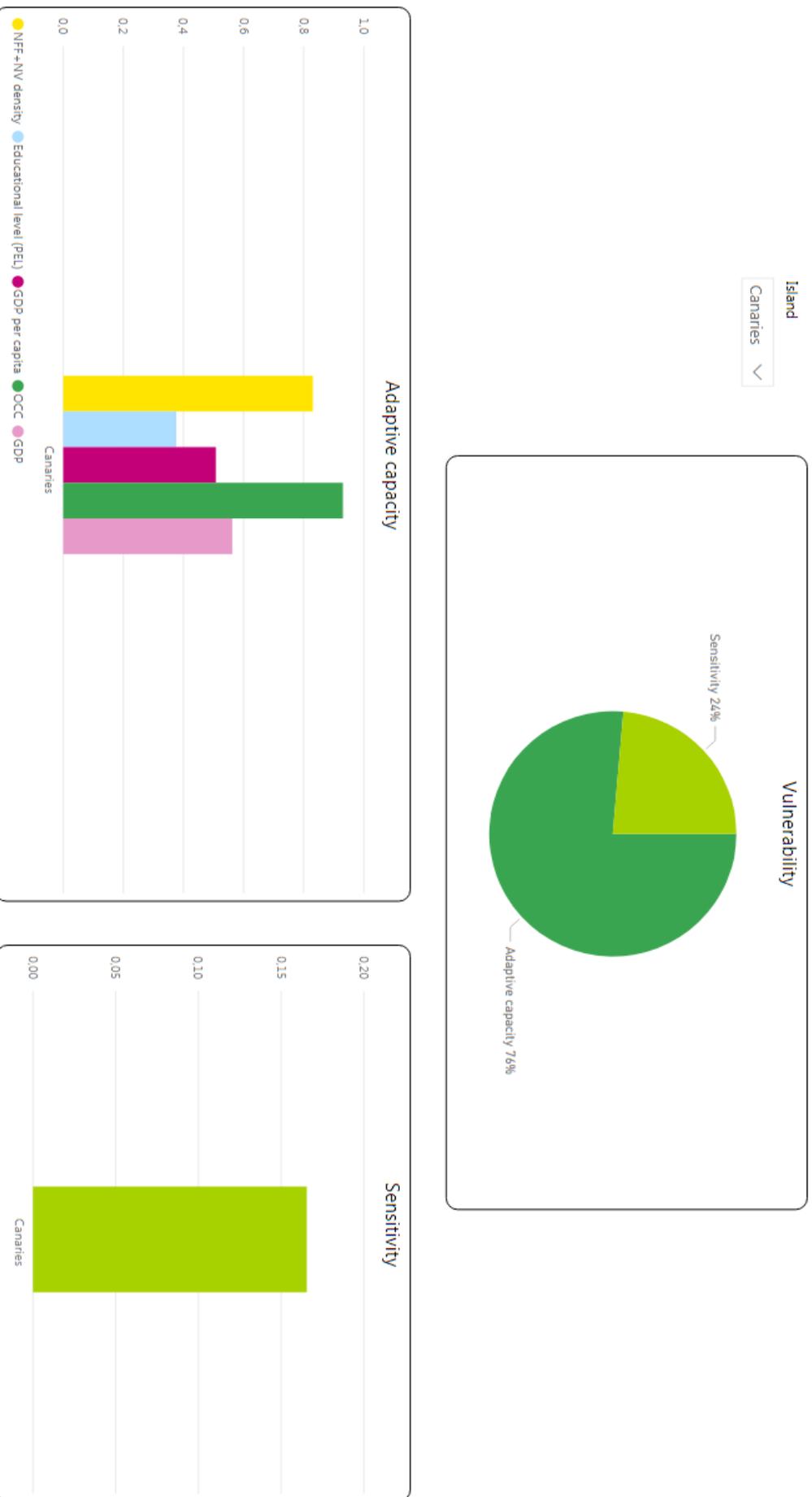


Figure 3.2.33. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Corsica

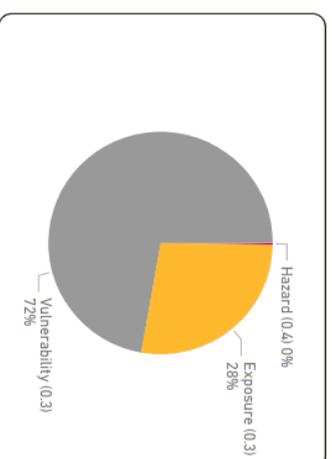
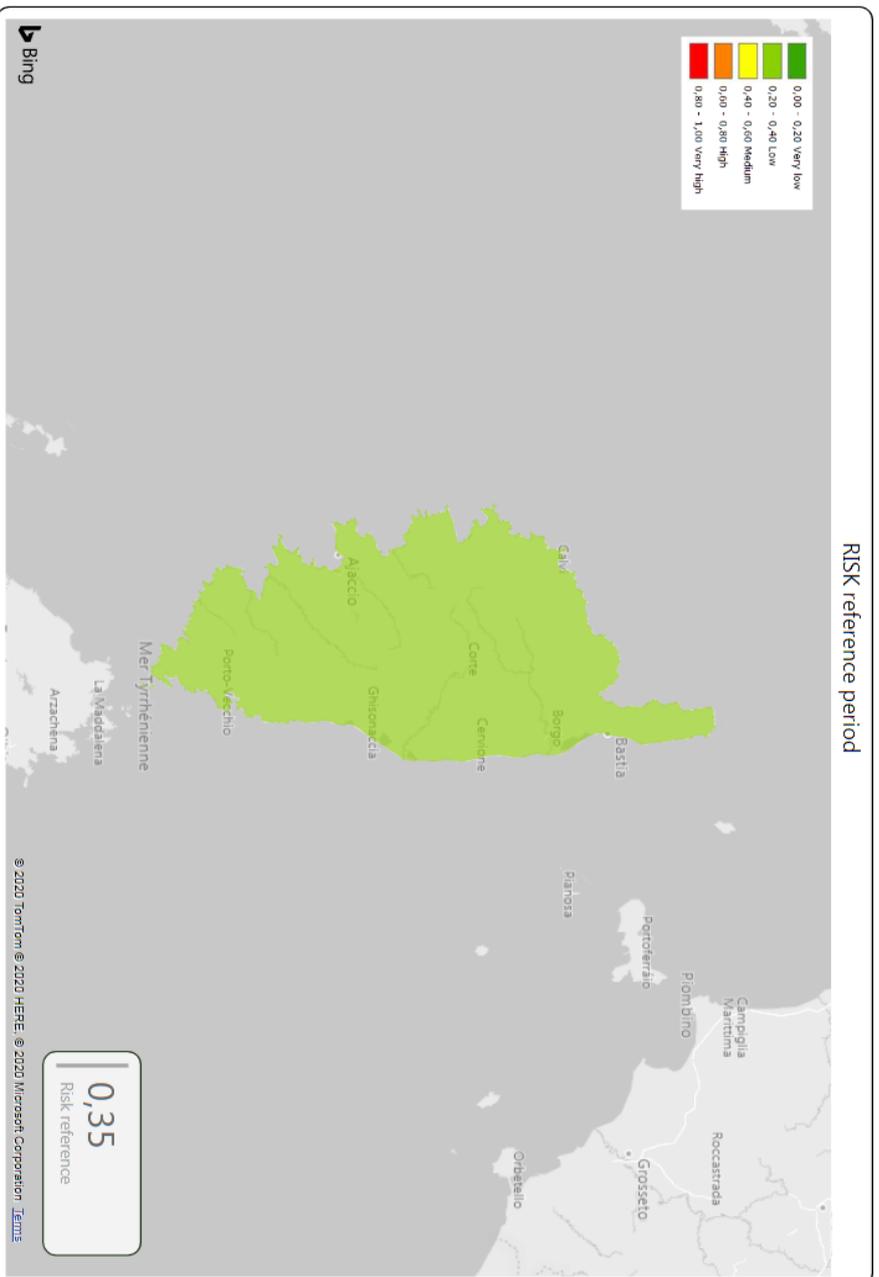


Figure 3.2.34. Risk score and components of the risk for the reference period



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Figure 3.2.35. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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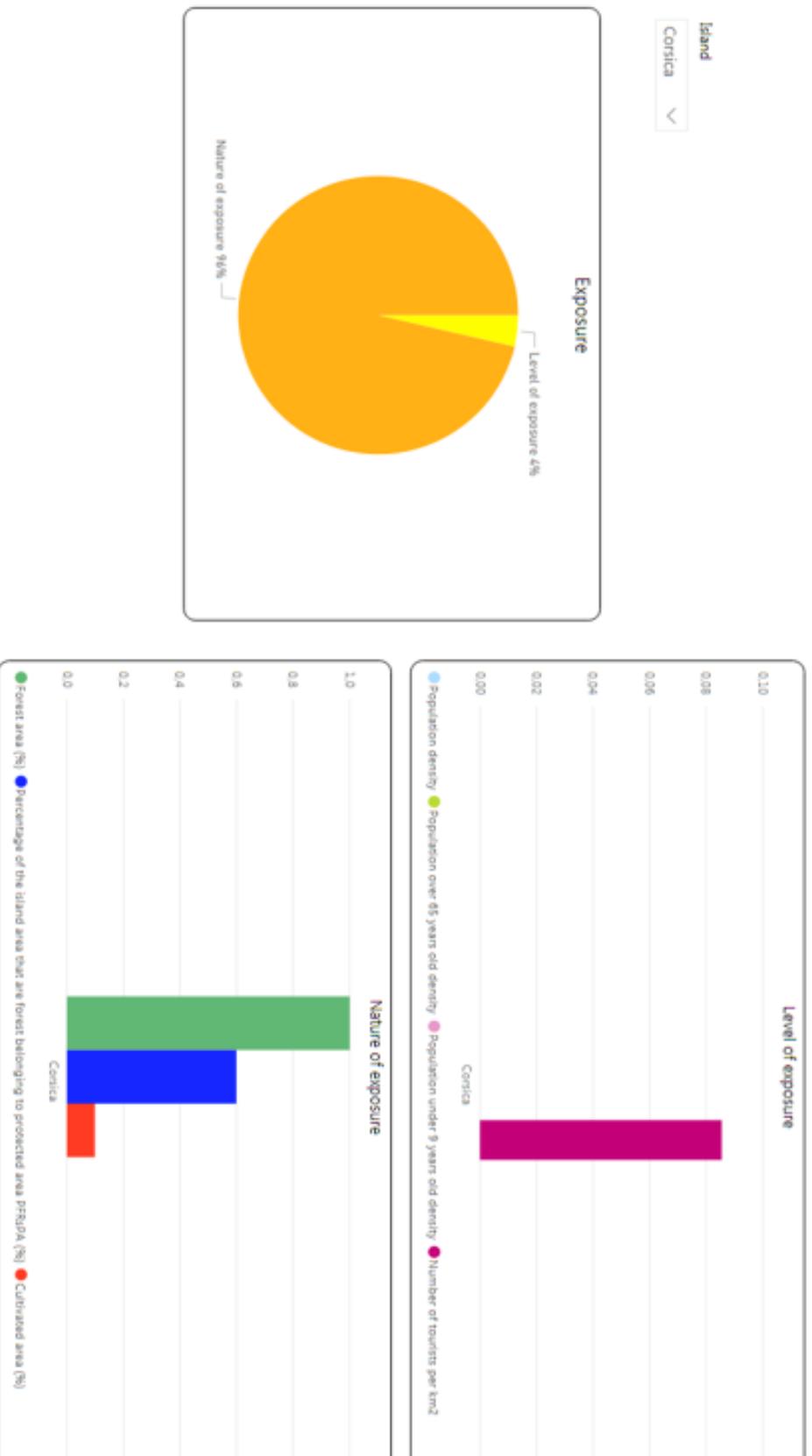


Figure 3.2.36. Detail and scores of the two subcomponents of exposure (nature and level of exposure) per island



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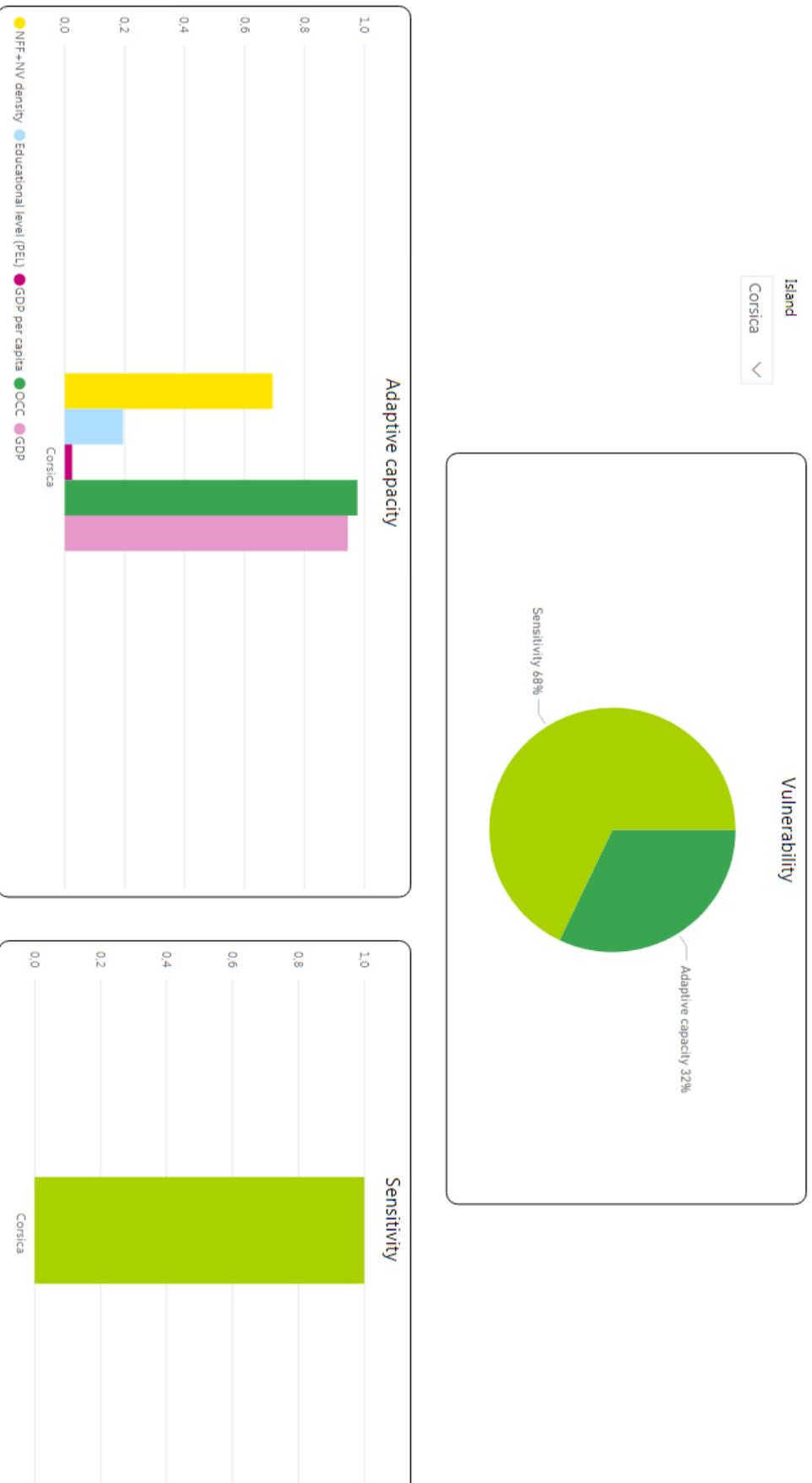


Figure 3.2.37. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Crete

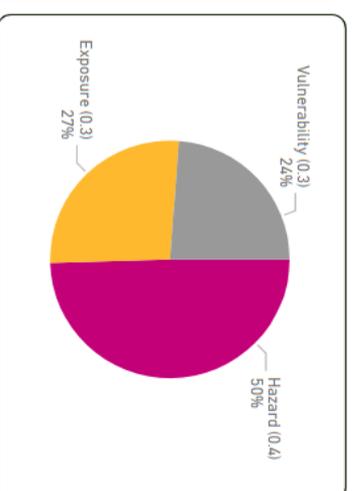
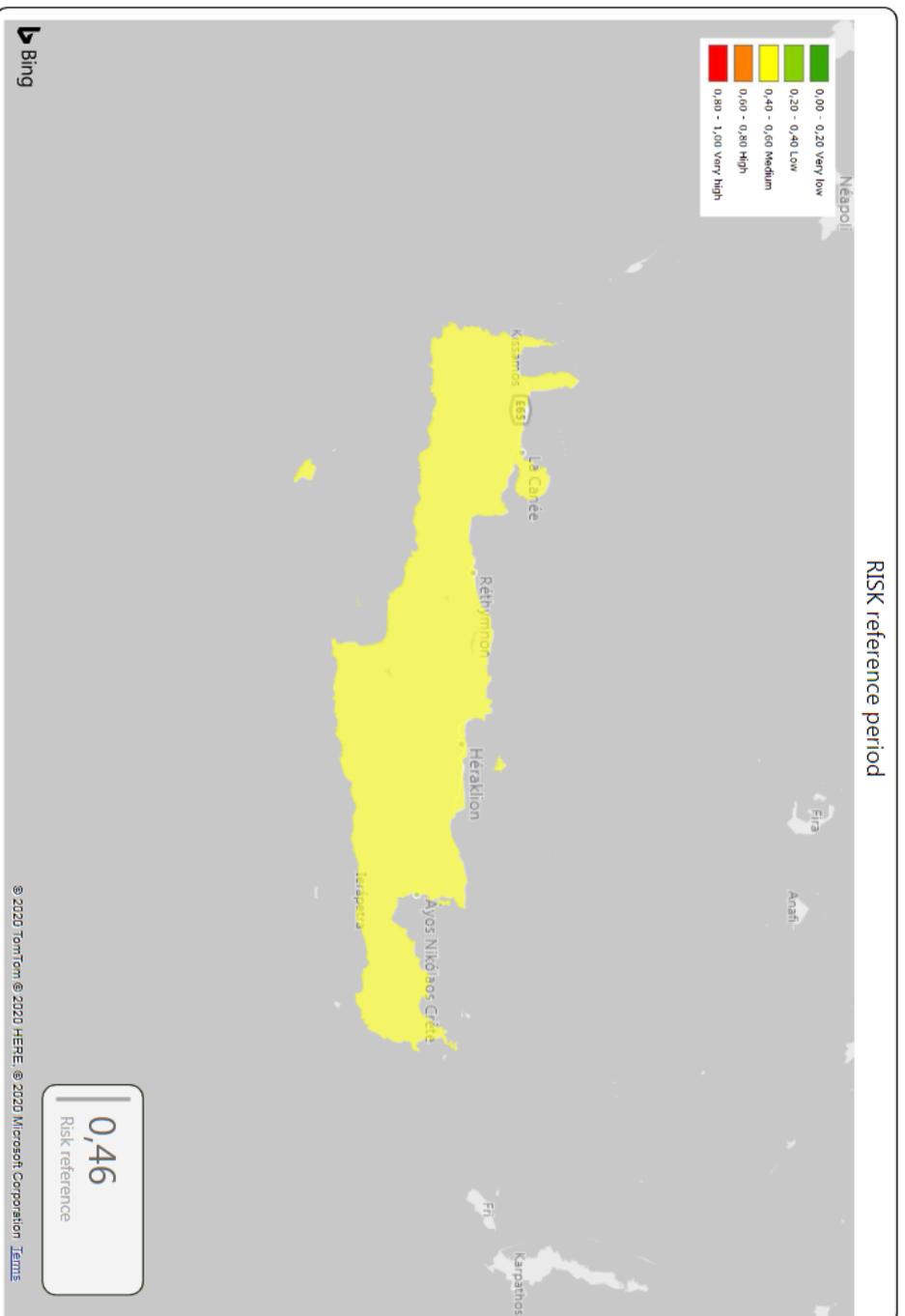


Figure 3.2.38. Risk score and components of the risk for the reference period



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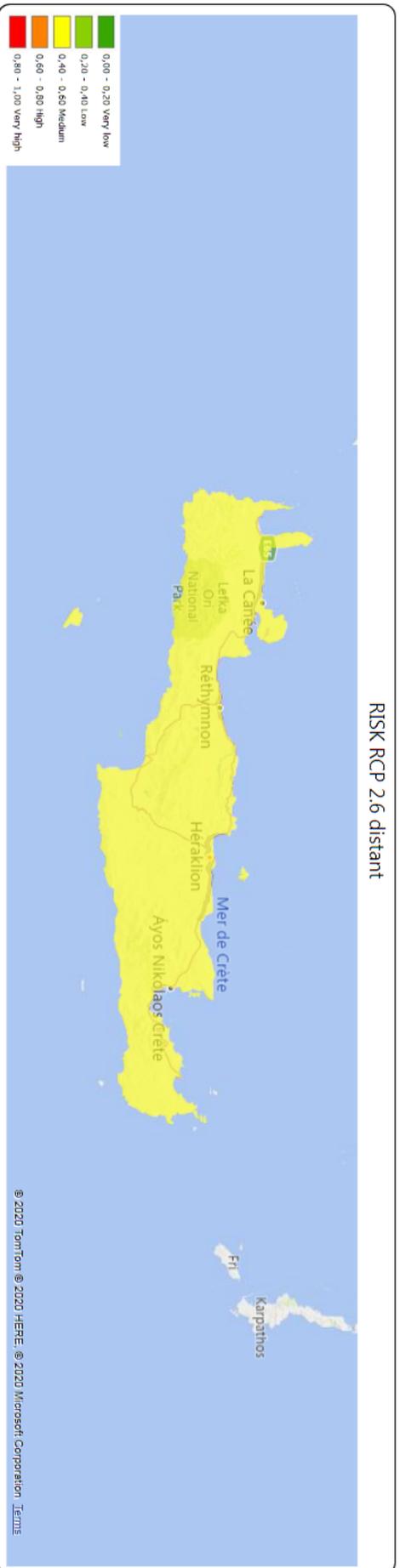


Figure 3.2.39. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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Island
Crete

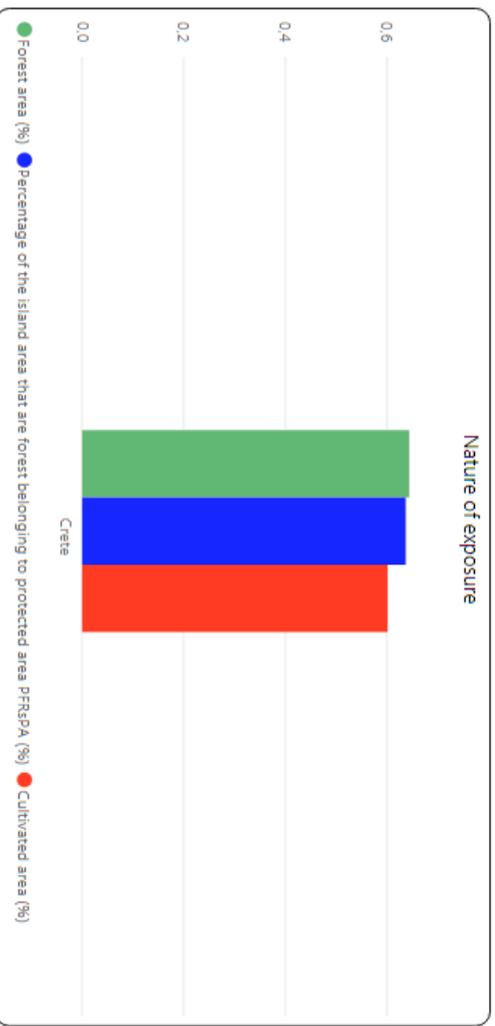
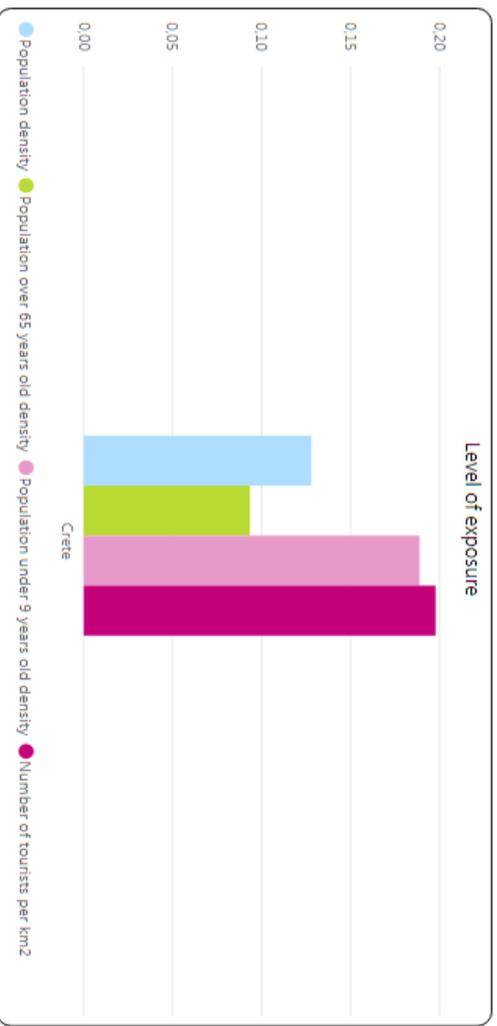
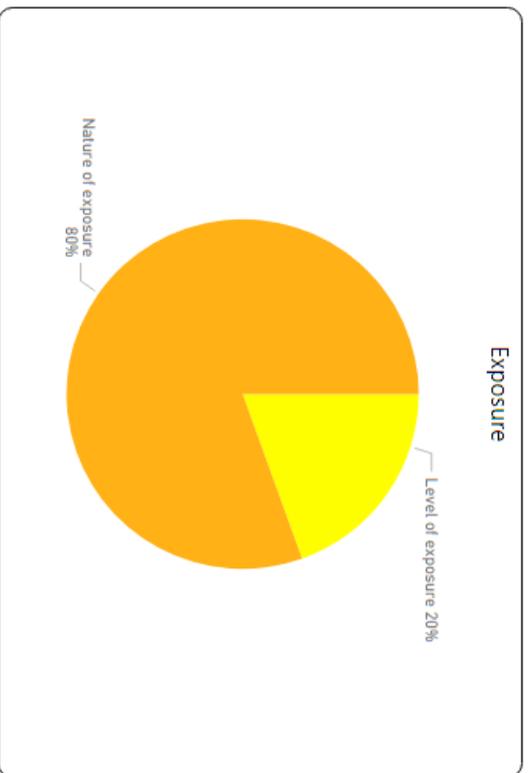


Figure 3.2.40. Detail and scores of the two subcomponents of exposure (nature and level of exposure)



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Island
Crete

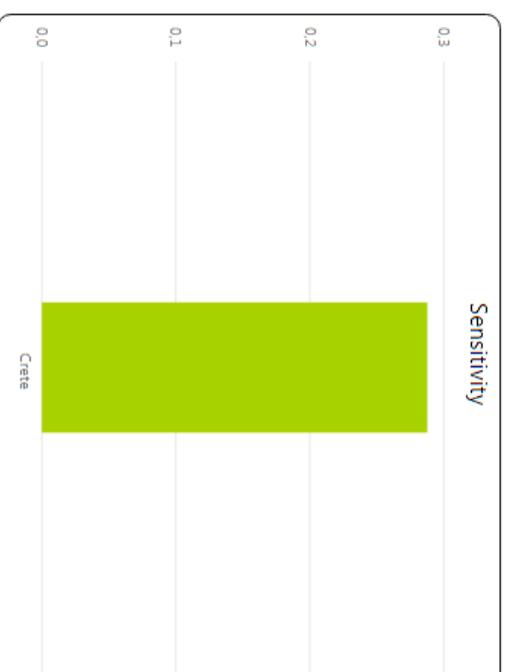
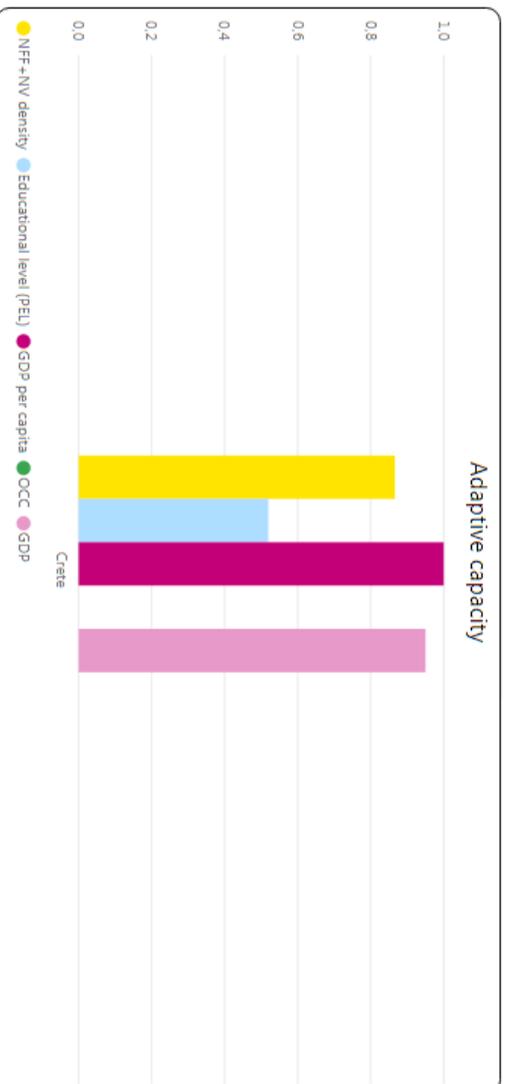
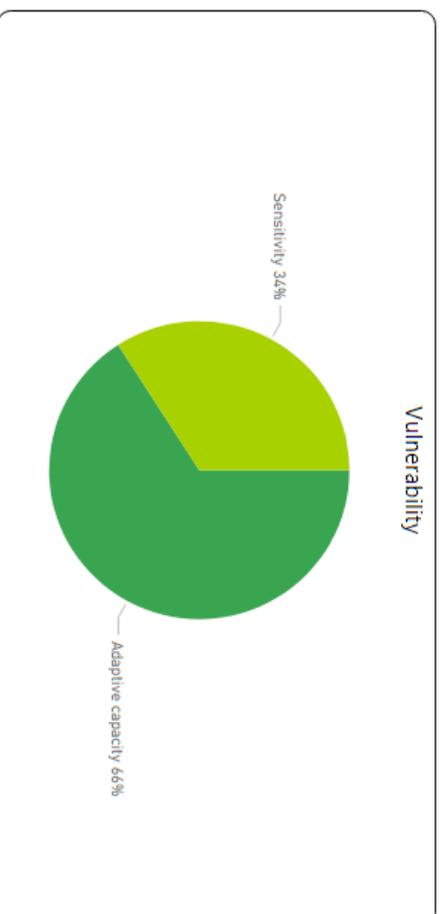


Figure 3.2.41- Detail and scores of the two subcomponents of vulnerability (adaptative capacity and sensitivity)



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Cyprus

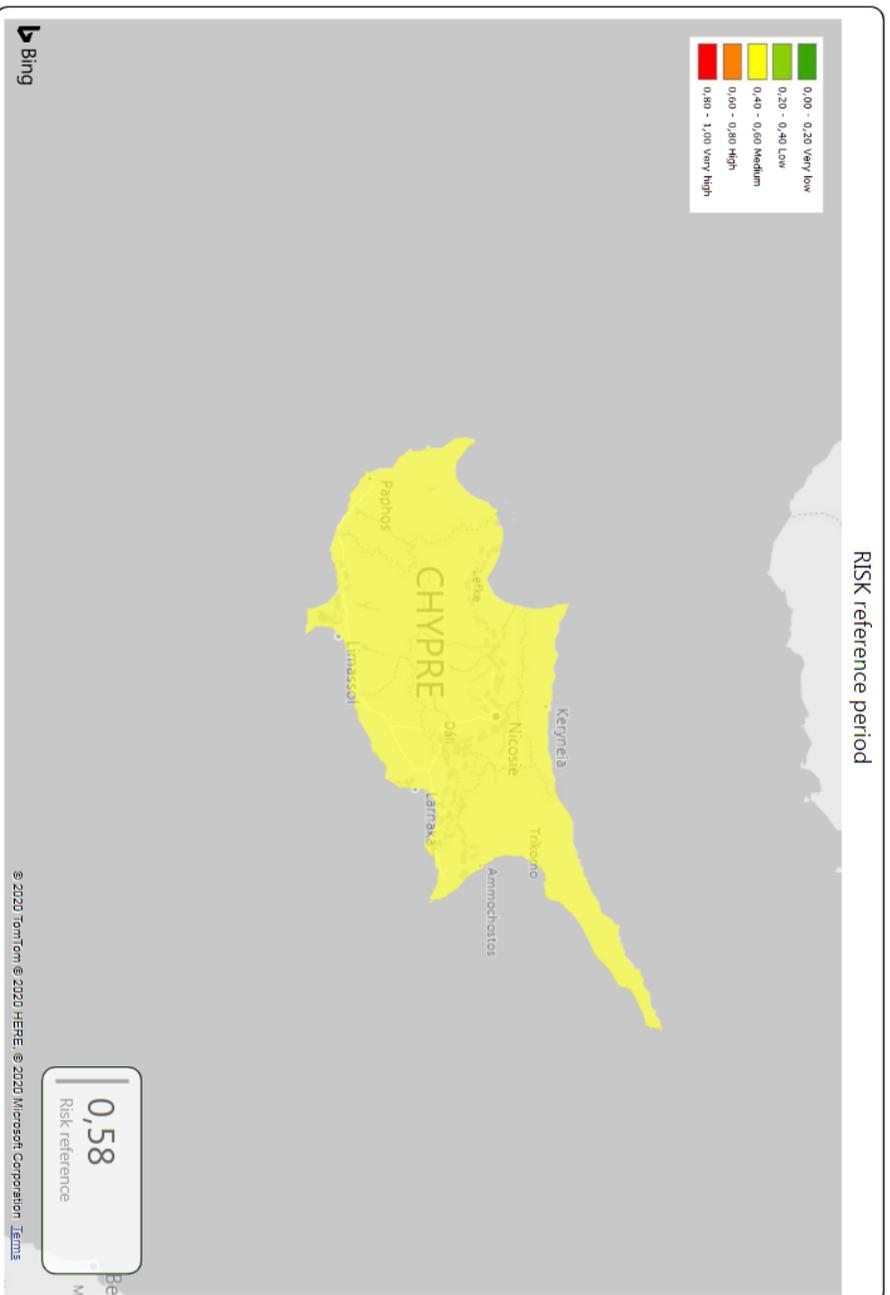


Figure 3.2.42. Risk score and components of the risk for the reference period



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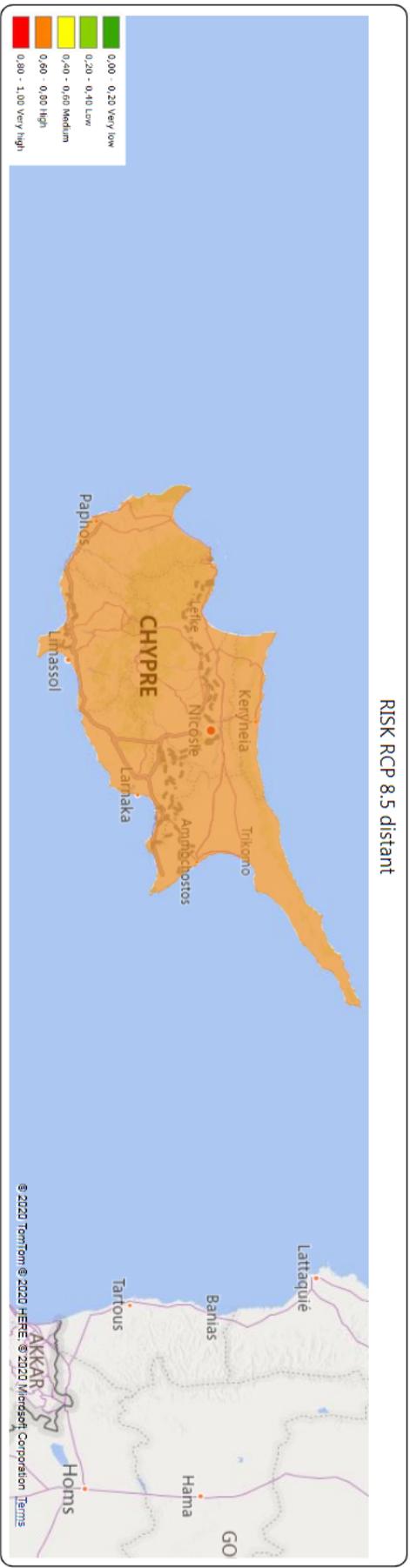
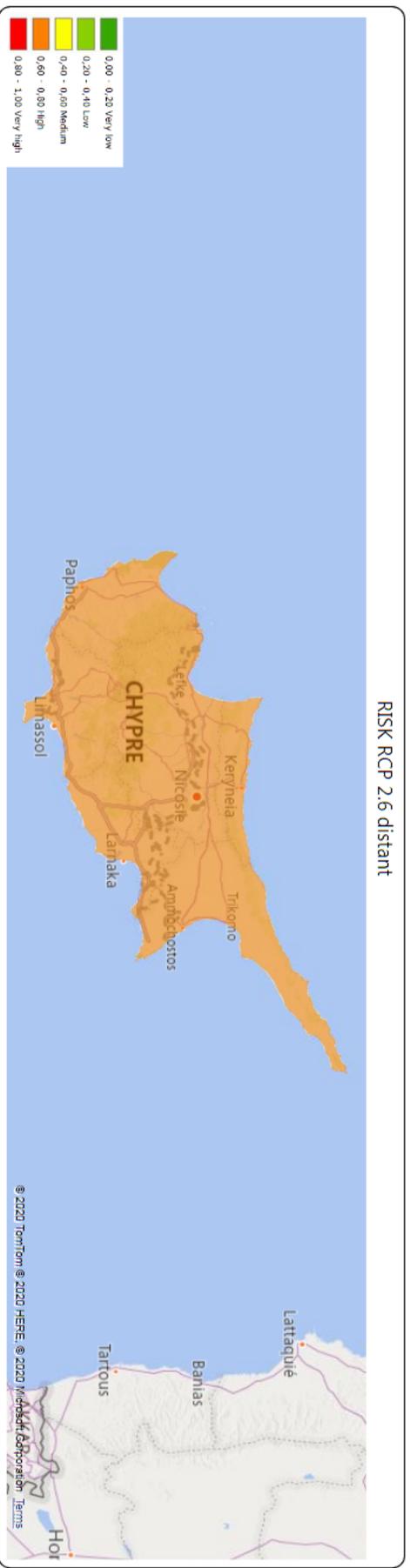


Figure 3.2.43. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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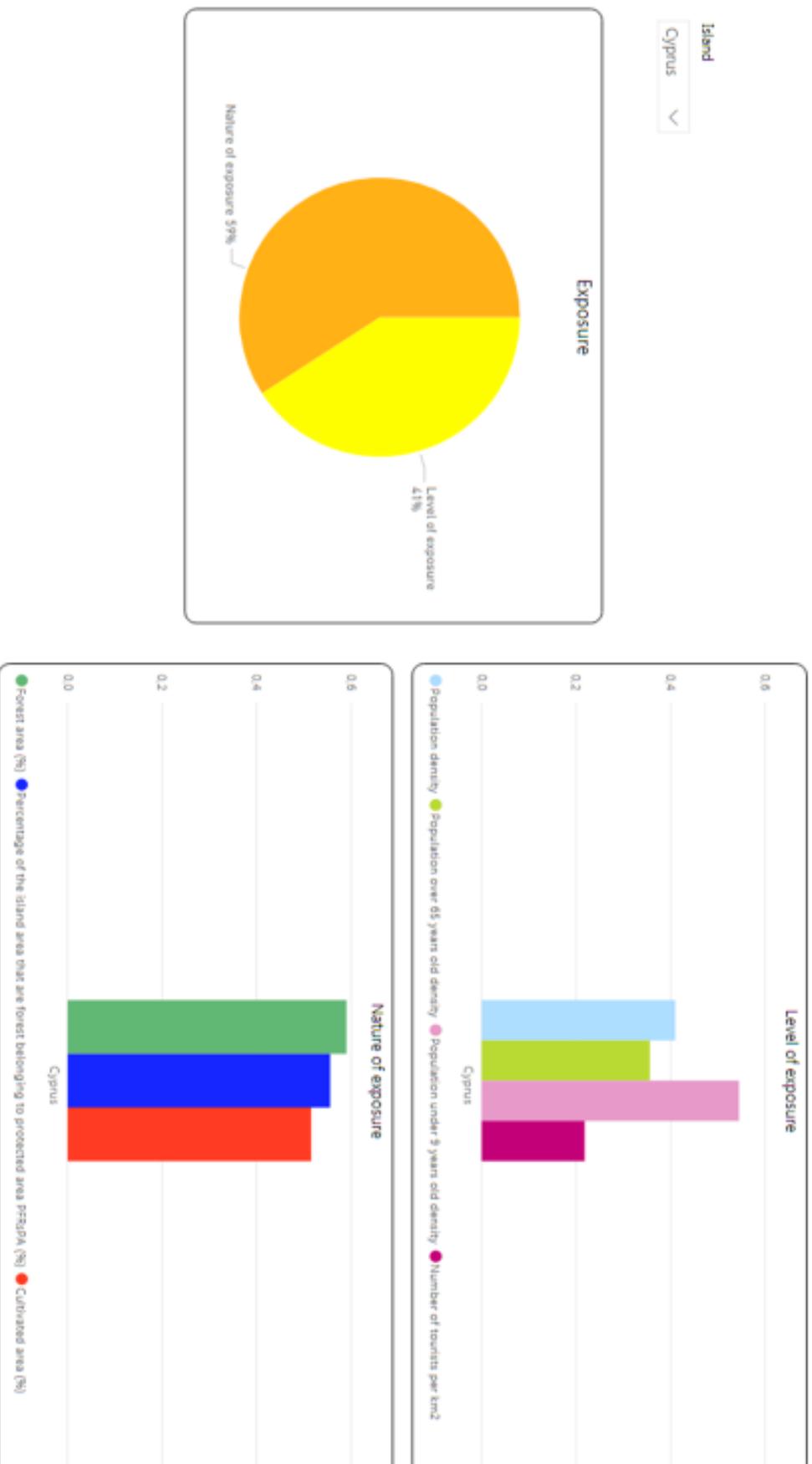


Figure 3.2.44. Detail and scores of the two subcomponents of exposure (nature and level of exposure)



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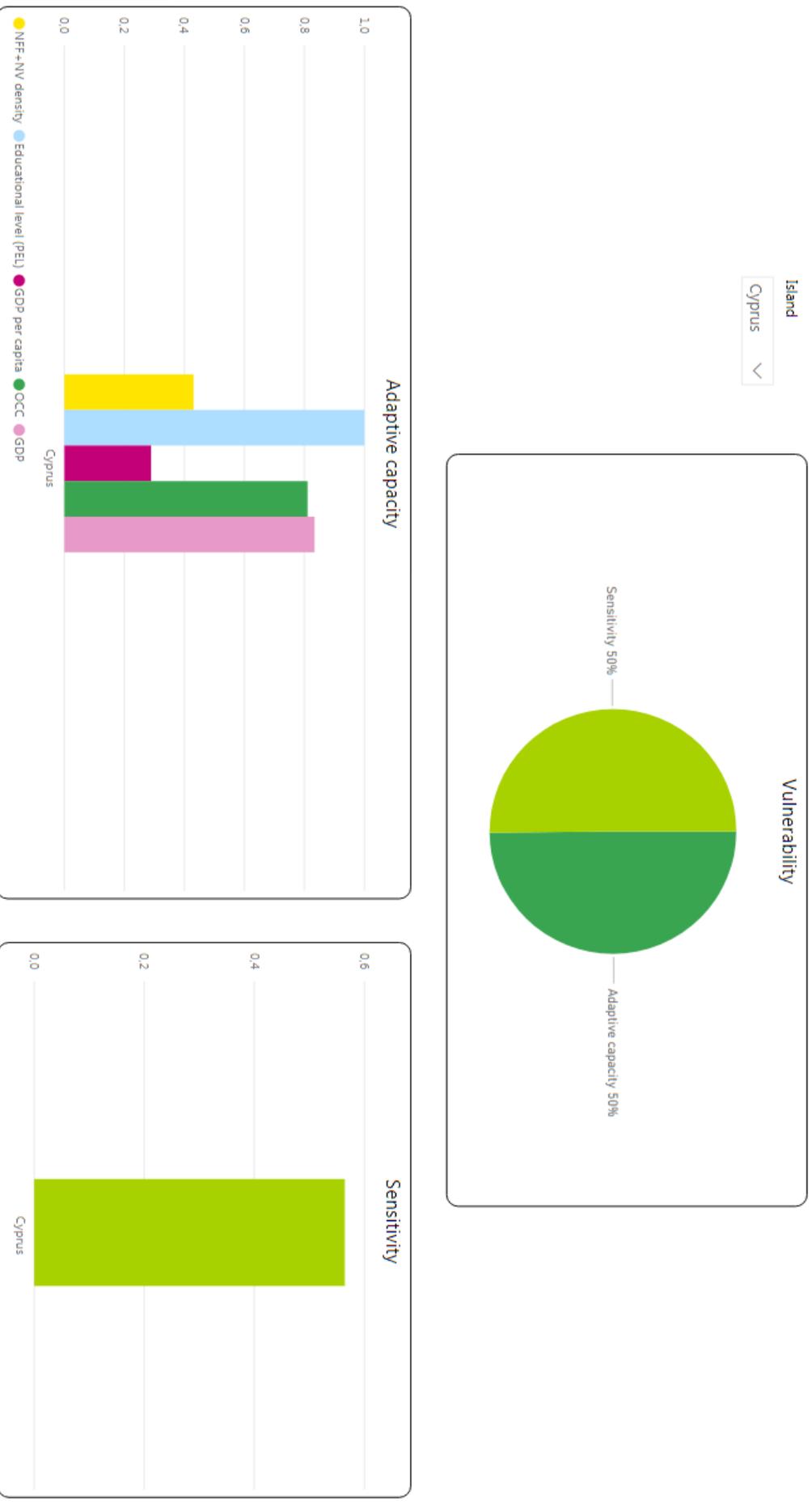


Figure 3.2.45. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Madeira

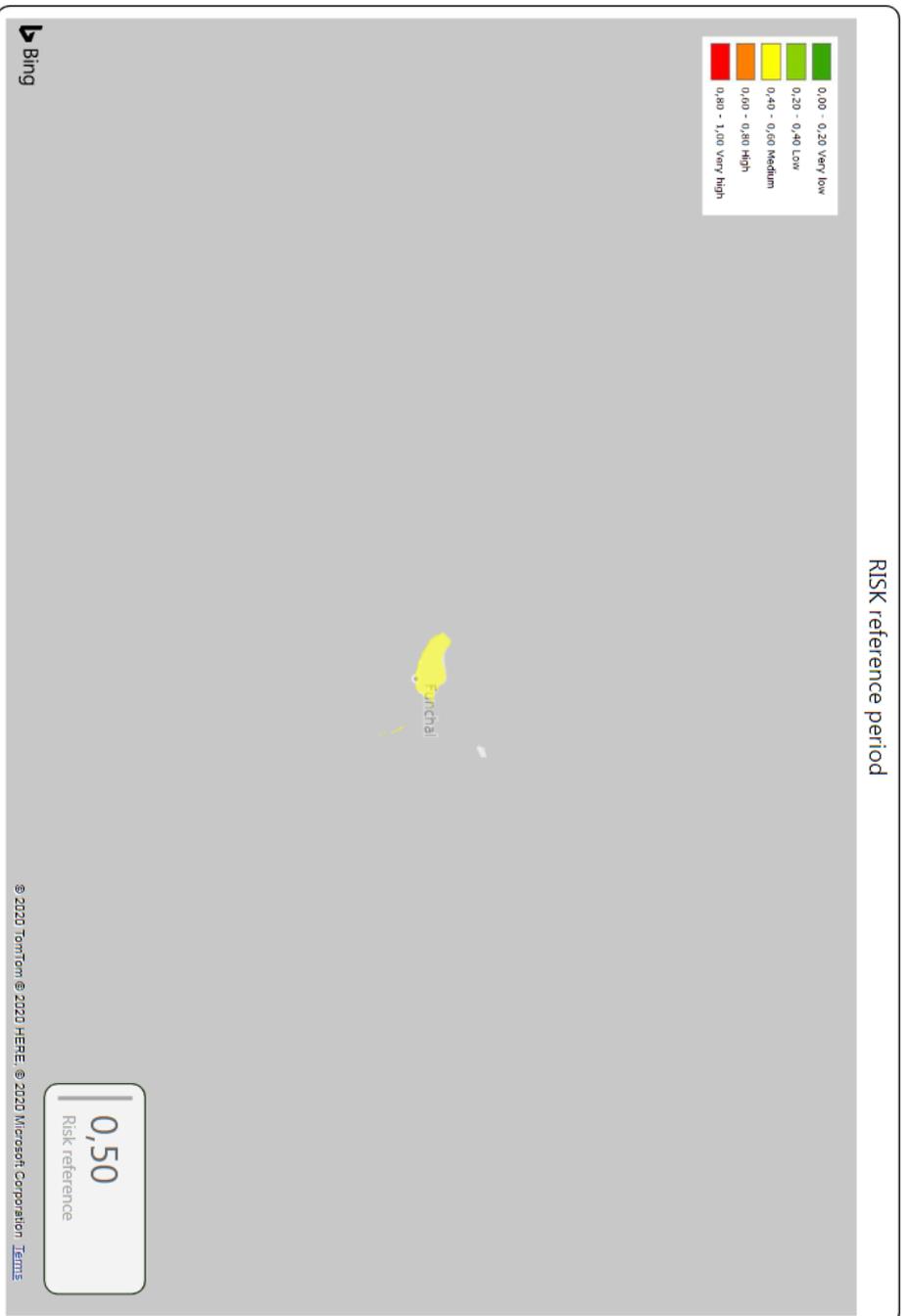


Figure 3.2.46. Risk score and components of the risk for the reference period



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Figure 3.2.47. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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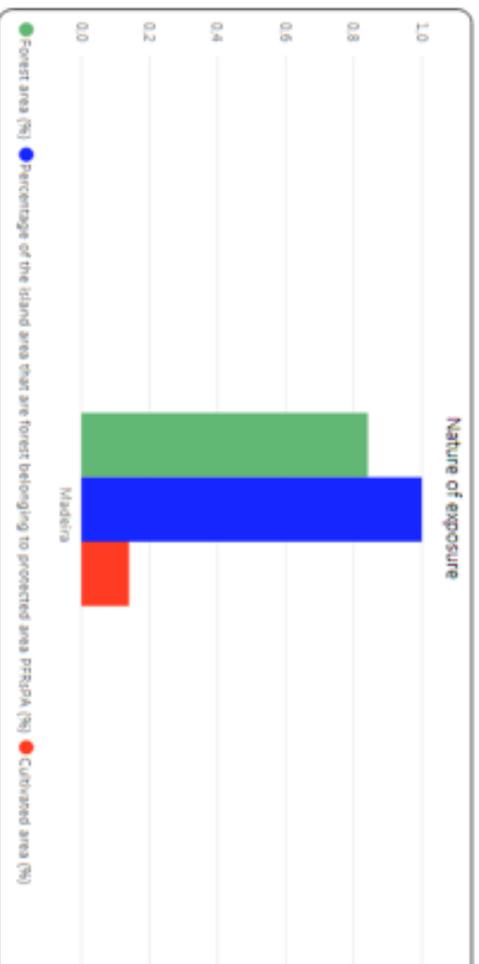
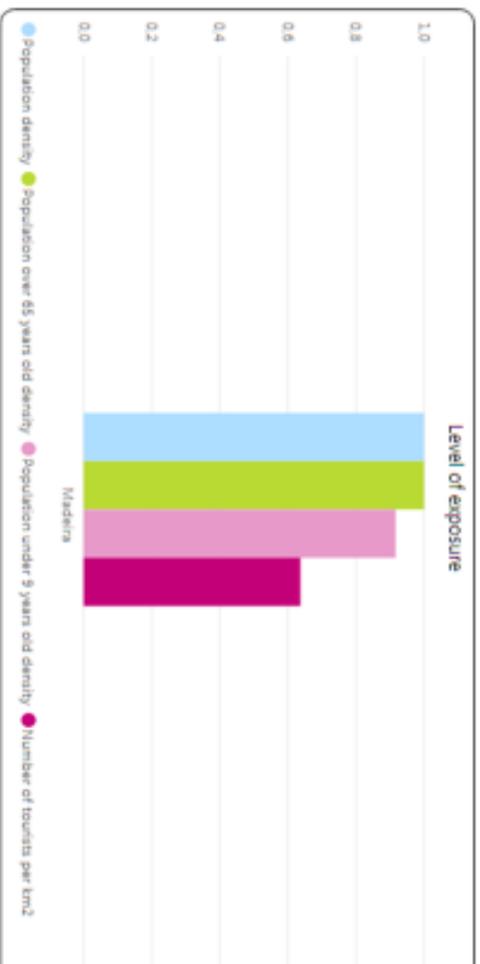
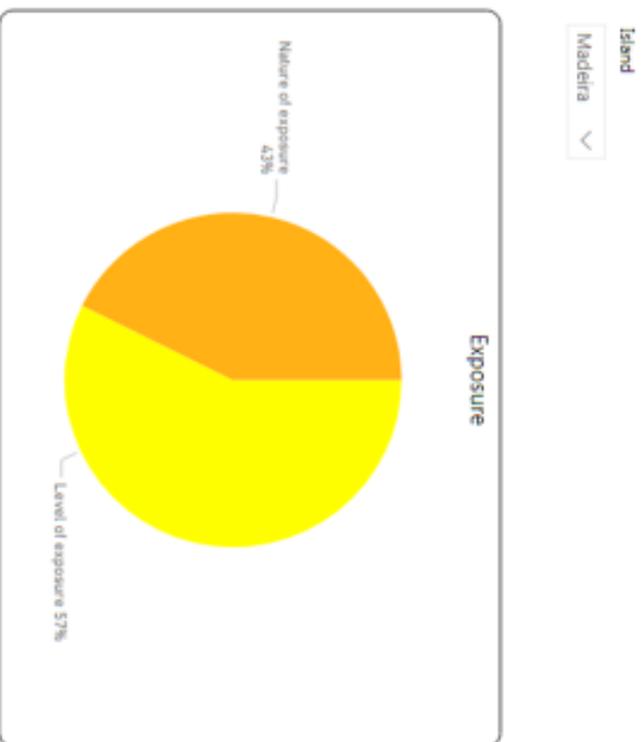


Figure 3.2.48. Detail and scores of the two subcomponents of exposure (nature and level of exposure) per island



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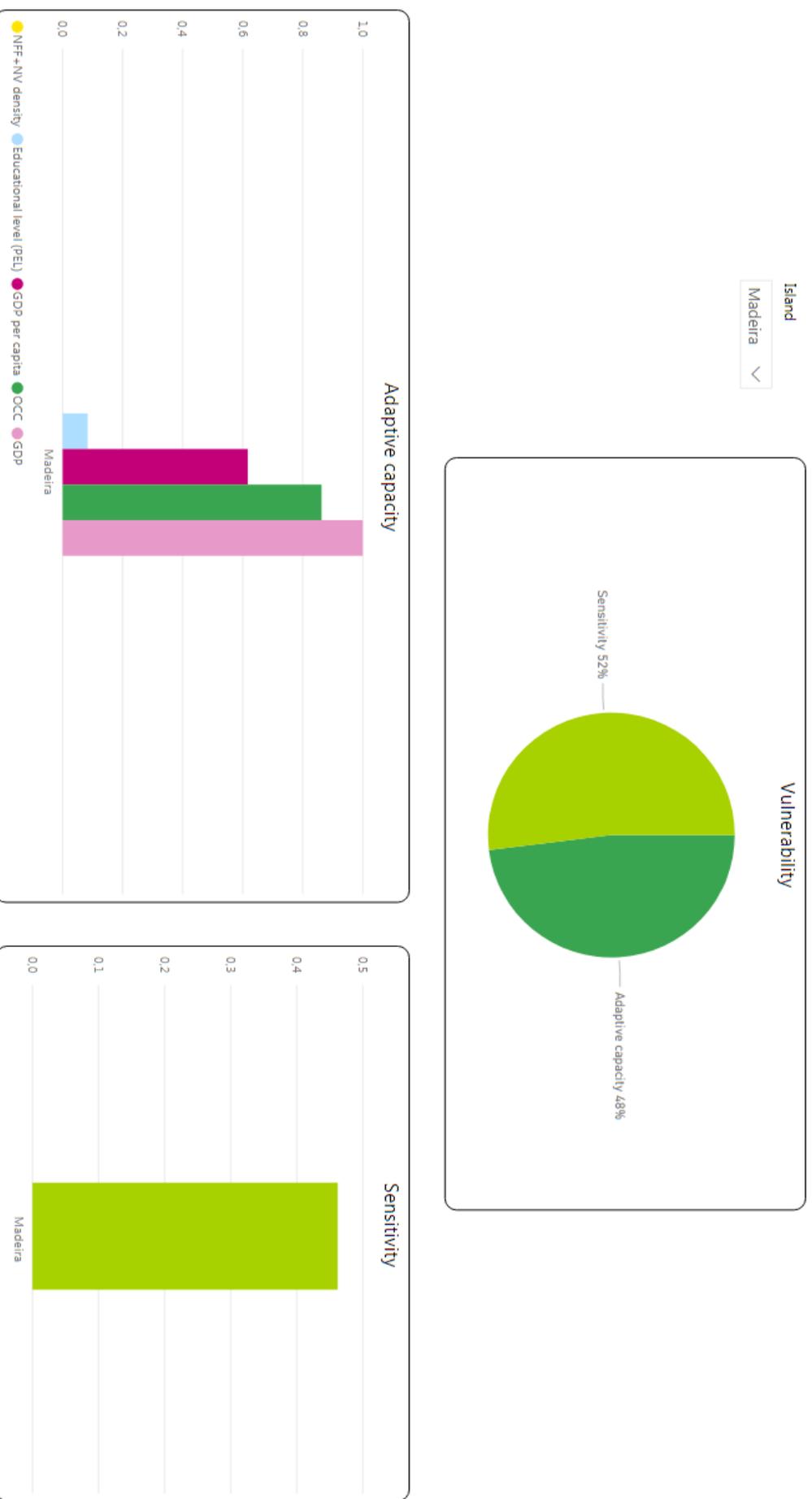


Figure 3.2.49. Detail and scores of the two subcomponents of vulnerability (adaptative capacity and sensitivity)



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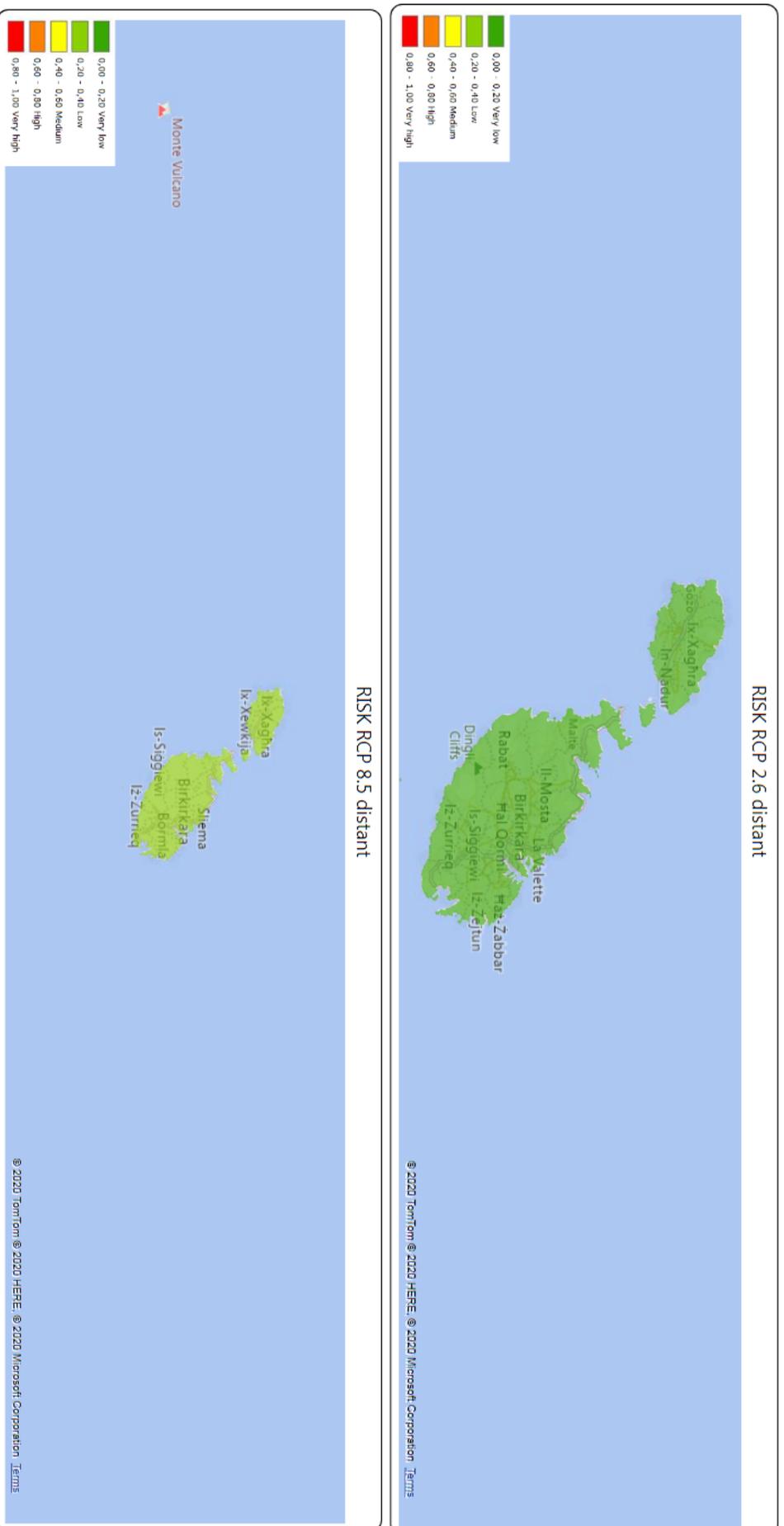


Figure 3.2.51. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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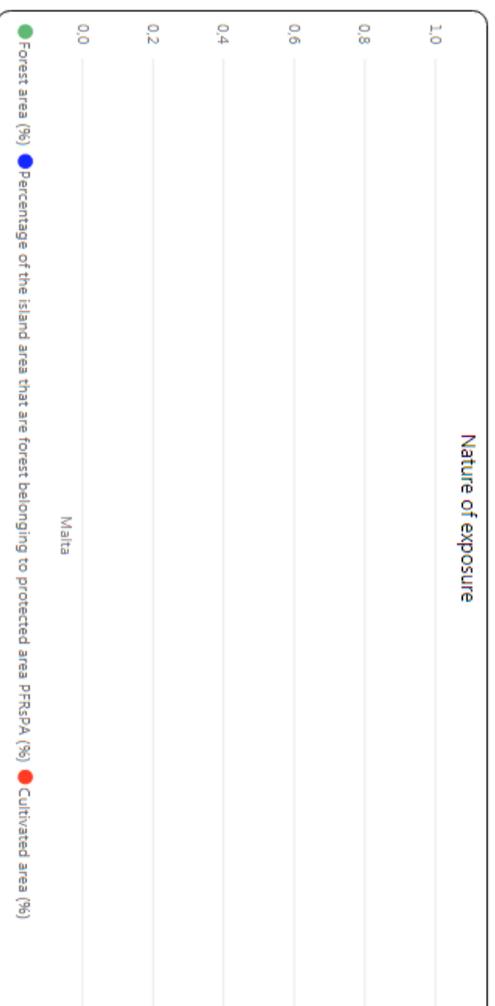
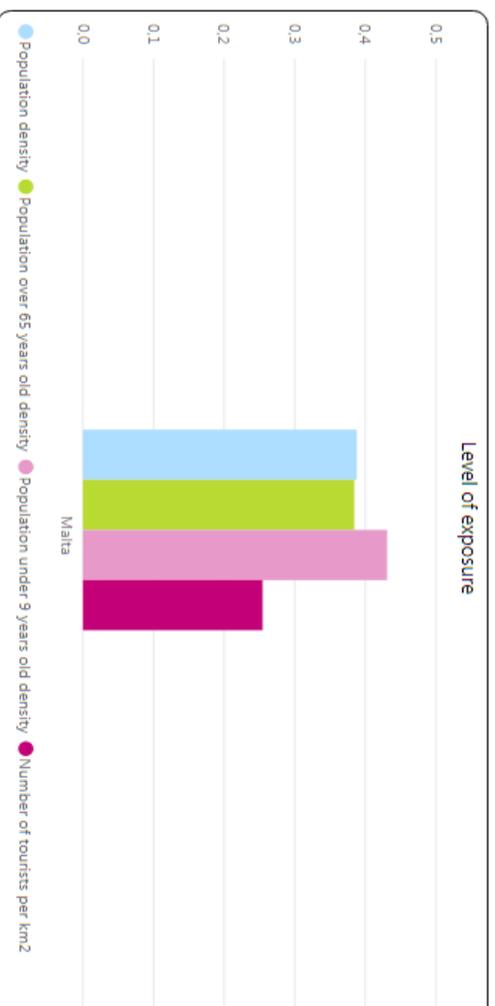
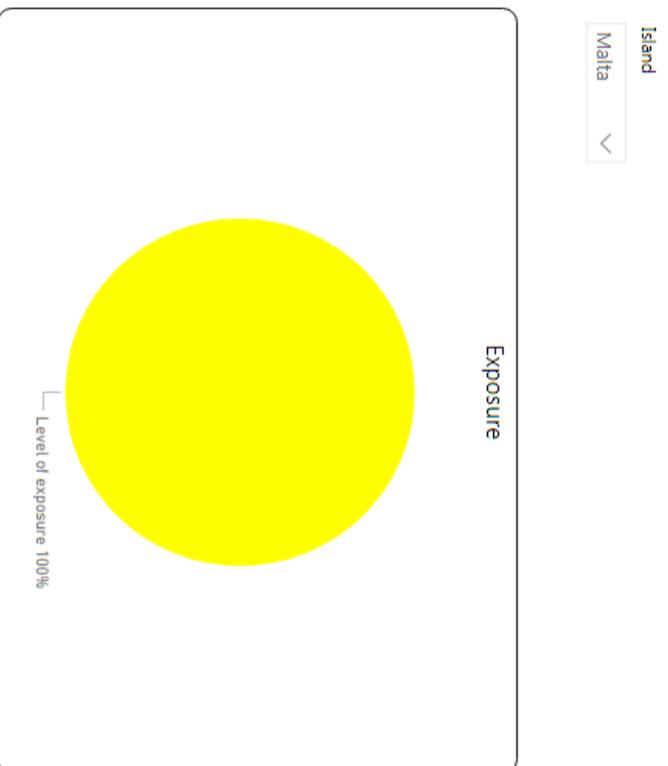


Figure 3.2.52. Detail and scores of the two subcomponents of exposure (nature and level of exposure)



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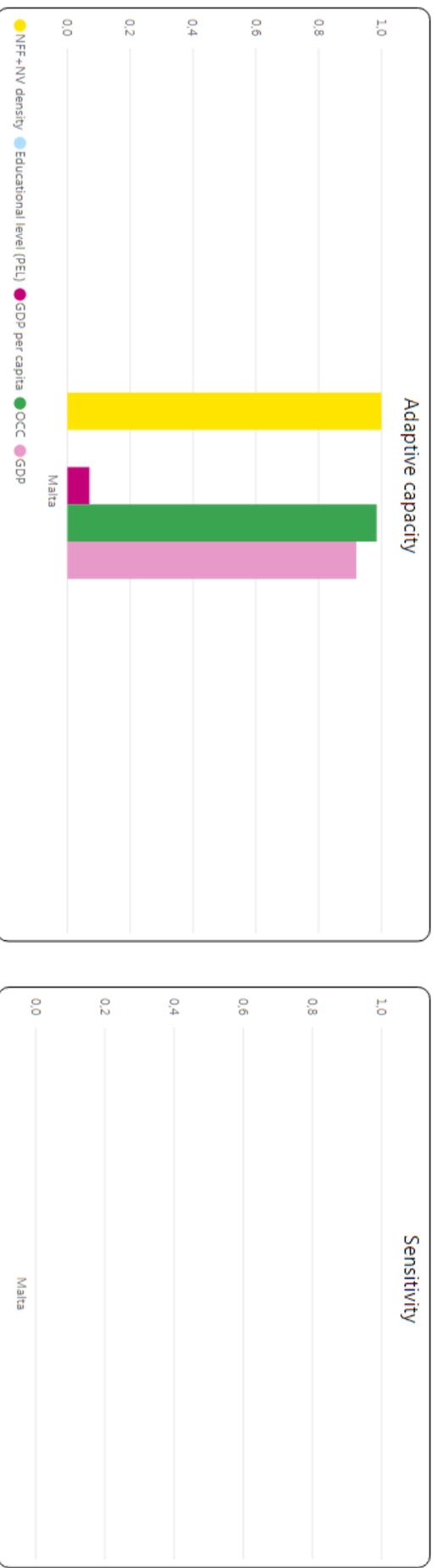
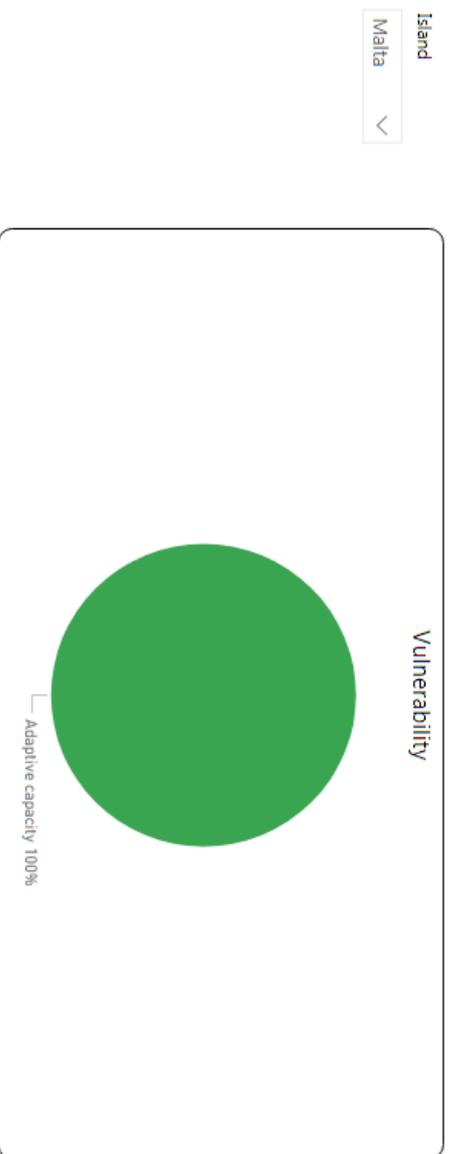


Figure 3.2.53. Details and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Sardinia

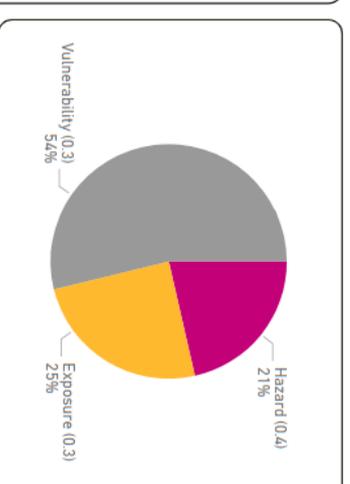
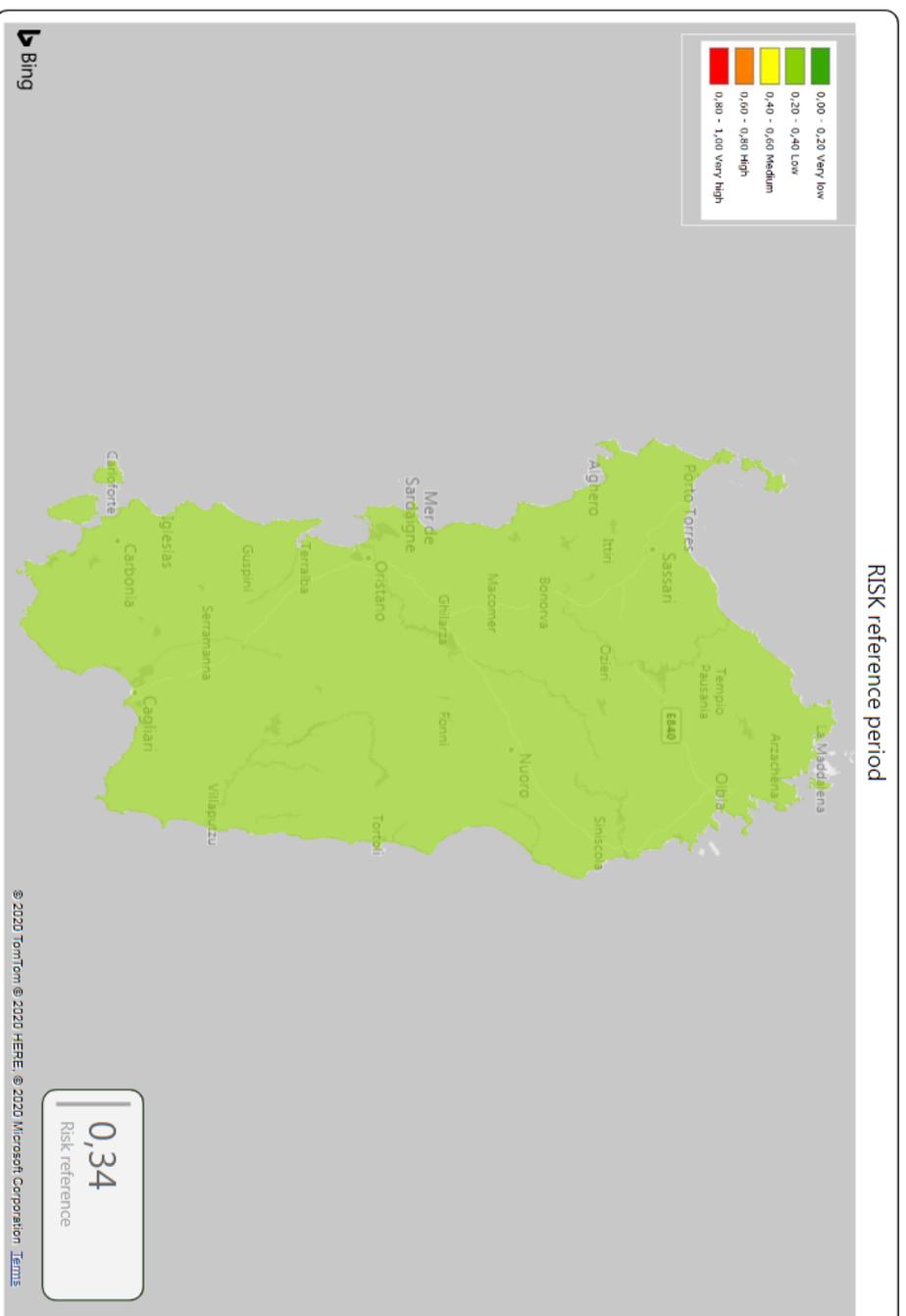


Figure 3.2.54. Risk score and components of the risk for the reference period



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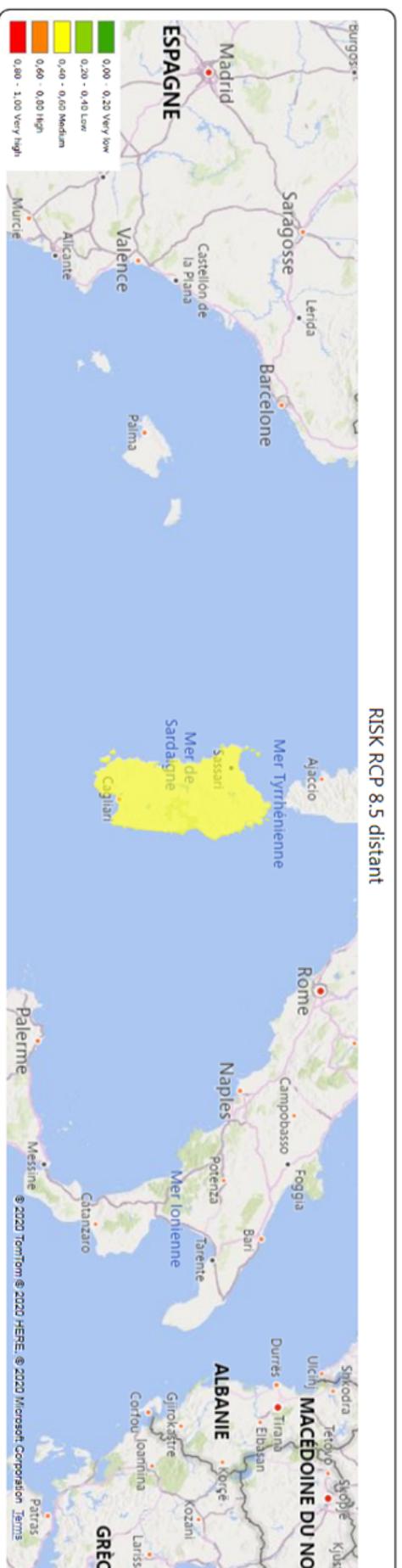


Figure 3.2.55. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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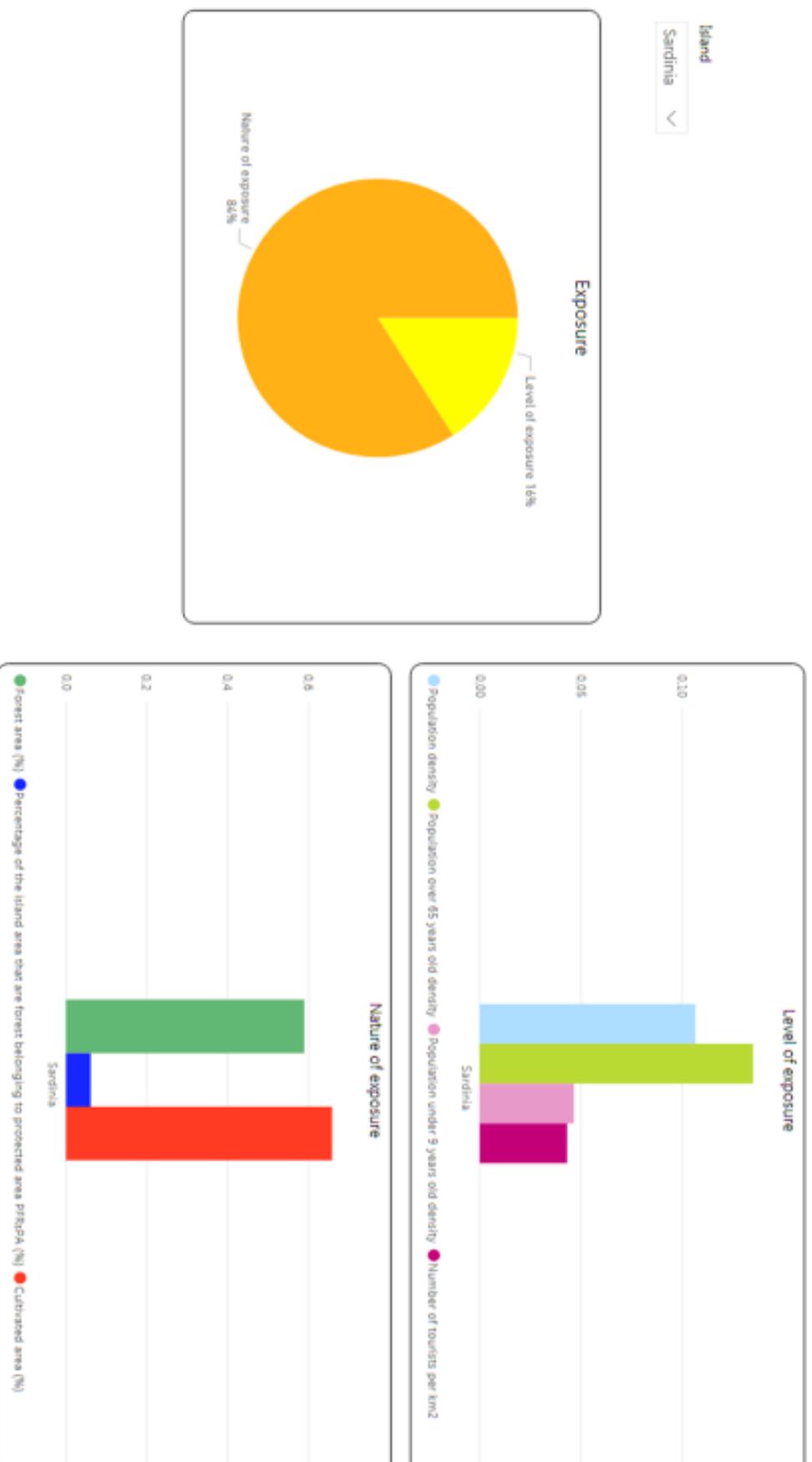


Figure 3.2.56. Detail and scores of the two subcomponents of exposure (nature and level of exposure) per island



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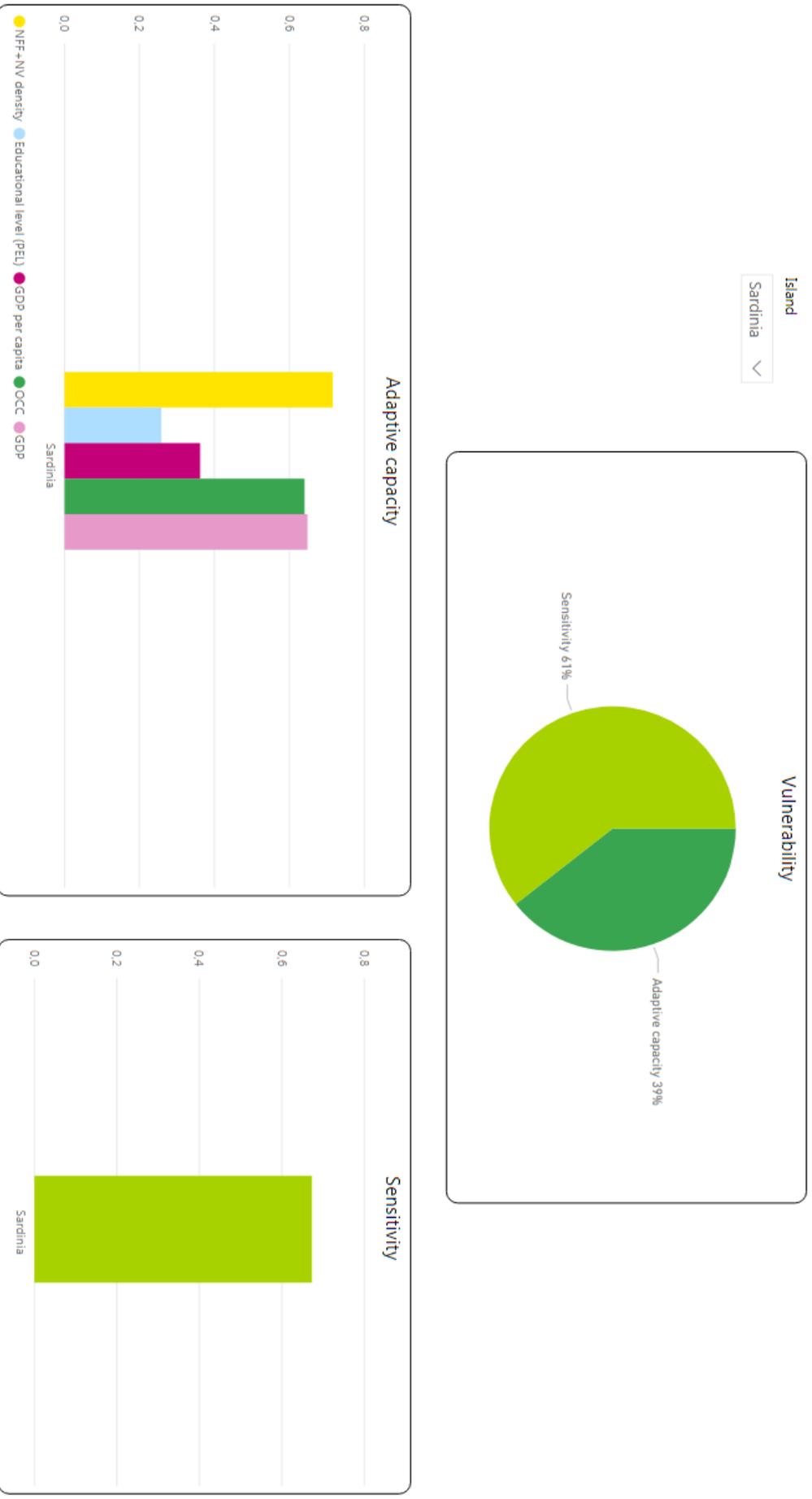


Figure 3.2.57. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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SOCIIMPACT



Sicily

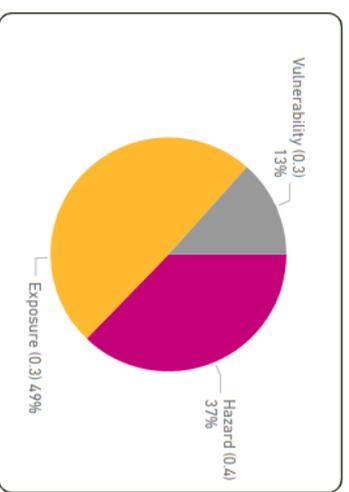
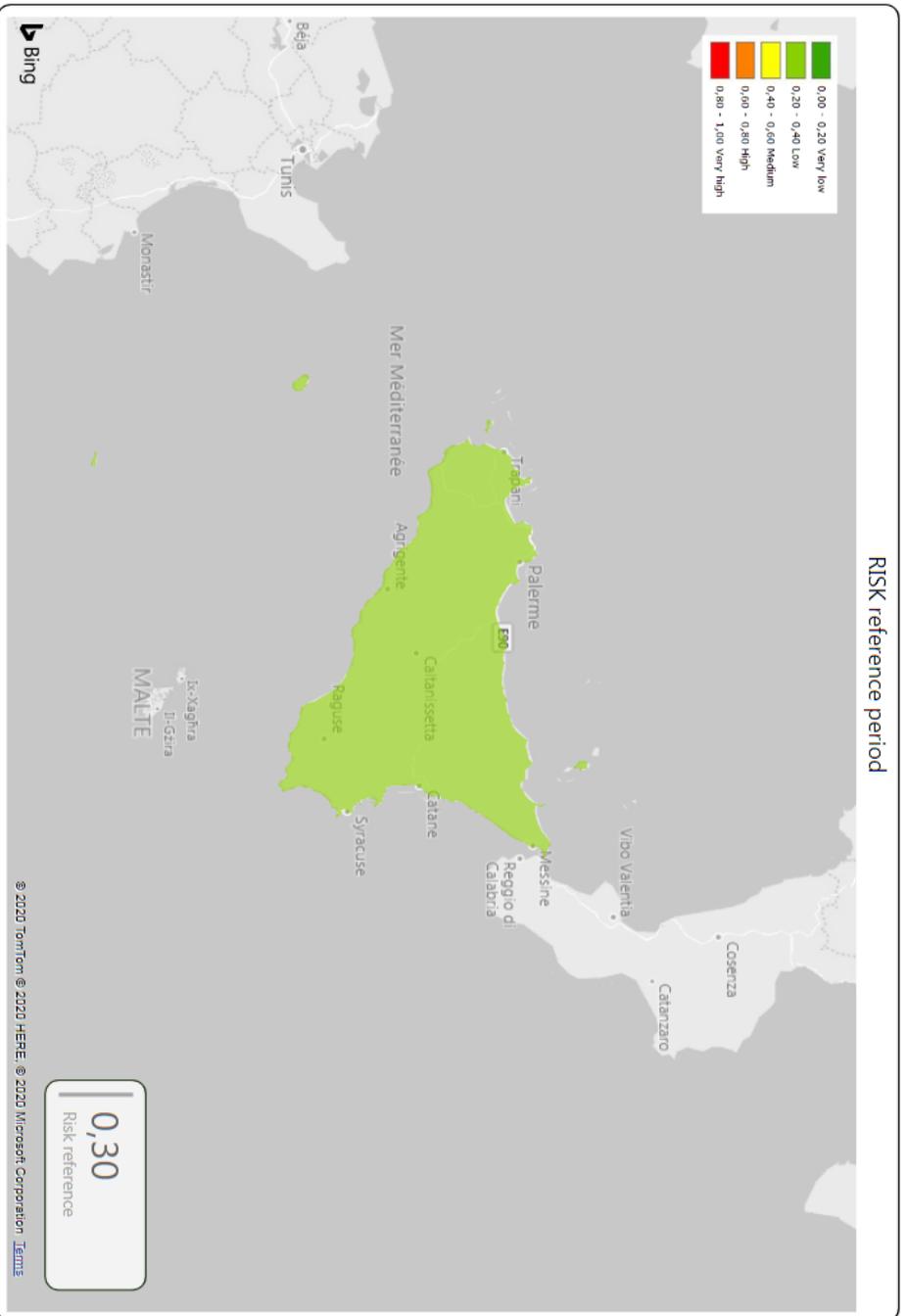


Figure 3.2.58. Risk score and components of the risk for the reference period



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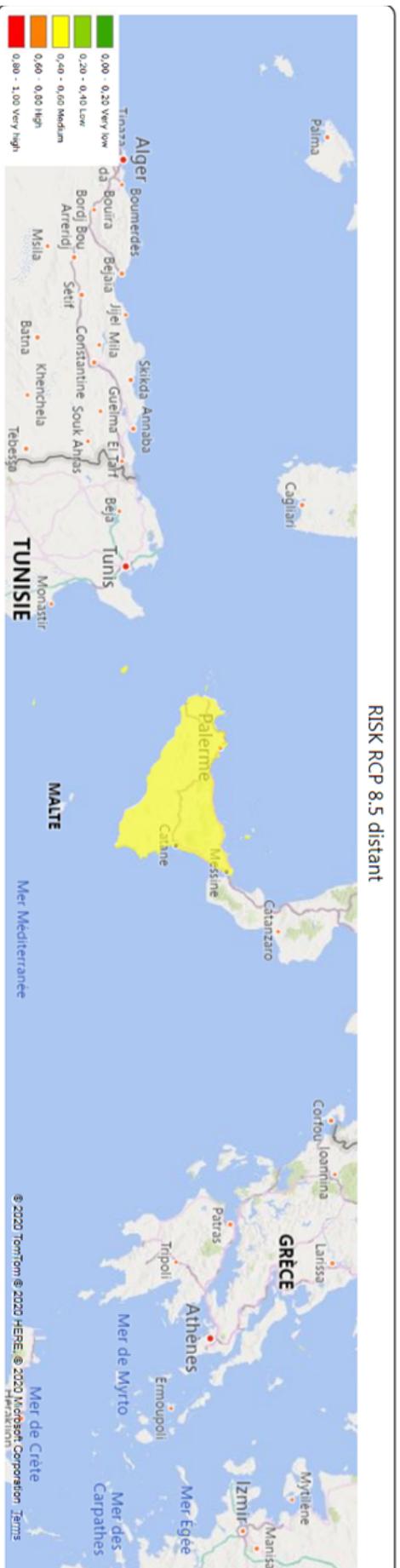


Figure 3.2.59. Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)



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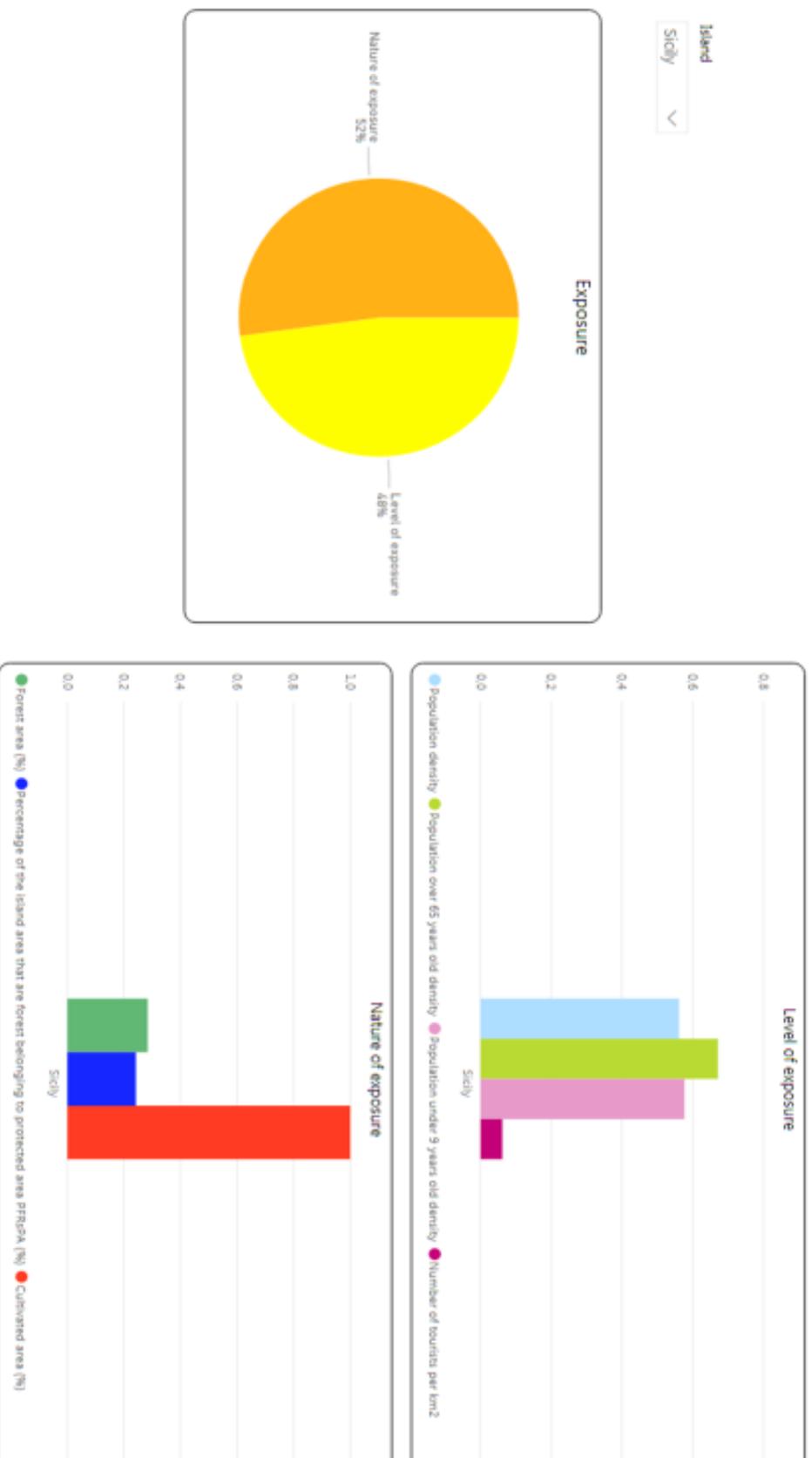


Figure 3.2.60. Detail and scores of the two subcomponents of exposure (nature and level of exposure) per island



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Figure 3.2.61. Detail and scores of the two subcomponents of vulnerability (adaptive capacity and sensitivity)



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Discussion of results

Impact chains describes a cause-effect-relationship among factors contributing to the consequences of a given combination of hazard and exposed object, making these relationships visible through the mean of impact chain diagrams. The methodology represented here is one of the first attempts to quantify the levels of fire risk under future climate for several Mediterranean islands. Impact chains are not exhaustive, but rather describe the common understanding, supported by studies and expertise, of cause-effect-relationships of the investigated phenomena. Indeed, the impact chains have the aim of reducing the complexity in order to make simpler the risk assessment and lower the time and economic resources necessary. Thus, compared to modelling approaches, they propose a simplified approach. But the more a modelling approach aspires to capture complexity and dynamics, the more it requires training and learning to be used. On the one hand, this approach can hardly describe the complexity of fire phenomenon in the environment and society and the chain dynamics triggered by climate change; on the other hand, this approach could provide regional and local administrators, engaged in institutional paths aimed at adapting their territories to climate change, the basic operating elements for defining a scientific knowledge framework that is preparatory to the planning of the most appropriate measures of adaptation. Indeed, the design of specific adaptation measures depends on local climatic scenarios, environmental characteristics, geographic location, and socio-economic constraints.

The reliability of the results depends on a number of elements, such as

- quality of the input data (including resolutions and completeness)
- uncertainties consideration
- normalization
- weighting of the indicators and limits to expert judgement
- participatory approach

Quality of data: many socio-economic, including demographics, income, education, labor for the impact chains are required at the provincial or municipal administrative levels. Many indicators for several islands were available only at NUTS2 or NUTS3 administrative levels, however, to obtain clear information about risk and thus define where to allocate resource to mitigate it or perform adaptation finer resolutions (at municipal or local scales) are needed.

Uncertainties due to the different calculation of the indicators:

The availability of the appropriate datasets for the calculation of FWI is often a limiting factor. This is often true when it comes to the exploitation of the model projections outputs that are usually provided as daily values, while the FWI system requires higher temporal resolution variables. Thus, a proxy variable combination needs to be selected (Bedia et al. 2013), though the optimum combinations have not been tested for the model datasets used in this study. Therefore, the possible biases in Atlantic FWI values derived from the proxy combination (daily T_{max} and RH_{min}, and local noon wind) cannot be estimated. A multi-model ensemble approach is important, as the inter-model variability can mask the proxy bias that may result from the FWI sensitivity to minimum relative humidity and/or maximum temperature.

Concerning the **weighting of the indicators**, we applied a participatory approach involving stakeholders and experts through one-to-one meetings and developed an effective, informed and shared process of recognition of the most relevant indicators and subsequent attribution of the individual weights. This approach ensures robustness in the analysis and reduction of any conflicts, as the result of full sharing and acceptance of both the methodology and product results.



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This approach has several strength points. As said above, it is accessible and easy to use and to implement, and it provides useful inputs for the identification and priorities of intervention and the preparation of adaptation measures. Also, this methodology allows the possibility to compare different reality based on appropriate indicators.

On the other hand, among the weak points we can recognize the limited availability of data concerning sensitivity and adaptive capacity, and thus the need to use proxy indicators, and the relative and not absolute significance of the risk results (“red” is more vulnerable than “green” but not “red” is highly vulnerable).

Regarding the participatory approach, a wide range of stakeholder was involved in the co-design process ranging from climate modelers and island focal points inside the consortium to fire risk experts. It is difficult to evaluate the overall approach and to which extent its implementation will contribute to the adaptation knowledge quality (usability, usefulness etc.).

Impact chain 3: loss of comfort due to an increase in thermal stress

Description of the Impact Chain and selection of the operationalization method

The initial impact chain was described in subsection 4.1 in deliverable D3.2. Specifically, it models the effect Climate Change would have on a potential tourist destination highlighting the risk of the decrease in tourists' level of comfort as a result of an increase in thermal stress. The impact chain is shown in Figure 3.2.62. As can be seen in the figure, the impact of Climate Change on the touristic attractiveness of an island depends on a set of multi-dimensional factors, including:

1. the frequency, intensity, and duration of heatwaves,
2. to what extent and how tourist activities and tourists become exposed to heatwaves, and how sensitive different segments of tourists are to extreme heat, and
3. the preparedness of the destination to cope with thermal discomfort episodes through information, technology, alternative activities, and medical attention.

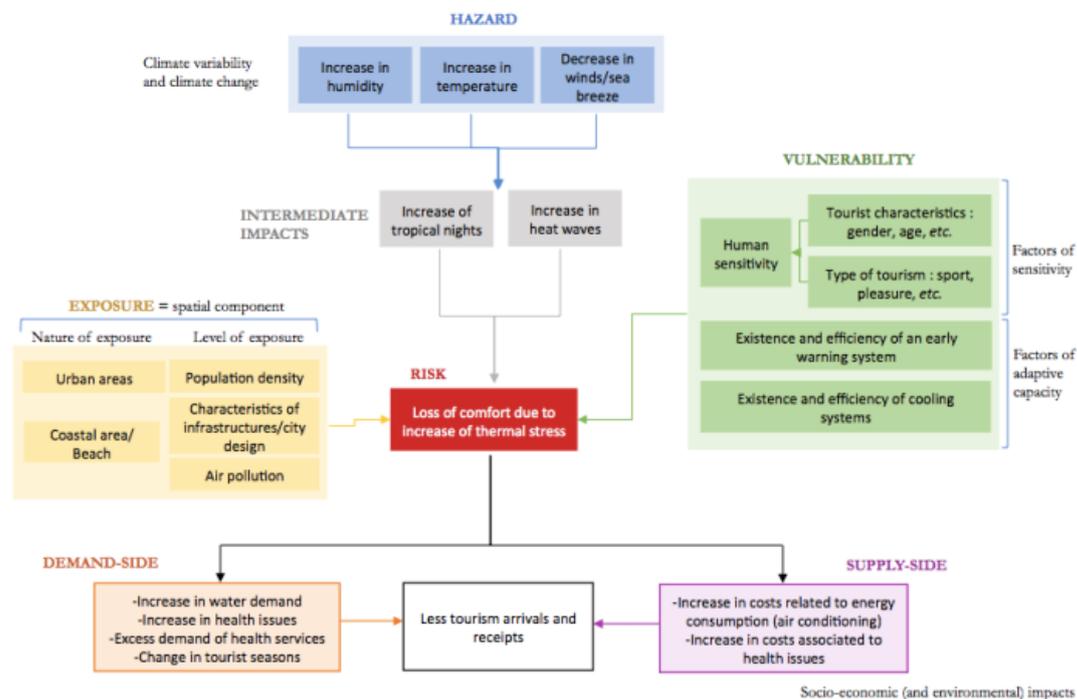


Figure 3.2.62. Loss of comfort due to increase of thermal stress.

For the purposes of the operationalization it was decided by the team to retile the risk as “*Loss of attractiveness of a destination due to a decrease in thermal comfort?*”. This was done in order for the risk to more accurately reflect the effects of the hazards, exposure and vulnerability on an island rather than an on an individual tourist.

The selection of islands to be compared was based on the availability of island data provided by the IFPs. The five islands selected for comparison were the Balearic Islands, the Canary Islands, Cyprus, Malta, and Sardinia.

The Analytical Hierarchy Process (AHP) method was selected as the technique to operationalize the impact chain since it is a well-grounded tool that allows for the prioritization/ranking of

alternatives using a weighting scheme that is established by expert judgement. Hence, for the purposes of the project, it was considered suitable as it would be able to reconcile the contribution of each risk factor (hazards, exposure, and vulnerability) towards the risk based on expert opinion and, subsequently, order the islands in terms of which one is most at risk of losing attractiveness due to a decrease in thermal comfort. For a detailed description of the AHP method, see Section 7.3 of this report.

Application of the AHP method

Hierarchy tree

The impact chain for the loss of comfort due to an increase in thermal stress was used as the basis for constructing the hierarchy tree, which is depicted in Figure 3.2.63. Some refinements were necessary regarding the indicators (at sub-criteria level) that were to be used for comparing the islands.

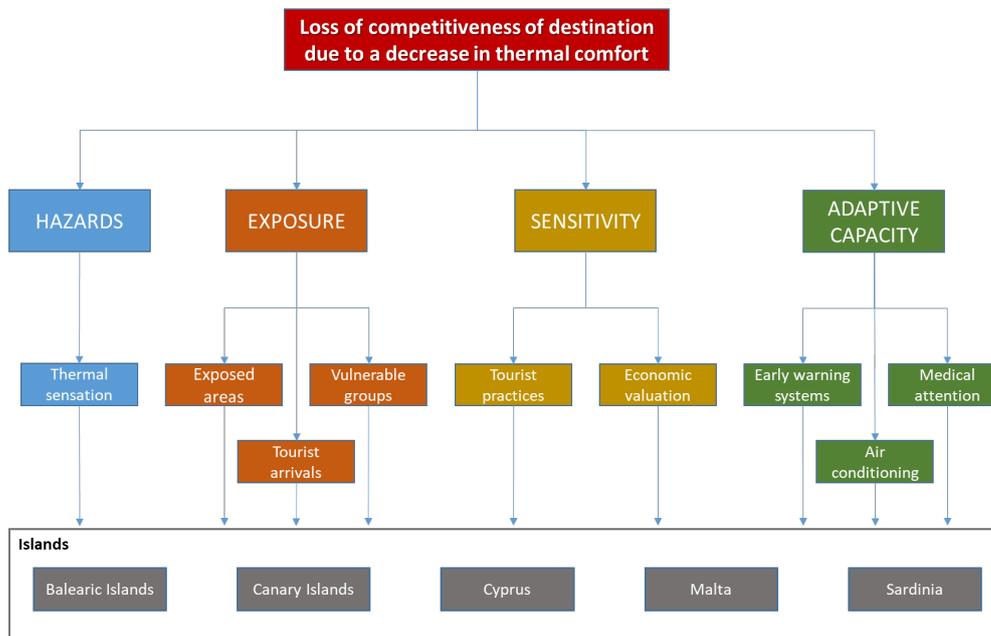


Figure 3.2.63 Hierarchy tree for thermal comfort impact chain.

Hazards are the climate events that instigate the climate-associated risk. For the AHP method, thermal sensation was considered as the most relevant indicator to assess changes in the thermal comfort of tourists while staying at their destination as it is a concept that combines temperature and humidity. Thus, it is the only sub-criterion of the Hazard criterion. Moreover, the humidity index (humidex) (Masterton and Richardson, 1979) was selected as the most appropriate metric for thermal sensation. The metric is an equivalent temperature that express the temperature perceived by people (i.e., the temperature that the human body would feel), given the actual air temperature and relative humidity.

Exposure denotes the range of ecological and social systems susceptible to be damaged by hazards. This criterion was decomposed into sub-criteria relating to three indicators. The first indicator



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relates to the exposure of tourists to heatwaves. The measure of the indicator combines the percentage of an island prone to heatwaves and the percentage of the tourist accommodations and facilities located in those areas prone to heatwaves. It is necessary to factor in both these aspects of exposure in order to allow for a better comparison of islands. For example, if an island has a small area that is prone to heatwaves with the majority of tourists frequenting in that small area, then the combination of the two factors will play a role when comparing, for instance, an island that has large areas prone to heatwaves, but with tourists frequenting in places outside these areas, since the overall exposure will be different. Specifically, it was decided to assign a weight of 75% to percentage of an island prone to heatwaves and the remaining 25% to the percentage of tourist accommodations and facilities located in heatwave-prone areas. The second indicator deals with the number of tourist arrivals during the hottest months. The indicator is represented by the percentage of tourists that visit an island between the months of May and September averaged over the last five years. Finally, the third indicator concerns vulnerable groups of tourists who have the highest risk of being affected by heatwaves. Literature confirms that under-6s and over-65s are the most vulnerable age groups, however, the statistical services of the islands homogeneously provide data for the under-14 and over-65 age groups. For this indicator, two values were computed:

1. the number of tourists visiting an island that were under 14 years of age during the months of May and September over the total number of tourists visiting during the same period, averaged over the last five years, and
2. the number of tourists visiting an island that were over 65 years of age during the months of May and September over the total number of tourists visiting during the same period, averaged over the last five years.

For purpose of combining the two values and adjusting the change to age groups, it was decided to apply a ratio of 15:85 in order to emphasize the proportion of over-65s (85%) to the proportion of under-14s (15%).

Sensitivity concerns the susceptibility of natural, cultural, and built resources to harm that is a direct or indirect result of Climate Change hazards. For the operationalization of this impact chain, sensitivity relates to the susceptibility of tourists and is broken down into sub-criteria pertaining to two indicators. The first indicator involves tourist activities. The effect of heatwaves on tourist activities varies greatly. For example, a tourist sunbathing at a beach will not feel the effects of a heatwave to the same degree as a tourist that is trekking. Different destinations have different rates of tourists practicing activities incompatible with heatwaves events. So, this indicator aims at catching these differences. More specifically, this indicator is a measure of the percentage of visitors who state that they practice activities not compatible with heatwave events. The second indicator concerns the economic valuation of heatwaves from the perspective of tourists. In the case of a heatwave event, all tourists will suffer from thermal discomfort to a certain degree. Hence, the indicator represents their willingness to avoid this discomfort as expressed in monetary terms. Therefore, it is measured by much money tourists are willing to pay to avoid a heatwave during their vacation time.

Adaptive capacity reveals the potential to face the hazards by reducing the level of exposure and/or increasing the resilience of the tourism system through providing information, adopting proper technology, supplying alternative activities, and improving medical attention. This criterion is split into sub-criteria concerning three indicators. The first indicator has deals with early warning systems. Setting up a proper early warning system can help tourists and service providers to plan effective responses to heatwaves, making them less distressing and reducing the destination's



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vulnerability. Hence, this indicator is measured with a score representing the quality of early warning systems in place and advisement of options for tourists. The second indicator involves air conditioning. Air conditioning is the most effective technology used to combat extreme heat. Therefore, the indicator uses the percentage of hotel accommodations and tourist facilities offering air conditioning systems as a measure of the capacity of the destination to cope with this hazard. The final indicator concerns the care and medical attention (such as in the case of heatstroke or similar) available on an island that may be necessary to help reduce pain or avoid casualties due to diseases related to heatwaves. Therefore, the number of hospital beds available on an island per 100,000 potential users, both residents and tourists, is taken as the measure of this indicator.

Pairwise comparison

Several experts coming from different areas of expertise were consulted for the pairwise comparison. The experts are listed in Table 3.2.21 showing their country, field of expertise, and years of experience. Each expert was provided with the Fundamental Scale (Table 7.3.1) and they provided judgements on the importance of each criterion, sub-criterion and alternative. In the case of disagreeing scores, the values were averaged.

Table 3.2.21. List of experts consulted for pairwise comparisons.

Expert	Country	Field of expertise	Years of experience
Dr Felipe Antonio Rodríguez Medina	Spain	Medical Environmental economics Health in tourism	30
Dr Matías Manuel González Hernandez	Spain	Environmental economics Sustainable tourism	25
Dr George Zittis	Cyprus	Climate Change Heatwaves Tourism	8
Haris Neophytou	Cyprus	Sustainable tourism	10
Dr Constantinos Stylianou	Cyprus	Sustainable tourism	3

- **Criteria vs risk**

Criteria				
	Hazards	Exposure	Sensitivity	Adaptive capacity
Hazards	1	1/1.6	1/2	1/1.25
Exposure	1.6	1	1/1.25	2
Sensitivity	2	1.25	1	2.5
Adaptive capacity	1.25	1/2	1/2.5	1
Consistency ratio: 0.0093 < 10%				



- Hazard-Exposure: Exposure is considered to contribute slightly more to the risk of loss of competitiveness due to decreased thermal comfort because a destination with smaller exposed areas and fewer tourists will not be impacted by the hazard to such a large degree as an island with greatly exposed areas and more tourists.
- Hazard-Sensitivity: If a destination offers tourist practices that are not affected by heatwaves then the hazard will not pose a risk. Similarly, if tourists are willing to pay to avoid heatwaves, then again, the hazard will not be a risk.
- Hazard-Adaptive capacity: The capability of an island to mitigate the risk through early warning systems, air-conditioning coverage and medical attention for tourists can minimize the loss of attractiveness irrespective of the severity of heatwave events.
- Exposure-Sensitivity: An islands' sensitivity to heatwaves contributes slightly more to the loss of competitiveness than exposure.
- Exposure-Adaptive capacity: The adaptive capacity of an island does not play as big as role in the risk as exposure.
- Sensitivity-Adaptive capacity: Providing tourists with ways to avoid heatwaves is more important than the measures adopted to deal with them.

• *Sub-criteria vs criteria*

Exposure			
	Exposed areas	Vulnerable groups	Tourist arrivals
Exposed areas	1	1/3.5	1/5
Vulnerable groups	3.5	1	1/2
Tourist arrivals	5	2	1
Consistency ratio: 0.0109 < 10%			

- Exposed areas-Vulnerable groups: Vulnerable groups are more important as they are the direct receptors of the hazard.
- Exposed areas-Tourist arrivals: Tourist arrivals are more significant than the areas exposed to the hazard, again since the higher the number of tourists, the more people will be exposed to the hazard.
- Vulnerable groups-Tourist arrivals: The total number of tourists is slightly more important overall.

Sensitivity		
	Tourist activities	Economic valuation
Tourist practices	1	5



Economic valuation	1/5	1
Consistency ratio: 0.0000 < 10%		

- Sensitive activities-Economic valuation: If most tourists' practices are not heatwave-compatible, then the willingness of tourists to pay to avoid heatwaves will have no bearing.

Adaptive capacity			
	Early warning systems	Air conditioning	Medical attention
Early warning systems	1	1/3.5	1
Air conditioning	3.5	1	3
Medical attention	1.5	1/3	1
Consistency ratio: 0.0023 < 10%			

- Early warning systems-Air conditioning: Air conditioning is much more important since all islands have early warning systems in place for tourists.
- Early warning systems-Medical attention: Both are equal in importance for the welfare of tourists, since the former is intended to advise tourists before a heatwave event, whereas the latter is intended to take care of tourists after a heatwave event.
- Air conditioning-Medical attention: Coverage of air conditioning is more important as it will alleviate the cases where medical attention is required.

- **Alternatives (islands) vs sub-criteria**

Hazard

For the sub-criterion Thermal sensation of the Hazards criterion, experts were asked to compare the islands using data from D4.3, and specifically were asked to used data concerning the predicted percentage of days per year with thermal sensation over 35° Celsius. Four scenarios were provided:

- Humidex for near future (2046-2065) under RCP 2.6 low emissions scenario
- Humidex for near future (2046-2065) under RCP 8.5 high emissions scenario
- Humidex for distant future (2081-2100) under RCP 2.6 low emissions scenario
- Humidex for distant future (2081-2100) under RCP 8.5 high emissions scenario

The percentages used for comparison are given in Table 3.2.22 below.

Table 3.2.22. Percentage of days in a year with humidity index greater than 35 °C in the near and distant future (for RCP2.6 and RCP8.5).



Time horizon	Emissions scenario	Balearic	Canary	Cyprus	Malta	Sardinia
Near	RCP 2.6	18.55	3.15	30.79	18.27	17.89
	RCP 8.5	19.15	7.45	32.44	19.51	18.79
Distant	RCP 2.6	18.14	3.48	31.23	18.55	17.53
	RCP 8.5	31.42	20.68	44.30	32.38	30.74

The following features were observed by the experts for all four scenarios:

- Cyprus has a higher predicted number of days with thermal sensation above 35° Celsius.
- The Balearic Islands, Malta and Sardinia all have roughly the same predicted number of days with thermal sensation above 35° Celsius.
- The Canary Islands have a much lower predicted number of days with thermal sensation above 35° Celsius compared to the other four islands.

Humidex for near future under RCP 2.6 low emissions scenario					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	5	1/5.5	1	1
Canary	1/5	1	1/9	1/5	1/5
Cyprus	5.5	9	1	5.5	5.5
Malta	1	5	1/5.5	1	1
Sardinia	1	5	1/5.5	1	1
Consistency ratio: 0.0350 < 10%					

Humidex for near future under RCP 8.5 high emissions scenario					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	4	1/5.5	1	1
Canary	1/4	1	1/7.5	1/4.5	1/4.5
Cyprus	5.5	7.5	1	5	5
Malta	1	4.5	1/5	1	1
Sardinia	1	4.5	1/5	1	1
Consistency ratio: : 0.0420 < 10%					

Humidex for distant future under RCP 2.6 low emissions scenario					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	5	1/5.5	1	1
Canary	5	1	1/9	1/5.5	1/5.5
Cyprus	5.5	1/9	1	5.5	5.5
Malta	1	1/5	5	1	1
Sardinia	1	1/5	5	1	1
Consistency ratio: 0.0350 < 10%					

Humidex for distant future under RCP 8.5 high emissions scenario					
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	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	4	1/4.5	1	1
Canary	1/4	1	1/6.5	1/3.5	1/3.5
Cyprus	4.5	6.5	1	4.5	4.5
Malta	1	3.5	1/4.5	1	1
Sardinia	1	3.5	1/4.5	1	1
Consistency ratio: 0.0243 < 10%					

Exposure

For the sub-criterion Exposed areas of the Exposure criterion, experts were asked to compare the islands using data combining the percentage of:

- The area of an island most prone to heatwaves, and
- The tourist accommodations and facilities located in those heatwave-prone areas.

The data for this indicator were provided by the IFPs and are shown in Table 3.2.23.

Table 3.2.23. Data used to compare the Exposed areas indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	71.50	55.00	75.50	74.25	73.00

The following comparisons were obtained:

- o The Balearic Islands, Cyprus, Malta, and Sardinia all shared around the same percentages (70-75%) of exposed areas.
- o The Canary Islands has a lower percentage compared to the other islands (around 55%), and thus is less exposed to heatwaves.

Exposed areas					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	3	1	1	1
Canary	1/3	1	1/3	1/3	1/3
Cyprus	1	3	1	1	1
Malta	1	3	1	1	1
Sardinia	1	3	1	1	1
Consistency ratio: 0.0000 < 10%					

For the sub-criterion Vulnerable groups of the Exposure criterion, experts were asked to compare the islands using data combining the percentage of:

- Tourists aged below 15, and
- Tourists aged above 65.

Again, the data for this indicator were provided by the IFPs and are given in Table 3.2.24.

Table 3.2.24. Data used to compare the Vulnerable groups indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	6.83	9.28	8.65	9.08	11.67



The following comparisons were made:

- Sardinia has the highest percentage of tourists that belong to the vulnerable age groups (around 11%) compared to all other islands.
- The Canary Islands, Cyprus, and Malta all have the same percentage of visitors belonging to the vulnerable age groups (between 8-9%).
- The Balearic Islands has a lower percentage of tourists belonging to the vulnerable age groups.

Vulnerable groups					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	1/3	1/2.5	1/3	1/4.5
Canary	3	1	1	1	1/2.5
Cyprus	2.5	1	1	1	1/2.5
Malta	3	1	1	1	1/2.5
Sardinia	4.5	1/2.5	1/2.5	1/2.5	1
Consistency ratio: 0.0063 < 10%					

For the sub-criterion Tourist arrivals of the Exposure criterion, experts were asked to compare the islands using data pertaining to the percentage of tourist arrivals during the months of May to September. Table 3.2.25 displays the data used for comparing the islands, which was provided by IFPs.

Table 3.2.25. Data used to compare the Tourist arrivals indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	75.12	39.66	66.29	54.11	80.82

The following comparisons were observed:

- The Balearic Islands and Sardinia have the highest percentage of tourists arriving between May and September compared to all other islands (75-80%).
- Cyprus and Malta have slightly less arrivals during the same period, with 66% and 54%, respectively.
- The Canary Islands have a much lower percentage of tourist arrivals (around 40%).

Tourist arrivals					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	6	2	3	1/1.5
Canary	1/6	1	1/4	1/2.5	1/6.5
Cyprus	1/2	4	1	2	1/2.5
Malta	1/3	2.5	1/2	1	1/3.5
Sardinia	1.5	6.5	2.5	3.5	1
Consistency ratio: 0.0078 < 10%					

Sensitivity



For the sub-criterion Tourist activities of the Sensitivity criterion, experts were asked to compare the islands using data related to the percentage of tourist practicing activities that are sensitive to heatwaves. Table 3.2.26 shows the percentages as provided by the IFPs.

Table 3.2.26. Data used to compare the Tourist activities indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	60.00	55.68	60.78	63.28	11.49

The following comparisons were made:

- Apart from Sardinia (with 11%), all islands have roughly the same percentage of tourists participating in outdoor activities sensitive to extreme heat (around 55-60%).

Tourist activities					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	1	1	1	6.5
Canary	1	1	1	1	6
Cyprus	1	1	1	1	6.5
Malta	1	1	1	1	6.5
Sardinia	1/6.5	1/6	1/6.5	1/6.5	1
Consistency ratio: 0.0002 < 10%					

For the sub-criterion Economic valuation of the Sensitivity criterion, experts were asked to compare the islands using data from WP5 containing the willingness of tourists to pay (€/day) in order to avoid the effects of extreme heat. These values are shown in Table 3.2.27.

Table 3.2.27. Data used to compare the Economic valuation indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (€/day)	4.11	3.38	8.52	12.31	6.00

The following comparisons were noted:

- Tourists visiting Cyprus and Sardinia are willing to pay more (6-9 Euros/day) to avoid heatwaves than those visiting the Balearic Islands and the Canary Islands (3-4 Euros/day).
- Malta tourists are willing to pay the most to avoid the effect of extreme heat (12 Euros/day).

Economic valuation					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	1/1.5	1/3.5	1/5	1/2.5
Canary	1.5	1	1/4	1/5.5	1/3.5
Cyprus	3.5	4	1	1/2.5	2
Malta	5	5.5	2.5	1	4



Sardinia	2.5	3.5	1/2	1/4	1
Consistency ratio: 0.0331 < 10%					

Adaptive capacity

For the sub-criterion Early warning systems of the Adaptive capacity criterion, experts were asked to compare the islands using the scoring of the effectiveness of early warning systems in place and recommendations for alleviation. IFPs supplied the values (Table 3.2.28) based on the following scoring system:

- 1: Nothing is done.
- 2: weather forecast is sent to tourism boards and businesses early.
- 3: tourism boards and businesses show weather alerts by screens and others at visible places.
- 4: tourism boards and businesses provide advisement on compatible activities, least exposed places and medical resources available.

Table 3.2.28. Data used to compare the Early warning systems indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (score)	3	3	3	3	2

The following features were observed:

- The Balearic Islands, the Canary Islands, Cyprus, and Malta have a relative higher score indicating that tourism boards and businesses show weather alerts by screens and digitally (like website, social media, etc.), and that they advise on compatible activities.
- Sardinia scores lower than the other islands.

Early warning systems					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	1	1	1	2.5
Canary	1	1	1	1	2.5
Cyprus	1	1	1	1	2.5
Malta	1	1	1	1	2.5
Sardinia	1/2.5	1/2.5	1/2.5	1/2.5	1
Consistency ratio: 0.0000 < 10%					

For the sub-criterion Air conditioning of the Adaptive capacity criterion, experts were asked to compare the islands using data regarding the percentage of air conditioning coverage of tourist accommodations and facilities on the islands. The IFPs provided the percentages for this indicator and are shown Table 3.2.29.

Table 3.2.29. Data used to compare the Air conditioning indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	95	70	95	85	95

The following features were observed:



- The Balearic Islands, Cyprus, and Sardinia were rated to have lower risk the highest coverage (95%).
- Malta was rated had a slightly lower coverage (85%).
- The Canary Islands have a relative higher score indicating that tourism boards and businesses show weather alerts by screens and digitally (like website, social media, etc.), and that they advise on compatible activities.
- The Canary Islands and Sardinia score lower than the other islands.

Air conditioning					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	1/4	1	1/2	1
Canary	4	1	4	2.5	4
Cyprus	1	1/4	1	2	1
Malta	2	1/2.5	1/2	1	1.5
Sardinia	1	1/4	1	1/1.5	1
Consistency ratio: 0.0030 < 10%					

For the sub-criterion Medical attention of the Adaptive capacity criterion, experts were asked to compare the islands using data regarding the number of beds available per 100,000 potential patients (residents plus tourists) during the months of May-September. These data were collected by the IFPs and are provided in Table 3.2.30.

Table 3.2.30. Data used to compare the Medical attention indicator.

	Balearic	Canary	Cyprus	Malta	Sardinia
Indicator (%)	206	287	318	411	295

The following features were observed:

- The Balearic Islands has the fewest number of beds available (206) and so is at greater risk with respect to this sub-criterion, whereas Malta has the greatest number of beds (411).
- The Canary Islands and Sardinia have the second and third fewest number of beds.

Medical attention					
	Balearic	Canary	Cyprus	Malta	Sardinia
Balearic	1	2.5	3.5	5	2.5
Canary	1/2.5	1	1.5	3.5	1
Cyprus	1/3.5	1/1.5	1	3	1.5
Malta	1/5	1/3.5	1/3	1	1/3.5
Sardinia	1/2.5	1	1/1.5	3.5	1
Consistency ratio: 0.0251 < 10%					

Weights

The weights of each indicator were determined as explained in Section 7.3, by performing normalization on the criteria and sub-criteria comparison tables and then calculating the



Eigenvectors. The following subsections present the tables of the weights calculated for each criterion and, subsequently, each sub-criterion. For the case of sub-criteria, the weight values representing the local importance (contribution towards its parent criterion) and the global importance (contribution towards the goal) are given.

- **Criteria vs goal (risk)**

Criteria		
	Weight	Rank
Hazards	0.1671	4
Exposure	0.2959	2
Sensitivity	0.3699	1
Adaptive Capacity	0.1672	3
Total	1.0000	

- **Sub-criteria vs criteria**

Criteria	Sub-criteria	Weight (local)	Total
Hazards	Thermal stress	1.0000	1.0000
Exposure	Exposed areas	0.1033	1.0000
	Vulnerable groups	0.3223	
	Tourist arrivals	0.5744	
Sensitivity	Tourist activities	0.8333	1.0000
	Economic valuation	0.1667	
Adaptive capacity	Early-warning systems	0.1861	1.0000
	Air conditioning	0.6180	
	Medical attention	0.1959	

- **Sub-criteria vs risk**

Criteria	Sub-criteria	Weight (global)	Total
Hazards	Thermal stress	0.1671	0.1671
Exposure	Exposed areas	0.0306	0.2959
	Vulnerable groups	0.0954	
	Tourist arrivals	0.1700	
Sensitivity	Tourist activities	0.3082	0.3699
	Economic valuation	0.0616	



Adaptive capacity	Early-warning systems	0.0311	0.1672
	Air conditioning	0.1033	
	Medical attention	0.0327	
Total			1.0000

- **Alternatives (islands) vs sub-criteria**

The table below show the values obtained from comparing the islands for each sub-criterion.

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	Thermal stress RCP 2.6 near	0.1309	0.0352	0.572	0.1309	0.1309
	Thermal stress RCP 8.5 near	0.1299	0.0414	0.5553	0.1367	0.1367
	Thermal stress RCP 2.6 distant	0.1309	0.0352	0.572	0.1309	0.1309
	Thermal stress RCP 8.5 distant	0.1448	0.0488	0.5275	0.1394	0.1394
Exposure	Exposed areas	0.2308	0.0769	0.2308	0.2308	0.2308
	Vulnerable groups	0.0691	0.1784	0.1712	0.1784	0.403
	Tourist arrivals	0.2949	0.0479	0.1729	0.103	0.3812
Sensitivity	Tourist practices	0.2415	0.2377	0.2415	0.2415	0.0378
	Economic valuation	0.0666	0.0722	0.2419	0.4618	0.1574
Adaptive capacity	Early-warning systems	0.2273	0.2273	0.2273	0.2273	0.0909
	Air conditioning	0.1106	0.4617	0.1106	0.2001	0.1170
	Medical attention	0.4212	0.1901	0.1633	0.0591	0.1663

Aggregation and ranking

Based on the global weights of each sub-criterion and the corresponding comparison of the islands, the overall ranking of each island is computed. Since the aim is to compare the islands under each different emission scenario (RCP 2.6 and RCP 8.5) and time horizon (near and distant future) the island rankings for each scenario are provided separately.

- **Near future (2046-2065) under RCP 2.6 low emissions scenario**

Alternatives (islands) vs sub-criteria

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	Thermal stress	0.0219	0.0059	0.0956	0.0219	0.0219



Exposure	Exposed areas	0.0071	0.0024	0.0071	0.0071	0.0071
	Vulnerable groups	0.0066	0.0170	0.0163	0.0170	0.0384
	Tourist arrivals	0.0501	0.0081	0.0294	0.0175	0.0648
Sensitivity	Tourist activities	0.0744	0.0733	0.0744	0.0744	0.0116
	Economic valuation	0.0041	0.0045	0.0149	0.0285	0.0097
Adaptive capacity	Early-warning systems	0.0071	0.0071	0.0071	0.0071	0.0028
	Air conditioning	0.0114	0.0477	0.0114	0.0207	0.0121
	Medical attention	0.0138	0.0062	0.0053	0.0019	0.0054
Total		0.1965	0.1721	0.2615	0.1960	0.1739
Rank		2	5	1	3	4

Alternatives (islands) vs criteria

Criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	0.0219	0.0059	0.0956	0.0219	0.0219
Exposure	0.0638	0.0275	0.0528	0.0416	0.1103
Sensitivity	0.0785	0.0777	0.0893	0.1029	0.0213
Adaptive capacity	0.0323	0.0610	0.0238	0.0297	0.0204
Total	0.1965	0.1721	0.2615	0.1960	0.1739
Rank	2	5	1	3	4

- *Near future (2046-2065) under RCP 8.5 high emissions scenario*

Alternatives (islands) vs sub-criteria

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	Thermal stress	0.0217	0.0069	0.0928	0.0228	0.0228
Exposure	Exposed areas	0.0071	0.0024	0.0071	0.0071	0.0071
	Vulnerable groups	0.0066	0.0170	0.0163	0.0170	0.0384
	Tourist arrivals	0.0501	0.0081	0.0294	0.0175	0.0648



Sensitivity	Tourist activities	0.0744	0.0733	0.0744	0.0744	0.0116
	Economic valuation	0.0041	0.0045	0.0149	0.0285	0.0097
Adaptive capacity	Early-warning systems	0.0071	0.0071	0.0071	0.0071	0.0028
	Air conditioning	0.0114	0.0477	0.0114	0.0207	0.0121
	Medical attention	0.0138	0.0062	0.0053	0.0019	0.0054
Total		0.1963	0.1731	0.2587	0.1970	0.1748
Rank		3	5	1	2	4

Alternatives (islands) vs criteria

Criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	0.0217	0.0069	0.0928	0.0228	0.0228
Exposure	0.0638	0.0275	0.0528	0.0416	0.1103
Sensitivity	0.0785	0.0777	0.0893	0.1029	0.0213
Adaptive capacity	0.0323	0.0610	0.0238	0.0297	0.0204
Total	0.1963	0.1731	0.2587	0.1970	0.1748
Rank	3	5	1	2	4

- *Distant future (2081-2100) under RCP 2.6 low emissions scenario*

Alternatives (islands) vs sub-criteria

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	Thermal stress	0.0219	0.0059	0.0956	0.0219	0.0219
Exposure	Exposed areas	0.0071	0.0024	0.0071	0.0071	0.0071
	Vulnerable groups	0.0066	0.0170	0.0163	0.0170	0.0384
	Tourist arrivals	0.0501	0.0081	0.0294	0.0175	0.0648
Sensitivity	Tourist activities	0.0744	0.0733	0.0744	0.0744	0.0116
	Economic valuation	0.0041	0.0045	0.0149	0.0285	0.0097
Adaptive capacity	Early-warning systems	0.0071	0.0071	0.0071	0.0071	0.0028
	Air conditioning	0.0114	0.0477	0.0114	0.0207	0.0121



	Medical attention	0.0138	0.0062	0.0053	0.0019	0.0054
	Total	0.1965	0.1721	0.2615	0.1960	0.1739
	Rank	2	5	1	3	4

Alternatives (islands) vs criteria

Criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	0.0219	0.0059	0.0956	0.0219	0.0219
Exposure	0.0638	0.0275	0.0528	0.0416	0.1103
Sensitivity	0.0785	0.0777	0.0893	0.1029	0.0213
Adaptive capacity	0.0323	0.0610	0.0238	0.0297	0.0204
Total	0.1965	0.1721	0.2615	0.1960	0.1739
Rank	2	5	1	3	4

- *Distant future (2081-2100) under RCP 8.5 high emissions scenario*

Alternatives (islands) vs sub-criteria

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	Thermal stress	0.0242	0.0082	0.0881	0.0233	0.0233
Exposure	Exposed areas	0.0071	0.0024	0.0071	0.0071	0.0071
	Vulnerable groups	0.0066	0.0170	0.0163	0.0170	0.0384
	Tourist arrivals	0.0501	0.0081	0.0294	0.0175	0.0648
Sensitivity	Tourist activities	0.0744	0.0733	0.0744	0.0744	0.0116
	Economic valuation	0.0041	0.0045	0.0149	0.0285	0.0097
Adaptive capacity	Early-warning systems	0.0071	0.0071	0.0071	0.0071	0.0028
	Air conditioning	0.0114	0.0477	0.0114	0.0207	0.0121
	Medical attention	0.0138	0.0062	0.0053	0.0019	0.0054
Total		0.1988	0.1744	0.2541	0.1975	0.1753
Rank		2	5	1	3	4

Alternatives (islands) vs criteria

Criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	0.0242	0.0082	0.0881	0.0233	0.0233
Exposure	0.0638	0.0275	0.0528	0.0416	0.1103
Sensitivity	0.0785	0.0777	0.0893	0.1029	0.0213
Adaptive capacity	0.0323	0.0610	0.0238	0.0297	0.0204
Total	0.1988	0.1744	0.2541	0.1975	0.1753
Rank	2	5	1	3	4

Result aggregation and island ranking

Based on the weights calculated from the AHP method and the comparison of the islands, the island rankings for all four RCP and time horizon scenarios are almost identical. Table 3.2.31 summarizes the results.

Table 3.2.31. Ranking of islands for all four of the emissions scenarios.

Overall Rank	Island	Near future		Distant future	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
1 (most risk)	Cyprus	0.2615	0.2587	0.2615	0.2541
2	Balearic	0.1965	0.1963	0.1965	0.1988
3	Malta	0.1960	0.1970	0.1960	0.1975
4	Sardinia	0.1739	0.1748	0.1739	0.1753
5 (least risk)	Canary	0.1721	0.1731	0.1721	0.1744

Cyprus is most at risk of loss of competitiveness due to a decrease in thermal comfort in all four scenarios as it is ranked the highest in all cases. This is mainly attributed to the fact that the number of days with a heatwave is predicted to increase greatly both in the near and distant future. In addition, the island's tourist accommodations and facilities are located in areas most prone to heatwaves, and these are visited by many tourists during the months of May to September. Cyprus also scores the highest in Sensitivity (0.0893) and average in Adaptive capacity (0.0238).

Overall, the Balearic Islands and Malta are ranked second and third, respectively, with regards to the risk of loss of competitiveness. However, their overall scores are very close: between 0.1963-0.1988 for the Balearic Islands and between 0.1963-0.1975 for Malta in all four scenarios. They score relatively high in Exposure and Sensitivity (the most important criteria for the risk) and average in Hazard and Adaptive capacity. In three of the four scenarios, the Balearic Islands are ranked second, whereas Malta is ranked third. In one of the scenarios (near future under RCP 8.5 high emissions scenario) the positions of these two islands are swapped.

Sardinia and the Canary Islands are the lowest at risk of loss of competitiveness. Sardinia scores overall a value between 0.1739-0.1753 in all four scenarios, while the Canary Islands score overall a value between 0.1721-0.1744 in all four scenarios. Even though Sardinia scores the highest for Exposure (0.1103), it has a low score for Sensitivity (which contributes most to the risk) and average scores for Hazard and Adaptive capacity. On the other hand, the Canary Islands has a low score for Hazard and Exposure, but relatively high for Sensitivity and Adaptive capacity.

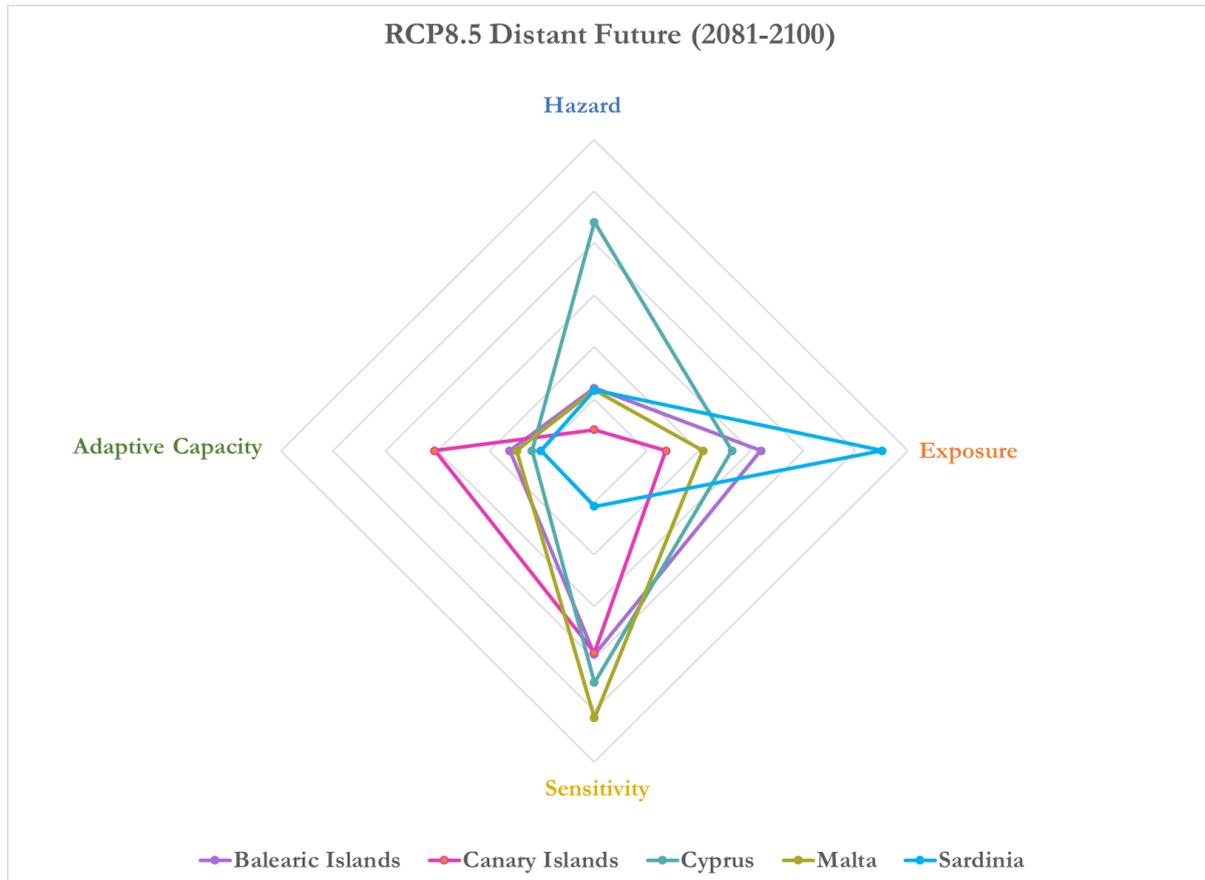


Figure 3.2.64. Comparison of criteria and islands for distant future under RCP8.5.

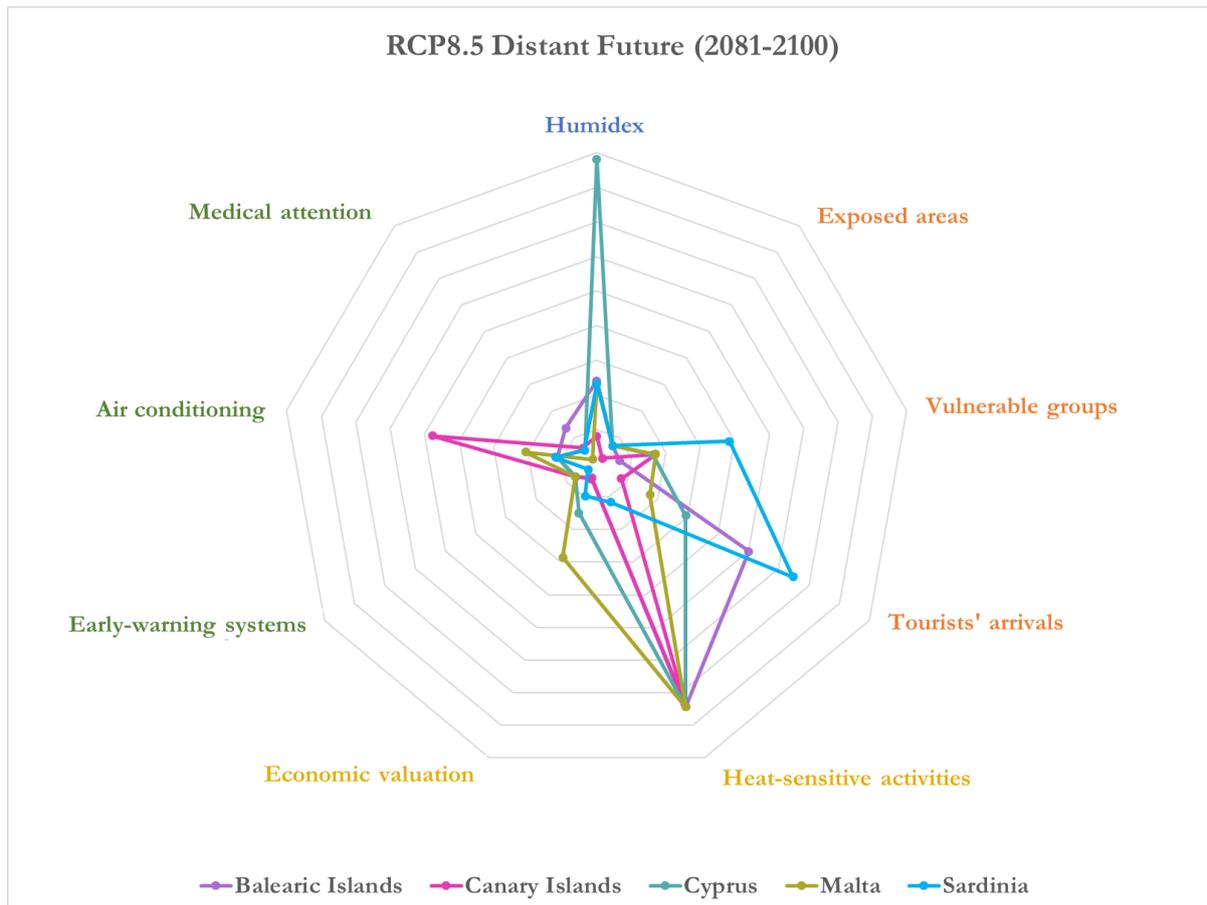


Figure 3.2.65. Comparison of sub-criteria and islands for distant future under RCP8.5

Conclusions

The operationalization of the impact chain for the loss of competitiveness due to the decrease of thermal comfort was conducted using the AHP method. The method proved to be appropriate, firstly, for dealing with the hierarchical nature of the impact chain and, secondly, for using expert judgements to assess the comparative risk for the islands over a large number of indicators (sub-criteria).

Because the AHP method determines a ranking of the islands, it can provide decision makers with relative values but not with absolute values. Such values will be delivered by the modelling activities of other work packages and will give stakeholders a more complete picture of this specific risk in terms of social, economic, and environmental impacts, such as the increase in water demand, change in tourist seasonality, as well as increase in costs related to energy consumption and medical care.



SOCLIMPACT

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3.3. Energy

General considerations

For the energy sector three general ICs have been developed in the SOCLIMPACT project (Deliverable 3.3): (a) risk of changes in power generation due to long term climate change and variability, (b) risk of changes in energy demand due to changes in precipitation and temperatures, (c) risk of damages to transmission grids due to extreme events.

We selected to operationalize the second IC, i.e., the one related to changes in energy demand. Data availability constraints have been a basic reason for this selection. In the case of the transmission risk, we also determined a low relevance for this risk, based on a literature and news review for past cases of damages to transmission infrastructure in the islands, and on the assessment of projected changes in relevant climate extremes (with most islands showing a decrease of extreme wind frequency). In the case of the power generation, the present renewables share is between low and medium in most islands, and has to increase strongly due to the decarbonization requirements of the EU. Therefore, future uncertain decisions will determine the mix of power sources and the storage amount and type, and a full impact chain (IC) operationalization would rely on uncertain and rather speculative assumptions about the future structure of the energy system. As a consequence, we have opted to make a hazard-based assessment of the impact of climate change on wind and PV energy productivity and variability, without assuming any specific energy mix or spatial distribution of plants.

Specifically, we have operationalized the general demand-side IC through two individual ICs, namely, the increased energy demand due to increased cooling demand and the increased energy demand due to increased desalination needs. Both risks depend on the temperature increase, which is a very certain effect of climate change.

The SOCLIMPACT islands considered for a full operationalization are Cyprus, Malta and Gran Canaria. The criteria for the selection of the islands have been: (a) availability of data for the computation of the exposure and vulnerability indicators of the demand-side ICs, (b) modeling constraints of the hazard component. Specifically, there are important limitations regarding the resolution of the climate data for the small Atlantic islands. The available simulations covering the Atlantic Ocean have a significantly lower spatial resolution than the simulations for the Mediterranean Sea. Thus, the demand-side ICs have been operationalized for Gran Canaria (a relatively large island) but not for smaller islands such as Madeira. In the case of Mediterranean islands, Malta and Cyprus have been selected as more data are available at the country level than at the regional level in databases like EUROSTAT, and also due to their strong exposure to the demand-side hazards. Cyprus is the European country with the highest present cooling degree days (CDD) values (Jakubcionis et al, 2017), and Malta obtains already more than half of its water from desalination.

The operationalization of the demand ICs for the indicated islands has been performed following the method explained in detail in the appendix. A fundamental aspect of the method is that we apply an objective procedure for obtaining the weights of the risk components (hazard, exposure and vulnerability) based on time-series correlations of observed data for energy demand and for the different indicators involved in the impact chains. This allows to detect which factors have a larger impact on the energy demand.



For the selection of risks and the assessment of the energy sector, we have relied on the knowledge and expertise of several partners of SOCLIMPACT.

The hazard assessment for all the islands is based on hazard scores for demand indicators (CDD, Standardized Precipitation-Evapotranspiration Index - SPEI) and supply indicators (wind energy, solar PV and combined productivity and droughts). The aim is to jointly consider future increases in energy demand due to temperature and precipitation changes and the potential for covering it with renewable energy sources in the future.

The calculation and normalization of the indicators is explained in detail in the appendix. For the interpretation of the hazard scores, the following details should be taken into account: CDD and SPEI scores are calculated with respect to the maximum projected values over islands, time-periods and emissions scenarios.

Renewable energy productivity indicators for present climate are normalized using global thresholds (5th and 95th percentiles of the respective technologies). Renewable energy drought indicators are a way of quantifying the time-variability of renewable energies that depend on meteorological conditions. Low values of energy droughts correspond to a stable output, while high values correspond to a highly variable output. Energy drought indicators are normalized comparing them to a maximum upper limit, taken among all the islands and renewable energy technologies. The combined renewable energy droughts represent the complementarity between wind and PV energy. A high complementarity of both sources reduces the need for energy storage or backup sources.

Regarding the normalization of projected values of the renewable energy indicators, we use an approach based on their future change. The available literature indicates that the future projected changes of renewable energy productivity frequently do not exceed a level of 10% relative to present values. Changes of about 10% would not modify substantially a normalized score like the one used for present climate (leading to a very limited variation range of the score), but they represent a significant impact on the productivity and profitability of the energy plants. Therefore, the future change of renewable energy productivity is compared to a 10% threshold, both on the negative (normalized values above 0.5) and the positive side (normalized values below 0.5). The normalization also includes a minor contribution of a comparison of the changes relative to other islands. The same normalization method is used for projected changes of renewable energy droughts.

The diagrams of the two operationalized impact chains are presented in figures 3.3.1 and 3.3.2, whereas Table 3.3.1 shows the color scale for the division in 5 categories of the risk and hazard scores.

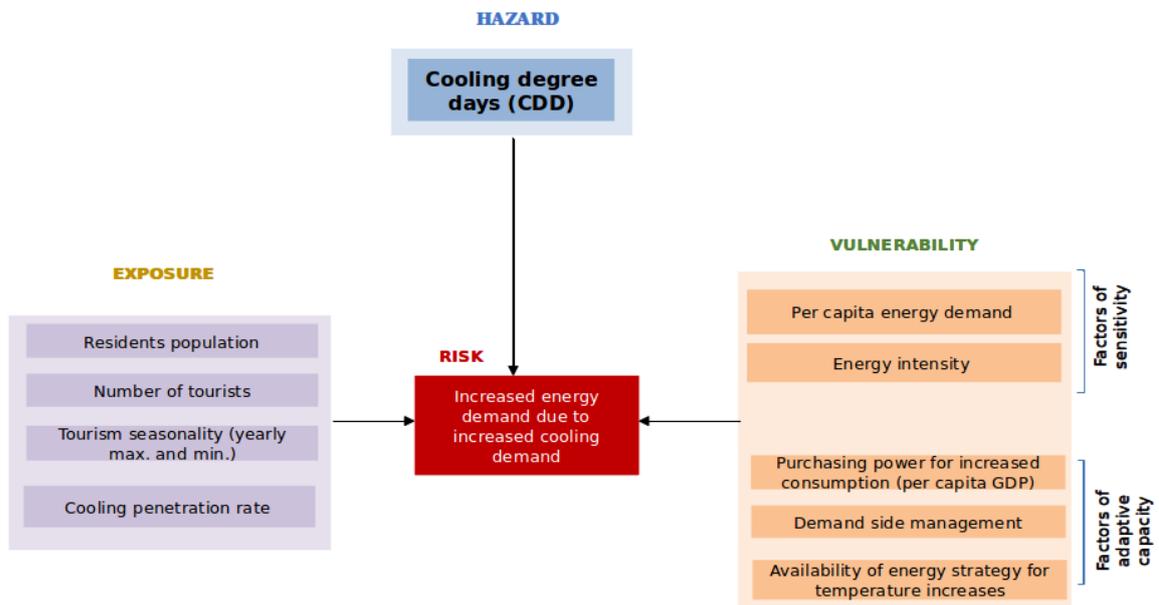


Figure 3.3.1. Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased cooling demand

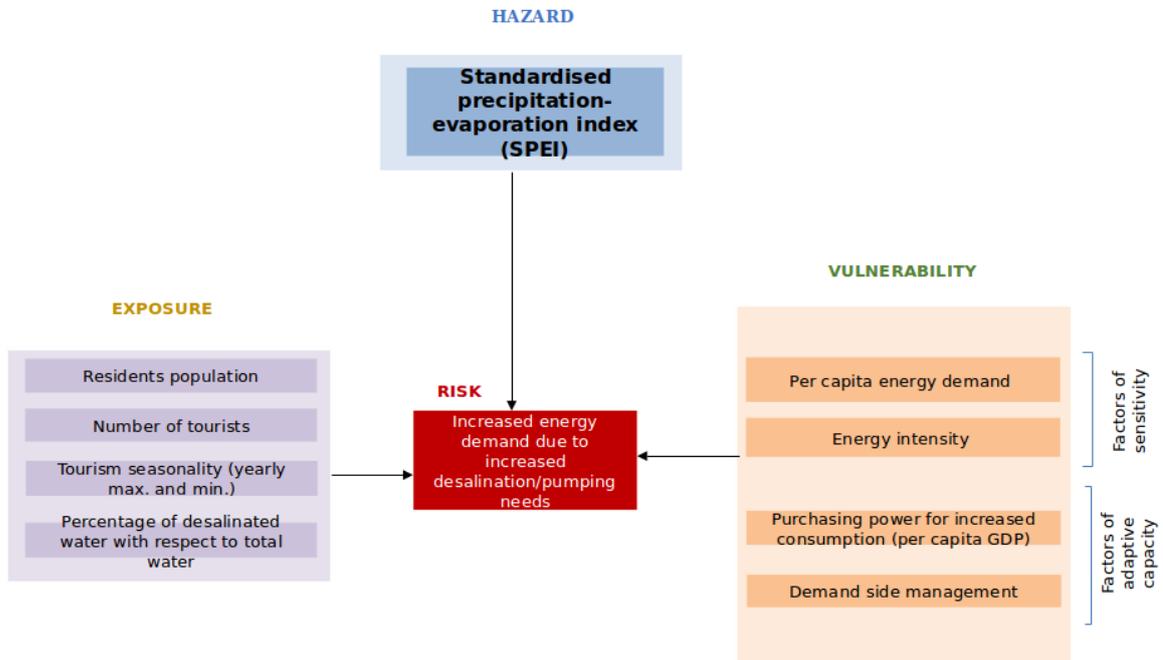


Figure 3.3.2. Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased desalination demand

0.00 – 0.20 Very low	0.20 – 0.40 Low	0.40 – 0.60 Medium	0.60 – 0.80 High	0.80 – 1.00 Very high
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Table 3.3.1. Categorization of the energy risk and hazard scores



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Results per island

Balearic Islands

Hazard assessment:

<i>Historical ref. (1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity		Droughts
	CDD	SPEI	Land	Sea	Land	Sea	
	0.16	0.00	0.99	0.25	0.95		
			0.22	0.25	0.13		
			Combined		0.23		

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
	CDD	SPEI	Land	Sea	Land	Sea	
	0.26	0.32	0.7	0.6	0.7		
			0.5	0.6	0.1		
			Combined		0.5		

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
	CDD	SPEI	Land	Sea	Land	Sea	
	0.36	0.60	0.9	0.8	0.8		
			0.6	0.7	0.6		
			Combined		0.8		

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
	CDD	SPEI	Land	Sea	Land	Sea	
	0.24	0.24	0.7	0.6	0.7		
			0.5	0.6	0.2		
			Combined		0.6		

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
	CDD	SPEI	Land	Sea	Land	Sea	
	0.60	0.92	1	0.9	1.0		
			0.6	0.8	0.4		
			Combined		0.9		

Table 3.3.2. Energy demand and supply hazard scores for Balearic Islands. Demand scores (left side): CDD and SPEI for the historical and future periods under RCP2.6 and RCP8.5 emissions scenarios. Supply scores (right side): wind and photovoltaic energy productivity and droughts, including the combined wind/PV droughts for the historical period, whereas for the future periods the hazard scores are shown for the change of energy productivity and droughts. Scores are spatial averages over land points of the islands, except for energy productivity and productivity change over the sea, which are spatial averages over sea points surrounding the islands.



The increase in cooling energy demand should be relatively moderate under the low-emissions scenario, reaching high values only at the end of the century under the high-emissions scenario. In contrast, drought conditions will be much worse under RCP8.5 scenario, which could threaten the availability of groundwater and reservoir water and induce a large increase in desalination demand. The contribution of desalinated water is already substantial, though the introduction of new surface and groundwater sources in Mallorca by 2009-2010, among other factors, reduced for a few years the high percentage of desalinated water. This percentage has increased again in the last years.

The present good solar PV resources will not change substantially under RCP2.6 scenario, while a slight reduction is expected under the high-emissions scenario. PV is already a stable resource, as shown by present climate PV droughts, and this stability will even improve under RCP2.6. Wind resources are rather limited and highly-variable over land, and will even decrease in the future, but offshore wind energy could play a significant role in the decarbonization process.

The large variability of wind energy could be compensated to a high degree through a combination with PV energy, which should limit the need for storage or backup power for the high RE shares planned by the regional government. The availability of a power interconnection to mainland is also helpful for the decarbonization of energy supply in the Balearic Islands. The potential coverage through RES of future cooling and desalination energy demand increases seems much easier under the mitigation scenario than under RCP8.5.



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Canary Islands

Hazard assessment:

<i>Histori-cal ref.(1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.08 (2.6)	0.16 (8.5)	0.00	0.00	0.56
SPEI	0.00		0.25	0.31	0.10
			Combined		0.39

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.12		0.5	0.5	0.3
SPEI	0.56		0.4	0.6	0.3
			Combined		0.2

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.33		0.3	0.3	0.1
SPEI	0.84		0.4	0.6	0.0
			Combined		0.1

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.14		0.6	0.6	0.6
SPEI	0.60		0.6	0.6	0.6
			Combined		0.5

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.56		0.2	0.3	0.0
SPEI	0.96		0.5	0.7	0.0
			Combined		0.0

Table 3.3.3. Energy demand and supply hazard scores for Canary Islands, as in Table 3.3.2.

Cooling energy demand, which is presently rather limited as indicated by the low cooling penetration rate in households (about 13% in 2018), should remain low in Canary Islands under the mitigation scenario, but could rise substantially under RCP8.5. But hydrological drought



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conditions will worsen clearly under the mitigation scenario, even for mid-century, and very strongly under RCP8.5.

Wind energy resources are very high, and PV resources are also good. The very high potential of offshore wind energy is reflected in the project for the first commercial floating wind energy plant near Gran Canaria (Roca, 2020), which has a projected productivity of 5222 kWh/kW, corresponding to a capacity factor of almost 60%. Wind energy is relatively stable for present conditions, in comparison to other islands. The stability of PV energy is high. Canary Islands are an exception regarding the future evolution of wind energy resources, which are expected to improve under the high emissions scenario both in terms of productivity and stability. Under the mitigation scenario, wind energy productivity would show small future changes, with a slight increase towards the end of the century. Solar PV will show limited future changes, showing larger stability under RCP8.5.

As the time-variability of wind energy is comparatively limited in Canary Islands, the stability benefits of combining wind and PV energy are smaller than in other islands.

Operationalized impact chains:

	<i>Hist. ref. RCP2.6</i>	<i>RCP2.6 (2046-2065)</i>	<i>RCP2.6 (2081-2100)</i>	<i>Hist. ref. RCP8.5</i>	<i>RCP8.5 (2046-2065)</i>	<i>RCP8.5 (2081-2100)</i>
Cooling	0.30	0.31	0.32	0.33	0.38	0.45
Desalin.	0.29	0.46	0.47	0.29	0.54	0.58

Table 3.3.4. Risk scores for Gran Canaria: cooling and desalination energy demand, for the historical and future periods. In this case, the historical risk scores are different for RCP2.6 and RCP8.5 scenarios as the number of available simulations for each scenario is different.

The risk associated to cooling energy demand shows low present values, that almost do not increase in the case of RCP2.6 scenario, while it increases to a medium value at the end of the century for RCP8.5 as a consequence of the temperature increase. The weights of the different components, obtained through an objective correlation method, indicate a higher importance for vulnerability indicators than for hazard and exposure indicators. Specifically, energy intensity and per capita energy demand (vulnerability indicators) show very high correlation with cooling energy demand. The ratio of the yearly number of tourists to population is very high, but it shows a low correlation with cooling energy demand. A possible explanation for this is the very low tourism seasonality in Gran Canaria, as a high number of tourists well distributed over the year seems to have a low impact on cooling energy demand. In contrast, population density shows a high correlation to cooling energy demand, while CDD correlates moderately with this demand.

The low present risk score for desalination energy demand increases clearly even in the mitigation scenario, and doubles toward the end of the century for RCP8.5 as result of the very strong increase of SPEI score. In this case, a higher correlation between the number of tourists and desalination energy demand is found, which increases the weight of the exposure component in such a way that the three risk components have nearly the same weight. The percentage of desalinated water with respect to total water (rising from 20% in 1990 to more than 50% in the



last years) shows the highest correlation with desalination energy demand. This indicates that other sources of water are already stressed, and this stress will only increase due to SPEI decreases. But as the percentage of desalinated water has a higher impact on energy demand than SPEI, once the percentage is near 100%, the increases of desalination energy demand might slow down.

Corsica

Hazard assessment:

<i>Histori-cal ref. (1986- 2005)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity		Droughts
			Land	Sea	Land	Sea	
	CDD	0.08	0.78	0.24	1.00		
	SPEI	0.00	0.26	0.28	0.19		
			Combined				0.38
<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
			Land	Sea	Land	Sea	
	CDD	0.14	0.3	0.4	0.4		
	SPEI	0.12	0.6	0.7	0.8		
			Combined				0.5
<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
			Land	Sea	Land	Sea	
	CDD	0.20	0.5	0.6	0.6		
	SPEI	0.40	0.6	0.7	0.6		
			Combined				0.8
<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
			Land	Sea	Land	Sea	
	CDD	0.13	0.3	0.3	0.4		
	SPEI	0.04	0.7	0.6	0.7		
			Combined				0.7
<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Productivity change		Droughts change
			Land	Sea	Land	Sea	
	CDD	0.39	0.6	0.8	0.7		
	SPEI	0.80	0.6	0.7	0.3		
			Combined				0.9

Table 3.3.5. Energy demand and supply hazard scores for Corsica, as in Table 3.3.2.



The power demand in Corsica is still characterised by a clear winter maximum, in contrast to other islands. The peak power demand in summer is 20-30% lower than the peak demand in winter (data corresponding to the period 2012-2016). The very low present CDD score reflects this fact well. The CDD score should remain very low for RCP2.6 scenario. For RCP8.5 scenario, CDD score would increase more, but it would not reach high values anyway. As the peak demand occurs presently in winter, some increase in summer cooling demand could be covered by present power generation capacity, but the interconnection to Sardinia is not secured in summer. A fact that could boost the cooling energy demand if temperature rises much is the very high tourism seasonality.

Regarding the hydrological drought indicator, a very strong contrast is found between both emissions scenarios, with small changes for RCP2.6 and a strong increase for the high-emissions scenario (reaching very high values by the end of the century). In the latter scenario, the substantial contribution of hydropower (20-30% in 2016-2018) to power generation could be strongly affected, and the presently negligible desalination demand could be progressively more important.

In Corsica, presently the most important renewable energy source is hydropower, followed by solar PV energy (with a share of about 8%). Wind energy is marginal today. Solar PV resources are good, and the PV droughts score indicates a fairly high stability. The opposite is found for wind energy, which shows a very high variability (the maximum among all considered islands). Wind energy shows modest potential over land, but high potential over sea. Small decreases in PV and wind energy potential are projected, except for wind energy in RCP2.6 scenario, where an increase in wind energy potential is projected. The “Regional air climate and energy scheme” has a target of 100% renewable energy coverage for 2050. Floating offshore wind energy could play a relevant factor for this objective if the technology can be successfully adapted to the deep bathymetry, as rather high capacity factors could be obtained at the northern coast and especially east of the Strait of Bonifacio.



Crete

Hazard assessment:

<i>Histori-cal ref.(1986- 2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.20		0.63	0.00	0.84
SPEI	0.00		0.19	0.21	0.16
			Combined		0.41

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.29		0.1	0.3	0.2
SPEI	0.32		0.4	0.6	0.1
			Combined		0.3

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.42		0.2	0.3	0.3
SPEI	0.68		0.6	0.7	0.4
			Combined		0.5

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.28		0.3	0.3	0.3
SPEI	0.32		0.5	0.6	0.3
			Combined		0.5

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.66		0.2	0.5	0.4
SPEI	0.96		0.6	0.7	0.1
			Combined		0.7

Table 3.3.6. Energy demand and supply hazard scores for Crete, as in Table 3.3.2.

The low present CDD score would not increase much under RCP2.6 scenario, pointing to a limited cooling energy demand in this case. The increase of Etesian winds in summer would help to moderate this demand. In contrast, under RCP8.5 this score would reach high values by the end of the century. Regarding the hydrological drought conditions, some increase during the first half



of the century is expected under RCP2.6. Under RCP8.5, a strong and sustained worsening is projected, which would imply a high pressure on desalination energy demand. The possibility of using large quantities of brackish water instead of seawater can lower the cost of desalination (Zotalis et al., 2014).

In 2017, the shares of wind energy and solar PV were respectively 17,0% and 4,6%. The relatively negative score of wind energy productivity over land is a spatial average, and in a mountainous island like Crete large spatial differences in wind energy potential are observed, and therefore the potential contribution of onshore wind is higher than what the 0.63 score could imply. Offshore wind energy resources are excellent, but the obstacles of deep bathymetry have to be overcome. Future projections show even an improvement of the wind energy potential, particularly over land. This highlights the importance of local factors in the future evolution of climate variables, as the opposite tendency predominates for other islands. Solar PV productivity has very good scores, and in the future it will change only slightly.

Present variability is high for onshore wind, whereas solar PV is characterised by low frequencies of energy droughts. The complementarity of PV and wind energy is less marked than for other islands, as the high summer wind potential coincides with the PV maximum. Variability will decrease in the future both for wind and PV energy.



Cyprus

Hazard assessment:

<i>Histori-cal ref.(1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.39		1.00	0.65	0.93
SPEI	0.00		0.16	0.22	0.12
			Combined		0.14

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.55		0.4	0.5	0.5
SPEI	0.32		0.5	0.6	0.1
			Combined		0.3

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.71		0.7	0.7	0.7
SPEI	0.76		0.5	0.7	0.1
			Combined		0.5

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.54		0.6	0.5	0.6
SPEI	0.32		0.5	0.6	0.1
			Combined		0.6

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	1.00		0.9	0.9	0.9
SPEI	0.96		0.6	0.7	0.0
			Combined		0.7

Table 3.3.7. Energy demand and supply hazard scores for Cyprus, as in Table 3.3.2.

Cyprus shows many differences compared to Crete, despite their relative proximity. The CDD score in Cyprus is nearly two times the score in Crete, for present climate and for RCP2.6 scenario, while for RCP8.5 it increases very strongly reaching the maximum value among all islands. For this high-emissions scenario, Cyprus would be the only island in which the threshold obtained by



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Jakubcionis et al. (2018) for full penetration of air conditioning equipment is exceeded by the end of the century (on average for the whole island). This highlights the strong increase in cooling energy demand expected under the high-emissions scenario.

SPEI scores would increase moderately under RCP2.6, with no change during the second half of the century, while a strong increase is expected under RCP8.5. In the latter case, the present percentage of desalinated water (between 4 and 31% from 2010-2017) would increase strongly.

Wind energy potential is much smaller than for Crete. Taken together with the very high score for wind energy droughts, wind energy could be considered as a rather low quality energy resource. But the scores are calculated from spatial and temporal averages of wind energy productivity, and some specific areas and seasons can show good wind energy potential. Koroneos et al. (2005) indicate that the southern coastal zone and certain exposed areas of the mountains are very promising for wind energy. Also, offshore wind energy near the southern coast of Cyprus is substantial in summer and shows a daily cycle with an afternoon/evening maximum (Tyrlis and Lelieveld, 2013) that, combined with PV, could match rather well the daily demand curve. This is important as maximum power demand occurs in summer.

Solar PV potential is high, and the productivity is very stable. In this case, a combination of PV and wind would be very beneficial in terms of stability of output, as the combined energy droughts (50/50 PV/wind energy) are at the very low level of solar PV.

Wind energy productivity projections show mostly some tendency of reduction, with relatively large reductions under RCP8.5 by the end of the century. Solar PV projections show either no change or small reductions in productivity.

Operationalized impact chains:

	<i>Hist. ref.</i>	<i>RCP2.6 (2046-2065)</i>	<i>RCP2.6 (2081-2100)</i>	<i>RCP8.5 (2046-2065)</i>	<i>RCP8.5 (2081-2100)</i>
<i>Cooling</i>	0.46	0.48	0.48	0.51	0.55
<i>Desalin.</i>	0.40	0.41	0.41	0.43	0.44

Table 3.3.8. Risk scores for Cyprus: cooling and desalination energy demand, for the historical and future periods.

The risk associated to cooling energy demand shows presently a medium score, which does not increase much for RCP2.6 scenario. The increase for RCP8.5 scenario is much clearer. The weights of the different components indicate a higher importance for exposure indicators, followed by vulnerability and finally hazard indicators. The indicator showing the largest correlation is the ratio of the number of tourists to population, in stark contrast to Gran Canaria. Though the tourism seasonality is high, its influence on cooling energy demand is low, at least for the period considered. It should be taken into account that the available cooling energy demand data cover only a 9-years period (2010-2018), which is a source of uncertainty as impacts over longer time periods will not be captured. Likely as a result of this short period, the correlation of CDD with cooling demand is low, and the correlation of cooling demand to energy intensity is negative. It seems that the very strong increase in the number of tourists (nearly doubling from 2010 to 2018) has been enough to



hide the influence of other factors. There is also little room for an increase of cooling demand linked to more air conditioning equipment, as the cooling penetration rate is already very high (80%).

The risk linked to desalination energy demand also presents now a medium score, and in this cases projected increases are very limited. This is due to the very low weight of the hazard component (SPEI) obtained through the correlation method, as the available desalination energy demand data cover only a limited period (2010-2017), in which the largest correlations are found for the percentage of desalinated water over total water, the GDP per capita and the number of tourists. SPEI may have a stronger impact over longer time-periods, as a sustained increase of temperatures and evaporation could show cumulative effects on desalination demand that outstrip other factors.

As a sensitivity calculation, we have obtained the desalination risk scores using equal weights for hazard, exposure and vulnerability. The risk score increases in this case by approximately 50% for RCP2.6, and more than doubles for RCP8.5 by the end of the century. This shows the strong dependency of risk scores on the applied weights.



Fehmarn

Hazard assessment:

<i>Histori-cal ref.(1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.00		0.55	0.00	0.79
SPEI	0.00		0.69	0.67	0.43
			Combined		0.40

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.00		0.7	0.7	0.6
SPEI	0.20		0.7	0.7	0.7
			Combined		0.9

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.01		0.5	0.3	0.4
SPEI	0.28		0.8	0.8	1.0
			Combined		0.8

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.00		0.8	0.8	0.8
SPEI	0.12		0.6	0.6	0.7
			Combined		1.0

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.03		0.4	0.4	0.5
SPEI	0.36		1.0	1.0	1.0
			Combined		0.9

Table 3.3.9. Energy demand and supply hazard scores for Fehmarn, as in Table 3.3.2.

As could be expected due to its high latitude, hazard scores for Fehmarn are very different to most other islands. CDD is zero for present conditions and under RCP2.6 scenario, and it increases very little under RCP8.5. Cooling energy demand will not be a problem here. SPEI shows some tendency to increase, particularly under RCP8.5, but it should be taken into account that this score



is relative to the present climate SPEI which defines the minimum threshold, and the climate in the area is wet. Therefore, no significant problems should be expected regarding water availability.

The renewable energies potential has also a different profile, with an excellent offshore wind energy potential and a clearly lower PV potential. Compared to other islands, wind energy is less variable and PV energy is clearly more variable. Nevertheless, a combined use of wind energy and PV could have a smaller variability than either wind or PV energy separately, which is also a feature not found for other islands.

Future productivity is projected to decrease, particularly solar PV for RCP8.5 scenario. The exception is wind energy, which would improve slightly for RCP8.5 scenario. There is also a tendency for higher variability, especially in the case of PV for the mitigation scenario.



Madeira

Hazard assessment:

<i>Histori-cal ref.(1986- 2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.01 (2.6)	0.06 (8.5)	0.20	0.00	0.67
SPEI	0.00		0.54	0.52	0.20
			Combined		0.47

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.04		0.7	0.7	0.8
SPEI	0.32		0.6	0.6	0.9
			Combined		1.0

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.18		0.6	0.5	0.5
SPEI	0.60		0.4	0.6	0.1
			Combined		0.6

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.04		0.8	0.7	0.8
SPEI	0.28		0.7	0.7	0.9
			Combined		1.0

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.35		0.6	0.5	0.5
SPEI	0.96		0.3	0.6	0.0
			Combined		0.5

Table 3.3.10. Energy demand and supply hazard scores for Madeira, as in Table 3.3.2.

For Madeira, CDD scores are presently very low, and should remain in this category except under RCP8.5 scenario by the end of the century. This implies only limited increases in cooling energy demand at least until mid-century. The projected evolution of SPEI scores is clearly worse. Under



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RCP2.6, this score increases to 0.32 by mid-century, stabilising thereafter. Under the high-emissions scenario, SPEI increase is already strong by mid-century, reaching almost the maximum score by the end of the century. This could imply a substantial pressure on water resources. Presently, there is only a desalination plant in the smallest island, Porto Santo. The observed time-series from this desalination plant show nevertheless the positive impact of efficiency measures, as the specific consumption has decreased from 5.5 kWh/m³ in 2006 to 4 kWh/m³, and the yearly maximum desalination consumption has also decreased from the highest value attained in August 2007 (807 MWh) to a clearly lower value of 626 MWh in August 2017 (this is the highest value in the last decade).

Regarding the potential of renewable energies, wind energy resources are really high. Wind energy is already a relevant energy source in Madeira, with a share of 12.6% in 2018. Wind variability is lower than for the other islands, except Canary Islands. PV energy had a share of 3.5% in 2018 (Electricidade da Madeira, 2019). Present PV productivity scores from the climate models show only medium scores, but these values should be taken with caution in this case, as they are average values over the island. The spatial resolution of the available models is limited (50 km) and is not able to capture in detail the distribution of surface solar radiation, which shows strong contrasts in Madeira due to the combined effect of the frequent NE trade winds and the mountain range that is oriented perpendicularly to it.

Future projections of renewable energy indicators show a marked contrast between RCP2.6 and RCP8.5. The productivity of both RES would decrease somewhat under RCP2.6, while it would remain roughly constant under RCP8.5. It should be taken into account that RCP2.6 data are more uncertain, as only one climate model simulation was available.

There is a comparatively strong improvement in PV stability under RCP8.5 scenario, coincident with the large increase in SPEI score. The droughts scores for both RES would be worse under RCP2.6, but there is more uncertainty in the results for this scenario as explained before.

The share of renewables is already fairly high in Madeira (about 30%), which is a remarkable value for an island without interconnections to mainland. In the ongoing process of increasing the share of RES, the issue of storage is receiving much attention (Miguel et al., 2017), and pumped storage is already part of the system in Madeira. The large and more stable offshore wind resources could play an important role in an electrical system with higher RES shares. In this respect, the special characteristics of the wind field, heavily influenced by the trade winds in the summer months, could be taken advantage of. The configuration of the mountains, perpendicular to the trade winds, generates strong and rather persistent winds near to the western and eastern extremes of the island as the flow is forced to go around the island. This could be a source of large wind energy resources, complementary to hydroelectric power that diminishes strongly in summer (Electricidade da Madeira, 2019). Solar PV participation should also be increased strongly due to its overall stability characteristics and also due to its summer maximum. Measures along these lines could limit the need for storage.



Malta

Hazard assessment:

<i>Histori-cal ref.(1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.24		0.61	0.31	0.89
SPEI	0.00		0.21	0.26	0.13
			Combined		0.51

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.37		0.7	0.6	0.7
SPEI	0.32		0.6	0.6	0.6
			Combined		0.8

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.49		0.7	0.7	0.8
SPEI	0.68		0.6	0.7	0.7
			Combined		1.0

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.36		0.6	0.5	0.6
SPEI	0.36		0.6	0.6	0.4
			Combined		0.9

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.75		1.0	0.9	1.0
SPEI	0.96		0.7	0.8	0.5
			Combined		1.0

Table 3.3.11. Energy demand and supply hazard scores for Malta, as in Table 3.3.2.

The CDD score for present climate is significant, particularly taking into account the high relative humidity affecting Malta. This reflects in the high cooling penetration rate, which was 70% already in 2009. CDD scores are projected to increase moderately under RCP2.6 scenario and strongly under RCP8.5 scenario, pointing to a large cooling energy demand increase in the latter case. An



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even larger contrast is found between emissions scenarios for SPEI, with scores nearing 1 under RCP8.5 by end of the century. Desalination demand, which is already high, should increase for both emissions scenarios, but much more under RCP8.5.

Malta is an island with large constraints on land-based RES, due to its small size and large population density. Additionally, present onshore wind energy resources are limited, as shown by the wind energy productivity score, and they are also highly variable. Offshore wind energy shows a better productivity score, though the potential is less than for other islands. Malta's 2030 NECP (National Energy and Climate Plan, 2019) excludes the installation of offshore wind energy plants until 2030, due to the deep bathymetry, resource limitations, cost and existence of marine protection areas. PV energy potential is good, and the energy droughts indicator shows a high stability. PV energy can be integrated in buildings and has therefore a higher potential, though its installation in apartment blocks faces uncertainties like the possibility of redevelopment of existing buildings based on an increase in the number of storeys. As a consequence, the NECP (2019) only projects a very limited increase of RES share from a present value of 9% to 11.5% in 2030. Such a low share moves Malta away from the EU targets. Offshore PV might be the main renewable energy technology with substantial potential, particularly if the capacity of the interconnector with Sicily could be increased or battery storage could be installed in sufficient quantities for grid stability reasons. In this respect, one of the first tests in the world with offshore PV was performed in Malta (Grech et al., 2016).

The scores for the expected change of renewable energy productivity point to a small decrease, except under RCP8.5 by end of the century, when a relatively large decrease is projected, particularly for wind energy. The stability characteristics would show limited changes under RCP2.6, and would worsen clearly under RCP8.5 for wind energy.

Operationalized impact chains:

	<i>Hist. ref.</i>	<i>RCP2.6 (2046-2065)</i>	<i>RCP2.6 (2081-2100)</i>	<i>RCP8.5 (2046-2065)</i>	<i>RCP8.5 (2081-2100)</i>
<i>Cooling</i>	0.49	0.51	0.51	0.53	0.57
<i>Desalin.</i>	0.47	0.54	0.55	0.61	0.67

Table 3.3.12. Risk scores for Malta: cooling and desalination energy demand, for the historical and future periods.

The risk associated to cooling energy demand shows presently a medium value, which would remain almost constant under RCP2.6 and would nearly reach a high value under RCP8.5 by the end of the century. The projected increase of the risk score is relatively small despite the large increase in CDD under RCP8.5 (CDD score increases twofold by mid of century and threefold by end of century), due to the low weight assigned to the hazard. In this case, the availability of observed cooling energy demand data was very low (only 4 years), which is insufficient for calculating meaningful weights through correlation with the different indicators. Therefore, we have taken the same weights as for Cyprus, which can be considered as a fair approximation due to its climate and present cooling penetration rate, which is similar to the rate in Malta. Anyway, the very short time-series for correlation points to a large correlation with per capita energy demand and number of tourists.



A medium score is also obtained for the risk linked to desalination energy demand, for present climate conditions. The projected increase of the risk is higher than for cooling energy demand, reaching high scores under RCP8.5. In this case, the weights offer a very interesting information about the impact of adaptation options. In this case, we have a rather long desalination energy demand series (2004-2018). If we take the whole series, there is a strong decreasing trend in demand until 2009. If we take the whole time-series for the correlations, these show counterintuitive values (e.g., the correlation with SPEI is +9% for the whole time series, implying that, if anything, wetter conditions are (weakly) associated to more desalination demand), while if we take the series from 2009-2018, the correlation is -40%, which is a result that lies within the expectations (drier conditions are associated to more desalination). Another example of this unexpected behaviour is the correlation between desalination demand and population or number of tourists: it is negative if the whole series (2004-2018) is used (implying less desalination demand for higher population or number of tourists), but it is strongly positive if the period 2009-2018 is taken.

A report from the Water Services Corporation of Malta (2018) offers a very likely reason for this behaviour: there was a strong reduction in water leakages from 2004 to 2009, while water losses have not varied much between 2009 and 2018. Therefore, the strong reduction in desalination energy demand from 2004 to 2009 is clearly driven by the infrastructure improvement, overriding the impact of the factors included quantitatively in the impact chain calculations. The reduction of water leakages is a demand side management option, and its impact over the short term shows the potential importance of these kind of measures.

We have opted therefore to calculate all correlations and weights using the desalination demand series from 2009-2018. As a result, the climate hazard receives a weight of 0.2, while the exposure and vulnerability components have a weight of 0.38 and 0.42, respectively. Most individual indicators for the exposure and vulnerability components show a high correlation with the observed desalination demand. It is noticeable that tourism seasonality has been decreasing through the selected period, and shows a large, but negative, correlation with desalination demand.



Sardinia

Hazard assessment:

<i>Histori-cal ref.(1986-2005)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts
			Productivity Land	Sea	
CDD	0.14		0.90	0.24	0.94
SPEI	0.00		0.25	0.28	0.18
			Combined		0.24

<i>RCP2.6 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.23		0.4	0.4	0.5
SPEI	0.16		0.6	0.7	0.7
			Combined		0.4

<i>RCP8.5 (2046-2065)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.32		0.5	0.6	0.6
SPEI	0.48		0.5	0.7	0.4
			Combined		0.6

<i>RCP2.6 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.22		0.4	0.3	0.5
SPEI	0.08		0.6	0.6	0.5
			Combined		0.6

<i>RCP8.5 (2081-2100)</i>	<i>Demand</i>		<i>Supply:</i>		Droughts change
			Productivity change		
CDD	0.55		0.6	0.8	0.7
SPEI	0.84		0.5	0.7	0.1
			Combined		0.9

Table 3.3.13. Energy demand and supply hazard scores for Sardinia, as in Table 3.3.2.

The CDD score for present climate is in the “very low” range, though the cooling penetration rate is substantial (47.5% in 2014, the highest for Italy) following an ISTAT survey. The results of this survey for Italy show a likely reason for this apparent lack of relationship between CDD and cooling demand: several northern regions show high cooling penetration rates (Veneto, Emilia-



Romagna are the second and third regions with highest cooling penetration rate), while some southern regions with higher temperatures like Calabria have a clearly lower cooling penetration rate. This suggests that purchasing power has a stronger impact on cooling demand than CDD.

CDD score is projected to increase in a limited way under RCP2.6 scenario, pointing to a comparatively low cooling energy demand increase in Sardinia due to this factor. The projected increases under the high-emissions scenario are much higher, with the score reaching a medium value by end of the century. The contrast is much stronger for the SPEI score, which rises only slightly under RCP2.6, but strongly under RCP8.5. Desalinated water is already used in Sardinia. Its demand should increase strongly under RCP8.5 scenario.

Renewable energies play already a relevant role in the power supply. In 2017, the wind energy share was 12.4%, while the PV share was 7.6%. Additionally, there is a significant amount of hydropower capacity (466 MW). The important share of wind energy seems contradictory with the low wind energy productivity obtained for present climate over land, but this may be associated to the fact that the score is a spatial average and the score is a relative value with respect to global values. Also, large contrasts in wind energy resources are found in a mountainous island like Sardinia. Wind energy resources over land are also highly variable in time. PV resources are good and much more stable. The combination of PV and wind energy has very positive impact on the power generation stability, reflecting a high complementarity of both sources.

Wind energy productivity is projected to increase slightly under RCP2.6 scenario, while PV productivity will decrease slightly. Small productivity changes are obtained over land under RCP8.5, but a substantial decrease of offshore wind energy productivity is projected by end of the century for this scenario. Energy drought scores do not change much in most cases, except under RCP8.5 by end of the century, with a strong improvement of PV stability which coincides with the very high SPEI score in this case.



Sicily

Hazard assessment:

<i>Histori-cal ref.(1986- 2005)</i>	Demand		Supply:		Productivity	Droughts
	CDD	0.18	Wind	1.00	Land Sea	0.95
	SPEI	0.00	Solar PV	0.21	0.26	0.15
			Combined			0.20
<i>RCP2.6 (2046-2065)</i>	Demand		Supply:		Productivity	Droughts
	CDD	0.28	Wind	0.5	change	change
	SPEI	0.24	Solar PV	0.5	0.6	0.4
			Combined			0.5
<i>RCP8.5 (2046-2065)</i>	Demand		Supply:		Productivity	Droughts
	CDD	0.38	Wind	0.7	change	change
	SPEI	0.56	Solar PV	0.6	0.7	0.4
			Combined			0.8
<i>RCP2.6 (2081-2100)</i>	Demand		Supply:		Productivity	Droughts
	CDD	0.27	Wind	0.6	change	change
	SPEI	0.24	Solar PV	0.5	0.6	0.3
			Combined			0.5
<i>RCP8.5 (2081-2100)</i>	Demand		Supply:		Productivity	Droughts
	CDD	0.63	Wind	0.9	change	change
	SPEI	0.92	Solar PV	0.6	0.8	0.1
			Combined			0.9

Table 3.3.14. Energy demand and supply hazard scores for Sicily, as in Table 3.3.2.

CDD and SPEI scores in Sicily are similar to Sardinia, but somewhat higher. This reflects higher temperatures in Sicily, and a slightly worse future evolution regarding hydrological drought conditions. Cooling penetration rate in Sicily (37.6% in 2014) is lower than in Sardinia, indicating again that other factors like purchasing power have more impact on this rate than CDD alone.



The importance of the economic factors is confirmed by the evolution of sales air conditioning equipment in Italy in the years before and after the crisis of 2008 (Marvuglia and Messineo, 2012).

The bad wind energy productivity score over land should be adequately interpreted, as it is a spatial average over a very mountainous and large island, where certain areas show good potential. This reflects in the importance that onshore wind energy has already now, as it is the renewable source contributing most to power generation, followed by PV and hydropower. RES share was nearly 25% in 2013 (Meneguzzo et al., 2016). The offshore wind energy productivity score is good, with important spatial differences. The sea area to the west-southwest of Sicily shows the best potential for offshore wind installations. Precisely in this area, a floating wind farm of 250 MW is projected near Marsala (Renewables Now, 2020). If the project is successful, it will be a large boost to the RES share of the island, and should also reduce the need for storage and backup due to the better variability characteristics of offshore wind energy in comparison to onshore wind energy.

Solar PV resources are good, and the low PV drought score indicates low variability. The combination of wind and PV energy is particularly positive in Sicily, as the combined drought score is almost as low as the PV drought score. The projected changes of wind and PV energy productivity and droughts are small under RCP2.6, while wind energy productivity could decrease significantly under RCP8.5 by end of the century. In contrast, in the high-emissions scenario, solar PV would increase its stability clearly.

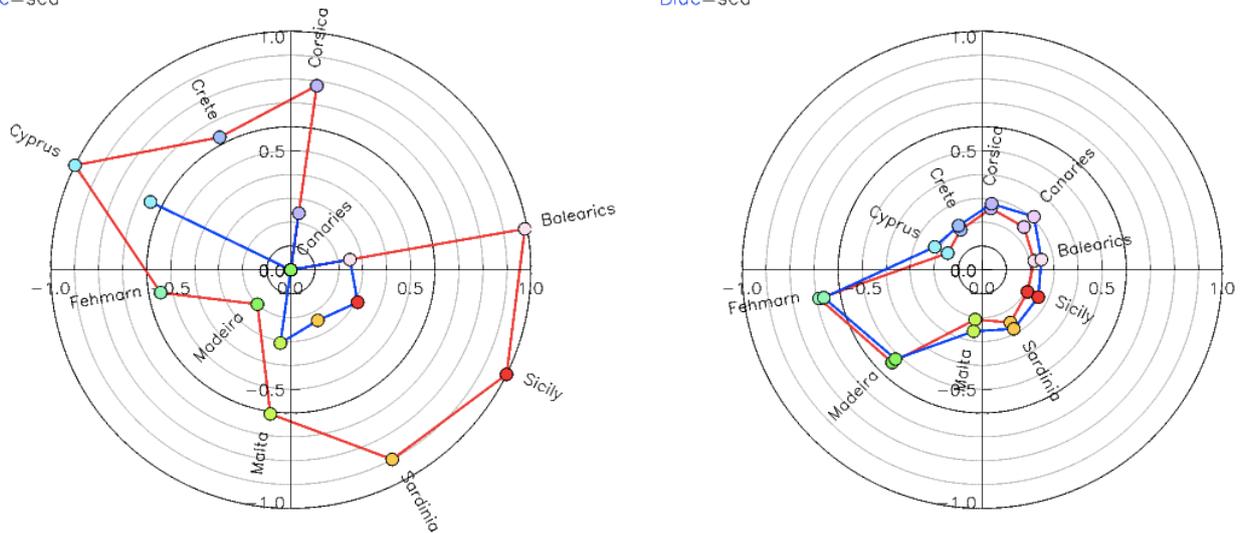


Visual representation of island inter-comparison

Energy supply - Renewable energy potential and droughts

Wind Energy Potential
Red =land
Blue=sea

PV Energy Potential
Red =land
Blue=sea



Energy Droughts
Red =wind
Blue=PV
Green=Combined

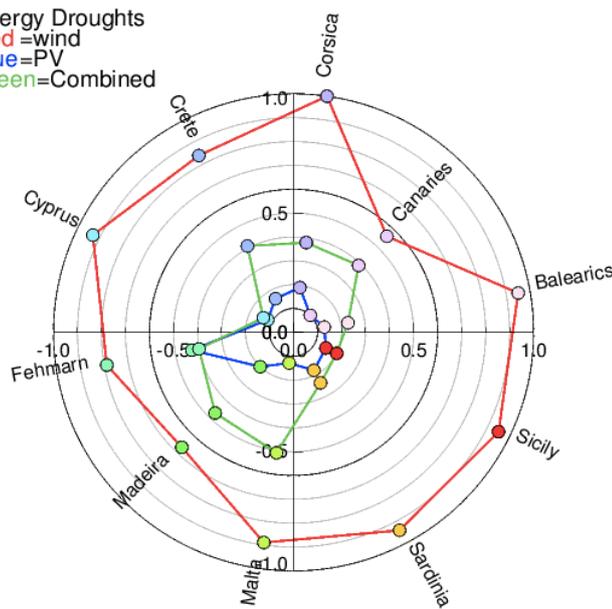
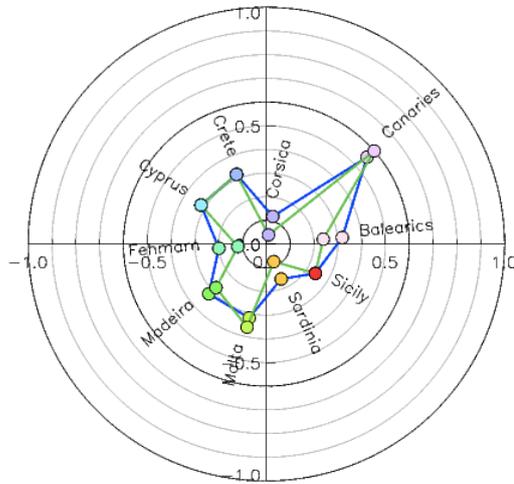


Figure 3.3.3. Upper left plot: normalized scores for onshore and offshore wind energy potential. Upper right plot: normalized scores for onshore and offshore PV energy potential. Thresholds for the minimum and maximum scores have been obtained from global data (IRENA, 2019). Lower plot: Frequency of renewable energy droughts. The minimum score corresponds to no droughts and the maximum score corresponds to the maximum drought frequency among islands. The considered islands are indicated in the plots.



Energy demand - Standardized precipitation-evapotranspiration index

SPEI – RCP2.6
Blue =mid-century
Green =end of century



SPEI – RCP8.5
Blue =mid-century
Green =end of century

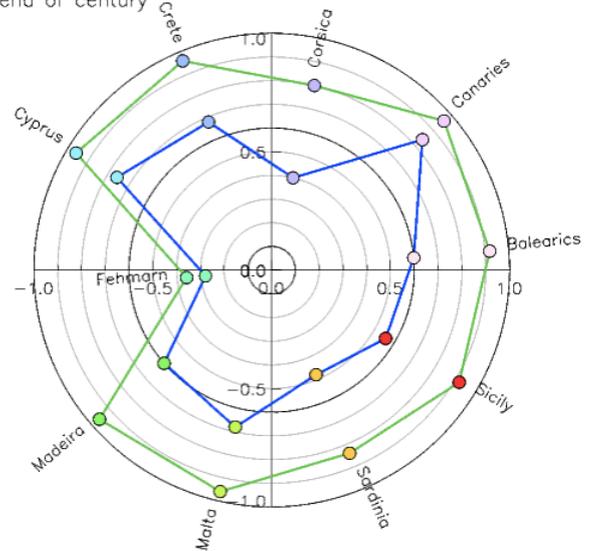
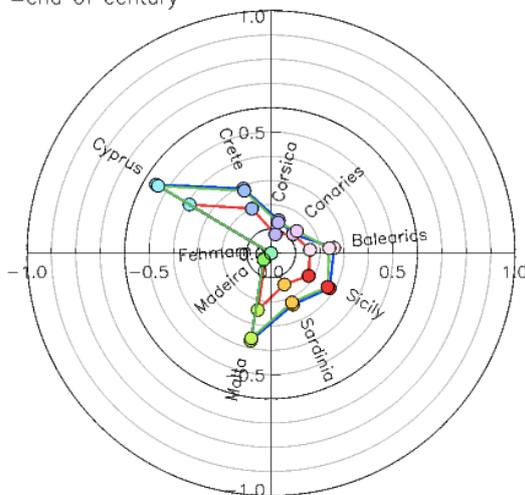


Figure 3.3.4. - Normalized scores for standardized precipitation-evapotranspiration index under present and future climate conditions. Scores for the reference period have not been included, because they are 0 by definition, as normal conditions (SPEI=0) are assigned to this reference period. The maximum score corresponds to the largest negative value found for all islands, emissions scenarios and time periods. Left plot: low emissions scenario RCP2.6. Right plot: high emissions scenario RCP8.5. The considered islands are indicated in the plots.

Energy demand - Cooling degree-days

CDD – RCP2.6
Red =reference period
Blue =mid-century
Green =end of century



CDD – RCP8.5
Red =reference period
Blue =mid-century
Green =end of century

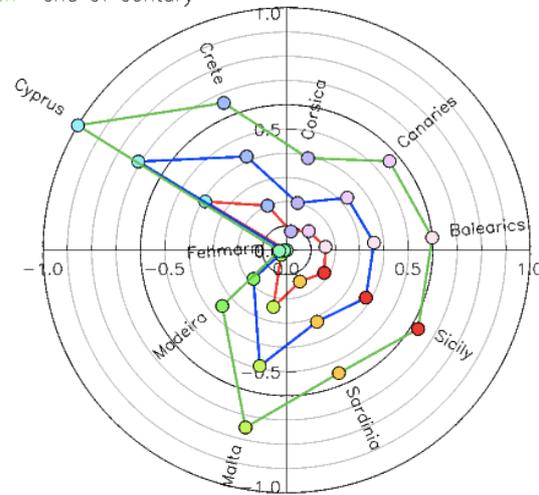
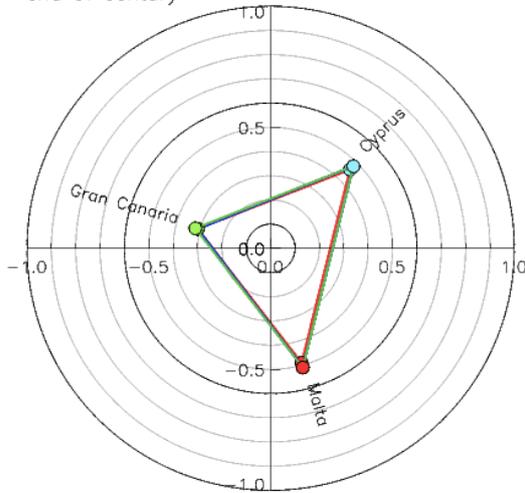


Figure 3.3.5. - Normalized scores for cooling degree-days under present and future climate conditions. The minimum score corresponds to CDD=0, while the maximum score corresponds to the maximum over all islands, emissions scenarios and time periods. Left plot: low emissions scenario RCP2.6. Right plot: high emissions scenario RCP8.5. The considered islands are indicated in the plots.



Risk associated to cooling energy demand

CED Risk- RCP2.6
 Red =reference period
 Blue =mid-century
 Green =end of century



CED Risk- RCP8.5
 Red =reference period
 Blue =mid-century
 Green =end of century

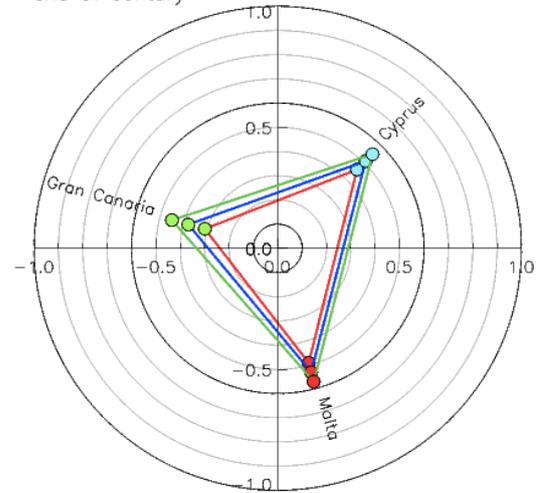
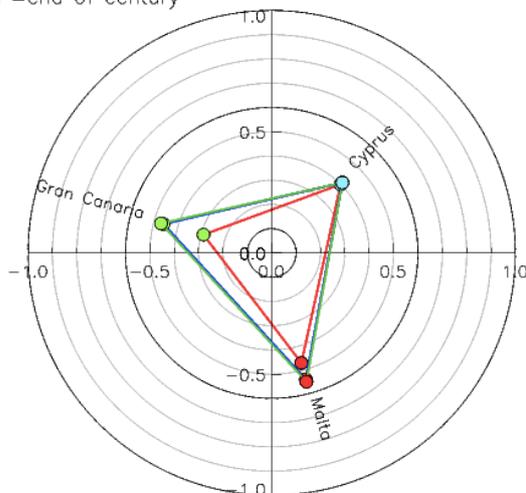


Figure 3.3.6. - Normalized risk scores for cooling energy demand under present and future climate conditions. Left plot: low emissions scenario RCP2.6. Right plot: high emissions scenario RCP8.5. The considered islands are indicated in the plots.

Risk associated to desalination energy demand

DED Risk- RCP2.6
 Red =reference period
 Blue =mid-century
 Green =end of century



DED Risk- RCP8.5
 Red =reference period
 Blue =mid-century
 Green =end of century

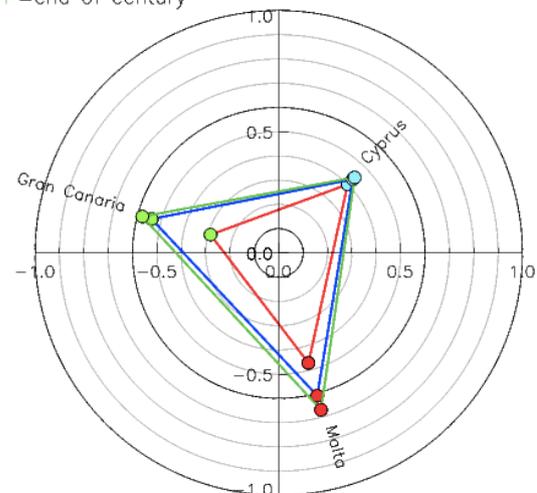


Figure 3.3.7. - Normalized risk scores for desalination energy demand under present and future climate conditions. Left plot: low emissions scenario RCP2.6. Right plot: high emissions scenario RCP8.5. The considered islands are indicated in the plots.

3.4. Aquaculture

Introduction

The work on operationalisation of aquaculture Impact Chains was conducted by the Sector Management Team (SMT) aquaculture. The team members are listed in Table 3.4.1.

Table 3.4.1: Participants of Sector Modelling team Aquaculture and their affiliation.

Participant Name	Partner
Giovanna Pisacane	ENEA
Mark Meyer	GWS
Kyra Hoevenaars	ABT
Lena Schenke	ABT
Hugo Vasconcelos	AREAM
Elizabeth Olival	AREAM

The selected Impact Chains for Aquaculture are:

- IC 1: Change in production due to an increase in surface water temperature (Figure 3.4.1)
- IC 2: Increased fragility of the aquaculture activity due to an increase of extreme weather (Figure 3.4.2)

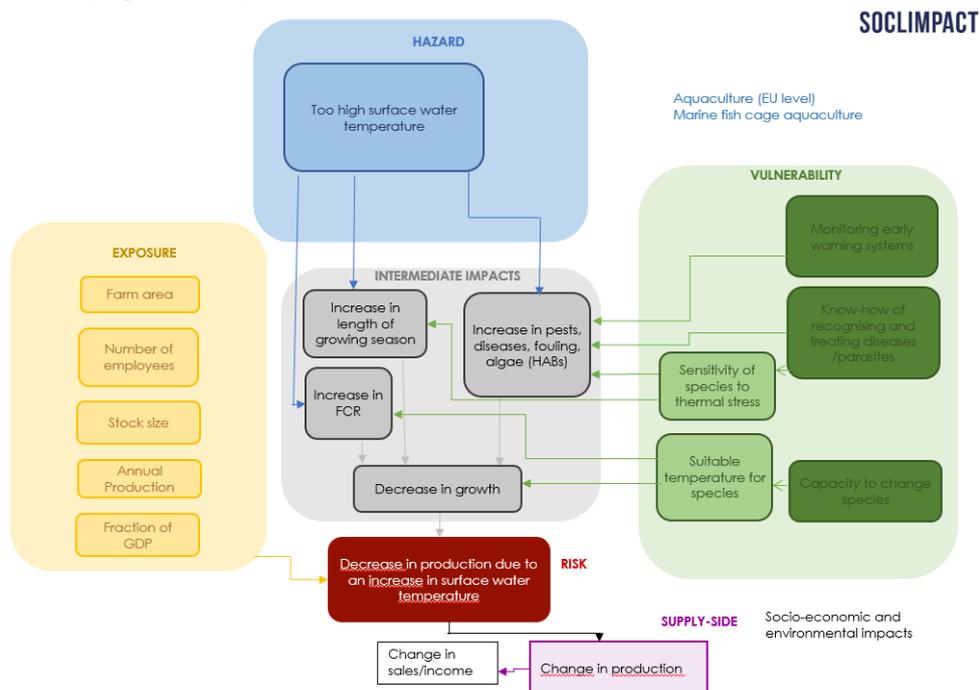


Figure 3.4.1 - Theoretical Impact Chain on the change in production due to an increase in surface water temperature

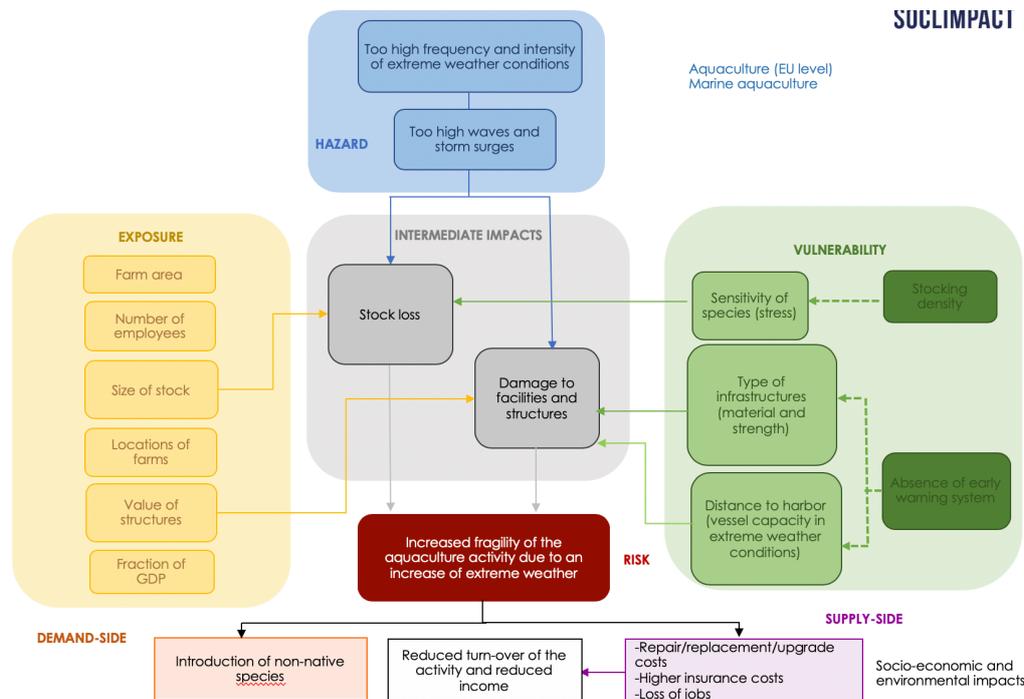


Figure 3.4.2 - Theoretical Impact Chain on Increased fragility of the aquaculture activity due to an increase of extreme weather

The selection of candidate islands for the operationalization was based on data availability from the island focal points (IFPs). Overall data availability also represented the primary criterion to determine which impact chains would be operationalized, and what method to adopt for the operationalisation process.

Selection of the operationalisation method

The expert team examined two possible methodologies for the implementation of the IC approach:

- the Analytic Hierarchy Process - AHP (Saaty, 1980)
- the Risk Assessment method proposed by Fritzsche et al.,2014, hereafter referred to as the GIZ method.

The AHP method provides a reference framework for decomposing a complex problem into more manageable sub-problems, thus concentrating on its constitutive elements, either quantifiable or not, and allowing the evaluation of their relative weights. It was therefore first adopted in order to familiarize with the structure and challenges of the Impact Chain approach. The method was applied to IC 2, “Increased fragility of the aquaculture activity due to an increase of extreme weather”. Once a better understanding of the nature and relevance of risk components was gained through discussion among experts, the GIZ method was applied to the risk assessment analysis.



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Evaluation of the AHP method in the context of IC implementation

The details of the AHP application to IC 2 are given in Section 7.7. Here only its overall evaluation is presented, in particular as to the insight offered for the subsequent risk assessment exercise.

In general, the scores computed via the AHP only give some a priori comparative information about which risk components are relevant for the different islands and why, based on the information provided by the relative scores of criteria and sub-criteria. However, the weighing of the main risk components (i.e. the criteria vs goal comparison in the AHP terminology) set a big challenge for experts, which deserves further discussion, in particular as to the relative importance of hazard with respect to exposure and vulnerability. This is probably a consequence of the difficulty encountered to switch from the traditional risk assessment framework, where risk components are treated as independent, to the IC approach, where they jointly concur to the overall risk (see also Section 2 above), and clearly lowers the confidence in the risk components ranking, while general consensus was reached for the other pair-wise comparisons.

The results provide values for each island which can be used to compare islands. No absolute scores for islands can be given. However, information regarding the structure of the risk in each island can be extracted by comparing the criteria and sub-criteria analysed in the hierarchy tree. Not only the final relative scores of the islands are important, but also the scores obtained for each criteria and sub-criteria in the different islands. This could give relevant information to stakeholders, by analysing which are the advantages and disadvantages of their aquaculture sector in comparison with other islands and learn from that.

Application of the GIZ method in the context of IC implementation

In this context, the GIZ method was applied to analyse the data collected for some specific indicators reported in the IC schemes above, for the islands that showed interest in the risk assessment exercise for the aquaculture sector and that were able to provide sufficient information. The corresponding ICs therefore needed to be simplified accordingly (ref. Section 7.7). When absolute criteria were available, the indicators were normalized, and the different risk components weighted, delivering risk scores for present and future conditions under different Representative Concentration Pathway (RCP) scenarios. Islands were then inter-compared.

The method consists of seven steps:

- Step 1:** Data collection by Island Focal Points
- Step 2:** Data review and selection of islands
- Step 3:** Review and selection of indicators
- Step 4:** Normalisation of indicator data for all islands
- Step 5:** Weighting of different risk components
- Step 6:** Calculations of risk for present conditions
- Step 7:** Calculations of risk for future conditions (different RCPs)

Details on the implementation of these steps is provided in Section 7.7, in particular as to the normalization of exposure and vulnerability components and as to the weighing of all the elements concurring to determine the overall risk scores. Some normalized values and all the weights were estimated by aquaculture experts based on subjective considerations, similar to those used in the AHP method. However, this time data availability was additionally considered, and weights lowered for the components that relied on less robust, outdated, or scarcer data. Components that were estimated from reliable datasets were given a higher weight. Conversely, wave hazards were



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normalized and classified based on absolute criteria, while for SST it was decided to present only the non-normalized hazard, due to the lack of a direct link relating warming to farm productivity. The reasons for this choice are described in the following section, followed by a brief analysis of model performance and reliability and by hazard maps (normalized hazard maps in the case of wave-related hazards).

Exposure and vulnerability sub-components had to be kept constant across scenarios and time horizons, due to insufficient information on future socio-economic development, and some had to be normalized via the max-min approach, which implies that they only allow the relative ranking of islands. However, in some cases (i.e. the economic exposure component) this latter limitation might be acceptable as it is representative of the competitive advantages/disadvantages of each island in the context of the local market. Some discussion arose as to how to combine the two economic indicators available for exposure, that is the number of operators and annual production. As a matter of fact, the number of producers was considered not to be relevant in itself, as it represents neither the absolute size of the sector nor its relevance for the island. The number of producers is, in fact, fairly homogeneous across the selected islands (from 7 to 12, with a mean value of 8.8), and fails to correctly rank the small but very active Malta with respect to, for instance, the much bigger, but apparently less developed in the sector, Sicily. The fact that weighted averaging the two indicators partly corrects this issue does not compensate for the apparent inconsistencies in the relative ranking. A new indicator, the average size of producers (computed as the ratio of production to the number of producers), was therefore proposed and examined, which proved to be more informative, as it effectively amplified differences between islands, at the same time retaining the absolute economic value of the sector (given by production), at least for the present situation. Indeed, the choice of the best indicators is affected by the necessity of guaranteeing their independence. Under current conditions, such independence is largely granted by the evident de-correlation of production and number of producers. Should a functional relation emerge in the future, revision of the indicators is recommended. Normalization to the island size, or to the size of its economy, was considered to introduce exogenous factors in the sector evaluation, and it was therefore discarded in this context.

Economic indicators were, instead, excluded in the evaluation of adaptive capacity, perhaps limiting the conclusions of the risk assessment. It might be argued that the relative size of an industry could possibly give a measure of its capacity of overcoming temporary crises and investing in technological advancements that improve its survivability under muted environmental conditions. Nevertheless, the relative relevance of Research and Development (R&D), profitability and long-term solvency in determining aquaculture firm survival is controversial (Cordón Lagares et al., 2018), and the degree of innovation implemented by the enterprises currently operating in the islands unknown. In addition, simultaneously using the same indicator (average size of producers) for the computation of different risk components is anyway not advisable. The issue was therefore set aside in the present study.

Hazard normalization and classification

The climate-induced hazard indicators selected to assess future risks for the aquaculture sector are:

- Impact Chain 1 - “Change in production due to an increase in surface water temperature”:
 - Ocean Heatwaves (i.e. duration of warm events as a function of specific temperature thresholds)
 - Mean Sea Surface Temperature (SST)
- Impact Chain 2 - “Increased fragility of the aquaculture activity due to an increase of extreme weather”:



- Mean Significant Wave Height
- Return Time of waves with Significant Wave Height exceeding 7 m (i.e. expected frequency of events with SWH exceeding 7 m).

Gridded fields of all indicators were computed and their geographical maps included in D4.3 and D4.4, except for Mean Sea Surface Temperature, which was later added to the list of relevant variables, to be used as input to the economic evaluation of the sector perspectives in WP5 of the SOCLIMPACT Project. Spatial averages of hazard indicators for each island, however, were computed over selected homogeneous areas where the presence of aquaculture farms is documented, and island averages subsequently computed when necessary.

For IC 2, which focuses on the mechanical stress exerted on cages and lines at sea, it was possible to relate the magnitude and frequency of extreme events and the amplitude of mean wave motion to potential damages to infrastructures, loss of stock and increased investment and maintenance costs, based on literature (Ryan, 2004; Falconer et al., 2013; Faltinsen and Shen, 2018) and stakeholders' advice, and therefore to derive actual hazard thresholds. Tables 3.4.2 and 3.4.3 summarize the normalization and classification performed for Return Time and Mean Significant Wave Height, respectively. It was assumed that a time period of 10 or more years allows to repay investments and represents a reasonable upper limit for the return time interval to be considered in the normalization exercise.

However, as the probability of having at least one event exceeding the return level (set at 7 m) associated with a N-year return period during a N-year time window is anyway greater than that of its complement (no events exceeding the limit in the N-year time window), long return periods cannot be considered as "risk-free" safety levels in evaluating the survivability and sustainability of structures or plants.



Table 3.4.2. – Probability of occurrence of a weather event inducing Significant Wave Heights above 7m, as a function of Return Period (first column, in blue) and of the time window considered (in green at the top of columns from 2 to 6). Probabilities higher than 50 % are highlighted in red. Normalized values are shown in column 7, their weighted contribution to total hazard in column 8 and their classification in column 9.

Return Period [years]	Probability of occurrence					Normalized value	Absolute contribution to final hazard score	Degree of hazard
	1 year	2 years	5 years	10 years	20 years			
1	100%	100%	100%	100%	100%	0.9	0.72	Extreme
2	50%	75%	97%	100%	100%	0.8	0.64	
3	33%	56%	87%	98%	100%	0.7	0.56	High
4	25%	44%	76%	94%	100%	0.6	0.48	
5	20%	36%	67%	89%	99%	0.5	0.40	Medium
6	17%	31%	60%	84%	97%	0.4	0.32	
7	14%	27%	53%	79%	95%	0.3	0.24	Moderate
8	13%	23%	49%	74%	93%	0.2	0.16	
9	11%	21%	45%	69%	91%	0.1	0.08	Low
10	10%	19%	41%	65%	88%	0	0	

$$R_{L,T} = 1 - (1 - 1/T)^L$$

where L=length of time window, T=Return Period.

Table 3.4.3. – Normalization and classification of hazard associated to Mean Significant Wave Height (Ryan, 2004).

Significant Wave Height (m)	Normalized value (NV)	Absolute contribution to final hazard score	Degree of hazard
> 3	> 0.8	> 0.16	Extreme
2÷3	0.6÷0.8	0.12÷0.16	High
1÷2	0.4÷0.6	0.08÷0.12	Medium
0.5÷1	0.2÷0.4	0.04÷0.08	Moderate
< 0.5	0÷0.2	0÷0.04	Low

$$NV = [(SWH - \text{Interval Lower Extreme}) / \text{Interval Length}] * \text{Normalized Interval Length} + \text{Normalized Interval Lower Extreme}$$



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Conversely, for IC 1 it was not possible to directly link the projected increase in SST to the productivity of farms via reliable growth functions, as these depend on a variety of non-linearly interacting factors and are based on complex bioenergetic models that need to also account for farming practices (Dumas et al., 2010), which usually constitute sensitive data that are not divulged by farmers. As a consequence, it is also hard to estimate to what extent aquaculture practices can adapt to the changing environment through tailored selection of farmed species or via the implementation of improved farming techniques, from the optimization of farming cycles to the reduction of other environmental stressors.

On the other hand, while temperature indeed sets the pace of physiological processes, it can influence fish growth in multiple ways, including the alteration of tolerance thresholds (Fry, 1947; Currie et al., 1998). The ongoing climate-change-induced increase in sea water temperature is in fact projected to affect individual organisms during all life stages, enhancing further specialization in local or regional climate regimes and triggering evolutionary adaptation of species to counteract stressful conditions, either via individual acclimation or genetic adaptation across generations (Pörtner and Peck, 2011; Hoffmann and Sgrò, 2011). The difference between upper and lower lethal temperatures (i.e. the thermal window) of marine fish species varies with latitude, and is narrowest for high and low latitude species and widest for fish inhabiting intermediate latitudes, where seasonal variability in water temperatures are usually largest and the ability of species to adapt to changes can be expected to be more effective (Pörtner and Peck, 2011; Currie et al., 1998). The latter condition is, in fact, met by all islands in SOCLIMPACT, except for Fehmarn and the West Indies. However, while it has been shown that, when exposed to higher temperatures, animals progressively develop protective mechanisms and enhance their heat-shock response (Pörtner and Peck, 2011), the flexibility of the upper critical heat limits is still being investigated, and the reasonable hypothesis that warming tolerance is reduced at higher acclimation temperatures constitutes a potential limit to the adaptive capacity of fishes to prolonged heatwaves in a warming climate (Sandblom et al., 2016; Beitinger et al., 2000).

For this latter reason, it was decided that, from a risk assessment perspective, heatwave duration (i.e. the duration of exceedingly warm periods) represented the most relevant parameter for hazard evaluation, regardless of the event being an isolated extreme or a persistent seasonal feature. This parameter also offers the advantage of being specifically related to individual species, for which optimal temperature thresholds can be found in the literature. Of course, the analysis can only be performed for the current estimation of optimal temperatures, while the potential future adaptation of species must necessarily be neglected.

Nevertheless, mean SST maps and tabulated SST integral increments for each island are also provided here, the latter to be used as input for the empirical economic evaluation of WP5. In this section, only maps for the whole Mediterranean basin and the North Atlantic Oceans are shown, while zooms over each island are provided in the following *Atlas of mean SST maps and normalized wave-induced hazards*. The corresponding maps for the normalized and classified wave-induced hazard are also presented.

Overview of model simulations and uncertainty

Table 3.4.4 summarizes the experiments used within SOCLIMPACT to assess climate-change-induced hazards for the aquaculture sector.

Table 3.4.4. – Numerical experiments available as a function of output variable

	Reference period	RCP2.6	RCP4.5	RCP8.5
SST Med	X	X	X	X
SWH Med	X		X	X
SST Atlantic	X	X		X
SWH Atlantic	X			X

The choice of scenarios was driven by data availability, as no wave simulations were available for RCP2.6 in the Mediterranean, while only RCP8.5 could be run for the Atlantic Sea as a consequence of the limited number of global wave experiments allowing the nesting of higher resolution wave models (i.e. providing the wave spectra needed to prescribe the boundary condition for the higher resolution runs). All three scenarios are provided for SST, although RCP2.6 is not used in the IC operationalization exercise for the Mediterranean islands, for the sake of consistency with the wave analysis.

Figures from 3.4.3 to 3.4.6 synthesize the modelling strategy and result characteristics for the thermal and wave-induced hazard assessment in the Mediterranean basin and in the North Atlantic Sea.

In SOCLIMPACT, four different modelling chains⁹ were used to force WAM (WAVE Model – WAMDI Group, 1988) over the Mediterranean basin, at a resolution of about 25 km. The new higher-resolution wave simulations that are currently being performed, often with the WaveWatch III model (Tolman et al., 2002), were not available at the time the project started, and still now do not offer sufficient coverage of future scenarios. On the other hand, WaveWatch III was specifically run within SOCLIMPACT to produce the necessary Atlantic wave fields, as no high-resolution projections were available for the Atlantic islands. For the Atlantic wave projections to reach the resolution needed to reasonably represent the selected Atlantic islands, a first wave simulation over the whole North Atlantic was run at about 25 km resolution (0.25°), taking the incoming wave boundary conditions from two coarser resolution (about 100 km, 1°) global simulations. WaveWatchtIII was forced with the wind fields produced by the HadGEM and ACCESS GCMs. Higher resolution runs (about 5 km, 0.05°) were then, in their turn, nested in this intermediate 0.25° resolution experiment, which provided wave the boundary conditions necessary to further zoom over the islands. In this case, the nesting process (see Footnote 6), only involves the wave models, while the same global wind fields that force the corresponding global wave simulations are also used to drive all the nested higher-resolution wave experiments. This implies that the local perturbing orographic effect of islands is not accounted for in the forcing

⁹ General Circulation Models (GCMs) have a resolution between 1° and 2° so, when higher-resolution atmospheric fields are needed (in the present case, the wind that forces the wave model), a Regional Circulation Model must be run that takes its boundary conditions (pressure, surface temperature, humidity and wind components) from the GCM, and produces regional projections at higher resolution (usually between 25 km and 10 km). This process is called *nesting*. Each GCM-RCM combination is called *modelling chain*. In this document, modelling chains are named after their constituting models, often coinciding with the name of the research institute that developed them. The same holds for the individual GCMs that provide the SST fields in the Atlantic Sea.



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wind fields, obviously introducing a source of uncertainty. The higher resolution of the Atlantic islands figures partly dissimulates this issue, but in fact they only depict how the islands obstruct the propagation of waves generated by large scale winds that are unaffected by their presence.

The Mediterranean Sea being a semi-enclosed basin, only connected to the Atlantic Ocean via the narrow Strait of Gibraltar, it was not necessary to nest WAM into another wave simulation and wave boundary conditions were only prescribed along the shorelines, where no incoming waves need to be accounted for.

The Mediterranean SST projections were instead obtained from a single alternative higher-resolution (about 10 km) modelling chain (CNRM- RCM4), the only one available through the MED-CORDEX database at the time SOCLIMPACT started (ref. D4.3). For the Atlantic simulations, SST fields were derived from four coarse global projections (100÷200 km - 1°÷2° - resolution), from the CMIP5 database¹⁰, selected so as to be consistent with the regional modelling chains used within WP4 to derive the atmospheric hazard indicators over the EURO-CORDEX 0.11°-resolution domain¹¹ presented in D4.3.

Sea Surface Temperature fields and Significant Wave Height are direct model outputs, while Return Times are computed from SWH fields, based on the stationary Gumbel distribution, a choice supported by the apparent absence of trends in SWH (ref. D4.3) and often recommendable even under changing environmental conditions (Serinaldi and Kilsby, 2014).

The rarity of extreme events, as well as their being characterized by limited spatial and temporal scales and by complex processes, recommends great caution in evaluating the Return Time results, as the reliability of the underlying statistics clearly depends on model ability to capture phenomena that are often at the limit of current predictive capabilities (e.g. predicting tropical and extratropical cyclones generation and trajectories in the Atlantic, or Medicanes in the Mediterranean Sea). When applied to climate data, extreme event analysis in fact mostly concentrates on “moderate” extremes over time scales longer than those typical of extreme events¹², rather than on acute episodes, in order to guarantee statistic robustness, in accordance with the definition of climate as the the *long-term average of weather*. This clearly requires that the reference thresholds for the extreme event analysis are lowered accordingly, so that the information provided can highlight the overall decrease/increase tendencies in the occurrence of extremes, but gives little hint as to the intensity and frequency of the actual potentially disruptive episodes that usually concern stakeholders (Klein Tank et al., 2009). In addition, the uncertainty in Return Time values increases as they approach the length of the selected time window (i.e. the length of the time series used for their calculation), so that confidence is progressively lowered for the most extreme and potentially damaging events over the timescales of interest (AghaKouchak et al., 2013).

A unique distribution could be obtained by pooling all model data together, with the aim to reduce uncertainty by inflating the statistical sample, and assuming that all models equally contribute to the statistical characterization of the real climate system¹³. However, the wind fields (four for the

¹⁰ <https://esgf-node.llnl.gov/projects/cmip5/>

¹¹ <https://www.euro-cordex.net/060374/index.php.en?print>

¹² The daily time scale usually represents the cutoff for analyses of climate extremes. This is reflected in the choice of lower thresholds to evaluate extremes, that implicitly account for the occurrence of more intense events over shorter periods. For example, the daily precipitation threshold used in the assessment of extreme hydrological events is often set to 20 mm/day, in order to account for the alternance of more or less intense precipitation rates along the day.

¹³ Ideally, each model explores a set of possible states of the real climate system, thus allowing to maximize its statistical representation by pooling all model realizations together, and thus to derive the statistical moments that describe it (e.g. mean, standard deviation, skewness, kurtosis of its representative climate variables) from the resulting enlarged sample. Therefore, it is not surprising that the four model realizations should exhibit significant differences. However, the number of model realizations and statistical analyses needed to avoid system undersampling, as well as the



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Mediterranean, two, for the Atlantic) used to drive the wave model exhibit differences that cannot be considered as mere "perturbations" of the same dynamical system, but rather systematic relative biases. For the Mediterranean basin, the model run forced by the LMD model even excludes the occurrence of events above the reference threshold, and was consequently ruled out as an outlier. In the hazard assessment, results from the different model simulations were therefore inter-compared and the the most and least "favourable" model projection retained in the risk analysis, so that an estimate of the relative uncertainty could be inferred.

The uncertainties associated with the mean wave projections for the Mediterranean basin are generally low, as the four model realizations are all in good agreement (ref. D4.3). In this case, ensemble means (i.e. averages computed by pooling all models together) were used for the evaluation of the hazards associated to mean SWH (Figure 3.4.13). The single model experiment used to derive SST projections clearly does not allow any speculation on the associated uncertainty, except for noting its overall qualitative agreement with the coarser resolution simulations of the MED-CORDEX programme, which could not be jointly used for the analysis of ocean heatwaves as the different spatial resolution would have impaired the selection of common temperature thresholds¹⁴.

In general, all the mentioned experiments highlight the progressive warming of the Mediterranean waters with both time and scenario severity, the overall pattern maintaining a northwest-southeast gradient and peaks reached along the eastern coast of the Levantine basin (Figure 3.4.7).

The Atlantic simulations are affected by comparatively higher uncertainty, originating from insufficient resolution, as well as from discrepancies across models in the intensity and spatial patterns of both SST and extreme waves (that is, in the forcing wind fields) in the sub-tropical zonal belt (see, for example, the maps of wind fields in the Atlantic presented in D4.4b). In the case of mean wave height, this feature is masked by the smoothing effect of averaging, but it in fact appears to be still notable in the higher-resolution island maps. Such displacement of the zonal patterns, that might even appear a minor shortfall from the global perspective, can in fact be crucial for the local hazard assessment. As a matter of fact, Figures 3.4.8, 3.4.9 and 3.4.12 exhibit sharp gradients located just in the areas of the islands of interest, whose direction and magnitude vary across simulation, although the projected climatological SST fields apparently tend to cluster in couples. Conversely, normalization and classification almost completely smooth out differences in the SWH fields (Figure 3.4.14). Such discrepancies are due to the documented disagreement between models in the representation of meridional mass and energy fluxes across the tropical and sub-tropical zonal belts (see D4.4b for a brief description and references), which is still a matter of research that will be specifically addressed in the forthcoming CMIP6 programme¹⁵. It is evident that the Azores and Madeira (but also the Canaries and West Indies) lie in very critical areas where models might be inaccurate in predicting large-scale patterns of climate variables, and even if regional models become available, they would possibly have to cope with such deficiencies anyway, also in view of their being exposed to extreme weather events that are not captured by climate models (e.g. tropical and extratropical cyclones and Medicanes).

Ensemble mean values would completely obscure model differences, and only partly retain such information in the magnitude of the ensemble standard deviation or maximum spread. The distinct

oversampling of a limited number of preferred states due to an involuntarily biased selection of models, is significantly larger than that obtained within SOCLIMPACT, which was limited by data availability and project duration.

¹⁴ Coarser resolution implies smoothing of variables, and the pixel value associated with larger grid cells allows for oscillations between higher and lower values at sub-grid scales, including that of the higher-resolution grid. In order to compare model output fields at different resolutions, all should be interpolated over the lowest resolution grid, degrading the information.

¹⁵ <https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6>



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model projections are therefore maintained here, so as to enhance the reader's perception of the complexity and of the inherent ambiguity of the information that can be derived from a limited number of climate model realizations. Spatially averaged ensemble mean SST increments are anyway reported in Table 3.4.6 for the Atlantic islands, to be used in the economic estimates of WP5, in a context where such approximations are methodologically acceptable. Likewise, Table 3.4.5 reports the spatially averaged SST increments for the Mediterranean islands, derived from the CNRM-RCSM4 simulation.

Despite the effort made to convert climate information into usable yet informative indicators, stakeholders, policy makers and the general public should anyway be aware that uncertainty is an ineradicable characteristic of any climate projection, and that any future planning must cope with it. Climatologists can only highlight potential threats and constraints; they cannot predict the future and pave the way to perfect or definitive solutions. Successfully conveying this concept is one of the most critical points of climate-change-related information.



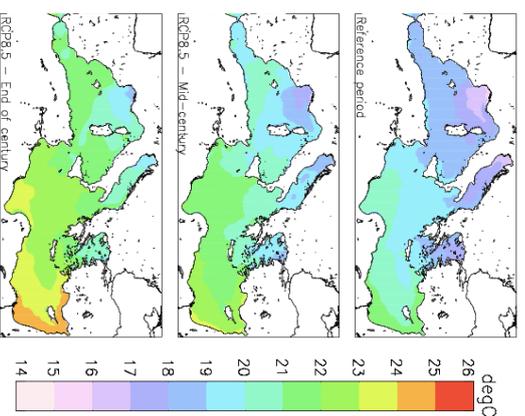
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SOCIIMPACT



Mediterranean islands: Thermal hazard

One high-resolution Ocean RCM (0.1° x 0.1°) provides projections of the SST field for RCP2.6, RCP4.5 and RCP8.5 (here shown for the present climate, RCP8.5 mid-century and RCP8.5 end-of-century, from top to bottom



SST

- Model projections in good agreement with previous lower resolution ensemble estimates, but offering greater detail along island shorelines
- Uncertainty to be rigorously estimated from ensemble STD when new simulations of comparable resolution become available, but overall tendency regarded as robust
- Due to lack of specific data, normalization was only possible via a max-min approach

Figure 3.4.3. – Synthesis of modelling strategy and result characteristics for the assessment of thermal hazard in the Mediterranean basin.



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Table 3.4.5. – Mean SST values per island and scenario.

	Reference period	RCP26		RCP45		RCP85	
		Mid-century	End of century	Mid-century	End of century	Mid-century	End of century
BALEARIC	18.4	19.3	19.2	19.4	19.9	19.9	21.3
CORSICA	17.8	18.7	18.6	18.8	19.3	19.2	20.6
CRETE	19.5	20.3	20.4	20.5	21.1	20.9	22.3
CYPRUS	20.9	21.8	21.9	21.9	22.5	22.4	23.9
MALTA	19.3	20.1	20.0	20.2	20.7	20.6	21.8
SARDINIA	18.0	18.8	18.7	18.9	19.4	19.3	20.6
SICILY	19.0	19.8	19.8	20.0	20.5	20.4	21.6
		Increment with respect to reference period (IRP)	Increment with respect to reference period (IRP)	IRP	IRP	Increment with respect to reference period (IRP)	Increment with respect to reference period (IRP)
BALEARIC		0.9	0.8	1.0	1.5	1.5	2.9
CORSICA		0.9	0.8	1.0	1.5	1.4	2.8
CRETE		0.8	0.9	1.0	1.6	1.4	2.8
CYPRUS		0.9	1.0	1.0	1.6	1.5	3.0
MALTA		0.8	0.7	0.9	1.4	1.3	2.5
SARDINIA		0.8	0.7	0.9	1.4	1.3	2.6
SICILY		0.8	0.8	1.0	1.5	1.4	2.6



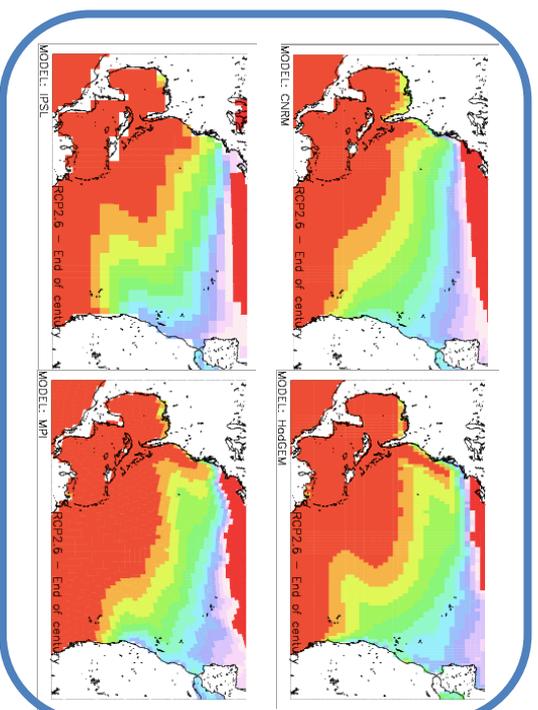
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Atlantic islands: Thermal hazard

Four low resolution GCMs (1°÷2°) provide projections of the SST field



SST

- Model projections differ as to overall pattern and local magnitude which represents a source of uncertainty
- Intensity and localization of meridional gradients in the tropical and sub-tropical zonal belts is a documented research issue
- Pessimistic CC scenario appears to reduce differences, but robustness of results needs to be further assessed in the context of ongoing research programmes
- Due to lack of specific data, normalization was only possible via a max-min approach

Figure 3.4.4. – Synthesis of modelling strategy and result characteristics for the assessment of thermal hazard in the North Atlantic Sea.



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Table 3.4.6. – Mean SST values per island and scenario

	Reference period				RCP26								RCP85							
					Mid-century				End of century				Mid-century				End of century			
AZORES	17.6	19.2	17.3	17.9	18.3	20.1	17.9	17.6	18.1	19.6	17.9	18.0	19.0	20.8	19.0	18.8	20.3	22.4	20.6	20.3
CANARIES	20.3	19.4	18.8	20.0	20.6	20.8	19.4	20.5	20.6	20.6	19.3	20.4	21.2	21.3	19.9	21.1	22.4	22.7	21.2	22.0
MADEIRA	19.2	18.8	18.7	19.4	19.8	20.0	19.6	20.2	19.6	19.7	19.6	20.1	20.4	20.5	20.3	20.9	21.8	21.8	21.6	22.2
WEST INDIES	25.8	26.3	25.3	27.2	26.5	27.4	26.2	27.9	26.5	27.2	26.2	27.8	27.0	28.1	27.1	28.7	28.2	29.3	29.0	30.0
					Increment with respect to reference period				Increment with respect to reference period				Increment with respect to reference period							
AZORES					0.7	0.9	0.6	-0.3	0.5	0.4	0.6	0.1	1.4	1.6	1.7	0.9	2.7	3.2	3.3	2.4
CANARIES					0.3	1.4	0.6	0.5	0.3	1.2	0.5	0.4	0.9	1.9	1.1	1.1	2.1	3.3	2.4	2.0
MADEIRA					0.6	1.2	0.9	0.8	0.4	0.9	0.9	0.7	1.2	1.7	1.6	1.5	2.6	3.0	2.9	2.8
WEST INDIES					0.7	1.1	0.9	0.7	0.7	0.9	0.9	0.6	1.2	1.8	1.8	1.5	2.4	3.0	3.7	2.8
					Mean Increment with respect to reference period				Mean Increment with respect to reference period				Mean Increment with respect to reference period							
AZORES					0.48				0.40				1.40				2.90			
CANARIES					0.70				0.60				1.25				2.45			
MADEIRA					0.88				0.73				1.50				2.83			
WEST INDIES					0.85				0.77				1.58				2.98			



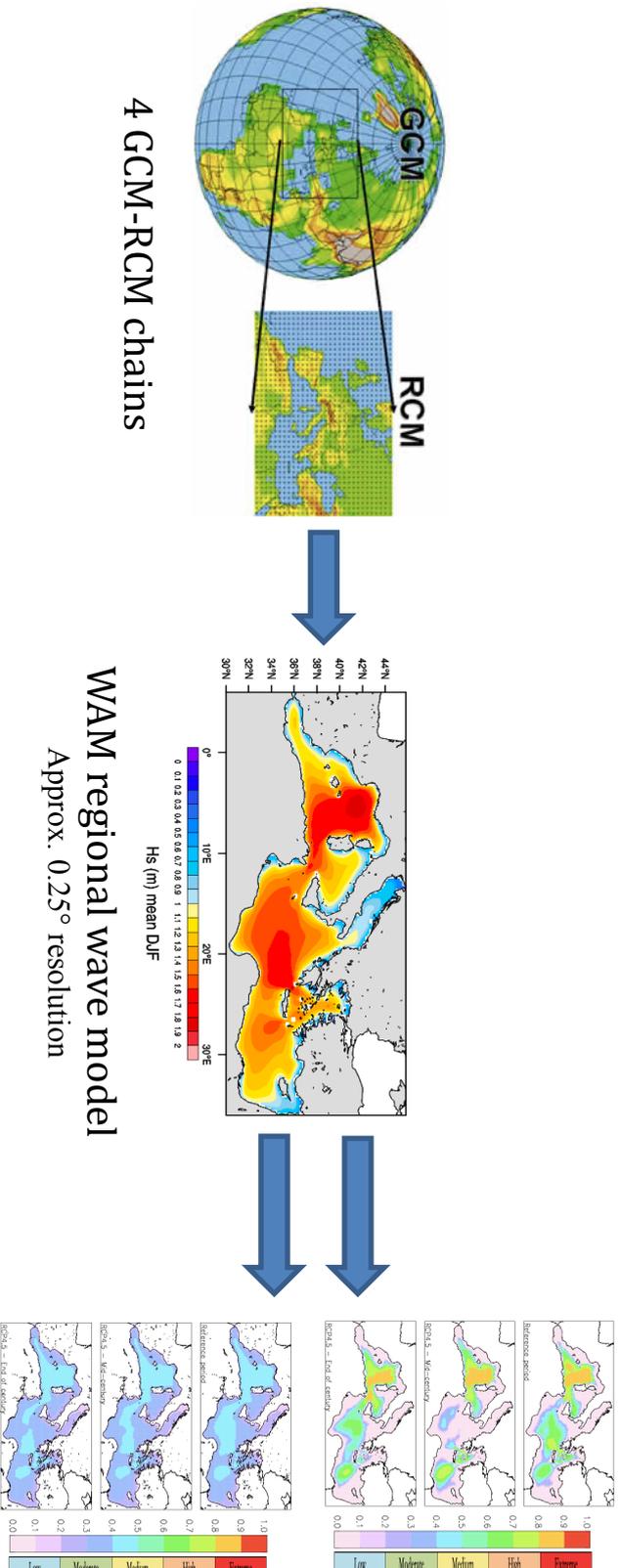
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Mediterranean Islands: Sea-state hazard

Normalized Return Time of extreme waves (SWH > 7m, 0-10 yrs)



4 GCM-RCM chains

WAM regional wave model
Approx. 0.25° resolution

*Normalized AMSWH
(0-3 m)*

Return Time

- Statistics of extreme events can significantly differ across the four model model realizations
- Hazard evaluated for the best and the worst projection, whose distance give an estimate of uncertainty

AMSWH

- Model projections in good agreement as to both pattern and values
- Hazard evaluated from ensemble mean, uncertainty from ensemble STD (not exceeding 15% - highest disagreement for highest values)

Figure 3.4.5. – Synthesis of modelling strategy and result characteristics for the assessment of wave-induced hazard in the Mediterranean basin

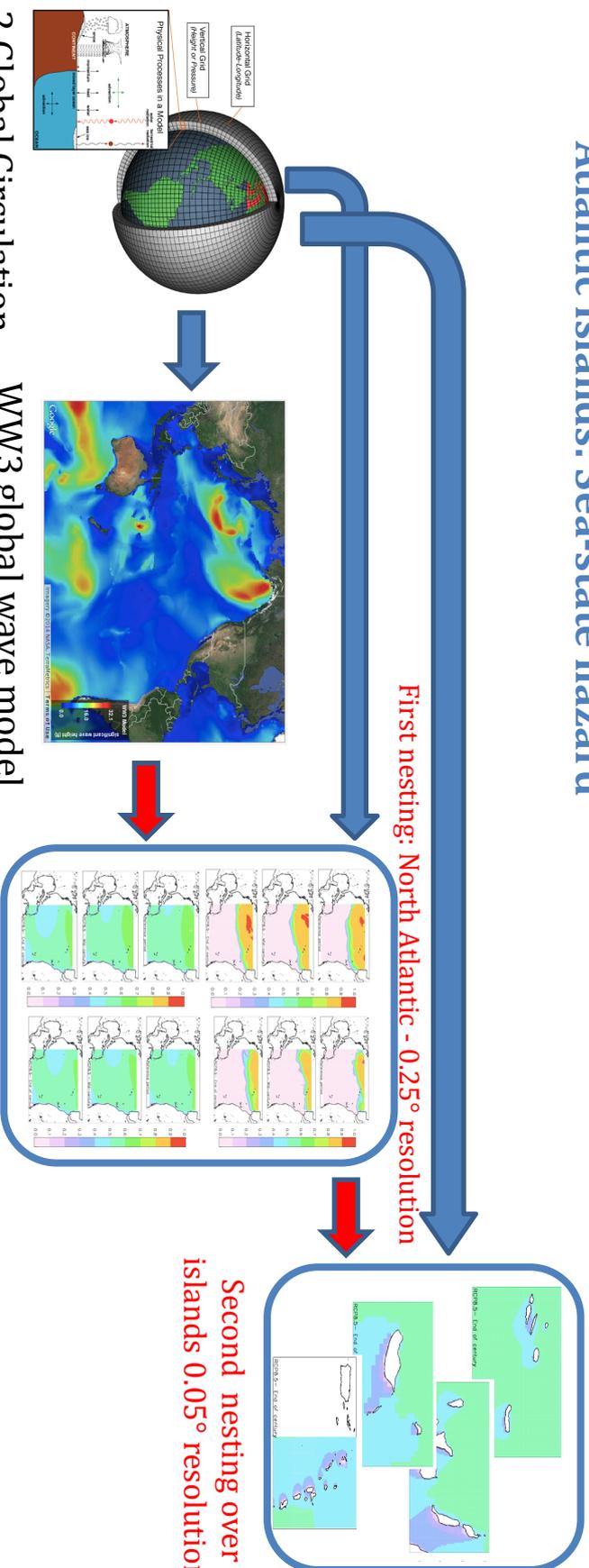


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Atlantic islands: Sea-state hazard



2 Global Circulation Models

WW3 global wave model

AMSWH

- Model projections in better overall agreement, but still exhibiting local differences that are neutralized by normalization and classification
- Given the very limited number of model realizations, hazard is separately presented for the two modelling chains and uncertainty is inferred from difference

Return Time

- Low resolution wind field compromises accuracy of local projections
- Statistics of extreme events for individual islands can dramatically differ between the two model realizations, switching from moderate to extreme, although CC seems to reduce such spread
- Hazard evaluated for the best and the worst projection, whose distance give an estimate of uncertainty

Figure 3.4.6 – Synthesis of modelling strategy and result characteristics for the assessment of wave-induced hazard in the North Atlantic Sea

Thermal hazard

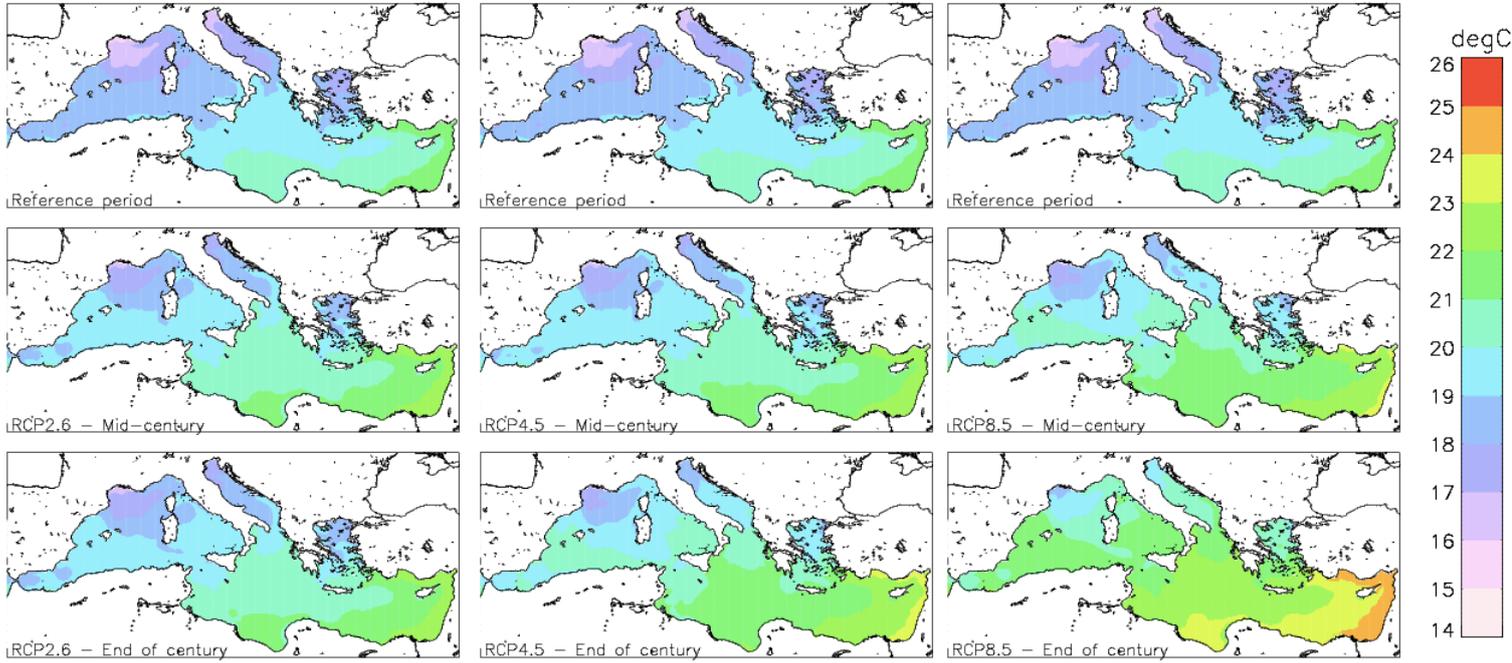


Figure 3.4.7 - Non-normalized hazard from rising mean SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future

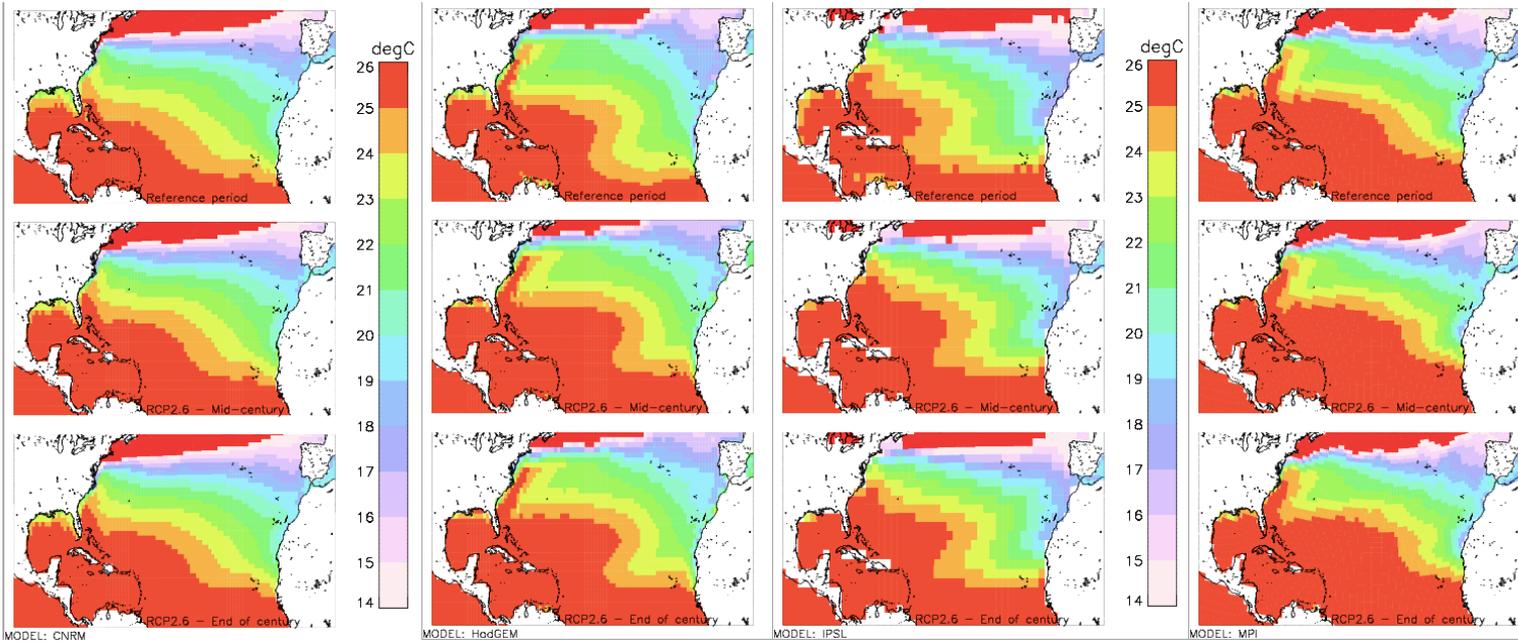


Figure 3.4.8. – RCP2.6 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

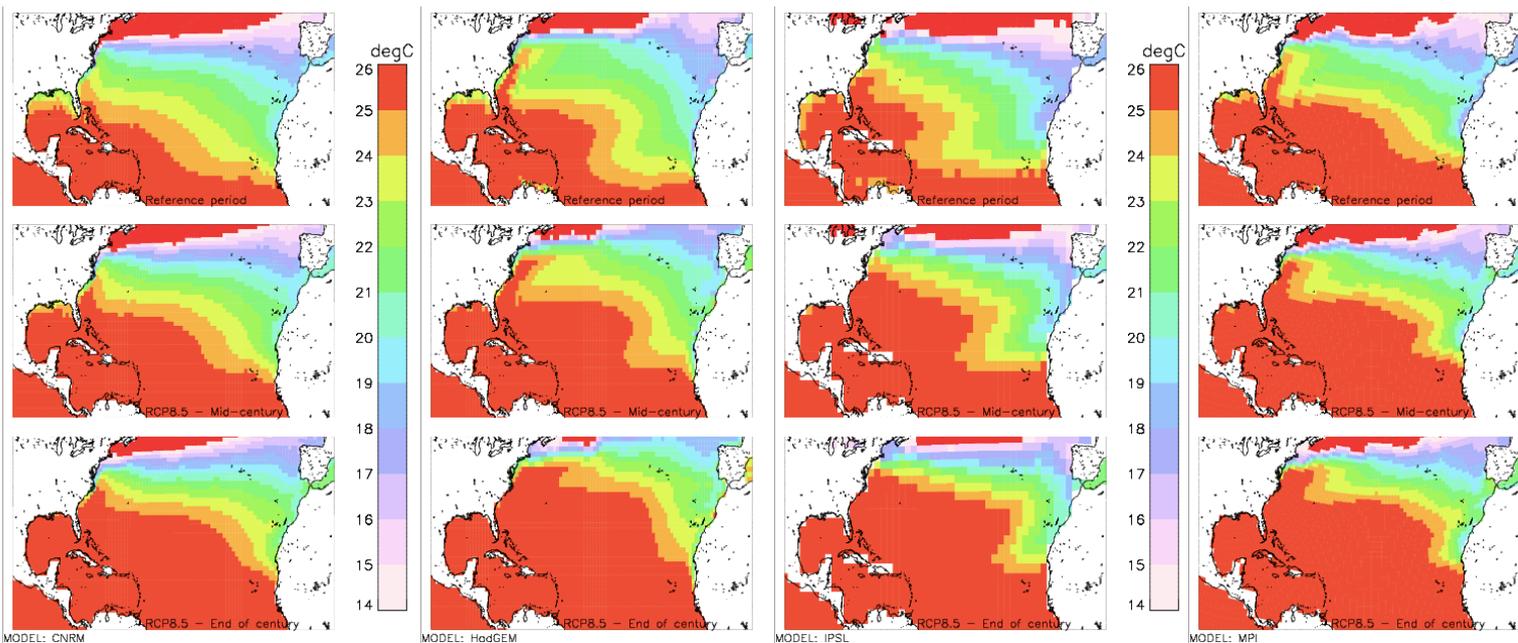


Figure 3.4.9. - RCP8.5 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future



Extreme wave hazard

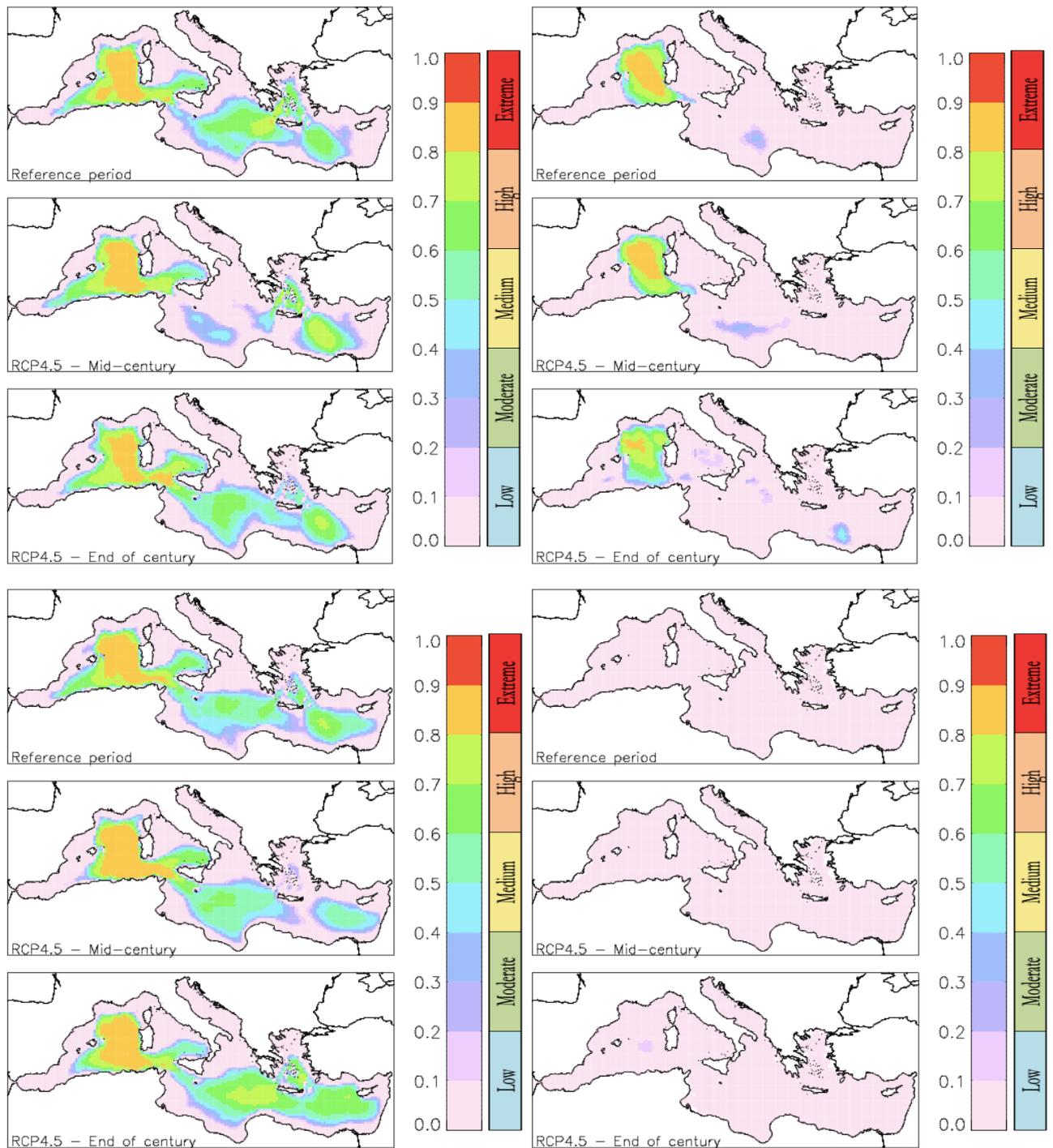


Figure 3.4.10. - RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

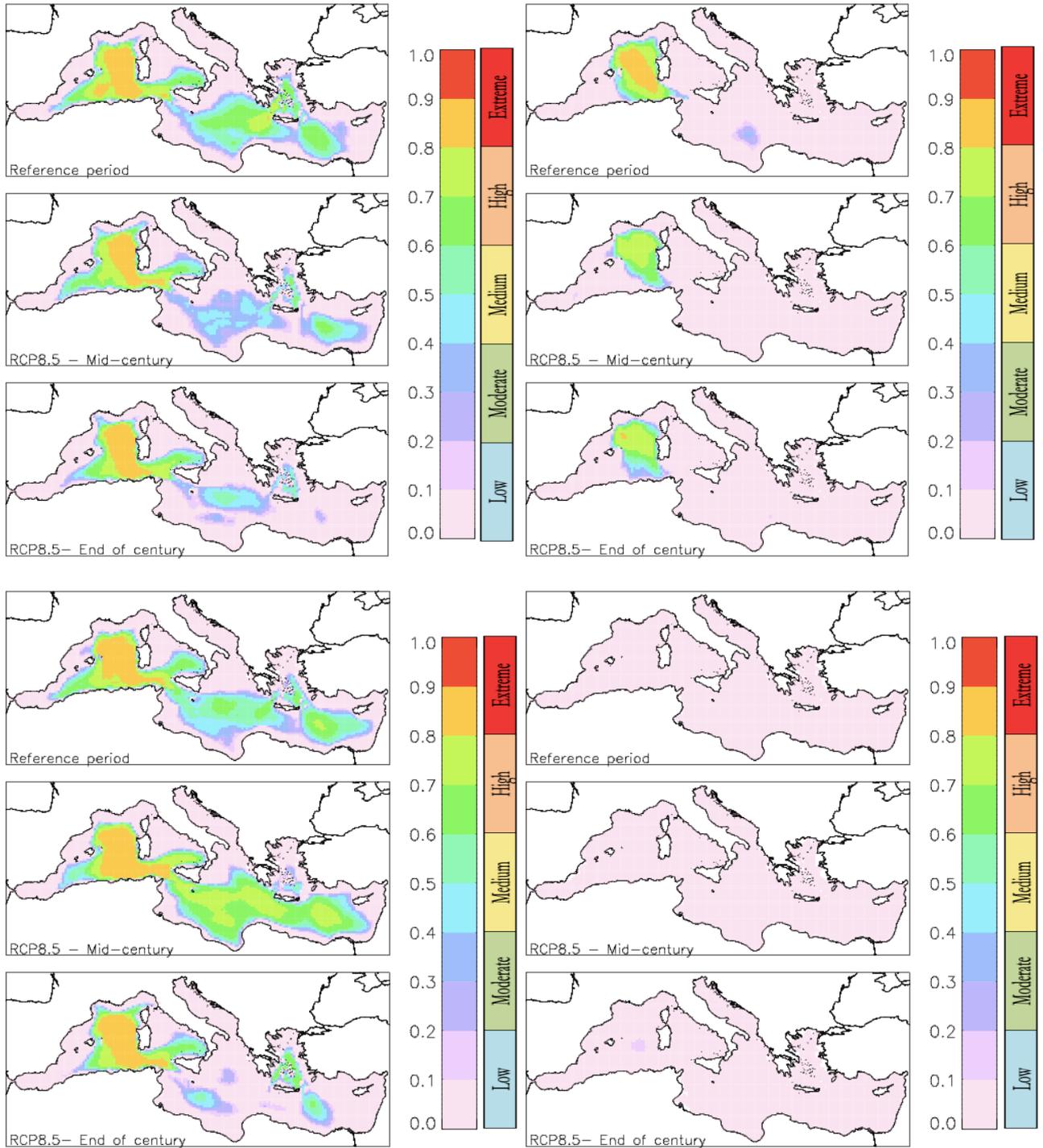


Figure 3.4.11. - RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

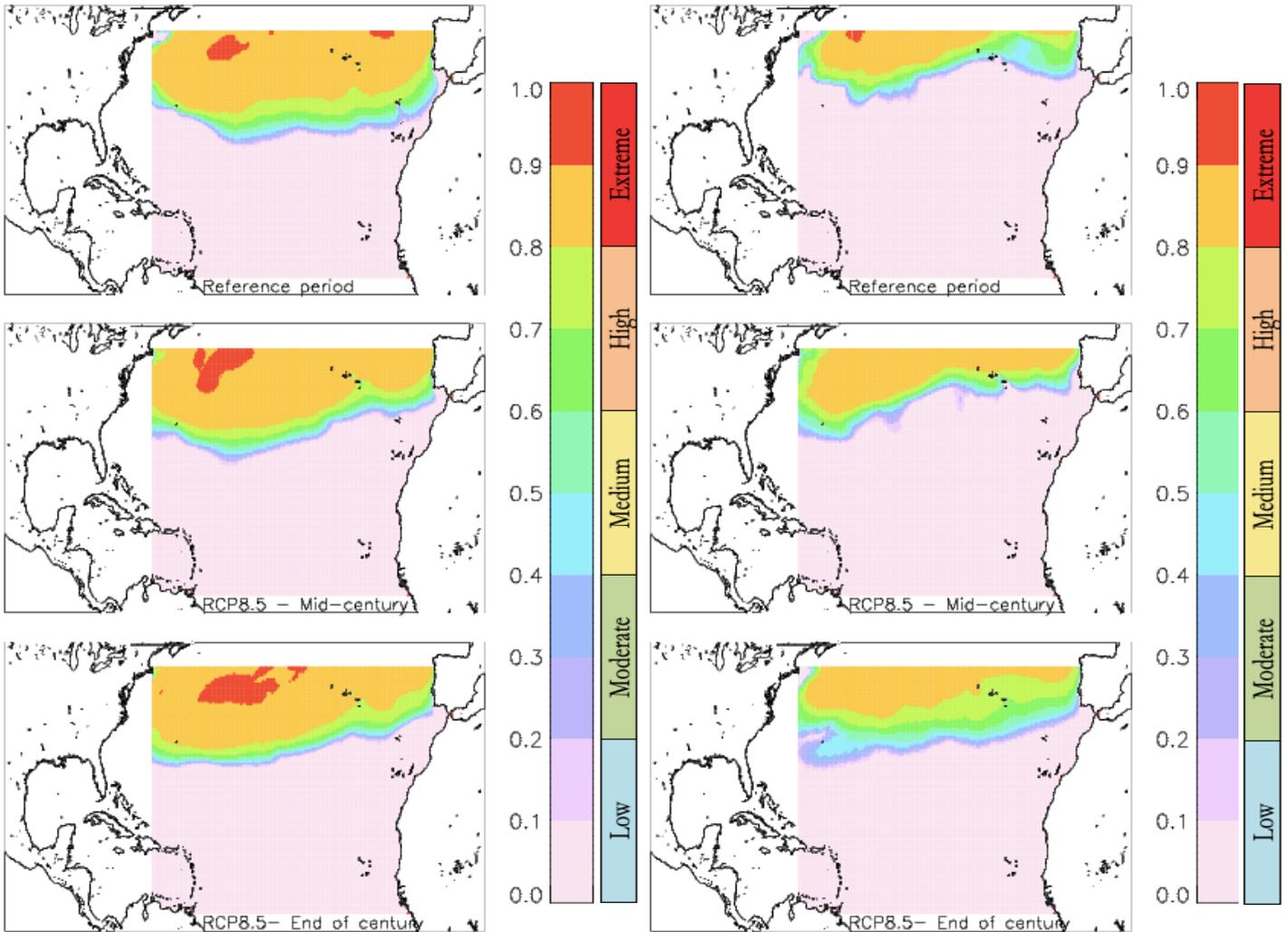


Figure 3.4.12 - RCP8.5 - Normalized hazard from extreme waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



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Mean wave hazard

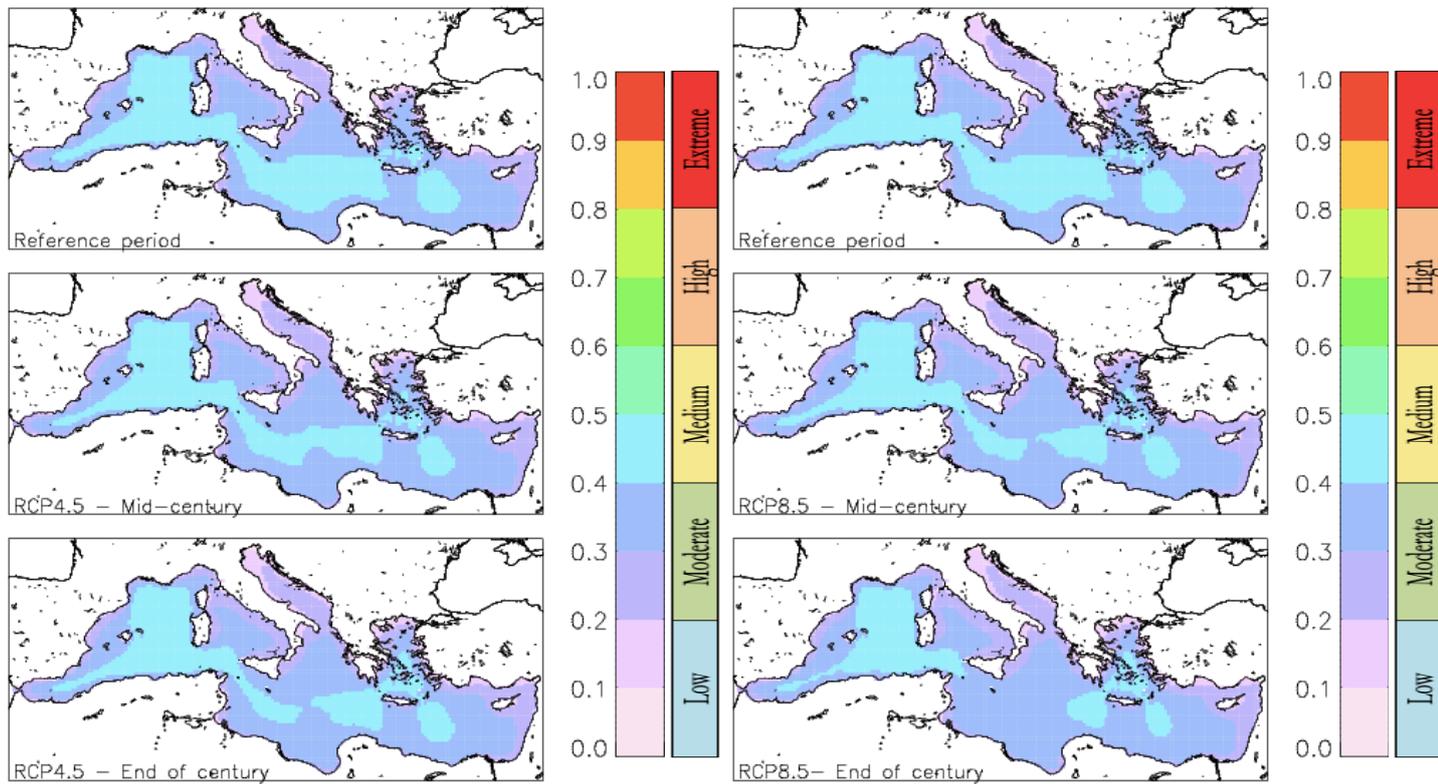


Figure 3.4.13. - Normalized hazard from mean waves – Left: RCP4.5; Right: RCP8.5 - From top to bottom: Reference Period; Mid-century; End of century

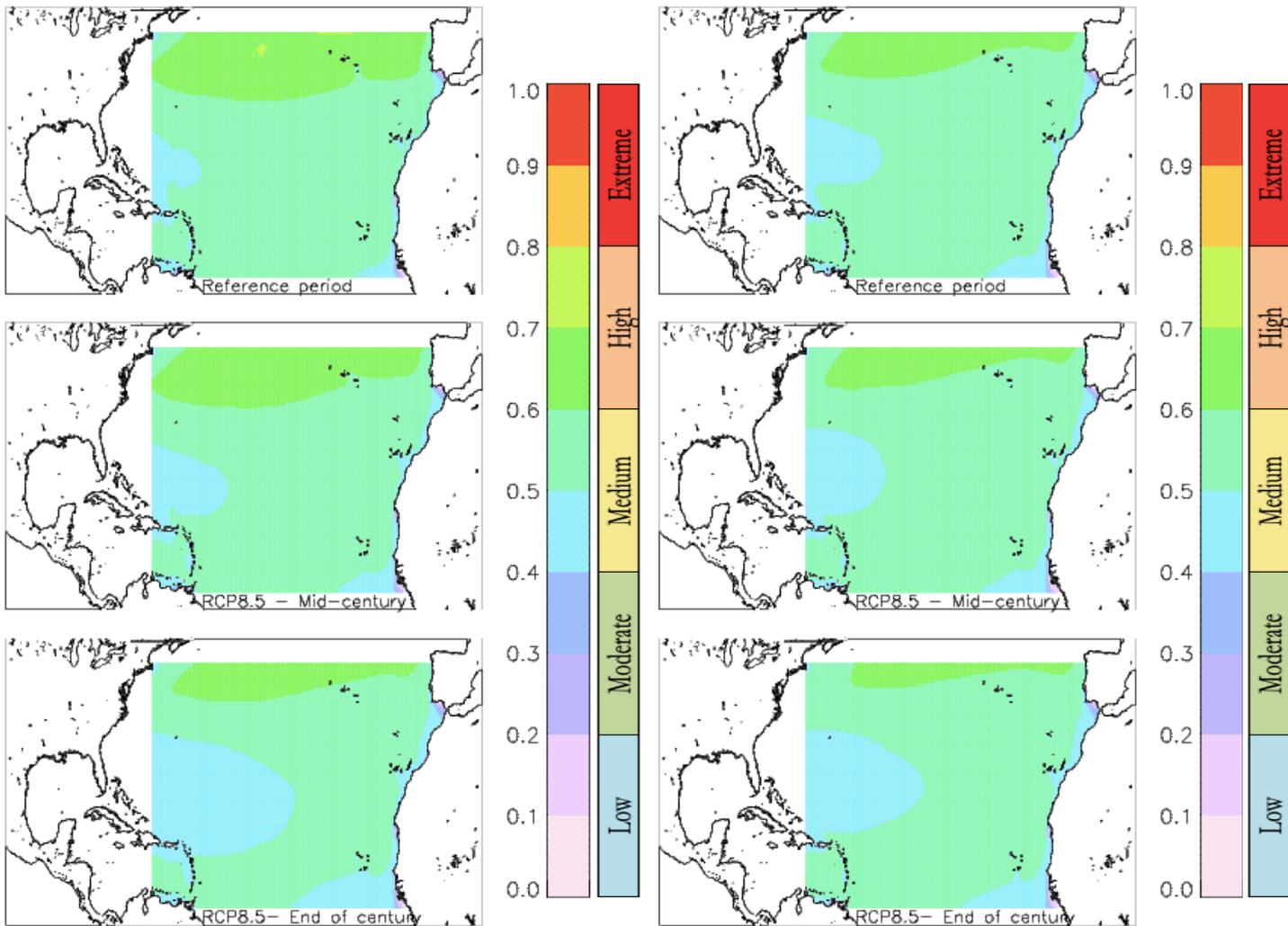


Figure 3.4.14 - RCP8.5 - Normalized hazard from mean waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



Atlas of mean SST maps and normalized wave-induced hazards

Azores

Thermal hazard

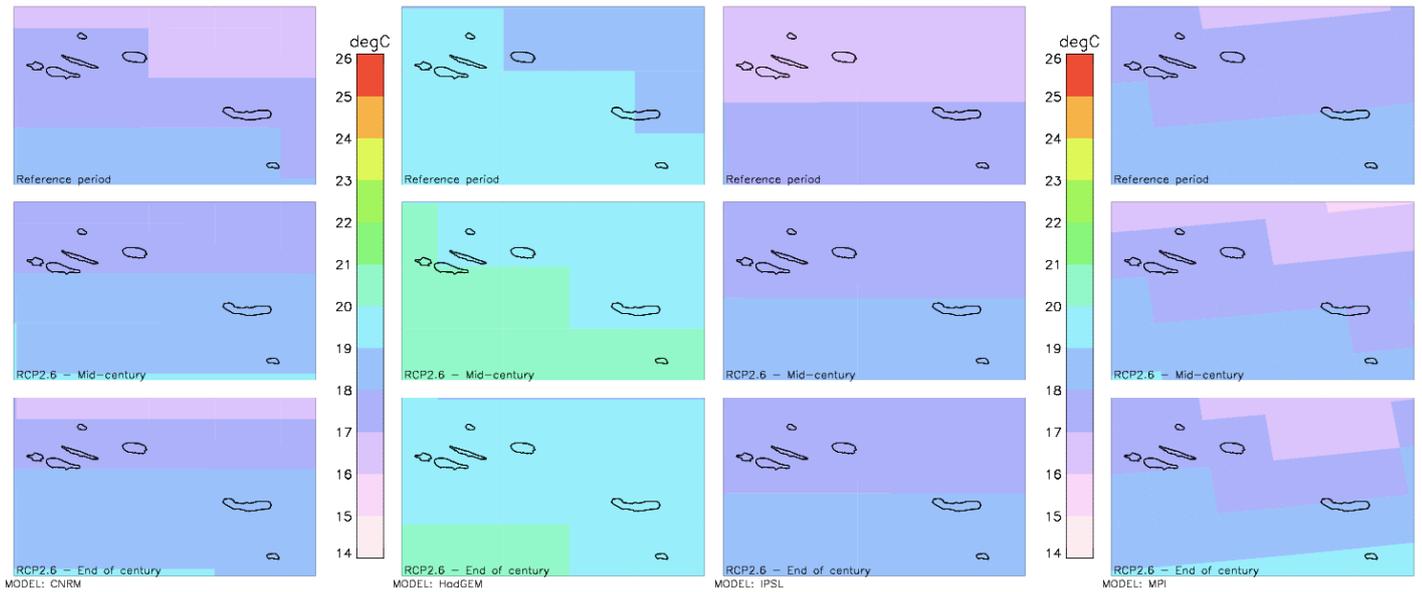


Figure 3.4.15 – RCP2.6 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

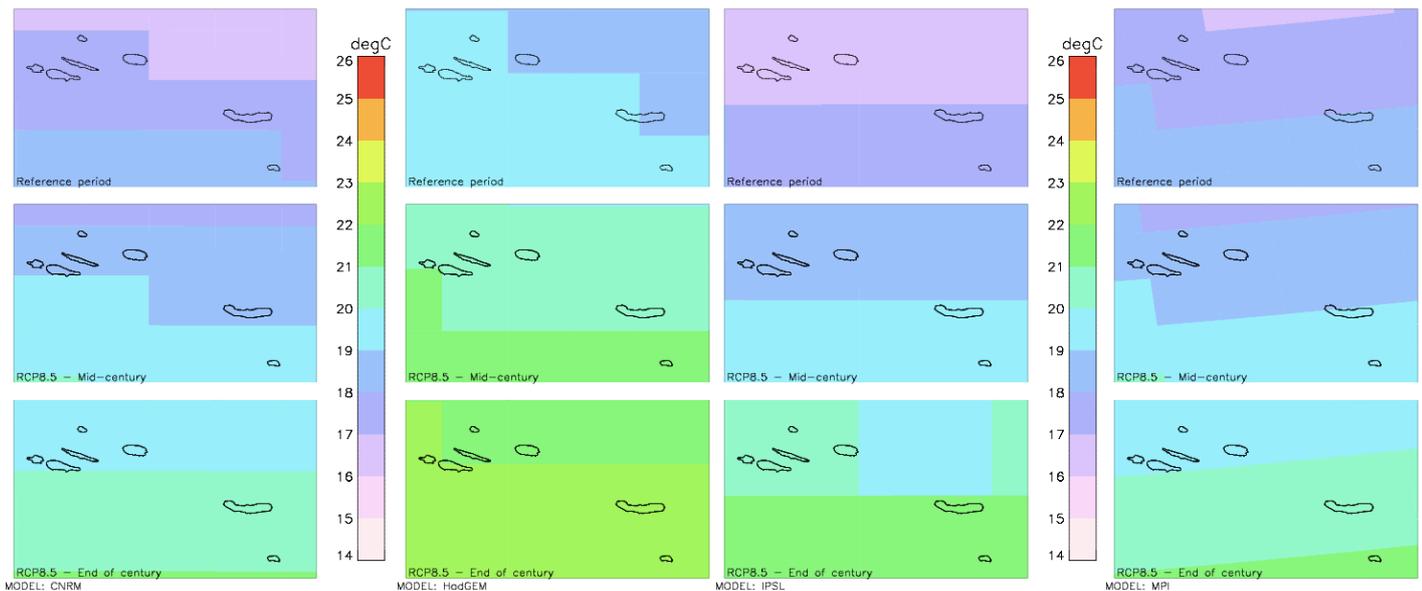


Figure 3.4.16 - RCP8.5 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

Extreme wave hazard

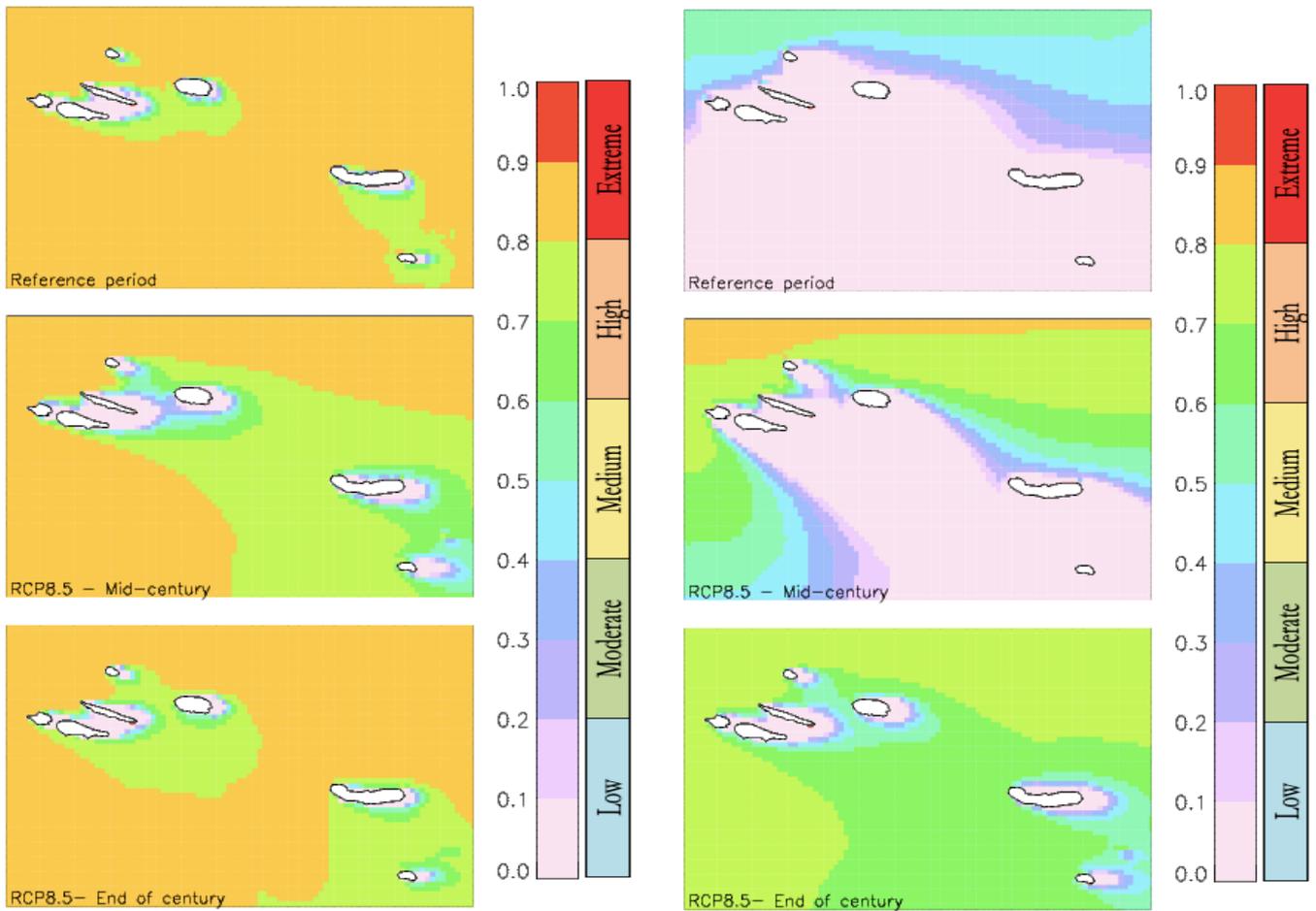


Figure 3.4.17 - RCP8.5 - Normalized hazard from extreme waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



Mean wave hazard

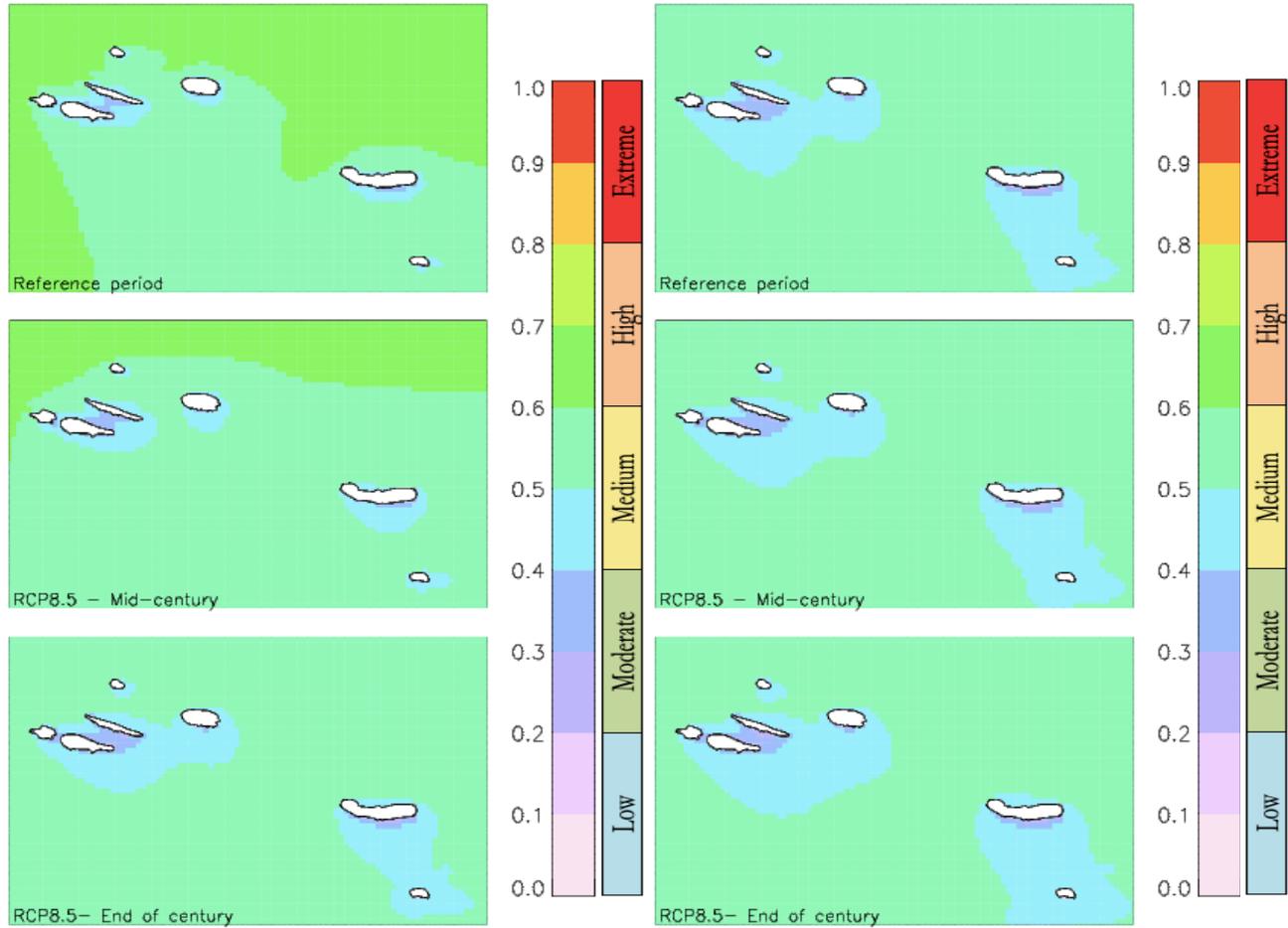


Figure 3.4.18 - RCP8.5 - Normalized hazard from mean waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



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Balearic Islands

Thermal hazard

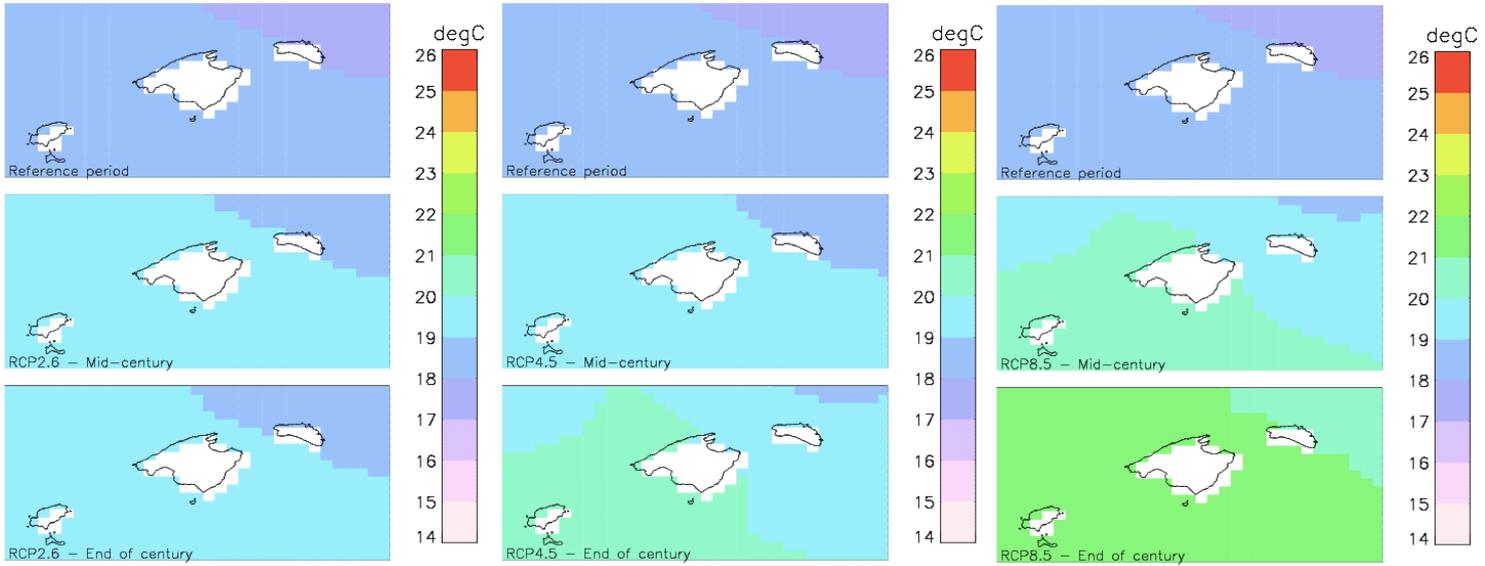


Figure 3.4.19 - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future



Extreme wave hazard

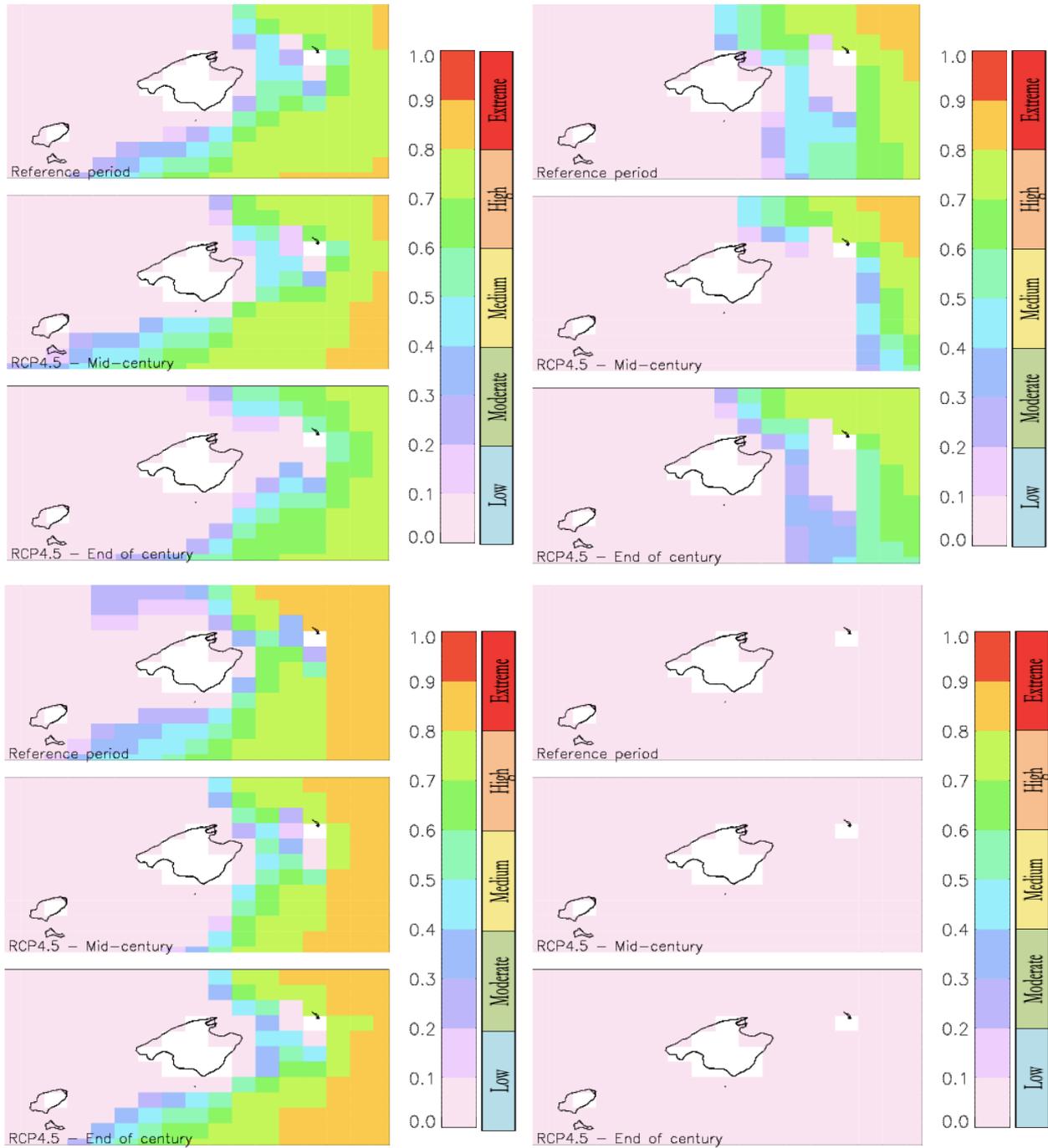


Figure 3.4.20. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

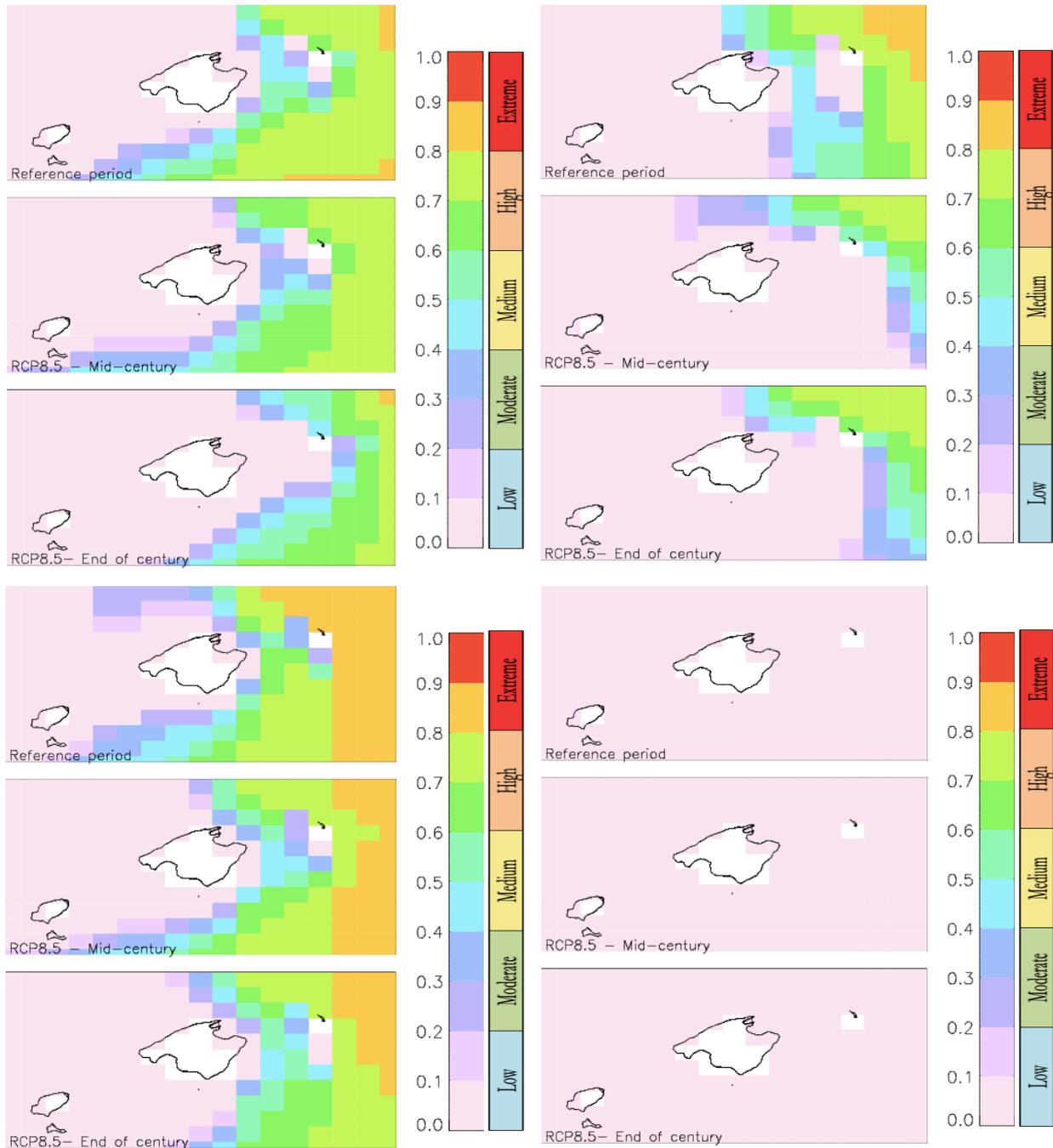


Figure 3.4.21. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD



Mean wave hazard

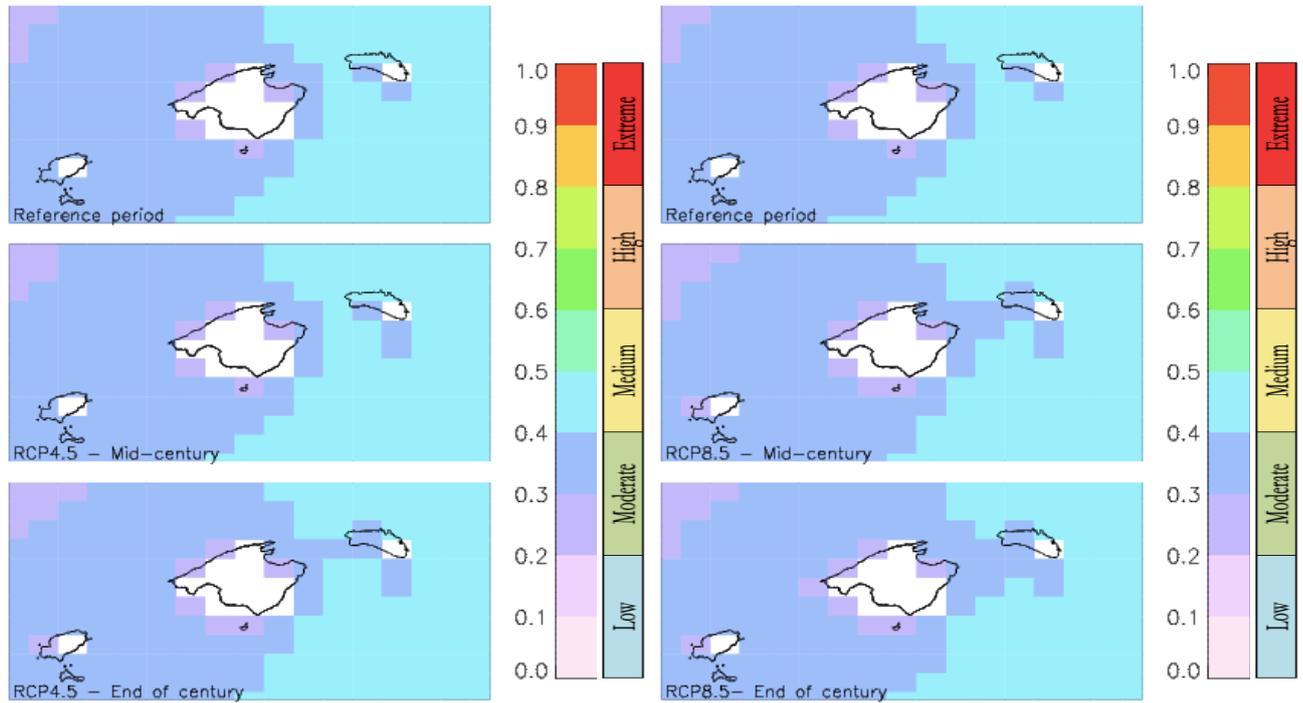


Figure 3.4.22 - Normalized hazard from mean waves - Left: **RCP4.5**; Right: **RCP8.5**; from top to bottom: reference period, near future, far future

Canaries

Thermal hazard

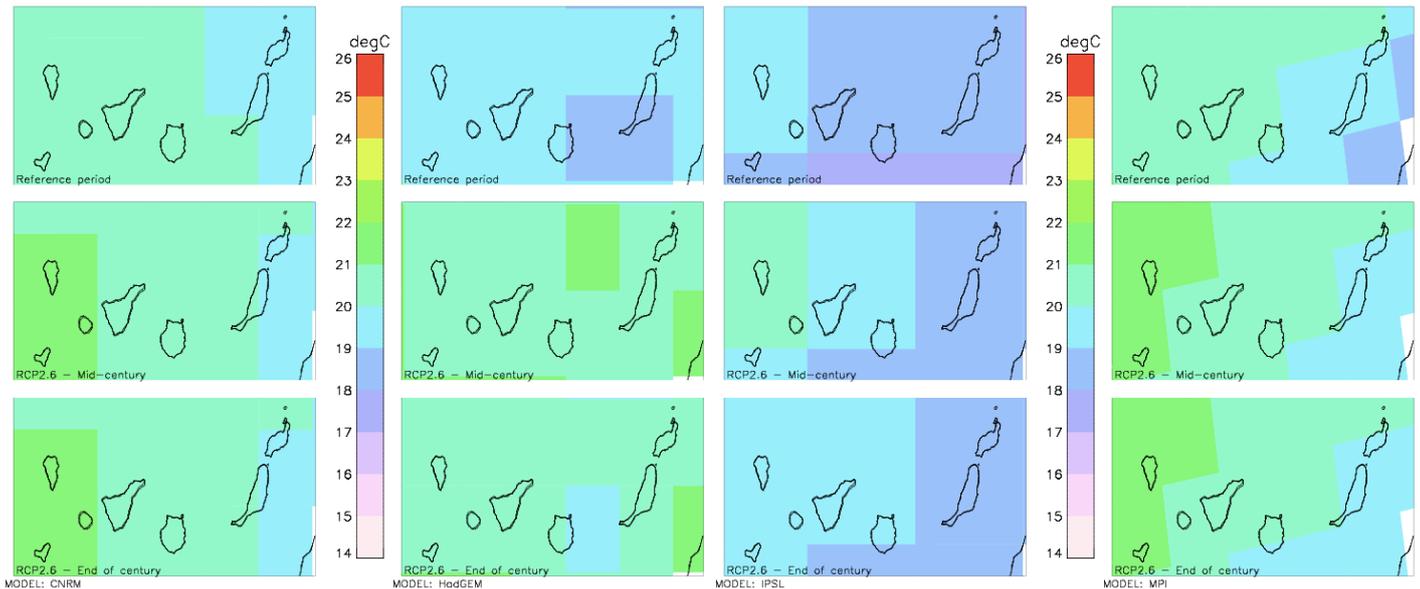


Figure 3.4.23 – RCP2.6 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

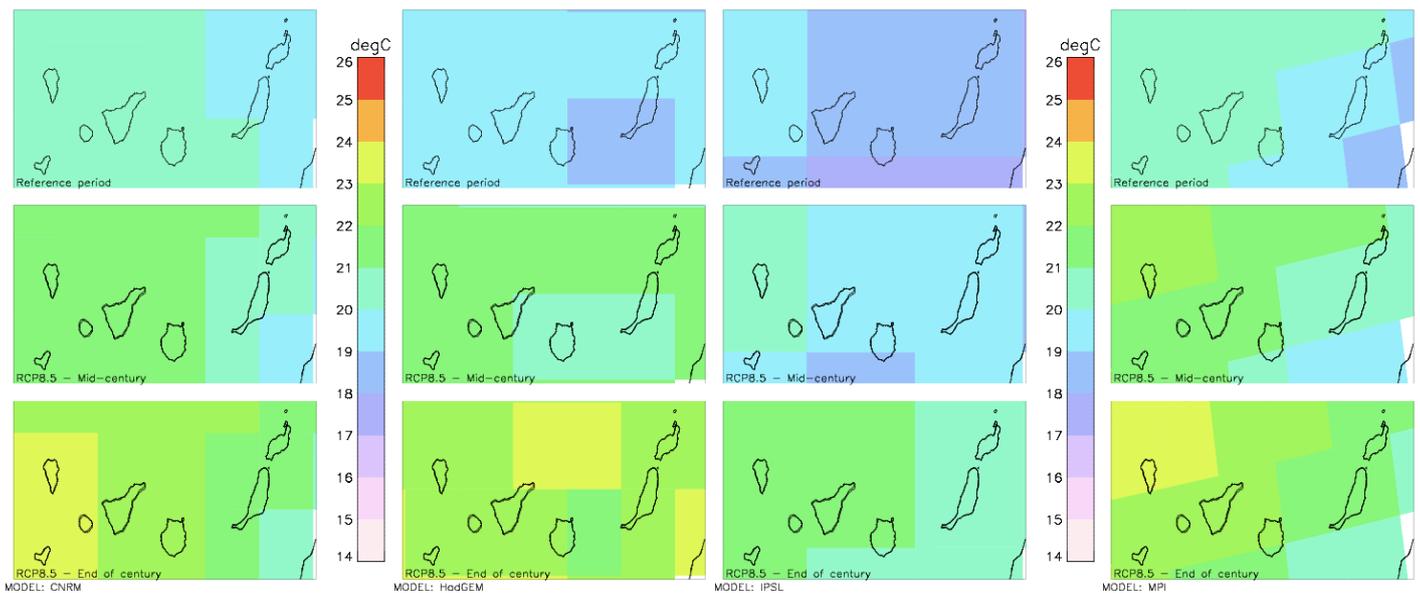


Figure 3.4.24 – RCP8.5 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future



Extreme wave hazard

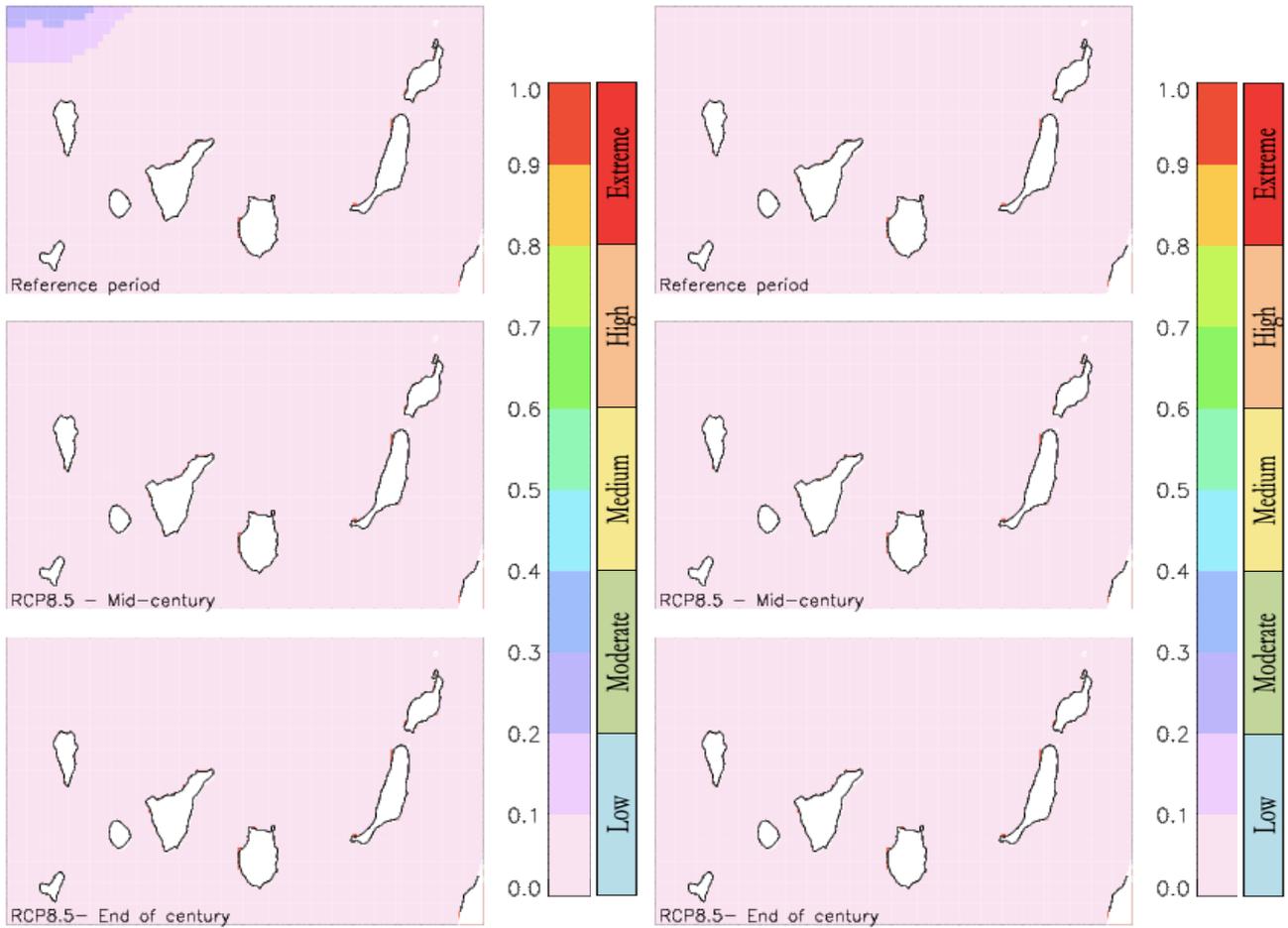


Figure 3.4.25 - RCP8.5 - Normalized hazard from extreme waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



Mean wave hazard

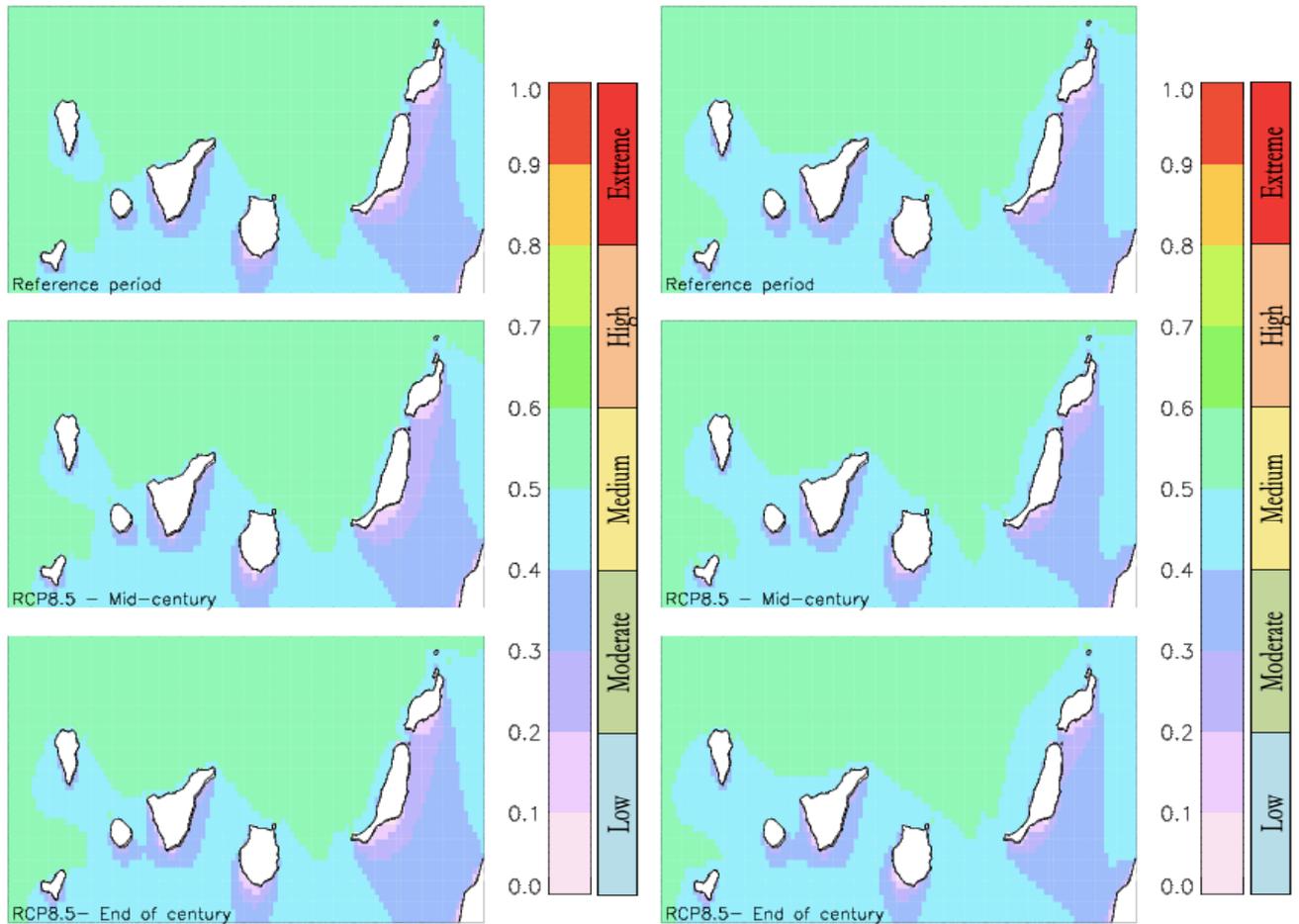


Figure 3.4.26 - RCP8.5 - Normalized hazard from mean waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



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Corsica

Thermal hazard

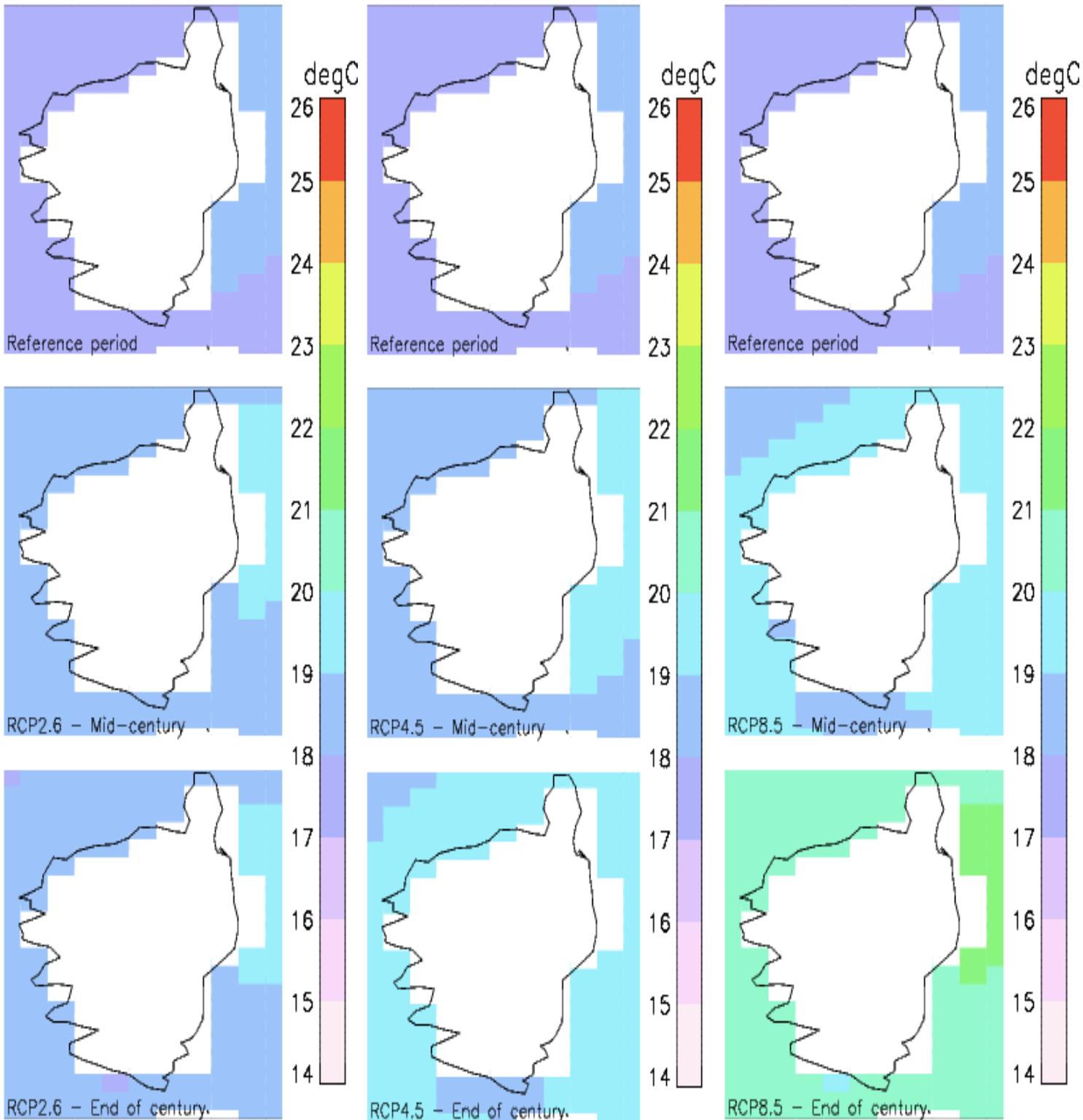


Figure 3.4.27 - Non-normalized hazard from rising SST- From left to right: RCP2.6, RCP4.5, RCP8.5; from top to bottom: reference period, near future, far future

Extreme wave hazard



Figure 3.4.28. RCP4.5 - Normalized risk from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

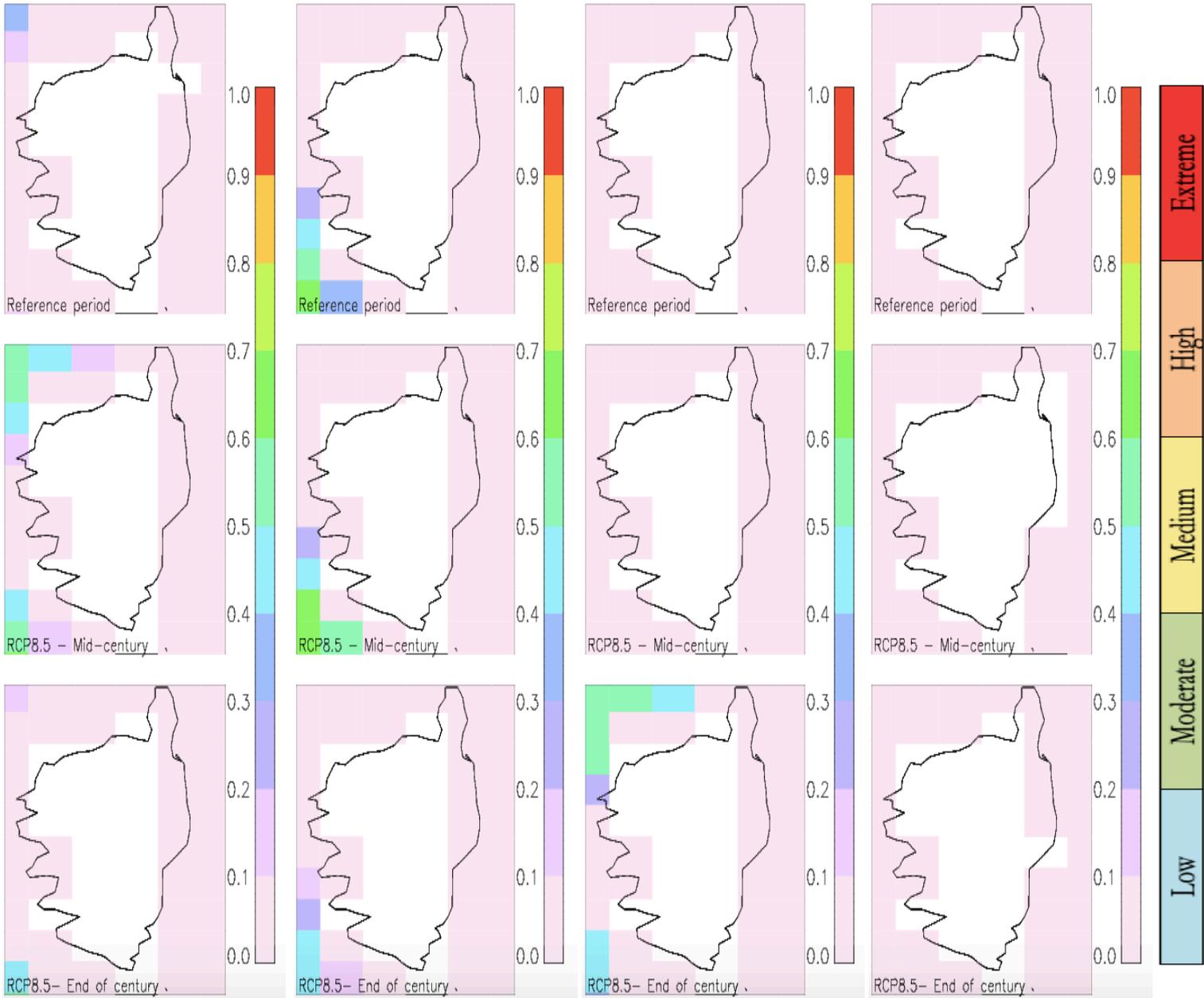


Figure 3.4.29. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD



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Mean wave hazard

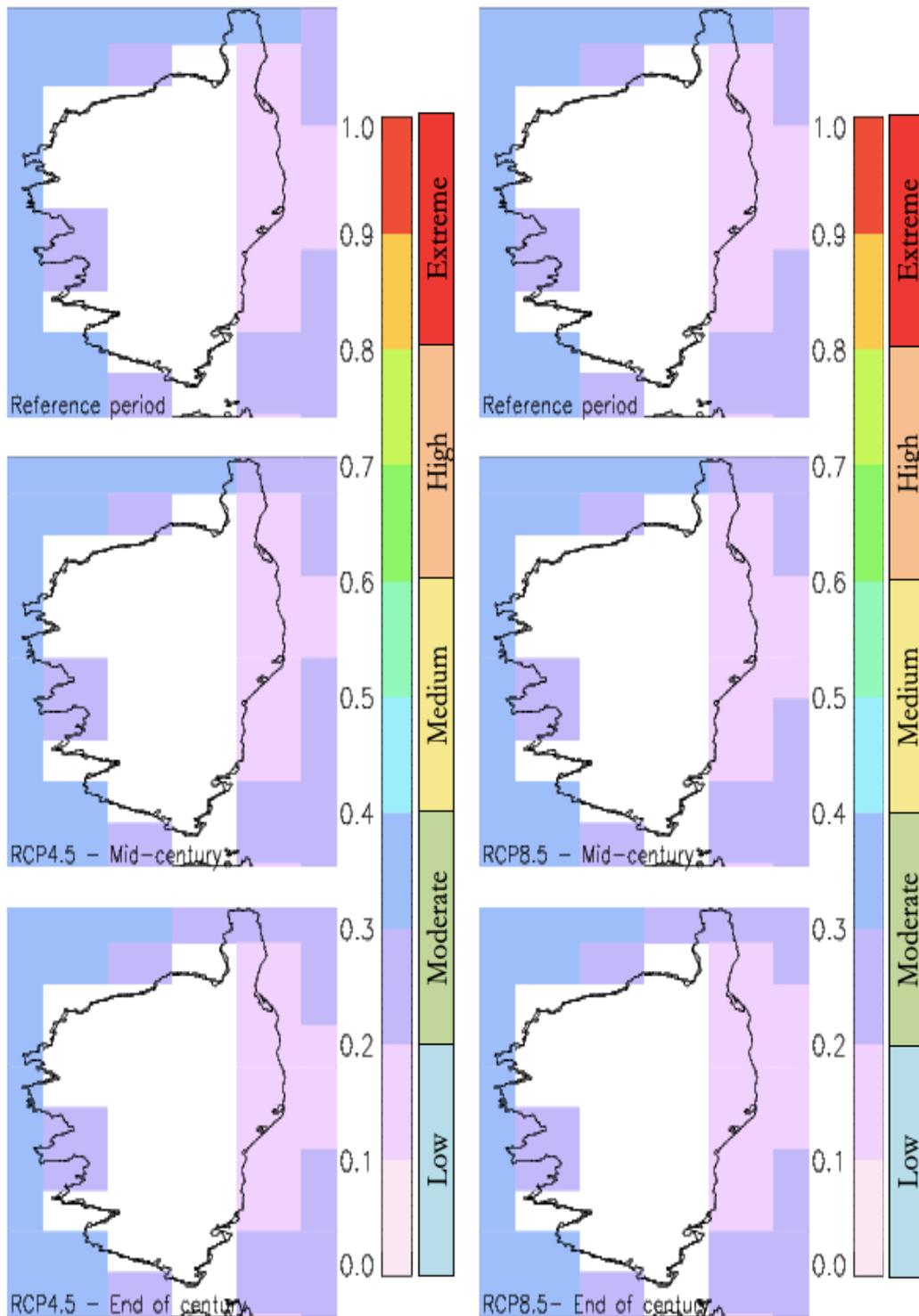


Figure 3.4.30 - Normalized hazard from mean waves - Left: **RCP4.5**; Right: **RCP8.5**; from top to bottom: reference period, near future, far future

Crete

Thermal hazard

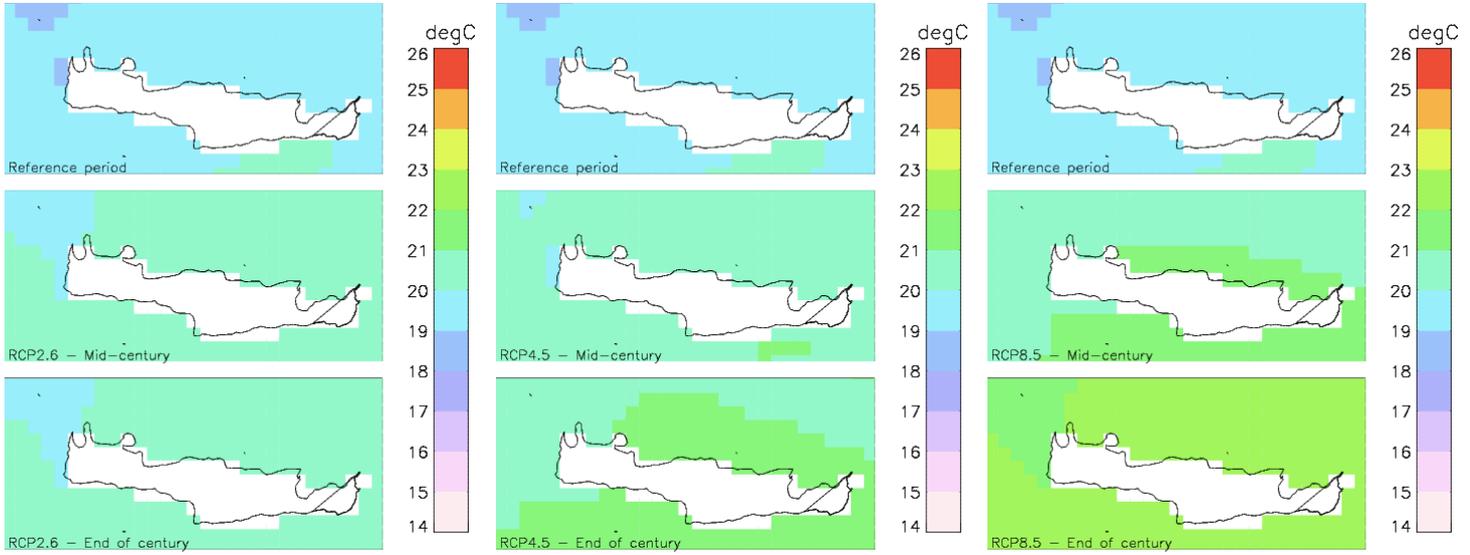


Figure 3.4.31 - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future



Extreme wave hazard

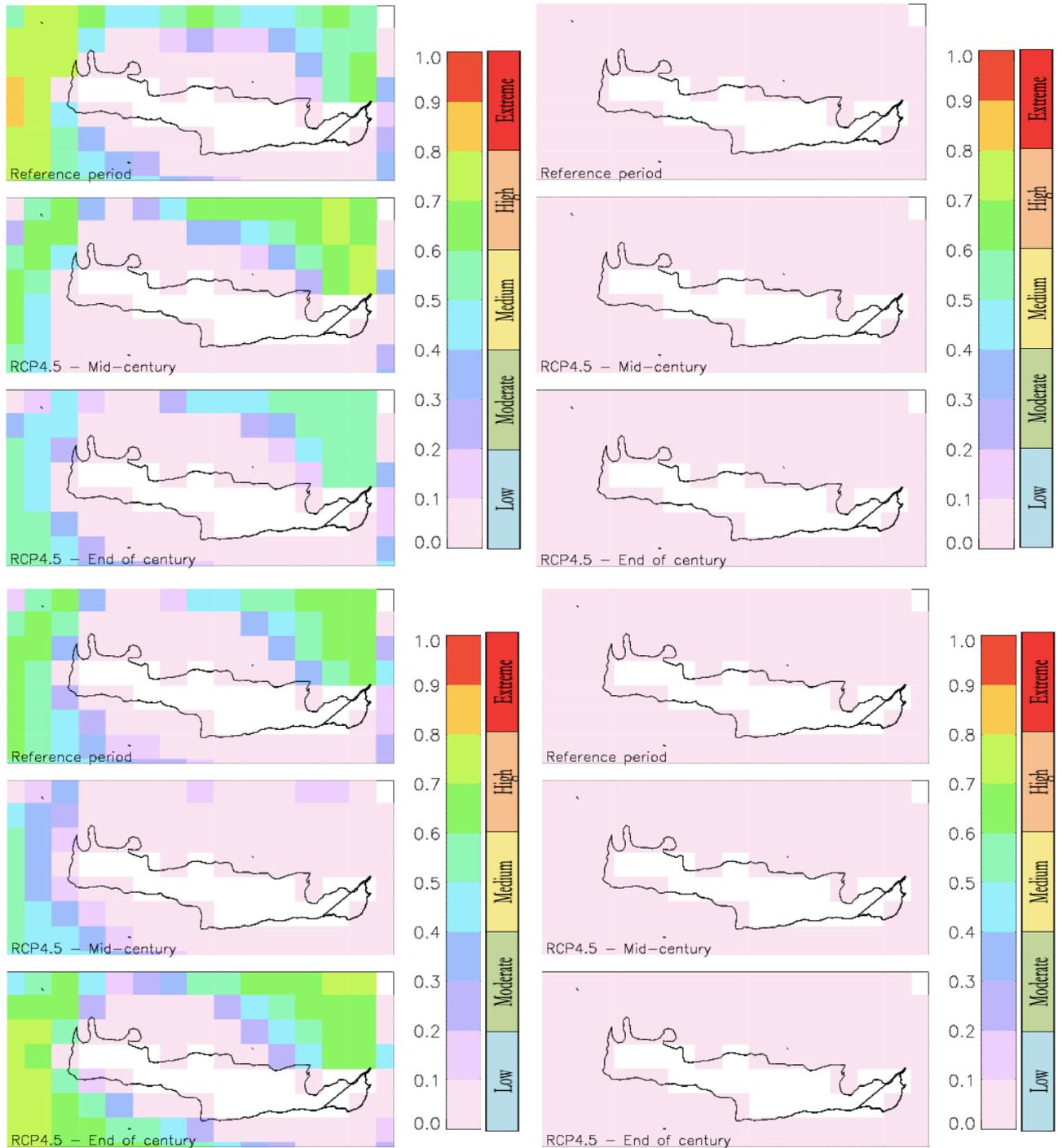


Figure 3.4.32. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

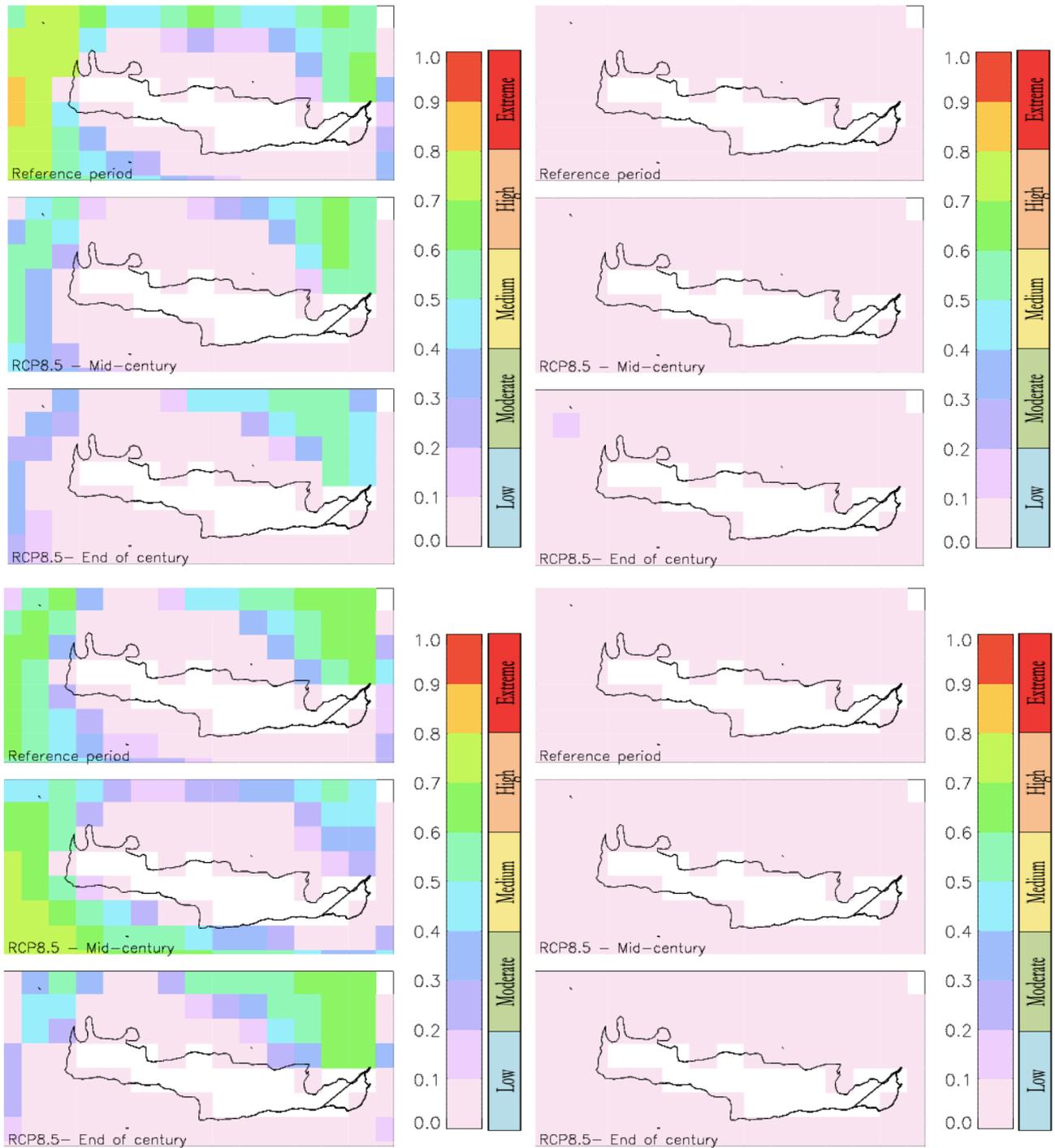


Figure 3.4.33. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD



Mean wave hazard

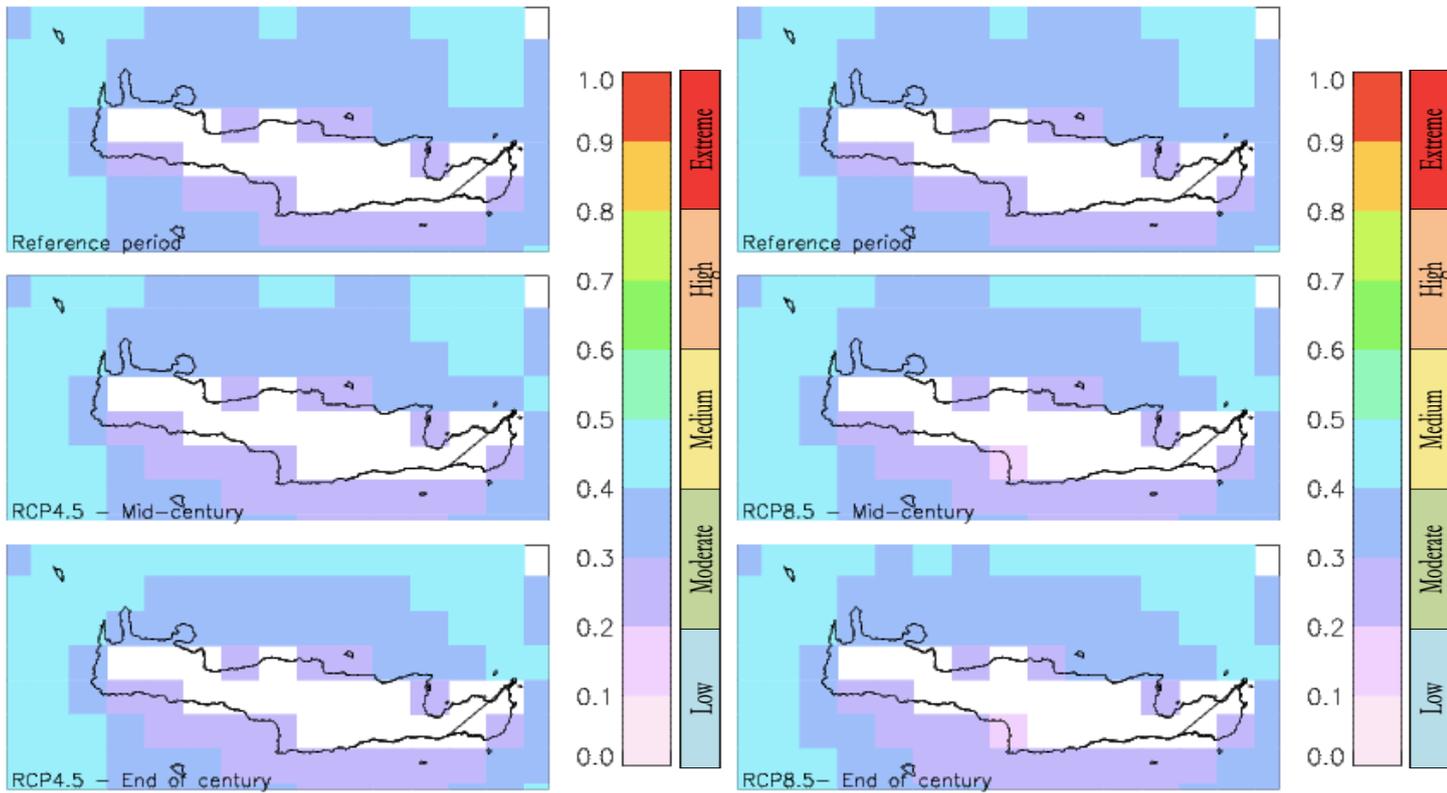


Figure 3.4.34 - Normalized hazard from mean waves - Left: RCP4.5; Right: RCP8.5; from top to bottom: reference period, near future, far future

Cyprus

Thermal hazard

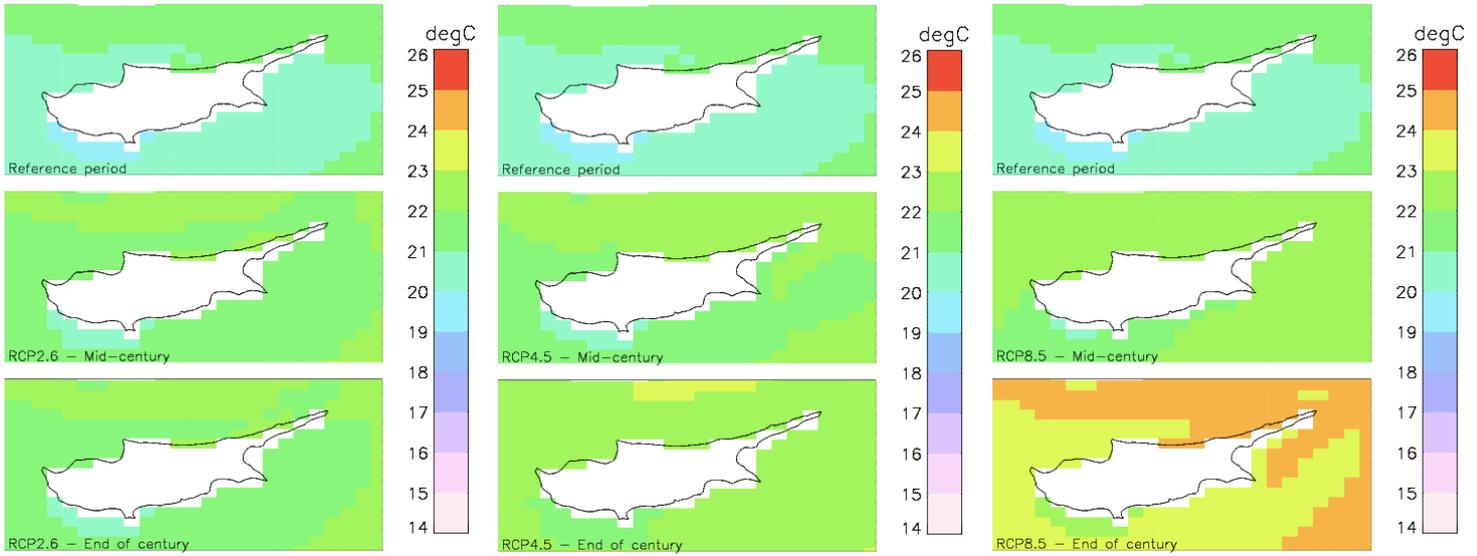


Figure 3.4.35 - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future



Extreme wave hazard

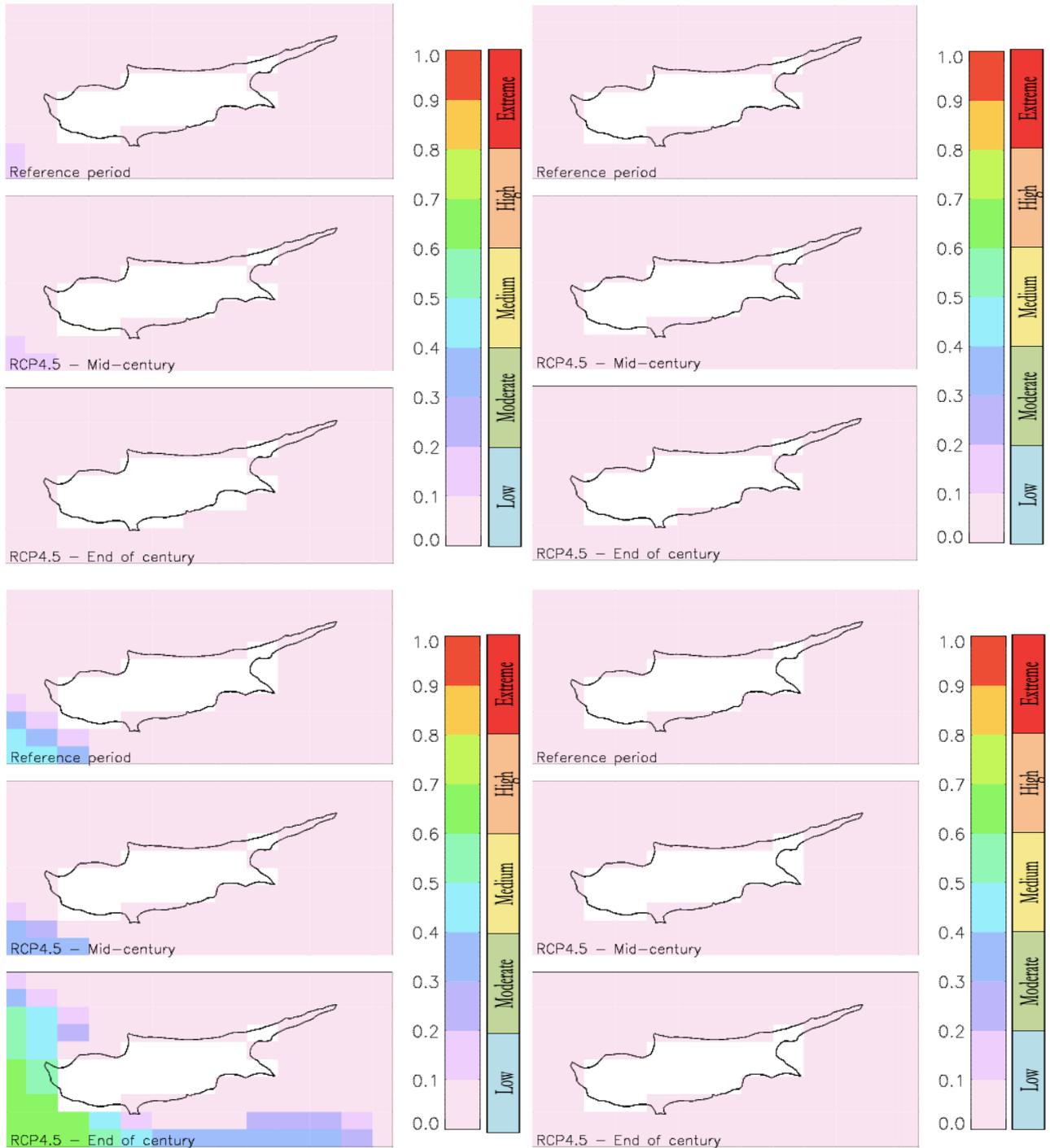


Figure 3.4.36. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

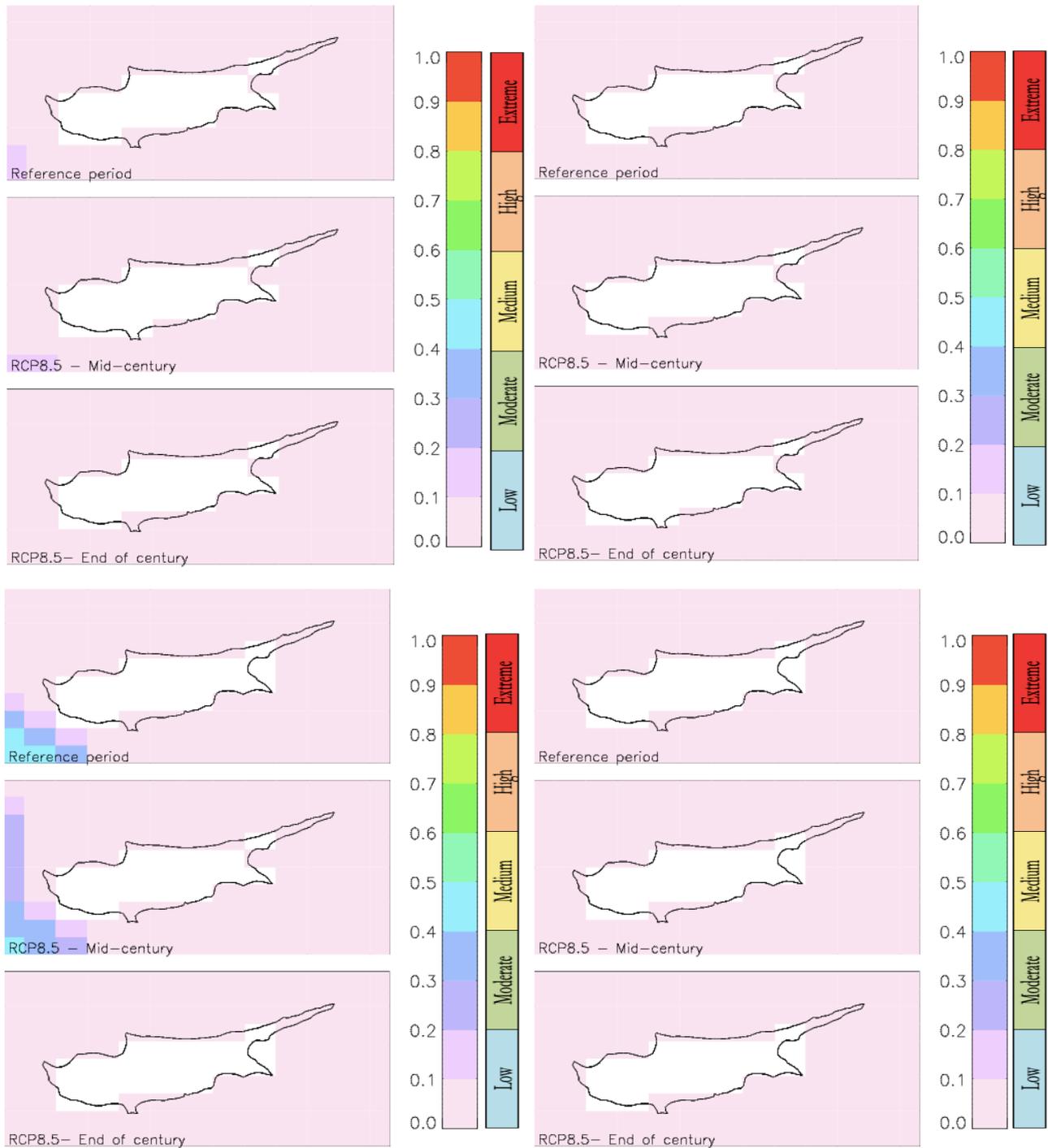


Figure 3.4.37. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

Mean wave hazard

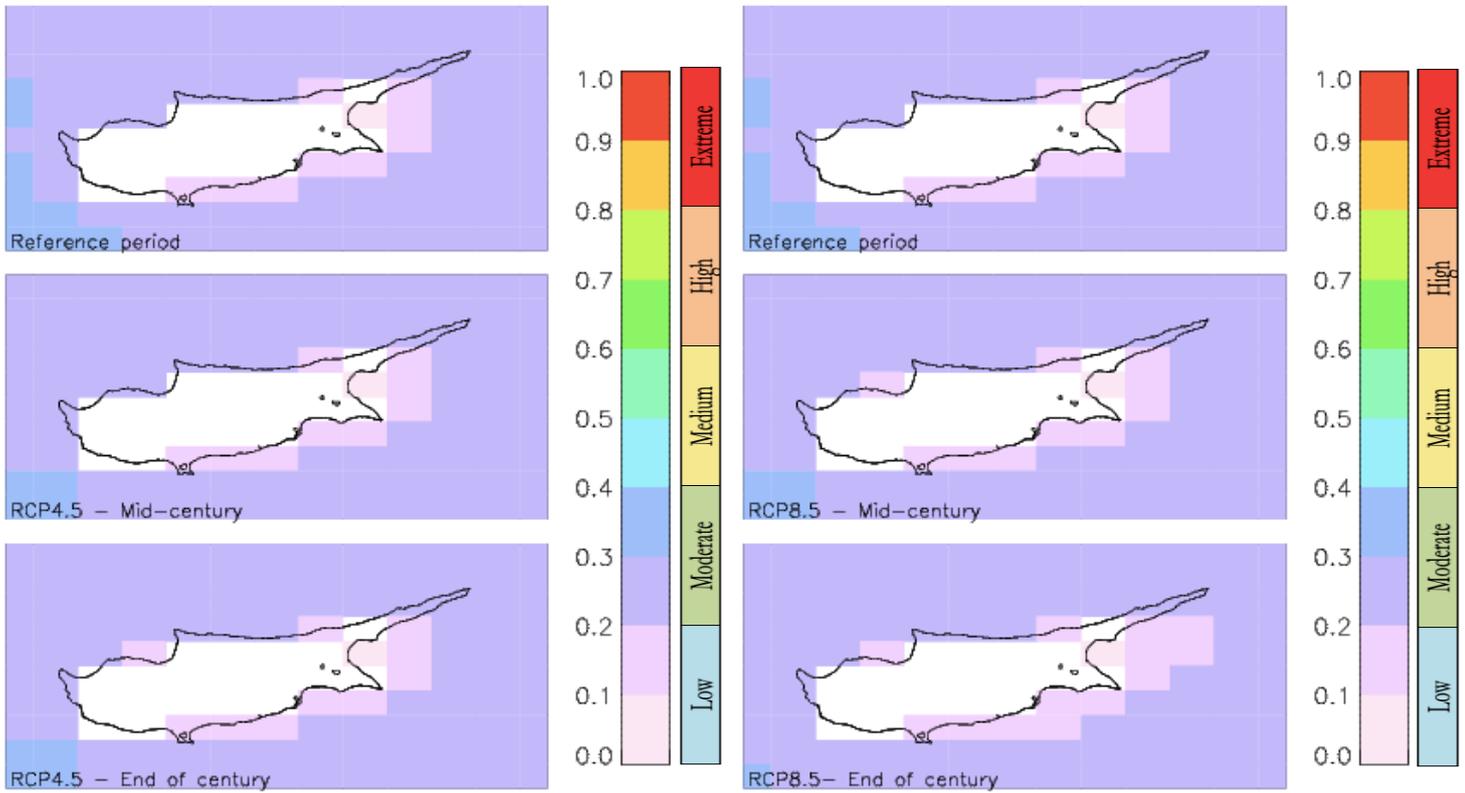


Figure 3.4.38 - Normalized hazard from mean waves - Left: **RCP4.5**; Right: **RCP8.5**; from top to bottom: reference period, near future, far future



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Madeira

Thermal hazard

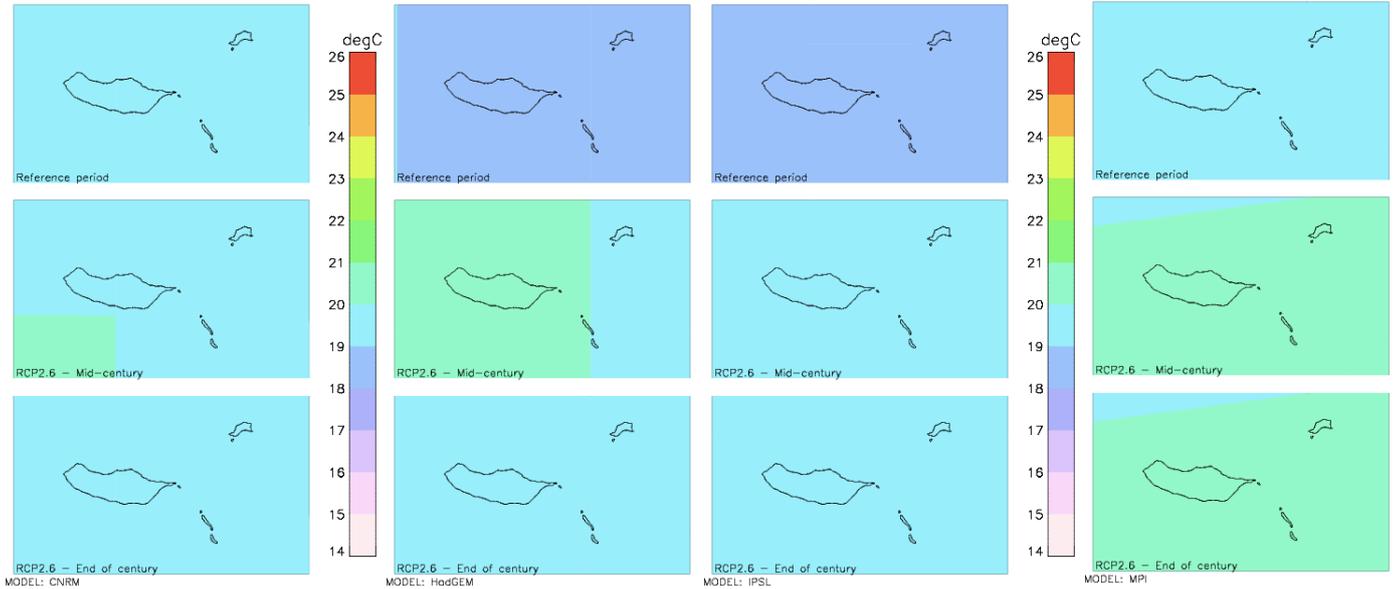


Figure 3.4.39 – RCP2.6 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

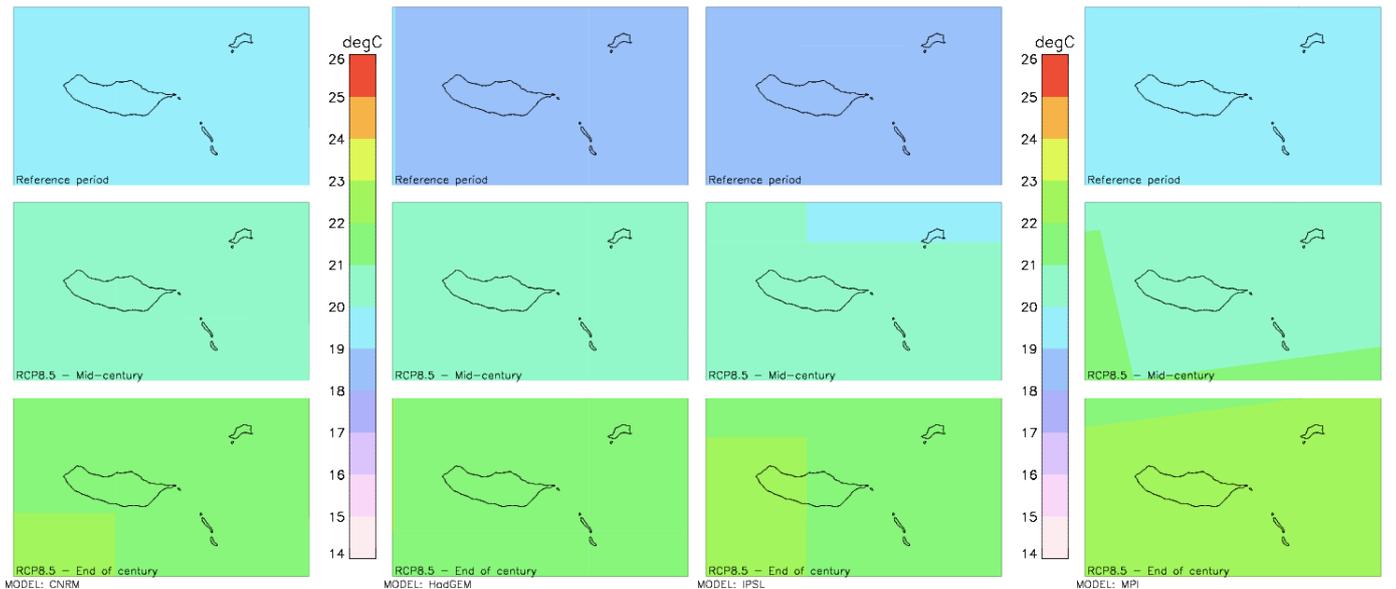


Figure 3.4.40 – RCP8.5 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

Extreme wave hazard

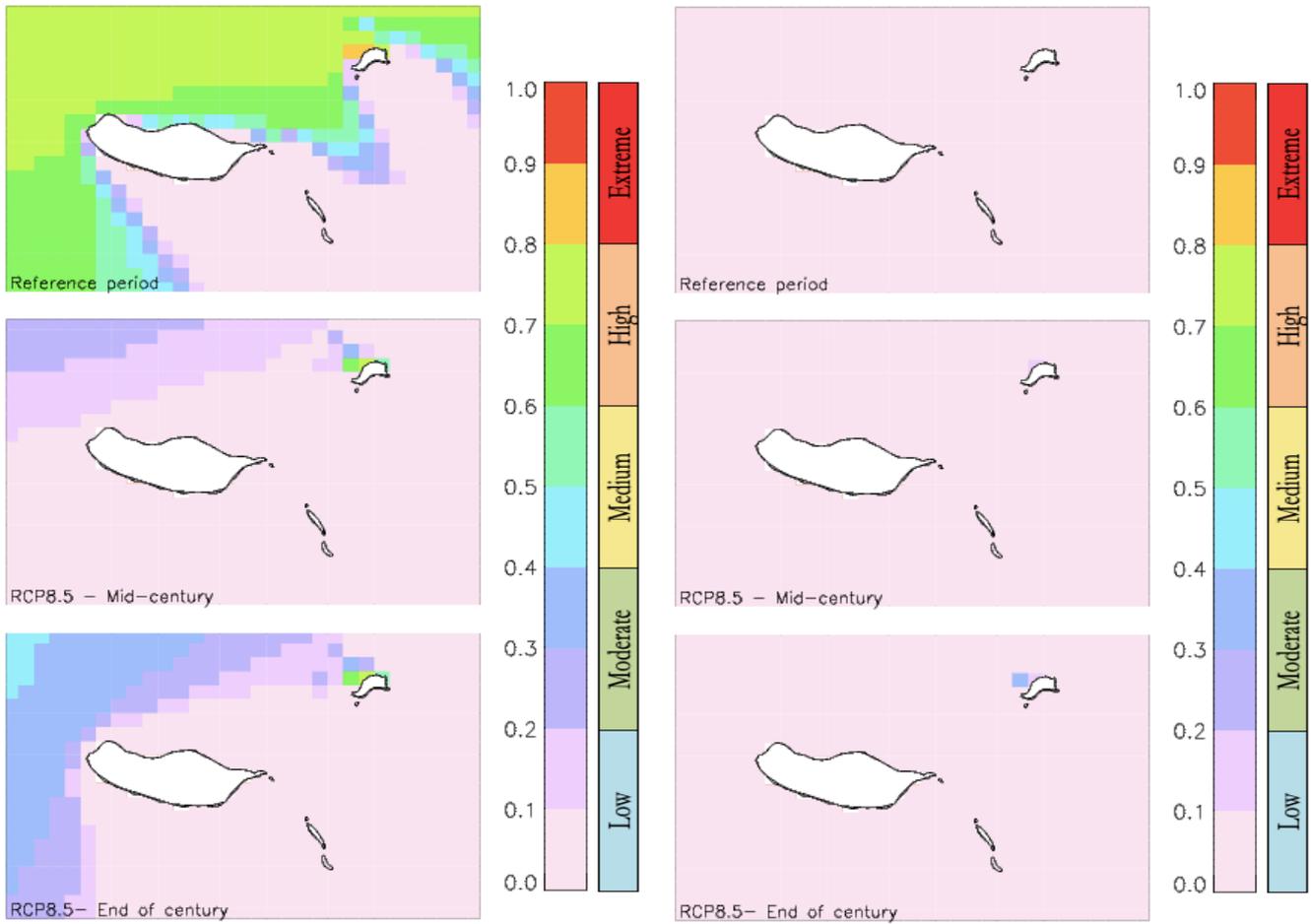


Figure 3.4.41 - RCP8.5 - Normalized hazard from extreme waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future

Mean wave hazard

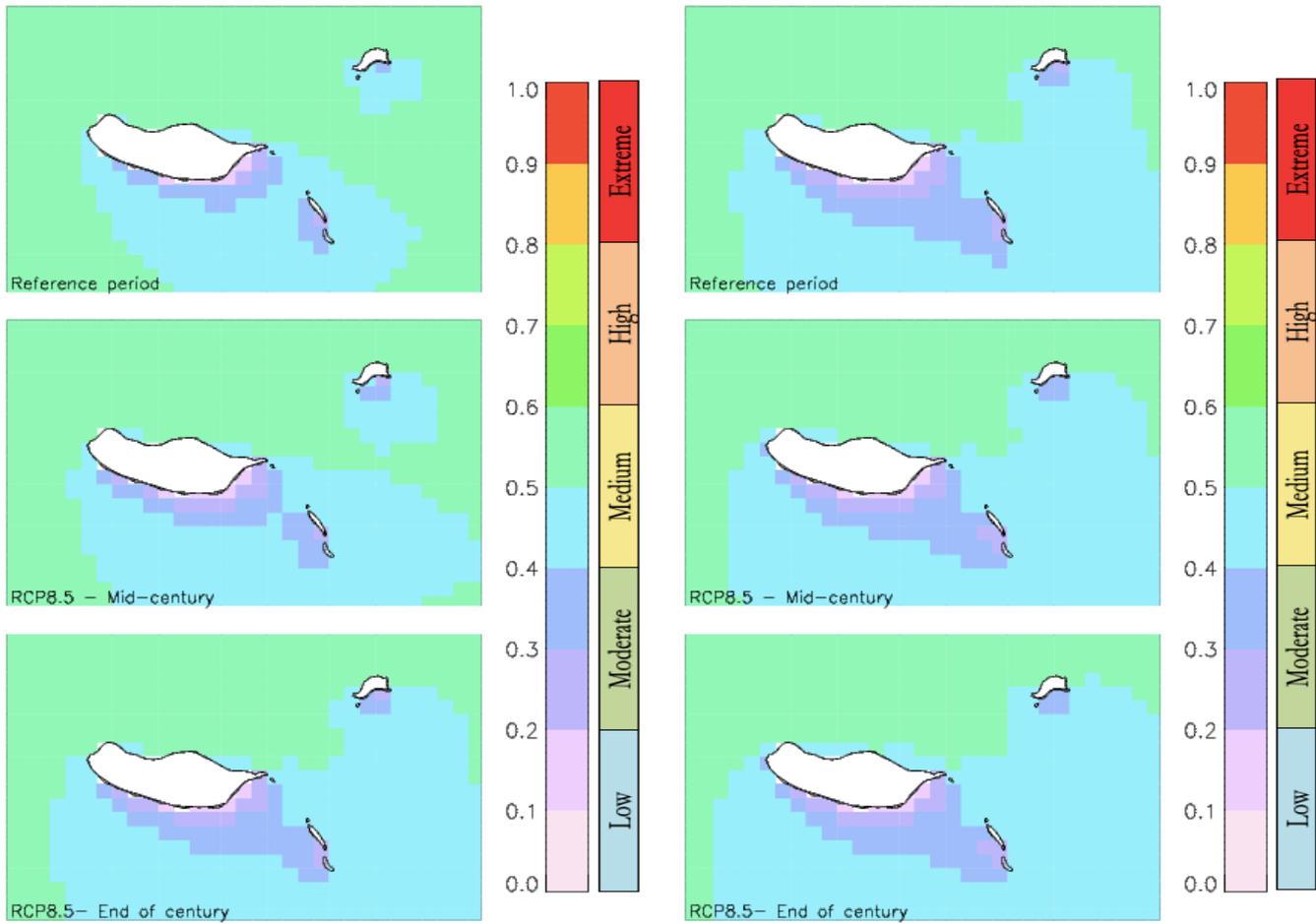


Figure 3.4.42 - RCP8.5 - Normalized hazard from mean waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future

Malta

Thermal hazard

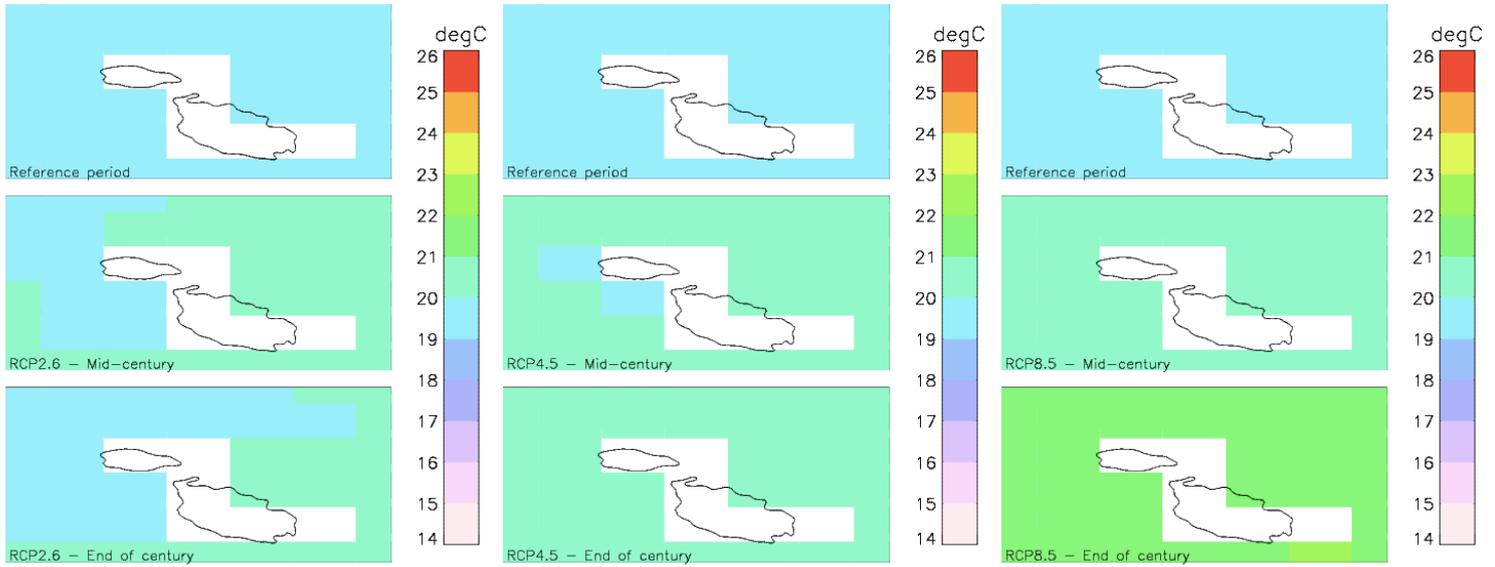


Figure 3.4.43 - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future



Extreme wave hazard

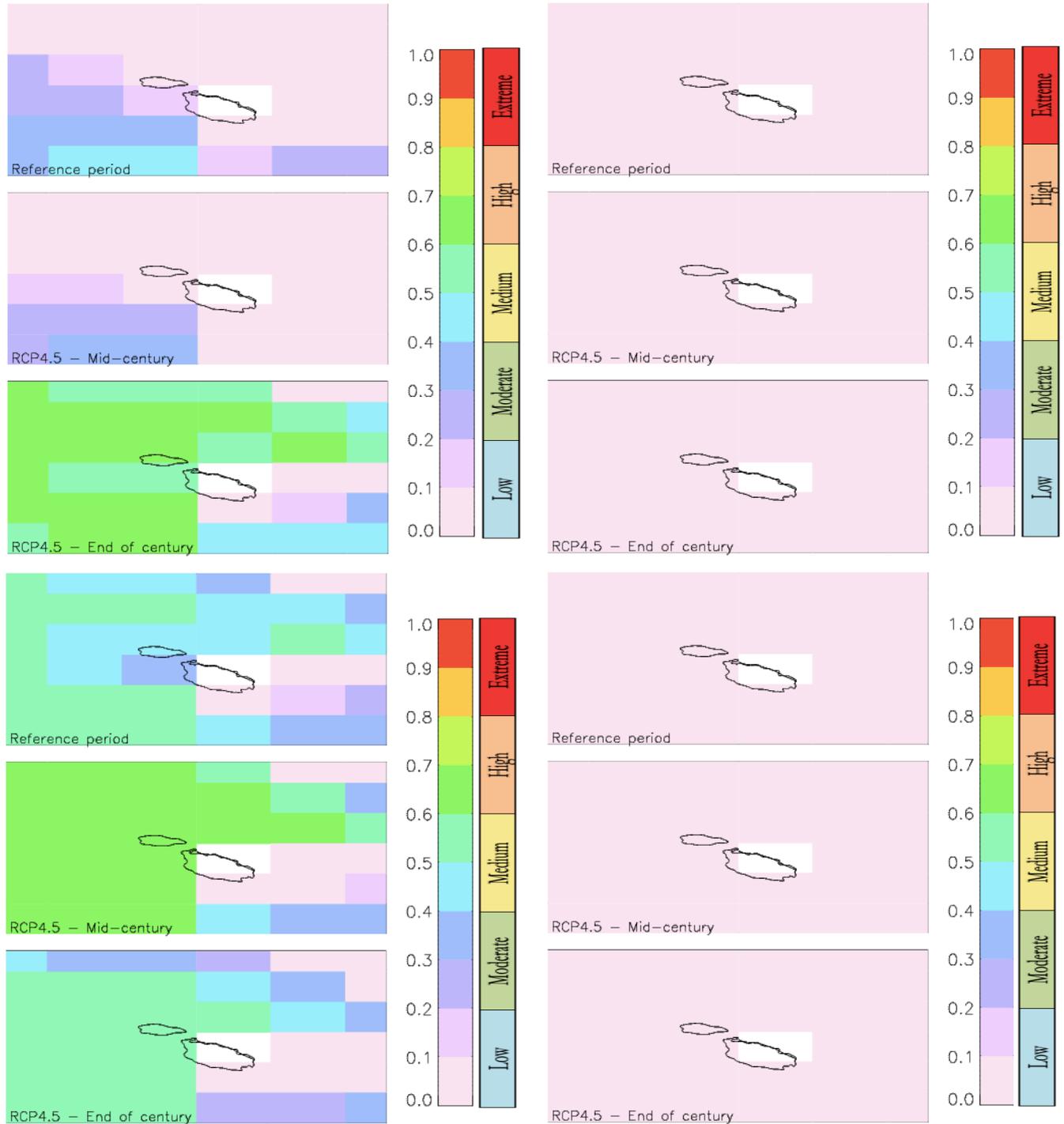


Figure 3.4.44. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

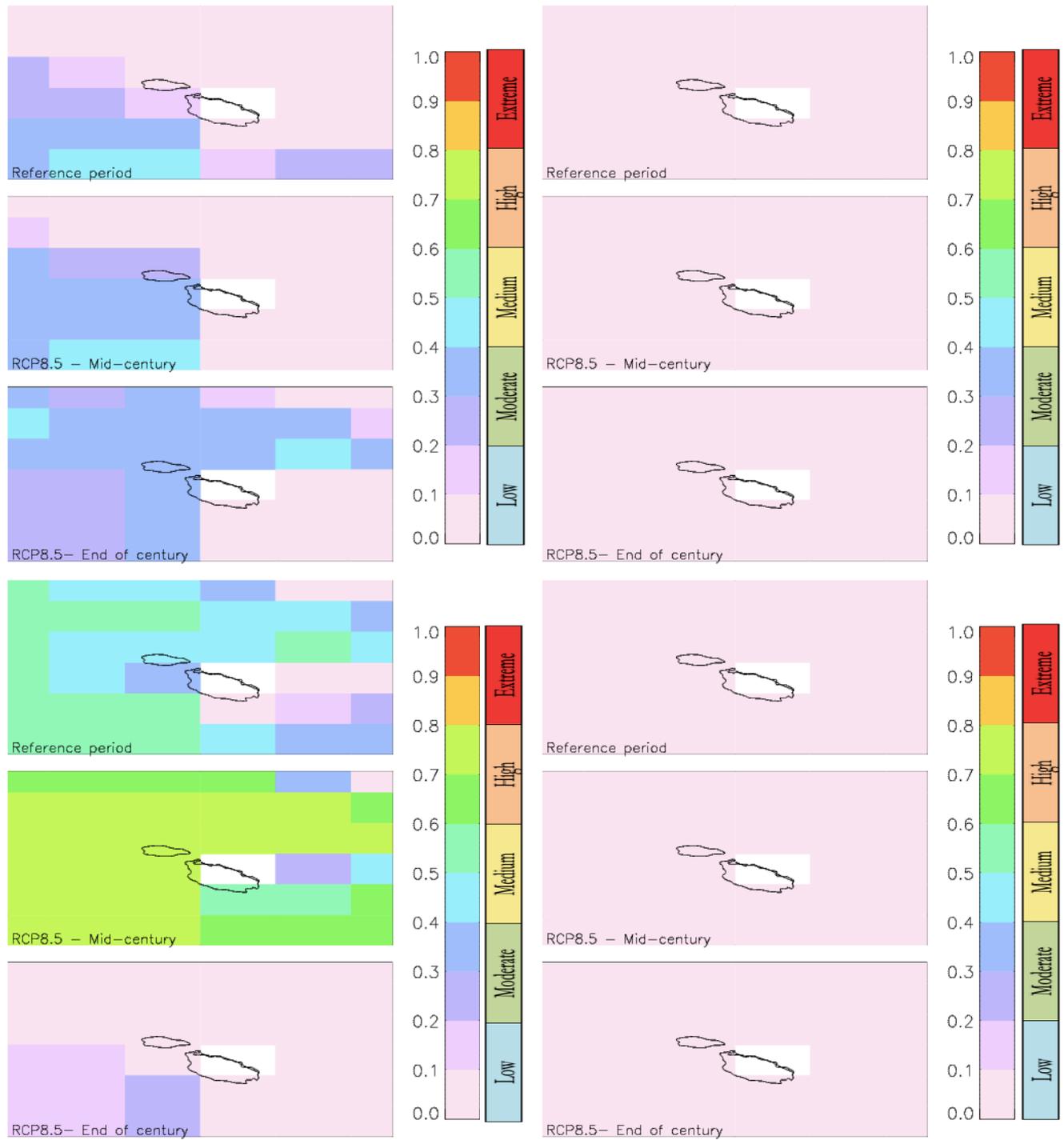


Figure 3.4.45. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD



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Mean wave hazard

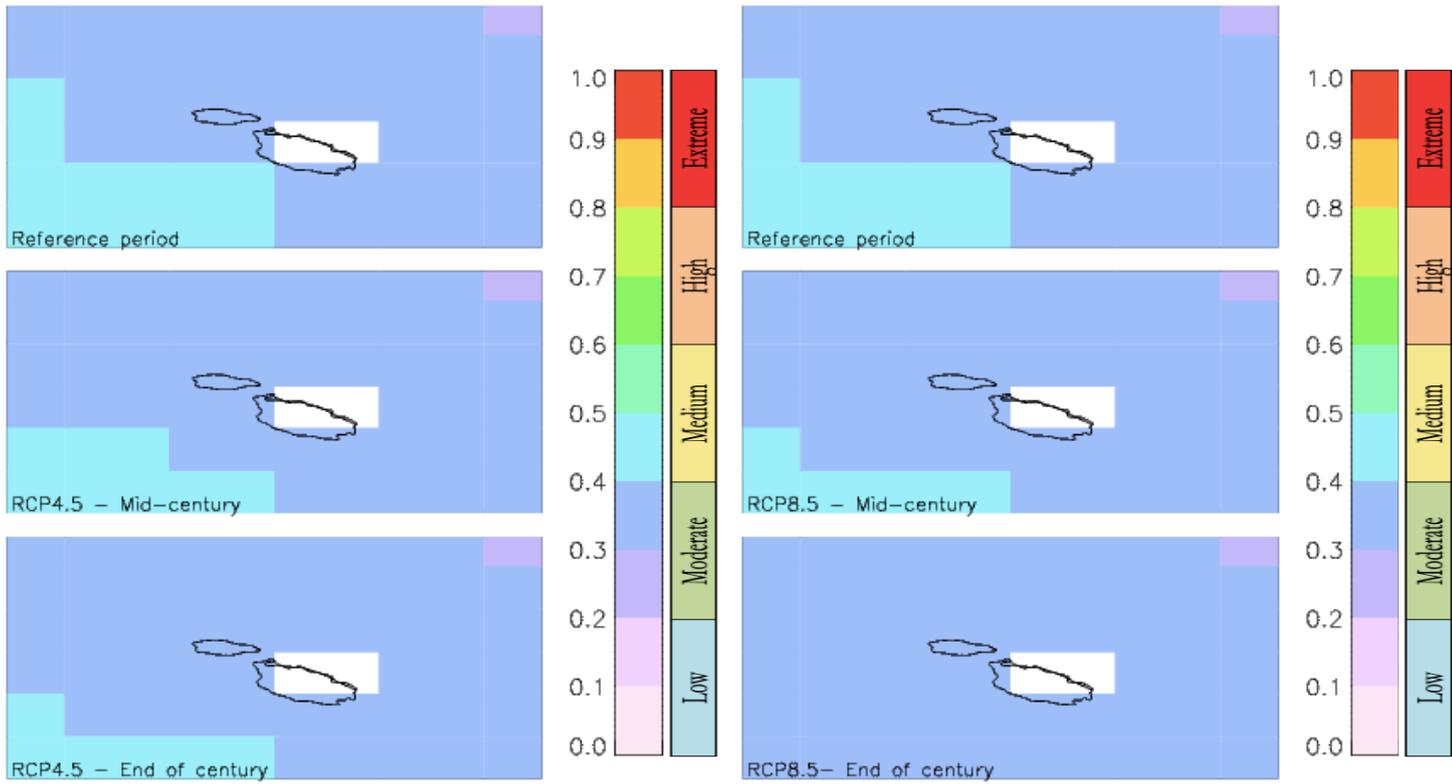


Figure 3.4.46. - Normalized hazard from mean waves - Left: **RCP4.5**; Right: **RCP8.5**; from top to bottom: reference period, near future, far future



Sardinia

Thermal Hazard

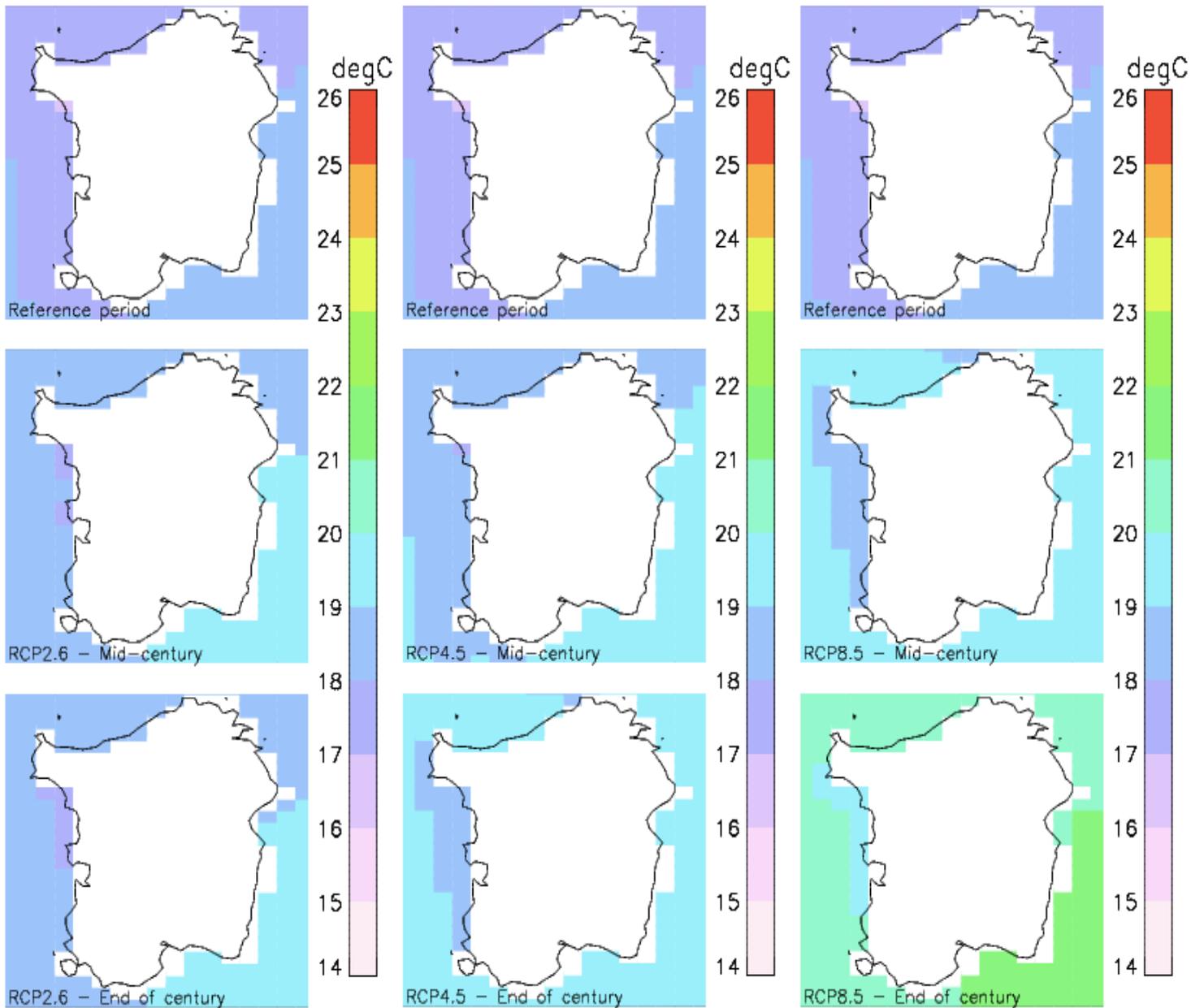


Figure 3.4.47. - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future

Extreme wave hazard

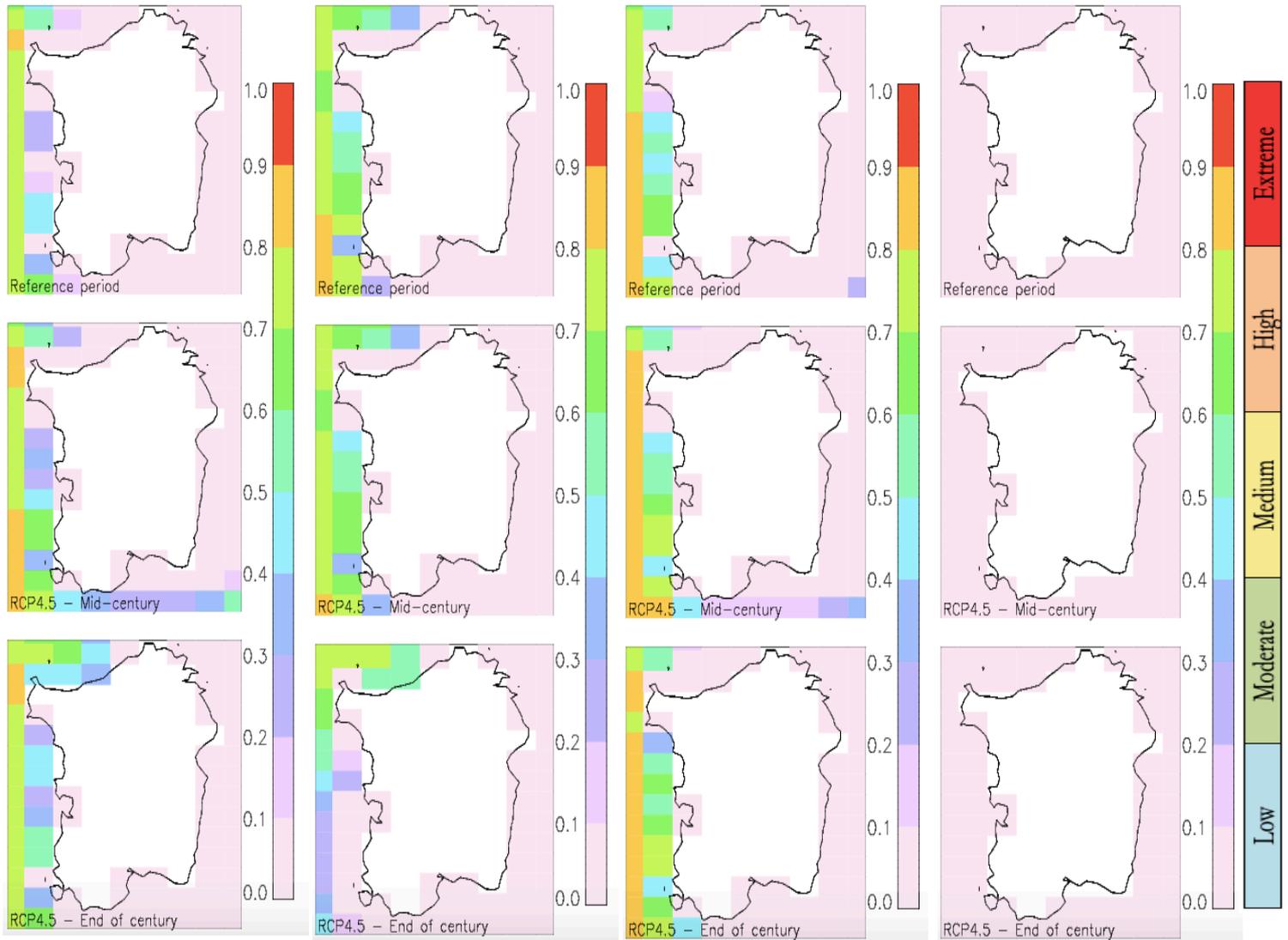


Figure 3.4.48. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

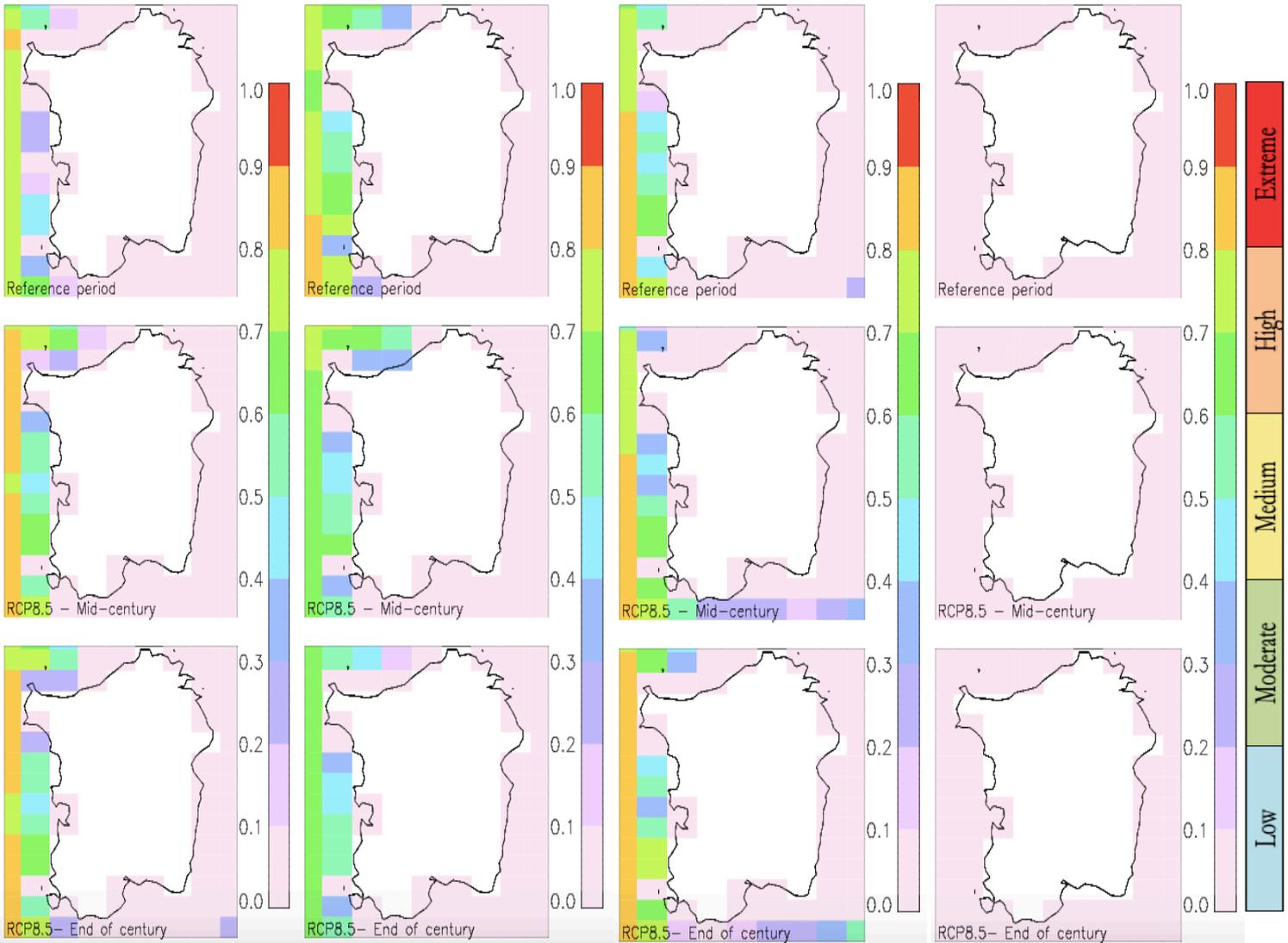


Figure 3.4.49. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD



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Mean wave hazard

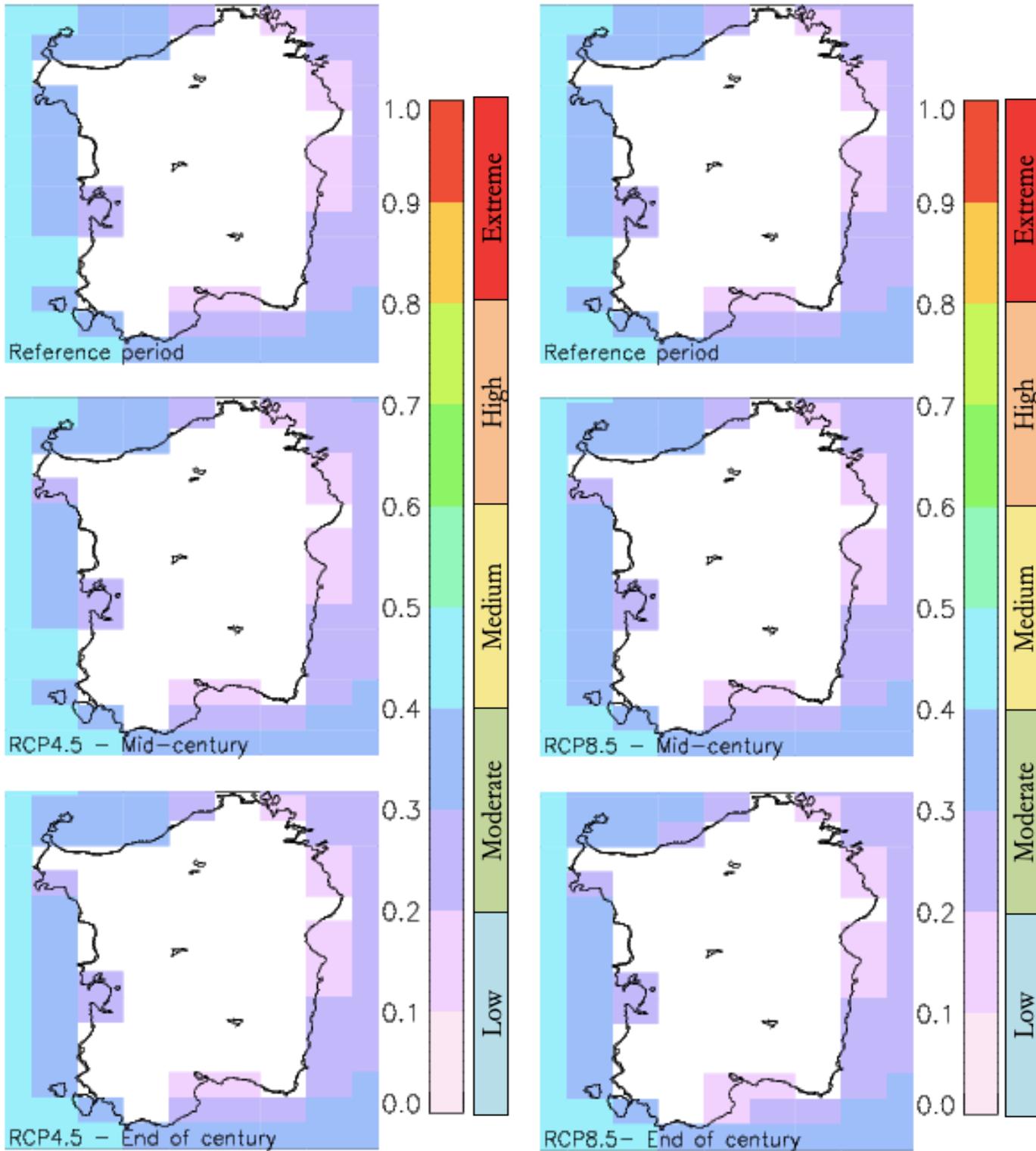


Figure 3.4.50. - Normalized hazard from mean waves - Left: RCP4.5; Right: RCP8.5; from top to bottom: reference period, near future, far future

Sicily

Thermal hazard

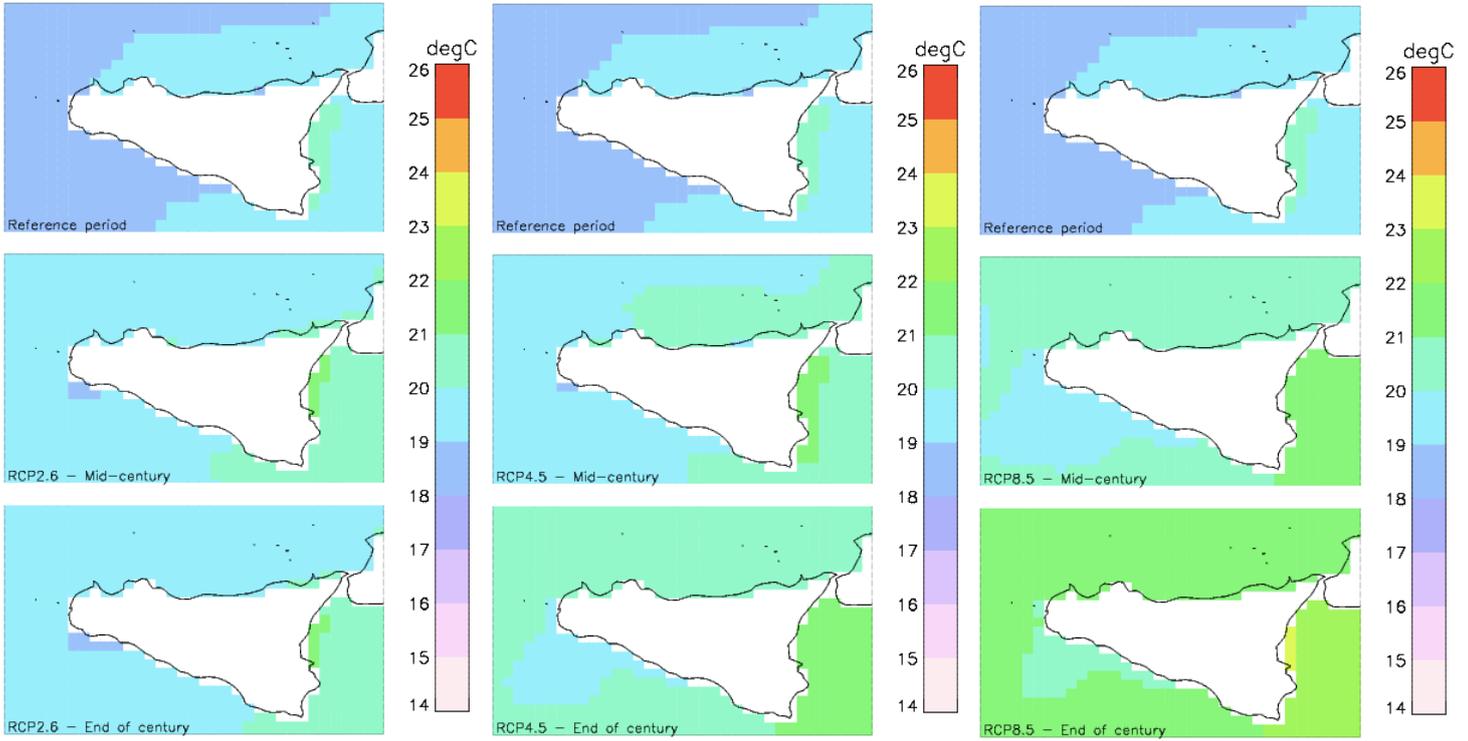


Figure 3.4.51. - Non-normalized hazard from rising SST- From left to right: **RCP2.6, RCP4.5, RCP8.5**; from top to bottom: reference period, near future, far future



Extreme wave hazard

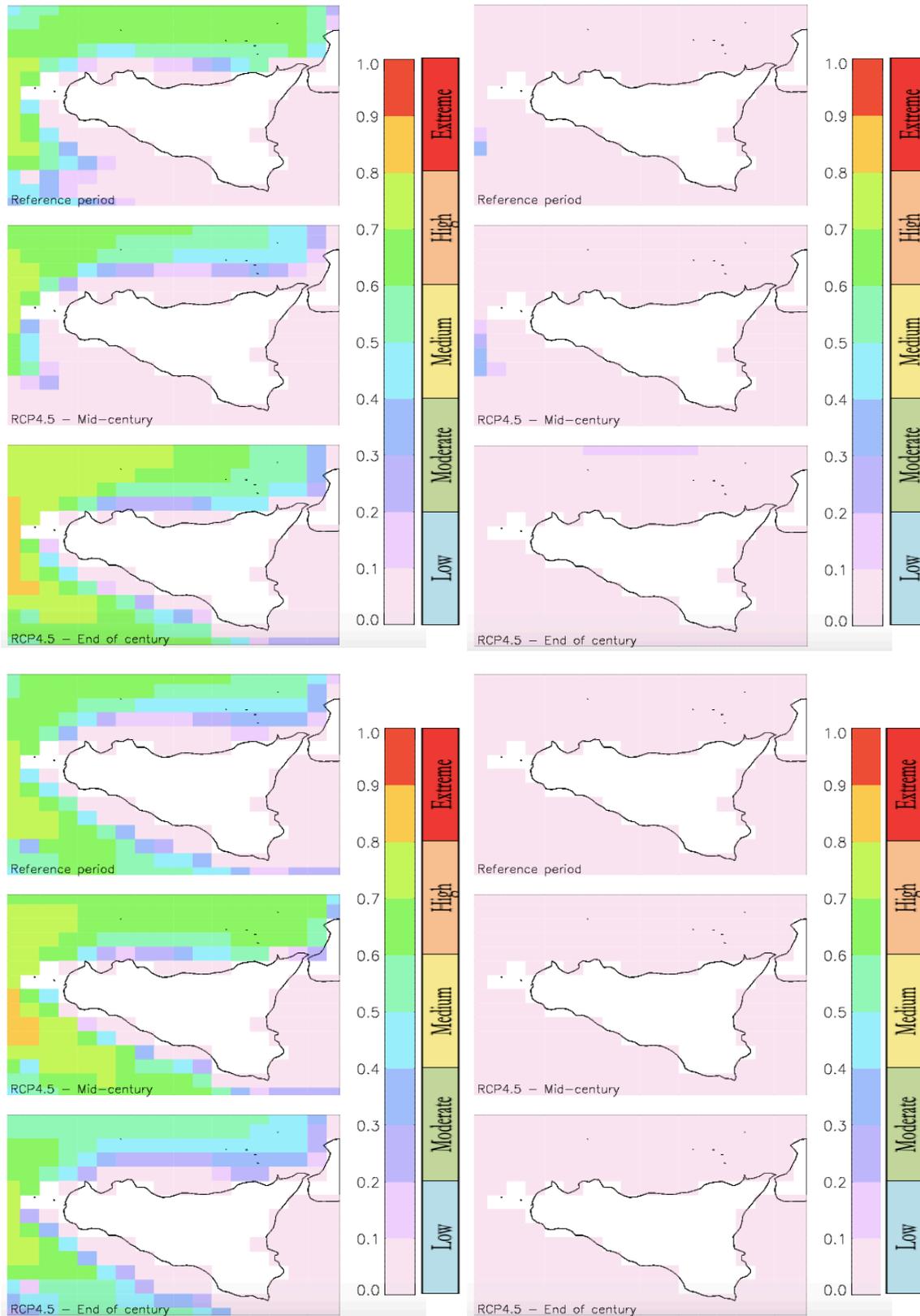


Figure 3.4.52. RCP4.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

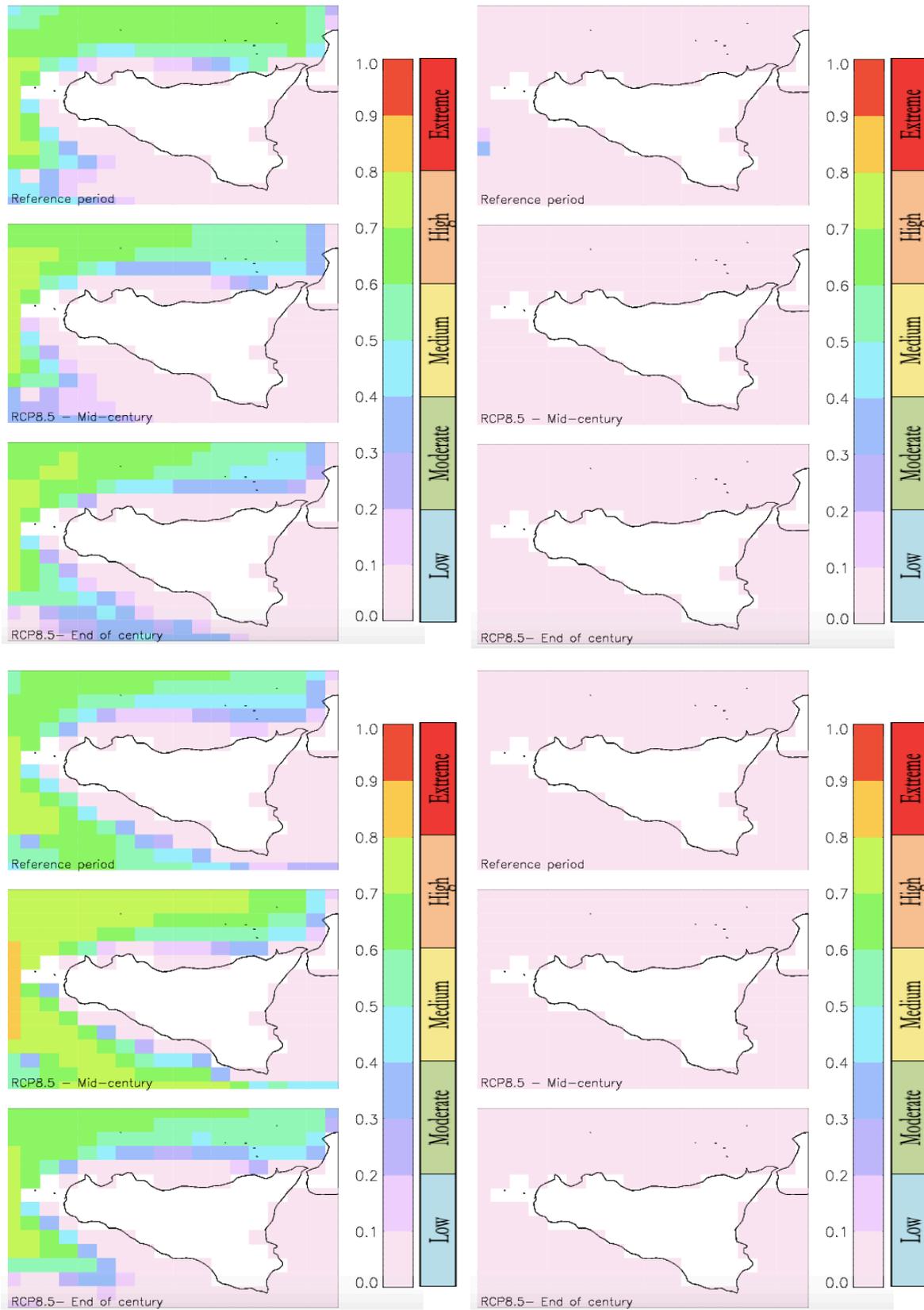


Figure 3.4.53. RCP8.5 - Normalized hazard from extreme waves - top left: CMCC; top right: CNRM; bottom left: GUF; bottom right: LMD

Mean wave hazard

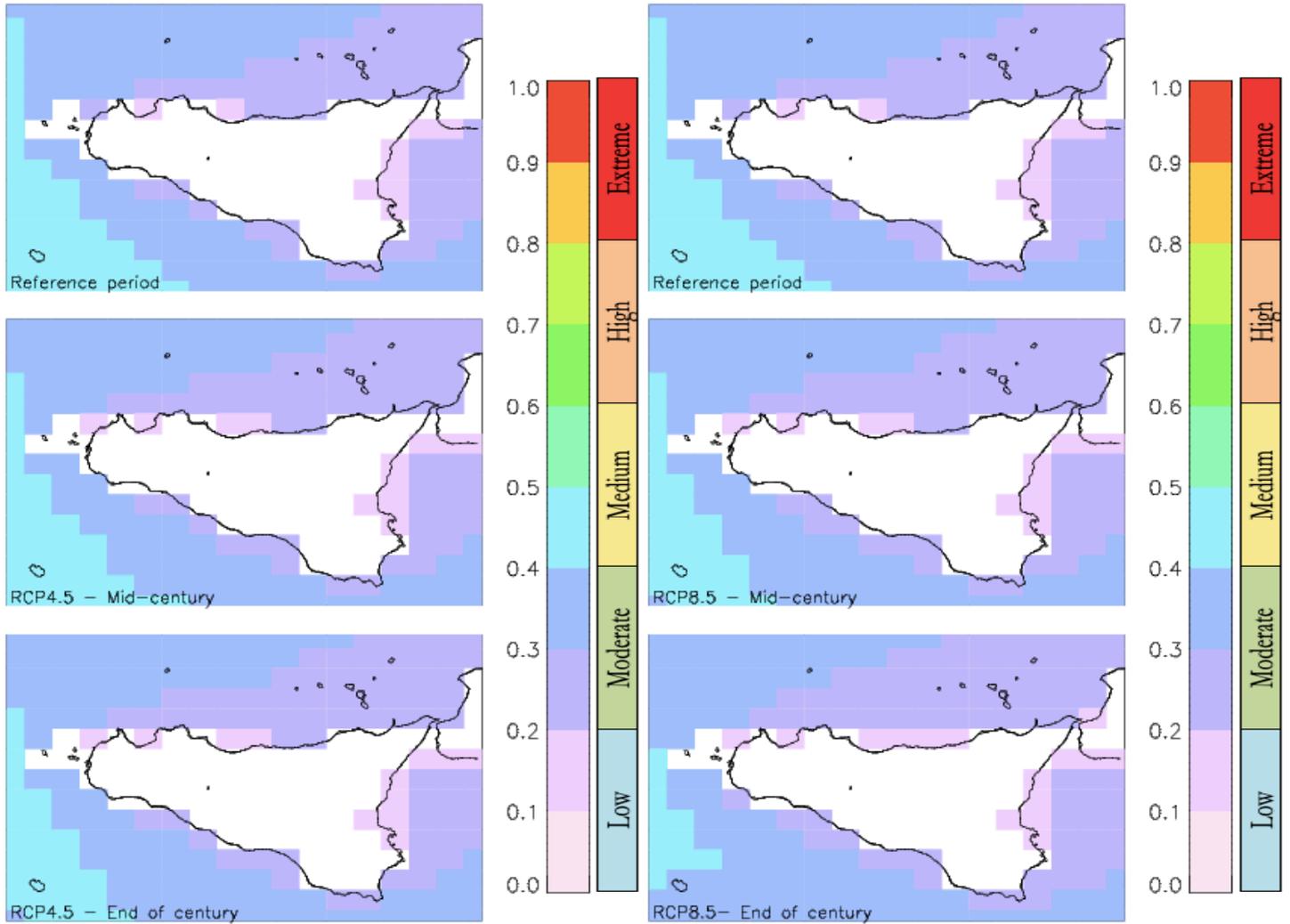


Figure 3.4.54. - Normalized hazard from mean waves - Left: **RCP4.5**; Right: **RCP8.5**; from top to bottom: reference period, near future, far future



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West Indies

Thermal hazard

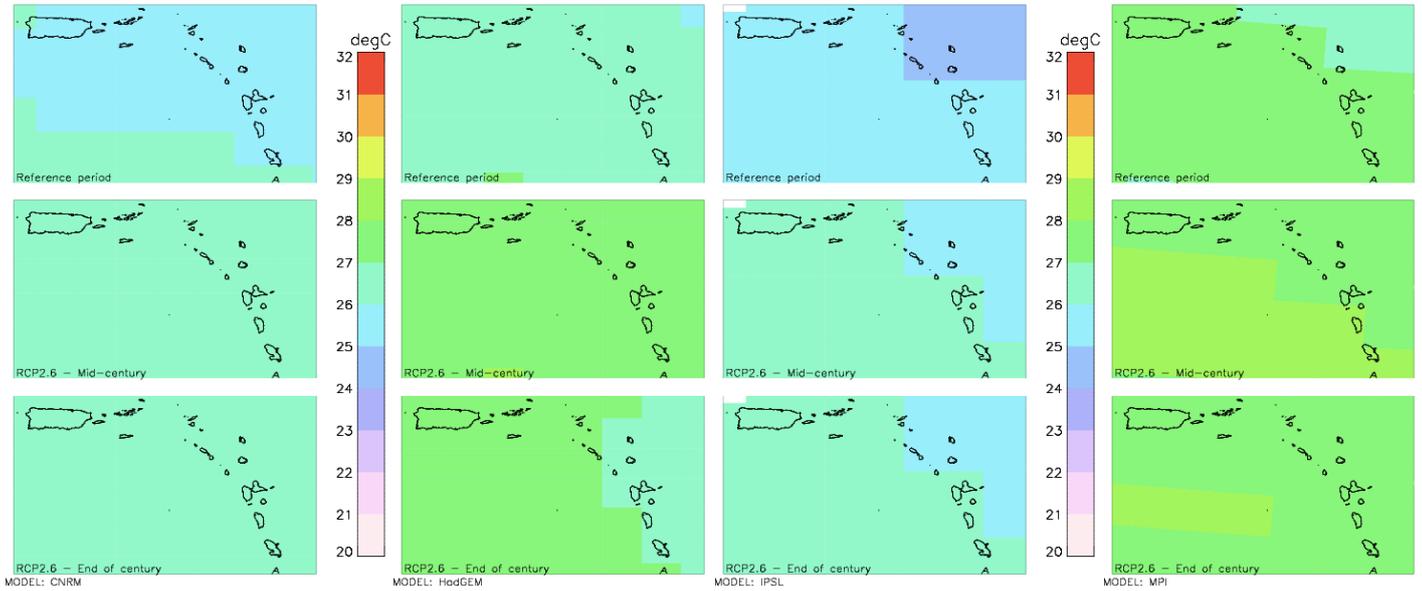


Figure 3.4.55. – RCP2.6 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

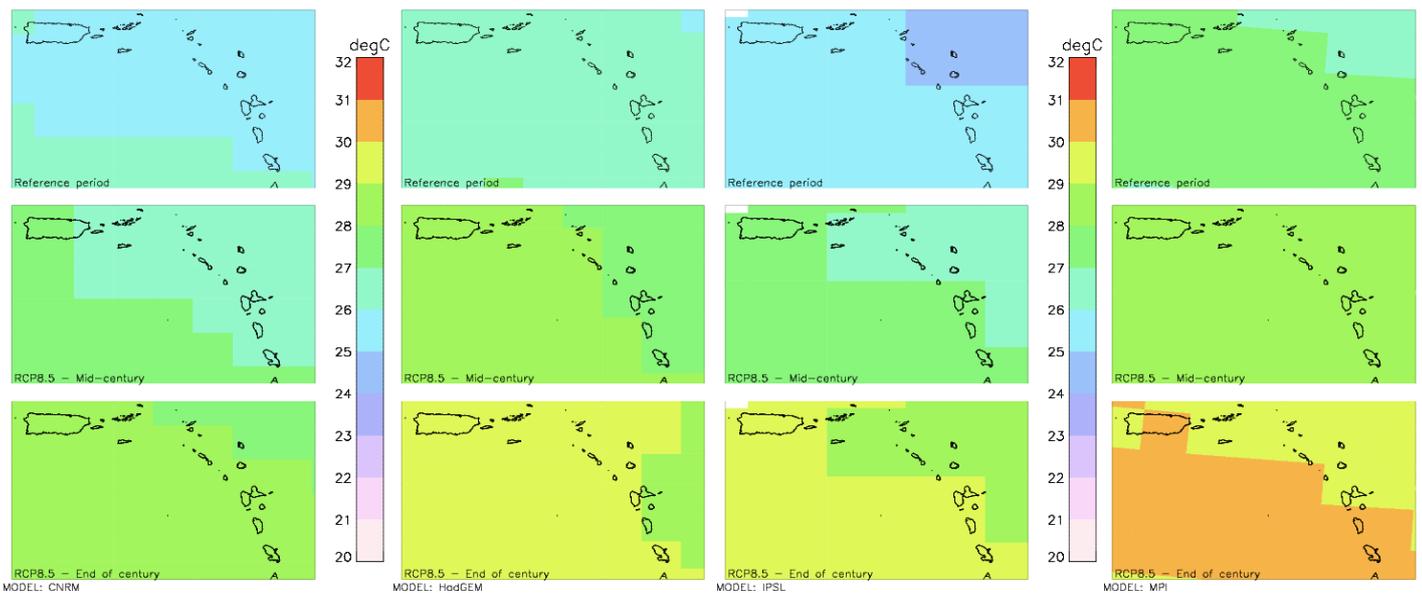


Figure 3.4.56. – RCP8.5 – Non-normalized hazard from rising SST- From left to right: CNRM, HadGEM, IPSL, MPI; from top to bottom: reference period, near future, far future

Extreme wave hazard

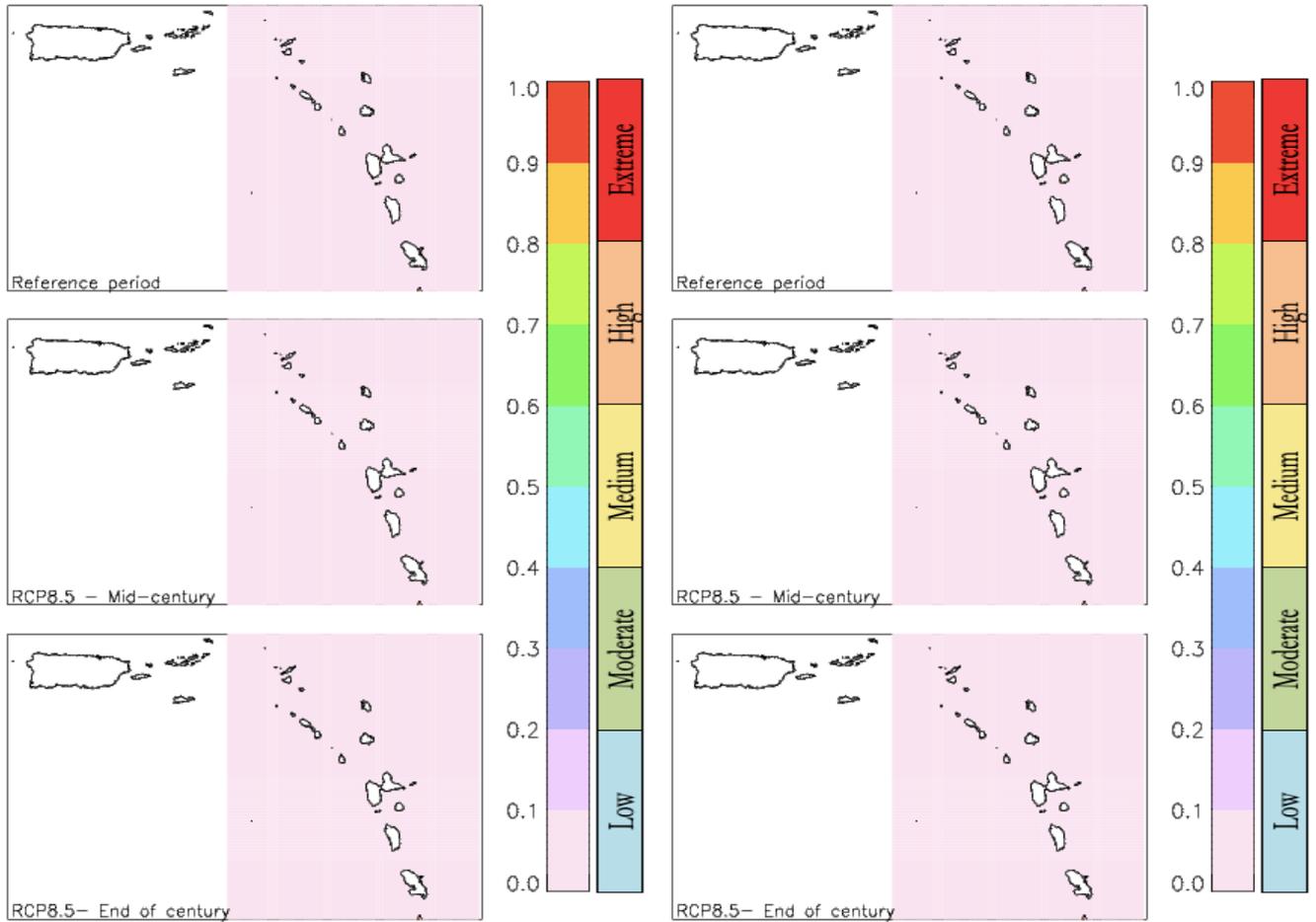


Figure 3.4.57. - RCP85 - Normalized hazard from extreme waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future

Mean wave hazard

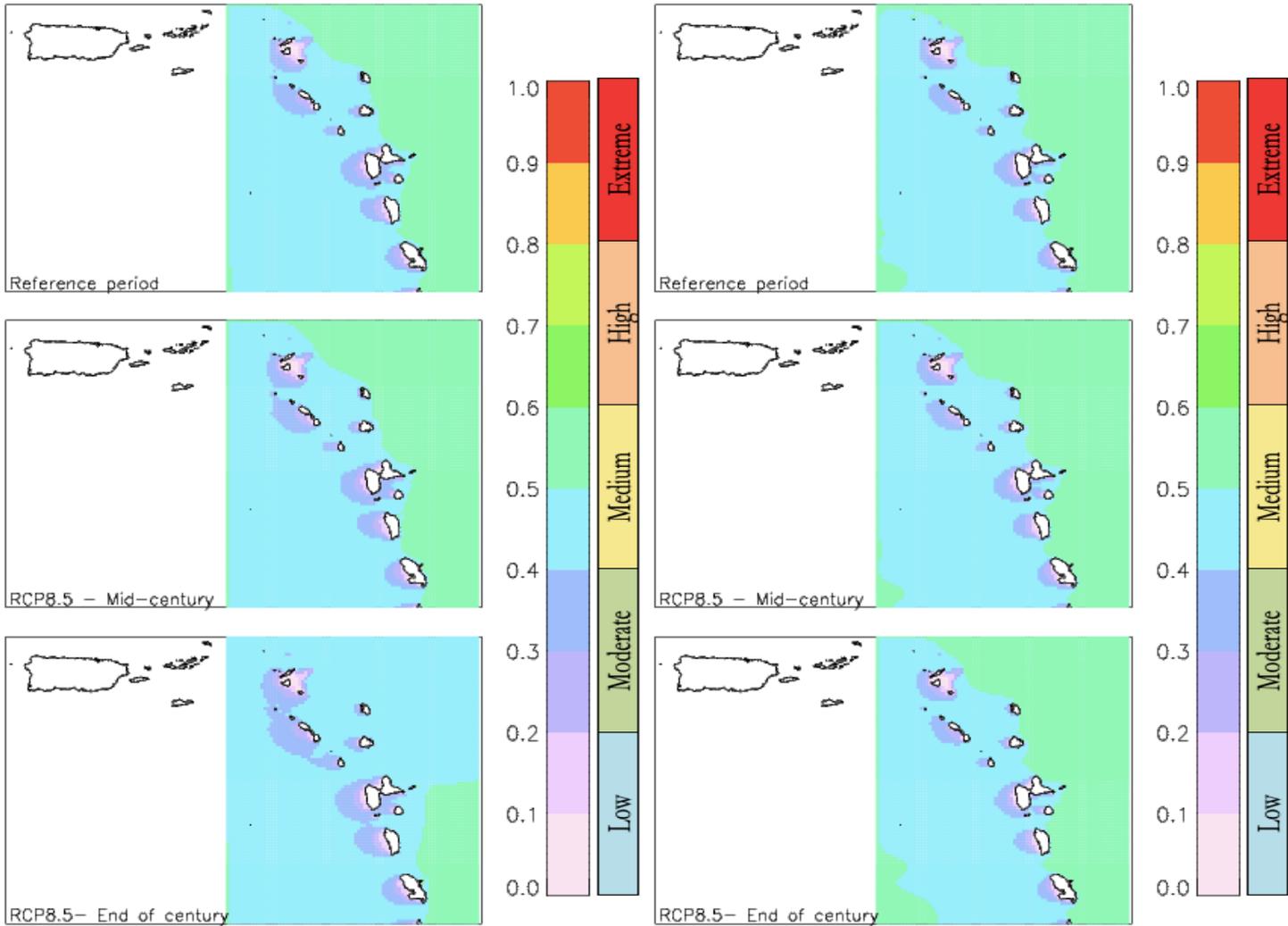


Figure 3.4.58. - RCP8.5 - Normalized hazard from mean waves - Left: Hadley Centre; Right: ACCESS; from top to bottom: reference period, near future, far future



Island inter-comparison: hazards for aquaculture areas

Figures 3.4.59 and 3.4.60 show the areas over which hazards indicators were averaged for the Mediterranean basin and the Atlantic Ocean, respectively, based on the information on farm location provided by IFPs. For the bigger islands, overall averages were then computed to allow the IC operationalization, all other risk components being relative to the whole island. The inter-comparison of hazard components is, however, also presented for selected islands and island sub-areas, for which the overall risk assessment could be completed. The hazard indicators computed for the remaining islands are included in section 7.7, in table form.

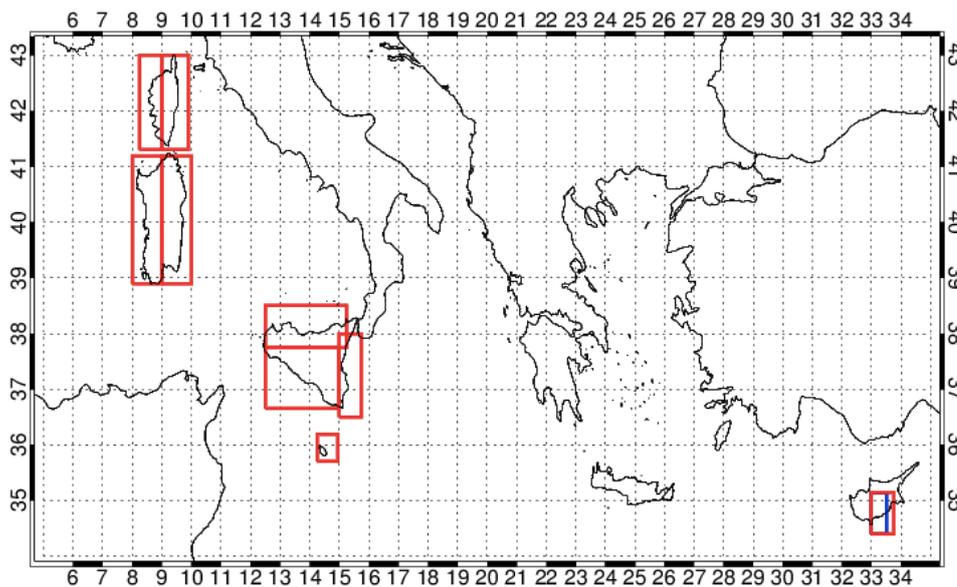


Figure 3.4.59 – Mediterranean basin: aquaculture farming areas

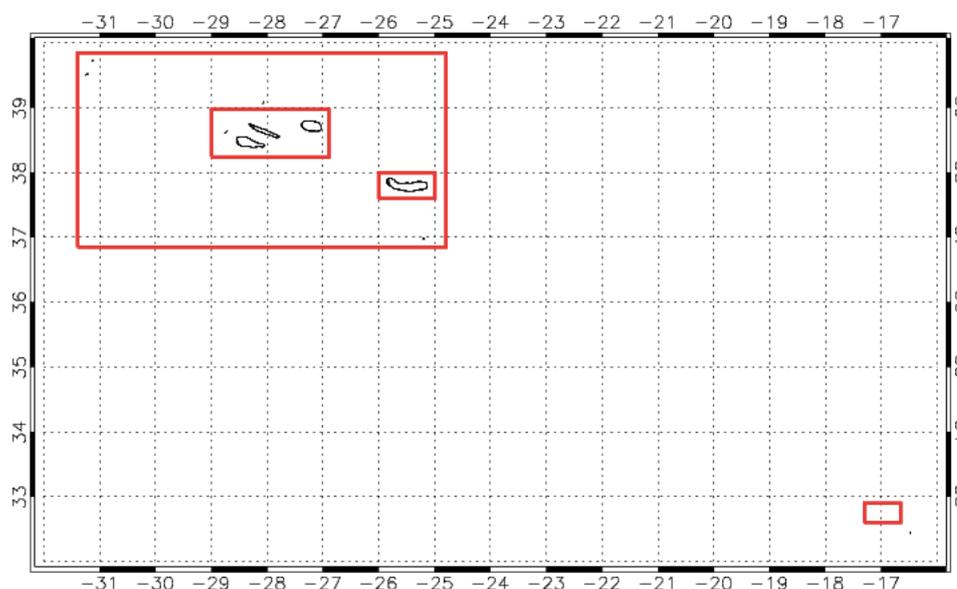


Figure 3.4.60 – Atlantic Ocean: aquaculture farming areas (Azores and Madeira)



Thermal stress indicator

Over the selected sub-areas, two alternative thermal stress indicators were computed for the duration of heatwaves (means were computed over the three time slices of interest):

- Mean duration of critical season: mean interval during which critical species-dependent SST thresholds are exceeded, computed (in days) from the first to the last day of threshold exceedance, disregarding any intermediate oscillation, for each warm season.
- Mean duration of the longest critical event in season: mean duration of the longest individual critical period occurred in each year of the time-slice of interest.

The time slices are the 20-year time windows that represent present climate, mid-century climate and end-of-century climate. Results for selected islands are shown in Table 3.4.7, 3.4.8 and 3.4.9, where cell background colors along each row are used to highlight comparable magnitudes across scenarios and time horizons of both the indicator itself and its increment (absolute and relative), increasing from blue, to green, to yellow, to orange. Relative increments below 50% are shown in black, between 50% and 100% in pink, between 100% and 150% in purple, between 150% and 200% in orange, and above 200% in dark red.

Table 3.4.7 - Non-normalized thermal hazard indicators for threshold 20 °C- Top: Mean longest critical event, bottom: mean duration of critical season

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	121	139.5		144		144		173.5	
CYPRUS	178	200		219,5		197.5		250	
MALTA	152	163		172		175		201	
SARDINIA	123	141.5		147.5		149.5		178.5	
SICILY	150	165		175		172		182	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		18.5	15 %	23	19 %	23	19 %	52.5	43 %
CYPRUS		22	12 %	41.5	23 %	19.5	11 %	72	40 %
MALTA		11	7 %	20	13 %	23	15 %	49	32 %
SARDINIA		18.5	15 %	24.5	20 %	26.5	22 %	55.5	45 %
SICILY		15	10 %	25	17 %	22	15 %	32	21 %

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	127.5	142.5		151.5		149.5		176	
CYPRUS	189.5	209		226,5		208		250	
MALTA	159	165		175		179		206	
SARDINIA	132	147		155.5		149.5		181	
SICILY	157.7	169		178.3		179.3		208	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		15	12 %	24	19 %	22	17 %	48.5	38 %
CYPRUS		19.5	10 %	37	20 %	18.5	10 %	60.5	32 %
MALTA		6	4 %	16	10 %	20	13 %	47	30 %
SARDINIA		15	11 %	23.5	18 %	17.5	13 %	49	37 %
SICILY		11.3	7 %	20.6	13 %	21.6	14 %	50.3	32 %



Table 3.4.8 - Non-normalized thermal hazard indicators for threshold 24 °C- Top: Mean longest critical event, bottom: mean duration of critical season

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	29.5	53		72.5		91.5		95.5	
CYPRUS	63	107.5		117.5		105		160.5	
MALTA	62	89		100		95		123	
SARDINIA	31	55		67		61.5		90.5	
SICILY	66,5	92		101		93		117.5	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		23.5	80 %	43	146 %	62	210 %	66	224 %
CYPRUS		44.5	71 %	54.5	87 %	42	67 %	97.5	155 %
MALTA		27	44 %	38	61 %	33	53 %	61	98 %
SARDINIA		24	77 %	36	116 %	30.5	98 %	59.5	192 %
SICILY		25.5	38 %	34.5	52 %	26.5	40 %	51	77 %

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	40.5	74		84.5		78.5		107	
CYPRUS	101	131.5		142		137.5		170.5	
MALTA	75	104		108		102		131	
SARDINIA	38.5	75		82.5		77.5		107	
SICILY	76	106		109.3		104.3		130	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		33.5	83 %	44	109 %	38	94 %	66.5	164 %
CYPRUS		30.5	30 %	41	41 %	36.5	36 %	69.5	69 %
MALTA		29	39 %	33	44 %	27	36 %	56	75 %
SARDINIA		36.5	95 %	44	114 %	39	101 %	68.5	178 %
SICILY		30	39 %	33.3	44 %	28.3	37 %	54	71 %

Table 3.4.9 - Non-normalized thermal hazard indicators for threshold 25 °C- Top: Mean longest critical event, bottom: mean duration of critical season

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	17.5	31.5		51.5		42		75	
CYPRUS	30	72.5		86		81.5		130	
MALTA	43	64		78		72		98	
SARDINIA	16.5	34.5		44		42		67	
SICILY	50	71.5		80.5		73.5		98.5	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		14	80 %	34	194 %	24.5	140 %	57.5	329 %
CYPRUS		42.5	142 %	56	187 %	51.5	172 %	100	333 %
MALTA		21	49 %	35	81 %	29	67 %	55	128 %
SARDINIA		18	109 %	27.5	167 %	25.5	155 %	50.5	306 %
SICILY		21.5	43 %	30.5	61 %	23.5	47 %	48.5	97 %

	Reference period	RCP45				RCP85			
		Mid-century		End of century		Mid-century		End of century	
CORSICA	20.5	64		67		59.5		87	
CYPRUS	67	107.5		117		101		151.5	
MALTA	56	81		89		81		111	
SARDINIA	21	49.5		61.5		57.5		87	
SICILY	52.7	86		91.7		86.7		112.3	
		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period		Increment with respect to reference period	
CORSICA		43.5	212 %	46.5	227 %	39	190 %	66.5 %	324 %
CYPRUS		40.5	60 %	50	75 %	34	51 %	84.5 %	126 %
MALTA		25	45 %	33	59 %	25	45 %	55 %	98 %
SARDINIA		28.5	136 %	40.5	193 %	36.5	174 %	66 %	314 %
SICILY		33.3	53 %	39	74 %	34	65 %	59.6 %	113 %

Differences between the two indicators give a qualitative idea of how intermittent the critical season is, both within each year and over the 20-year time slice. If the critical threshold is stably exceeded every year, the values for the two indicators are very similar (e.g. for the lowest 20 °C threshold) or even coincide, while any oscillation about the threshold during the warm season (i.e. more than one event occurring during a single year), and/or any interannual variability, lead to significant discrepancies, which might want further analyses to be fully understood. This being the case, as it is for the higher 24 °C and 25 °C thresholds, very detailed knowledge might be needed as to how the process under study reacts to thermal stress, if not a dedicated model to be run under the different SST scenarios by using the original SST daily time series as input.

Although the Tables do not include such a case, it is possible that the *mean longest event* is found to be longer than the *mean season duration*, as the former is calculated only on actual extremes (i.e., years with no events are discarded in the computation), while the latter also considers years with no events (i.e. zero duration, which causes the overall mean to decrease). In other words, the mean season is always calculated over 20 values, including years when the season duration is zero, while

the computation of the mean longest event can happen to only consider a subset of the original 20 years.

The general tendency towards warmer sea temperatures is well captured by both indicators, which show systematic increments under climate change, whose relative magnitude with respect to their baseline values can anyway significantly differ. Following the considerations presented in Section 3.4 – “Hazard normalization and classification”, however, an *increase in the mean duration of above-optimal-threshold events* was chosen as most representative of the occurrence of prolonged heatwaves, while changes in the overall duration of the warm season were considered to be more indicative of the potential onset of acclimation processes of the farmed species. The focus was then set on the characterization of potential extreme adverse events, also considering that, after all, the optimal thresholds considered here are regularly exceeded every year under present climate already, at least in the Mediterranean islands, and that the information relevant to stakeholders is if such events risk to become unsustainable in the future.

No normalization and classification of the thermal hazard was anyway attempted, the problem being too complex to be addressed without a biological model that also includes farming practices and additional environmental parameters, allowing to rigorously construct an ensemble of fish growth scenarios and provide detailed information to farmers. Absolute indicator values only are provided, for a first qualitative evaluation of the necessity of future investments in this research area.

As already mentioned above, although based on a single high-resolution model projection, the overall tendency of SST is in good agreement with lower resolution ensemble estimates, and therefore regarded as robust. Nevertheless, uncertainty should be rigorously estimated from ensemble spread when new simulations of comparable resolution become available. Figures from 3.4.61 to 3.4.69 allow island-intercomparison, while the actual degree of impact for the aquaculture sector can be qualitatively inferred by stakeholders, based on the absolute increments of critical event duration for the different SST thresholds considered, i.e. 20 °C (Mussels and Clams), 24 °C (Sea bream and Tuna) and 25 °C (Sea bass). Background colors here do not correspond to absolute hazard threshold, but only help distinguish the 0-50, 50-100, 100-150, 150, 200, 200-250 duration intervals (in days). **Due to graphical constraints, it was not possible convert the negative axis into reversed positive axis. Of course, negative values do not make sense in this context, and only their magnitude should be considered.**

A general increase in the duration of critical events is evident for both scenarios, whose severity worsens with both time and greenhouse gas concentration in the atmosphere (i.e. increments under RCP8.5 are larger than those under RCP4.5). The integral mean values computed for bigger islands correspond to different local conditions in sub-areas. Climate change appears to have a fairly uniform impact across island and island-sub-regions, although its timing can locally vary.

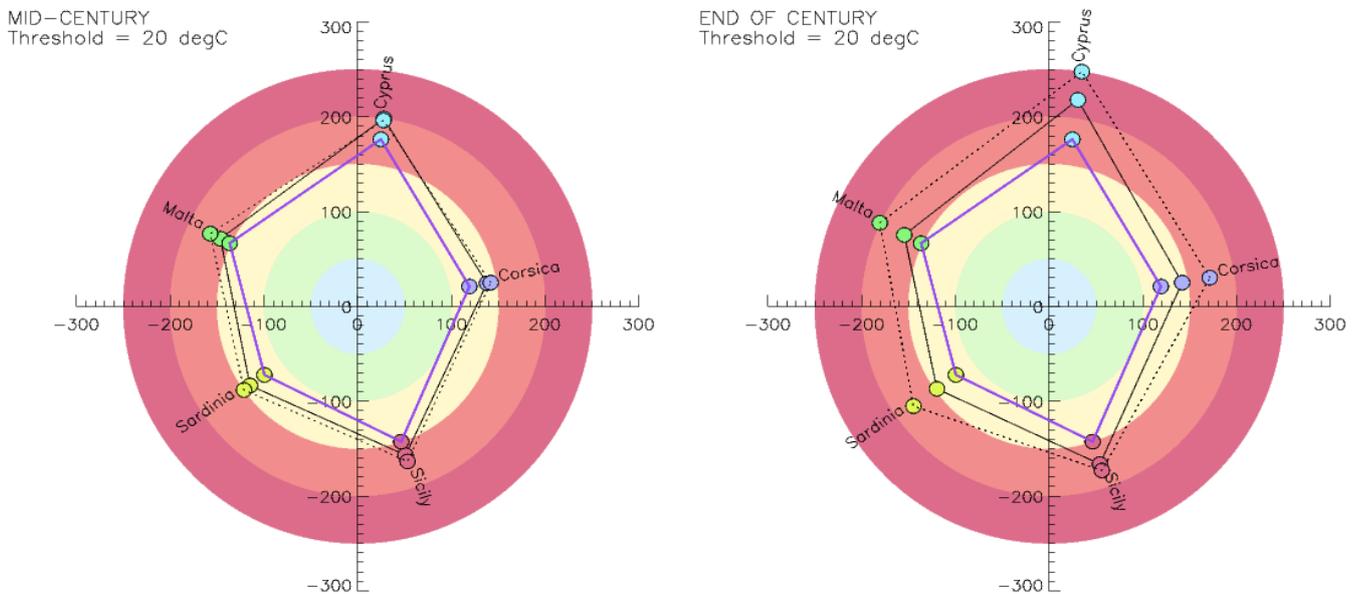


Figure 3.4.61 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **20 °C** (Mussels and Clams) – Comparison between selected **Mediterranean Islands** for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

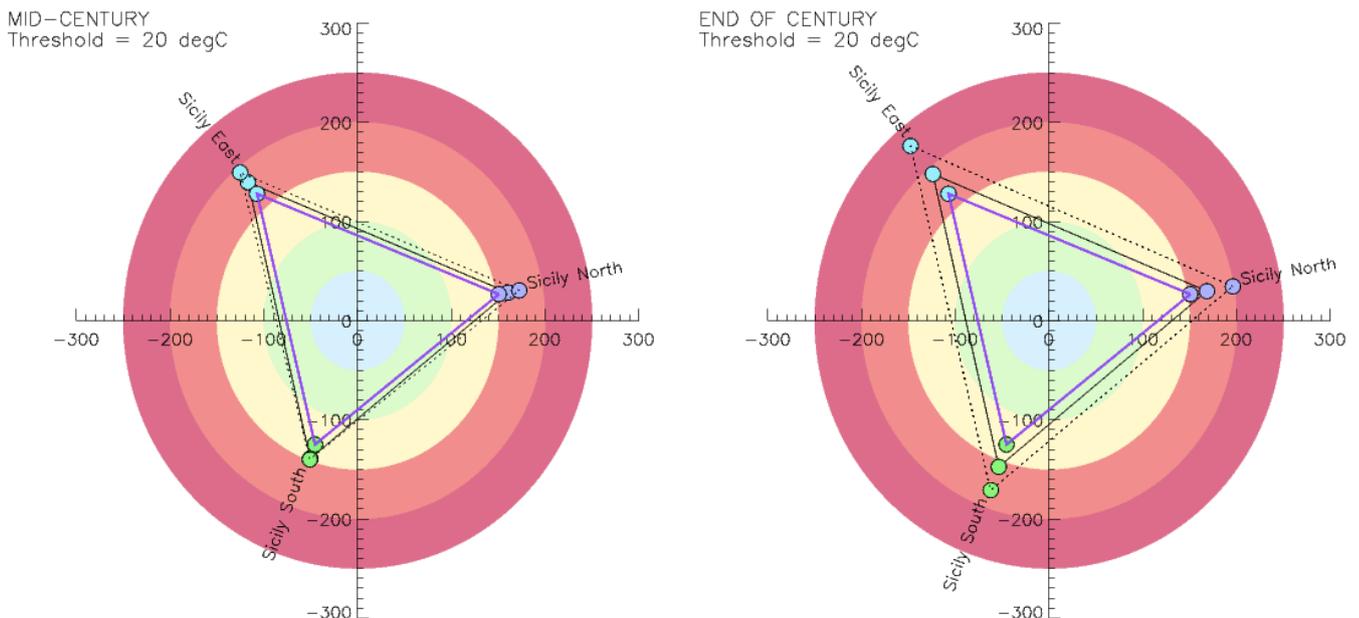


Figure 3.4.62 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **20 °C** (Mussels and Clams) – **Sicily**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

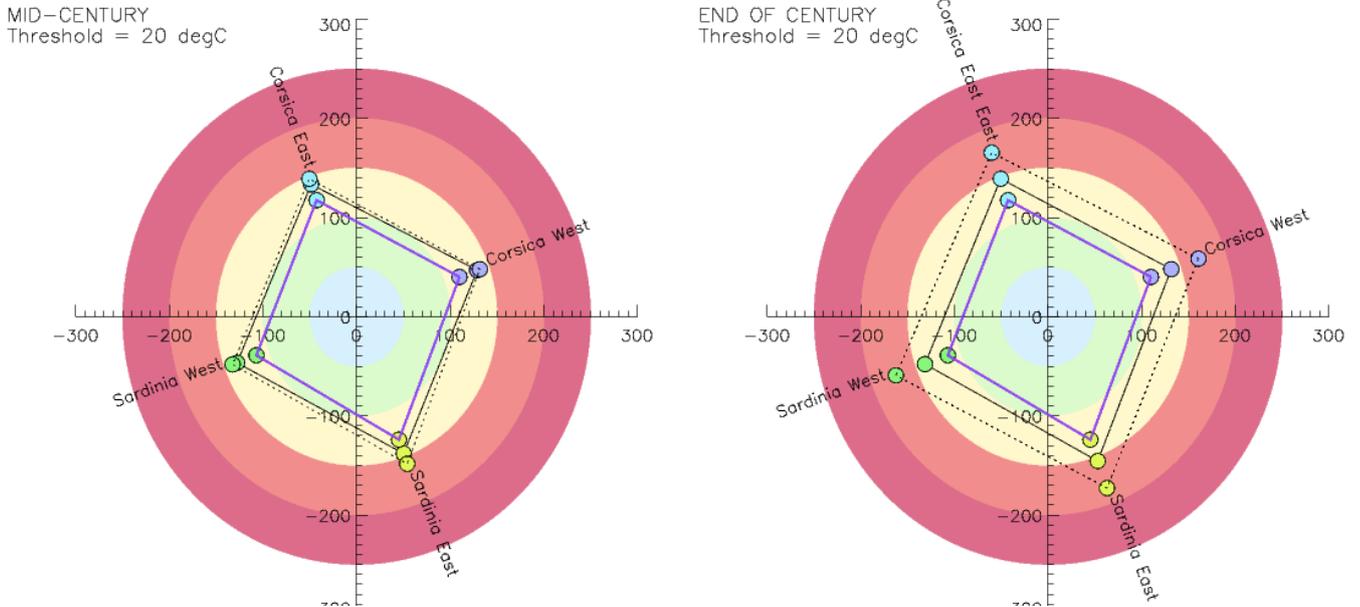


Figure 3.4.63 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **20 °C** (Mussels and Clams) – **Sardinia and Corsica**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

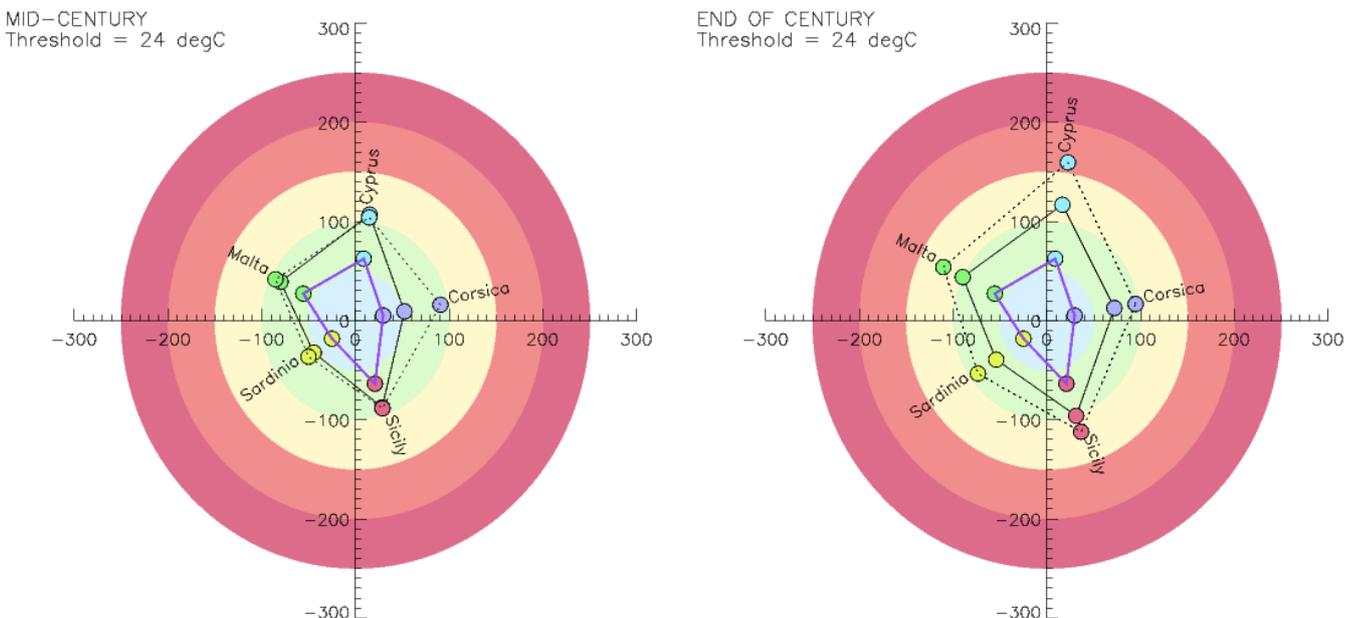


Figure 3.4.64 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **24 °C** (Sea bream and Tuna) – Comparison between selected **Mediterranean Islands** for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

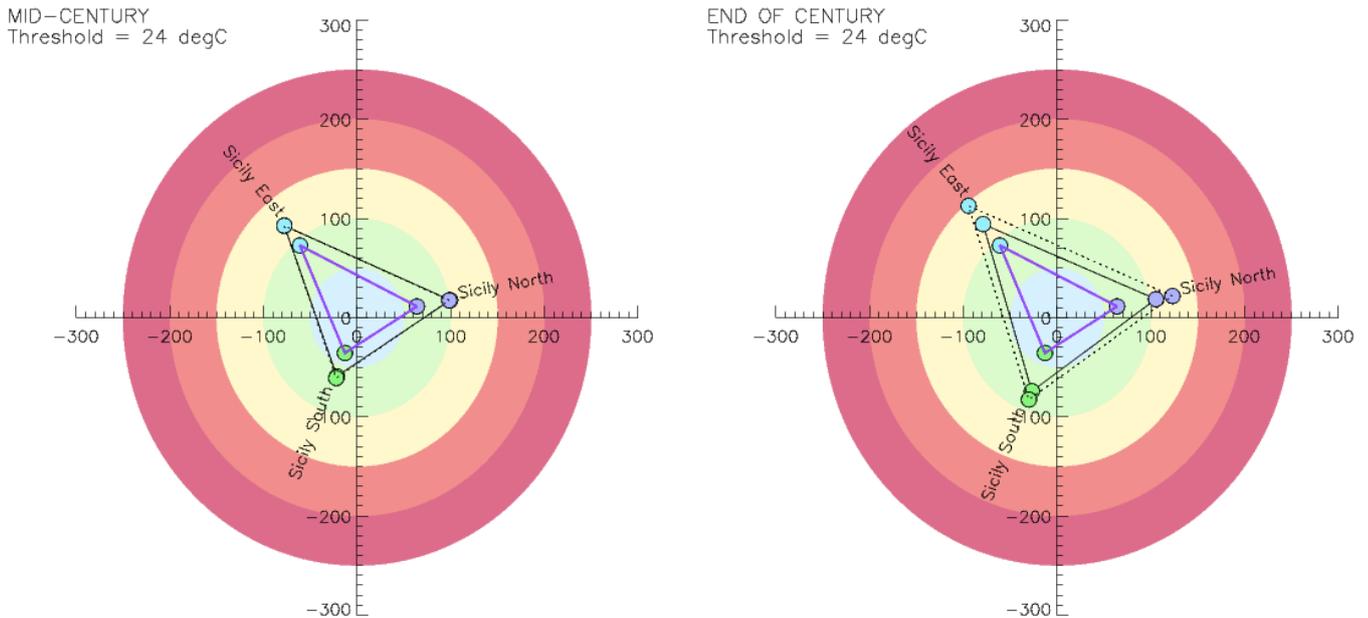


Figure 3.4.65 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **24 °C** (Mussels and Clams) – **Sicily**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

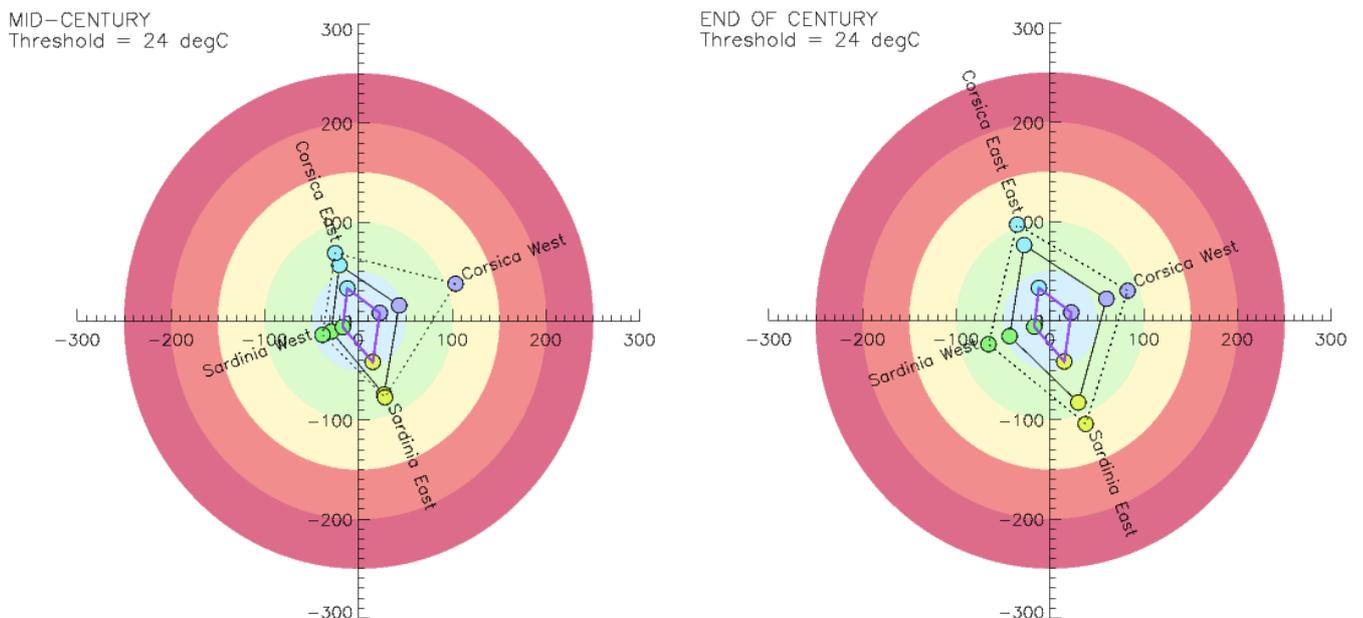


Figure 3.4.66 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **24 °C** (Sea bream and Tuna) – **Sardinia and Corsica**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) – Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

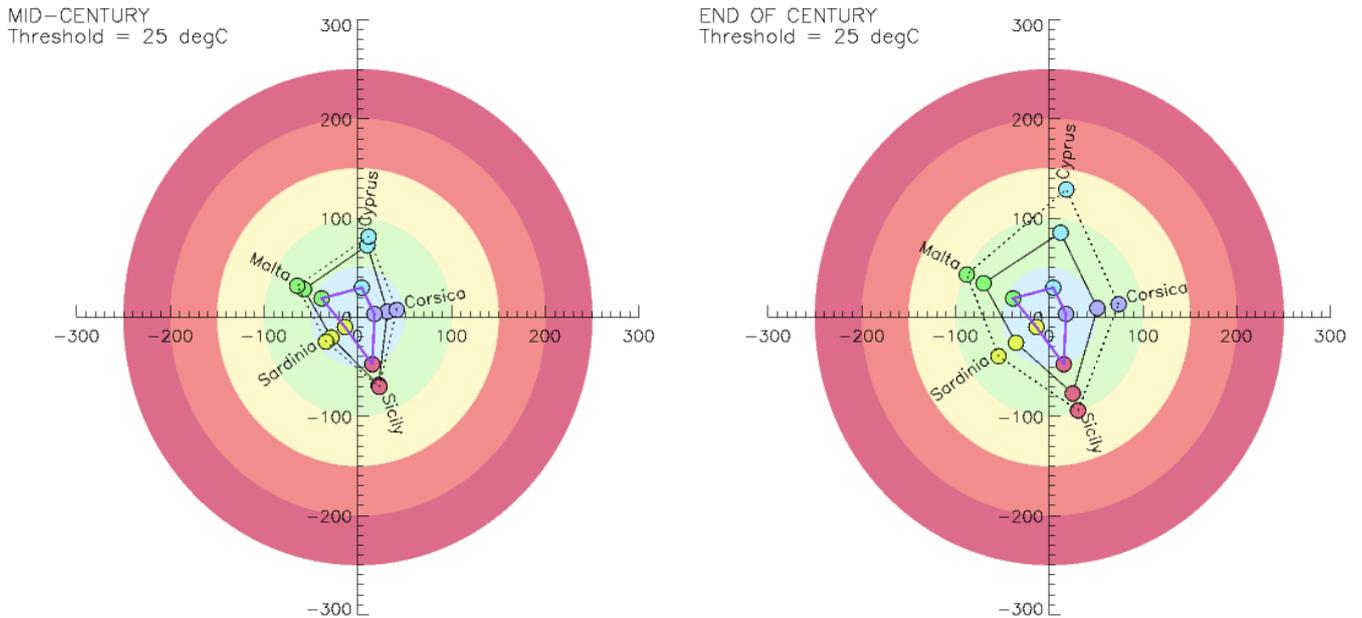


Figure 3.4.67 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **25 °C** (Sea bass) – Comparison between selected **Mediterranean Islands** for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

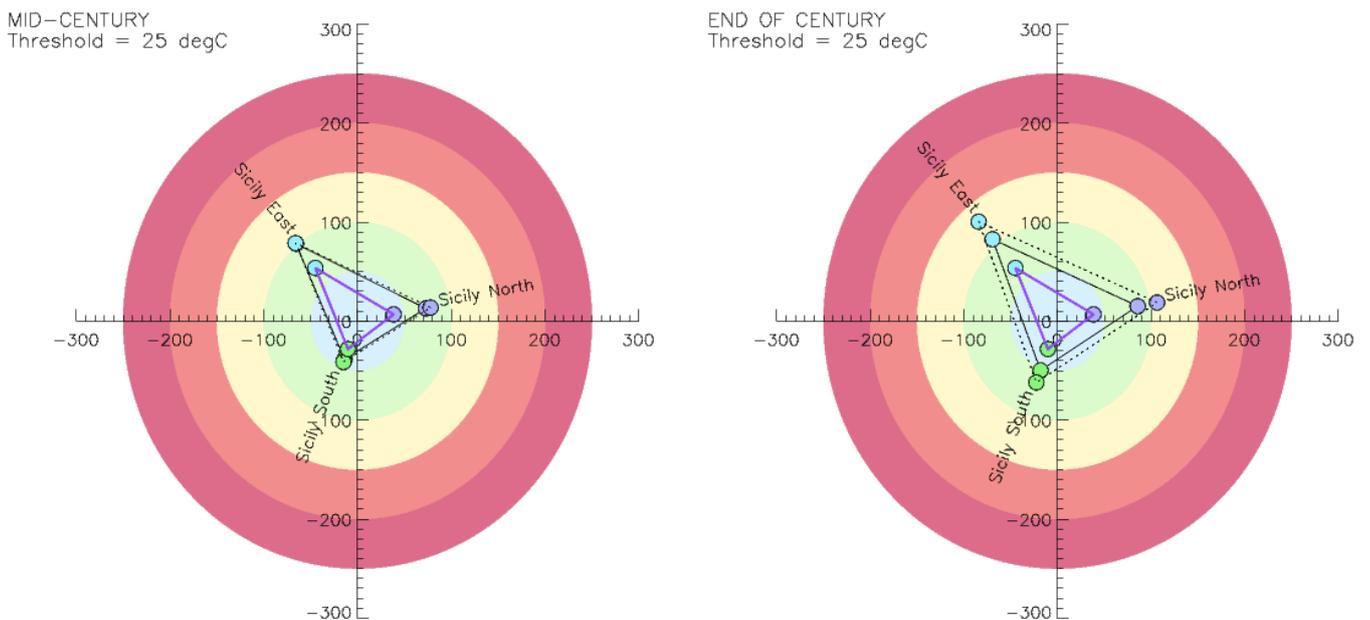


Figure 3.4.68 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of **25 °C** (Sea bass) – **Sicily**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - mid-century projections are shown in the left plot, end-of-century projections in the right plot.

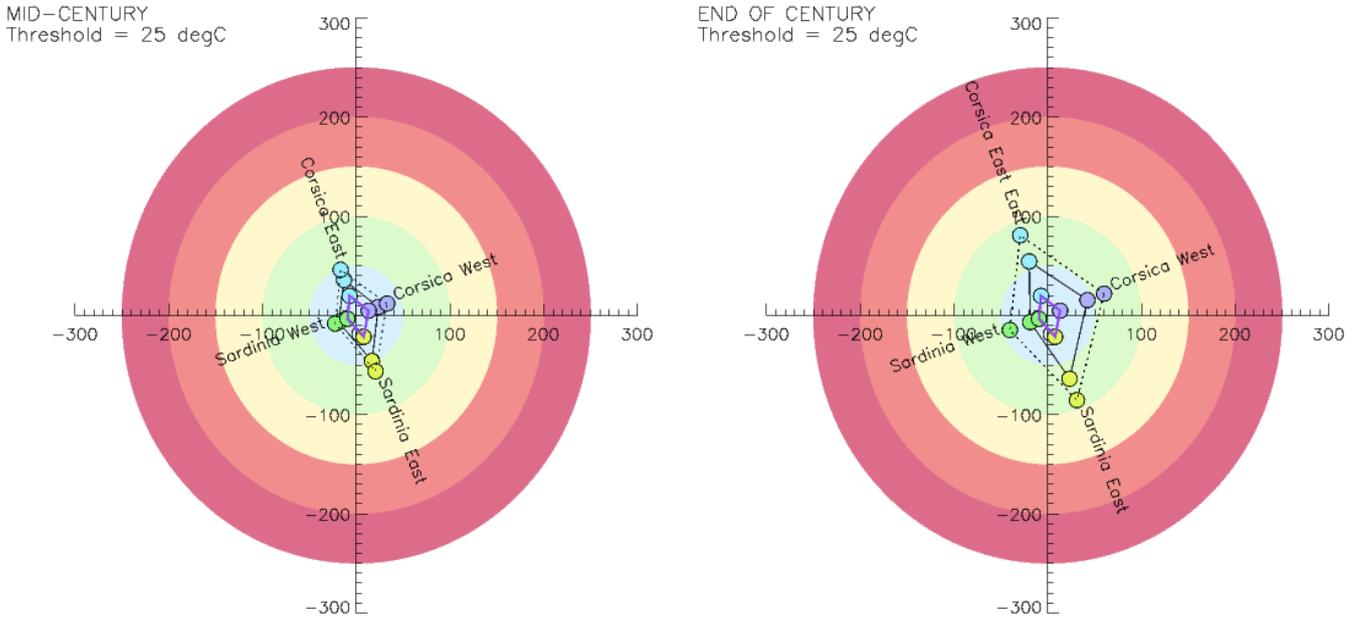


Figure 3.4.69 – Thermal hazard, measured as the mean duration (in days) of the longest above-threshold event during the warm season, for a critical threshold of 25 °C (Sea bass) – **Sardinia and Corsica**: comparison between sub-areas for the reference period (purple), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plot, end-of-century projections in the right plot.

Sea-state hazard indicators

The overall hazard induced by wave motion was computed as the combination of the mean stress exerted on infrastructures, estimated via mean significant wave height, and of the potentially disruptive impact of extreme events, measured via their probability of occurrence, based on return times. For both, an absolute scale was available (see the *Hazard normalization and classification* section above). While maps for both the normalized indicators can be found in the preceding Atlas, here we present a visual representation of their relative magnitude in selected Mediterranean islands, for which sufficient data were available to complete the overall risk assessment. **Due to graphical constraints, it was not possible to convert the negative axis into a reversed positive axis. Of course, negative values do not make sense in this context, and only their magnitude should be considered.**

As already mentioned, in the case of extreme events, both the worst and best projections were retained, in order to provide a rough measure of the associated uncertainty. *Worst* and *best* cases respectively refer to the least and most favorable projection in the set of available model realizations, and are shown in different plots. Likewise, different time horizons appear in distinct graphs, while the red (or purple) and black (solid and dotted) lines in each plot refer to different scenarios. For example, in the plots relative to extreme events and the mid-century time horizon (that is, the two plots on the left in Figure 3.4.70), the best-case graph highlights that there is at least one model predicting no hazard for all islands and low hazard for Sardinia, with no significant variations across scenarios. In fact, all circles cluster and overlap at the centre, while those that represent Sardinia all lie very close to the limit between the two lower hazard classes. On the other hand, at least one other model predicts appreciable yet low hazard for Corsica, Sicily and Sardinia, and a hazard going from moderate (reference period, red) to medium (RCP4.5, solid black), to high (RCP8.5, dotted black) for Malta, while for Cyprus the hazard is irrelevant even for the most negative projection. This means that:

- a) the results for Sardinia and Cyprus are stable across models,
- b) models slightly disagree for Sicily and Corsica, but generally predict low hazard,
- c) the projection for Malta is affected by greater uncertainty for all scenarios.

This is due to the fact that Malta is located in the Sicily Channel, where the dynamics exhibit significant gradients in the direction perpendicular to the channel axis, which are differently represented by different models.

The worst or best cases do not necessarily come from the same model for all islands, that is, one model can predict the lowest hazard for Sicily while the most favorable projection for Sardinia results from another, and these distinct projections separately provide the bullets that will appear in the same plot, associated to either island.

On the other hand, good model agreement was observed for Significant Wave Height, and hazard and uncertainty could therefore be estimated from ensemble means and from the associated standard deviation (see D4.3).

The combined indicators, as well as the overall risk indicators, will clearly retain the distinction between the worst and best case. As for the thermal hazard, plots for island sub-areas are also shown.

Hazard from extreme events

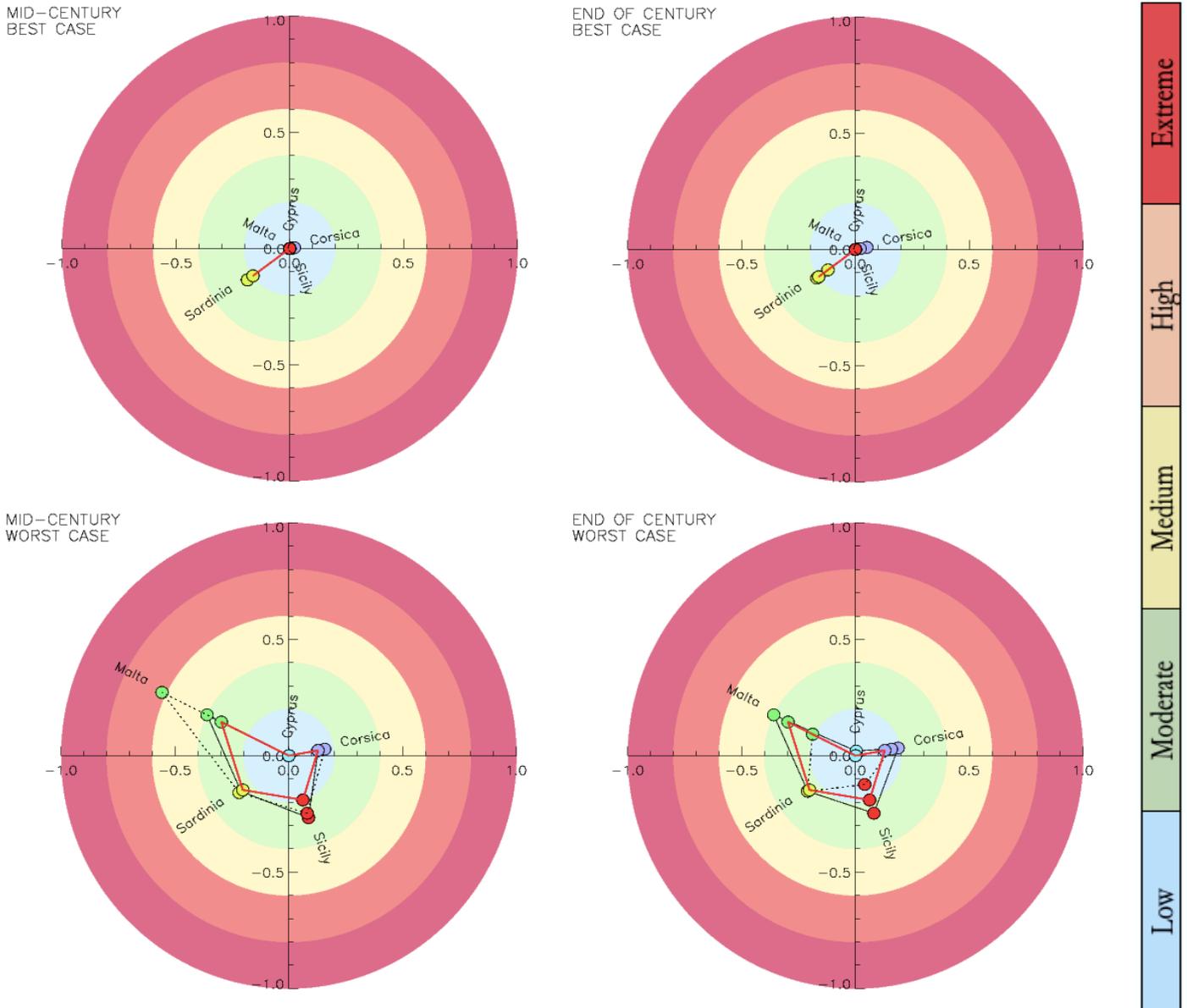


Figure 3.4.70 – Normalized sea-state hazard: **return time** - Comparison between selected **Mediterranean Islands** for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

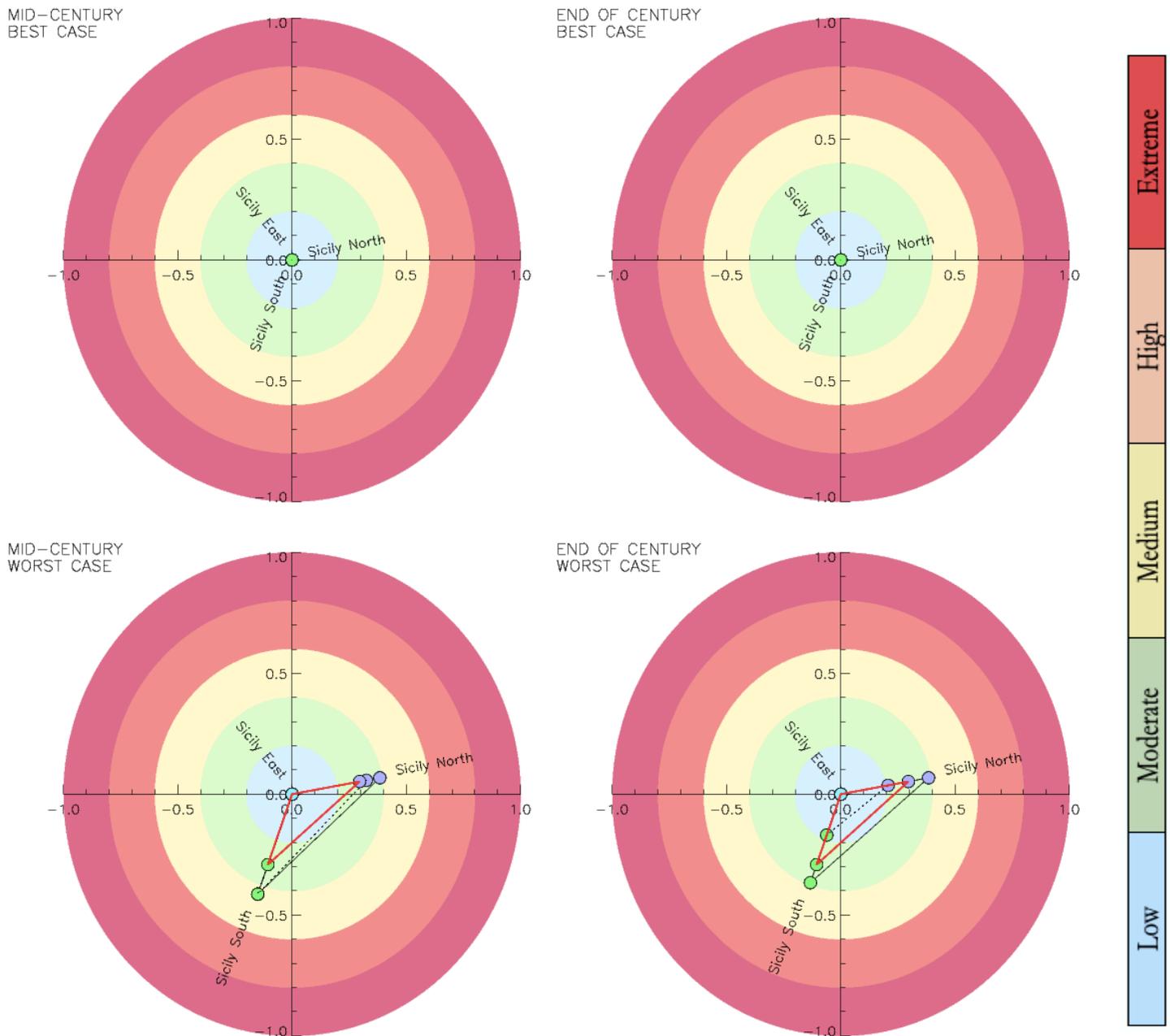


Figure 3.4.71 – Normalized sea-state hazard: **return time** – **Sicily**: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

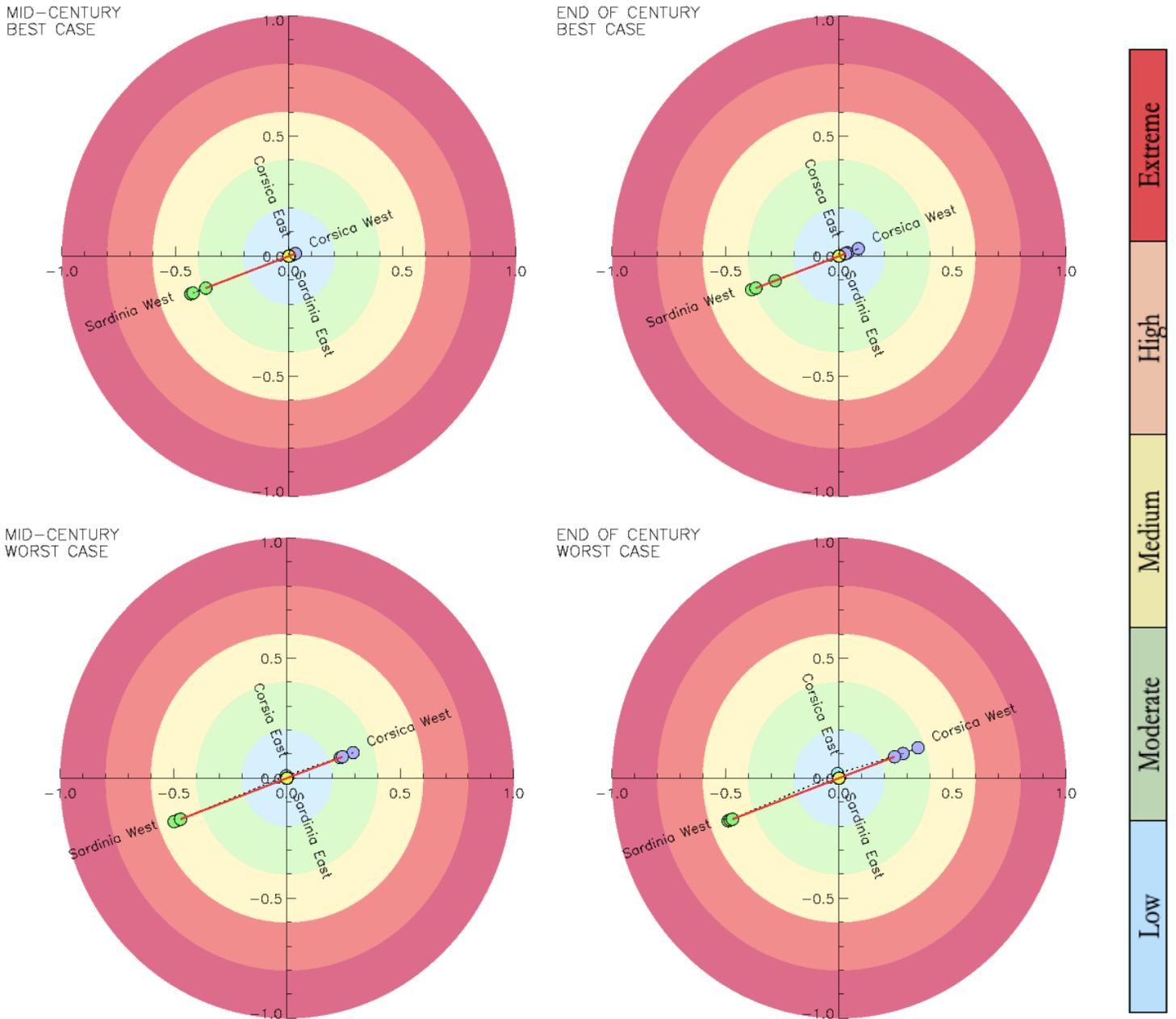


Figure 3.4.72 – Normalized sea-state hazard: **return time** – **Sardinia and Corsica**: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

Hazard from mean wave stress

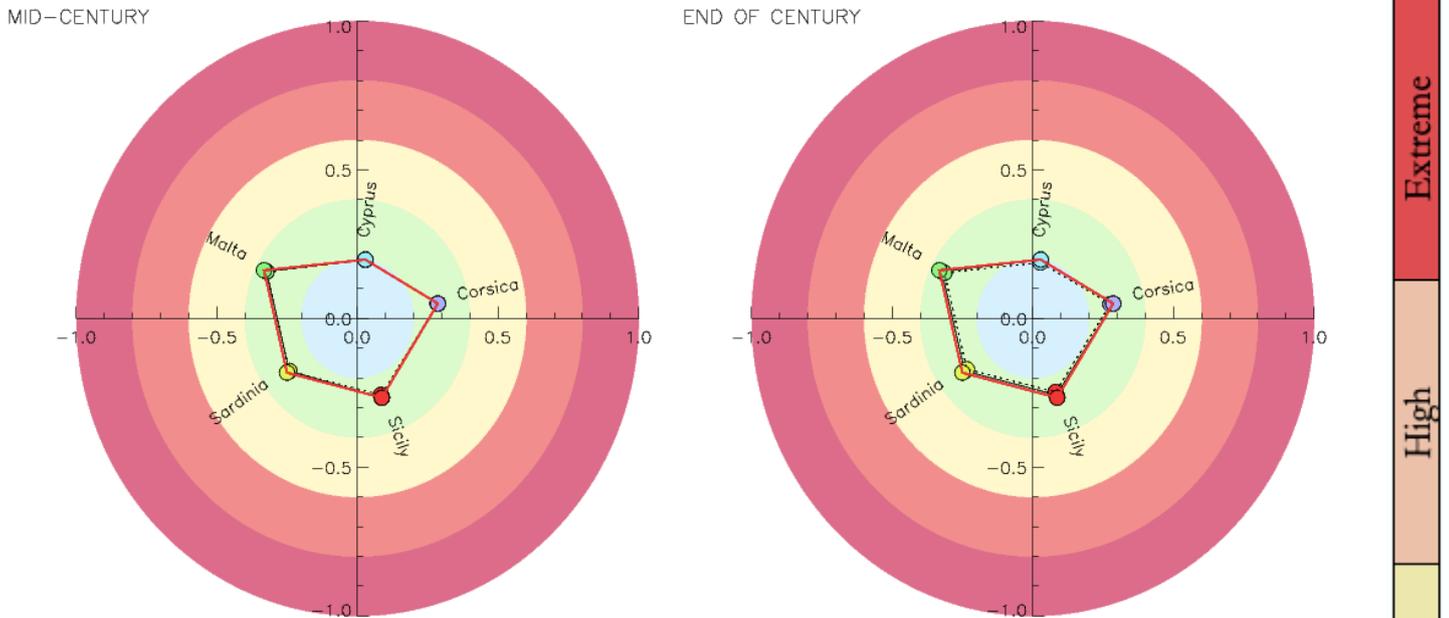


Figure 3.4.73 – Normalized sea-state hazard: **mean Significant Wave Height** - Comparison between selected **Mediterranean Islands** for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

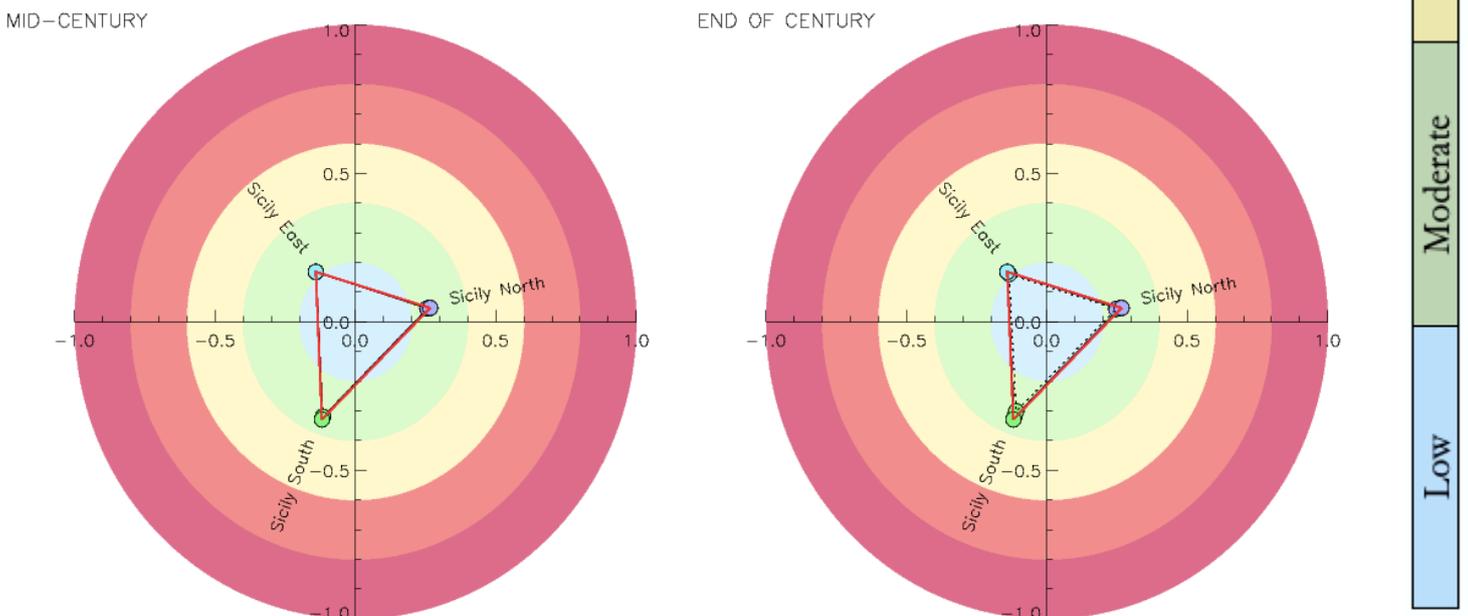


Figure 3.4.74 – Normalized sea-state hazard: **mean Significant Wave Height**– **Sicily**: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.



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This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No776661



MID-CENTURY

END OF CENTURY

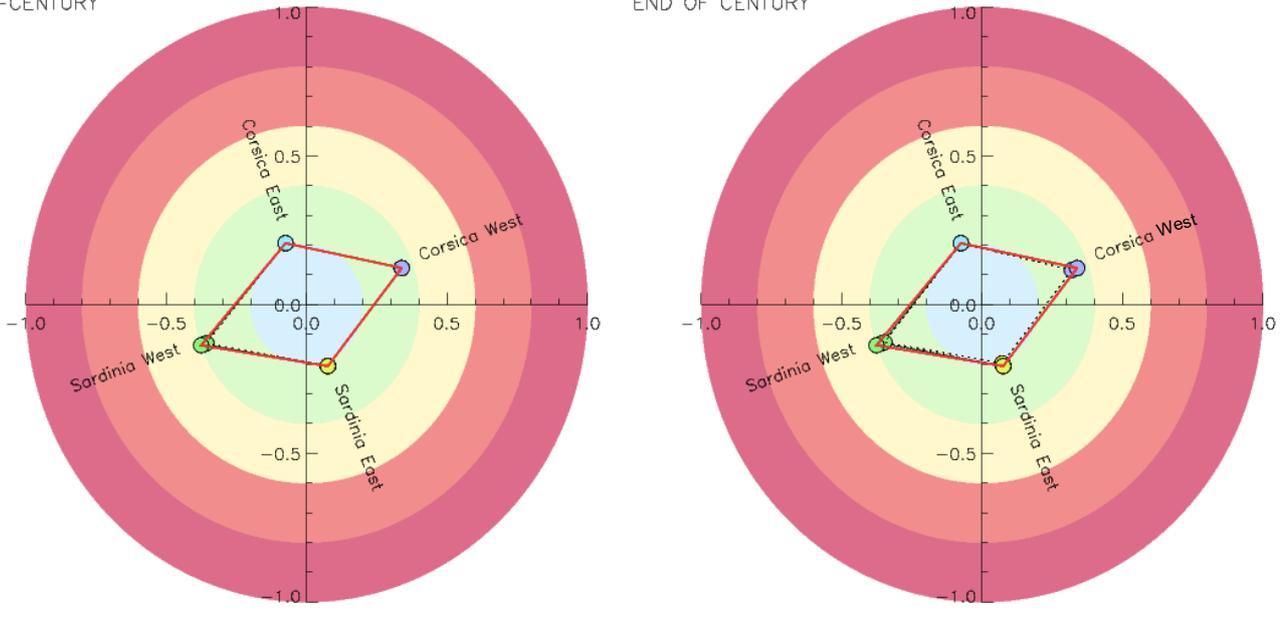


Figure 3.4.75 – Normalized sea-state hazard: mean Significant Wave Height– Sardinia and Corsica: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

Cumulative wave-induced hazard

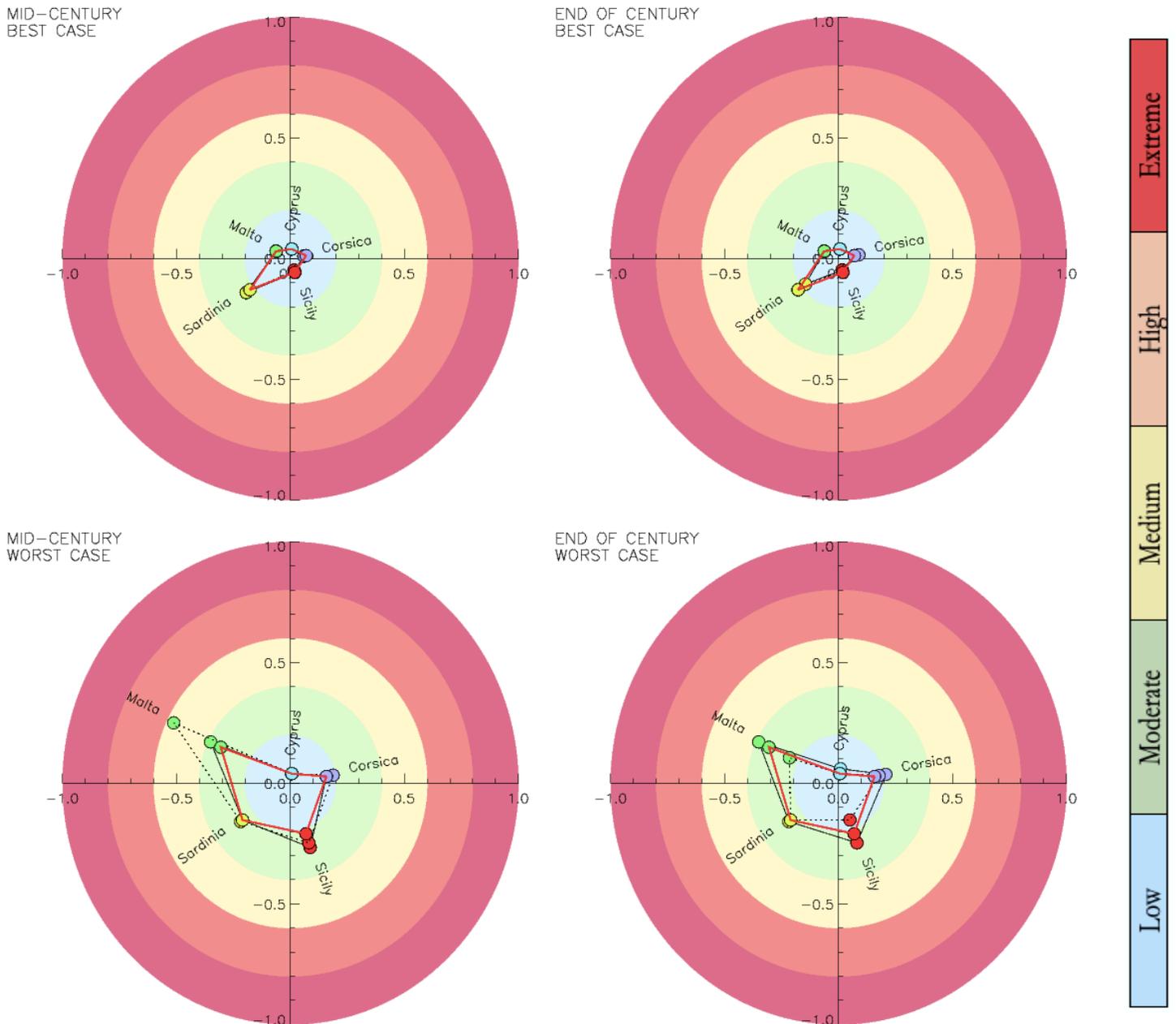


Figure 3.4.76 – Normalized cumulative sea-state hazard - Comparison between selected **Mediterranean Islands** for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

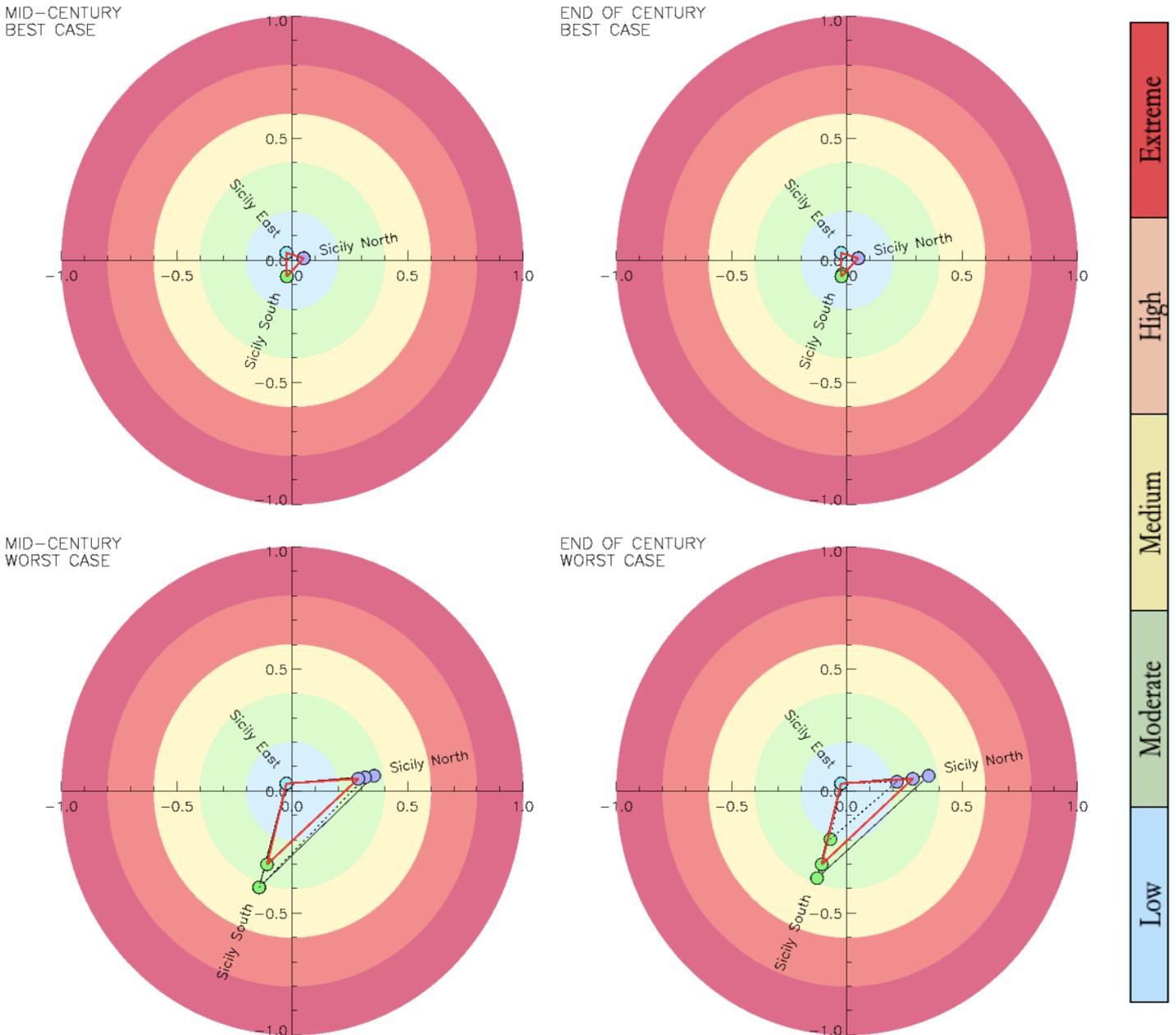


Figure 3.4.77 – Normalized cumulative sea-state hazard– Sicily: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

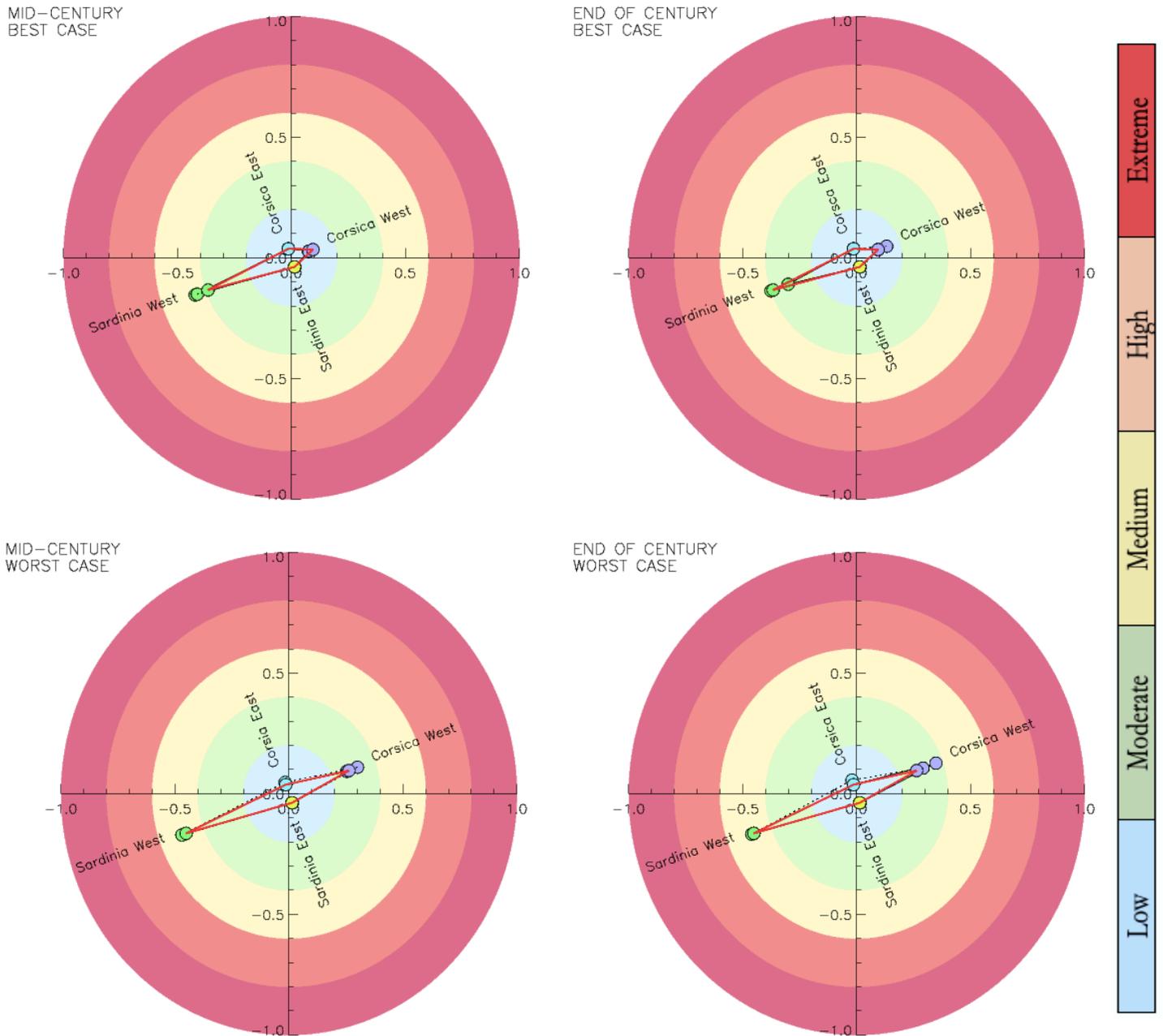


Figure 3.4.78 – Normalized cumulative sea-state hazard– Sardinia and Corsica: comparison between sub-areas for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots report the most favourable model projection among the four model realizations considered for each scenario, bottom plots the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.

Island intercomparison: exposure and vulnerability of aquaculture areas

Here the estimates for the exposure and vulnerability components are presented, for selected islands, both as tabulated values and plots, based on the GIZ method described above. Tables also report the weights used in the overall risk assessment.

Exposure and vulnerability associated to thermal hazard

Table 3.4.10 - Exposure and vulnerability indicators, the data for each island and the normalized values.

Component	Exposure			Vulnerability				
	0.4			0.3				
Sub-component				Factor of sensitivity		Factors of adaptive capacity		
Sub-component weight				0.75		0.25		
Indicator	Average Size of producers		Score for level of exposure	Sensitivity of species (stress)	Score of factor of sensitivity	Monitoring early warning systems	Capacity to change species	Score of factor of adaptive capacity
Proxy indicator	Yearly production /Number of operators		Average of normalised indicators	Temperature sensitivity of species (expert guess)	Indicator	Monitoring early warning systems	Capacity to change species	Average of indicator
	Data	Normalised		Normalised		Normalised	Normalised	
Corsica	328.6	0.12	0.12	0.7	0.7	0	1	0.5
Cyprus	811.4	0.29	0.29	0.6	0.6	0	1	0.5
Madeira	125.3	0.05	0.05	0.6	0.6	0	1	0.5
Malta	2,755.9	1.00	1.00	0.6	0.6	0	1	0.5
Sardinia	537.2	0.19	0.19	0.9	0.9	0	1	0.5
Sicily	399.6	0.14	0.14	0.8	0.8	0	1	0.5

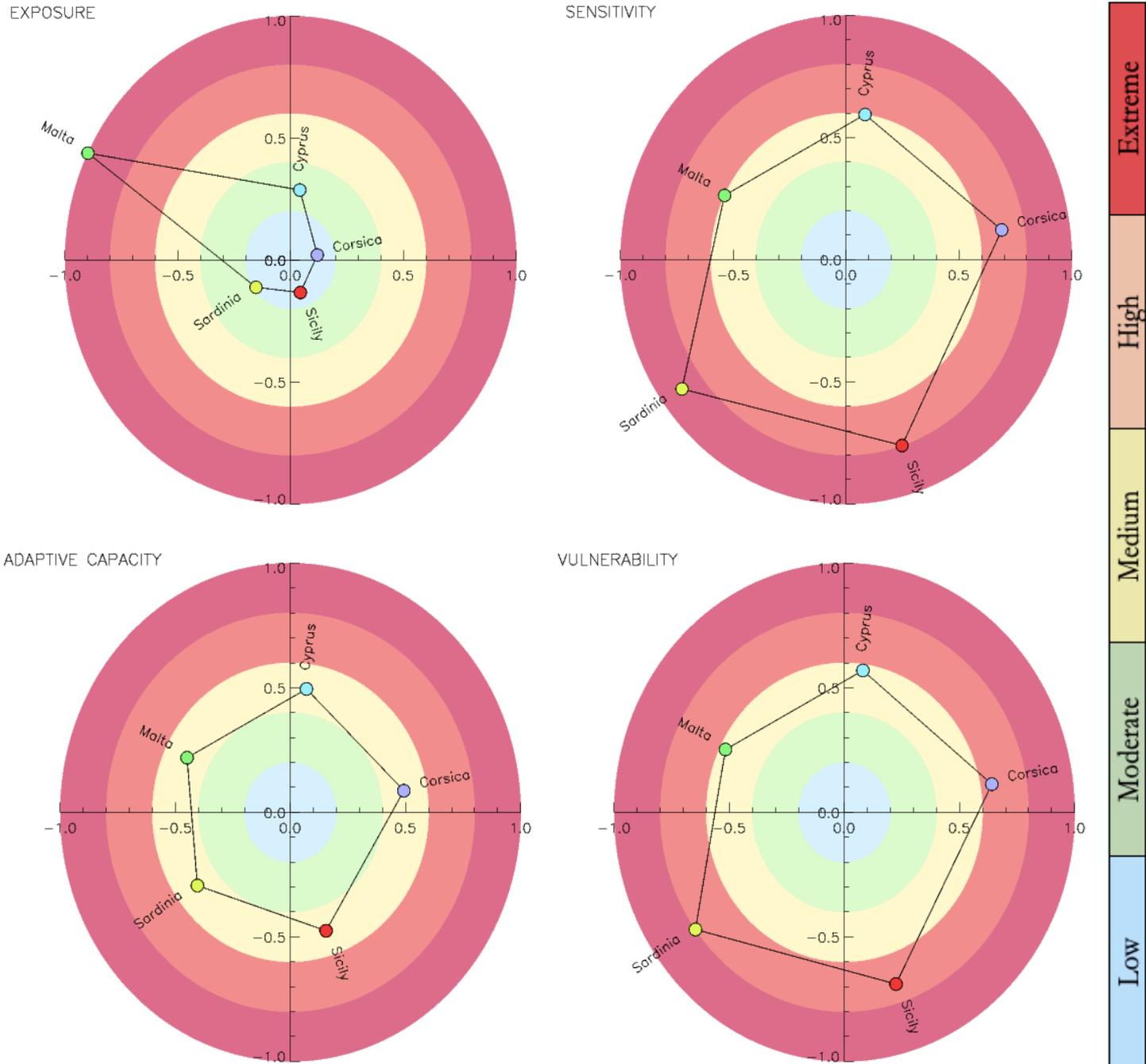


Figure 3.4.79 – Thermal hazard - Normalized exposure and vulnerability – Comparison between selected Mediterranean Islands – Vulnerability is further decomposed into sensitivity and adaptive capacity – Estimates do not change with either time or scenario.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No776661

SOCIIMPACT



Exposure and vulnerability associated to sea-state hazard

Table 3.4.11 - Exposure and vulnerability indicators, the data for each island and the normalized values.

Component	Exposure				Vulnerability								
Component Weight	0.2												
Sub-component	Factor of sensitivity				Factors of adaptive capacity								
Sub-component weight	0.75				0.25								
Indicator	Average Size of producers	Location of farms	Score for level of exposure	Sensitivity of species (stress)	Type of infrastructures (material and strength)	Score of factor of sensitivity	Distance to harbour (vessel capacity in extreme weather conditions) [average & m]	Absence of warning system	Score of factor of adaptive capacity				
Proxy indicator	Yearly production /Number of operators	Farms sheltered from wind direction	Average of normalised indicators	Estimated sensitivity of species	Type of infrastructure (based on species)	Average of indicators	Average distance to harbour (m)	Presence of warning system	Average of normalised indicators				
	Data	Normalised	Normalised	Data	Normalised	Data	Normalised	Normalised	Data				
Corstica	328.6	0.12	0.4	644	0.16	0.20	0.7	0.5	0.59	4789	0.96	0	0.48
Cyprus	811.4	0.29	0.5	3923	1.00	0.53	0.6	0.4	0.48	4616	0.92	0	0.46
Malta	2,755.9	1.00	0.5	1731	0.44	0.74	0.3	0.3	0.31	4165	0.83	0	0.42
Sardinia	537.2	0.19	0.4	1193	0.30	0.27	0.9	0.6	0.71	2183	0.44	0	0.22
Sicily	399.6	0.14	0.5	1000	0.25	0.27	0.7	0.5	0.61	5000	1.00	0	0.50

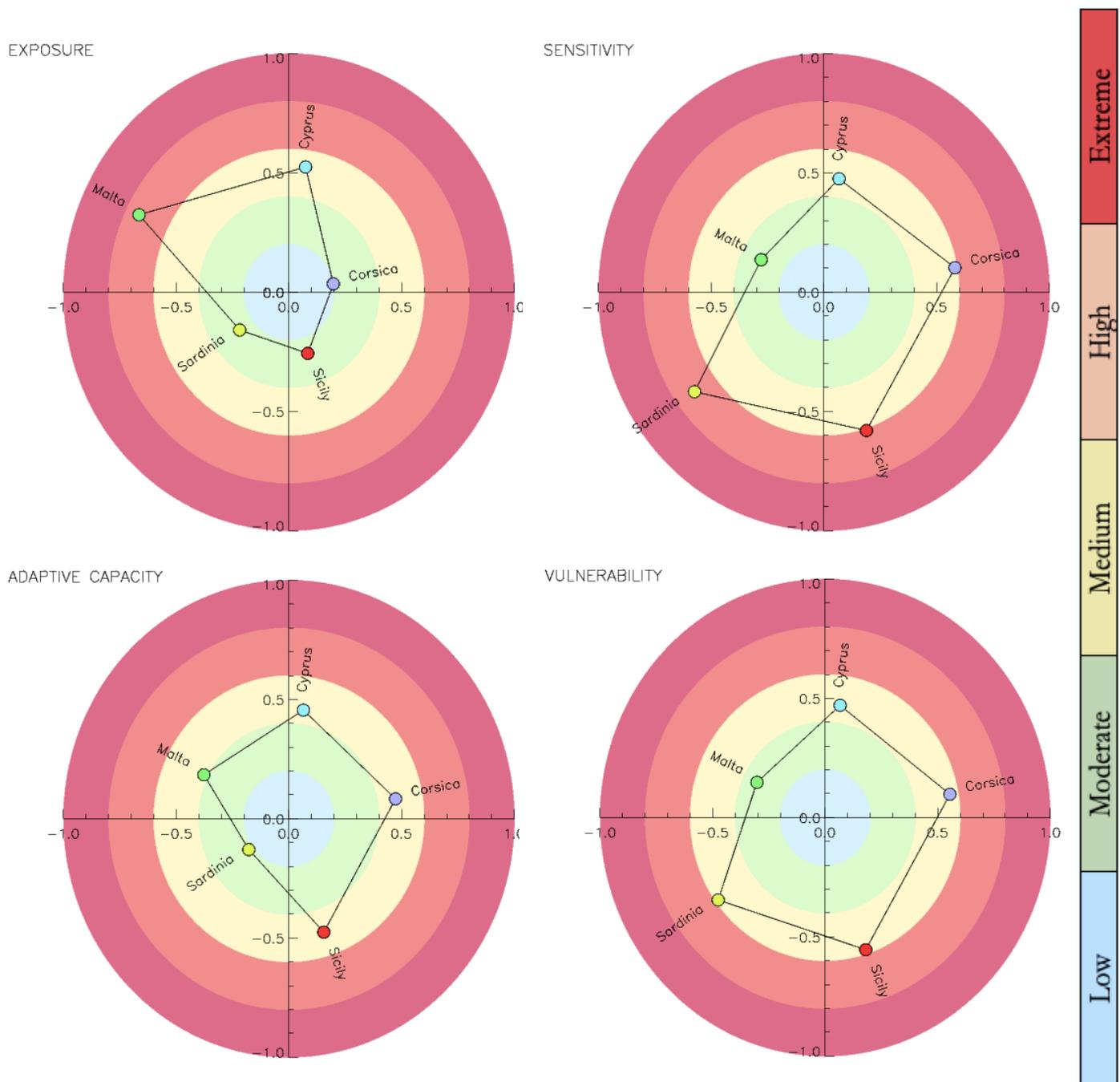


Figure 3.4.80 – Sea-state hazard - Normalized exposure and vulnerability – Comparison between selected **Mediterranean Islands** – Vulnerability is further decomposed into **sensitivity** and **adaptive capacity** – Estimates do not change with either time or scenario.



Island intercomparison: wave-induced risk for aquaculture areas

Table 3.4.12: - Weights for risk components and sub-components

(Sub)Component	Weight
	<i>Extreme events</i>
Hazard	0.6 wave height 0.2 return time 0.8
Exposure	0.2
Vulnerability	0.2
Sensitivity	0.75
Adaptive Capacity	0.25

Best-case scenario

Table 3.4.13: - Risk results for best-case scenario for impact chain Extreme weather events

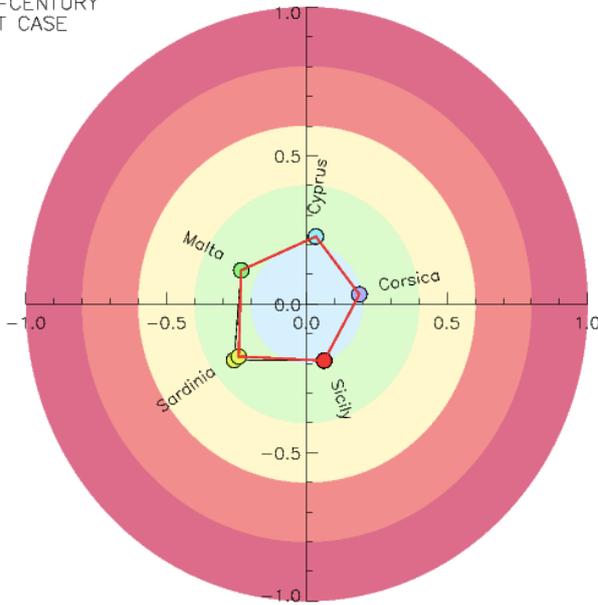
Risk	Reference period	Mid century		End century	
	Hist.	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Corsica	0.19	0.19	0.19	0.20	0.21
Cyprus	0.23	0.23	0.23	0.23	0.22
Malta	0.26	0.26	0.26	0.26	0.26
Sardinia	0.30	0.32	0.32	0.28	0.31
Sicily	0.20	0.20	0.20	0.20	0.20

Worst-case scenario

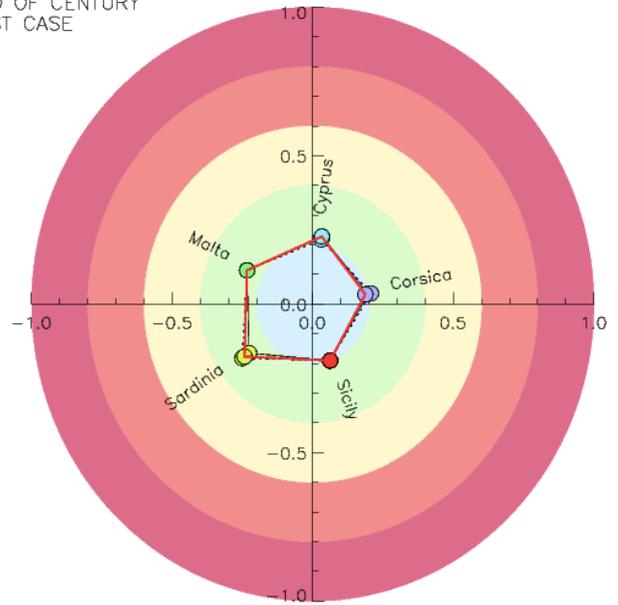
Table 3.4.14 - Risk results for worst-case scenario for impact chain Extreme weather events

Risk	Reference period	Mid century		End century	
	Hist.	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Corsica	0.25	0.25	0.26	0.28	0.26
Cyprus	0.23	0.23	0.23	0.23	0.22
Malta	0.42	0.45	0.56	0.45	0.36
Sardinia	0.33	0.33	0.34	0.33	0.33
Sicily	0.30	0.34	0.33	0.33	0.26

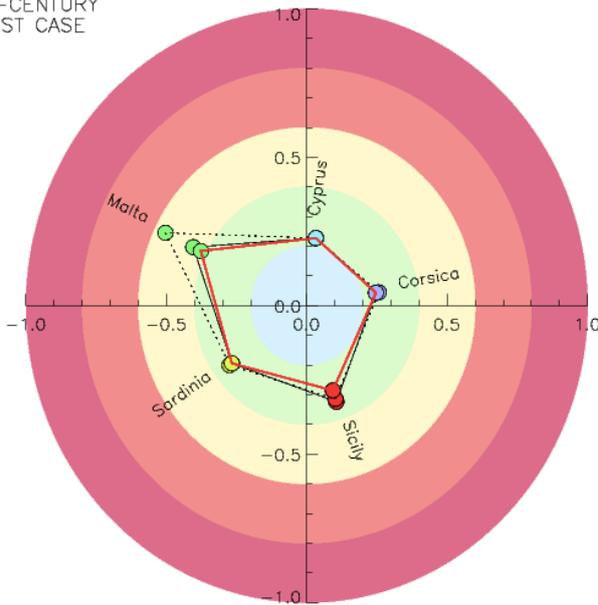
MID-CENTURY BEST CASE



END OF CENTURY BEST CASE



MID-CENTURY WORST CASE



END OF CENTURY WORST CASE

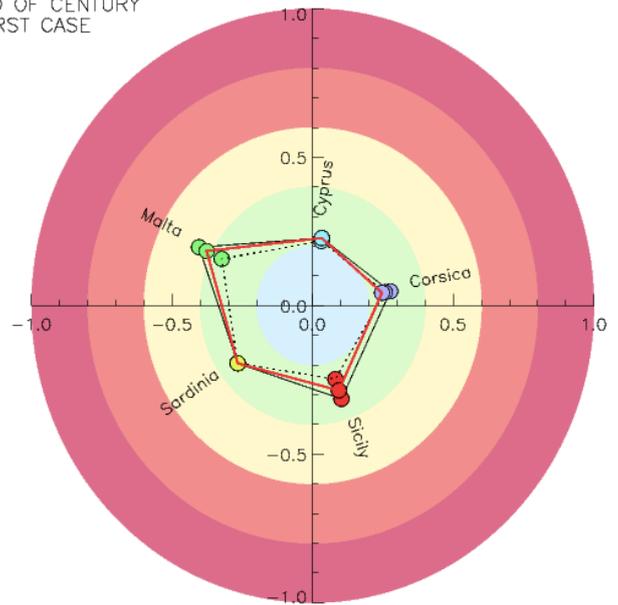


Figure 3.4.81 – Cumulative sea-state risk- Comparison between selected **Mediterranean Islands** for the reference period (red), RCP4.5 (solid black) and RCP8.5 (dotted black) - Top plots are based on the most favourable model projection among the four model realizations considered for each scenario, bottom plots on the least favourable one - Mid-century projections are shown in the left plots, end-of-century projections in the right plots.



Conclusions

- Results for the hazard induced by mean wave motion appear to qualitatively confirm those obtained by Ryan (2004), who generally classified most Mediterranean offshore farm locations as Class 3 sites, based on his overall evaluation of the mean wave field. Indeed, Ryan's rough estimate, while being unspecific, referred to non-sheltered sites and to the basin as a whole, and is therefore more severe than ours. On the other hand, our study considered existing farm locations for Malta and Cyprus (which might be expected to have been sited in comparatively sheltered areas), and average values for the bigger islands, while the sub-areas exposed to the prevailing winds (from the Atlantic in the case of Sardinia and from Africa in the case of Sicily) do, in fact lie at the limit between Classes 2 and 3. Such classification does not change across time horizons and scenarios.
- Including the probability of occurrence of extreme events that might prove unendurable for infrastructures moderately lowers the cumulative hazard (resulting from the weighted average of indicators), except for Malta, which is, however, affected by higher uncertainty under all scenarios, as inferred from the difference between the best and worst cases. Results for Sicily and Corsica also exhibit increased uncertainty, clearly deriving from the extreme event component. Again, considering sub-areas for the bigger islands leads to different classification with respect to the average values. Results for Sardinia appear to be stable across time horizons and scenarios, probably due to the Atlantic winds being well captured by the atmospheric modelling chain. The same holds for Cyprus, this time thanks to the farm area being sheltered from extreme winds.
- Thermal hazard sustainedly increases for all islands with both time and greenhouse-gas concentration. However, no normalization and classification were attempted due to the lack of absolute criteria that might guide such exercise. Likewise, although both exposure and vulnerability were estimated, the overall risk was not assessed in order to prevent misinterpretation of results, all the more as no quantitative evaluation of uncertainties was possible. Further research should be dedicated to this specific issue, by using climate projections to drive specific biological models that include farming practices and additional environmental parameters. This would allow to rigorously construct an ensemble of fish growth scenarios, exporting methods that are well established in climate sciences, and to provide farmers with detailed information as to the alternatives and trade-offs they are expected to manage.
- Vulnerability and exposure parameters had to be kept constant for future scenarios, due to the lack of information as to the development strategy of the specific islands along the global pathways. Malta appears to be the most exposed among the islands considered, due to the local size of the sector both in absolute and relative terms.
- For the Atlantic islands, uncertainties in the hazard components were too large to allow a reliable assessment, as shown in the exemplary table 3.4.15. The available projections models are highly variable, and for the Azores even the direction of change is different, with the Hadley model predicting a decrease and the ACCESS model a significant increase. For Madeira, it seems that the risk in the future will be negligible, and it could be concluded that climate change has no effect, or even a positive impact, on the occurrence of extreme events in Madeira. However, since this data cannot be considered accurate, more work needs to be done, in particular as to making higher-resolution reliable climate projections available for this area.



Table 3.4.15. - Impact Chain: Extreme weather events – Integral normalized hazard for two Atlantic areas as predicted by two different downscaled global projections

	Hadley centre			ACCESS		
Hazard	Historic	RCP 8.5 Mid-century	RCP 8.5 End-century	Historic	RCP 8.5 Mid-century	RCP 8.5 End-century
Azores	0.83	0.76	0.79	0.15	0.41	0.67
Madeira	0.20	0	0.01	0	0	0

- Conclusions are largely based on limited data and on the subjective evaluation of the experts that participated in the project. They therefore need to be further tested within interdisciplinary discussions with external specialists, and would largely benefit from a closer interaction with farmers. However, one major obstacle to be removed is the renitence of private enterprises to provide detailed data to feed the public scientific debate, as well as to incorporate externalities into their business plans.
- Despite the impossibility to rigorously normalize and classify the hazard implied for aquaculture activities by rising seawater temperatures (SST), a simplified approach can be adopted by taking past island mean SST as an indicator that can be grossly related to past productivity rates. This approach will be exploited in the context of WP5 activities, in order to assess the potential impact of water warming on future farm productivity, through the following steps:
 - production is computed as a function of temperature, via a growth function **f**
 - the growth function **f** is postulated to be given by the difference between two exponential functions, whose constant parameters are unknown and need to be estimated from data
 - such constant parameters (per species) are estimated from literature and/or by empirically fitting production to observed seawater temperature data under present climate, accounting for the mean seasonal cycle
 - the derived growth functions are used to compute future annual variations in production on a climatological basis, by summing the expected climate-change-induced mean temperature variations (from Table 3.4.??) to the observed seasonal cycle as an offset.

Overall, the method does not address the problem from the risk assessment perspective, but only aims to estimate potential mean economic losses in the hypothetical case of unchanged farming practices, no acclimation of species and a seasonal cycle that is unaffected by climate change. Any combined effect of temperature and other parameters is overlooked, as well as that of temperature variations over time scales shorter than monthly mean climatologies.

On the other hand, this report concentrates on the characterization of potentially adverse extreme events, and proposes the *increase in the mean duration of above-optimal-threshold events* as a possible indicator. As a matter of fact, optimal thresholds are exceeded every year under present climate already, and the relevant information is if they risk to be unsustainable in the future. The hypothesis of species acclimation could be further included, by exploring the sensitivity of results to changing optimal thresholds.



4. Climate-change-induced risks for the four blue economy sectors

4.1. The Impact Chain approach: comparative evaluation of results

The three tables below, one for each time horizon, are meant to visually convey information on the data gaps (per island) encountered during the risk assessment exercise and to allow island and sector inter-comparison, as to present and future risk.

For each specific IC (stated in the column header), the colour used for the scores indicates whether:

- It was possible to normalize most risk components using absolute risk criteria, either reported in the literature or suggested by experts and stakeholders (red). In this case, a proper risk scale was defined, ranking from *low* (<0.2) to *extreme* (>0.8).
- Either the AHP method was adopted (black) or most risk components were normalized via a max-min approach (green), so that the reported scores cannot, in general, be interpreted as a measure of actual risk, but definitely allow island ranking. In the case of max-min normalization, however, a quantitative risk scale has been in fact defined by SMTs, as the involved experts relied on the robustness of their informed conclusions.

In the present climate table (Table 4.1.1), the cell background colour tentatively indicates whether non-negligible, albeit small, future **increases** in the risk score were found at some time for any scenario (yellow, usually for the far-end rcp8.5 scenario), or if no relevant change was noted (grey) for either scenario. A green background corresponds to cases when future increases were only found for the worst projection, while the most favorable one (in parenthesis) does not project any change (this only applies to the aquaculture sea-state IC, for which the most and least favourable model projections were separately considered). Decreases were not considered in this specific analysis.

In each future scenario table (Tables 4.1.2 and 4.1.3), the cell background colour tentatively indicates, regardless of the magnitude and direction of change with respect to present conditions, whether there is no appreciable difference between the two different pathways considered (light grey), whether RCP8.5 gives higher scores than either RCP2.6 or RCP4.5 (dark blue), or whether RCP8.5 gives lower scores (light blue). Other colours are only used to distinguish different scenarios. RCP4.5 was only considered for aquaculture in the Mediterranean islands, A1B and B1 only for the Azores.

Island were arranged according to their geographical position, from west to east in the Mediterranean and from north-west to south-east in the Atlantic, so as to highlight any geographical pattern that should arise. However, at the moment the matrix is too sparse for this sort of consideration.

Fehman and the West Indies constitute isolated cases.

The sparsity of the resulting matrix constitutes an evident issue with the risk assessment exercise, and in particular the lack of sufficient information for the Baltic and Atlantic islands, for at least one of the risk components. Likewise, the different methods used to define risk classes for the Impact Chains that have been fully operationalized impairs cross-sectorial comparison and, in some cases, an absolute risk assessment beyond island ranking with respect to a not fully quantifiable threat. The reasons for these limitations have been discussed in the sectoral sections above, but here they stand as a severe warning for any forthcoming work and help set the requirements for effective and profitable future research.

One robust conclusion can be drawn by comparing scores for the Aquaculture and Maritime Transport ICs only, which is that the classification of the Mediterranean basin as relatively mild with regard to wave climate is not expected to significantly change in the future. On the other hand, no conclusive overall inference can be drawn from the inter-comparison of the variety risks that are directly induced by rising temperatures, both in the atmosphere and the ocean, which are expected to pose the most severe threats to the island economies, usually under the severe RCP8.5 scenario.



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RISK per Impact Chain – PRESENT CLIMATE

Table 4.1.1.	Marine habitat degradation	Forest fires	Thermal comfort	Economic losses from extreme events	Energy demand: Cooling	Energy demand: Desalminization	Transport disruption
Balearic Islands	0.19	0.35	0.20	0.30			0.33
Sardinia		0.34	0.17	0.19			0.22
Corsica		0.35		0.20			
Sicily	0.17	0.30		0.26			
Malta	0.18	0.15	0.20	0.49		0.47	0.38
Crete		0.47					0.23
Cyprus	0.28	0.58	0.26	0.23	0.46	0.40	0.24
Azores		0.32					
Madeira		0.51					
Canary Islands	0.18	0.52	0.17		0.31	0.29	0.34
Fehmarn							



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RISK per Impact Chain – MID-CENTURY

Table 4.4.2	Marine habitat degradation		Forest fires		Thermal comfort		Economic losses from extreme events		Energy demand: Cooling		Energy demand: Desalminization		Transport disruption	
	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP4.5	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Balearic Islands	0.19	0.19	0.35	0.37	0.20	0.20							0.28	0.33
Sardinia			0.35	0.39	0.17	0.17	0.33 (0.32)	0.34 (0.32)						
Corsica			0.36	0.39			0.25 (0.19)	0.26 (0.19)					0.19	0.24
Sicily	0.17	0.17	0.32	0.36			0.34 (0.20)	0.33 (0.20)						
Malta	0.18	0.17	0.16	0.17	0.20	0.20	0.45 (0.26)	0.56 (0.26)	0.51	0.53	0.54	0.61	0.35	0.40
Crete			0.51	0.56									0.21	0.26
Cyprus	0.28	0.28	0.61	0.66	0.26	0.26	0.23 (0.23)	0.23 (0.23)	0.48	0.51	0.41	0.43	0.21	0.26
Azores			AIB	B1										
			0.39	0.42										
Madeira			0.51	0.52										
Canary Islands	0.18	0.19	0.52	0.54	0.17	0.17			0.31	0.38	0.46	0.54	0.29	0.35
Fehmarn														
West Indies														



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RISK per Impact Chain – END OF CENTURY

Table 4.4.3	Marine habitat degradation		Forest fires		Thermal comfort		Economic losses from extreme events		Energy demand: Cooling		Energy demand: Desalminization		Transport disruption	
	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP4.5	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Balearic Islands	0.19	0.20	0.34	0.42	0.20	0.20							0.26	0.34
Sardinia			0.33	0.45	0.17	0.18	0.33 (0.28)	0.33 (0.31)						
Corsica			0.35	0.44			0.28 (0.20)	0.26 (0.21)					0.19	0.27
Sicily	0.17	0.17	0.32	0.44			0.33 (0.20)	0.26 (0.20)						
Malta	0.18	0.17	0.16	0.22	0.20	0.20	0.45 (0.26)	0.36 (0.26)	0.51	0.57	0.55	0.67	0.34	0.41
Crete			0.51	0.64									0.20	0.28
Cyprus	0.28	0.27	0.61	0.69	0.26	0.25	0.23 (0.23)	0.22 (0.22)	0.48	0.55	0.41	0.44	0.22	0.29
Azores														
Madeira			0.50	0.54										
Canary Islands	0.18	0.18	0.52	0.55	0.17	0.17			0.32	0.45	0.47	0.58	0.25	0.34
Fehmarn														
West Indies														



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4.2. Key climate risks, vulnerabilities and opportunities for the selected islands

For the **aquaculture** sector, future wave-induced risks, even under the worst-case scenarios, are not expected to exceed medium scores for all the Mediterranean islands. This still holds if wave periods are considered (see 7.7), as they remain around 5 sec, a moderate/medium risk class if considered in combination with the relatively low SWH (Faltinsen and Shen, 2018). With respect to extreme weather, Malta, southern Sicily and west Sardinia are found to be the most critical areas, Sardinia and Sicily also exhibiting higher vulnerability, as the local sector includes a high percentage of mussel culture, which is more sensitive than fish farming. The main impact of climate change is expected to be associated to warming seawater. However, although a gross estimate of the implied potential economic losses has been carried out in WP5, a thorough assessment of its consequences for the productivity of farms would need additional specific modelling efforts in close collaboration between enterprises and scientists. In this case, as for the less threatening wave-induced hazard, Malta is liable to exhibit the highest risk score, due its higher exposure.

Rising temperatures are also directly and indirectly responsible for the expected increase in **energy** demand, caused either by the necessity of guaranteeing public safety, health and food security through widespread access to electric cooling, or by the need of an additional supply of desalinated water. The Atlantic islands show a more contained increase of CDD than the Mediterranean islands, while the SPEI decrease is similar in both basins. One reason for this different behaviour can be the higher sea surface temperatures of the Mediterranean Sea in summer. Another factor may be the different wind regimes in summer, as trade winds are strong and persistent over Canary Islands and Madeira, contributing to moderate temperatures, while over the Mediterranean Sea winds are generally low in summer. In general, the risk induced by the increased cooling demand is lower and less uniform than that associated to increased desalination, as the drought hazard scores indicate a much more homogeneous and extended impact on water availability. A reason for this is that more severe drought conditions will develop due to the superposition of two trends, the temperature increase and the precipitation decrease, both in the Mediterranean and Atlantic islands, under the high-emissions scenario (RCP8.5). It is an open question if on long time-scales (several decades, variations between 20-year average values) the impact of the climate hazards is larger, but this seems reasonable, as cumulative effects of persistently higher temperatures and sustained droughts will likely have a profound effect on the cooling and desalination energy demand. In order to fulfil the augmented demand, renewable energies like wind and solar are a safe bet, as they will maintain its present potential with only limited and slow changes, that will be even positive in some cases.

Coming thus to the supply side, the frame for the energy sector are the binding targets established in the 2030 climate and energy EU framework and the long-term horizon of a decarbonized energy system by 2050. The future change of wind energy and PV productivity should be rather small in general: around 5% or less with respect to the reference period in many cases, with maximum changes of about 10% for some islands at the end of the century under RCP8.5 scenario (particularly for wind energy productivity over land). A 10% productivity change could have a significant impact on a planned or existing plant if it occurs over the lifetime of the power plant, but in this case such a change would extend over many decades, which will facilitate adaptation and efficiency measures.

In general, projections show a decreasing tendency of wind energy productivity over the Mediterranean region, with a more important decrease for the RCP8.5 scenario. The main exception is Crete, which shows a consistent increasing tendency. Projected PV productivity changes are generally smaller than wind energy changes. In most cases PV productivity remains constant or slightly decreases. The main exception is Fehmarn, which shows a clear decreasing tendency in PV productivity under RCP8.5 scenario, reaching a 10% decrease by end of the century.



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Renewable energy productivity droughts are a measure of the variability of the resource. Wind droughts are much more frequent (around 50% of the days for most islands) than PV droughts (10% or less of the days). This agrees with results from the study of Raynaud et al. (2018), and highlights the stable character of the solar productivity in comparison to wind productivity over time. Wind energy droughts are more frequent in the Mediterranean islands than in the Atlantic islands or Fehmarn. The best quality resources in terms of stability are found for Canary Islands, which show the minimum values of both wind energy and PV droughts among all islands. Fehmarn shows by far the worse PV drought score, corresponding a drought frequency of 23% of the days.

Projected changes in the frequency of droughts are small, with future variations that generally do not attain a magnitude greater than 5% of the days. This indicates that the time-variability characteristics of wind and PV energy are a robust feature, which is relevant for planning the amount of storage or backup needed. The combination of PV and wind energy has generally a very positive impact on the frequency of droughts as a result of the complementarity of both sources. This impact also exists but is less clear for islands with substantial summer wind energy resources (Canary Islands, Madeira and Crete).

As part of the pathway towards very high or 100% RES shares, offshore wind energy should play a very relevant role, although solutions need to overcome the obstacle posed by the deep bathymetry surrounding most of the islands. Nevertheless, some technologies are now approaching commercial deployment, so that floating offshore wind plants are already planned near Gran Canaria and Sicily. Offshore PV could also be an interesting option for some islands, particularly when land surface limitations are large. There is growing interest in this option, as shown by the test plants being installed and the references made to this technology in the Roadmap for the Offshore Renewable Energy Strategy of the European Commission or in the report of Monitor Deloitte and Endesa (2020) about the accelerated decarbonization of Canary and Balearic Islands.

The combination of different types of offshore renewable energy sources in the same platform is also attracting interest, as the different sources can exhibit complementarity in time and the combined output can thus be more stable and reliable. The different RES can also share part of the installations, like the connection to land, reducing their cost (Pisacane et al., 2018; MarineEnergy, 2019a). The European Union is trying to promote such combinations, through projects like MUSICA (Multiple Use of Space for Island Clean Autonomy) which will design and test a floating offshore platform integrating wind, PV and wave energy for use on islands (MarineEnergy, 2019b), and plans to develop roadmaps for its deployment in three case study islands, among them Malta and the Canaries (MaREI, 2020). Interconnections to the mainland will anyway remain very important for supply safety, although excessive dependency on interconnections to mainland should be avoided, to reduce the risk of blackouts, as the failure of a single element (one transmission line) can knock out instantaneously a large proportion of the power of an island and even cause an island-wide blackout, as has occurred several times in Malta in the last years. Again, Malta is particularly vulnerable to climate change impacts on the energy sector: on the demand side, at present it already has a high rate of cooling installations and a high percentage of desalinated water with respect to total water consumption, so that future temperature and drought increases will worsen an already difficult situation; on the supply side, it is an island with large constraints on onshore wind and PV energy, due to its small size and large population density. There are also physical obstacles for the installation of offshore wind energy plants, among which the local deep bathymetry. However, Malta has already applied strong demand side management measures in the water sector through the significant reduction of water leakages from 2004 to 2009. This factor has been decisive in the evolution of the desalination energy demand, which decreased by 20% from 2004 to 2018. During the same period, the GDP grew by 80%, the number of tourists doubled and drought conditions worsened. The



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downside of this positive results is that the possibilities for further action in this respect are very limited.

New financing possibilities linked to the recently approved EU COVID-19 recovery fund and, over the longer term, associated to the European Green Deal, should facilitate the deployment of renewables in the islands, as the energy transition is a key target. Indeed, accelerating the transition to a decarbonized society would effectively counteract future risks, as there is a radical contrast between the scenario in which robust emission reduction policies are implemented (RCP2.6) and the high-emissions scenario (RCP8.5). Not only are the hazard scores much lower for RCP2.6, but they even tend to decrease slightly during the second half of the century, while for RCP8.5 the hazard scores tend to rise in a sustained way. Nevertheless, the full implementation of an energy system based on RES requires further progress in the automation of energy production and distribution, so as to integrate variable sources of electricity into the distribution grid and to automatically minimize the impact of generation peaks and troughs, thus maintaining a constant balance between electricity supply and demand avoiding a blackout or any other cascading problem.

Consistently with the moderate/medium risk associated to wave-induced hazard in aquaculture, the future risk for **Maritime Transport** disruption is not expected to exceed medium risk scores, even under the business-as-usual pathway. As expected, our analysis highlighted a higher risk for most islands towards the end of the 21st century and under the business-as-usual RCP8.5. Malta was found to be most vulnerable (risk values 0.335-0.414) also as to the maritime sector. This is because of the higher exposure and vulnerability components in this particular island. On the contrary, Corsica is the island less susceptible to climate change impacts (risk values 0.194-0.273). For some islands (e.g. the Canary Islands), the future risk increase is constrained by a reduction of the exposure indicators, which is driven by population decrease. This is found to counterbalance the projected augmentation of climatic conditions due to climate change.

Regarding the **tourism** sector, tourism-related industries represents a significant component of the GDP in European islands, and all projections agree that such relevance to is expected to be maintained throughout the 21st century. Tourism is strongly dependent on climate, and consequently climate change may significantly affect this sector, altering the geography of international and domestic tourist flows, and possibly requiring resizing/restructuring efforts and the development of new products and activities.

The selected ICs are representative of different dimensions of the complex relationship between climate change, the ecosystems affected by climate change, and the environmental services those ecosystems provide to sustain coastal and marine tourism in European islands. The weather discomfort IC reports on the direct impact of changes in climate variables on the comfortability of vacation stays in the islands. The forest fire IC informs on the impact that this climate change-powered phenomenon may pose on the terrestrial ecosystems that hold the rich and endemic biodiversity of the islands, which in its turn is a patrimony of all Europeans; fires also put at risk public and private assets and the safety of tourists and residents. The marine habitats IC accounts for the impacts of climate change on the ecosystem that mainly supports the coastal and marine tourism activities, such as seawater bathing, diving snorkelling, surfing, windsurfing.

The main purpose of the ICs operationalisation is to compare the abovementioned risks amongst a selected set of European islands. For the case of thermal discomfort and marine habitats degradation five islands were chosen, representative of the Atlantic Ocean islands (the Canary Islands), and the East (Balearic Islands), the Middle (Malta and Sicilia for the case of Marine Habitats and Malta and Sardinia for Thermal Discomfort) and the West Mediterranean (Cyprus) ones.

In both cases, the relatively smooth expected changes in the hazard component over the Atlantic region surrounding the Canary Islands were determinant for this Archipelago to be located at the low end of the risk scale, despite its high socioeconomic exposition. At the other extreme, under the



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RCP8.5 scenario (no control of emissions), Cyprus is expected to experience notable higher variability and periods of extreme high temperatures both in the atmosphere and the ocean, as well as additional stresses on its marine environment originating from the neighbour Red Sea. Cyprus therefore exhibits the highest risk scores, its adaptive capacity not being sufficient to compensate for the hazards.

The Balearic Islands show comparatively high risk for marine habitat degradation, due to very high natural and industrial exposition, while the irrelevance of sun and sand tourism (low exposition) makes Malta display a relative low risk from marine habitat degradation, although significantly higher scores as to thermal discomfort. For Sicily, which is significantly exposed to marine habitat degradation, the main strength in coping with climate change threats is represented by its potential to substitute marine-based tourist activities, thanks to its extraordinary endowment of assets in culture, inland landscapes, gastronomy, archaeology. Finally, Sardinia benefits from a relative low risk from thermal discomfort, due to the relative mild hazard, intermedium level of exposition and medium-high adaptive capacities.

As regards forest fires, for the reference period (1986-2005), the overall risk is medium for Atlantic Islands (Madeira and Canary Islands – predominance of the exposure component) and Eastern Mediterranean Islands (Crete and Cyprus predominance of the hazard component). Risk for other islands is low (Sicily and Balearic Islands – predominance of the exposure component, Corsica and Sardinia - predominance of the vulnerability component) and very low for Malta (the only island with a quite balanced distribution across components).

The hazard scores increase from West to East and from North to South, with the exception of Malta, which is much smaller, and where the selected grid cells are mostly influenced by maritime conditions. Under RCP2.6, fire danger appears to return to present conditions towards the end of the century, except for Crete, whose score will increase from medium to high. Under RCP8.5, the increase is much more prominent, ranging from 22% to 46%, with the highest values for Corsica, Sardinia and Sicily, which implies that under this scenario at the end of the century, the western and central Mediterranean will be more affected.

As to the exposure component, Atlantic Islands (Madeira and Canary Islands) exhibit higher values than Mediterranean Islands (from low to medium score), while in the Mediterranean basin it increases from North to South. This result is mainly explained by differences in the *level* of exposure rather than in its *nature*, which shows similar values across Mediterranean islands, except for Malta, whose score is very low. However, the specific characteristics that determine the nature of exposure vary across islands, despite such comparative homogeneity: Corsica has the highest score for forest areas, followed by Madeira and the Canary Islands. The latter two, in particular, have the highest score for forests belonging to protected areas. We can find a significant proportion of cultivated areas in other islands, namely: Sicily, Sardinia, Balearic Islands, Crete and Cyprus. At the same time, the level of exposure is particularly important for the Canary Islands and Madeira, due to their high scores in each of the 4 considered indicators: population density, population over 65 years, population under 9 years, and tourist density.

In terms of vulnerability, results show large variability across islands. The vulnerability score for Corsica is very high, followed by Sardinia (high), Madeira, Balearic Islands, Cyprus and Crete. The scores for Malta, Canary Islands and Sicily are low. Breakdown by sub-component highlights quite homogeneous scores for adaptive capacity, whereas sensitivity scores (Flammability Index) are very different across islands, Corsica and Sardinia having the highest scores, Malta, Sicilia and Canary Islands the lowest. As to the adaptive capacity sub-component, despite its quite homogeneous scores, factors of influence are quite different across the islands. It must be noticed that all islands, apart from Crete and Sicily, have high scores for employees in the primary sector, indicating low ability to adjust to changes. Cyprus presents a very high score for education, which is, on the contrary, very



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low for Madeira, Corsica and Malta. Scores for density of firefighters and volunteers are very high in Crete, Canary Islands and Malta and high for the rest of the islands except for Cyprus (medium).

From a wider perspective, when European islands are compared to other competing tourism destinations, it is worth reflecting on the overall risk they are expected to face. In islands, the proximity of the sea mitigates temperature variability with respect to continental territories, which means they maintain a relative advantage as to weather comfort. For example, the Canary Islands are now perceiving a recovery in summertime fluxes originating from the regions of southern Germany, that experience extreme temperatures. This must not distract the attention from the fact that European islands are a paradigm of clear waters and nice marine landscapes, and that they will therefore have to face demanding challenges to prevent the degradation of their marine habitats. The complete elimination of other human-induced threats to marine habitats other than climate change, such as sewage discharges, and the development of substitutive products and tourism activities that are less dependent of pristine marine environments, will be crucial for European islands to keep their competitive position in global tourism.

5. Conclusions and outlook

The quality of the impact chain operationalization strongly depends on data availability over long periods, and the lack of sufficient data severely constrained the work of all SMTs in SOCLIMPACT. On the side of hazards, few model projections were available for peripheral areas such as the Atlantic islands, and even where significant modelling efforts have provided sufficient coverage in terms of the statistical sample size, resolution is still too coarse, or relevant processes are not represented in climate model parameterizations. There is a specific uncertainty source in the photovoltaic projections, as most regional climate model simulations, including the ones used here, do not include a projected evolution of aerosols in future climate runs. The missed effect of the likely evolution of aerosols should probably increase to some degree the future surface solar radiation and PV productivity over most of the islands (Gutiérrez et al., 2020), in comparison to the projections presented here. This will likely strengthen the good perspectives for PV energy. More future simulations should include this effect in order to obtain improved future projections. As to the data gap that affects peripheral island, there is presently no good source of regional climate model data for the Azores, which are not included in the MENA-CORDEX ensemble used for Madeira and the Canary Islands, which anyway themselves lie at the boundary of the regional model domain, where regionalization basically amounts to the interpolation of the global driver. In order to solve this issue in the future, coordinated climate model experiments like CORDEX should consider new domains (e.g. a North-Atlantic domain) or expand one of the existing domains, in such a way that all European islands are fully included. The situation is even more dramatic for the West Indies, which can only rely on global models if a model ensemble of reasonable size is to be created.

However, some of these limitations might not necessarily represent a major drawback from the point of view of impact assessment and intervention planning, except for the regions where reliable climate projections are altogether lacking, as improved climate models have been proved to often produce wider rather than smaller ranges of uncertainty in their predictions, while local impacts appear to depend more on the relative resilience of a given society than on the magnitude of environmental change (Maslin and Austin, 2012). For the energy sector, for example, the objective method used for obtaining the weights of the risk components, based on correlations between observed energy demand and observed data for the indicators, pointed out that several exposure and vulnerability factors have a stronger weight than the climate hazards on short time-scales (interannual variations for periods of about 10 years). This is consistent with the drivers considered in the national forecasts,



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for periods of 10 years, performed as part of the EU Energy Efficiency Directive (Jakubcionis et al., 2018). A consequence of this is the relatively low weights assigned to the climate hazards in the operationalization.

This clearly shifts the focus to the exposure and vulnerability components of risk, as also highlighted in the sector analyses and in the previous section, whose characterization indeed represented a major challenge for this work, as to both their quantification and weighing. Indeed, the amount of relevant and/or detailed publicly available data was limited, and the Island Focal Points could not remedy the long-lasting habit of inaccurate reporting or the tendency of both scientists, governments and enterprises to regard data as personal or private property (see, for example, Trujillo et al., 2012, in the case of aquaculture, and Boulton et al., 2011, for a reflexion on the scientific community). Even data for current cooling energy demand and the efficiency classes of buildings are still scarce and difficult to obtain, despite the requirements of the European Commission for information regarding the national energy efficiency targets, and their relevance for the improvement of the built environment, which constitutes a primary management option for the adaptation to rising temperatures. Desalination demand data should also strongly improve, including information about the energy efficiency of the desalination processes used, and they should be ideally centralized in EUROSTAT.

The digitalisation of socio-economic and local environmental data, the creation of widely shared databases, public information on industrial practices, sustained monitoring and a closer connection between the industrial sector, the scientific community and the public, all constitute key instruments to foster progress in environmental research, in climate risk assessment and in the design of suitable adaptation strategies, as they all contribute to a better definition of a number of risk sub-components that are still waiting for adequate treatment.

The need to merge and blend quantitative and qualitative information in the risk assessment exercise, and to root the risk analysis in a well-founded appraisal of complex phenomena, made it necessary for experts not to be limited by the information provided by analysts, and to freely exploit additional knowledge based on scientific literature and experience, so as to complete a balanced picture of the problem. Although this effort could not always provide an absolute risk assessment, it significantly contributes to further research by gathering current relevant knowledge to build the basis for improved future evaluations.

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7. Appendix

ANNEX to D4.5



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7.1. Detailed methodology for Maritime Transport

Normalization of sub-component indicators

Hazard

Extreme Waves (SWHX98)

Extreme waves (98th percentile of significant wave height: SWHX98) are defined as the annual 98th percentile of the model-based daily wave height values. The values are averaged for each of the SOCLIMPACT islands under investigation for the Maritime sector (Cyprus, Crete, Malta, Corsica, Canary Islands and Balearics). The selection of islands was based on the importance and dependency on the Maritime Transport sector and on data availability. The units of the SWHX98 index are meters. According to the modelled values provided through D4.3, for the 1986-2005 control reference period SWHX98 values range from 1.43 m for Cyprus to 2.27 m for the Canary Islands (Table 7.1.1). We have used the minimum-maximum normalization method. However, since the range of data for the different islands is very small, in order to provide meaningful values after the normalization we have set the minimum/maximum values manually according to expert judgement in a similar way as it is described in OECD (2008) and GIZ (2017). In more detail, a minimum value of 0 is assigned for extreme waves of 1.25 m height and a maximum value of 1 is assigned for waves of 9 m. The minimum and maximum values correspond to the upper limits of Douglas Scale Level 3 (slight waves) and Douglas Scale Level 7 (high waves) respectively. A description of the Douglas Sea Scale can be found in Owens (1982). The normalized values of this hazard indicator for each island are presented in Table 7.1.1 for the historical reference period. For the projected future raw and normalized data are presented in Tables 7.1.2-7.1.5.

Extreme Wind (WiX98)

Daily values of the model-derived wind speeds around each of the selected islands (Cyprus, Crete, Malta, Corsica, Canary Islands and Balearics) were used for the calculation of the 98th percentiles of this meteorological variable. The average of these values for each sub-period of analysis was used as the WiX98 hazard indicator. According to the regional climate simulations, for our historical reference period, extreme wind values range from 11.6 m/sec for the Canary Islands to 13.7 m/sec for Corsica (Table 7.1.1). The normalization approach for this variable is similar to the one of SWHX98, however, it is based on the Beaufort Wind Scale instead of the Douglas Sea Scale. In more detail, values of 0 were assigned for wind speeds of 9.3 m/sec which is described as “fresh breeze” or Beaufort Scale 5, while values of 1 were assigned for wind speeds of 18.9 m/sec which is described as “gale” or Beaufort Scale 8. The projected future raw and normalized data are accordingly presented in Tables 7.1.2-7.1.5.

Mean Sea Level Rise (MSLAVE)

For the mean sea level rise we considered by default zero values for the historical reference period for all islands. For the future we employed the mean sea level rise projections based on ocean-atmosphere coupled simulations. Under RCP8.5, maximum MSLAVE (74 cm) is expected for the Canary Islands. The best-case scenario is for Cyprus where a MSLAVE

of about 20cm is projected under pathway RCP2.6. The normalization of this indicator was based on expert judgement. We have assigned values of 0 is MSLAVE 0 cm and values of 1 for MSLAVE of 100 cm which is the top range of RCP8.5 global sea level rise.

Table 7.1.1. Risk indicators' values for the Maritime Transport Impact Chain of "Risk of isolation due to transport disruption" for the raw and the normalized data, representative for the historical reference period 1986-2005. Fields of NA indicate that accurate information was not available.

MARITIME TRANSPORT (HISTORICAL)			RAW DATA						NORMALIZED DATA					
RISK FACTORS	Risk of isolation due to transport disruption		CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS	CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS
			HAZARD	NSWHX98	Extreme Wave (m)	1.43	2.01	2.27	1.91	2.81	2.08	0.02	0.10	0.13
WIX98	Extreme Wind (m/sec)	12.1		13	13.4	13.7	11.6	12.7	0.29	0.39	0.43	0.46	0.24	0.35
MSLAVE	Mean Sea Level Rise (cm)	0		0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
EXPOSURE	NPax	Number of Passengers (thousands)	75	2206	10145	3481	11102	8248	0.00	0.19	0.91	0.31	1.00	0.74
	NTotP	Island's population (thousands)	855	633	451	330	2142	491	0.29	0.17	0.07	0.00	1.00	0.09
	VGSTot	Value of goods (freight in tonnes)	7655	3188	3466	1935	26104	9011	0.24	0.05	0.06	0.00	1.00	0.29
SENSITIVITY	NPo	Number of ports	4	6	3	6	10	5	0.50	0.25	0.75	0.25	0.00	0.50
	NIID	Nr. Of isolation days	0	NA	0-1	1	NA	NA						
	NAgePo	Renovated infrastructure	ALL	NA	ALL	ALL	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
ADAPTIVE CAPACITY	PErRR	% of renewables	9.85	25	7.17	12.5	12	4.5	0.88	0.69	0.91	0.84	0.85	0.94
	NTrCoRM	Nr. Of courses/trainings	4	NA	YES	0	NA	NA						
	NOCSta	Early warning systems	1	1	1	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00
	NApt	Harbour alternatives	4	3	1	4	8	3	0.50	0.75	1.00	0.50	0.00	0.75

Table 7.1.2. Same as Table 7.1.1 for the mid-21st century (2046-2065) under pathway RCP2.6.

MARITIME TRANSPORT (RCP2.6 - MID-21st)			RAW DATA						NORMALIZED DATA					
RISK FACTORS	Risk of isolation due to transport disruption		CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS	CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS
			HAZARD	NSWHX98	Extreme Wave (m)	1.40	1.99	2.24	1.91	2.82	2.05	0.02	0.10	0.13
WIX98	Extreme Wind (m/sec)	12.00		13.10	13.30	13.50	11.50	12.40	0.28	0.40	0.42	0.44	0.23	0.32
MSLAVE	Mean Sea Level Rise (cm)	10.15		11.60	12.05	10.65	13.64	12.46	0.10	0.12	0.12	0.11	0.14	0.12
EXPOSURE	NPax	Number of Passengers (thousands)	77	1831	10449	3759	10214	7588	0.00	0.16	0.94	0.33	0.92	0.68
	NTotP	Island's population (thousands)	872	525	465	356	1971	452	0.30	0.11	0.07	0.01	0.91	0.07
	VGSTot	Value of goods (freight in tonnes)	7808	2646	3570	2090	24016	8290	0.24	0.03	0.07	0.01	0.91	0.26
SENSITIVITY	NPo	Number of ports	4	6	3	6	10	5	0.50	0.25	0.75	0.25	0.00	0.50
	NIID	Nr. Of isolation days	0	NA	0-1	1	NA	NA						
	NAgePo	Renovated infrastructure	ALL	NA	ALL	ALL	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
ADAPTIVE CAPACITY	PErRR	% of renewables	50	50	50	50	50	50	0.38	0.38	0.38	0.38	0.38	0.38
	NTrCoRM	Nr. Of courses/trainings	4	NA	YES	0	NA	NA						
	NOCSta	Early warning systems	1	1	1	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00
	NApt	Harbour alternatives	4	3	1	4	8	3	0.50	0.75	1.00	0.50	0.00	0.75



Table 7.1.3. Same as Table 7.1.1 for the end-21st century (2081-2100) under pathway RCP2.6.

MARITIME TRANSPORT (RCP2.6 - END-21st)			RAW DATA						NORMALIZED DATA					
RISK FACTORS	Risk of isolation due to transport disruption		CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS	CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS
HAZARD	NSWX98	Extreme Wave (m)	1.40	2.00	2.22	1.89	2.79	2.05	0.02	0.10	0.13	0.08	0.20	0.10
	WIX98	Extreme Wind (m/sec)	11.80	13.10	13.20	13.50	11.40	12.30	0.26	0.40	0.41	0.44	0.22	0.31
	MSLAVE	Mean Sea Level Rise (cm)	20.31	23.19	24.10	21.31	27.29	24.92	0.20	0.23	0.24	0.21	0.27	0.25
EXPOSURE	NPax	Number of Passengers (thousands)	89	1390	9029	3655	8104	6021	0.00	0.12	0.81	0.32	0.73	0.54
	NTotP	Island's population (thousands)	1,009	398.79	401.39	346.5	1563.66	358.43	0.37	0.04	0.04	0.01	0.68	0.02
	VGSTot	Value of goods (freight in tonnes)	9032.9	2008.4	3084.7	2031.75	19055.92	6578.03	0.29	0.00	0.05	0.00	0.71	0.19
	NPo	Number of ports	4	6	3	6	10	5	0.50	0.25	0.75	0.25	0.00	0.50
SENSITIVITY	NIID	Nr. Of isolation days	0	NA	0-1	1	NA	NA						
	NAgePo	Renovated infrastructure	ALL	NA	ALL	ALL	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
ADAPTIVE CAPACITY	PErRR	% of renewables	60	60	60	60	60	60	0.25	0.25	0.25	0.25	0.25	0.25
	NTrCoRM	Nr. Of courses/trainings	4	NA	YES	0	NA	NA						
	NOcSta	Early warning systems	1	1	1	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00
	NApt	Harbour alternatives	4	3	1	4	8	3	0.50	0.75	1.00	0.50	0.00	0.75

Table 7.1.4. Same as Table 7.1.1 for the mid-21st century (2046-2065) under pathway RCP8.5.

MARITIME TRANSPORT (RCP8.5 - MID-21st)			RAW DATA						NORMALIZED DATA					
RISK FACTORS	Risk of isolation due to transport disruption		CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS	CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS
HAZARD	NSWX98	Extreme Wave (m)	1.40	2.00	2.22	1.89	2.79	2.00	0.02	0.10	0.13	0.08	0.20	0.10
	WIX98	Extreme Wind (m/sec)	12.1	13.1	13.3	13.7	11.7	12.6	0.29	0.40	0.42	0.46	0.25	0.34
	MSLAVE	Mean Sea Level Rise (cm)	28.9	31.7	32.5	29.2	37.0	32.9	0.29	0.32	0.32	0.29	0.37	0.33
EXPOSURE	NPax	Number of Passengers (thousands)	76.5	1831	10449	3759.48	10213.84	7588	0.00	0.16	0.94	0.33	0.92	0.68
	NTotP	Island's population (thousands)	872.1	525.39	464.53	356.4	1970.64	451.72	0.30	0.11	0.07	0.01	0.91	0.07
	VGSTot	Value of goods (freight in tonnes)	7808.1	2646	3570	2089.8	24015.68	8290.12	0.24	0.03	0.07	0.01	0.91	0.26
	NPo	Number of ports	4	6	3	6	10	5	0.50	0.25	0.75	0.25	0.00	0.50
SENSITIVITY	NIID	Nr. Of isolation days	0	NA	0-1	1	NA	NA						
	NAgePo	Renovated infrastructure	ALL	NA	ALL	ALL	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
ADAPTIVE CAPACITY	PErRR	% of renewables	25	25	25	25	25	25	0.69	0.69	0.69	0.69	0.69	0.69
	NTrCoRM	Nr. Of courses/trainings	4	NA	YES	0	NA	NA						
	NOcSta	Early warning systems	1	1	1	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00
	NApt	Harbour alternatives	4	3	1	4	8	3	0.50	0.75	1.00	0.50	0.00	0.75

Table 7.1.5. Same as Table 7.1.1 for the end-21st century (2081-2100) under pathway RCP8.5.



MARITIME TRANSPORT (RCP8.5 - END-21st)			RAW DATA						NORMALIZED DATA					
RISK FACTORS	Risk of isolation due to transport disruption		CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS	CYPRUS	CRETE	MALTA	CORSICA	CANARY ISLANDS	BALEARIC ISLANDS
HAZARD	NSWHX98	Extreme Wave (m)	1.33	2.01	2.18	1.86	2.76	1.95	0.0105	0.0976	0.1202	0.07874	0.19464	0.090503
	WIX98	Extreme Wind (m/sec)	11.6	13.1	13.1	13.7	11.7	12.3	0.2396	0.3958	0.3958	0.45833	0.25	0.3125
	MSLAVE	Mean Sea Level Rise (cm)	57.81	63.48	64.99	58.41	74.06	65.86208	0.5781	0.6348	0.6499	0.58408	0.7406	0.6586
EXPOSURE	NPax	Number of Passengers (thousands)	88.5	1389.8	9029.1	3655.05	8104.46	6021	0.00	0.12	0.81	0.32	0.73	0.54
	NTotP	Island's population (thousands)	1,009	398.79	401.39	346.5	1563.66	358.43	0.37	0.04	0.04	0.01	0.68	0.02
	VGSTot	Value of goods (freight in tonnes)	9032.9	2008.4	3084.7	2031.75	19055.9	6578.03	0.29	0.00	0.05	0.00	0.71	0.19
SENSITIVITY	NPo	Number of ports	4	6	3	6	10	5	0.5	0.25	0.75	0.25	0	0.5
	NIID	Nr. Of isolation days	0	NA	0-1	1	NA	NA						
ADAPTIVE CAPACITY	NAgePo	Renovated infrastructure	ALL	NA	ALL	ALL	NA	NA	0	0	0	0	0	0
	PErrR	% of renewables	25	25	25	25	25	25	0.69	0.69	0.69	0.69	0.69	0.69
	NTrCoRM	Nr. Of courses/trainings	4	NA	YES	0	NA	NA						
ADAPTIVE CAPACITY	NOCSta	Early warning systems	1	1	1	1	1	1	0	0	0	0	0	0
	NApt	Harbour alternatives	4	3	1	4	8	3	0.50	0.75	1	0.5	0	0.75

Exposure

Islands' Population (NTotP)

As a first exposure indicator for the risk of Maritime Transport Disruption we used the total population for each island (expressed in thousands of inhabitants). These numbers were also derived from NUTS (Nomenclature of territorial units for statistics) 2 and 3 classifications data. The normalization approach used was again the minimum/maximum methodology. Future population projections (years 2050 and 2090) were derived from the United Nations Department of Economic and Social Affairs (<https://population.un.org/wpp/>). This was the case for Cyprus and Malta that are island countries. For the rest of the cases where island-based projections were not available, we assumed that the population trajectories will follow the trends of the countries they belong. Raw and normalized values are presented in Tables 7.1.1-7.1.5.

Number of passengers (NPax)

As a second exposure indicator we employed the annual total number of passengers per island. These numbers were derived from the European Union's Statistical Office (EUROSTAT). Regional data are available for the NUTS 2 and 3 classifications. Basic regions for the application of regional policies are included in NUTS 2, while small regions for specific diagnoses are part of NUTS 3. For our case the EU country islands of Cyprus and Malta are included in NUTS 2 while the rest of the islands under investigation (Crete, Corsica, Canary Islands and Balearics) are included in the NUTS 3 classification. Since this indicator is dynamic through time, we have used the average number of the five more recent years available in the EUROSTAT database. The units of this indicator are thousands of passengers per year. According to the historical data, the greatest annual number of passengers (including cruises) is found for the Canary Islands, while the lowest number is found for Cyprus (Table 7.1.1). In order to facilitate an island inter-comparison, we have used the minimum/maximum methodology, with values of 0 assigned to the island with the lowest number of passengers and values of 1 assigned to the island with the highest number of passengers. For the timescales discussed in the SOCLIMPACT project, no future projections' information was available for NPax. Nevertheless, we scaled



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the historical values for this indicator according to the population changes in order to provide a more realistic assessment for future risk.

Value of Goods (VGTSTot)

An important component of exposure is the total value of goods transferred by ships. Since it was difficult to obtain absolute numbers of values, we have used the total freight in tones. These were available per NUTS 2 and NUTS 3 region covering all SOCLIMPACT islands under investigation. A minimum/maximum normalization method was applied to facilitate the inter-island comparison. Values of this indicator were considered static for the future. According to the values of this indicator, the Canary Islands are the ones that are most dependent on Maritime Transport for the transfer of goods. Similarly, to the number of passengers, we have scaled the historical values of the value of goods according to the population change in order to provide a more realistic assessment for future risk.

Number of Ports (NPo)

The final exposure indicator that was used for the operationalization of the selected Impact Chain of the Maritime Transport sector is the number of ports per island or archipelago. Information on the number of ports was either provided by the Island Focal Points (IFPs) or was obtained through online resources. The normalization of this indicator was based on a rating scale that was defined by expert judgement (GIZ 2017). In more detail, higher sub-component risk (values of 1) were assigned to islands that fall in the class [0,1], value of 0.75 were assigned to islands that fall in the [2-3], values of 0.50 were assigned to islands that fall in the class [4-5], values of 0.25 were assigned to islands that fall in the class [6-7] and values of 0 were assigned to islands or archipelagos that have more than 8 ports operating. This indicator was considered static for the future.

Sensitivity

Number of Isolation Days (NIID)

This indicator of sensitivity was in the end excluded from the analysis since for most of the SOCLIMPACT islands under investigation there was no accurate information available.

Renovated Infrastructure (NAgePo)

This indicator is defined as the number of ports with critical infrastructures not renovated since 1993. For three of the considered islands (Cyprus, Malta and Corsica) there was available information that all ports have been partially and/or gradually renovated during the last decades. We assumed that this was the case for the three remaining case studies (Crete, Canary Islands and Balearics). We therefore assigned values of 0 for this sub-component of sensitivity for all islands and all future scenarios.

Adaptive Capacity

Percentage of Renewables (PEnRR)



This indicator of adaptive capacity describes how self-sustainable are the SOCLIMPACT islands in terms of energy resources. For the present situation, the PEnRR indicator values were extracted through online resources and regional reports. The island of Crete in Greece is the one with higher percentages of electricity provided by renewable energy sources (25%). On the other hand, the Balearic Islands are the ones with the lowest percentage of renewables in their energy production mix (currently 4.5%). These numbers are expected to increase for all islands due to the cost reduction and the increase in efficiency of the relevant technologies. Moreover, all EU countries are committed to adopt mitigation and decarbonization policies. In this context, for the future pathways we have used different scenarios. For the strong mitigation pathway (RCP2.6), we assumed for all islands a "sustainability" pathway (e.g. SSP1 from Riahi et al. 2017). This corresponds to values of PEnRR of 50-60%. Noteworthy, this is a very conservative scenario since according to the EU long-term strategy (https://ec.europa.eu/clima/policies/strategies/2050_en) Europe will aim in being climate neutral by 2050. For the "business-as-usual" RCP 8.5, we have considered a "regional rivalry" pathway similar to the SSP3 in Riahi et al. (2017). Under this pathway the average contribution of renewable sources in the total energy production is 25%. For the normalization of this indicator we have used minimum/maximum values manually according to expert judgement. Based on information obtained from the Cyprus Organization for Storage and Management of Oil Stocks (<https://www.kodap.org.cy/>), we approximate that about 20% of the annual total needs of crude oil and petroleum products is in stock at any time. We therefore assign optimum risk values (0) when there is an 80% coverage of the needs of an island from renewables. In this context, risk values of 1 are assigned for 0% renewable energy sources.

Number of Courses/Training (NTrCoRM)

Although this indicator could be an important component of the adaptive capacity to the risk of transport disruption, we did not use it in the calculation of the risk values since for most of the SOCLIMPACT islands there was no information provided from the local port authorities.

Early Warning Systems (NOcSta)

Information on the existence of Early Warning Systems was difficult to be obtained. Nevertheless, since all SOCLIMPACT islands under investigation strongly depend on maritime means for the transportation of passengers and goods we assumed that all ports are equipped with Early Warning Systems. Therefore, values of 0 were assigned to this risk sub-component.

Harbour Alternatives (NApt)

This indicator is of great relevance to the Risk of Transport Disruption. We considered as harbor alternatives the number of airports that can facilitate the transport of passengers or goods in the unfortunate case of a seaport closure. This number was obtained through online resources. The normalization of this indicator, that was considered as static for the future, was similar to the one applied for the number of ports. In more detail, it was based on a rating scale that was defined by expert judgement (GIZ 2017). The highest sub-component risk (values of 1) were assigned to islands that have 0 or 1 harbour alternatives, value of 0.75 were assigned to islands that fall in the [2-3] class, values of 0.50 were



assigned to islands that fall in the [4-5] class, values of 0.25 were assigned to islands that fall in the [6-7] class and values of 0 were assigned to islands or archipelagos that have 8 or more airports operating.

Weighted aggregation of sub-components and components

Table 7.1.6. Operationalization of the Impact Chain of the Risk of Maritime Transport Disruption for the control reference period.

Component	Hazard 0.33				Exposure 0.33					Vulnerability 0.33							RISK		
Component Weight																			
Sub-component					Nature of exposure 0.33		Level of exposure 0.66			Factor of sensitivity 0.25			Factors of adaptive capacity 0.75						
Sub-component weight	Extreme wave	Extreme wind	Mean sea level rise	Score for hazard	Number of ports	Score for nature of exposure	Number of passengers	Population of the island	Value of goods	Score for level of exposure	Number of isolation days	Renovated infrastructure	Score of factor of sensitivity	% of RES	Number of courses/trainings	Early warning systems		Harbor alternatives	Score of factor of ad. capacity
CYPRUS	0.02	0.29	0.00	0.10	0.50	0.50	0.00	0.29	0.24	0.18		0.00	0.00	0.88		0.00	0.50	0.46	0.241
CRETE	0.10	0.39	0.00	0.16	0.25	0.25	0.19	0.17	0.05	0.14		0.00	0.00	0.69		0.00	0.75	0.48	0.229
MALTA	0.13	0.43	0.00	0.19	0.75	0.75	0.91	0.07	0.06	0.35		0.00	0.00	0.91		0.00	1.00	0.64	0.376
CORSICA	0.08	0.46	0.00	0.18	0.25	0.25	0.31	0.00	0.00	0.10		0.00	0.00	0.84		0.00	0.50	0.45	0.220
CANARY ISLANDS	0.20	0.24	0.00	0.15	0.00	0.00	1.00	1.00	1.00	1.00		0.00	0.00	0.85		0.00	0.00	0.28	0.336
BALEARIC ISLANDS	0.11	0.35	0.00	0.15	0.50	0.50	0.74	0.09	0.29	0.37		0.00	0.00	0.94		0.00	0.75	0.56	0.326

Table 7.1.7. Same as Table 7.1.6 for the mid-21st century (2046-2065) and pathway RCP2.6.

Component	Hazard 0.33				Exposure 0.33					Vulnerability 0.33							RISK		
Component Weight																			
Sub-component					Nature of exposure 0.33		Level of exposure 0.66			Factor of sensitivity 0.25			Factors of adaptive capacity 0.75						
Sub-component weight	Extreme wave	Extreme wind	Mean sea level rise	Score for hazard	Number of ports	Score for nature of exposure	Number of passengers	Population of the island	Value of goods	Score for level of exposure	Number of isolation days	Renovated infrastructure	Score of factor of sensitivity	% of RES	Number of courses/trainings	Early warning systems		Harbor alternatives	Score of factor of ad. capacity
CYPRUS	0.02	0.28	0.10	0.13	0.50	0.50	0.00	0.30	0.24	0.18		0.00	0.00	0.38		0.00	0.50	0.29	0.210
CRETE	0.10	0.40	0.12	0.20	0.25	0.25	0.16	0.11	0.03	0.10		0.00	0.00	0.38		0.00	0.75	0.38	0.208
MALTA	0.13	0.42	0.12	0.22	0.75	0.75	0.94	0.07	0.07	0.36		0.00	0.00	0.38		0.00	1.00	0.46	0.347
CORSICA	0.09	0.44	0.11	0.21	0.25	0.25	0.33	0.01	0.01	0.12		0.00	0.00	0.38		0.00	0.50	0.29	0.194
CANARY ISLANDS	0.20	0.23	0.14	0.19	0.00	0.00	0.92	0.91	0.91	0.91		0.00	0.00	0.38		0.00	0.00	0.13	0.292
BALEARIC ISLANDS	0.10	0.32	0.12	0.18	0.50	0.50	0.68	0.07	0.26	0.34		0.00	0.00	0.38		0.00	0.75	0.38	0.281

Table 7.1.8. Same as Table 7.1.6 for the end of 21st century (2081-2100) and pathway RCP2.6.

Component	Hazard 0.33				Exposure 0.33					Vulnerability 0.33							RISK		
Component Weight																			
Sub-component					Nature of exposure 0.33		Level of exposure 0.66			Factor of sensitivity 0.25			Factors of adaptive capacity 0.75						
Sub-component weight	Extreme wave	Extreme wind	Mean sea level rise	Score for hazard	Number of ports	Score for nature of exposure	Number of passengers	Population of the island	Value of goods	Score for level of exposure	Number of isolation days	Renovated infrastructure	Score of factor of sensitivity	% of RES	Number of courses/trainings	Early warning systems		Harbor alternatives	Score of factor of ad. capacity
CYPRUS	0.02	0.26	0.20	0.16	0.50	0.50	0.00	0.37	0.29	0.22		0.00	0.00	0.25		0.00	0.50	0.25	0.218
CRETE	0.10	0.40	0.23	0.24	0.25	0.25	0.12	0.04	0.00	0.05		0.00	0.00	0.25		0.00	0.75	0.33	0.201
MALTA	0.13	0.41	0.24	0.26	0.75	0.75	0.81	0.04	0.05	0.30		0.00	0.00	0.25		0.00	1.00	0.42	0.335
CORSICA	0.08	0.44	0.21	0.24	0.25	0.25	0.32	0.01	0.00	0.11		0.00	0.00	0.25		0.00	0.50	0.25	0.194
CANARY ISLANDS	0.20	0.22	0.27	0.23	0.00	0.00	0.73	0.68	0.71	0.71		0.00	0.00	0.25		0.00	0.00	0.08	0.250
BALEARIC ISLANDS	0.10	0.31	0.25	0.22	0.50	0.50	0.54	0.02	0.19	0.25		0.00	0.00	0.25		0.00	0.75	0.33	0.264



Table 7.1.9. Same as Table 7.1.6 for the mid-21st century (2046-2065) and pathway

Component	Hazard 0.33				Exposure 0.33						Vulnerability 0.33						RISK		
Component Weight																			
Sub-component					Nature of exposure 0.33		Level of exposure 0.66				Factor of sensitivity 0.25			Factors of adaptive capacity 0.75					
Sub-component weight	Extreme wave	Extreme wind	Mean sea level rise	Score for hazard	Number of ports	Score for nature of exposure	Number of passengers	Population of the island	Value of goods	Score for level of exposure	Number of isolation days	Renovated infrastructure	Score of factor of sensitivity	% of RES	Number of courses/trainings	Early warning systems		Harbor alternatives	Score of factor of ad. capacity
Island:																			
CYPRUS	0.02	0.29	0.29	0.20	0.50	0.50	0.00	0.30	0.24	0.18		0.00	0.00	0.69		0.00	0.50	0.40	
CRETE	0.10	0.40	0.32	0.27	0.25	0.25	0.16	0.11	0.03	0.10		0.00	0.00	0.69		0.00	0.75	0.48	
MALTA	0.13	0.42	0.32	0.29	0.75	0.75	0.94	0.07	0.07	0.36		0.00	0.00	0.69		0.00	1.00	0.56	
CORSICA	0.08	0.46	0.29	0.28	0.25	0.25	0.33	0.01	0.01	0.12		0.00	0.00	0.69		0.00	0.50	0.40	
CANARY ISLANDS	0.20	0.25	0.37	0.27	0.00	0.00	0.92	0.91	0.91	0.91		0.00	0.00	0.69		0.00	0.00	0.23	
BALEARIC ISLANDS	0.10	0.34	0.33	0.26	0.50	0.50	0.68	0.07	0.26	0.34		0.00	0.00	0.69		0.00	0.75	0.48	

RCP8.5.

Table 7.1.10. Same as Table 7.1.6 for the end of 21st century (2081-2100) and pathway RCP2.6.

Component	Hazard 0.33				Exposure 0.33						Vulnerability 0.33						RISK		
Component Weight																			
Sub-component					Nature of exposure 0.33		Level of exposure 0.66				Factor of sensitivity 0.25			Factors of adaptive capacity 0.75					
Sub-component weight	Extreme wave	Extreme wind	Mean sea level rise	Score for hazard	Number of ports	Score for nature of exposure	Number of passengers	Population of the island	Value of goods	Score for level of exposure	Number of isolation days	Renovated infrastructure	Score of factor of sensitivity	% of RES	Number of courses/trainings	Early warning systems		Harbor alternatives	Score of factor of ad. capacity
Island:																			
CYPRUS	0.01	0.24	0.58	0.28	0.50	0.50	0.00	0.37	0.29	0.22		0.00	0.00	0.69		0.00	0.50	0.40	
CRETE	0.10	0.40	0.63	0.38	0.25	0.25	0.12	0.04	0.00	0.05		0.00	0.00	0.69		0.00	0.75	0.48	
MALTA	0.12	0.40	0.65	0.39	0.75	0.75	0.81	0.04	0.05	0.30		0.00	0.00	0.69		0.00	1.00	0.56	
CORSICA	0.08	0.46	0.58	0.37	0.25	0.25	0.32	0.01	0.00	0.11		0.00	0.00	0.69		0.00	0.50	0.40	
CANARY ISLANDS	0.19	0.25	0.74	0.40	0.00	0.00	0.73	0.68	0.71	0.71		0.00	0.00	0.69		0.00	0.00	0.23	
BALEARIC ISLANDS	0.09	0.31	0.66	0.35	0.50	0.50	0.54	0.02	0.19	0.25		0.00	0.00	0.69		0.00	0.75	0.48	

7.2. Detailed methodology for the Forest Fire IC

Description of the implementation method

Step 1: Data collection

Data were collected by the Forest Fire Task Force (FFTF, composed by RAMBOLL, CMCC, and NOA) and by Island Focal Points (IFPs) of the SOCLIMPACT project.

Current and future Fire Weather Indicator (FWI) values, environmental, socio-economic, and spatial planning data (e.g. land use and cover) was required. Regarding FWI calculations, climatic output from state-of-the-art RCM/GCM pairs, developed within the CORDEX initiative have been utilized (<https://cordex.org/>)¹.

Environmental data on forest and agriculture, socio-economic data on the number of inhabitants, tourists, on the ratio of people employed in the primary economic sectors, people involved in active firefighting - all these datasets were obtained from multiple sources. For example, a questionnaire was submitted to IFPs to collect data and information concerning several indicators. The IFPs reached out to local stakeholders and authorities to collect the requested data which was then resubmitted to the FFTF. The data search and enquiry at the various institutions identified the following data sources: National Survey Office (e.g. ISTAT), Regional Statistical Office (e.g. ISTAC), National Offices for Forest and Fire Management. The present and future climate model outputs that were used for FWI calculations have been obtained by ENEA, for the Mediterranean and Azores islands and by CYI servers for Madeira/Canary Islands, respectively.

Step 2: Data review and selection of islands

Out of the 12 islands assessed in the SOCLIMPACT project, nine were included in the operationalization of the impact chains using the risk assessment method from GIZ: Azores, Balearic Islands, Canary Islands, Crete, Corsica, Cyprus, Madeira, Malta, Sardinia and Sicily. The other two (Baltic Island and French West Indies) do not have fire activity or show insufficient data availability. Several islands provided the information regarding the dataset availability or only information on where the data could be found. Thus, the FFTF provided an additional effort in looking at and collecting data for the successful operationalization of the impact chains. Finally, the data were checked in order to verify similar coverage and timeframes.

Step 3: Review and selection of indicators

Hazard

In order to assess the hazard component of the impact chain, the Canadian Fire Weather Index (FWI) is used. The FWI system provides numerical non-dimensional ratings of relative fire potential for a generalized fuel type based solely on weather observations. FWI is part of the Canadian Forest Fire Danger Rating System established in Canada since 1971 (van Wagner 1987). Furthermore, since 2007, FWI has been adopted at the EU level and used in a harmonized way throughout Europe by the European Forest Fire Information System (EFFIS) of the Copernicus Emergency Management Service (since 2015). It is selected for exploring the mechanisms of fire danger change for the islands of interest in the framework of the project, as it has been proved to adequately perform for several

¹ For Azores islands, outputs from RCM/GCM pairs used were produced within the ESCENA project.



locations, including the Mediterranean basin (e.g. Viegas et al. 1999; Dimitrakopoulos et al. 2011; Giannakopoulos et al. 2012; Bedia et al. 2013; Karali et al. 2014).

The meteorological inputs to the FWI System are daily noon values of air temperature, relative humidity, wind speed and 24h accumulated precipitation. It consists of different components that assess the responses of moisture to atmospheric variables at different soil depths and then combine these in order to derive fire behavior indices in terms of ease of spread and intensity. As FWI is based solely on meteorological variables, projected changes in temperature, precipitation, humidity and wind patterns under future emission scenarios are reflected in the FWI patterns throughout the domain of study. In the framework of the project, the FWI values for the fire season (May to October) were used as a climate hazard indicator.

In order to calculate the index, climatic output from state-of-the-art RCM/GCM pairs, developed within CORDEX and more specifically within the Middle East North Africa (MENA) and Europe (EURO) sub-domains, were used. In particular, for the Mediterranean islands (Balears, Corse, Sardinia, Sicily, Malta, Crete and Cyprus), 3-hourly climatic output from EURO-CORDEX initiative at a horizontal resolution of 0.11° were used, while for Madeira and Canary Islands, daily climatic output for the MENA-CORDEX initiative at a horizontal resolution of 0.44°, were utilized.

As the FWI system requires local noon values for its calculation, as far as the Mediterranean islands are concerned, the 12 UTC model output was considered to be the most suitable and used for FWI calculation. For Madeira and Canary Islands, as only daily model values were available in the MENA-CORDEX database, the proxy variable combination of daily maximum temperature, relative humidity, wind speed and precipitation was used for index calculation.

The selected time periods for the analysis follow the respective periods of IPCC AR5, i.e.:

- **historical (reference): 1986-2005**
- **near future: 2026-2045**
- **distant future: 2081-2100**

The future period simulations of the models are based on the Representative Concentration Pathways (RCPs) 2.6 and 8.5, where available. The selected RCM/GCM pairs, experiments and input variables for each island are presented in Table 7.2.1.

Island	Domain	GCM/RCM pairs	Experiments	Input variables
Mediterranean islands	EURO-CORDEX (0.11°)	ICHEC-EC-EARTH/RCA4	Historical RCP2.6 RCP8.5	Air temperature, wind speed, rel. humidity at 12UTC, daily precipitation
Mediterranean islands	EURO-CORDEX (0.11°)	MPI-M-MPI-ESM-LR/RCA4	Historical RCP2.6 RCP8.5	Air temperature, wind speed, rel. humidity at 12UTC,



				daily precipitation
Mediterranean islands	EURO-CORDEX (0.11°)	MOHC-HadGEM2-ES/RCA4	Historical RCP2.6 RCP8.5	Air temperature, wind speed, rel. humidity at 12UTC, daily precipitation
Madeira/Canary Islands	MENA-CORDEX (0.44°)	CNRM-CERFACS-CNRM-CM5/SMHI-RCA4	Historical RCP8.5	Daily maximum air temperature, wind speed, rel. humidity, precipitation
Madeira/Canary Islands	MENA-CORDEX (0.44°)	NOAA-GFDL-GFDL-ESM2M /SMHI-RCA4	Historical RCP8.5	Daily maximum air temperature, wind speed, rel. humidity, precipitation
Madeira/Canary Islands	MENA-CORDEX (0.44°)	ICHEC-EC-EARTH/SMHI-RCA4	Historical RCP2.6 RCP8.5	Daily maximum air temperature, wind speed, rel. humidity, precipitation

Table 7.2.1. Climatic input variables and data sources for hazard component calculation

For the **Azores**, which are not included or are included marginally in the EURO and MENA-CORDEX domains, the ESCENA Project model runs (Jiménez-Guerrero et al. 2013) were employed. They have been produced under the AR4 IPCC scenarios with 25 km spatial resolution. Here, SRES B1 and A1B scenarios are selected, considered to be closer to RCP2.6 and RCP8.5, respectively.

The historical period (reference) is 1981-2000 and the near future period is 2031-2050. The selected RCM/GCM pairs that were available are presented in Table 7.2.2:

GCM/RCM pairs	Experiments
ECHAM5 r2/PROMES	Historical SRES A1B SRES B1
ARPEGE (version 3)/ PROMES	Historical



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	SRES A1B SRES B1
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Table 7.2.2. Climatic input variables and data sources for hazard component calculation for Azores

The index was calculated for the fire season over the study islands (both for the Mediterranean and Atlantic islands) for all models, scenarios and periods. The calculation was performed for each one of the selected GCM/RCM pairs and their ensemble mean was then provided for the reference period, as well as the two future periods of interest for the two selected RCPs or SRESs.

Exposure

Three indicators concerning the “nature of exposure” subcategory were selected to be operationalized. The percentage of cultivated and forest area over the total island area were derived, for all islands, from the Corine Land Cover 2018 considering till the IV thematic level. Forest areas correspond thus to the following class codes 311, 312, 313, 321, 322, 323, 324, while the agricultural areas correspond to 211, 221, 222, 223, 224, 231, 243, 244 classes. The percentage of the island area that is forest but belonging to protected areas was derived from the World Database on Protected Areas (WDPA), the most comprehensive global database on terrestrial (and marine) protected areas (<https://www.protectedplanet.net/>).

Four indicators concerning the “level of exposure” subcategory, were then selected: population density, population under 9 years old density, Population over 65 years old density, and number of tourists per km²



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	Population density (N _{TOT} P)	N./km ²	Population under 9 yrs (D9P)	N./km ²	Population over 65 yrs (D65P)	N./km ²	Tourist density (DT _{TOT} P)	N./km ²
Islands	Source	Resolution	Source	Resolution	Source	Resolution	Source	Resolution
Azores	INE	LAU1	INE	LAU1	INE	LAU1	INE	LAU1
Balearic Islands	IBESTAT	LAU1	IBESTAT	LAU1	IBESTAT	LAU1	IBESTAT	LAU1
Canary Islands	ISTAC	LAU1	ISTAC	LAU1	ISTAC	LAU1	ISTAC	LAU1
Crete	Hellenic Statistical Authority	LAU1	Hellenic Statistical Authority	NUT03	Hellenic Statistical Authority	NUT03	HCAA, AIA, Processing INSETE Intelligence	NUT02 (airport traffic)
Corse	INSEE	LAU1	INSEE	LAU1	INSEE	LAU1	INSEE	NUT02
Cyprus	Statistical Service of the Republic of Cyprus	LAU1	Statistical Service of the Republic of Cyprus	NUT01	Statistical Service of the Republic of Cyprus	NUT01	Statistical Service of the Republic of Cyprus	NUT01
Madeira	INE	LAU1	INE	LAU1	INE	LAU1	INE	LAU1
Malta	NATIONAL STATISTICS OFFICE	LAU1	NATIONAL STATISTICS OFFICE	LAU1	NATIONAL STATISTICS OFFICE	LAU1	NATIONAL STATISTICS OFFICE	NUT02
Sardinia	ISTAT	LAU1	ISTAT	LAU1	ISTAT	LAU1	Sardegna statistico Osservatorio turistico	LAU1
Sicily	ISTAT	LAU1	ISTAT	LAU1	ISTAT	LAU1	Osservatorio turistico	NUT03

Table 7.2.3. "Level of exposure" indicators



Vulnerability

Sensitivity

The information concerning the flammability of vegetation has been processed from the CORINE Land Cover data (CLC 2018) for the macro-category wooded and semi-natural areas following the approach of Corona et al. (2014). Fuel flammability is defined as the relative ease with which the vegetable fuel ignites and burns. The different forest types have different intrinsic "basic" flammability, depending on the susceptibility to combustion of the main tree species forming the forest cover. The approach involves the association of the flammability level proposed by Xanthopoulos et al. (2012) to the wooded and semi-natural areas. This work allows in fact to assign a basic flammability index (FI) that reflects the typical hazard of fire for 60 forest typologies in Europe and North Africa. The variability of the index FI is therefore classified into five classes. Finally, we derived the percentage of the area classified as "very high" and "high" flammability over the total area of the municipality.

Adaptive capacity

The adaptive capacity to fire risk has been evaluated according to the following elements: human capital (PEL), governance, institutions and policies (DNFF+NV, NFRPla), economic factors (GDP, GDPc) and flexibility (OCC).

The level of education and economic resources available in the selected islands are considered as indicators of the system's ability to respond or manage an event. People with a high-level education (such as an academic degree) and with higher per capita income can have easier access to information and tools to understand and prevent the risk of forest fires. In addition, the percentages of workers in the primary sector (agriculture and forestry) was considered as an adaptive capacity element. Indeed, according to a study, the recent abandonment of agriculture due to a high unemployment rate and higher employment in the services sector led to a change in the fire regime. Based on these considerations, also in this work it has been considered that the greater the percentage of the population employed in the primary sector, the more the territory will be "equipped" to anticipate the potential negative effects of fires or to respond during the occurrence of fire events.

Finally, the density of the Firefighters and the Volunteers involved in the different phases of the fire management and the presence or absence of fire risk plans were also collected to inform about the availability of governance and institutions able to respond to the fire emergency.



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	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit
	Density of firefighters and voluntary (DNFP+NV)	N./km2	Percentage educational level (PEL)	%	Percentage of employees in the primary sector (OCC)	%	Presence or absence of fire risk plans (MERRPA)	Boolean (YES or NO) variable	Gross domestic product (GDP)	Min. of euros	Gross domestic product per capita (GDPc)	Thousand of euros per capita
Islands	Source	Resolution	Source	Resolution	Source	Resolution	Source	Resolution	Source	Resolution	Source	Resolution
Azores									https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/	NUT02	https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/	NUT02
Balearic Islands	Personal communication, Servicio de Bomberos de Mallorca	NUT01	IBESTAT	NUT01	IBESTAT	NUT01	Govern de les Illes Balears	NUT01				
Canary Islands	Personal communication, Cabildo de Gran Canaria	NUT01	ISTAC	LAU1	www.ccelda.org/	NUT01	Gobierno de Canarias	NUT01				
Crete												
Corsica	SDIS https://www.pompiers.com/annuaire-sdis/sdis-201.htm	NUT03					http://www.corse.developpement-durable.gouv.fr/les-plans-de-prevention-des-risques-incendie-4281.html	LAU1				
Cyprus												
Madeira	INE	LAU1										
Malta	N.A.	N.A.					Civil Protection Department	NUT02				
Sardinia	http://www.sardignambiente.it/documenti/20_4_67_20170519120018.pdf	NUT02	ISTAT	LAU1	ISTAT	LAU1	Piano AIB 2018 Regione Sardegna	NUT02				
Sicily	Piano AIB 2018 Regione Sicilia	NUT02	ISTAT	LAU1	ISTAT	LAU1	Piano AIB 2018 Regione Sicilia	NUT02				

Table 7.2.4. “Adaptive capacity” indicators

Step 4: Normalisation of indicator data for all islands

In order to normalize the index, the min-max method was applied. Min-max normalizes indicators to have an identical range [0, 1] by subtracting the minimum value and dividing by the range of the indicator values (OECD 2008). The mathematical formula and more information on min-max normalization method are presented in the following section.

Hazard

For the Mediterranean and Canary/Madeira islands², the lowest grid point value of the present climate of all islands was used as min, while as max, the highest grid point value of the index of all islands under RCP8.5 was selected. Afterwards, the normalized index was categorized into five equal interval classes representing values from "Very low" to "Very high". With respect to Azores, the same methodology was used, however, as the models, emission scenarios and future periods differ the results are not comparable with the rest of the islands. For this reason, Azores are discussed separately.

Exposure, sensitivity and adaptive capacity

In the presence of multiple indicators for each component of exposure, sensitivity and adaptive capacity, we proceeded to standardize the data through the process of normalization, to finally allow the calculation of a synthetic global index for each component (e.g., exposure index, sensitivity index and adaptive capacity index).

Normalization transformed the indicator values, measured at different scales and in different units, in comparable unitless values. The values of indicators were normalized between 0 and 1, with '0' representing an optimal and '1' representing a critical state, by applying the min-max method. This method transforms all values to scores ranging from 0 to 1 by subtracting the minimum score and dividing it by the range of the indicator values. The following formula is used to apply min-max:

$$x_{normalized} = \frac{(x - x_{min})}{(x_{max} - x_{min})}$$

The new indicator values have been then "aligned" so that "the direction" of the interval is the same for all indicators in the same category: lower values (close to zero) reflect positive conditions (e.g. low exposure, low sensitivity) and higher values (close to 1) represent more critical / negative conditions (the higher the value, the greater the vulnerability).

A different case is represented by the adaptive capacity: lower values indicate negative conditions for risk (e.g. low ability to adaptation) while higher values represent positive conditions (the greater the ability to adaptation, the less vulnerable/at risk). In in this case the range of values of the adaptive capacity indicators has therefore been inverted so that the lowest value is represented by the standardized value 1 and highest is represented by the standardized value 0. This inversion was made by subtracting the value of the indicator from 1.

² The method of calculation differs for Canary/Madeira as only daily data were available, but the scenarios and periods are the same as for Mediterranean islands.



Step 5: Weighting of different risk components

This section explains the weighting applied to consider factors of greater influence on the different components and sub-components of the risk.

We decided to implement a participatory approach through an expert consultation in order to collect their judgments.

Four experts were selected for their expertise on forest fires and background:

- Expert 1: a modeler with a specialty on thermodynamic, ignition and fire propagation
- Expert 2 : a forest manager
- Expert 3: a former fire fighter with a thesis on large fires
- Expert 4: a researcher on Mediterranean ecosystems and risks.

A dedicated meeting with each expert was organized to discuss and to weight the set of selected indicators. A tailored approach was proposed for this exercise.

- First step is to assess the criticality of each indicator (the so-called “class”) from very important (max 5) to low (0).
- Second step is to rank the selected indicators of a sub-component regarding a component and each component in respect to the risk.
- Last step is to aggregate the results across experts and to define the weight for each sub-component and component with the following formula:

$$weight_i = \frac{score_i}{\sum_i scores\ of\ all\ indicator\ of\ the\ subcomponent)}$$

The logical approach is provided in the example below.

	Expert 1		Expert 2		Expert 3		Expert 4		Average class	Weighting
	Class	Rank	Class	Rank	Class	Rank	Class	Rank		
Cultivated area	3	2	4	3	5	2	4	3	4	0,3265 = 4/ (4+5+3,25)
Forest area (size)	5	1	5	1	5	1	5	1	5	0,4081
Protected area (PFrsPA)	3	3	3	2	3	3	4	2	3,25	0,2653

Table 7.2.5. Weighting system for the sub-component “nature of exposure

The final weighting system applied to the Impact Chain “forest fires and consequences on tourism attractiveness” is the following:

	Component	Subcomponent	Average weight
Risk:	Hazard	Total component	0,4
	Exposure	Nature of exposure	0,55
		Level of exposure	0,45
		Total component	0,3
	Vulnerability	Sensibility	0,70
		Adaptive Capacity	0,30
		Total component	0,3

Table 7.2.6. Weighting system

Step 6: Calculations of risk for present and future conditions

The indicators previously normalized have been aggregated to elaborate three sub-component indices (hazard, exposure, vulnerability) and the final risk index. The normalized scores of the indicators thus standardized were multiplied by the weight (w) assigned to them and finally added together according to the following formula:

- 1) Score of subcomponent = $\sum weight_{indicator} * score_{indicator}$
- 2) Score of component = $\sum weight_{subcomponent} * score_{subcomponent}$
- 3) Risk = $(Hazard * W_a) + (Vulnerability * W_v) + (Exposure * W_e)$

Synthetic indicator description

Sensitivity	Flammability index (IF)	Flammability relates to the intrinsic properties of fuels and fuel types in regard to ignitability, combustibility, sustainability and consumability. First each land cover types was associated to flammability value according to Xanthopoulos et al (2012). Then we calculated the % of vegetation (ha) classified highly flammable and very highly flammable over the total vegetation	%
Exposure	Population density (NTotP)	Total population of the Island (including both permanent residents, and tourist equivalent)	n people / km2
Exposure	Population (P6-65P)	Percentage of population younger than 6 years and older than 65 years	%
Exposure	Tourists (NTouP)	Number of Tourist	n tourist / km2
Exposure	Cultivated area (Acrops)	Size of cultivated area	ha
Exposure	Cultivated area (Pcrops)	Percentage of cultivated area	
Exposure	Forest area (Afrs)	Size of forest area	ha
Exposure	Forest area (Pfrs)	Percentage of forest area	percentage
Exposure	Protected area (PfrsPA)	Percentage of forest that belongs to protected area	percentage
Adaptive Capacity	Firefighters (NFF)	Number of firefighters OR ratio of firefighters in relation to exposed land cover area	number OR %
Adaptive Capacity	Fire risk Plan (NRFPIa)	Number of fire risk plans	number
Adaptive Capacity	Volunteers (NV)	Number of volunteers OR ratio of volunteers in relation to exposed land cover area	number OR %
Adaptive Capacity	Surveillance areas	Number of surveillance look-out	number
Adaptive Capacity	Educational Level (PEL)	Percentage of people with high degree over total population	%
Adaptive Capacity	Funds available for warning system (FAWS)		euros
Adaptive Capacity	Gross domestic product (GDP)		€/pro-capite
Adaptive Capacity	Occupation rate	Ratio of primary sector occupied over the total population	%



Final normalized and weighted data

HAZARD (FWI)											
0,4											
Score for Hazard						Score for Hazard - weighted					
reference	rcp2.6/ near	rcp2.6/ distant	rcp8.5/near	rcp8.5/ distant		reference	rcp2.6/ near	rcp2.6/ distant	rcp8.5/near	rcp8.5/ distant	
Canaries	0,58	0,59	0,58	0,63	0,66	0,23	0,24	0,23	0,25	0,26	
Madeira	0,35	0,36	0,32	0,37	0,44	0,14	0,14	0,13	0,15	0,18	
Balearic	0,03	0,04	0,02	0,09	0,20	0,01	0,02	0,01	0,03	0,08	
Corsica	0,00	0,03	0,00	0,10	0,23	0,00	0,01	0,00	0,04	0,09	
Crete	0,58	0,69	0,67	0,80	1,00	0,23	0,28	0,27	0,32	0,40	
Cyprus	0,68	0,74	0,74	0,86	0,94	0,27	0,30	0,30	0,34	0,38	
Malta	0,13	0,15	0,15	0,19	0,31	0,05	0,06	0,06	0,08	0,12	
Sardinia	0,18	0,20	0,17	0,32	0,47	0,07	0,08	0,07	0,13	0,19	
Sicily	0,28	0,33	0,31	0,41	0,63	0,11	0,13	0,13	0,16	0,25	
Azores	reference	A1B	B1			0,15	0,23	0,26			
	0,38	0,57	0,64								
EXPOSURE											
0,30											
Nature of exposure					Level of exposure						
0,55					0,45						
Cultivated area (Pcrops) %	Forest area (PFrs) %	Forest that belongs to protected area (PFrsPA) %	Score for nature of exposure	Score for nature of exposure - weighted	Population density (NTotP) n°/km²	Population under 9 years old density (P9) n°/km²	Population over 65 years old density (P65) n°/km²	Tourists (NTouP) n°/km²	Score for level of exposure	Score for level of exposure - weighted	Score for exposure - weighted
Canaries	0,21	0,74	0,73	0,56	0,31	0,85	1,00	0,67	0,68	0,80	0,36
Madeira	0,14	0,84	1,00	0,66	0,36	1,00	0,92	1,00	0,64	0,89	0,40
Balearic	0,71	0,49	0,60	0,60	0,33	0,67	0,80	0,59	1,04	0,77	0,35
Corsica	0,10	1,00	0,60	0,57	0,31	-	-	-	0,09	0,02	0,01
Crete	0,60	0,64	0,64	0,63	0,34	0,13	0,19	0,09	0,20	0,15	0,07
Cyprus	0,52	0,59	0,56	0,55	0,30	0,41	0,54	0,36	0,22	0,38	0,17
Malta	-	-	-	-	-	0,39	0,43	0,38	0,25	0,36	0,16
Sardinia	0,66	0,59	0,06	0,44	0,24	0,11	0,05	0,14	0,04	0,08	0,04
Sicily	1,00	0,28	0,24	0,51	0,28	0,56	0,58	0,67	0,06	0,47	0,21
Azores	0,78	0,43	0,50	0,57	0,32	0,24	0,27	0,14	0,10	0,19	0,08
											0,40
VULNERABILITY											
0,30											
SENSITIVITY				ADAPTIVE CAPACITY							
0,7				0,3							
Flammability index (IF)	Score for level of sensitivity - weighted	NFF+NV density	Fire risk plan (NfFPLA)	Educational level (PEL)	Gross domestic product (GDP), million euros	GDP per capita	OCC	Score of factor of adaptive capacity	Score of factor of adaptive capacity - weighted	Score for vulnerability - weighted	
Canaries	0,18	0,13	0,83	-	0,38	0,56	0,51	0,93	0,53	0,16	
Madeira	0,47	0,33	-	-	0,08	0,99	0,62	0,86	0,43	0,13	
Balearic	0,45	0,31	0,68	-	0,30	0,71	-	1,00	0,45	0,13	
Corsica	1,00	0,70	0,69	-	0,19	0,94	0,02	0,98	0,47	0,14	
Crete	0,30	0,21	0,87	-	0,52	0,94	1,00	-	0,56	0,17	
Cyprus	0,57	0,40	0,43	-	1,00	0,83	0,29	0,81	0,56	0,17	
Malta	0,02	0,01	1,00	-	-	0,91	0,07	0,98	0,49	0,15	
Sardinia	0,68	0,48	0,72	-	0,26	0,64	0,36	0,64	0,44	0,13	
Sicily	0,06	0,04	0,62	-	0,31	-	0,67	0,54	0,36	0,11	
Azores	0	-	0,58	-	0,43	1,00	0,73	0,25	0,50	0,15	
										0,15	
RISK											
reference rcp2.6/ near rcp2.6/ distant rcp8.5/near rcp8.5/ distant											
Canaries	0,52	0,52	0,52	0,54	0,55						
Madeira	0,51	0,51	0,50	0,52	0,54						
Balearic	0,35	0,35	0,34	0,37	0,42						
Corsica	0,35	0,36	0,35	0,39	0,44						
Crete	0,47	0,51	0,51	0,56	0,64						
Cyprus	0,58	0,61	0,61	0,66	0,69						
Malta	0,15	0,16	0,16	0,17	0,22						
Sardinia	0,34	0,35	0,33	0,39	0,45						
Sicily	0,30	0,32	0,32	0,36	0,44						
Azores	reference	A1B	B1								
	0,32	0,39	0,42								

7.3. Detailed methodology for the Marine Habitat Degradation and Thermal Comfort ICs

Description of the AHP method

The Analytical Hierarchy Process (AHP) method was introduced by T.L. Saaty (1980) as a mathematical tool for solving complex, real-world problems that require the subjective assessment of multiple criteria in a hierarchical manner in order to evaluate, prioritize or select from a number of different alternatives or options. The AHP method has been applied in a wide range of application domains, such as in project management to help select and prioritize projects in a portfolio (Vargas, 2010) and in the environment to help in the evaluation of transport policies to reduce climate change impacts (Beritella et al., 2008). The technique is simple to understand and, because it requires very basic mathematic calculations, it is easy to apply.

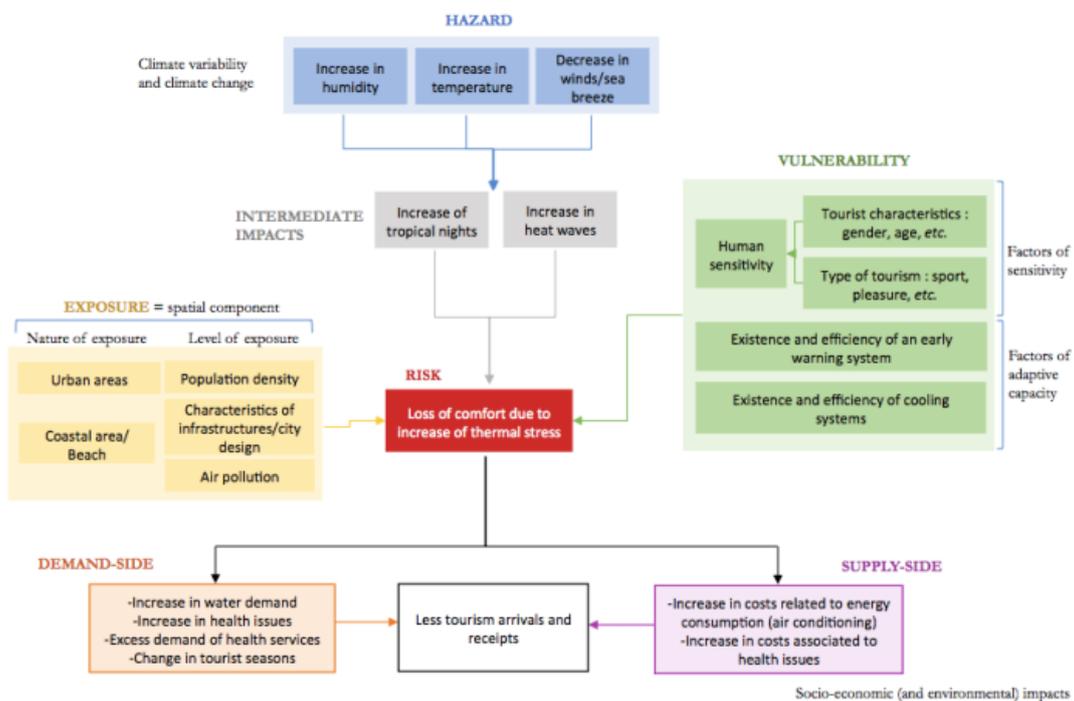


Figure 7.3.1 Loss of comfort due to increase of thermal stress.

The AHP method begins by examining the problem that needs to be solved, here illustrated in Figure 7.3.1, and the alternative solutions proposed to solve the problem.

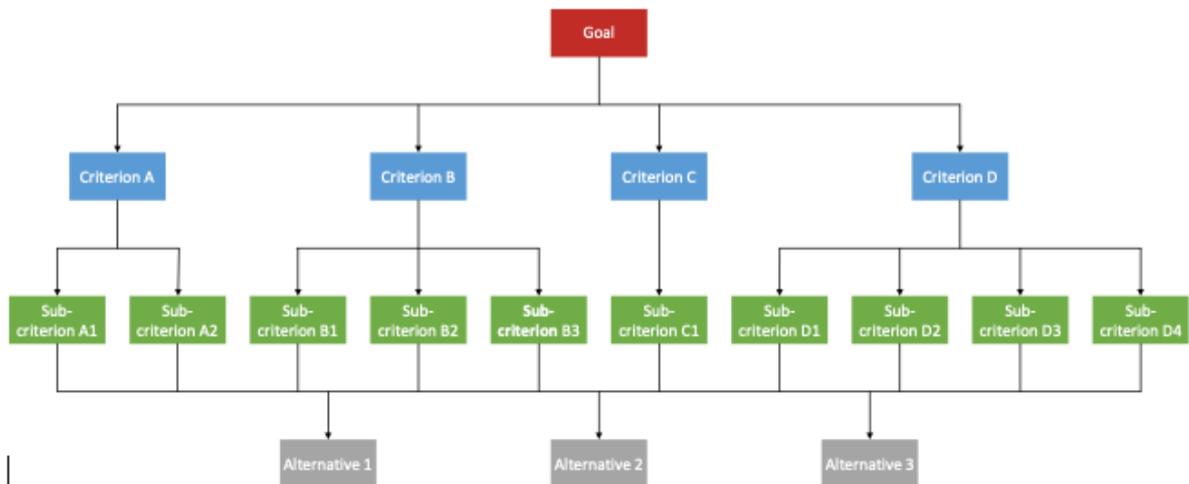


Figure 7.3.2 Structure of a hierarchy tree in the AHP method.

The problem forms the “goal” of the AHP method. Following this, the method then identifies the criteria that will be used to evaluate each of these alternative solutions. In most cases, a criterion is further decomposed into sub-criteria. The result is the representation of the problem as a hierarchy tree with (i) the goal as the root of the tree, (ii) the criteria and sub-criteria as the nodes of the tree, and (iii) the alternatives as the leaves of the tree. An example hierarchy tree is illustrated in Figure 7.3.2, in which there are four criteria that will be used to evaluate three alternative solutions that satisfy the goal. Each criterion is broken down to a number of sub-criteria: two for Criterion A, three for Criterion B, one for Criterion C and four for Criterion D.

Weighting in the AHP method

A significant aspect of AHP is that it considers the fact that not all criteria involved in the assessment of an alternative are equally significant – some criteria may contribute more to determining which alternative is best and, thus, are more important than others. Therefore, each criterion is assigned a weight value that reflects its relative contribution towards a decision in comparison with the other criteria. In other words, weight values are a measure of the importance/priority (or ranking or comparative strength) of one criterion against all other criteria. The higher the weight value of a criterion, the larger the role it will play in the ranking of an alternative. The same also applies for sub-criteria; the weight value of a sub-criterion shows how much it contributes with respect to other sub-criteria of its parent criterion.

Weight values are determined through consultation with domain experts relative to problem domain. Specifically, the experts provide their judgements on the importance of each criterion against all others with respect to the goal. This is done by performing a pairwise comparison using the fundamental scale for pairwise comparison (Table 7.3.1). The purpose of the scale is to help experts identify the importance relationship between two criteria. For example, if Criterion A is favoured

“very strongly” by an expert over Criterion B, then they would provide a comparison value of around 7, indicating that Criterion A contributes very much more to the goal than Criterion B.

Table 7.3.1. The Fundamental Scale for pairwise comparison of criteria.

Intensity of importance	Interpretation	Value
Equal importance	The two criteria contribute equally to the goal.	1
Equal to moderate importance		2
Moderate importance	Experience and judgment slightly favour one criterion over another in terms of contribution to the goal.	3
Moderate to strong importance		4
Strong importance	Experience and judgment strongly favour one criterion over another in terms of contribution to the goal.	5
Strong to very strong importance		6
Very strong importance	One criterion is favoured very strongly over another in terms of contribution to the goal.	7
Very strong to extreme importance		8
Extreme importance	The evidence favouring one criterion over another in terms of contribution to the goal is of the highest possible order of affirmation.	9
Values of 1.1, 1.2, 1.3, etc., can be used for elements that are very close in importance.		

These expert assessments on importance are recorded in a comparison matrix, as shown in Table 7.3.2 from which the weight values of the criteria are later calculated. The comparison matrix is an $n \times n$ matrix where n is the number of criteria being assessed and each pairwise judgement is recorded in the corresponding element of the matrix. The elements on the diagonal of the matrix are always assigned a value of 1 since each criterion is equally important as itself. Also, since the matrix contains pairwise comparisons, the lower left triangle of the matrix contains the reciprocal values of the upper right triangle of the matrix. In the example of Table 7.3.2, since the pairwise comparison of Criterion B against Criterion D indicates that Criterion B is four times more important as Criterion D (with a value of 4 in the corresponding element), then the pairwise comparison of Criterion D against Criterion B must indicate the inverse of this value, that is, that Criterion D is four times less important than Criterion B (with a value of $1/4$ in the corresponding element).

Table 7.3.2. Example of a comparison matrix of criteria.

	Criterion A	Criterion B	Criterion C	Criterion D
Criterion A	1	$1/2$	7	5
Criterion B	2	1	9	4



Criterion C	1/7	1/9	1	1/3
Criterion D	1/5	1/4	3	1
Sum	3.34	1.86	20.00	10.33

In the same manner, all sub-criteria of a certain criterion are compared against each other by experts to determine their importance/priority with respect to the criterion they are a part of. Using the example in Figure 7.3.1, since Criterion B contains three sub-criteria, experts will need make a total of three pairwise comparisons to compare each one sub-criterion of Criterion B with its other two sub-criteria.

For the next step in determining the overall weight value of each criterion, the AHP method proceeds to normalize the comparison matrix of criteria. The normalization simply divides each element of the corresponding comparison matrix by the sum of its column. Table 7.3.3 shows the result of the normalization given the values of the pairwise comparison matrix of Table 7.3.2. The same normalization procedure is also applied for each pairwise comparison matrix of sub-criteria.

Table 7.3.3. Normalization of a comparison matrix of criteria.

	Criterion A	Criterion B	Criterion C	Criterion D
Criterion A	$1/3.34 = 0.30$	$0.5/1.86 = 0.27$	$7/20.00 = 0.35$	$5/10.33 = 0.48$
Criterion B	0.60	0.54	0.45	0.39
Criterion C	0.04	0.06	0.05	0.03
Criterion D	0.06	0.13	0.15	0.10
Sum	1.00	1.00	1.00	1.00

Finally, the overall weight value of each criterion is calculated using the Eigenvector. The Eigenvector represents the comparative strength of each criterion by approximating the average of all criteria, as demonstrated in Table 7.3.4 following the normalized values obtained in Table 7.3.3.

Table 7.3.4. Calculation of Eigenvector to determine overall weight value of each criterion.

	Eigenvector	Result
Criterion A	$(0.30 + 0.27 + 0.35 + 0.48)/4 = 1.40/4$	$0.3504 = 35.04\%$
Criterion B	$(0.60 + 0.54 + 0.45 + 0.39)/4 = 1.97/4$	$0.4932 = 49.32\%$
Criterion C	$(0.04 + 0.06 + 0.05 + 0.03)/4 = 1.18/4$	$0.0462 = 04.62\%$
Criterion D	$(0.06 + 0.13 + 0.15 + 0.10)/4 = 1.44/4$	$0.1102 = 11.02\%$

In the example, Criterion A is assigned a weight value of 0.3504 indicating an importance/priority of 35.04% in contribution towards the goal. This value is calculated by averaging the elements of the corresponding row of the normalized comparison matrix. The most important criterion is Criterion B, since it has a weight value of 0.4932 (that is, a 49.32% contribution), whereas the least important criterion is Criterion C, which has a weight value of 0.0462 (that is, a 4.62% contribution). It should

be noted that these all these values are the result of the judgements provided by experts. Hence, the degree of importance/priority of each criterion and sub-criterion is a reflection of the beliefs and expertise of the individuals consulted for the pairwise comparisons.

In the case of sub-criteria, the weight values that are calculated using the comparison matrices symbolize their “local” importance/priority regarding their parent criterion, that is, the weight values denote the contribution of each sub-criterion in relation to their parent criterion. It does not provide any information on their contribution to the goal as a whole. Therefore, it is crucial to also calculate the overall weight values to represent their “global” importance/priority with respect to the problem at hand. This is simply done by multiplying the weight value of each sub-criterion with the weight value of its parent criterion. For example, in the hierarchy tree of Figure 7.3.2, Criterion D has four sub-criteria, D1-D4. Also, from Table 7.3.4 above, the weight value calculated for Criterion D was determined to be 0.1102 (that is, the contribution of Criterion D towards the goal is valued at 11.02%). Hence, it is now necessary to compute how much of this 11.02% importance is distributed to its sub-criteria. If all four sub-criteria are judged to be equally as important, then the AHP method would calculate their weight values to be equal to $1/4 = 0.25$, meaning a 25% contribution to Criterion D. Consequently, each sub-criterion would have a $0.1102 \times 0.25 = 0.0276$ (or roughly a 2.76%) weight in determining the ranking of alternatives. If, however, the four sub-criteria are not equally as important, for instance as in Figure 7.3.3 below, each sub-criterion will have a different overall weight value (as shown in the global importance column). The sum of the local weight values equal 1.00 (or, 100%), whereas the sum of the overall weight values equals the weight value of Criterion D, in this case, 0.1102. From this, it can be observed that based on the experts’ judgements, Sub-criterion D3 has the highest contribution towards Criterion D with a local importance of 0.4071 (40.71%), and towards the goal with a global importance of $40.71\% \times 0.1102 = 0.0449$ (4.49%).

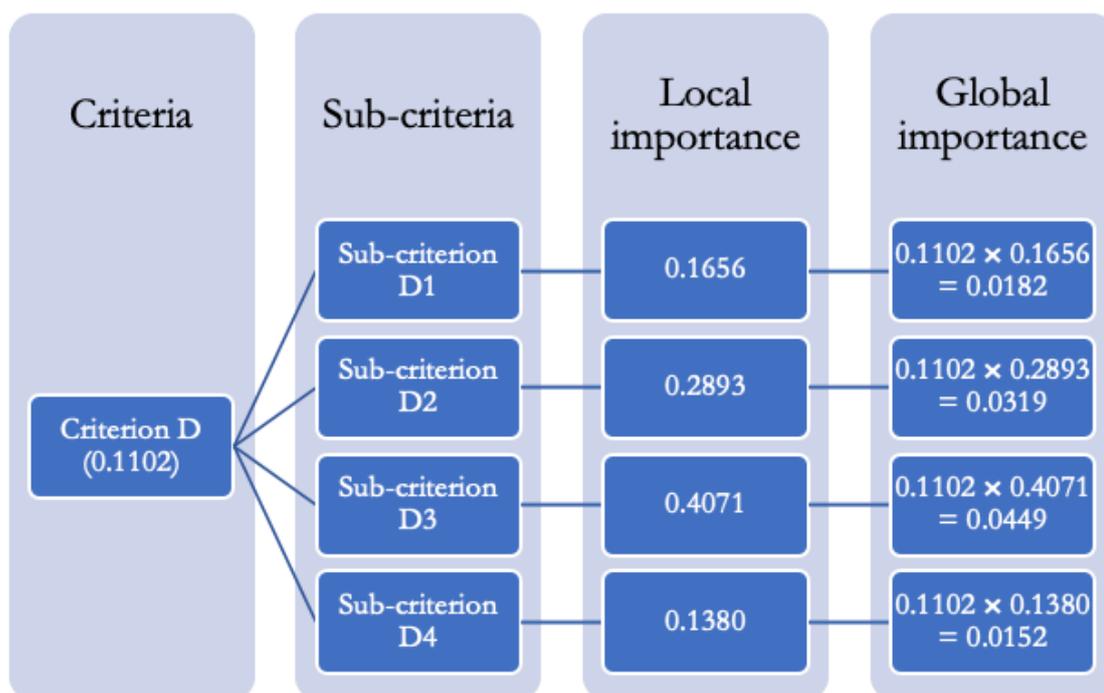


Figure 7.3.3. Example of the calculation of the global importance/priority for each sub-criterion of Criterion D

Once the pairwise comparison of sub-criteria has also been carried out by the experts and the global weight of each sub-criterion has been computed, the next step of the AHP method involves having the experts compare the alternatives against each other with respect to each sub-criterion separately. This again involves the use of pairwise comparison matrices and work similarly as before: the experts assign a value indicating how much better (alternatively, more suitable or appropriate) one alternative is over another in regard to the sub-criterion using the fundamental scale. Similar to before, the comparison matrix is normalized and the Eigenvector is calculated, so that eventually for each sub-criterion the local importance/priority of each alternative is determined. These values basically act as a rating of the alternatives with regards to each sub-criterion, with the most-valued alternative achieving the largest importance/priority. However, it is also necessary to compute the rating of the alternatives with respect to the goal. This is achieved by simply multiplying the weight (global importance) of a sub-criterion by the importance/priority of each alternative determined for that specific sub-criterion to find its the importance/priority in relation to the goal, and repeat the procedure for each sub-criterion. For example, Figure 7.3.4 below shows the importance/priority for the three alternatives for Sub-criterion D3, which has a global importance of 0.0449. Specifically, for Sub-criterion D3, the experts' comparisons have led to the best alternative to be Alternative 3 since it scores the highest local importance value of 0.4762 (46.72%) followed by Alternative 1 (33.57%) and finally Alternative 2 (18.81%). Hence, by multiplying the weight (global importance) of Sub-criterion D3 with these values, it is possible to determine how much each alternative score with respect to the goal. This procedure is carried out for each sub-criterion, meaning that in the end each alternative will have a score representing how good of a fit it is for the goal with respect to each sub-criterion.

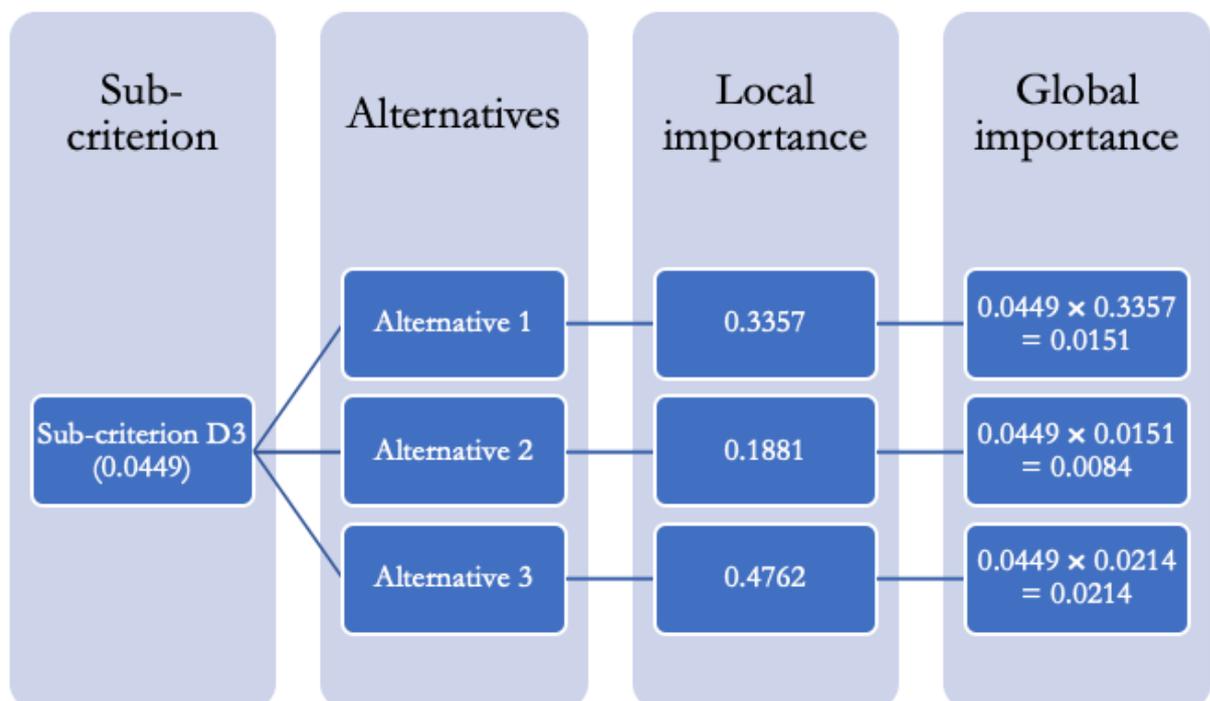


Figure 7.3.4. Example of the calculation of global importance/priority for alternatives.



In order to determine the best alternative overall, the final step of the AHP method requires the global importance values of each alternative in each sub-criterion to be summed. In this way, the alternative that has the highest overall value will be ranked first and the alternative with the second highest overall value will be ranked second, and so on. An example of the final rankings using the hierarchy tree of Figure 7.3.1 is presented in Table 7.3.5. In the final rankings, Alternative 1 scores the highest aggregation of global importance values (0.4363) followed by Alternative 3 (0.3868) and lastly Alternative 2 (0.1769).

Table 7.3.5. Final ranking of alternatives.

Criteria	Weight Criteria	Sub-criteria	Weight Sub-criteria	Alternative 1	Alternative 2	Alternative 3
A	0.3504	A1	0.2452	0.1844	0.0072	0.0536
		A2	0.1052	0.0123	0.0091	0.0838
B	0.4932	B1	0.2272	0.1420	0.0352	0.0500
		B2	0.0943	0.0295	0.0041	0.0607
		B3	0.1717	0.0141	0.0837	0.0739
C	0.0462	C1	0.0462	0.0118	0.0143	0.0201
D	0.1102	D1	0.0182	0.0162	0.0012	0.0008
		D2	0.0319	0.0093	0.0068	0.0158
		D3	0.0449	0.0151	0.0084	0.0214
		D4	0.0152	0.0016	0.0069	0.0067
Total	1.0000		1.0000	0.4363	0.1769	0.3868
Rank				1	3	2



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7.4. Detailed results for the Marine Habitat Degradation IC

Island scores

Table 7.4.1. Scores and islands' ranking for near future (2046-2065) under RCP 2.6 low emissions scenario

Island	Exposure				Sensitivity			Adaptive Capacity				Total	Rank	
	Hazard	Surface of phanerogams	Number of divers	Tourists' arrivals	Total	Phanerogams' susceptibility to heat	Economic valuation	Total	Products substitution	Seagrass removal	Sewage treatment			Total
Balearic I.	0,020	0,029	0,008	0,012	0,049	0,048	0,002	0,050	0,032	0,018	0,019	0,069	0,187	2
Canary I.	0,010	0,002	0,004	0,012	0,018	0,082	0,024	0,106	0,032	0,002	0,019	0,053	0,186	3
Cyprus	0,103	0,004	0,001	0,002	0,007	0,011	0,004	0,014	0,093	0,006	0,056	0,154	0,279	1
Malta	0,045	0,008	0,001	0,001	0,011	0,020	0,006	0,025	0,032	0,006	0,056	0,094	0,175	4
Sicily	0,045	0,020	0,001	0,005	0,026	0,017	0,009	0,026	0,017	0,003	0,056	0,075	0,173	5
Sub-criteria	0,222	0,063	0,016	0,032	0,111	0,178	0,044	0,222	0,205	0,034	0,205	0,444	1,00	
Criteria	0,222	0,111				0,222			0,444				1,00	

Table 7.4.2. Scores and islands' ranking for near future (2081-2100) under RCP 2.6 low emissions scenario

Island	Exposure				Sensitivity			Adaptive Capacity				Total	Rank	
	Seawater heating	Surface of phanerogams	Number of divers	Tourists' arrivals	Total	Phanerogams' susceptibility to heat	Economic valuation	Total	Products substitution	Seagrass removal	Sewage treatment			Total
Balearic I.	0,020	0,029	0,008	0,012	0,049	0,048	0,002	0,050	0,032	0,018	0,019	0,069	0,187	2
Canary I.	0,010	0,002	0,004	0,012	0,018	0,082	0,024	0,106	0,032	0,002	0,019	0,053	0,186	3
Cyprus	0,103	0,004	0,001	0,002	0,007	0,011	0,004	0,014	0,093	0,006	0,056	0,154	0,279	1
Malta	0,045	0,008	0,001	0,001	0,011	0,020	0,006	0,025	0,032	0,006	0,056	0,094	0,175	4
Sicily	0,045	0,020	0,001	0,005	0,026	0,017	0,009	0,026	0,017	0,003	0,056	0,075	0,173	5
Sub-criteria	0,222	0,063	0,016	0,032	0,111	0,178	0,044	0,222	0,205	0,034	0,205	0,444	1,00	
Criteria	0,222	0,111				0,222			0,444				1,00	



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Table 7.4.3. Scores and Islands' ranking for near future (2046-2065) under RCP 8.5 low emissions scenario

Island	Hazard		Exposure				Sensitivity			Adaptive Capacity				Total	Rank
	Seawater heating	heating	Surface of phanerogams	Number of divers	Tourists' arrivals	Total	Phanerogams' susceptibility to heat	Economic valuation	Total	Products substitution	Seagrass removal	Sewage treatment	Total		
Balearic I.	0,025		0,029	0,008	0,012	0,049	0,048	0,002	0,050	0,032	0,018	0,019	0,069	0,193	2
Canary I.	0,008		0,002	0,004	0,012	0,018	0,082	0,024	0,106	0,032	0,002	0,019	0,053	0,185	3
Cyprus	0,101		0,004	0,001	0,002	0,007	0,011	0,004	0,014	0,093	0,006	0,056	0,154	0,277	1
Malta	0,043		0,008	0,001	0,001	0,011	0,020	0,006	0,025	0,032	0,006	0,056	0,094	0,172	5
Sicily	0,045		0,020	0,001	0,005	0,026	0,017	0,009	0,026	0,017	0,003	0,056	0,075	0,173	4
Sub-criteria	0,222		0,063	0,016	0,032	0,111	0,178	0,044	0,222	0,205	0,034	0,205	0,444	1,00	
Criteria	0,222		0,111				0,222			0,444				1,00	

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Table 7.4.4. Scores and Islands' ranking for near future (2081-2100) under RCP 8.5 low emissions scenario

Island	Hazard		Exposure				Sensitivity			Adaptive Capacity				Total	Rank
	Seawater heating	heating	Surface of phanerogams	Number of divers	Tourists' arrivals	Total	Phanerogams' susceptibility to heat	Economic valuation	Total	Products substitution	Seagrass removal	Sewage treatment	Total		
Balearic I.	0,032		0,029	0,008	0,012	0,049	0,048	0,002	0,050	0,032	0,018	0,019	0,069	0,199	2
Canary I.	0,007		0,002	0,004	0,012	0,018	0,082	0,024	0,106	0,032	0,002	0,019	0,053	0,184	3
Cyprus	0,096		0,004	0,001	0,002	0,007	0,011	0,004	0,014	0,093	0,006	0,056	0,154	0,271	1
Malta	0,044		0,008	0,001	0,001	0,011	0,020	0,006	0,025	0,032	0,006	0,056	0,094	0,174	4
Sicily	0,044		0,020	0,001	0,005	0,026	0,017	0,009	0,026	0,017	0,003	0,056	0,075	0,172	5
Sub-criteria	0,222		0,063	0,016	0,032	0,111	0,178	0,044	0,222	0,205	0,034	0,205	0,444	1,00	
Criteria	0,222		0,111				0,222			0,444				1,00	

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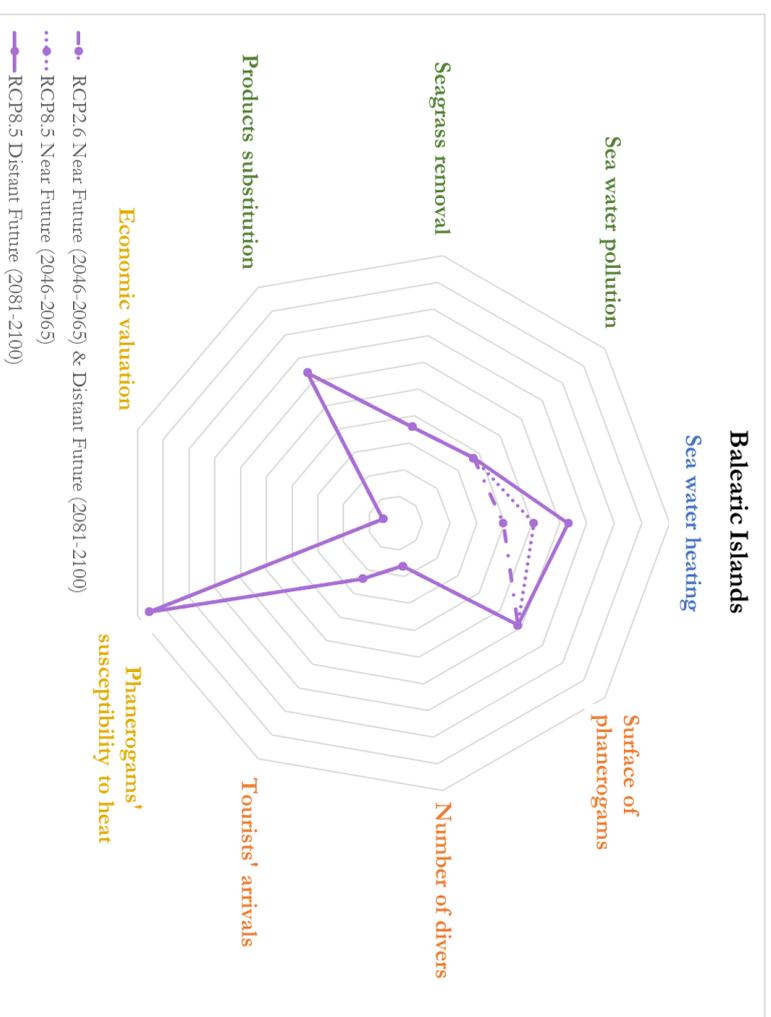
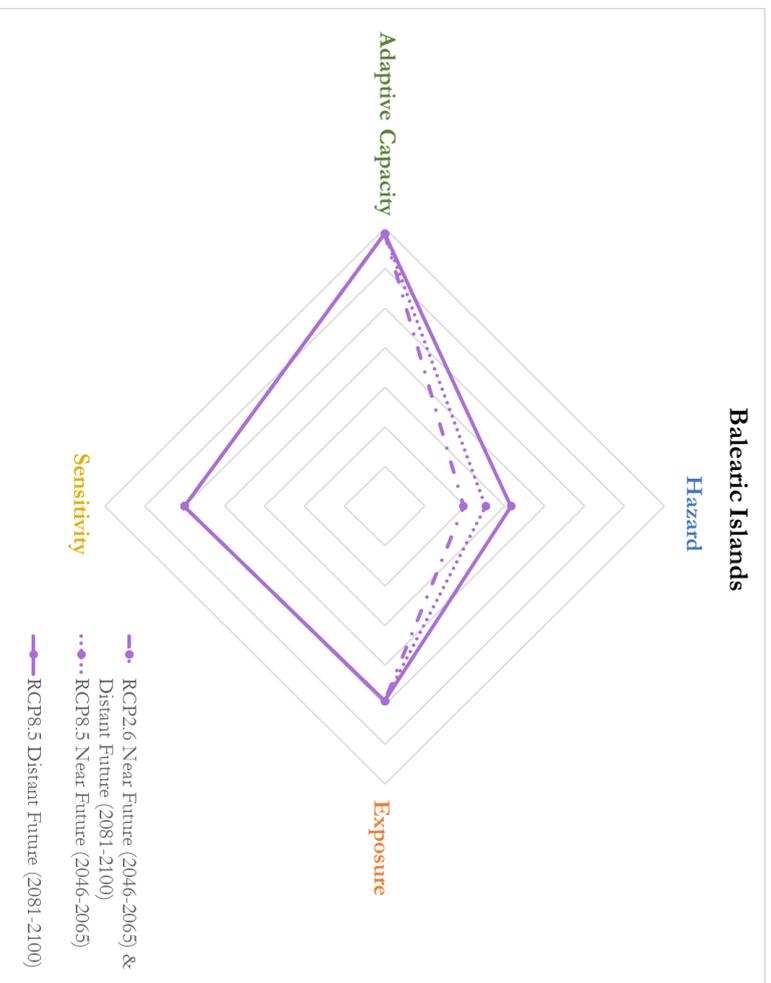
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Visualization of risk component relative weight per island

Balearic Islands



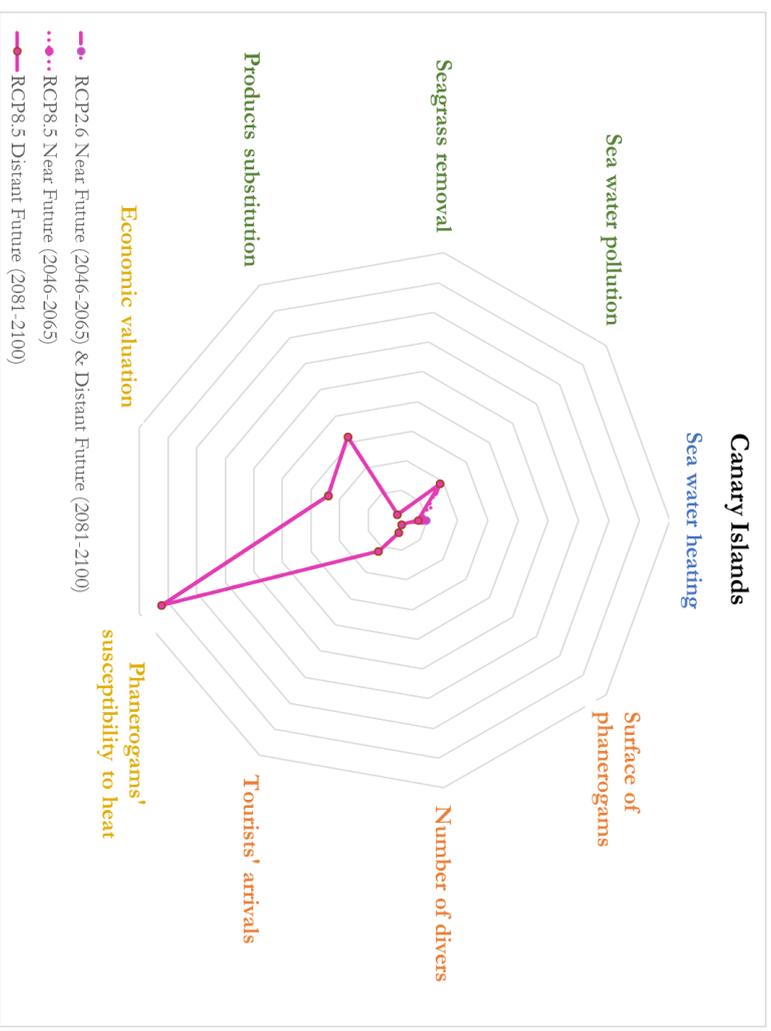
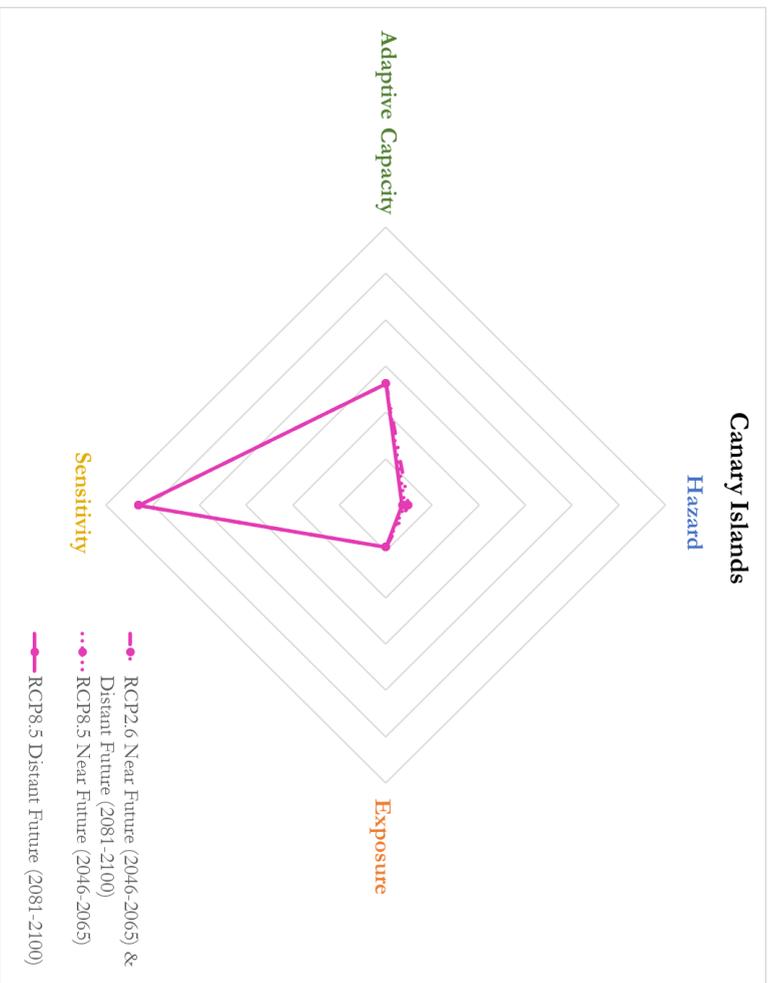


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Canary Islands



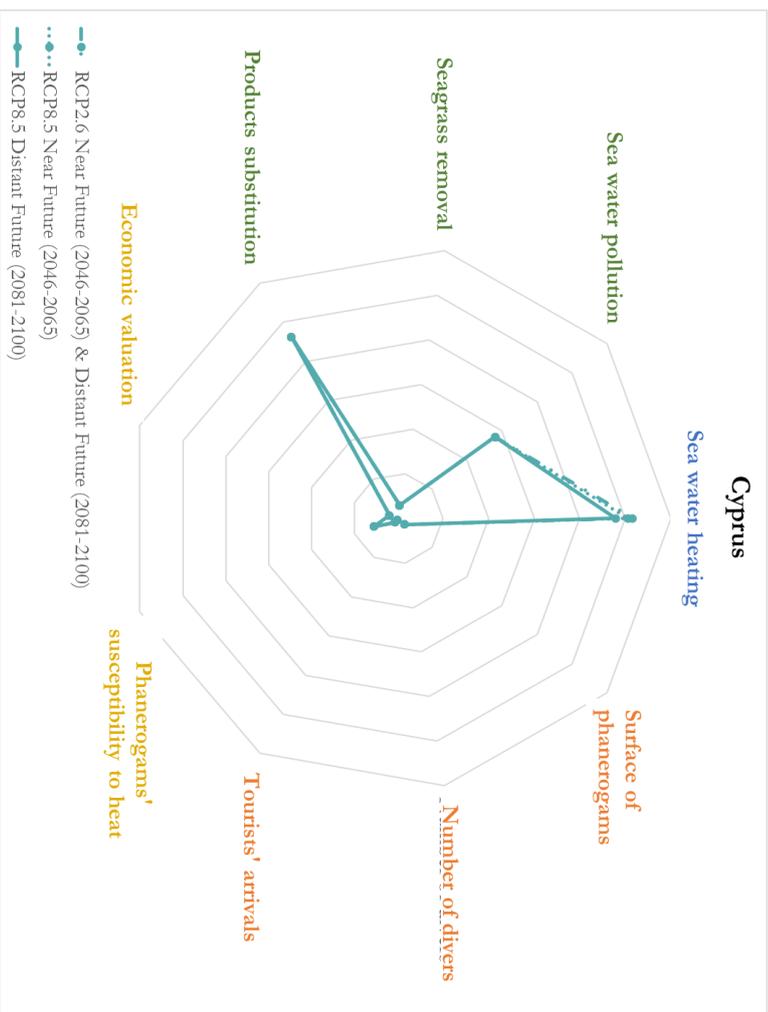
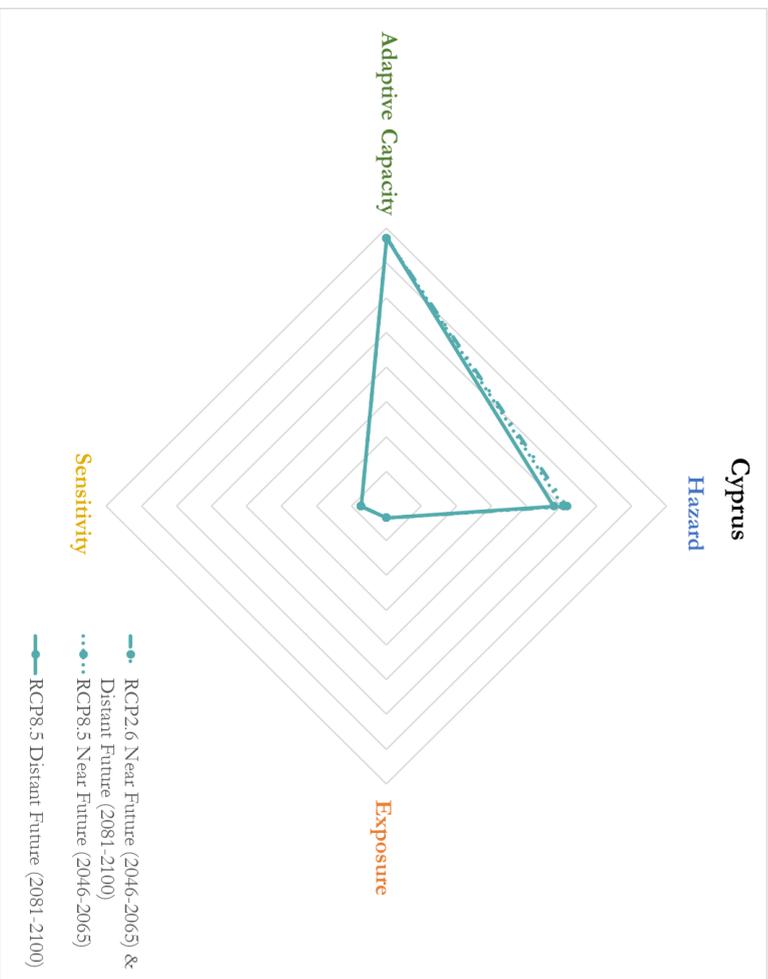


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Cyprus



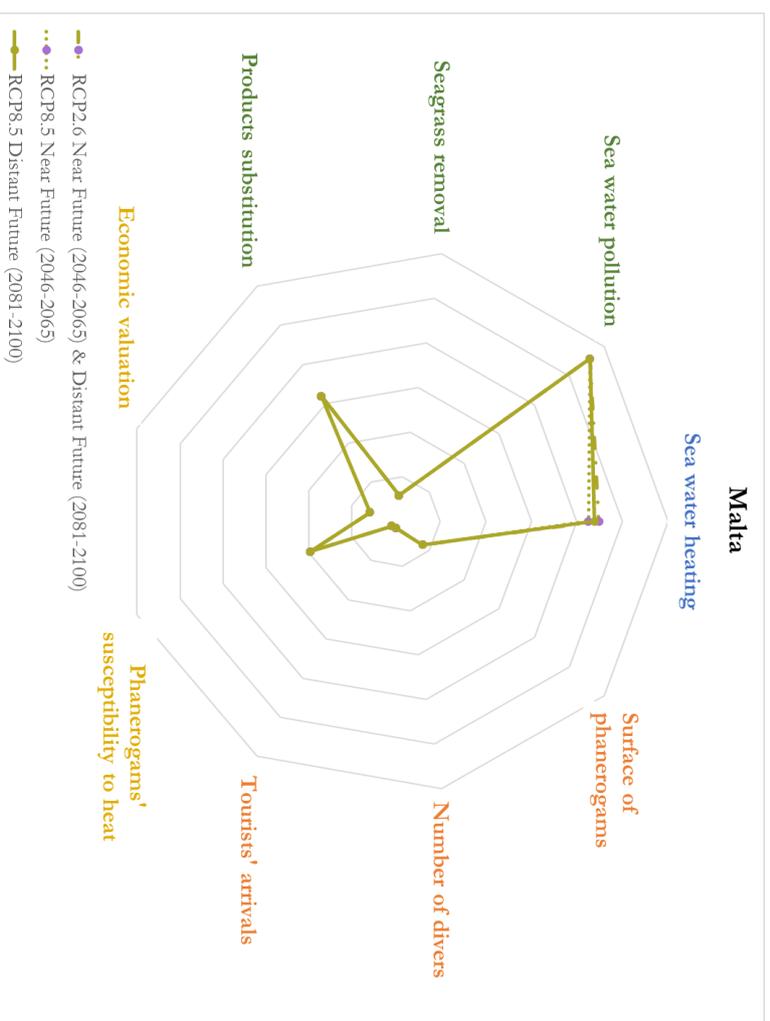
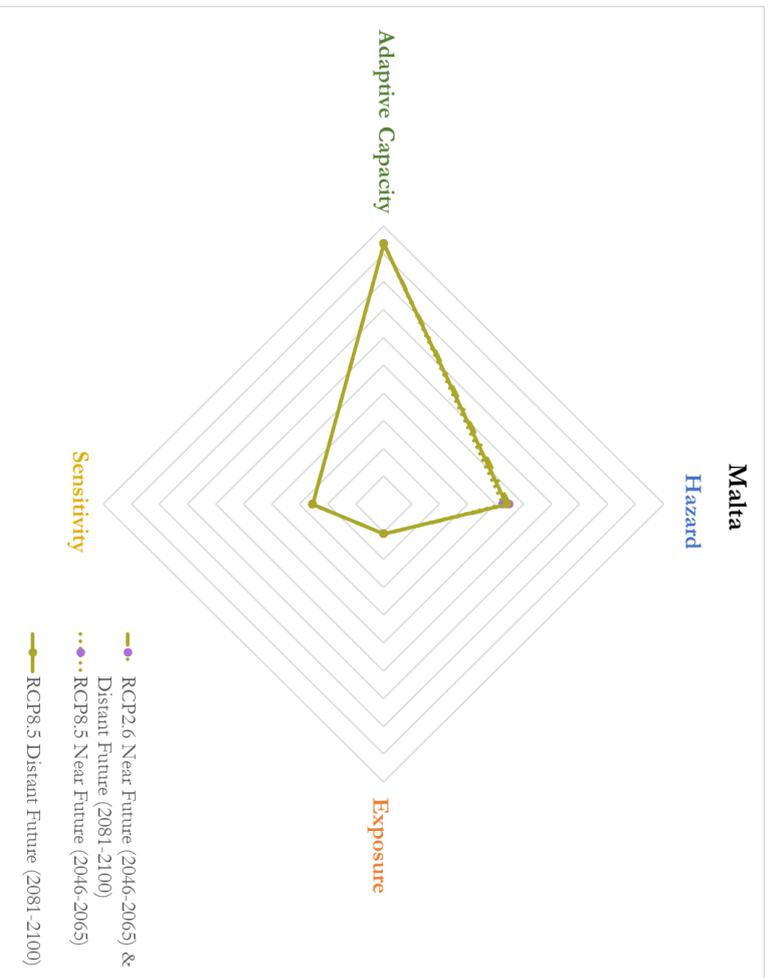


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Malta



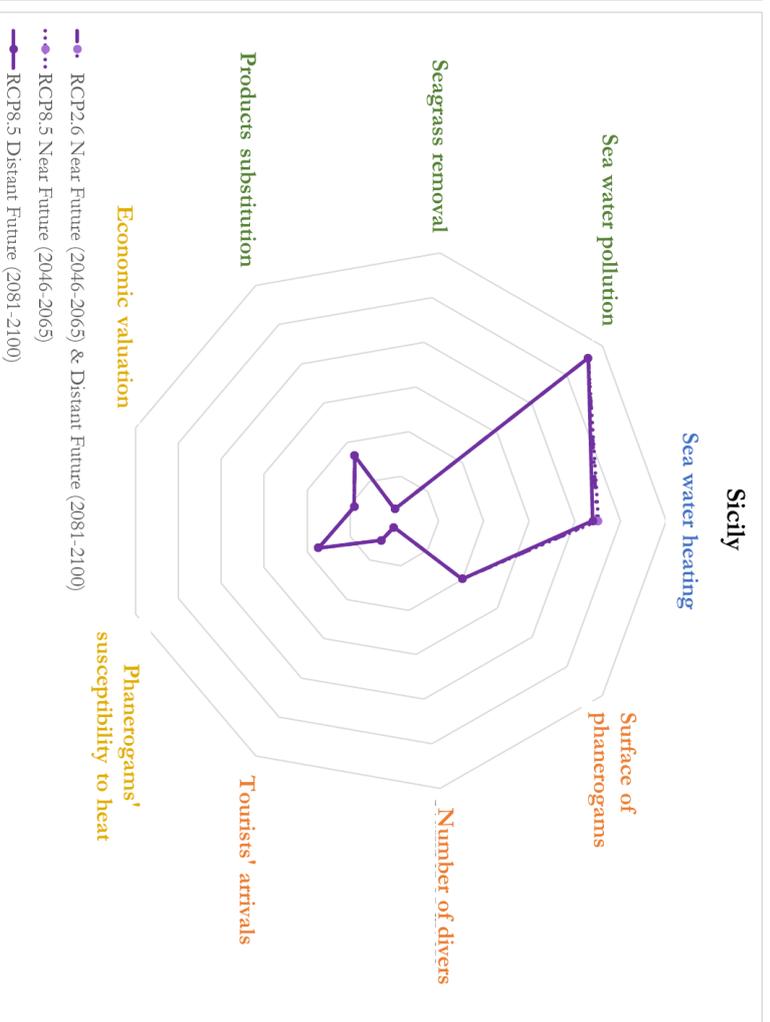
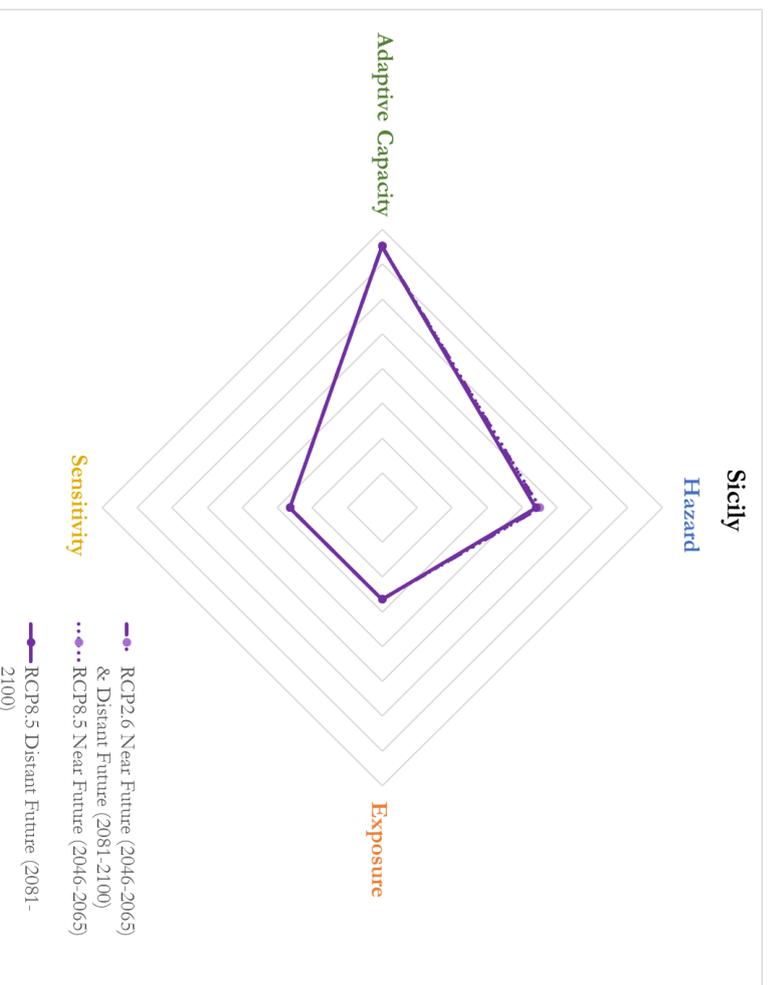


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Sicily



Indicator data

Hazard

Seawater heating: Number of days per year in which sea water temperature is over 25°C.

	Historical	RCP2.6		RCP8.5	
	Mean (1985-2005)	Near future (2046-2065)	Distant future (2081-2011)	Near future (2046-2065)	Distant future (2081-2011)
Balearic	-	-	-	-	-
Canary	-	-	-	-	-
Cyprus	70	105	104	111	151
Malta	56	80	70	81	111
Sicily	53	81	74	87	112

Seawater heating: Number of days per year in which sea water temperature is over 26°C.

	Historical	RCP2.6		RCP8.5	
	Mean (1985-2005)	Near future (2046-2065)	Distant future (2081-2011)	Near future (2046-2065)	Distant future (2081-2011)
Balearic	9	29	26	47	87
Canary	0	0	0	4	12
Cyprus	60	95	93	105	138
Malta	31	55	49	61	95
Sicily	29	54	49	64	95

Exposure

Surface of marine Phanerogams: Surface, in km²; and expected % of surface loss for RCP8.5 distant future.

	Balearic	Canary	Cyprus	Malta	Sicily
Surface (km ²)	1032.5	91.7	84.3	143.6	996.3
% of loss	35.0	0.0	0.0	20.1	28.3

Number of divers: Number of tourists practising Diving at the destination.

	Balearic	Canary	Cyprus	Malta	Sicily
# divers	882,000	450,000	50,000	155,300	400,000

Tourists' arrivals: Average tourists' arrivals in the last three years (2017-2019).

	Balearic	Canary	Cyprus	Malta	Sicily
# tourists	16,450,000	15,560,000	3,855,825	2,541,922	4,991,439
Index	6.5	6.1	1.5	1.0	2.0

Sensitivity

Phanerogams' reduction due to heat: Expected reduction of phanerogams' surface (%) due to seawater heating.

	Specie	Present area covered (km ²)	RCP2.6		RCP8.5	
			Near future (2046-2065)	Distant future (2081-2011)	Near future (2046-2065)	Distant future (2081-2011)
Balearic	<u>Cymodocea</u>	30.2	0.0	0.0	0.0	0.0
	<u>Zostera</u>	0.3	0.0	16.7	100.0	100.0
	<u>Posidonia</u>	1002.0	0.0	0.0	0.0	35.1
Canary	<u>Cymodocea</u>	83.1	0.0	0.0	0.0	0.0
	<u>Zostera</u>	4.3	0.0	0.0	0.0	0.0
	<u>Halophila</u>	4.3	0.0	0.0	0.0	0.0
Cyprus	<u>Posidonia</u>	84.3	0.0	0.0	0.0	0.0
Malta	<u>Posidonia</u>	143.6	0.0	0.0	0.0	20.1
Sicily	<u>Posidonia</u>	966.3	0.0	0.0	0.0	28.3

Economic valuation: Tourists' willingness to pay (€/day) to implement policies aiming at avoiding marine habitats degradation.

	Balearic	Canary	Cyprus	Malta	Sicily
€/day	5.7	10.7	5.8	6.4	6.8

Adaptive capacity

Products substitution capacity: Score (1-4) for the capacity to derive tourist demand to non-marine habitat-based activities.

	Balearic	Canary	Cyprus	Malta	Sicily
Score	2	2	2	2	3

- 1: **No** capacity; the destination strongly depends on marine habitats with no alternatives;
- 2: Destination shows **slight** capacity to derive tourist demand from marine habitats;
- 3: Destination shows **significant** capacity to derive tourist demand from marine habitats;
- 4: Destination shows **high** capacity to derive tourist demand from marine habitats.



Seagrass removal: Score (1-4) for the capacity to remove dead seagrass lying on beaches.

	Balearic	Canary	Cyprus	Malta	Sicily
Score	3	3	3	3	3

- 1: **No** removal at all; the destination does not do it and authorities do not plan doing it;
- 2: **Sometimes**; just in case of very high accumulation of dead seagrass on the main tourist beaches;
- 3: Destination **regularly** remove dead seagrass from the main tourist beaches;
- 4: All dead seagrass is removed from beaches **as soon it arrives**.

Sea water pollution: Score (1-4) for the quality of management of inshore and offshore sewages.

	Balearic	Canary	Cyprus	Malta	Sicily
Score	2	3	4	4	4

- 1: Sewage treatment capabilities are low, **treatment is very poor**, and littoral **pollution, high**;
- 2: Some treatment capabilities exist, but **law and enforcement are weak**, so coastal marine environment is **quite polluted**;
- 3: Treatment capabilities are high but **enforcement still fails** so some discharges persist and seawaters around show **slightly polluted**;
- 4: Almost **all inshore and offshore sewage are treated** and seawater around the island looks **very clean**.



SOCCLIMPACT

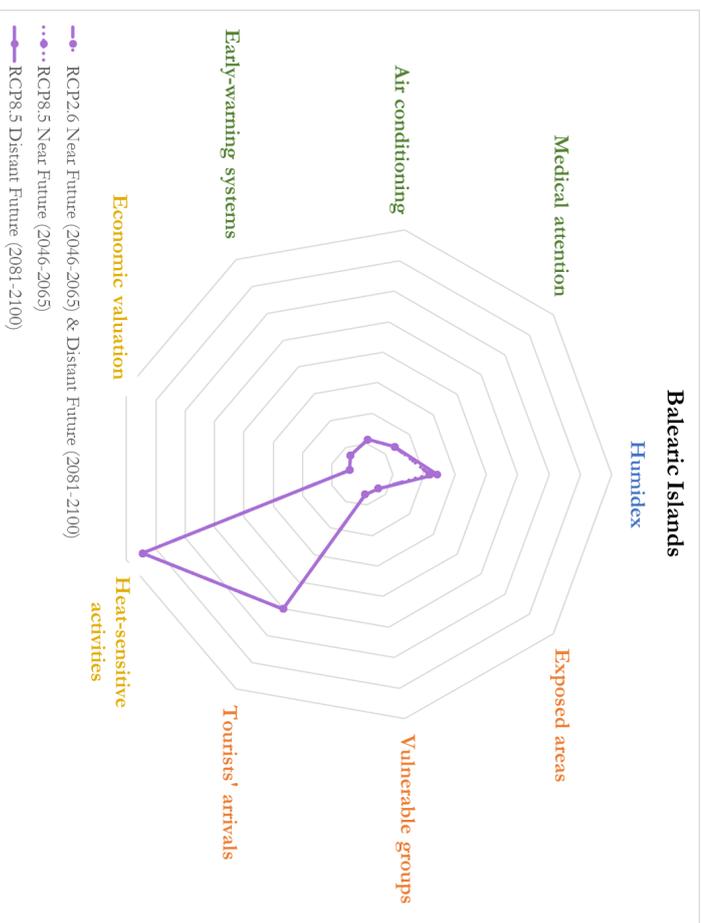
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No776661



7.5. Detailed results for the Thermal Comfort IC

Visualization of risk component relative weight per island

Balearic Islands



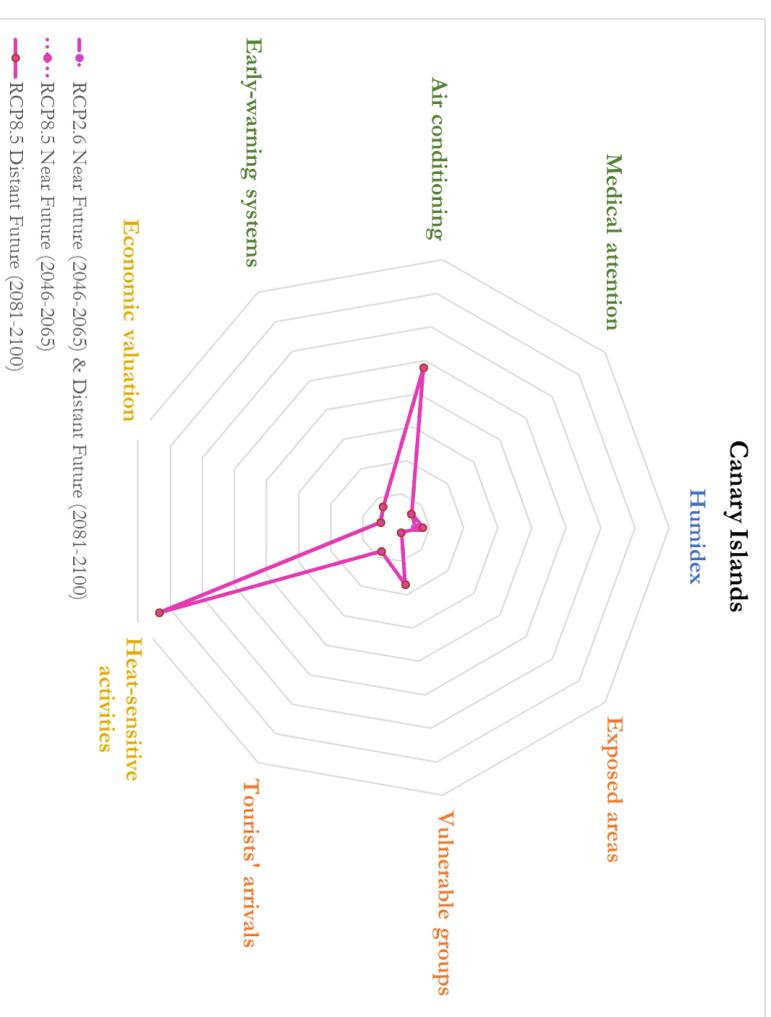
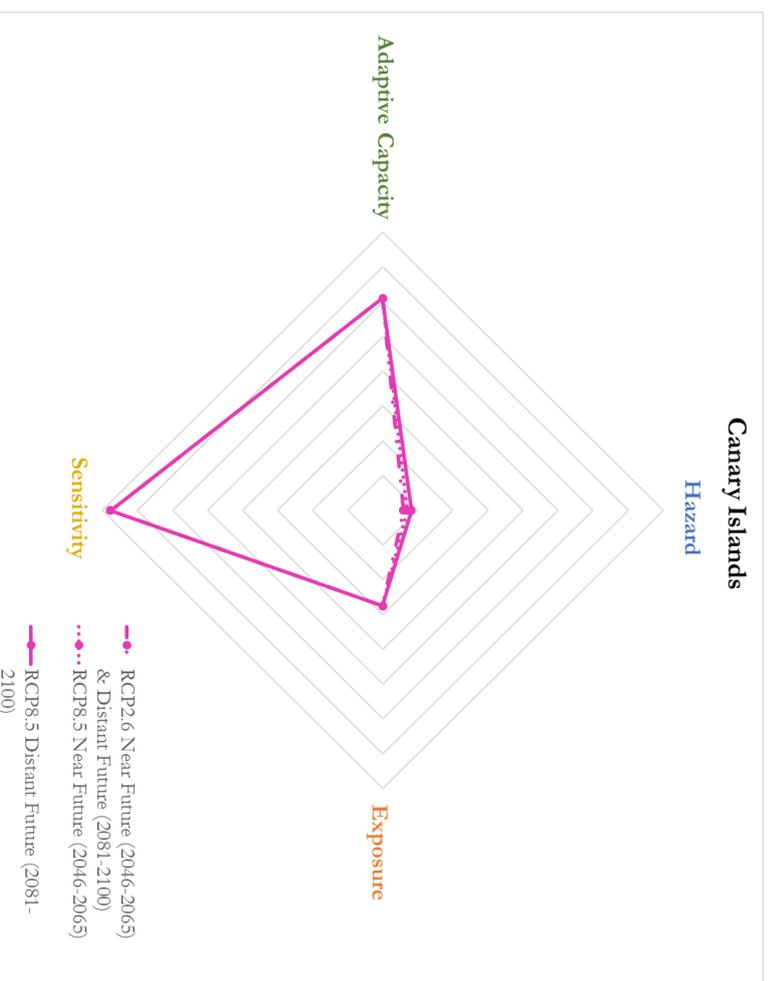


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SOCCLIMPACT



Canary Islands



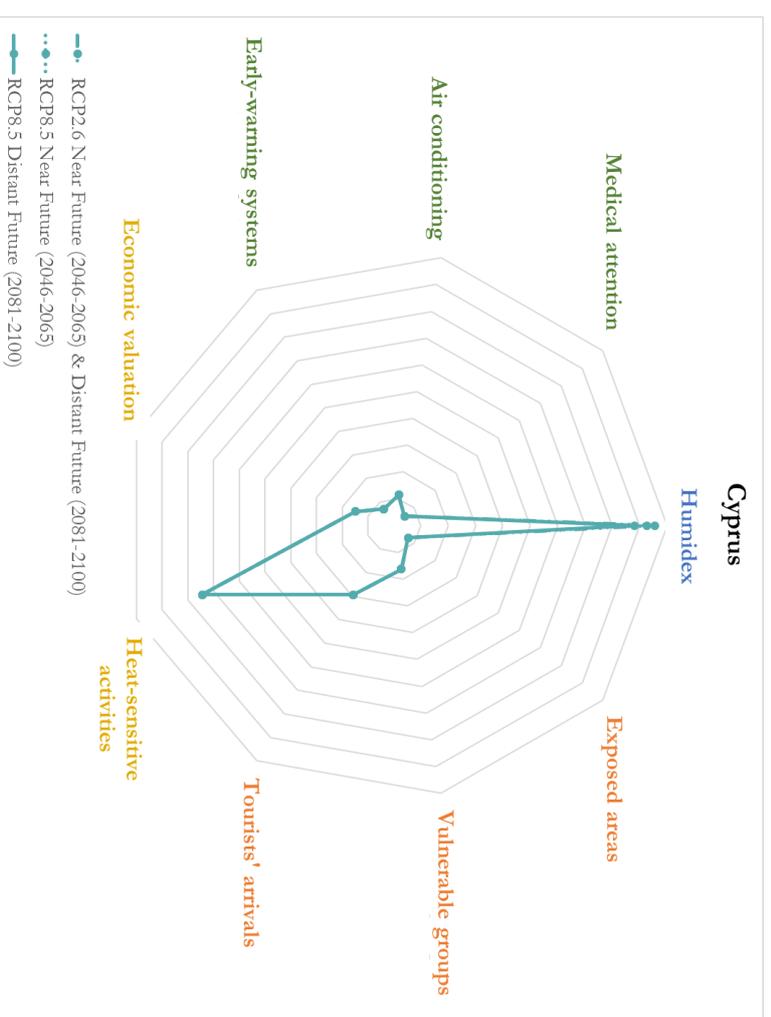
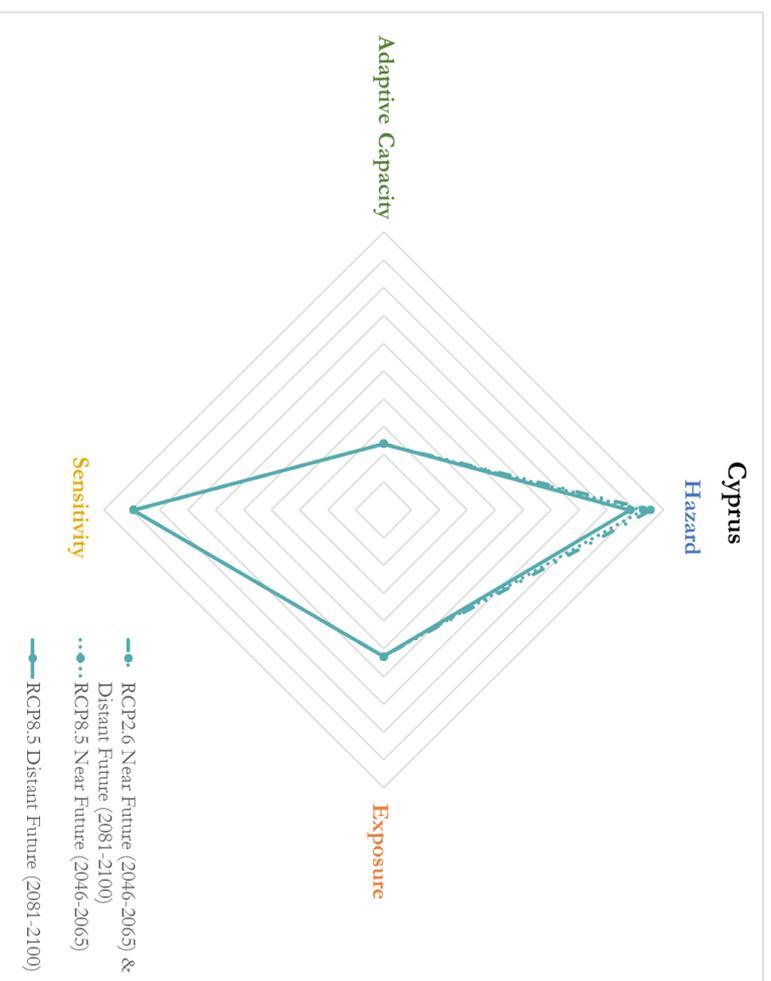


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Cyprus



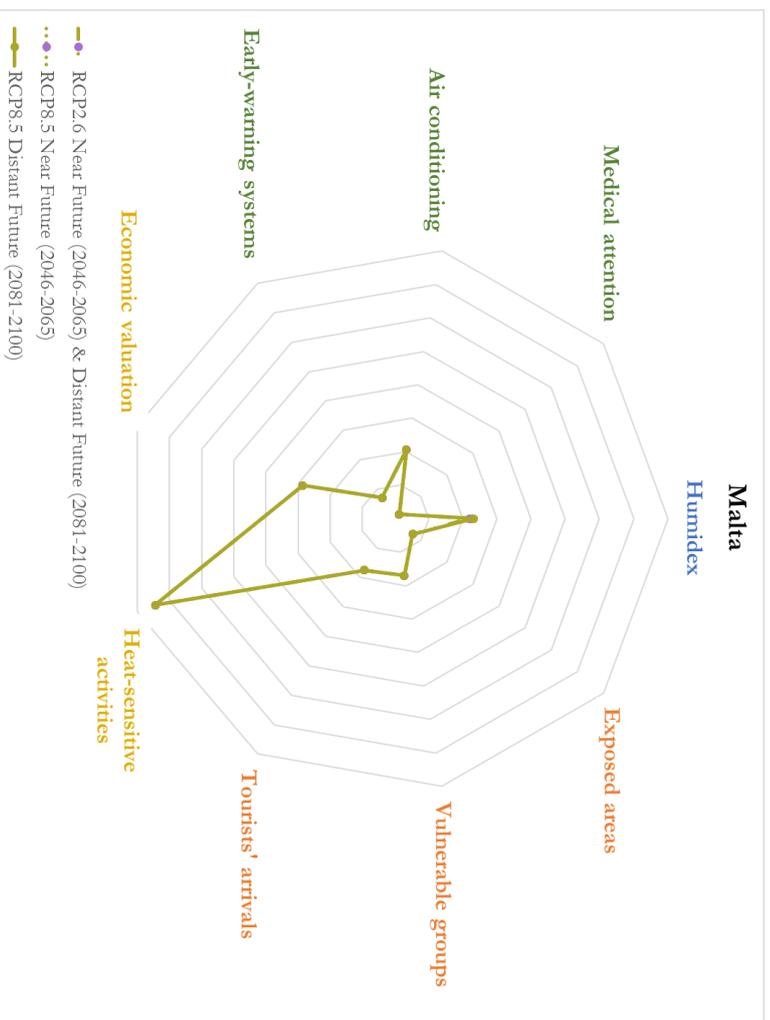
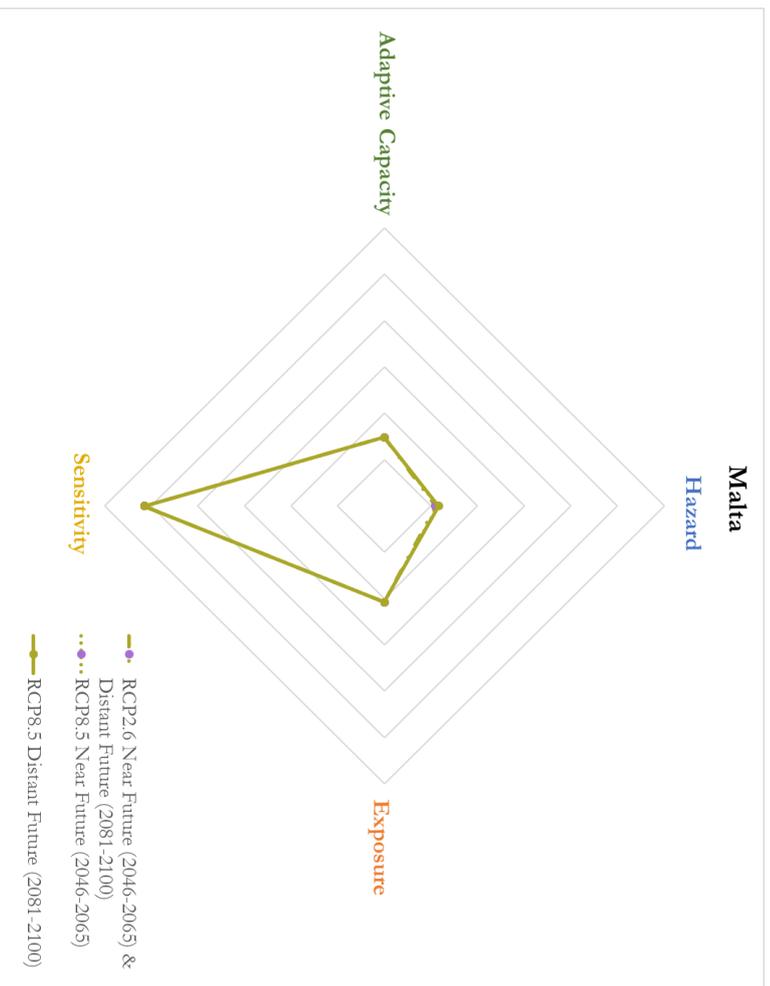


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SOCCLIMPACT



Malta





SOCCLIMPACT

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Sardinia



7.6. Detailed methodology for Energy

Hazard indicator computation and normalization

Cooling Degree Days (CDD)

Cooling degree days (CDD) are used to give an indication of the effect of outside air temperature on building energy consumption during a specified period of time. **The Cooling Degree Days (CDD) index** gives the number of degrees and number of days that the outside air temperature at a specific location is higher than a specified base temperature.

The calculation of CDD relies on the base temperature, defined as the highest daily mean air temperature not leading to indoor cooling. The value of the base temperature depends in principle on several factors associated with the building and the surrounding environment. Different base temperatures have been tested in order to select the value that can adequately represent all the islands of the current analysis. The base temperature here has been set as $T_{base} = 21^{\circ}C$.

Then the index is calculated as follows:

If $T_m \geq 24^{\circ}C$ Then $[CDD = \sum_i T_m - 21^{\circ}C]$ Else $[CDD = 0]$ where T_m is the mean air temperature of day i .

The index has been calculated on a monthly basis for the period 1981-2100 for all islands, climate models, and scenarios. The calculation was performed for each one of the selected pairs of global climate models/regional climate models. The ensemble mean and uncertainty (described by the pooled standard deviation) have been obtained for 20-year time-averages, for the reference period (1986-2005), as well as the two future periods of interest (2046-2065 and 2081-2100) for the two selected RCPs for EURO-CORDEX and MENA-CORDEX simulations. Then, the grid cells that represent a land fraction: l.f. > 15 % for the islands were retained for the analysis.

For the indicator weight calculation in the islands where the impact chain has been operationalized, observed values of CDD (EUROSTAT) have been used. For Gran Canaria, the NUTS3 data for the whole archipelago have been taken as for the island itself only 2 years were available.

With respect to the normalization of the indicator, we have used a fixed lower threshold and a relative maximum as upper threshold. The minimum CDD value has been taken as 0, while the maximum CDD value has been taken as the maximum over all islands, emissions scenarios and time periods (1183.49 $^{\circ}C \cdot \text{days}/\text{year}$, corresponding to Cyprus for RCP8.5 scenario, end of century period).

Standardised Precipitation-Evapotranspiration Index (SPEI)

SPEI is a drought index that takes into account not only the effect of precipitation variations, but also the effect of temperature variations on evapotranspiration. The calculation is based on the monthly difference between precipitation and potential evapotranspiration, which represents the monthly water surplus or deficit. The monthly differences can be aggregated at different time-scales, depending on the type of drought to be monitored. In our case, a 12-month aggregation has been used. More details on SPEI and its computation can be found in Beguería et al.

Temperature and precipitation data for SPEI calculation have been taken from the selected regional climate model simulations. Regarding the indicator weight calculation for the islands for which the impact chain has been operationalized, ECA&D (European Climate Assessment & Dataset) data have been used for Malta and Cyprus, while for Gran Canaria local data have been applied (Plan Hidrológico de Gran Canaria, 2019).

The normalization of the indicator has taken into account the fact that by definition, present conditions correspond to reference conditions (SPEI=0), and that all future changes are towards negative SPEI values, that is towards drier conditions. Therefore, the best score value (0) has been assigned to SPEI=0, while the worst score value (1) has been assigned to the largest negative value found for all islands, emissions scenarios and time periods (SPEI=-2.5, obtained for several islands under RCP8.5 emissions scenario by the end of century).

Wind energy productivity

This indicator (W_{prod}) will show the present wind energy potential and its projected future evolution. Here, productivity (kWh/kW) is defined as the energy produced in a period of time divided by the power installed, which is considered as unitary. The methodology followed is the same used in the previous deliverable 4.3.

We first derive the wind speed at the surface (10 m, W_{10}) from 6-hourly U_{10} and V_{10} wind components of the simulations considered. Then, we calculate the wind speed W_H at the turbine hub height ($H = 100$ m for wind energy over land; $H = 150$ m over the sea). From Tobin et al. (2015):

$$W_H = W_{10} \cdot \left(\frac{H}{10}\right)^\alpha$$

$$\alpha = \frac{1}{7}$$

After calculating W_H at the turbine hub height, we calculate wind potential (W_{pot}) as in Jerez et al. (2015). However, in order to do that, W_H must be regarded as the average of the wind speed at 6-hours intervals (W_{av}):

$$W_{av} \left(\frac{t_{2i+1}}{2}\right) = \frac{[W_H(t_i) + W_H(t_{i+1})]}{2}$$

$$W_{pot} = \begin{cases} 0 & \text{if } V < V_I \\ \frac{V^3 - V_I^3}{V_R^3 - V_I^3} & \text{if } V_I \leq V < V_R \\ 1 & \text{if } V_R \leq V < V_O \\ 0 & \text{if } V \geq V_O \end{cases}$$

where $V_I = 3$ m/s (cut-in wind velocity); $V_R = 12$ m/s (rated velocity); $V_O = 25$ m/s (cut-out velocity) and $V = W_{av}$.

Finally, wind productivity (W_{prod}) is calculated from the wind potential produced by the 6-hr averaged wind multiplied by the number of hours (6 hours).

The indicator is calculated separately for land and sea. Offshore wind energy is the most developed ocean energy, and it is likely to be an important future energy source for the analysed islands. Its characteristics are typically very different to onshore wind energy, due to the large differences in surface friction. The energy productivity values are averaged respectively over the island land points and over the sea points in a domain that reaches a maximum distance of one degree latitude and longitude respectively to the maximum and minimum longitude/latitude land points of the islands.

The normalization is performed using absolute thresholds, that represent high or low global values of productivity. These thresholds have been obtained from a global renewable power report (IRENA, 2019). In this report, 5th and 95th percentiles of renewable energy capacity factors (CFs) are given for the period 2010-2018. The minimum and maximum thresholds are estimated as rounded values deduced respectively from the 5th and 95th percentiles shown in the report. The conversion from productivity values to CFs in percentage terms is done as follows:

$$CF = (Productivity/8760)*100$$

where 8760 is the annual number of hours. The maximum annual productivity would be 8760 kWh/kW, corresponding to a 100% capacity factor.

The obtained CF thresholds for onshore wind energy are 20% (corresponding to a normalized score of 1) and 45% (normalized score of 0), while for offshore energy they are 30% and 50%.

Photovoltaic productivity

This indicator will show the present solar photovoltaic (PV) potential and its projected future evolution. Productivity (kWh/kW) is defined as the energy produced in a period of time divided by the power capacity installed.

In order to obtain photovoltaic productivity, daily surface solar radiation (SSR) and ambient temperature from the climate simulations are used as input variables for a parametric PV model.

The PV modelling process can be summarised in two steps: first, incident solar radiation that reaches solar cells inside the panels is obtained through the decomposition of global solar irradiation and the transposition to the plane-of-array. After that, the electrical performance of the photovoltaic system is modelled in order to obtain daily PV productivity (PV_{prod}). To obtain annual or monthly statistics, the respective sum of daily productivity is computed in each case. A detailed description of the methodology was presented in Deliverable 4.3 (the methodology is the same followed in Gutiérrez et al., 2017).

The normalization is performed using absolute thresholds, that represent high or low global values of productivity, taken from the same report as for wind energy. In this case, the maximum threshold is adapted taking into account that the calculations performed here assume fixed panels, while



IRENA global report does not differentiate between fixed and sun-tracking panels. The use of tracking increases the capacity factor by 5 percentage points for the best resource locations (Bolinger and Seel, 2019). Therefore, we estimate an upper CF threshold (normalized score of 0) of 20% for fixed panels, from the 25% value deduced from IRENA global report. The lower CF threshold obtained from the latter report is 10% (normalized score of 1).

Renewable energy productivity droughts

Photovoltaic and wind energy productivity droughts are calculated as an indicator of productivity steadiness in the analysed European islands. Renewable energy droughts can be regarded as low-productivity periods during which the daily productivity takes values below a low-productivity threshold. To systematically identify energy droughts, a Deficiency Index (DI) is computed following Raynaud et al. (2018). This is defined as follows:

$$\begin{aligned} DI(i,j) &= 1 \text{ if } P(i,j) \leq P_0(i,j) \\ DI(i,j) &= 0 \text{ if } P(i,j) > P_0(i,j) \end{aligned}$$

where P is the daily productivity (kWh/kW) computed as explained in Sections 2.1 and 2.2 and P_0 the corresponding low-productivity threshold. Productivity thresholds are calculated as a percentage of the mean daily productivity estimated for the control time period, which goes from 1986 to 2005. These thresholds are also used to determine energy productivity droughts in the scenarios. Two different thresholds are calculated to determine moderate (50% of mean daily productivity) and severe (20% of mean daily productivity) energy productivity droughts, respectively. For clarity, only the moderate energy productivity droughts are presented in the tables in section 3. In order to illustrate the level of complementarity of solar and wind energy, combined photovoltaic and wind productivity droughts are also calculated, assuming a 50/50 distribution of solar and wind power capacity. Energy productivity droughts have been calculated as spatial averages over land points. More details about the methodology followed to compute energy productivity droughts can be found in the Methodology Section of Deliverable 4.3 dealing with energy indicators.

For the normalization of these energy drought indicators, we have used a combination of an absolute threshold (a value of 0% of drought days) corresponding to a score of 0 and a relative maximum upper limit, taken among all the islands and renewable energy technologies (55% of days with moderate droughts, obtained for wind energy in Corsica) corresponding to a score of 1. The same normalization limits are applied for wind, PV and combined productivity droughts.

Renewable energy productivity changes

The available literature on the impact of climate change on wind and PV energies shows that the future projected changes frequently do not exceed a level of 10% relative to present values over the studied area (Devis et al., 2018; Solaun and Cerdá, 2019; Solaun and Cerdá, 2020). Such a change would produce rather limited changes in the normalized scores if we maintained the same approach for future values. Though changes of about 10% do not impact strongly on a normalized score, they are a significant impact on the productivity and profitability of the energy plants. On the other hand, in the case of renewable energies, both increases and decreases in future productivity are projected, and this should be taken into account in the normalized values.

Also, the relatively large uncertainty in certain variables like wind from climate models makes relative changes more reliable than absolute values (Solaun and Cerdá, 2019). Therefore, we have used change indicators instead of the future values of the same indicators used for present climate conditions, in such a way that positive changes can be differentiated from negative changes. The normalized values for the projected changes are calculated through a weighted combination of a term comparing the change in the particular island to an overall fixed change threshold of 10% and a term comparing the change in a particular island to the changes in other islands.

These normalized values in the different islands, time periods and scenarios of study are expressed through the Nc index. A value of Nc equal to 0.5 indicates no future change. When Nc>0.5, projected changes are unfavorable, being Nc=1 the worst possible scenario. This entails that productivity (droughts) decreases (increase). On the contrary, values of Nc<0.5 indicate a favorable future change, being Nc=0 the best possible scenario. The Nc index is defined as follows:

$$Nc = 0.25 \cdot A + 0.75 \cdot B$$

The terms A and B are individually normalized as explained below:

A: this term serves to estimate the projected change in a region with respect to the rest of the islands.

To calculate it we first compute (for each indicator, time period and scenario), the absolute maximum ensemble mean increase (Δ_{max}) and the absolute maximum ensemble mean decrease (Δ_{min}) of all the islands. In the case of productivity, Δ_{max} and Δ_{min} are provided in kWh/kWp. In the case of energy productivity droughts, Δ_{max} and Δ_{min} are given in absolute change (%).

Then, we compare the ensemble mean change for a given island, time period and scenario (Δ_{mean}) to the maximum change encountered for the corresponding case taking into account all islands. For the productivity case, Δ_{mean} is given in kWh/kWp. In energy productivity droughts, Δ_{mean} is provided as absolute change (%). Specifically, if $\Delta_{mean}>0$, Δ_{mean} is compared to Δ_{max} . Alternatively, if $\Delta_{mean}<0$, Δ_{mean} is compared to Δ_{min} . In each case, the value of A is estimated with a linear regression as follows:

- *Wind and photovoltaic productivity:*

When productivity changes are positive ($\Delta_{mean}>0$), the normalized A would go from 0 to 0.5, whereas if they are negative ($\Delta_{mean}<0$), the normalized value of A would go from 0.5 to 1. In order to obtain the value of A within each interval the productivity changes correspond to, a linear regression is applied as follows:

Positive mean changes:

$$A = \frac{-0.5 \cdot \Delta_{mean}}{\Delta_{max}} + 0.5$$

Negative mean changes:

$$A = \frac{0.5 \cdot \Delta_{mean}}{\Delta_{min}} + 0.5$$

- *Energy productivity droughts:*

If productivity changes are positive ($\Delta\text{mean} > 0$), the normalized A ranges from 0.5 to 1, whereas negative changes ($\Delta\text{mean} < 0$) correspond to a normalized value of A that varies between 0 and 0.5. In order to obtain the value of A, a linear regression is applied as specified below:

Positive mean changes:

$$A = \frac{0.5 \cdot \Delta\text{mean}}{\Delta\text{max}} + 0.5$$

Negative mean changes:

$$A = \frac{-0.5 \cdot \Delta\text{mean}}{\Delta\text{min}} + 0.5$$

B: this term allows us to evaluate the magnitude of the change projected for each island, time period and scenario with respect to a fixed change threshold.

To do so, we express the relative change of the indicators with respect to the control time period (1986-2005) in percentage ($\Delta\text{mean}_{\text{per}}$) and compare it to a threshold of $\pm 10\%$.

In each case, the value of B is calculated with a linear regression as specified below:

- *Wind and photovoltaic productivity:*

When productivity changes are positive, and bigger than 10% ($\Delta\text{mean}_{\text{per}} \geq 10\%$), the normalized B is set to 0, whereas if they are negative, and smaller than -10% ($\Delta\text{mean}_{\text{per}} \leq -10\%$), the normalized value of B is set to 1. In order to obtain the normalized value of B between -10% and 10% a linear regression is applied as follows:

$$B = \frac{1}{20} \cdot (10 - \Delta\text{mean}_{\text{per}})$$

- *Energy productivity droughts:*

Relative changes in the frequency of energy productivity droughts which are positive and greater than 10% ($\Delta\text{mean}_{\text{per}} \geq 10\%$) correspond to a normalized B of 1. If relative changes in the occurrence of energy productivity droughts are negative and smaller than -10% ($\Delta\text{mean}_{\text{per}} \leq -10\%$), the normalized value of B is set to 0. The normalized value of B is obtained with a linear regression as follows:

$$B = \frac{1}{20} \cdot (10 + \Delta\text{mean}_{\text{per}})$$

Normalization of indicators

For the operationalization of the full impact chains regarding cooling and desalination energy demand, the normalization of exposure and vulnerability indicators has been performed as follows (the normalization of climate hazard indicators CDD and SPEI has been explained above):

Exposure

- **Residents Population**

For this exposure indicator we have selected population density, as this quantity allows for a direct comparison among islands independently of their land area. For the normalization, we have used a fixed lower threshold (0 persons/km²) corresponding to a score of 0, while for the maximum threshold we have used the maximum population density in the EU, found in Malta (1372.76 persons/km², in average over 2007-2018), corresponding to a score of 1. EUROSTAT values have been used for Cyprus and Malta, while the data for Canary Islands have been obtained from ISTAC (Canary Statistical Institute).

- **Number of tourists**

In this case, we have assumed that the impact of tourists on electricity demand will depend more on a tourism intensity indicator than on the absolute number of tourists. We have selected the ratio Tourist Number/Population, used in Manera and Valle (2018). In this paper, a maximum value of 4.42 tourists/resident is found over the EU in 2014. This value is used as a maximum threshold for normalization (score 1), while a fixed absolute value of 0 tourists/resident is used as the minimum threshold (score 0). The annual numbers of tourists are taken from local statistical sources for Cyprus and Gran Canaria, while for Malta they are taken from EUROSTAT.

- **Tourism seasonality**

We have developed an indicator summarising the main characteristics of tourism variability over the year. Tourism seasonality will be high if the maximum monthly number of tourists is much higher than the average monthly number of tourists. There will be no seasonality if the monthly maximum number of tourists is equal to the monthly average number of tourists (this corresponds to a constant monthly number of tourists). For the normalization, we have used the following equation:

$$\text{Tourism seasonality} = (\text{Monthly maximum} / \text{Monthly average}) - 1$$

which will be equal to 0 if there is no seasonality. If the monthly maximum is double the average, the score will reach a value of 1. Values above this are capped to 1. Local data sources are used in this case for the 3 islands.

- **Cooling penetration rate**

The cooling penetration rate is the percentage of households using air conditioning. Though it could be variable, and particularly increasing in a warming climate, we have not found data sources with time-series for this variable. Its value is rather high in Cyprus (80,8% in 2009, 80,15% in 2019) and Malta (70% in 2009), and low in Canary Islands (12,8% in 2018; La Vanguardia, 2018), in good correspondence with summer temperatures. Due to the absence of time-varying data for this indicator, it is not possible to apply in this case the same correlation-based method for weighting as for other indicators, and therefore we have not used it in the operationalization of the impact chains.

- **Percentage of desalinated water with respect to total water**

For this indicator, time-series are available from local sources. For Gran Canaria, the percentage has increased from 20% in 1990 to more than 50% during the last years. For Cyprus, data from 2010 to 2017 show variations between 4% in 2012 and 31% in 2017, while for Malta this indicator varies between 55% and 61% in the period 2004-2018. The normalization in this case is straightforward, based on fixed thresholds: 0% of desalinated water corresponds to a score of 0, while 100% of desalinated water is associated to a score of 1.

Vulnerability (Sensitivity)

- **Energy intensity**

This indicator is an efficiency measure, calculated here as electricity consumption divided by GDP (2000-2018 average). Data have been taken from EUROSTAT for Malta and Cyprus, while for Gran Canaria they have been obtained from ISTAC. A minimum/maximum approach has been used for normalizing this indicator. The island values have been compared to EU values, taking two extreme percentiles (10 and 90) among EU countries. Percentiles have been used instead of direct minimum/maximum values in order to remove the effect of outliers. In this case, a score of 0 has been associated to the 10th percentile of energy intensity, while a score of 1 has been assigned to the 90th percentile of energy intensity.

- **Per capita energy demand**

Data for per capita electricity demand have been obtained from the same sources as energy intensity, and the normalization has been done using the same approach (minimum/maximum with 10th and 90th percentile among EU countries). The calculation has been done dividing the electricity consumption by the population, and the score has been calculated using the 2000-2018 average value of per capita electricity demand.

Vulnerability (Adaptive Capacity)

- **Purchasing power for increased consumption (Per capita GDP)**

This indicator is a measure of the capacity to fulfill consumption needs. It has been calculated dividing the GDP by the population, using the same sources as for the above sensitivity indicators. A 2000-2018 average value has been used for calculating the score. A minimum/maximum approach has been applied for the normalization, using again 10th and 90th percentiles among EU countries. In this case, a high per capita GDP indicates a higher capacity for covering consumption needs, so the best score (0) has been assigned to the 90th percentile of per capita GDP, while the worst score (1) has been assigned to the 10th percentile of per capita GDP.

- **Demand side management**

This indicator is a qualitative measure of the existence or absence of demand side management measures, for reducing cooling or desalination consumption. An example of management measure is the reduction of water leakages in the water distribution network. As a qualitative (binary) indicator, it is only assigned “yes” or “no” values, which are considered in the discussion of the risk, but not in the calculation of the risk score. Local data sources have been used in this case.

Weighted aggregation of components

The weighting of the different risk components has been done using an objective approach. The observed time-series of cooling and desalination demand have been correlated to the observed time-series of every indicator. Higher correlation values for an indicator have been associated to a higher weight. The detailed weight calculation for the risk components (hazard, exposure and vulnerability) has been performed applying the following method, developed by ITC (Gran Canaria).

The mathematical procedure developed proposes the definition of weights per group of variables (hazard, vulnerability and exposure) that allow identifying the relationship between each of the explanatory variables (the indicators defined in the previous section) and the response analyzed (in this case, energy demand due to desalination or energy demand due to cooling). The procedure consists of several steps:

Step 1 - Linear correlation

In this step, the linear correlation coefficient of n pairs (x, y) is calculated as follows:

$$r_{xy} = \frac{SS_{xy}}{\sqrt{SS_{xx} \cdot SS_{yy}}}$$

where:

$$S_{xx} = \sum x^2 - \frac{1}{n} \left(\sum x \right)^2$$

$$S_{xy} = \sum xy - \frac{1}{n} \left(\sum x \right) \left(\sum y \right)$$

$$S_{yy} = \sum y^2 - \frac{1}{n} \left(\sum y \right)^2$$

- x = every explanatory variable (population density, GDP per capita, etc)
- y = objective variable (energy demand due to desalination)
- n = years of historic data (considering the last year as the last for which there are values for the objective variable)
- r_{xy} = Linear correlation between x (explanatory variables) and y (risk)

In the case of the desalination demand IC, the detailed calculations are as follows:

Exposure:

- r_{DR} = Linear correlation coefficient between total annual energy demand for desalination and resident population density.
- r_{DT} = Linear correlation coefficient between total annual energy demand for desalination and the yearly tourist number indicator.
- r_{DMAXT} = Linear correlation coefficient between total annual energy demand for desalination and the tourism seasonality indicator (based on the yearly maximum number of tourists).

- r_{DDWD} = Linear correlation coefficient between total annual energy demand for desalination and the percentage of desalinated water with respect to total water demand.

Vulnerability:

- r_{DGDP} = Linear correlation coefficient between total annual energy demand for desalination and the yearly gross domestic product per capita.
- r_{DC} = Linear correlation coefficient between total annual energy demand for desalination and per capita energy demand.
- r_{DEI} = Linear correlation coefficient between total annual energy demand for desalination and energy intensity.

Hazard:

- r_{DSPEI} = Linear correlation coefficient between total annual energy demand for desalination and standardized precipitation evapotranspiration index.

In the case of the cooling demand IC, the calculations are the same except that the correlation between the desalination demand and the percentage of desalinated water is not used, and for the hazard correlation, cooling degree days are used instead of the standardized precipitation evapotranspiration index for calculating r_{DCDD} .

Step 2 – Weighting of components

In this step, the weight per group of variables (exposure, vulnerability and hazard) is established.

$$w_{Exposure} = \frac{W_{exp}}{W_{exp} + W_{vul} + w_{haz}}$$

$$w_{Vulnerability} = \frac{W_{vul}}{W_{exp} + W_{vul} + w_{haz}}$$

$$w_{Hazard} = \frac{W_{haz}}{W_{exp} + W_{vul} + w_{haz}}$$

where:

$$W_{exp} = \frac{\sum_{i=1}^{n_{exp}} |r_{Dexp}|}{n_{exp}}$$

$$W_{vul} = \frac{\sum_{i=1}^{n_{vul}} |r_{Dvul}|}{n_{vul}}$$

$$W_{haz} = \frac{\sum_{i=1}^{n_{haz}} |r_{Dhaz}|}{n_{haz}}$$

- $W_{Exposure}$ = weight of the exposure group
- $n_{exp}, n_{vul}, n_{haz}$ = number of variables for each type (exposure, vulnerability and hazard)
- $|r_{Dexp}|$ = absolute value of the linear correlation coefficient between every exposure variable and the energy demand due to desalination.

In the case of the desalination demand IC:

$$W_{exp} = \frac{|r_{DR}| + |r_{DT}| + |r_{DMAXT}| + |r_{DDWD}|}{4}$$

$$W_{vul} = \frac{|r_{DGDP}| + |r_{DC}| + |r_{DEI}|}{3}$$

$$w_{haz} = |r_{DSPEI}|$$

In the case of the cooling demand IC, r_{DDWD} is not used for the exposure weight, and r_{DCDD} is used instead of r_{DSPEI} for the hazard weight.

The weights obtained for every IC and island are the following:

<i>Desalination IC</i>	W_{haz}	W_{exp}	W_{vul}
Gran Canaria	0,31	0,35	0,34
Malta	0,20	0,38	0,42
Cyprus	0,04	0,52	0,44

<i>Cooling IC</i>	W_{haz}	W_{exp}	W_{vul}
Gran Canaria	0,31	0,27	0,42
Malta	0,16	0,48	0,36
Cyprus	0,16	0,48	0,36

7.7. Detailed methodology for Aquaculture

AHP method

Methodology

The AHP methodology is a well-grounded and worldwide recognised methodology to compare and order alternatives in many different fields of decision making. In the context of Soclimpact Project the aim of adopting AHP is to reach a compromise between the specificities of the relationships under study (climate change, ecosystem services, economic valuation for sectors and the whole economies, islands) and the convenience of providing a normalization and weighting framework widely known and accepted.

The AHP methodology was developed by Saaty, in the context of cold war, to assist USA government in adopting strategic decisions related to nuclear weapon race (Saaty and Vargas, 2012). Later on, it was very successfully transferred to all types of strategic decision making in business and politics; and then to the field of land planning and environmental management, amongst other relevant fields of decision making. It is useful for choosing the best alternative or to hierarchically order a set of them (Forman et al. 1990, Harker 1986, Harker and Vargas 1987, Saaty 1986, 1988, Saaty and Vargas 1987).

Fundamentally, the AHP works by developing priorities for alternatives and the criteria used to judge the alternatives. First, priorities are derived for the criteria in terms of their importance to achieve the goal, then priorities are derived for the performance of the alternatives on each criterion. These priorities are derived based on pair-wise assessments using judgments, or ratios of measurements from a scale if one exists. Finally, a weighting and adding process is used to obtain overall priorities for the alternatives as to how they contribute to the goal (Saaty and Vargas, 2012).

In our context, it would be to allocate weights to different criteria to obtain a score of the risk faced for a particular Blue Economy sector with respect to a particular set of climate change hazards for each island under study, and then compare them.

The AHP application rests on two main pillars:

1) The formulation of the decision problem in terms of a hierarchy diagram

One of the most important elements in the AHP methodology is the hierarchy tree. It is essential to define the risk and criteria properly in order to obtain relevant information from the comparisons of interest. The hierarchy diagram has the goal of the decision making process at the top (in this case a particular climate based risk for a particular sector and island); the criteria and, eventually, sub-criteria that are going to be taken into account to reach the goal, at the middle (e.g. climatic, ecosystem, socioeconomic and governance aspects of the relationship between the climate hazards and the blue economy sector being studied); and the alternatives to be compared (e.g. the European islands) at the bottom of the hierarchy.

In this project, the hierarchy tree is derived from the definition of the Impact Chains. However, some refinements were made in order to define the risk according to its socioeconomic impact, and to work with a quantifiable concept.

2) A pairwise comparison of all components of the hierarchy at each level.

The pairwise comparisons are done by experts in the scientific field using the scale developed by Saaty (table 7.7.1). When conducting the pairwise comparisons the following question is asked: Which criteria is more relevant to explain differences between islands regarding climate change impacts on their aquaculture industry? As the methodology is based on comparing alternatives, all are relative scores. Please consider that hazards and exposure are not comparable in absolute terms but in relative ones, with respect to what you have defined as the risk. The consistency of the comparisons made by experts is measured through a consistency rate which should be < 0.1 .

Table 7.7.1: Scale used for pairwise comparisons developed by Saaty (1994) adjusted to the Soclimpact project

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
$a_{ij}=1$	Equal importance	Two criteria contribute equally to the risk
$a_{ij}=3$	Moderate importance	Experience and judgment slightly favour one criterion over another in terms of contribution to the risk
$a_{ij}=5$	Strong importance	Experience and judgment strongly favour one criterion over another in terms of contribution to the risk
$a_{ij}=7$	Very strong importance	One criterion is favoured very strongly over another in terms of contribution to the risk
$a_{ij}=9$	Extreme importance	The evidence favouring one criterion over another in terms of contribution to the risk is of the highest possible order of affirmation

Critical for the reliability of results are the appropriateness of the hierarchy diagram that have to be made by the SMT and the selection of experts for making pairwise comparisons. With respect to the experts, as ICs integrate relationships falling under the scope of different disciplines, so it has to be reflected in the experts' profile. Additionally, it is beneficial to work with experts from different islands. In this project, the experts decided on the values through a workshop approach, where experts discussed each comparison and decided on the values together to come to a consensus as opposed to each expert doing the exercise individually. An example of pairwise comparison can be found in Table 7.7.2.

Table 7.7.2: An example of a pairwise comparison matrix comparing different criteria for selection of a job



	Location	Salary	Type	LT prospects
Location	1	1/5	1/3	1/2
Salary	5	1	2	4
Type	3	1/2	1	3
LT prospects	2	1/4	1/3	1

- The diagonal takes on value 1
- Note that the inverse of the value is used for the reverse comparison
- The scale determines the relative importance of the different criteria.
- The higher the value, the more the criteria contributes to the goal

Once pairwise comparisons are done, weights between 0 and 1 are calculated for all criteria, sub-criteria and alternatives. Finally, the overall values are calculated for each alternative. The sum of the values for all alternatives (islands) is 1.

Consistency ratios (CR) were calculated for each matrix, values up to 0.1 were accepted (Lamata and Pelaez 2002). The CR was calculated by multiplying the values from the pairwise comparison table with the weights of each component (criteria, sub criteria and alternatives). For each component these are then summed and divided by the weights (SUMWeigh).

Then, Lamda is calculated for each matrix by adding up the SUMWeighs and dividing the result by the number of rows.

Next, the Coefficiency Index (CI) is calculated as following:

$$CI = (\text{Lamda} - \text{number of rows}) / (\text{number of rows} - 1)$$

The CR is then calculated by dividing CI with the constant given by Saaty for each size of matrix as given in table 7.7.3.

Table 7.7.3: Random consistency (RI) values depending on size of matrix provided by Saaty (1994).

Size of Matrix	Random Consistency Index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45



10	1.49
----	------

Results

Hierarchy tree

The IC aims at measuring how extreme weather events affect the aquaculture activity. A way to quantify this impact would be by looking at the benefits obtained in the sector. Therefore, the risk was defined taking into account the economic impact: "Economic losses in aquaculture". The hazard was taken out of the risk since else comparisons of criteria (hazard to other criteria) cannot be done in relation to the risk.

The indicators defined in the IC were evaluated based on relevance and availability of data which led to the selection of the sub criteria for the hierarchy tree.

Hazards: wave height; return time (frequency of extreme wave heights) were selected to represent the hazard.

Exposure: some indicators, such as farm area, number of employees, and value of structures, are very correlated: the area determines the number of employees, size of stock and value of structures (given that the characteristics of the infrastructure are considered in sensitivity). Regarding "total value of cages", assuming a standard technology, the value is almost the same per m2 across the islands, so the potential differentiation is already contained in "farm area".

Moreover, fraction of GDP may not be relevant to understand the influence of climate change on the benefits obtained in the aquaculture activity. "Fraction of GDP" would be interesting if the RISK was defined in terms of the economic impact of climate change through aquaculture on the island economy, but we think it is not the case of this exercise. Therefore, we selected farm area and value of stock. The location of the farm is difficult to use for comparison between islands. This would only be useful if comparing farms.

Sensitivity: strength of infrastructure and sensitivity of species were selected. Distance from shore was removed since this is an indicator for adaptive capacity.

Adaptive capacity: early warning system; quick supporting intervention (instead of distance to harbour or vessel capacity. The sooner the intervention takes place, the lower the cost incurred) and power and adequacy of insurance market (there exists appropriate risks coverage and costs) were selected. If an event will take place, first early warning system could mitigate the losses. If it takes place, quick intervention to minimize the costs is crucial, and then comes into place the insurance issue.

Six of 12 islands declared that the local aquaculture sector was sufficiently large to be included in the operationalisation process of the impact chains. However, only three of these islands submitted adequate and appropriate data which could be used for the AHP method. Therefore, the three islands were selected: Malta, Madeira and Cyprus.

The final hierarchy tree developed based on the IC is shown in Figure 7.7.1.

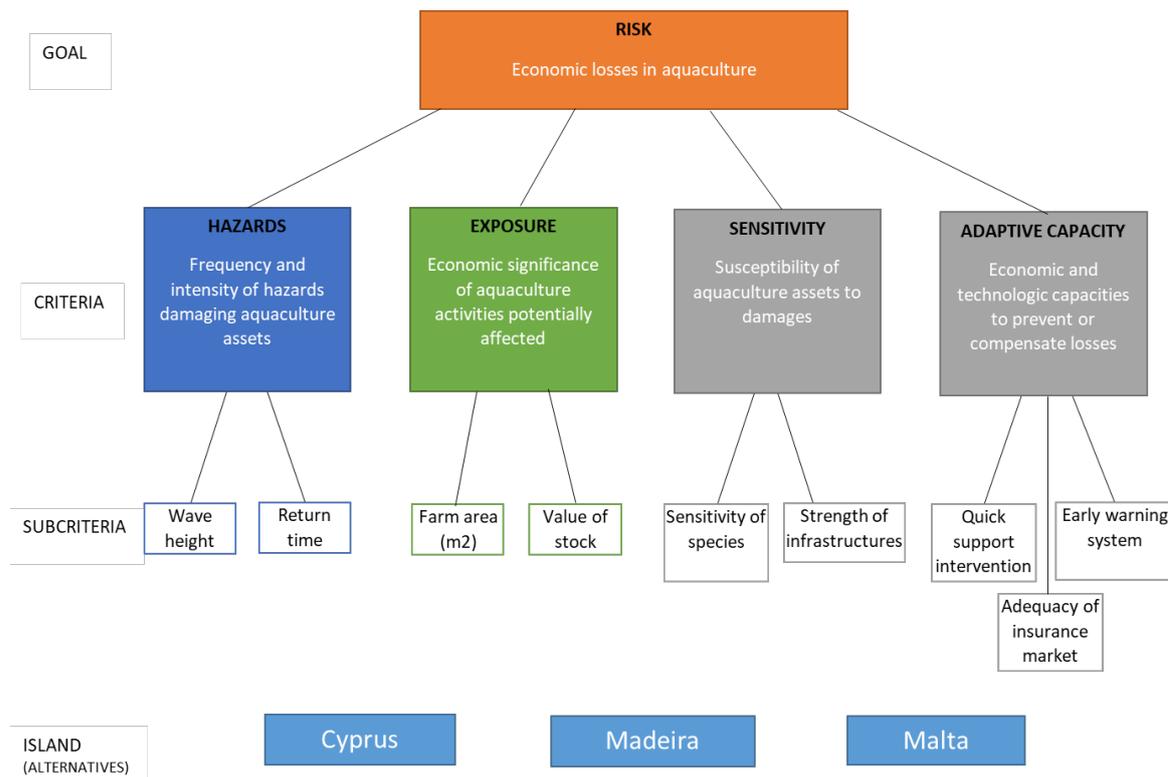


Figure 7.7.1: Hierarchy tree based on the IC

To ensure the scope of the criteria and sub criteria were clear to the experts, they were defined and shared during the workshop. The criteria and sub criteria were defined as following as can be seen in Table 7.7.4.

Table 7.7.4: Definitions of criteria and sub criteria.

Explanations of criteria and sub criteria		
Criteria	Hazard	Increase in wave height and return time due to climate change
	Exposure	Economic significance of aquaculture activities potentially affected
	Sensitivity	Susceptibility of aquaculture assets to damages
	Adaptive Capacity	Economic and technologic capacities to prevent or compensate losses
Sub criteria	Wave height	Average Annual Mean -Height of waves in meters
	Return time	Time between extreme wave heights (above threshold of 7 m)



Farm area (m2)	Area occupied by sea cages
Value of stock	Value of biomass in the cages
Sensitivity of species	Resilience to stress and fasting periods (no feeding during extreme event)
Strength of infrastructures	Type and materials of cages (shape, mooring, number of rings, size of rings, number of nets etc.)
Quick support intervention	Distance from port to farm, possibility to strengthen infrastructure, move cages to safer place, financial support etc.
Early warning system	Availability of an early warning system
Adequacy of Insurance market	Available insurance schemes to adequately compensate firms from losses

Pairwise comparisons

A group of experts was formed with experts in different fields; aquaculture, climatology and economics. The experts represented the islands of Malta and Madeira. Three workshops were held, an initial workshop between the members of the SMT, one with experts from Malta on Sep 20, 2019 and one online workshop that also included the experts from Madeira on Sep 26, 2019. The list of experts can be found in Table 7.7.5.

Table 7.7.5: List of experts

Expert name	Field	Year of experience
Lena Schenke	Marine Aquaculture & GIS	3
Kyra Hoevenaars	Aquaculture	10
Giovanna Pisacane	Climatology	>20
Mark Meyer	Econometrics and statistics	12
Dr. Adriana Carillo	Climatology-Oceanography	>20
Dr. Maria Vittoria Struglia	Climatology	>20
Simeon Deguara	Aquaculture research	27
Nicolas de Wilde	Aquaculture	12
Carlos Andrade*	Aquaculture research	20
Ricardo José*	Aquaculture research	7
Michele Gallo	Aquaculture	5
Shane Hunter	Insurance in aquaculture	20

*Centro de Maricultura da Calheta – Madeira

Below follow the results of the pairwise comparisons made by the experts followed by the rationale behind the decisions.

Criteria vs goal

Risk	Hazards	Exposure	Sensitivity	A. Capacity
Hazards	1	0.14	0.20	0.25
Exposure	7	1	4	7
Sensitivity	5	0.25	1	3
A. Capacity	4.00	0.14	0.33	1

CR=0.1

- Hazard-Exposure: If exposure of the industry is higher than the damage will be higher regardless of the hazard causing the damage, if there is nothing to destroy the hazard does not matter. It is not just for physical reasons, i.e., the larger the industry, the higher the economic losses due to climate change impact; but also for economic ones: it is expected that a bigger, more developed industry, has a higher part of the firms working close to the *normal* benefit region. So, if they face climate induced losses, they could easily fall below normal benefits that push them out of the industry. The relevance of hazard is not so high to explain differences in the way climate change is affecting and will affect aquaculture throughout the European islands.
- Hazard- Sensitivity: Most important factor is the type and strength of the material of the structure. If the cages are strong enough to withstand the waves, the hazard is not a risk anymore.
- Hazard- A. Capacity: Respond to minimise a potential risk can minimise the damage, regardless of the magnitude of the hazard.
- Exposure-Sensitivity: They use the same type of cages in all islands so exposure will explain the difference more.
- Exposure- A. Capacity: Adaptive capacity could reduce the damage a bit, but exposure has a large impact on the risk.
- Sensitivity- A. Capacity: Both are quite equal in each island however stronger infrastructures are more important than what can be adapted against the hazard.

Sub criteria vs criteria

Hazards	Wave heights	Return time
Wave heights	1	0.14
Return time	7.00	1

CR=0

Wave height- Return time: Return time is more important, because in the return time the threshold of damage is included. Wave height is the average annual mean and just measures the constant stress on infrastructure.

Exposure	Area of cages (m2)	Total value of stock
Area of cages (m2)	1	0.14
Total value of stock	7.00	1

CR=0

Area of cages- Total value of stock: Value of stock can differ much more between islands than value of cages.



Sensitivity	Sensitivity of species	Strength of cages/lines
Sensitivity of species	1	0.1
Strength of cages/lines	9	1

CR=0

Sensitivity of species- Strength of cages/lines: If infrastructure breaks, fish stress is not important.

Adaptive capacity	Quick support intervention	Early warning system	Adequacy of insurance market
Quick support intervention	1	5	0.20
Early warning system	0.20	1	0.11
Adequacy of insurance market	5	9	1

CR=0.1

Quick support intervention- Early warning system: quick support is much more important than early warning because all islands have early warning (weather forecast).

Quick support intervention/Early warning system- Adequacy of insurance market: Insurance is the most important since it will compensate for the losses.

Islands vs sub criteria

Pairwise comparisons for hazards are based on climate modelling results.

Wave heights	Cyprus	Madeira	Malta
Cyprus	1	0.3	0.5
Madeira	3	1	3
Malta	2	0.33	1

CR=0.05

- Malta has slightly higher waves heights because it is exposed to open sea waves.
- Madeira is located in the middle of the Atlantic, which in general has higher waves than Mediterranean. However, the aquaculture zonation is just on the south side of Madeira, with much calmer weather and wave regimes, therefore Madeira was only given moderate importance over the other islands.
- Cyprus, although exposed to higher wind stress on its South-West side, is generally more sheltered.

Return time	Cyprus	Madeira	Malta
Cyprus	1	0.20	0.33
Madeira	5	1	4.5
Malta	3	0.22	1

CR=0.097

- Although return times are comparable for Malta and Cyprus, the portion of coastline exposed to waves is larger in Malta.
- Madeira exhibits higher frequency of extreme events.



Area of cages (m2)	Cyprus	Madeira	Malta
Cyprus	1	3	0.2
Madeira	0.3	1	0.1
Malta	5	9	1

CR=0.03

This was based on data on farm volumes since farm area data was not available.

- Cyprus: est. 350,000 m3
- Madeira: 101,500 m3
- Malta: 1,758,534 m3

Total value of stock	Cyprus	Madeira	Malta
Cyprus	1	2.5	0.11
Madeira	0.4	1	0.11
Malta	9	9	1

CR=0.08

These pairwise comparisons are based on production and capacity data.

Sensitivity of species	Cyprus	Madeira	Malta
Cyprus	1	1	9.0
Madeira	1	1	9.0
Malta	0.1	0.1	1

CR=0

No data for mortality for none of the islands was collected. All islands have seabream and seabass, Malta has 83% tuna. Therefore, as tuna is less sensitive, Malta has higher values. Tuna is stocked at 30 kg and sea bream at 2-8 grams. Smaller fish are more vulnerable. Note: more sensitive fish means a higher fish so a higher value.

Strength of cages/lines	Cyprus	Madeira	Malta
Cyprus	1	1	5
Madeira	1	1	5
Malta	0.2	0.2	1

CR=0

Cyprus and madeira only have seabream & seabass cages while Malta has 83% tuna cages which are much stronger. Note: weaker infrastructure means a higher risk so a higher value.

Quick support intervention	Cyprus	Madeira	Malta
Cyprus	1	1	0.20
Madeira	1	1	0.20
Malta	5	5	1

CR=0

Tuna cages are further from shore so risk in Malta is higher. In Madeira and Cyprus risks are equal.

Early warning system	Cyprus	Madeira	Malta
Cyprus	1	1	1
Madeira	1	1	1
Malta	1	1	1

CR=0

There are no records of early warning systems for any of the islands, all have access to general weather forecast and warnings.

Adequacy of insurance market	Cyprus	Madeira	Malta
Cyprus	1	1	1
Madeira	1	1	1
Malta	1	1	1

CR=0

Every island in the EU has the same opportunity to get insurance (note: less than 7% of aquaculture assets worldwide are insured).



Weighting

The weight of the criteria and sub criteria were calculated by first normalising the values in the matrix (dividing the values by the sum of values in the same column). The weight is then calculated by the sum of all values in the row of the criteria.

Criteria vs goal

Risk	Weight
Hazards	0.05
Exposure	0.60
Sensitivity	0.23
A. Capacity	0.12

Sub criteria vs criteria

Criteria	Sub criteria	Weight
Hazards	Wave heights	0.13
	Return time	0.88
Exposure	Area of cages (m2)	0.13
	Total value of stock	0.88
Sensitivity	Sensitivity of species	0.10
	Strength of cages/lines	0.90
Adaptive capacity	Quick support intervention	0.22
	Early warning system	0.06
	Adequacy of insurance market	0.72

Sub criteria vs goal

Criteria	Sub criteria	Weight
Hazards	Wave heights	0.01
	Return time	0.05
Exposure	Area of cages (m2)	0.08
	Total value of stock	0.53
Sensitivity	Sensitivity of species	0.02
	Strength of cages/lines	0.20
Adaptive capacity	Quick support intervention	0.03
	Early warning system	0.01
	Adequacy of insurance market	0.09

Sub criteria vs goal

Criteria	Sub criteria	Cyprus	Madeira	Malta
Hazards	Wave heights	0.16	0.59	0.25
	Return time	0.10	0.68	0.22
Exposure	Area of cages (m2)	0.18	0.07	0.75
	Total value of stock	0.13	0.07	0.80
Sensitivity	Sensitivity of species	0.47	0.47	0.05
	Strength of cages/lines	0.45	0.45	0.09
Adaptive capacity	Quick support intervention	0.14	0.14	0.71
	Early warning system	0.33	0.33	0.33
	Adequacy of insurance market	0.33	0.33	0.33

Aggregation

A final score for each island is obtained by aggregating the criteria and sub-criteria according to the computed weights.

Criteria	Sub criteria	Cyprus	Madeira	Malta
Hazards	Wave heights	0.0010	0.0039	0.0017
	Return time	0.0047	0.0311	0.0101
Exposure	Area of cages (m2)	0.0136	0.0054	0.0563
	Total value of stock	0.0680	0.0368	0.4220
Sensitivity	Sensitivity of species	0.0107	0.0107	0.0012
	Strength of cages/lines	0.0925	0.0925	0.0185
Adaptive capacity	Quick support intervention	0.0037	0.0037	0.0184
	Early warning system	0.0024	0.0024	0.0024
	Adequacy of insurance market	0.0288	0.0288	0.0288
		0.2254	0.2152	0.5594

- Malta has the highest risk compared to Cyprus and Madeira. This is mainly due to the higher exposure in Malta cause of the Tuna farms (high value and volume) because exposure was given the highest weight (0.60) for criteria. Cyprus and Madeira both only have seabass/seabream and in lower volumes.
- Cyprus has a slightly higher risk than Madeira. Madeira has a smaller aquaculture sector in terms of stock and asset value.
- Madeira has the highest score for hazard (0.59-0.68) since it is exposed to higher waves. Malta (0.25-0.22) is more exposed to open sea waves compared to Cyprus (0.16-0.1).
- Malta has less vulnerability risk in terms of sensitivity of species and strength of infrastructure because a large share of the production is Tuna, however a higher risk in quick support intervention cause Tuna cages are offshore.

- Early warning system and adequacy of insurance market is the same for all islands.

GIZ method structure

Step 1: Data collection by Island Focal Points

To be able to apply the GIZ risk assessment method, a solid data basis is crucial. Therefore, data was collected by the Island Focal Points (IFPs) of the SOCLIMPACT project. The questionnaire requested datasets for 16 indicators and topics with several subcategories on exposure and vulnerability. The IFPs reached out to local stakeholders and authorities to collect the requested data which was then resubmitted to the Sectoral Modelling Team (SMT) Aquaculture.

Step 2: Data review and island selection

Data were submitted by most of the islands to the SMT Aquaculture. Most datasets were incomplete with major data missing regarding important information for the successful operationalization of the impact chains. Therefore, and for the fact that some islands do currently not have any active marine aquaculture operations running, some islands were excluded from the operationalization.

Out of the 12 islands assessed in the SOCLIMPACT project, six were included in the operationalization of the impact chains using the risk assessment method from GIZ: Corsica, Cyprus, Madeira, Malta, Sardinia and Sicily. The other six islands (Azores, Balearic Islands, Baltic Island, Canary Islands, Crete and French West Indies) do currently not have active marine cage aquaculture operations or show insufficient data availability. Data on hazards was provided by the models developed in Work Package 4.

Eventually, Madeira was excluded for the impact chain on extreme weather events due to lack of reliable hazard data. A qualitative analysis will be provided in the result section.

Step 3: Review and selection of indicators

The data collection and review revealed that not all indicators of the impact chains could be used for the operationalisation process. Therefore, these indicators were reviewed carefully and the ones which were not represented by sufficient data were excluded. The revised impact chain was developed depending on the indicators selected.

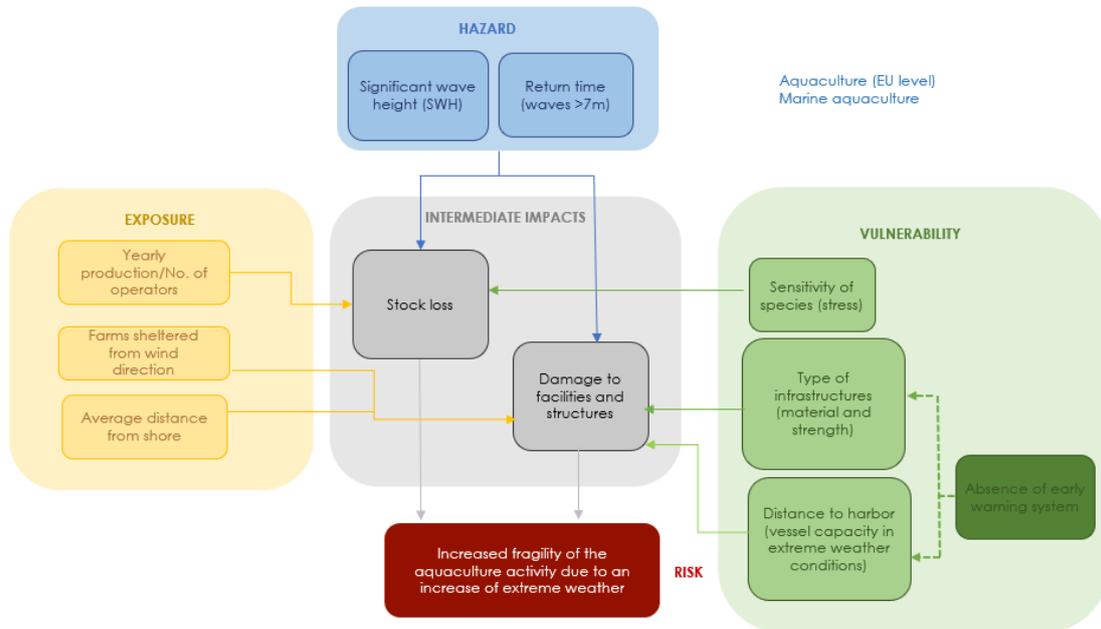


Figure 7.7.2: Impact chain on Increased fragility of the aquaculture activity due to an increase of extreme weather adjusted depending on data availability and used for the operationalisation.

Production data of farmed species per island

Some indicators require data on the proportions of species farmed on a specific island. Therefore, a table with % of each species farmed on each island was prepared. This data was obtained directly from the IFPs or from the FAO or national statistics offices.

Table 7.7.6: Proportions of aquaculture species farmed per island.

Species	Proportion of species production			
	Mussels & clams	Tuna	Sea bream	Sea bass
Corsica	0.43		0.265	0.265
Cyprus			0.84	0.16
Madeira			1.0	
Malta		0.94	0.048	0.012
Sardinia	0.84		0.08	0.08
Sicily	0.44		0.3	0.26

Impact chain: extreme weather events

Hazard

For the component hazard both indicators were used for the operationalisation. The **wave amplitude** was shown as significant wave height (SWH) in m and the **return time** number of years between extreme events quantified with a threshold of >7m. The data was derived from the climate models of Deliverable 4.4 at the exact locations where the fish farms are located and then averaged for all locations on one island. This allows a more accurate assessment than taking the average values for the entire island.

Exposure

Four indicators were selected to be operationalized. The **number of aquaculture operators** was provided by the IFPs and additional literature.

There was no data available on the actual **size of stock**, therefore the yearly production of aquaculture products (fish and shellfish) in tons was used as a proxy indicator.

The **location of farms** was rated by using two different proxy indicators: the location of the farms in relation to the prevailing wind direction and the average distance of the farms to shore. To be able to rate the location in relation to the wind direction, the values were estimated (with 0 being completely sheltered and 1 being exposed to wind and possible storms). After normalizing the

distance from shore (measured by using GIS software and the exact coordinates of the fish farms), both values were averaged and represent the exposure of the location of farms.

Sensitivity (vulnerability)

Two indicators were applied to calculate the score of factors of sensitivity. The **sensitivity of species** was estimated by reviewing literature and interviewing experts regarding the vulnerability of species to extreme weather events. After receiving these data, average values were calculated of all values for the present species on each island.

Table 7.7.7: Estimated vulnerability factors for the sensitivity of species to wave stress.
1= very vulnerable to stress: 0=very resilient to stress.

<i>Sensitivity of species for wave stress threshold</i>				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.55	0.65	0.3	0.9

The same approach was implemented to calculate the vulnerability of the **infrastructure types** used on each island based on the type of species farmed.

Table 7.7.8: Estimated vulnerability values for the vulnerability of infrastructure in case of an extreme weather event.
1= very vulnerable to stress: 0=very resilient to stress.

<i>Vulnerability of aquaculture infrastructure in case of an extreme weather event</i>			
Infrastructure for species	Sea bream & Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.4	0.3	0.6

Adaptive capacity (vulnerability)

The indicators distance to harbor and the presence of warning systems were used to describe the adaptive capacity. As there is a weather forecast available for all islands, the values for the **presence of warning systems** are all the same and represent low values.

The **distance to harbors** was moved to the subcomponent adaptive capacity and measured using GIS software and the exact locations of the farms which were provided by the IFPs and literature data. It represents the average distance of all farms to their closest harbor for each island and is shown in meters.

The indicator stocking density and engineering of structures were excluded from the operationalisation. For the **stocking density** there were no data available from all islands and in

any case, it was estimated to be similar for all islands. The **engineering of structures** was already covered with the type of infrastructures in the sensitivity subcomponent.

Impact chain: sea surface temperature

Hazard

Changes in surface water temperature was chosen to be the indicator representing the component hazard. The temperature data for this indicator was obtained from the location of each farm from the climate models of Deliverable 4.4 and averaged per island. To calculate the hazard for each island and each RCP, the species' temperature thresholds were taken into account. According to a literature review (see Annex) the temperature thresholds for farmed species is the following:

Table 7.7.9: Temperature threshold per species.

<i>Temperature thresholds for different species</i>				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Threshold (°C)	24	25	24	20.5

It must be noted that the threshold for Tuna was set to 24°C since in the project only Tuna fattening is done (in Malta) and for adult fish the threshold is 24°C while in the review the whole life cycle as well as prey species was taken into account which is not relevant for this exercise.

Based on these thresholds, the duration of the longest event per year (in days) was calculated for the temperatures 20 °C, 24 °C and 25 °C for RCP 4.5 and 8.5 from the models developed in WP4. After normalizing these values (which is described in detail in Step 4), the values for each temperature and therefore each species threshold were averaged using the sum product of the normalized values and the species' proportion on the total production of the island. The final values represent the score of the hazard.

The indicator **changes in seawater characteristics** was not included in the operationalization as there is no additional data related to this indicator which is not covered by the surface water temperature indicator.

Exposure

Two indicators were used for the component exposure: the **number of aquaculture operators** and the yearly production (in tons) as a proxy indicator for the **size of stock**.

Sensitivity (vulnerability)

The subcomponent sensitivity includes two indicators which were combined to one indicator for the operationalization. The sensitivity of species directly correlates with suitable temperature for

species and therefore it is summarized as **temperature sensitivity of species**. It was calculated by using temperature threshold values for each species obtained from a literature review and expert opinion. These values were averaged depending on which species and in which quantities they are farmed on the islands.

Table 7.7.10: *Estimated vulnerability factors for the sensitivity of species to temperature stress.*

1= very vulnerable to stress: 0=very resilient to stress.

<i>Sensitivity of species for temperature stress threshold</i>				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.6	0.6	0.3	1

Adaptive capacity (vulnerability)

Two out of four indicators from the impact chain were utilized for the operationalization. The **monitoring early warning systems** were included and show all the same values for all islands as there is a sea surface temperature forecast available for each island.

The **capacity to change species** was included with all the islands displaying the same value as well. The risk value is high in this case, as it would be quite difficult to change species farmed on the islands in general as this would result in high economic expenditures.

For the indicator of the impact chain **know-how of recognizing and treating diseases/parasites** there is no data available for any island. As this could vary a lot between the islands, the indicator was removed instead of making assumptions, to not negatively influence the risk values. A similar case arises from the indicator **availability of alternative place for farming**. There is no data available to make correct assumptions regarding the occurrence of alternative areas on the islands and therefore the indicator was not used for the operationalization.

Step 4: Normalization of indicator data for all islands

In order to come up with one final risk value per island and to be able to compare these values between islands, the indicator values were transferred into unit-less values on a common scale. The normalized values range between 0 and 1 with 0 being low risk and 1 being very high risk.

Different ways of normalizing the indicator values were considered:

- Minimum/maximum normalization (i.e. fraction of maximum when expected minimum is zero);
- Normalization with respect to objective criteria;
- Expert judgement.

Fraction of maximum normalization

This normalization method was used for **exposure** and **vulnerability** indicators which were expressed by real data and not by expert judgement. The value for each island was calculated as a fraction of the maximum value in the data set. Meaning the island with the maximum value was given 1 and the rest as a fraction thereof.

The following indicators were normalized using this method:

- Extreme weather events:
- yearly production/ number of aquaculture operators
 - average distance from shore (location of farms)
 - average distance to harbour
- Sea surface temperature:
- yearly production/ number of aquaculture operators

Minimum/maximum normalization

This normalization method can be used for indicators which were expressed by real data and not by expert judgement, in cases when the minimum expected value is different from zero, via the formula:

$$x_{normalized} = \frac{(x - x_{min})}{(x_{max} - x_{min})}$$

Normalization with respect to objective criteria

Hazards were normalized and classified according to the absolute scale found in literature (Mean Wave Height) or according to a scale specifically developed by the experts involved in SOCLIMPACT (ref. Section 3.4 “Hazard Classification”).

Expert judgement

For some indicators from both impact chains there was no data available which is the reason why expert judgement and estimations were applied. The following indicators were expressed using expert's estimations:

- Extreme weather events:
- farm locations (in relation to main wind direction)
 - sensitivity of species
 - vulnerability of type of infrastructure
 - presence of warning system
- Sea surface temperature:
- estimated temperature sensitivity of species
 - capacity to change species
 - monitoring early warning systems

In all cases the normalization scale of 0 to 1 was applied with 0 being low risk and 1 being very high risk.



Step 5: Weighting of different risk components

In this step, the different risk components hazard, exposure and vulnerability (including the sub-components sensitivity and adaptive capacity) were rated. The total of the values sums up to 1. The weights were estimated by aquaculture experts and the basis of the estimations were subjective estimations, similar to the ones used in the AHP method. However, in this method the data availability was additionally taken into account. Components for which the available data was scarce, outdated or more unreliable the weights were set lower on purpose, while components with accurate datasets were given a higher weight as following:

Table 7.7.11: Components and their weights.

(Sub)Component	Weight	
	Sea surface temperature	Extreme events
Hazard	0.3	0.6 wave height 0.2 return time 0.8
Exposure	0.4	0.2
Vulnerability	0.3	0.2
Sensitivity	0.75	0.75
Adaptive Capacity	0.25	0.25

Step 6: Calculations of risk for present conditions

Before being able to calculate the risk values, the scores for each component/ subcomponent had to be calculated by taking the average of the corresponding weighted indicators:

$$s_{comp} = \frac{(ind_1 + ind_2 + \dots + ind_n)}{n}$$

- s* – score
- comp* – component or subcomponent
- ind* – weighted indicator
- n* – number of indicators

The final risk value was calculated by summing up the scores of the components multiplied individually with the corresponding risk component weightings:

$$Risk = s_{haz} * w_{haz} + s_{exp} * w_{exp} + w_{vul} * (s_{sen} * w_{sen} + s_{ac} * w_{ac})$$

- s* – score
- w* – weight
- haz* – hazard
- exp* – exposure
- vul* – vulnerability
- sen* – sensitivity
- ac* – adaptive capacity



These risk values were calculated for each island individually and range between 0 and 1. After completing these calculations, it was possible to compare the islands between each other.

Step 7: Calculations of risk for future conditions (different RCPs)

To be able to project the risk values to future conditions, the operationalization was adjusted to the different Representative Concentration Pathways (RCPs). Therefore, the whole operationalization was duplicated and different values for the hazard indicators per island were inserted. These values were taken directly from the climate models provided in work package 4 for the different RCP scenarios (RCP 4.5 and 8.5). The resulting values can be compared between the islands as well as between the different RCP scenarios.

Thermal hazard integral indicators

Integral indicators are averaged over the areas illustrated in Figures 3.4.59 and 3.4.60.

Reference should be made to section 3.4 for the explanation of the differences between the *duration of critical season* (calculated over the whole set of 20 - or 10 - years available and including years with no events), and the *longest event in season* (calculated only over events that actually occurred). Mean, minimum and maximum values found over the time interval are given, a zero minimum duration clearly indicates that there was at least one year with no events (not always explicitly reported in the tables).

The *number of events during critical season* (in black) indicates, out of the 20 (or 10) years in the time window under scrutiny, how many (in parenthesis) were characterized by intermittency, that is, how often the whole warm season was constituted by more than one single event, and how many these events were. The *duration of intermittent events* indicates the mean, minimum and maximum length, over the time window under scrutiny, of the minor events during the season, that is, excluding the *longest event*. Together with the *interval between intermittent events*, such indicator is meant to give some information on whether the intermittencies are isolated or whether the whole season happens to be characterized by oscillations about the critical threshold. Of course, these latter indicators do not have the ambition to be exhaustive, only to ring an alarm that more in depth analysis is needed.

When, usually for lower thresholds under high-end warming scenarios, the critical thresholds are sustainedly exceeded, such simple characterization of intermittency fails, as well as the distinction between the duration of critical season and the length of the longest event. In these cases, an approximate value for the overall duration of the season is reported. For the Atlantic islands, only the three models (out of the four available) that provided continuous times series were used.



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Mediterranean areas

Table 7.7.12 - SST threshold overpasses - 20 °C – RCP2.6 – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	159 129 181	2 (4) 3 (2)	152 123 181	7 3 15	9 2 22	171 152 195	2 (2) 3 (1)	169 152 187	3 1 6	7 2 20	168 144 182	2 (2) 3 (1) 4 (1)	164 128 182	6 3 13	7 3 17
Sicily North	157 137 180	2 (3)	153 135 180	5 4 6	17 12 22	169 150 186	2 (5)	167 147 186	3 2 4	7 2 16	167 144 196	2 (2) 3 (1)	164 144 185	9 7 11	6 1 13
Sicily East	170 153 187	2 (3)	167 148 187	6 4 10	9 3 15	186 165 218	2 (2)	183 165 194	12 9 15	13 3 22	185 162 202	2 (3)	182 157 202	6 2 14	12 8 17
Sicily South	146 118 183	2 (7) 3 (3)	133 96 168	12 1 39	9 2 43	161 138 181	2 (8) 3 (2)	144 99 178	21 3 57	6 2 12	160 132 182	2 (10) 3 (2)	143 102 182	13 4 25	11 2 31
Corstica West	126 112 173	2 (8) 3 (1)	117 81 173	8 3 15	9 2 22	142 115 167	2 (3) 3 (1)	137 98 167	9 3 21	12 5 27	144 122 167	2 (8) 3 (2)	129 98 155	16 2 31	9 1 34
Corstica East	129 113 169	2 (4) 3 (1)	125 107 169	6 3 10	9 1 15	141 102 166	2 (1) 3 (1)	139 102 166	13 5 28	5 1 9	144 108 160	2 (6)	139 108 160	12 1 28	6 3 10
Sardinia West	127 96 177	2 (6) 4 (1) 5 (1)	114 58 177	14 1 36	6 2 14	148 125 168	2 (10) 3 (2)	132 74 168	16 3 42	6 2 15	149 132 170	2 (6) 3 (4)	134 98 170	13 2 42	9 1 34
Sardinia East	137 123 160	2 (6) 4 (1) 5 (1)	132 108 158	9 4 21	5 2 15	150 122 168	2 (1) 3 (1)	148 122 168	10 2 25	8 5 13	152 137 182	2 (2) 3 (1)	149 125 171	8 3 14	9 3 18
Cyprus Farm Area (Bream & Brass)	190 170 215	2 (5) 3 (1) 4 (1)	179 145 207	16 4 37	6 2 12	214 197 246	2 (10) 3 (1)	205 180 224	8 3 16	9 1 23	210 184 238	2 (7) 4 (1)	204 175 223	6 1 22	7 1 23
Cyprus Farm Area (Tuna)	189 170 214	2 (6) 3 (1) 4 (1)	177 144 207	14 3 36	7 4 14	214 196 247	2 (10) 3 (2)	202 180 225	7 2 24	9 3 23	209 183 237	2 (6) 4 (1)	202 174 224	7 1 21	9 2 23



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Table 7.7.13 - SST threshold overpasses - 20 °C – RCP4.5 – Units=days

	Historical					rcp45 Midcentury					rcp45 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	159 129 181	2 (4) 3 (2)	152 123 181	7 3 15	9 2 22	165 142 188	2 (3)	163 142 188	7 3 9	8 3 13	175 158 195	2 (3)	172 140 186	6 4 8	11 8 14
Sicily North	157 137 180	2 (3)	153 135 180	5 4 6	17 12 22	167 143 187	2 (5)	163 143 185	6 2 13	8 2 21	177 161 202	2 (6)	171 158 191	7 1 12	11 1 16
Sicily East	170 153 187	2 (3)	167 148 187	6 4 10	9 3 15	183 165 199	2 (2)	182 165 197	3 2 4	5 3 7	195 174 215	2 (3)	193 174 212	8 5 11	7 3 12
Sicily South	146 118 183	2 (7) 3 (3)	133 96 168	12 1 39	9 2 43	157 129 182	2 (6) 3 (1)	148 121 177	17 4 24	6 2 19	163 140 187	2 (4) 3 (1)	157 117 184	12 4 24	8 3 15
Corisca West	126 112 173	2 (8) 3 (1)	117 81 173	8 3 15	9 2 22	141 123 184	2 (5)	137 112 166	7 4 10	8 2 14	149 119 190	2 (6) 3 (4)	140 118 165	6 1 16	6 1 15
Corisca East	129 113 169	2 (4) 3 (1)	125 107 169	6 3 10	9 1 15	144 125 167	2 (3)	142 125 167	4 3 7	5 3 8	152 126 179	2 (6)	148 126 164	8 4 10	8 2 13
Sardinia West	127 96 177	2 (6) 4 (1) 5 (1)	114 58 177	14 1 36	6 2 14	143 124 167	2 (5) 3 (1)	136 110 167	9 6 17	9 4 16	152 112 190	2 (7) 3 (1) 4 (1)	140 112 167	10 2 29	9 1 19
Sardinia East	137 123 160	2 (6) 4 (1) 5 (1)	132 108 158	9 4 21	5 2 15	151 130 170	2 (4) 3 (1)	147 130 170	7 2 16	4 2 5	159 133 182	2 (4)	155 133 170	5 1 9	11 5 17
Cyprus Farm Area (Bream & Brass)	190 170 215	2 (5) 3 (1) 4 (1)	179 145 207	16 4 37	6 2 12	209 192 234	2 (10) 3 (1)	201 182 218	7 1 14	7 3 17	228 201 261	2 (9)	220 184 257	5 1 11	15 5 31
Cyprus Farm Area (Tuna)	189 170 214	2 (6) 3 (1) 4 (1)	177 144 207	14 3 36	7 4 14	209 192 234	2 (11) 3 (1)	199 181 218	7 1 15	8 2 18	225 182 262	2 (6)	219 182 257	6 3 11	14 5 29



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Table 7.7.14 - SST threshold overpasses - 20 °C – RCP8.5 – Units=days

	Historical					rcp85 Midcentury					rcp85 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	159 129 181	2 (4) 3 (2)	152 123 181	7 3 15	9 2 22	179 155 202	2 (6)	175 146 193	5 1 11	8 3 13	206 187 233	2 (6)	201 182 233	5 2 13	9 2 20
Sicily North	157 137 180	2 (3)	153 135 180	5 4 6	17 12 22	179 157 199	2 (7)	175 149 189	6 3 14	6 2 12	201 181 225	2 (5)	199 181 217	6 3 12	5 1 9
Sicily East	170 153 187	2 (3)	167 148 187	6 4 10	9 3 15	196 171 215	2 (3)	195 171 208	8 8 8	6 4 9	≈230				
Sicily South	146 118 183	2 (7) 3 (3)	133 96 168	12 1 39	9 2 43	163 125 183	2 (7) 3 (1) 4 (1)	149 111 178	17 2 44	6 1 10	193 168 231	2 (7) 3 (2)	182 150 219	13 1 44	7 3 16
Corisca West	126 112 173	2 (8) 3 (1)	117 81 173	8 3 15	9 2 22	146 121 181	2 (8)	140 107 171	6 2 24	9 4 15	174 147 208	2 (5) 3 (1)	171 140 208	4 1 7	5 2 13
Corisca East	129 113 169	2 (4) 3 (1)	125 107 169	6 3 10	9 1 15	153 124 180	2 (5)	148 124 167	11 2 27	11 6 25	178 149 209	2 (2) 3 (1)	176 149 209	6 4 7	7 3 13
Sardinia West	127 96 177	2 (6) 4 (1) 5 (1)	114 58 177	14 1 36	6 2 14	148 120 179	2 (7) 3 (1)	141 107 164	10 1 18	7 2 13	177 152 208	2 (3) 3 (1)	173 137 208	12 3 37	4 3 6
Sardinia East	137 123 160	2 (6) 4 (1) 5 (1)	132 108 158	9 4 21	5 2 15	161 146 179	2 (6)	158 126 179	5 1 9	7 2 12	185 163 208	2 (3)	184 159 208	8 4 14	4 2 8
Cyprus Farm Area (Breem & Brass)	190 170 215	2 (5) 3 (1) 4 (1)	179 145 207	16 4 37	6 2 12	208 196 240	2 (8) 3 (1)	199 178 235	12 1 25	6 1 17	≈250				
Cyprus Farm Area (Tuna)	189 170 214	2 (6) 3 (1) 4 (1)	177 144 207	14 3 36	7 4 14	208 192 239	2 (8) 3 (2)	196 178 231	13 3 25	6 1 18	≈250				



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Table 7.7.15 - SST threshold overpasses - 21 °C – RCP2.6 – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	141 116 171	2 (9) 3 (1)	132 107 160	7 1 21	8 1 41	155 134 172	2 (5)	152 119 172	8 2 18	5 2 8	149 114 169	2 (3) 3 (1)	145 97 169	8 1 19	7 1 12
Sicily North	139 117 173	2 (3)	137 110 173	5 4 6	8 3 13	152 118 169	2 (2)	150 118 169	18 14 22	4 3 5	150 118 171	2 (5) 3 (1)	171 118 144	7 2 16	8 2 25
Sicily East	155 138 176	2 (3) 3	152 138 176	4 1 7	11 3 23	168 150 186	2 (2)	167 150 179	4 4 4	9 2 15	167 146 191	2 (3)	165 139 182	5 3 9	8 1 17
Sicily South	127 87 171	2 (5) 3 (6)	109 46 141	14 1 40	7 1 14	146 112 168	2 (8) 3 (2) 4 (2)	124 75 168	17 6 36	8 2 24	143 113 169	2 (7) 3 (4) 5 (1)	122 32 169	13 1 40	9 2 28
Corisca West	103 82 160	2 (9) 3 (1)	94 54 160	11 1 47	7 1 27	121 86 156	2 (9) 3 (1)	109 59 144	18 3 39	5 2 14	122 91 144	2 (13) 3 (1)	105 73 136	11 4 26	12 3 33
Corisca East	112 93 148	2 (5) 3 (3)	106 83 130	5 2 7	8 1 26	125 97 153	2 (4)	123 97 144	9 3 21	7 5 9	126 94 146	2 (9) 3 (1)	116 93 135	11 3 29	7 1 18
Sardinia West	104 62 162	2 (8) 3 (4) 4 (1)	83 35 116	14 1 36	7 1 21	132 112 160	2 (7) 3 (5)	113 55 160	12 1 45	11 2 39	127 90 158	2 (12) 3 (2) 4 (1)	107 58 148	11 1 54	10 2 27
Sardinia East	114 91 148	2 (4) 3 (1)	111 86 148	8 1 22	3 2 6	136 110 158	2 (6)	131 91 150	9 2 20	7 2 17	136 109 158	2 (6)	131 109 158	9 2 14	7 1 15
Cyprus Farm Area (Bream & Brass)	176 160 198	2 (10) 3 (3)	159 136 179	13 3 47	8 4 17	191 170 214	2 (4) 3 (2)	183 170 209	10 3 19	7 2 19	189 159 205	2 (5) 3 (2)	181 144 203	12 2 24	6 2 12
Cyprus Farm Area (Turna)	175 158 197	2 (12) 3 (4)	152 131 174	16 2 46	8 1 28	190 170 214	2 (5) 3 (2)	180 150 209	10 2 21	12 1 31	188 159 204	2 (2) 3 (4)	177 113 203	15 2 50	7 2 18



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Table 7.7.16 - SST threshold overpasses - 21 °C – RCP4.5 – Units=days

	Historical						rcp45 Midcentury						rcp45 End of Century					
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Malta Farm Area	141 116 171	2 (9) 3 (1)	132 107 160	7 1 21	8 1 41	149 131 172	2 (4)	145 123 172	13 2 25	8 3 19	155 116 174	2 (2)	153 116 174	20 10 29	3 2 4			
Sicily North	139 117 173	2 (3)	137 110 173	5 4 6	8 3 13	148 133 176	3 (1)	147 131 176	7 5 8	5 2 8	158 141 182	2 (3)	156 137 182	6 1 9	8 1 16			
Sicily East	155 138 176	2 (3) 3	152 138 176	4 1 7	11 3 23	165 143 189	2 (4)	163 143 181	7 3 14	3 3 4	175 161 192	2 (3)	173 161 192	8 5 13	7 1 10			
Sicily South	127 87 171	2 (5) 3 (6)	109 46 141	14 1 40	7 1 14	139 113 162	2 (6) 3 (3)	129 59 162	13 3 33	6 3 13	146 106 170	2 (9) 3 (1)	135 99 170	13 2 44	7 4 16			
Corisca West	103 82 160	2 (9) 3 (1)	94 54 160	11 1 47	7 1 27	126 96 154	2 (6) 3 (1)	117 84 154	13 2 33	10 4 23	130 106 150	2 (5)	125 106 148	6 2 14	12 5 26			
Corisca East	112 93 148	2 (5) 3 (3)	106 83 130	5 2 7	8 1 26	130 111 146	2 (5)	126 106 146	9 4 12	8 4 15	133 111 150	2 (3) 3 (1)	128 107 150	8 3 18	7 3 15			
Sardinia West	104 62 162	2 (8) 3 (4) 4 (1)	83 35 116	14 1 36	7 1 21	127 103 154	2 (5) 3 (2)	116 84 146	16 3 56	7 1 25	132 105 151	2 (7) 3 (2)	122 76 148	10 3 25	6 2 11			
Sardinia East	114 91 148	2 (4) 3 (1)	111 86 148	8 1 22	3 2 6	136 122 152	2 (2)	134 122 150	6 3 8	10 6 13	142 122 157	2 (3)	140 122 157	8 4 13	6 1 11			
Cyprus Farm Area (Breem & Brass)	176 160 198	2 (10) 3 (3)	159 136 179	13 3 47	8 4 17	189 175 206	2 (8) 4 (1) 5 (1)	180 157 202	6 1 15	5 1 14	201 169 235	2 (4) 3 (3)	192 159 219	10 2 21	7 3 27			
Cyprus Farm Area (Tuna)	175 158 197	2 (12) 3 (4)	152 131 174	16 2 46	8 1 28	188 167 216	2 (6) 3 (2) 4 (1)	178 127 201	8 1 33	8 2 30	200 168 234	2 (5) 3 (4)	189 154 218	10 1 20	6 2 27			



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Table 7.7.17 - SST threshold overpasses - 21 °C – RCP8.5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)		
Malta Farm Area	141 116 171	2 (9) 3 (1)	132 107 160	7 1 21	8 1 41	161 142 179	2 (5)	156 128 179	9 4 16	9 1 16	181 153 208	2 (2)	180 150 208	6 4 7	5 3 7
Sicily North	139 117 173	2 (3)	137 110 173	5 4 6	8 3 13	158 141 176	2 (3)	155 133 176	7 4 9	8 5 1	181 157 203	2 (3)	179 152 203	8 4 15	3 1 4
Sicily East	155 138 176	2 (3) 3	152 138 176	4 1 7	11 3 23	177 160 194	2 (3)	175 146 187	8 5 13	7 6 9	202 184 219	2 (3)	200 184 219	8 2 15	4 1 7
Sicily South	127 87 171	2 (5) 3 (6)	109 46 141	14 1 40	7 1 14	145 120 175	2 (9) 3 (2) 4 (2)	127 94 156	9 2 29	9 3 20	173 138 202	2 (8) 3 (1)	160 119 202	19 2 63	8 1 12
Corsica West	103 82 160	2 (9) 3 (1)	94 54 160	11 1 47	7 1 27	127 96 153	2 (7)	122 96 144	8 3 13	7 2 13	153 119 193	2 (2)	152 119 193	6 2 10	7 5 8
Corsica East	112 93 148	2 (5) 3 (3)	106 83 130	5 2 7	8 1 26	135 116 157	2 (6)	130 106 147	8 4 20	7 2 15	160 135 195	2 (5)	157 125 195	5 2 7	7 4 13
Sardinia West	104 62 162	2 (8) 3 (4) 4 (1)	83 35 116	14 1 36	7 1 21	128 101 158	2 (10) 3 (1)	120 101 146	9 4 21	5 2 10	158 120 196	2 (8) 3 (2)	146 117 189	13 2 33	6 1 17
Sardinia East	114 91 148	2 (4) 3 (1)	111 86 148	8 1 22	3 2 6	141 124 164	2 (2) 3 (1)	139 118 164	8 3 14	7 2 15	167 136 197	2 (2)	165 136 197	8 4 11	4 2 5
Cyprus Farm Area (Breem & Brass)	176 160 198	2 (10) 3 (3)	159 136 179	13 3 47	8 4 17	199 164 224	2 (8) 3 (3)	187 164 214	10 4 23	8 2 22	234 195 255	2 (5) 3 (3)	228 195 253	9 3 18	8 3 14
Cyprus Farm Area (Tuna)	175 158 197	2 (12) 3 (4)	152 131 174	16 2 46	8 1 28	198 162 226	2 (8) 3 (3)	186 159 213	10 3 21	9 3 24	234 195 258	2 (5) 3 (3)	226 195 252	9 3 17	7 1 15



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Table 7.7.18 - SST threshold overpasses – 23 °C – RCP26 – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	98 80 122	2 (7) 3 (1) 4 (1)	87 45 117	8 2 22	10 1 29	116 95 138	2 (6) 4 (1)	108 80 129	10 3 30	7 4 12	112 85 144	2 (7) 3 (2)	103 83 144	6 1 13	10 3 20
Sicily North	98 69 118	2 (6) 4 (1)	91 42 115	7 2 12	7 1 13	116 99 141	2 (7)	111 74 138	7 2 15	6 4 17	113 83 139	2 (5)	108 83 132	10 3 19	7 1 21
Sicily East	119 101 139	2 (5)	115 101 125	8 2 14	8 2 20	134 112 150	2 (3)	133 112 150	8 6 10	6 4 8	132 109 159	2 (2)	131 109 159	8 7 8	5 2 8
Sicily South	77 24 115	2 (9) 3 (2) 4 (1)	59 13 100	12 1 26	11 2 24	106 63 143	2 (9) 3 (6)	77 29 120	18 2 53	10 1 23	98 67 124	2 (10) 3 (3) 4 (1)	78 27 117	10 2 31	10 1 30
Corstica West one year with no events	60 0 87	0 (1) 2 (10) 3 (4) 4 (2)	39 14 87	9 1 28	9 1 28	88 53 111	2 (7) 3 (8) 4 (1)	59 17 111	14 3 29	8 2 20	78 44 105	2 (6) 3 (4) 4 (3) 5 (1)	50 18 105	10 1 28	10 1 36
Corstica East	70 54 92	2 (8) 3 (2) 4 (2)	57 9 85	8 1 20	7 1 27	93 75 117	2 (13)	79 47 117	15 4 34	7 3 18	90 69 109	2 (9) 3 (2) 4 (2)	74 45 107	8 1 26	10 1 33
Sardinia West	52 1 88	2 (8) 3 (8) 4 (1)	28 1 62	10 1 26	8 1 29	86 53 110	2 (8) 3 (5) 4 (5)	50 13 76	13 1 36	9 1 34	71 47 102	2 (2) 3 (5) 4 (4) 5 (1)	49 12 90	8 1 18	8 2 23
Sardinia East	74 60 95	2 (6) 3 (2) 4 (1)	64 21 92	9 1 21	7 1 14	101 75 118	2 (9) 3 (1)	94 59 113	9 1 14	4 1 9	99 81 133	2 (12) 3 (1)	88 62 110	6 1 24	10 2 27
Cyprus Farm Area (Breem & Brass)	129 95 148	2 (9) 3 (3) 4 (2) 5 (1)	102 40 148	13 1 37	8 2 28	153 139 169	2 (9) 3 (2) 4 (2)	133 89 158	15 1 36	6 1 16	152 126 178	2 (8) 3 (6) 4 (2)	124 83 160	15 3 40	7 1 17
Cyprus Farm Area (Tuna)	124 78 146	2 (6) 3 (7) 4 (1) 5 (1) 6 (1)	87 23 142	16 2 56	7 1 30	151 139 169	2 (6) 3 (8) 4 (2) 5 (1)	119 89 157	13 1 38	7 1 22	147 110 168	2 (6) 3 (6) 4 (3)	116 56 160	15 3 43	8 1 16



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Table 7.7.19 - SST threshold overpasses – 23 °C – RCP4.5 – Units=days

	Historical					rcp45 Mildcentury					rcp45 End of Century				
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	98 80 122	2 (7) 3 (1) 4 (1)	87 45 117	8 2 22	10 1 29	121 104 142	2 (7) 1 (4)	111 68 142	13 1 34	8 1 24	121 95 143	2 (6)	117 95 140	9 3 26	6 1 11
Sicily North	98 69 118	2 (8) 4 (1)	91 42 115	7 2 12	7 1 13	119 104 140	2 (3)	117 103 140	9 2 15	9 6 12	123 103 141	2 (4)	121 99 138	8 3 14	6 4 7
Sicily East	119 101 139	2 (5)	115 101 125	8 2 14	8 2 20	134 119 148	2 (1)	133 115 148	8 8 8	5 5 5	141 118 151	2 (2)	140 118 151	2 1 3	4 3 4
Sicily South	77 24 115	2 (9) 3 (2) 4 (1)	59 13 100	12 1 26	11 2 24	113 90 138	1 (7) 3 (4) 4 (2)	86 34 138	15 2 44	10 1 38	111 73 135	2 (10) 3 (3)	94 51 126	12 2 53	9 2 26
Corstica West	60 0 87 one year with no events	0 (1) 2 (10) 3 (4) 4 (2)	39 14 87	9 1 28	9 1 28	91 64 121	1 (8) 3 (7) 5 (1)	61 26 97	15 3 44	8 1 32	98 67 127	2 (11) 3 (2)	84 30 114	10 2 29	9 2 25
Corstica East	70 54 92	2 (8) 3 (2) 4 (2)	57 9 85	8 1 20	7 1 27	97 81 123	2 (5)	92 63 123	12 7 26	9 4 15	105 86 132	2 (4) 3 (1)	100 77 123	7 2 16	6 3 16
Sardinia West	52 1 88	2 (8) 3 (8) 4 (1)	28 1 62	10 1 26	8 1 29	88 41 126	(5) 3 (10) 4 (1)	57 24 100	13 2 46	9 1 30	96 58 128	(10) 3 (3) 4 (1)	73 40 112	15 3 38	8 1 24
Sardinia East	74 60 95	2 (6) 3 (2) 4 (1)	64 21 92	9 1 21	7 1 14	106 90 126	2 (4) 3 (1)	101 70 126	9 4 13	7 4 10	109 88 133	2 (3)	107 88 129	5 1 9	9 7 12
Cyprus Farm Area (Bream & Brass)	129 95 148	2 (9) 3 (3) 4 (2) 5 (1)	102 40 148	13 1 37	8 2 28	155 137 172	2 (11) 3 (6)	132 109 156	14 2 48	6 1 14	165 141 190	2 (9) 3 (6)	144 111 166	14 3 33	6 2 15
Cyprus Farm Area (Tuna)	124 78 146	2 (6) 3 (7) 4 (1) 5 (1) 6 (1)	87 23 142	16 2 56	7 1 30	153 136 171	(11) 3 (5) 5 (1)	129 107 157	10 2 29	9 3 23	164 139 190	2 (9) 3 (7)	139 110 165	13 2 40	7 3 17



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Table 7.7.20 - SST threshold overpasses – 23 °C – RCP8.5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	98 80 122	2 (7) 3 (1) 4 (1)	87 45 117	8 2 22	10 1 29	119 97 145	2 (7) 1 (3)	113 81 145	7 1 20	7 2 16	147 120 190	2 (6)	141 111 177	9 3 29	8 4 18
Sicily North	98 69 118	2 (8) 4 (1)	91 42 115	7 2 12	7 1 13	122 99 144	2 (6)	117 97 144	9 2 24	5 1 13	145 122 171	2 (4)	143 122 171	3 1 5	7 1 12
Sicily East	119 101 139	2 (5)	115 101 125	8 2 14	8 2 20	141 120 160	2 (1)	140 120 160	8 8 8	4 4 4	167 140 196	2 (2)	166 140 196	7 5 8	6 4 7
Sicily South	77 24 115	2 (9) 3 (2) 4 (1)	59 13 100	12 1 26	11 2 24	104 56 132	2 (8) 3 (2) 4 (1)	87 40 128	14 1 38	8 3 19	132 111 171	2 (8) 3 (1) 4 (4)	108 69 144	15 2 51	7 1 22
Corisca West	60 0 87 one Year with no events	0 (1) 2 (10) 3 (4) 4 (2)	39 14 87	9 1 28	9 1 28	94 61 119	2 (9) 3 (4) 4 (1)	73 37 119	14 1 35	7 1 23	119 98 163	2 (6) 3 (2)	113 89 163	7 4 11	5 2 11
Corisca East	70 54 92	2 (8) 3 (2) 4 (2)	57 9 85	8 1 20	7 1 27	102 78 123	2 (5) 3 (1)	97 66 123	6 1 13	8 2 18	124 106 154	2 (4)	121 99 154	7 5 10	5 3 6
Sardinia West	52 1 88	2 (8) 3 (8) 4 (1)	28 1 62	10 1 26	8 1 29	91 60 122	2 (9) 3 (5)	68 27 121	16 2 41	8 1 19	120 91 169	2 (9) 3 (2) 4 (1)	107 73 153	11 1 35	5 1 14
Sardinia East	74 60 95	2 (6) 3 (2) 4 (1)	64 21 92	9 1 21	7 1 14	105 92 126	2 (7)	100 80 125	11 2 23	3 1 5	131 111 157	2 (9) 3 (2)	126 111 157	8 2 23	4 3 6
Cyprus Farm Area (Bream & Brass)	129 95 148	2 (9) 3 (3) 4 (2) 5 (1)	102 40 148	13 1 37	8 2 28	162 137 186	2 (8) 3 (4)	148 106 181	10 2 28	8 1 23	191 153 220	2 (9) 3 (2)	180 153 214	9 2 27	9 2 27
Cyprus Farm Area (Tuna)	124 78 146	2 (6) 3 (7) 4 (1) 5 (1) 6 (1)	87 23 142	16 2 56	7 1 30	161 136 185	2 (13) 3 (1) 4 (3)	134 68 168	15 1 55	7 1 27	191 152 219	2 (10) 3 (2)	178 152 212	8 2 24	11 4 30



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Table 7.7.21 - SST threshold overpasses – 24 °C – RCP2.6 – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	75 19 104	2 (7) 3 (2) 1 (4)	62 10 99	11 1 34	7 2 16	100 67 120	2 (7) 3 (2)	87 37 115	14 3 36	10 4 32	93 59 121	2 (9) 3 (1)	83 43 108	9 1 30	8 1 25
Sicily North	73 22 96	2 (6) 3 (2)	65 8 96	8 3 13	8 2 16	99 74 118	2 (11)	92 61 114	8 1 31	6 2 15	93 66 111	2 (6) 3 (4)	84 66 100	6 2 14	7 1 18
Sicily East	98 70 117	2 (5)	95 60 117	7 2 11	6 3 13	116 93 136	2 (3)	113 85 131	4 2 6	7 6 7	114 90 143	2 (3)	112 90 137	8 1 15	4 1 5
Sicily South	57 8 99	2 (7) 3 (5)	38 6 85	11 3 24	11 1 28	86 47 109	2 (7) 3 (5) 4 (2)	60 25 105	13 1 32	10 1 25	75 42 110	2 (7) 3 (4) 6 (1)	56 17 105	10 2 27	8 1 22
Corisca West	34 0 61	0 (2) 2 (9) 4 (1)	24 6 60	8 2 20	13 1 42	70 42 99	2 (6) 3 (10) 4 (1) 5 (1)	32 12 59	10 1 29	13 2 43	52 17 90	2 (13) 3 (3)	32 8 85	11 3 28	8 3 21
Corisca East	47 0 76	0 (1) 2 (8) 3 (2) 4 (1)	35 6 64	8 2 23	9 3 29	75 54 103	2 (8) 3 (6) 4 (1)	54 27 82	10 1 24	8 1 21	64 38 91	2 (6) 3 (4) 5 (1)	50 16 91	9 2 26	6 1 23
Sardinia West	24 0 64	0 (2) 2 (5) 3 (2)	18 3 47	8 1 15	10 2 25	62 9 100	2 (9) 3 (7) 4 (2)	30 9 57	9 1 22	14 2 39	47 0 83	0 (1) 2 (8) 3 (1) 4 (2)	32 5 68	7 1 20	15 2 59
Sardinia East	53 3 75	2 (4) 3 (2) 4 (2)	44 3 69	5 1 11	9 4 20	86 65 108	2 (7) 3 (6) 4 (1)	67 37 101	10 1 31	7 3 15	73 48 95	2 (5) 3 (3)	65 28 87	9 2 26	5 3 9
Cyprus Farm Area (Bream & Brass)	103 53 137	2 (7) 3 (5) 4 (2) 6 (1) 9 (1)	70 12 129	10 1 33	8 1 18	132 113 152	0 (3) 2 (7) 3 (8) 4 (2) 5 (1)	94 52 132	16 1 60	8 1 24	130 84 153	2 (8) 3 (6) 4 (2) 6 (1)	93 34 142	15 1 33	9 1 34
Cyprus Farm Area (Tuna)	99 52 136	2 (7) 3 (4) 4 (5) 5 (1) 8 (1)	56 10 92	11 1 37	10 1 35	130 105 152	2 (6) 3 (8) 4 (3) 5 (2)	84 38 128	14 1 52	9 1 31	127 81 153	2 (5) 3 (7) 4 (4) 6 (1)	87 32 141	12 1 31	10 1 27



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Table 7.7.22 - SST threshold overpasses – 24 °C – RCP4.5 – Units=days

	Historical				rcp45 Midcentury				rcp45 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)		
Malta Farm Area	75 19 104	2 (7) 3 (2) 1 (4)	62 10 99	11 1 34	7 2 16	104 70 133	2 (3)	89 36 127	10 1 41	7 1 27	108 84 129	2 (9)	100 62 126	11 4 32	7 3 16
Sicily North	73 22 96	2 (6) 3 (2)	65 8 96	8 3 13	8 2 16	104 82 125	2 (3)	101 71 125	8 1 12	10 2 20	109 94 129	2 (3)	107 93 125	7 4 10	7 5 9
Sicily East	98 70 117	2 (5)	95 60 117	7 2 11	6 3 13	121 105 136	2 (1)	121 105 136	13 13 13	1 1 1	125 107 138	2 (3)	123 107 137	9 5 14	4 2 6
Sicily South	57 8 99	2 (7) 3 (5)	38 6 85	11 3 24	11 1 28	93 28 122	1 (8) 3 (4) 4 (4)	63 21 109	12 1 33	9 1 30	94 48 118	2 (9) 3 (2)	79 28 118	15 3 49	8 2 13
Corstica West	34 0 61	0 (2) 2 (9) 4 (1)	24 6 60	8 2 20	13 1 42	68 23 90	1 (8) 3 (3) 5 (1)	46 18 84	13 2 29	12 2 36	80 53 114	2 (10) 3 (1) 4 (1)	64 20 99	14 1 33	8 1 21
Corstica East	47 0 76	0 (1) 2 (8) 3 (2) 4 (1)	35 6 64	8 2 23	9 3 29	80 54 102	2 (9) 3 (3) 4 (1)	60 25 94	13 1 44	7 2 19	89 68 119	2 (6) 3 (1)	81 33 113	15 3 38	6 2 23
Sardinia West	24 0 64	0 (2) 2 (5) 3 (2)	18 3 47	8 1 15	10 2 25	62 18 91	1 (4) 3 (7) 4 (4)	31 10 83	9 1 31	11 2 29	74 45 115	2 (6) 3 (5) 4 (3) 5 (1)	46 14 96	10 1 22	8 1 26
Sardinia East	53 3 75	2 (4) 3 (2) 4 (2)	44 3 69	5 1 11	9 4 20	88 74 113	2 (9)	79 58 113	9 3 24	11 2 31	91 62 114	2 (3) 3 (1)	88 62 114	7 2 14	4 2 7
Cyprus Farm Area (Bream & Brass)	103 53 137	2 (7) 3 (5) 4 (2) 6 (1) 9 (1)	70 12 129	10 1 33	8 1 18	134 94 161	1 (9) 3 (5) 4 (1)	112 82 140	11 3 42	9 1 26	143 106 181	2 (9) 3 (5) 5 (1)	121 72 151	11 1 30	8 1 23
Cyprus Farm Area (Tuna)	99 52 136	2 (7) 3 (4) 4 (5) 5 (1) 8 (1)	56 10 92	11 1 37	10 1 35	129 91 160	1 (0) 3 (3) 4 (3)	103 31 139	12 1 40	9 2 28	141 104 181	2 (7) 3 (4) 4 (4) 5 (1)	114 61 150	10 1 25	8 1 25



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Table 7.7.23 - SST threshold overpasses – 24 °C – RCP 8.5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)		
Malta Farm Area	75 19 104	2 (7) 3 (2) 1 (4)	62 10 99	11 1 34	7 2 16	102 65 132	2 (6) 3 (1)	95 65 132	8 1 15	10 4 19	131 104 169	2 (7) 1 (3)	123 78 154	7 2 17	9 2 23
Sicily North	73 22 96	2 (6) 3 (2)	65 8 96	8 3 13	8 2 16	104 90 128	2 (6)	100 77 119	8 2 16	6 2 10	127 106 153	2 (3)	125 106 148	11 5 17	5 4 7
Sicily East	98 70 117	2 (5)	95 60 117	7 2 11	6 3 13	123 100 141	2 (2)	121 100 141	5 2 7	8 7 9	147 123 182		147 123 182		
Sicily South	57 8 99	2 (7) 3 (5)	38 6 85	11 3 24	11 1 28	86 44 121	2 (6) 3 (4) 4 (2)	65 22 115	13 1 37	8 1 23	116 84 147	2 (9) 3 (4) 4 (1) 5 (1)	88 39 117	15 2 47	9 3 27
Corstica West	34 0 61	0 (2) 2 (9) 4 (1)	24 6 60	8 2 20	13 1 42	74 45 110	2 (9) 3 (4)	110 20 57	10 1 25	9 1 25	99 85 119	2 (5) 3 (4)	88 35 116	11 1 32	6 1 18
Corstica East	47 0 76	0 (1) 2 (8) 3 (2) 4 (1)	35 6 64	8 2 23	9 3 29	83 57 114	2 (8) 3 (3)	73 35 114	8 2 22	6 1 21	107 93 124	2 (4)	103 79 120	6 1 11	9 2 17
Sardinia West	24 0 64	0 (2) 2 (5) 3 (2)	18 3 47	8 1 15	10 2 25	66 35 111	2 (6) 3 (4) 4 (4)	41 9 81	11 1 32	8 2 16	101 68 127	2 (3) 3 (3) 4 (5) 5 (1) 6 (1)	70 23 117	13 2 38	6 1 16
Sardinia East	53 3 75	2 (4) 3 (2) 4 (2)	44 3 69	5 1 11	9 4 20	89 76 115	2 (7) 3 (1)	82 62 115	8 2 15	8 2 20	113 99 130	2 (3)	111 95 130	5 2 7	13 6 22
Cyprus Farm Area (Bream & Brass)	103 53 137	2 (7) 3 (5) 4 (2) 6 (1) 9 (1)	70 12 129	10 1 33	8 1 18	139 105 170	2 (9) 3 (7) 4 (3)	108 56 143	12 2 32	7 1 24	172 145 194	2 (8) 3 (1)	163 140 194	8 1 22	9 2 20
Cyprus Farm Area (Tuna)	99 52 136	2 (7) 3 (4) 4 (5) 5 (1) 8 (1)	56 10 92	11 1 37	10 1 35	136 94 181	2 (7) 3 (8) 4 (2) 5 (1)	102 54 142	13 1 37	8 1 24	169 137 193	2 (8) 3 (2)	158 120 193	11 2 22	7 1 21



Table 7.7.24 - SST threshold overpasses – 25 °C – RCP2.6 – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	56 0 89 one year with no events	0 (1) 2 (8) 3 (3)	43 10 88	8 2 19	13 2 35	80 47 106	2 (10) 3 (2) 4 (1)	62 21 95	11 1 36	10 1 31	70 34 86	2 (5) 3 (9) 4 (1)	59 22 86	9 1 24	7 1 23
Sicily North	50 0 83 one year with no events	0 (1) 2 (8) 3 (3)	39 7 73	9 2 22	9 3 28	79 60 99	2 (10) 3 (12)	62 35 93	15 1 35	9 2 30	67 46 85	2 (8) 3 (1)	60 27 84	8 3 23	6 4 8
Sicily East	75 31 101	2 (4) 3 (1)	70 15 101	10 1 27	5 1 14	98 65 117	2 (3)	97 65 117	9 4 17	3 2 6	97 79 112	2 (5) 3 (1)	92 74 112	6 2 10	9 4 18
Sicily South	33 0 75 three years with no events	0 (3) 2 (6) 3 (1)	30 3 75	9 3 15	11 1 26	65 21 86	2 (10) 3 (4) 4 (1)	38 16 79	12 1 32	14 4 31	57 6 82	2 (10) 3 (5)	38 6 70	8 1 33	11 1 33
Corstica West	16 0 51 seven years with no events	0 (7) 2 (3) 3 (1) 4 (1)	14 1 31	7 3 12	9 4 18	38 0 70 one year with no events	0 (1) 2 (9) 3 (3)	23 3 53	6 1 17	15 2 40	30 0 64 three years with no events	0 (3) 2 (5) 3 (4) 4 (1)	20 3 42	6 3 16	9 1 22
Corstica East	25 0 58 two years with no events	0 (2) 2 (6)	21 1 58	7 1 12	14 5 21	48 11 72	2 (8) 3 (3)	33 8 67	8 1 19	13 2 42	42 0 66 one year with no events	0 (1) 2 (8) 3 (2)	33 6 65	6 1 18	11 3 24
Sardinia West	12 0 48 eight years with no events	0 (8) 2 (5)	10 2 29	6 3 9	18 10 39	33 0 70 one year with no events	0 (1) 2 (12) 3 (2)	15 3 44	8 3 18	16 1 47	21 0 55 three years with no events	0 (3) 2 (7)	16 1 51	9 2 22	12 6 21
Sardinia East	30 0 57 two years with no events	0 (2) 2 (8) 3 (3)	23 3 50	8 2 19	6 2 11	57 29 75	2 (9) 3 (4) 4 (1)	41 24 68	9 2 22	7 2 26	50 17 76	2 (6) 3 (2)	43 13 74	7 2 21	7 1 16
Cyprus Farm Area (Brean & Brass)	72 38 121	2 (10) 3 (3) 4 (9) 5 (1)	33 7 68	12 1 31	10 1 57	108 82 135	2 (5) 3 (8) 4 (3) 6 (2)	67 25 118	11 1 27	10 1 30	105 66 147	2 (3) 3 (6) 4 (4) 5 (1)	72 18 120	9 1 30	12 1 26
Cyprus Farm Area (Tuna)	62 5 120	2 (6) 3 (4) 4 (7)	27 5 52	10 2 25	10 2 30	102 69 134	2 (6) 3 (4) 4 (7)	61 2 26	11 2 26	12 1 40	103 58 147	2 (4) 3 (7) 4 (3) 5 (1)	68 16 119	8 1 28	15 2 45



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Table 7.7.25 - SST threshold overpasses – 25 °C – RCP4.5 – Units=days

	Historical				rcp45 Midcentury				rcp45 End of Century						
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Malta Farm Area	56 0 89 one year with no events	0 (1) 2 (9) 3 (3)	43 10 88	8 2 19	13 2 35	81 49 111	2 (9) 3 (7) 4 (1)	64 13 111	9 1 28	8 1 18	89 50 115	2 (8) 3 (11) 4 (1)	78 27 115	11 1 31	6 2 13
Sicily North	50 0 83 one year with no events	0 (1) 2 (9) 3 (3)	39 7 73	9 2 22	9 3 28	86 73 104	2 (7) 3 (12)	74 37 101	13 3 33	8 1 28	90 63 108	2 (4)	87 53 108	14 5 31	5 3 6
Sicily East	75 31 101 three years with no events	2 (4) 3 (11)	70 15 101	10 1 27	5 1 14	105 92 124	2 (4)	102 82 124	6 4 8	9 3 11	109 97 125	2 (2)	108 97 125	5 3 6	8 7 8
Sicily South	33 0 75 seven years with no events	0 (3) 2 (6) 3 (1)	30 3 75	9 3 15	11 1 26	67 24 97	2 (7) 3 (7) 4 (1)	41 12 85	11 2 27	10 1 38	76 44 99	2 (7) 3 (5) 5 (1)	53 14 89	12 1 34	8 2 19
Corfica West	16 0 51 seven years with no events	0 (7) 2 (9) 3 (1) 4 (1)	14 1 31	7 3 12	9 4 18	46 10 81	2 (10) 3 (6) 4 (1)	25 8 56	7 1 20	10 1 25	62 37 96	2 (7) 3 (4) 4 (1)	45 13 80	9 1 22	9 2 18
Corfica East	25 0 58 two years with no events	0 (2) 2 (6)	21 1 58	7 1 12	14 5 21	82 21 82	2 (11) 3 (9) 4 (1)	38 16 73	10 1 26	11 2 38	72 50 103	2 (10) 3 (2)	58 25 87	13 1 41	7 1 23
Sardinia West	12 0 48 eight years with no events	0 (8) 2 (5)	10 2 29	6 3 9	18 10 39	34 0 79	0 (2) 2 (10) 3 (2) 5 (1)	20 3 51	6 1 14	12 1 34	46 6 100	2 (7) 3 (8) 4 (4)	20 6 43	8 1 21	12 3 37
Sardinia East	30 0 57 two years with no events	0 (2) 2 (9) 3 (3)	23 3 50	8 2 19	6 2 11	65 30 86	2 (9) 3 (3)	49 14 86	15 4 35	5 1 16	77 51 101	2 (6) 3 (2)	68 25 151	11 3 29	8 3 25
Cyprus Farm Area (Bream & Brass)	72 38 121	2 (10) 3 (3) 4 (5) 5 (1)	33 7 68	12 1 31	10 1 57	110 74 140	2 (5) 3 (6) 4 (4) 5 (1)	77 22 122	12 2 37	9 1 33	119 100 133	2 (9) 3 (3) 4 (1) 5 (2)	89 32 118	14 1 47	8 1 22
Cyprus Farm Area (Tuna)	62 5 120	2 (6) 3 (4) 4 (7)	27 5 52	10 2 25	10 2 30	105 69 139	2 (5) 3 (6) 4 (7)	68 20 103	11 1 36	10 1 34	115 94 132	2 (10) 3 (3) 4 (1) 5 (2)	83 30 117	15 2 51	9 2 24



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Table 7.7.26 - SST threshold overpasses – 25 °C – RCP8.5 – Units=days

	Historical						rcp85 Midcentury						rcp85 End of Century					
	Total duration of critical season (mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max) not counting years with no events	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season	Number of events during critical season (multiplicity)	Longest event in season (mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Malta Farm Area	56 0 89 one year with no events	0 (1) 2 (8) 3 (3)	43 10 88	8 2 19	13 2 35	81 52 115	2 (5) 3 (2)	72 34 115	13 1 33	8 2 21	111 87 139	2 (8) 3 (1)	98 54 130	19 3 49	8 2 29			
Sicily North	50 0 83 one year with no events	0 (1) 2 (8) 3 (3)	39 7 73	9 2 22	9 3 28	86 73 110	2 (8) 3 (1)	79 62 110	7 3 20	7 2 18	110 92 127	2 (3)	108 90 127	11 4 22	7 5 9			
Sicily East	75 31 101 three years with no events	2 (4) 3 (1)	70 15 101	10 1 27	5 1 14	106 89 123	2 (3)	103 89 123	6 1 14	9 2 17	131 107 154		131 107 154					
Sicily South	33 0 75 three years with no events	0 (3) 2 (6) 3 (1)	30 3 75	9 3 15	11 1 26	68 35 108	2 (11) 3 (5)	44 13 87	12 1 34	12 1 26	96 67 123	2 (8) 3 (4) 4 (4)	66 18 102	12 2 34	10 1 34			
Corstica West	16 0 51 seven years with no events	0 (7) 2 (3) 3 (1) 4 (1)	14 1 31	7 3 12	9 4 18	54 12 93	2 (8) 3 (4) 4 (1)	35 10 93	10 1 30	10 1 18	82 55 108	2 (8) 3 (6)	64 21 102	11 2 25	7 2 15			
Corstica East	25 0 58 two years with no events	0 (2) 2 (6)	21 1 58	7 1 12	14 5 21	65 45 93	2 (9) 3 (3) 4 (1)	49 13 93	10 1 34	8 1 24	92 65 114	2 (8) 3 (1)	86 56 114	9 2 32	4 2 10			
Sardinia West	12 0 48 eight years with no events	0 (8) 2 (5)	10 2 29	6 3 9	18 10 39	49 0 195	0 (1) 2 (8) 3 (5) 4 (2)	24 2 71	8 1 16	13 1 33	76 42 108	2 (5) 3 (9) 4 (1) 5 (2)	43 10 82	10 2 25	10 1 36			
Sardinia East	30 0 57 two years with no events	0 (2) 2 (8) 3 (3)	23 3 50	8 2 19	6 2 11	66 51 97	2 (4) 3 (2)	60 23 97	9 1 20	7 4 11	98 79 114	2 (3) 3 (3)	91 58 113	9 4 18	5 2 8			
Cyprus Farm Area (Bream & Brass)	72 38 121	2 (10) 3 (3) 4 (5) 5 (1)	33 7 68	12 1 31	10 1 57	114 74 147	2 (6) 3 (6) 4 (2) 5 (1)	83 27 126	13 1 53	9 1 24	153 125 181	2 (7) 3 (6)	136 114 153	12 1 18	6 1 18			
Cyprus Farm Area (Tuna)	62 5 120	2 (6) 3 (4) 4 (7)	27 5 52	10 2 25	10 2 30	108 49 145	2 (6) 3 (6) 4 (3)	80 16 122	12 1 51	9 2 26	150 123 180	2 (10) 3 (5) 4 (2)	124 87 153	14 2 53	6 1 18			



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Atlantic areas

Table 7.7.27 - SST threshold overpasses – 20 °C – RCP2.6 - CNRM-CM5 – Units=days

	Historical						rcp26 Midcentury						rcp26 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	100 58 140	2 (3) 3 (2)	93 38 140	9 2 30	12 2 25	114 84 155	2 (3) 3 (1)	108 31 155	11 5 20	13 5 22	114 86 150	2 (7)	107 86 150	7 2 13	11 3 21			
Azores Central	84 50 119	2 (3) 3 (2)	77 18 103	13 5 18	8 2 21	100 38 137	2 (6)	93 13 137	9 4 19	12 3 19	99 68 145	2 (6)	94 68 145	5 2 6	12 6 19			
Azores Sao Miguel	101 63 141	2 (7) 3 (2) 4 (1)	85 37 115	10 2 20	12 1 39	123 80 159	2 (6) 3 (1)	115 26 159	9 3 20	12 4 19	115 75 147	2 (5) 3 (1)	109 75 144	5 3 9	14 6 23			
Madeira Farm Area	158 115 201	2 (7) 3 (1)	148 115 185	8 1 23	12 3 24	179 127 219	2 (2) 3 (2)	174 127 219	6 2 11	11 3 24	174 109 224	2 (9)	165 109 201	7 4 15	14 34 31			

Table 7.7.28 - SST threshold overpasses – 20 °C – RCP8.5 - CNRM-CM5 – Units=days

	Historical						rcp85 Midcentury						rcp85 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	100 58 140	2 (3) 3 (2)	93 38 140	9 2 30	12 2 25	137 81 170		137 81 170		6 1 12	170 140 229	2 (3)	168 136 229	8 6 11	11 6 22			
Azores Central	84 50 119	2 (3) 3 (2)	77 18 103	13 5 18	8 2 21	125 77 164	2 (6) 3 (1)	119 77 164	9 4 18	6 1 12	160 132 203	2 (5)	155 130 203	7 2 12	11 5 20			
Azores Sao Miguel	101 63 141	2 (7) 3 (2) 4 (1)	85 37 115	10 2 20	12 1 39	145 114 174	2 (3)	142 81 174	5 3 7	14 6 28	177 133 238	2 (4)	173 131 238	10 3 21	9 3 12			
Madeira Farm Area	158 115 201	2 (7) 3 (1)	148 115 185	8 1 23	12 3 24	201 169 235	2 (3) 3 (2)	195 165 235	8 3 15	7 1 22	256 222 333							



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Table 7.7.29 - SST threshold overpasses – 20 °C – RCP2.6 - MPI-ESM-LR – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	95 49 128	2 (3)	92 13 128	8 3 15	16 3 33	88 51 119	2 (2)	88 46 119	2 1 2	4 3 4	131 76 131	2 (2) 3 (1)	102 76 131	4 2 6	4 1 8
Azores Central	82 0 119	2 (4) 3 (1)	81 18 119	6 1 11	11 1 24	85 40 117	2 (3) 4 (1)	81 26 117	7 2 10	8 2 23	85 48 116	2 (1)	84 48 116	13 13 13	5 5 5
Azores Sao Miguel	104 35 159	2 (1)	104 35 151	2 2 2	6 6 6	96 51 140	2 (3)	93 43 140	7 1 16	7 4 11	119 76 162	2 (5)	115 76 154	7 2 15	9 3 17
Madeira Farm Area	159 128 187	2 (5)	156 128 183	6 2 10	6 3 11	182 125 235	2 (1)	181 125 235	9 9 9	1 1 1	179 147 219	2 (1)	179 147 219		

Table 7.7.30 - SST threshold overpasses – 20 °C – RCP8.5 - MPI-ESM-LR – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	95 49 128	2 (3)	92 13 128	8 3 15	16 3 33	135 94 166	2 (3)	133 94 166	6 1 14	7 4 11	172 142 212	2 (2)	170 142 212	8 6 9	8 6 10
Azores Central	82 0 119	2 (4) 3 (1)	81 18 119	6 1 11	11 1 24	128 87 153	2 (4)	125 84 153	8 1 12	8 3 11	165 122 212	2 (2)	163 122 212	3 2 4	12 9 14
Azores Sao Miguel	104 35 159	2 (1)	104 35 151	2 2 2	6 6 6	146 117 186	2 (4)	144 117 176	4 2 8	6 2 9	192 149 245	2 (3)	190 149 245	5 4 8	6 4 9
Madeira Farm Area	159 128 187	2 (5)	156 128 183	6 2 10	6 3 11	199 179 238	2 (5)	195 179 233	6 4 11	7 2 22	264 216 318	2 (5)			



Table 7.7.31 - SST threshold overpasses – 20 °C – RCP2.6 - IPSL-CM5A-MR – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	102 65 127		102 65 127		122 105 141	2 (1)	122 105 141		119 93 146	2 (1)	119 93 146	2 (1)	119 93 146	2 2 2	2 2 2
Azores Central	91 37 114	2 (1)	90 37 114	11 11 11	5 5 5	2 (1)	109 86 130	3 3 3	4 4 4	2 (1)	108 86 130	2 (1)	108 86 125	6 6 6	3 3 3
Azores Sao Miguel	110 80 140	2 (1)	109 80 140	6 6 6	21 21 21	2 (1)	130 103 152	4 4 4	7 7 7	2 (1)	127 102 156	2 (1)	127 102 156		
Madeira Farm Area	119 63 144	2 (3)	117 63 144	8 2 19	5 3 6	2 (3)	162 129 203	4 1 7	16 9 26	2 (2)	144 132 211	2 (2)	162 132 197	6 4 8	18 9 27

Table 7.7.32 - SST threshold overpasses – 20 °C – RCP8.5 - IPSL-CM5A-MR – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	102 65 127		102 65 127		139 94 163	2 (2)	139 94 163		175 148 205	2 (2)	175 148 205	2 (2)	175 148 205		
Azores Central	91 37 114	2 (1)	90 37 114	11 11 11	5 5 5	2 (1)	124 77 150	6 3 8	7 4 10	2 (1)	163 140 186	2 (1)	163 140 186		
Azores Sao Miguel	110 80 140	2 (1)	109 80 140	6 6 6	21 21 21	2 (1)	148 115 168	7 4 10	7 4 10	2 (1)	167 156 218	2 (1)	167 156 218		
Madeira Farm Area	119 63 144	2 (3)	117 63 144	8 2 19	5 3 6	2 (2)	175 141 211	6 3 8	7 4 10	2 (2)	273 224 331	2 (2)	273 224 331		



Table 7.7.33 - SST threshold overpasses – 21 °C – RCP2.6 - CNRM-CM5 – Units=days

	Historical						rcp26 Midcentury						rcp26 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	76 51 110	2 (4) 3 (2)	69 16 102	9 4 14	9 1 26	87 0 128	2 (3)	89 56 128	10 5 14	7 1 11	84 56 117	2 (2)	82 56 112	10 10 10	7 6 8			
Azores Central	65 37 100	2 (10) 3 (1) 4 (1)	49 9 93	8 1 17	13 3 46	76 0 119	2 (2) 3 (3)	74 30 119	9 2 17	7 1 16	75 52 100	2 (3)	72 37 100	16 3 26	7 1 16			
Azores Sao Miguel	71 33 109	2 (8) 3 (2) 4 (1)	55 9 98	12 2 25	9 2 30	92 0 136	2 (3)	94 60 136	9 6 11	13 6 21	82 58 109	2 (4)	77 43 109	15 8 36	6 1 15			
Madeira Farm Area	116 58 168	2 (8) 3 (1)	105 33 134	7 3 23	14 4 37	141 96 189	2 (5) 3 (2) 4 (1)	127 69 172	10 2 23	12 2 50	133 80 182	2 (7) 3 (1)	123 80 182	5 4 8	14 2 30			

Table 7.7.34 - SST threshold overpasses – 21 °C – RCP8.5 - CNRM-CM5 – Units=days

	Historical						rcp85 Midcentury						rcp85 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	76 51 110	2 (4) 3 (2)	69 16 102	9 4 14	9 1 26	114 70 148	2 (7)	107 43 148	9 2 24	9 2 19	145 121 187	2 (3)	143 119 187	6 4 8	9 7 13			
Azores Central	65 37 100	2 (10) 3 (1) 4 (1)	49 9 93	8 1 17	13 3 46	103 68 146	2 (5)	97 40 146	10 3 23	12 5 24	134 108 175	2 (1)	133 108 175	2 2 2	5 5 5			
Azores Sao Miguel	71 33 109	2 (8) 3 (2) 4 (1)	55 9 98	12 2 25	9 2 30	117 69 151	2 (3)	114 69 151	11 4 16	10 7 15	150 112 196	2 (2)	149 112 196	4 3 5	8 4 12			
Madeira Farm Area	116 58 168	2 (8) 3 (1)	105 33 134	7 3 23	14 4 37	155 115 212		155 115 212			201 176 257							



Table 7.7.35 - SST threshold overpasses – 21 °C – RCP2.6 - MPI-ESM-LR – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	58 0 90	2 (5) 4 (1) 2 years with no events	57 21 86	11 4 19	7 1 23	54 0 94	2 (2) 3 (1)	54 10 83	7 4 9	7 3 15	70 33 93	2 (2) 3 (2)	67 31 93	6 2 14	6 3 11
Azores Central	44 0 82	2 (6) 3 years with no events	46 8 82	9 4 14	7 2 9	46 0 93	2 (2) 3 (2) 3 years with no events	48 1 88	7 2 12	12 3 28	53 0 86	2 (5) 3 (1)	50 11 86	9 1 15	7 3 11
Azores Sao Miguel	70 17 129	2 (3) 3 (1)	66 6 129	6 2 10	11 5 27	63 0 111	2 (4) 3 (1)	61 13 111	10 2 21	7 3 15	81 18 130	2 (3) 3 (1)	76 18 130	11 4 16	6 2 15
Madeira Farm Area	119 90 153	2 (4)	116 90 153	7 4 11	7 2 14	143 103 188	2 (2)	142 103 188	2 2 2	11 2 19	144 110 183	2 (2)	142 110 180	3 1 4	14 11 16

Table 7.7.36 - SST threshold overpasses – 21 °C – RCP8.5 - MPI-ESM-LR – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	58 0 90	2 (5) 4 (1) 2 years with no events	57 21 86	11 4 19	7 1 23	107 67 131	2 (3) 3 (1)	119 69 143	7 3 14	6 2 10	145 106 180	2 (1)	145 106 180		
Azores Central	44 0 82	2 (6) 3 years with no events	46 8 82	9 4 14	7 2 9	99 56 127	2 (6)	92 17 127	5 2 12	16 7 37	139 98 181	2 (1)	139 98 181	4 4 4	4 4 4
Azores Sao Miguel	70 17 129	2 (3) 3 (1)	66 6 129	6 2 10	11 5 27	118 81 152	2 (3) 4 (1)	113 66 152	8 2 15	8 1 13	166 123 214	2 (1)	165 123 214	5 5 5	3 3 3
Madeira Farm Area	119 90 153	2 (4)	116 90 153	7 4 11	7 2 14	169 140 204	2 (1)	168 140 204	9 9 9	8 8 8	219 183 267				



Table 7.7.37 - SST threshold overpasses – 21 °C – RCP2.6 - IPSL-CM5A-MR – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot Central	86 36 110	2 (1)	84 36 110	7 7 7	10 10 10	102 77 117		102 77 117		102 82 122		102 82 122			
Azores Sao Miguel	72 21 98	2 (2)	70 21 98	9 7 10	7 4 10	91 58 108	2 (1)	90 58 108	3 3 3	5 5 5	88 61 112		88 61 112		
Azores Sao Miguel	91 42 120	3 (1)	89 35 120	12 8 16	7 3 11	109 83 127	2 (1)	109 83 127	4 4 4	4 4 4	107 86 138	2 (4)	106 82 138	7 2 11	3 1 5
Madeira Farm Area	83 38 119	2 (4) 3 (1)	76 14 117	12 1 35	11 3 42	126 80 156	2 (2)	125 80 156	4 2 5	7 6 8	126 85 164	2 (3)	123 85 164	3 2 4	16 7 22

Table 7.7.38 - SST threshold overpasses – 21 °C – RCP8.5 - IPSL-CM5A-MR – Units=days

	Historical					rcp85 Midcentury					rcp85 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot Central	86 36 110	2 (1)	84 36 110	7 7 7	10 10 10	119 69 143		119 69 143		157 132 181		157 132 181			
Azores Sao Miguel	72 21 98	2 (2)	70 21 98	9 7 10	7 4 10	108 60 140		108 60 140		147 125 164		147 125 164			
Madeira Farm Area	91 42 120	3 (1)	89 35 120	12 8 16	7 3 11	127 86 151	2 (1)	127 86 151	4 4 4	4 4 4	162 129 182		162 129 182		
Madeira Farm Area	83 38 119	2 (4) 3 (1)	76 14 117	12 1 35	11 3 42	154 108 178	2 (2)	152 108 178	1 1 2	19 9 28	211 179 263		211 179 263		



Table 7.7.39 - SST threshold overpasses – 23 °C – RCP2.6 - CNRM-CM5 – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	16 0 56	2 (2)	19 6 56	11 5 17	25 11 39	50 0 97	2 (7) 3 (2)	42 5 88	10 4 24	8 2 20	42 6 80	2 (5)	37 6 80	9 5 17	12 1 37
Azores Central	10 0 51	2 (2)	15 2 51	1 1 1	20 10 29	38 0 88	2 years with no events	33 3 88	9 2 27	9 2 19	34 0 76	2 (7) 3 (1)	28 1 76	5 2 12	10 3 39
Azores Sao Miguel	12 0 57	2 (4)	16 1 57	6 4 8	9 3 21	49 0 91	2 (7) 3 (2) 4 (1)	39 6 91	7 1 13	10 2 22	38 0 82	2 (5) 3 (2)	33 6 82	6 3 10	7 1 20
Madeira Farm Area	12 0 51	2 (3) 4 (1) no events	15 2 39	6 2 12	5 1 9	37 0 100	2 (6) 3 (1) 4 years with no events	35 2 85	7 4 11	16 5 29	26 0 73	2 (5) 3 (1) 7 years with no events	22 3 55	5 2 11	27 3 68

Table 7.7.40 - SST threshold overpasses – 23 °C – RCP8.5 - CNRM-CM5 – Units=days

	Historical					rcp85 Midcentury					rcp85 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	16 0 56	2 (2)	19 6 56	11 5 17	25 11 39	70 20 104	2 (5) 3 (2)	63 12 87	8 1 15	9 3 22	103 60 139	2 (3)	100 54 133	13 1 26	5 4 6
Azores Central	10 0 51	2 (2)	15 2 51	1 1 1	20 10 29	60 9 87	2 (3) 3 (1)	54 9 82	7 5 10	16 4 30	94 58 137	2 (2) 3 (1)	90 50 137	12 7 17	10 9 11
Azores Sao Miguel	12 0 57	2 (4)	16 1 57	6 4 8	9 3 21	71 26 102	2 (11)	60 13 93	12 1 27	9 1 26	102 57 134	2 (1) 3 (1)	99 29 134	13 8 23	6 5 7
Madeira Farm Area	12 0 51	2 (3) 4 (1) no events	15 2 39	6 2 12	5 2 9	71 0 147	2 (9) 3 (2)	59 1 120	7 2 26	16 1 59	138 106 162	2 (4) 3 (2)	132 104 162	9 3 26	6 3 8



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Table 7.7.41 - SST threshold overpasses – 23 °C – RCP2.6 - MPI-ESM-LR – Units=days

	Historical				rcq26 Midcentury				rcq26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	1 0 17	18 years with no events	12 7 17			1 0 9	17 years with no events	7 4 9			2 0 29	15 years with no events	9 3 29		
Azores Central	1 0 21	18 years with no events	13 5 21			0 0 3	19 years with no events	3 3 3			3 0 35	16 years with no events	13 4 35		
Azores Sao Miguel	3 0 20	2 (1) 15 years with no events	7 2 19	3 3 3	14 14 14	4 0 36	15 years with no events	16 3 36			16 0 72	2 (13) 10 years with no events	26 4 54	10 3 16	9 6 10
Madeira Farm Area	14 0 68	2 (6) 9 years with no events	20 1 68	4 1 8	7 3 13	50 0 100	2 (4) 3 (1) 9 years with no events	47 8 108	7 3 14	9 2 16	55 0 116	2 (4) 3 (1) 2 years with no events	54 19 116	15 3 22	8 1 22

Table 7.7.42 - SST threshold overpasses – 23 °C – RCP8.5 - MPI-ESM-LR – Units=days

	Historical				rcq85 Midcentury				rcq85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	1 0 17	18 years with no events	12 7 17			41 0 82	2 (2) 4 (1) 4 years with no events	46 13 82	11 7 21	5 2 13	97 67 137	2 (1) 2 years with no events	96 66 137	4 4 4	10 10 10
Azores Central	1 0 21	18 years with no events	13 5 21			27 0 74	2 (4) 4 (1) 5 years with no events	30 6 74	7 3 15	7 1 20	87 50 126	2 (3) 3 (1) 3 years with no events	84 50 126	10 2 17	4 2 6
Azores Sao Miguel	3 0 20	2 (1) 15 years with no events	7 2 19	3 3 3	14 14 14	46 0 100	2 (1) 3 (1) 5 years with no events	59 11 100	6 1 13	6 3 8	111 71 168	2 (2) 2 years with no events	110 65 168	6 6 6	9 7 10
Madeira Farm Area	14 0 68	2 (6) 9 years with no events	20 1 68	4 1 8	7 3 13	91 21 134	2 (7) 3 (1) 9 years with no events	83 9 123	5 2 9	12 3 34	145 98 198	2 (3) 3 (1) 3 years with no events	141 98 198	3 1 9	7 4 13



Table 7.7.43 - SST threshold overpasses – 23 °C – RCP2.6 - IPSL-CM5A-MR – Units=days

	Historical						rcp26 Midcentury						rcp26 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	39 0 76	2 (1) 3 years with no events	46 12 76	4 4 4	4 4 4	64 32 82	2 (3)	60 18 82	17 10 25	11 3 25	57 1 92	2 (3)	55 1 92	7 6 7	4 3 7			
Azores Central	27 0 68	2 (1) 4 years with no events	32 5 68	16 16 16	4 4 4	50 0 70	2 (1) 3 (2)	48 15 70	9 3 20	6 2 12	46 0 78	2 (3)	46 12 78	11 4 16	5 1 9			
Azores Sao Miguel	39 0 82	2 (1) 3 years with no events	46 10 82	8 8 8	4 4 4	67 32 90	2 (3) 3 (1)	60 24 88	15 11 17	12 3 19	57 2 97	2 (1)	56 2 97	6 6 6	6 6 6			
Madeira Farm Area	5 0 68	2 (1) 16 years with no events	22 2 68	5 5 5	12 12 12	33 0 82	2 (1) 3 (2) 6 years with no events	39 6 82	7 3 13	15 7 45	31 0 100	2 (2) 3 (2) 6 years with no events	36 3 100	9 4 14	10 1 33			

Table 7.7.44 - SST threshold overpasses – 23 °C – RCP8.5 - IPSL-CM5A-MR – Units=days

	Historical						rcp85 Midcentury						rcp85 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	39 0 76	2 (1) 3 years with no events	46 12 76	4 4 4	4 4 4	84 51 112	2 (1)	84 51 112	3 3 3	4 4 4	120 101 143		120 101 143					
Azores Central	27 0 68	2 (1) 4 years with no events	32 5 68	16 16 16	4 4 4	74 20 105		74 20 105			112 93 136		112 93 136					
Azores Sao Miguel	39 0 82	2 (1) 3 years with no events	46 10 82	8 8 8	4 4 4	89 58 113		89 58 113			123 101 142		123 101 142					
Madeira Farm Area	5 0 68	2 (1) 16 years with no events	22 2 68	5 5 5	12 12 12	93 40 132	2 (3) 3 (1)	85 35 132	10 2 19	11 5 34	133 102 159		133 102 159					



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Table 7.7.45 - SST threshold overpasses – 24 °C – RCP2.6 - CNRM-CM5 – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	4 0 38	13 years with no events	12 1 38			23 0 56	2 (9) 6 years with no events	24 1 43	11 1 23	10 3 19	17 0 54	2 (9) 3 (1) 6 years with no events	20 2 54	4 1 8	7 2 14
Azores Central	3 0 35	16 years with no events	14 6 35			20 0 80	2 (9) 3 (1) 7 years with no events	21 2 44	12 2 23	12 2 23	12 0 54	2 (1) 10 years with no events	22 4 54	8 9 8	6 6 6
Azores Sao Miguel	3 0 33	15 years with no events	12 1 33			20 0 53	2 (7) 3 (1) 5 years with no events	18 6 36	9 2 16	7 2 18	12 0 55	2 (4) 9 years with no events	16 2 39	12 8 17	5 2 10
Madeira Farm Area	1 0 14	17 years with no events	8 4 14			10 0 61	2 (1) 3 (2) 14 years with no events	22 13 36	5 2 8	8 2 17	2 0 25	2 (1) 18 years with no events	16 15 18	4 4 4	6 6 6

Table 7.7.46 - SST threshold overpasses – 24 °C – RCP8.5 - CNRM-CM5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)
Azores Tot	4 0 38	13 years with no events	12 1 38			43 0 77	2 (9) 3 (2) 2 years with no events	40 6 77	9 1 18	6 2 15	83 43 113	2 (5) 76 28 113	17 3 39	10 5 16
Azores Central	3 0 35	16 years with no events	14 6 35			37 0 73	2 (9) 2 years with no events	36 3 73	8 2 18	9 2 14	78 39 110	2 (5) 70 25 110	12 4 23	13 7 22
Azores Sao Miguel	3 0 33	15 years with no events	12 1 33			43 0 81	2 (9) 2 years with no events	35 4 81	8 1 14	14 3 53	83 35 123	2 (4) 3 (1) 4 (1) 76 23 108	9 3 20	7 2 14
Madeira Farm Area	1 0 14	17 years with no events	8 4 14			23 0 86	2 (4) 7 years with no events	30 5 65	7 1 18	11 4 16	97 44 143	2 (3) 3 (2) 90 44 140	7 1 17	16 4 45



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Table 7.7.47 - SST threshold overpasses – 24 °C – RCP2.6 - MPI-ESM-LR – Units=days

	Historical						rcp26 Midcentury						rcp26 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	0	no events	0			0	no events	0			0 0 9	19 years with no events	9 9 9					
Azores Central	0	no events	0			0	no events	0			1 0 17	19 years with no events	17 17 17					
Azores Sao Miguel	0	no events	0			0	no events	0			2 0 21	17 years with no events	13 12 13	6 6 6	3 3 3			
Madeira Farm Area	1 0 13	17 Years with no events	7 4 13			9 0 58	3 (1) 13 years with no events	23 6 58	4 4 4	9 3 15	7 0 38	2 (3) 13 years with no events	12 1 38	4 2 7	15 13 17			

Table 7.7.48 - SST threshold overpasses – 24 °C – RCP8.5 - MPI-ESM-LR – Units=days

	Historical						rcp85 Midcentury						rcp85 End of Century					
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)			
Azores Tot	0	no events	0			11 0 44	2 (1) 3 (1) 11 years with no events	19 3 44	6 2 11	6 5 6	67 30 109	2 (1)	66 30 109	4 4 4	16 16 16			
Azores Central	0	no events	0			7 0 51	14 years with no events	24 4 51	9 3 20	6 1 17	58 8 100	2 (3)	55 8 100	14 4 26	3 2 6			
Azores Sao Miguel	0	no events	0			18 0 61	2 (4) 4 (1) 11 years with no events	27 11 46	9 3 20	6 1 17	81 37 154	81 37 154	81 37 154					
Madeira Farm Area	1 0 13	17 Years with no events	7 4 13			42 0 108	2 (4) 3 (2) 2 years with no events	39 2 108	9 1 30	8 3 21	104 7 156	2 (3)	101 7 156	11 4 20	8 4 15			



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Table 7.7.49 - SST threshold overpasses – 24 °C – RCP2.6 - IPSL-CM5A-MR – Units=days

	Historical					rcp26 Midcentury					rcp26 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	16 0 58	2 (3) 3 (1) 7 years with no events	21 1 58	7 2 14	5 2 8	40 0 61	2 (1) 3 (1) 3 years with no events	43 17 61	13 10 14	8 2 17	33 0 63	2 (5) 4 years with no events	35 9 63	9 6 11	8 3 15
Azores Central	7 0 49	2 (1) 15 years with no events	23 6 49	5 5 5	13 13 13	28 0 55	2 (4) 3 (1) 3 years with no events	29 7 47	4 1 7	9 1 17	20 0 54	2 (3) 6 years with no events	26 9 54	3 2 4	8 2 18
Azores Sao Miguel	17 0 65	2 (3) 3 (2) 8 years with no events	23 3 65	5 2 15	4 1 8	38 0 67	2 (6) 3 years with no events	37 8 62	10 3 21	12 4 27	27 0 66	2 (3) 3 (2) 5 years with no events	29 5 66	6 2 14	8 2 19
Madeira Farm Area	1 0 25	2 (1) 19 years with no events	6 6 6	6 6 6	13 13 13	3 0 24	2 (1) 15 years with no events	9 2 17	3 3 3	14 14 14	4 0 43	2 (1) 16 years with no events	14 1 27	9 9 9	7 7 7

Table 7.7.50 - SST threshold overpasses – 24 °C – RCP8.5 - IPSL-CM5A-MR – Units=days

	Historical					rcp85 Midcentury					rcp85 End of Century				
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	16 0 58	2 (3) 3 (1) 7 years with no events	21 1 58	7 2 14	5 2 8	67 12 96	2 (1) 4 years with no events	67 12 96	5 1 17	27 8 70	105 86 126	2 (6) 4 years with no events	98 53 129	9 6 11	8 3 15
Azores Central	7 0 49	2 (1) 15 years with no events	23 6 49	5 5 5	13 13 13	56 0 89	2 (1) 4 years with no events	59 21 89	3 3 3	3 3 3	95 68 121	2 (1) 15 years with no events	95 68 121	3 3 3	8 2 18
Azores Sao Miguel	17 0 65	2 (3) 3 (2) 8 years with no events	23 3 65	5 2 15	4 1 8	68 36 98	2 (1) 4 years with no events	68 26 98	4 4 4	14 14 14	105 87 129	2 (1) 15 years with no events	105 87 129	6 2 14	8 2 19
Madeira Farm Area	1 0 25	2 (1) 19 years with no events	6 6 6	6 6 6	13 13 13	46 0 100	2 (6) 4 years with no events	46 6 94	5 1 17	27 8 70	98 53 129	2 (6) 4 years with no events	98 53 129	9 6 11	8 3 15



Table 7.7.51 - SST threshold overpasses – 25 °C – RCP2.6 - CNRM-CM5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century								
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)		
Azores Tot	1 0 27	19 years with no events	27 27 27			7 0 35	2 (2)	20 years with no events	9 1 22	5 4 6	18 14 22	3 0 28	2 (1)	15 years with no events	9 1 17	9 9 9	2 2 2
Azores Central	1 0 11	19 years with no events	11 11 11			4 0 21	2 (1)	12 years with no events	10 1 21	2 2 2	2 2 2	2 0 26	2 (1)	16 years with no events	8 2 14	6 6 6	6 6 6
Azores Sao Miguel	1 0 23	2 (1) 19 years with no events	11 11 11	9 9 9	3 3 3	5 0 30	2 (2)	13 years with no events	7 2 20	7 5 8	17 13 20	2 0 22	2 (1)	16 years with no events	8 5 10	3 3 3	9 9 9
Madeira Farm Area	0	No events	0			0 0 5	18 years with no events	4 2 5				0	No events	0			

Table 7.7.52 - SST threshold overpasses – 25 °C – RCP8.5 - CNRM-CM5 – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century							
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	
Azores Tot	1 0 27	19 years with no events	27 27 27			20 0 60	2 (4)	5 years with no events	24 3 56	5 2 13	6 2 9	66 30 93	2 (7)	59 16 93	7 2 16	12 1 22
Azores Central	1 0 11	19 years with no events	11 11 11			18 0 48	2 (4)	5 years with no events	20 4 48	4 1 10	14 4 35	61 16 91	2 (7) 3 (1)	53 16 91	8 2 19	9 2 23
Azores Sao Miguel	1 0 23	2 (1) 19 years with no events	11 11 11	9 9 9	3 3 3	18 0 56	2 (2)	7 years with no events	24 7 56	11 10 11	6 4 7	63 9 92	2 (6) 3 (1)	51 4 92	9 1 21	14 6 39
Madeira Farm Area	0	No events	0			6 5 33	3 (1) 15 years with no events	18 12 31	3 1 5	8 2 13	42 0 122	2 (2) 3 (1) 6 years with no events	52 1 122	7 6 8	22 2 43	



Table 7.7.53 - SST threshold overpasses – 25 °C – RCP2.6 - MPI-ESM-LR – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	0	no events	0			0	no events	0			0	no events	0		
Azores Central	0	No events	0			0	No events	0			0	No events	0		
Azores Sao Miguel	0	No events	0			0	No events	0			0	No events	0		
Madeira Farm Area	0	No events	0			0 0 5	19 years with no events	5 5 5			1 0 22	19 years with no events	22 22 22		

Table 7.7.54 - SST threshold overpasses – 25 °C – RCP8.5 - MPI-ESM-LR – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	0	no events	0			2 0 25	18 years with no events	19 13 25			28 0 88	2 (3) 3 (1) 2 years with no events	27 1 75	7 3 16	8 15 12
Azores Central	0	No events	0			2 0 20	18 years with no events	17 13 20			20 0 72	2 (4) 8 years with no events	28 2 67	8 1 16	9 4 14
Azores Sao Miguel	0	No events	0			3 0 24	16 years with no events	16 7 24			51 12 128	2 (8) 3 (1) 4 (1)	41 5 116	6 2 10	8 1 18
Madeira Farm Area	0	No events	0			8 0 63	13 years with no events	10 3 25	10 3 22	19 1 43	61 0 131	2 (7) 3 (1) 2 years with no events	60 9 108	8 1 22	10 1 33



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Table 7.7.55 - SST threshold overpasses – 25 °C – RCP2.6 - IPSL-CM5A-MR – Units=days

	Historical				rcp26 Midcentury				rcp26 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	2 0 38	2 (1)	9 2 17	8 8 8	13 13 13	12 0 38	2 (1)	19 5 38	13 13 13	4 4 4	9 0 51	2 (1)	20 3 51	9 9 9	4 4 4
Azores Central	0	No events	0			5 0 29	2 (1)	11 4 18	5 5 5	10 10 10	5 0 44	2 (1)	13 1 28	4 4 4	15 15 15
Azores Sao Miguel	3 0 38	2 (1)	12 4 20	9 9 9	9 9 9	10 1 45	2 (1)	17 1 45	10 10 10	6 6 6	10 0 54	2 (3)	18 4 33	9 6 12	7 3 10
Madeira Farm Area	0	No events	0			0	No events	0			1 0 8	18 years with no events	7 5 8		

Table 7.7.56 - SST threshold overpasses – 25 °C – RCP8.5 - IPSL-CM5A-MR – Units=days

	Historical				rcp85 Midcentury				rcp85 End of Century						
	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)	Total duration of critical season (Mean Min Max)	Number of events during critical season (multiplicity)	Longest event in season (Mean Min Max)	Duration of intermittent events (mean Min Max)	Interval between intermittent events (mean Min Max)
Azores Tot	2 0 38	2 (1)	9 2 17	8 8 8	13 13 13	48 0 80	2 (1)	48 17 80			87 60 111	2 (1)	86 60 111	5 5 5	12 12 12
Azores Central	0	No events	0			37 0 73	2 years with no events	41 3 73			77 54 108	2 (2)	75 49 108	14 3 25	5 4 6
Azores Sao Miguel	3 0 38	2 (1)	12 4 20	9 9 9	9 9 9	48 0 84	2 (4)	47 15 77	9 1 17	5 1 11	88 53 111		88 53 111		
Madeira Farm Area	0	No events	0			8 0 43	12 years with no events	19 8 43			60 0 103	2 (2)	64 7 103	14 12 15	11 10 12



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Sea-state hazard integral indicators
Integral indicators are averaged over the areas illustrated in Figures 3.4.59 and 3.4.60.

Mediterranean areas

Table 7.7.57a – SWH – Mediterranean areas - RCP4.5 and RCP8.5 – Units=m

	Historical			rcp45 Midcentury			rcp45 End of Century			rcp85 Midcentury			rcp85 End of Century		
	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)
Malta Farm Area	0.93	0.06	0.12-0.15	0.91 0.68	0.05	0.14-0.16	0.90 0.67	0.05	0.13-0.15	0.90 0.67	0.05	0.13-0.15	0.87 0.65	0.05	0.11-0.13
Sicily North	0.68	0.12	0.04-0.09	0.66 0.49	0.12	0.06-0.12	0.65 0.48	0.12	0.05-0.10	0.65 0.48	0.11	0.06-0.10	0.62 0.46	0.11	0.05-0.10
Sicily East	0.56	0.16	0.04-0.12	0.55 0.41	0.15	0.05-0.13	0.55 0.41	0.15	0.05-0.13	0.55 0.41	0.15	0.05-0.13	0.53 0.39	0.15	0.04-0.11
Sicily South	0.87	0.12	0.07-0.14	0.86 0.63	0.13	0.09-0.16	0.85 0.63	0.12	0.08-0.14	0.84 0.62	0.12	0.08-0.15	0.81 0.60	0.12	0.06-0.13
Corisca West	0.91	0.09	0.06-0.15	0.90 0.66	0.09	0.08-0.18	0.89 0.66	0.09	0.07-0.18	0.89 0.66	0.09	0.07-0.17	0.86 0.64	0.09	0.07-0.16
Corisca East	0.55	0.14	0.05-0.15	0.56 0.41	0.14	0.05-0.17	0.55 0.41	0.14	0.05-0.18	0.55 0.41	0.14	0.05-0.17	0.54 0.40	0.13	0.04-0.16
Sardinia West	0.99	0.14	0.07-0.18	0.97 0.72	0.14	0.09-0.20	0.96 0.71	0.14	0.08-0.17	0.96 0.71	0.14	0.08-0.18	0.93 0.70	0.13	0.07-0.16
Sardinia East	0.55	0.12	0.02-0.14	0.55 0.48	0.12	0.03-0.16	0.54 0.40	0.12	0.03-0.16	0.54 0.40	0.12	0.03-0.16	0.53 0.40	0.11	0.02-0.15
Cyprus Farm Area (Bream & Brass)	0.51	0.14	0.04-0.09	0.49 0.36	0.14	0.05-0.10	0.49 0.36	0.14	0.04-0.09	0.49 0.36	0.14	0.05-0.09	0.47 0.35	0.13	0.04-0.09
Cyprus Farm Area (Tuna)	0.49	0.16	0.04-0.09	0.47 0.35	0.16	0.05-0.10	0.47 0.35	0.16	0.04-0.09	0.47 0.35	0.16	0.05-0.09	0.45 0.33	0.15	0.04-0.09



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Table 7.7.57b – Normalized SWH – Mediterranean areas - RCP4.5 and RCP8.5 – Units for non-normalized values=m

	Historical		rcp45 Midcentury		rcp45 End of Century		rcp85 Midcentury		rcp85 End of Century	
	SWH	Normalized value	SWH	Normalized value	SWH	Normalized value	SWH	Normalized value	SWH	Normalized value
Malta Farm Area	0,93	0,37	0,91	0,36	0,9	0,36	0,9	0,36	0,87	0,35
Sicily North	0,68	0,27	0,66	0,26	0,65	0,26	0,65	0,26	0,62	0,25
Sicily East	0,56	0,22	0,55	0,22	0,55	0,22	0,55	0,22	0,53	0,21
Sicily South	0,87	0,35	0,86	0,34	0,85	0,34	0,84	0,34	0,81	0,32
Corsica West	0,91	0,36	0,9	0,36	0,89	0,36	0,89	0,36	0,86	0,34
Corsica East	0,55	0,22	0,56	0,22	0,55	0,22	0,55	0,22	0,54	0,22
Sardinia West	0,99	0,40	0,97	0,39	0,96	0,38	0,96	0,38	0,93	0,37
Sardinia East	0,55	0,22	0,55	0,22	0,54	0,22	0,54	0,22	0,53	0,21
Cyprus Farm Area (Bream & Brass)	0,51	0,20	0,49	0,20	0,49	0,20	0,49	0,20	0,47	0,19
Cyprus Farm Area (Tuna)	0,49	0,20	0,47	0,19	0,47	0,19	0,47	0,19	0,45	0,18



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Table 7.7.58 – Wave Period – Mediterranean areas - RCP4.5 and RCP8.5 – Units=sec

	Historical			rcp45 Midcentury			rcp45 End of Century			rcp85 Midcentury			rcp85 End of Century		
	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean over area	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)	Spatial average of ensemble mean	Spatial STD of ensemble mean (estimates homogeneity over area)	min-max of ensemble spread over area (estimates model uncertainty)
Malta Farm Area	5.03	0.06	0.27-0.31	5.00	0.06	0.28-0.32	4.99	0.06	0.27-0.30	4.98	0.06	0.27-0.32	4.94	0.06	0.24-0.27
Sicily North	4.62	0.10	0.16-0.29	4.56	0.09	0.18-0.31	4.53	0.09	0.17-0.28	4.53	0.09	0.16-0.28	4.47	0.09	0.14-0.25
Sicily East	4.54	0.19	0.13-0.28	4.51	0.19	0.14-0.30	4.51	0.19	0.14-0.28	4.50	0.19	0.13-0.29	4.46	0.18	0.11-0.25
Sicily South	5.06	0.07	0.20-0.37	5.02	0.07	0.24-0.39	5.00	0.07	0.22-0.34	4.99	0.07	0.21-0.35	4.94	0.07	0.18-0.31
Corstica West	5.16	0.16	0.23-0.34	5.13	0.16	0.25-0.37	5.10	0.15	0.22-0.34	5.09	0.15	0.22-0.33	5.04	0.15	0.19-0.30
Corstica East	4.30	0.41	0.10-0.33	4.31	0.39	0.11-0.35	4.28	0.39	0.11-0.31	4.29	0.39	0.10-0.30	4.28	0.37	0.11-0.27
Sardinia West	5.32	0.11	0.28-0.41	5.28	0.11	0.32-0.43	5.25	0.10	0.29-0.39	5.24	0.11	0.28-0.39	5.18	0.11	0.25-0.34
Sardinia East	4.36	0.32	0.12-0.34	4.36	0.31	0.12-0.36	4.33	0.31	0.13-0.32	4.33	0.30	0.13-0.31	4.30	0.29	0.09-0.28
Cyprus Farm Area (Bream & Brass)	4.47	0.27	0.20-0.34	4.43	0.27	0.20-0.36	4.44	0.27	0.20-0.36	4.43	0.28	0.22-0.37	4.39	0.28	0.16-0.32
Cyprus Farm Area (Tuna)	4.47	0.32	0.22-0.34	4.44	0.33	0.22-0.36	4.44	0.33	0.22-0.36	4.43	0.33	0.23-0.37	4.39	0.33	0.18-0.32



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Table 7.7.60 – Normalized hazard from extreme waves – Mediterranean areas – RCP8.5 - Red values indicate an increase with respect to the reference period, regardless of its magnitude. Results can be better appreciated through comparison with the maps presented in Section 3.4, in particular as to the origin of spatial inhomogeneities (comparatively high STD)

Experiment	Historical												rcp85 Midcentury												rcp85 End of Century												
	CMCC			CNRM			GUF			LMD			CMCC			CNRM			GUF			LMD			CMCC			CNRM			GUF			LMD			
Driver	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean SST (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean SST (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)	Spatial STD of mean (estimates homogeneity over area)	Mean hazard (estimates homogeneity over area)			
Malta	0.08	0.14	0	0	0.33	0.21	0	0	0	0.12	0.17	0	0	0.62	0.19	0	0	0.21	0.18	0	0	0.04	0.08	0	0	0.18	0	0	0.04	0.08	0	0	0	0	0		
Farm Area	0.30	0.24	0	0	0.14	0.17	0	0	0	0.21	0.22	0	0	0.33	0.27	0	0	0.21	0.23	0	0	0.18	0.20	0	0	0.23	0	0	0.18	0.20	0	0	0	0	0		
Sicily North	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sicily East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sicily South	0.05	0.11	0	0	0.31	0.27	0	0	0.04	0.08	0	0	0.44	0.30	0	0	0	0.18	0.18	0	0	0.12	0.19	0	0	0.18	0	0	0.12	0.19	0	0	0	0	0	0	
Sicily West	0.09	0.14	0.26	0.26	0.03	0.11	0	0	0.31	0.26	0.22	0.29	0.01	0.03	0	0	0	0.09	0.16	0.14	0.20	0.30	0.26	0	0	0.16	0.14	0.20	0.30	0.26	0	0	0	0	0	0	
Corica East	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.08	0	0	0	0	0		
Sardinia West	0.39	0.34	0.50	0.31	0.46	0.35	0	0	0.53	0.32	0.45	0.27	0.45	0.36	0	0	0	0.51	0.32	0.41	0.29	0.50	0.37	0	0	0.32	0.41	0.29	0.50	0.37	0	0	0	0	0	0	
Sardinia East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cyprus Farm Area (Bevan & Brass)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cyprus Farm Area (Tuna)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	



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Atlantic areas

Table 7.7.61 – SWH – Atlantic areas - RCP8.5 – Units=m

Driver	Historical				rcp85 Midcentury				rcp85 End of Century			
	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS
Azores Tot	Spatial average	Spatial STD (estimates homogeneity over area)	Spatial average	Spatial STD (estimates homogeneity over area)	Spatial average	Spatial STD (estimates homogeneity over area)	Spatial average	Spatial STD (estimates homogeneity over area)	Spatial average	Spatial STD (estimates homogeneity over area)	Spatial average	Spatial STD (estimates homogeneity over area)
Azores Central	1.99	0.24	1.67	0.22	1.84	0.23	1.65	0.21	1.67	0.21	1.61	0.21
Azores Sao Miguel	1.62	0.31	1.35	0.28	1.49	0.30	1.33	0.27	1.35	0.28	1.30	0.27
Madeira Farm Area	1.42	0.31	1.21	0.29	1.31	0.29	1.19	0.28	1.19	0.28	1.16	0.27
Madeira Farm Area	1.28	0.31	1.13	0.30	1.20	0.30	1.12	0.29	1.13	0.28	1.11	0.28

Table 7.7.62 – Normalized SWH – Atlantic areas - RCP8.5 – Units for non-normalized values=m

Driver	Historical				rcp85 Midcentury				rcp85 End of Century			
	Hadley Centre	ACCESS										
Azores Tot	Spatial average of ensemble mean over area	Normalized value	Spatial average of ensemble mean over area	Normalized value	Spatial average of ensemble mean over area	Normalized value	Spatial average of ensemble mean over area	Normalized value	Spatial average of ensemble mean over area	Normalized value	Spatial average of ensemble mean over area	Normalized value
Azores Central	1.99	0.60	1.67	0.53	1.84	0.57	1.65	0.53	1.67	0.53	1.61	0.52
Azores Sao Miguel	1.62	0.52	1.35	0.47	1.49	0.50	1.33	0.47	1.35	0.47	1.3	0.46
Madeira Farm Area	1.42	0.48	1.21	0.44	1.31	0.46	1.19	0.44	1.19	0.44	1.16	0.43
Madeira Farm Area	1.28	0.46	1.13	0.43	1.2	0.44	1.12	0.42	1.13	0.43	1.11	0.42



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Table 7.7.63 – Normalized integral hazard from extreme waves – Atlantic areas – RCP8.5 - Red values indicate an increase with respect to the reference period, regardless of its magnitude. Results can be better appreciated through comparison with the maps presented in Section 3.4, in particular as to the origin of spatial inhomogeneities (comparatively high STD)

Global driver	Historical				rcp85 Midcentury				rcp85 End of Century			
	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS	Hadley Centre	ACCESS
	Mean hazard	Spatial STD of mean (estimates homogeneity over area)	Mean hazard	Spatial STD of mean (estimates homogeneity over area)	Mean hazard	Spatial STD of mean (estimates homogeneity over area)	Mean hazard	Spatial STD of mean (estimates homogeneity over area)	Mean hazard	Spatial STD of mean (estimates homogeneity over area)	Mean hazard	Spatial STD of mean (estimates homogeneity over area)
Azores Tot	0.83	0.14	0.15	0.21	0.76	0.19	0.41	0.33	0.79	0.15	0.67	0.16
Azores Central	0.62	0.31	0.03	0.09	0.46	0.33	0.16	0.27	0.58	0.31	0.42	0.28
Azores Sao Miguel	0.53	0.31	0	0	0.29	0.30	0.01	0.04	0.42	0.33	0.23	0.27
Madeira Farm Area	0.20	0.26	0	0	0	0	0	0	0.01	0.06	0	0



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