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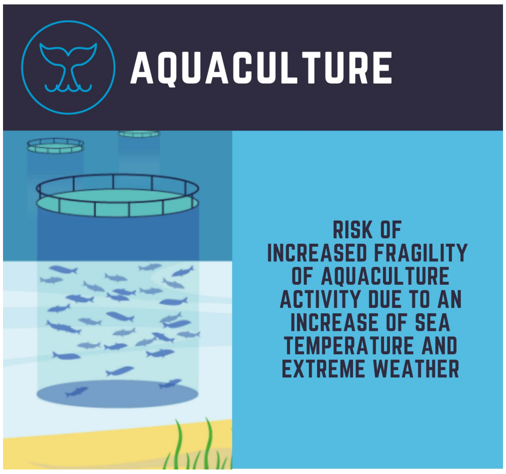

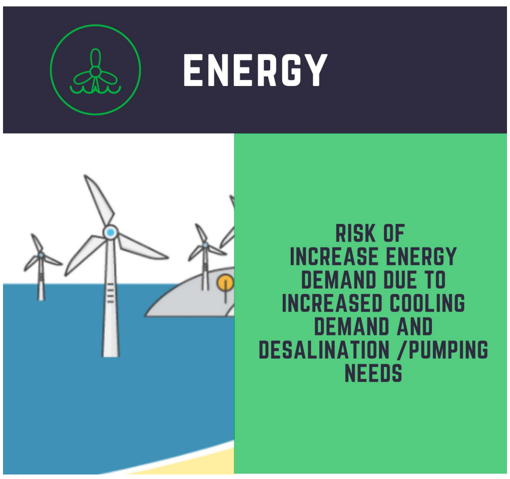

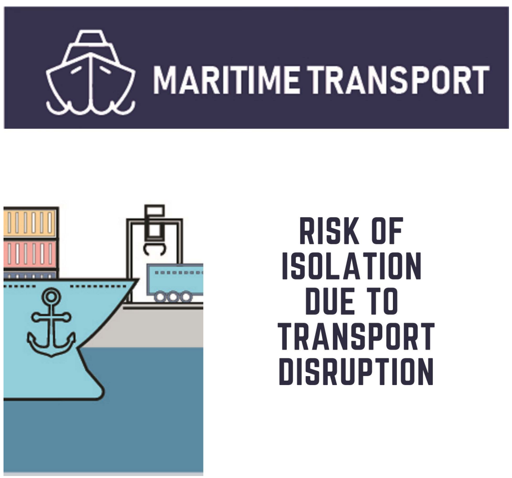

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Loss of attractiveness due to increased danger of forest fires in touristic areas

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 study 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 operationalization: the three Atlantic Islands (Azores, Canary Islands and Madeira) and the Mediterranean ones (Balearic Islands, Crete, Corsica, Cyprus, Malta, Sardinia and Sicily).

The concept of Impact Chain (Schneiderbauer *et al.* 2013; Fritzsche *et al.* 2014) is applied as a climate risk assessment method (with 6 steps) for research of decision making. Impact Chains propose diagrams articulating the causal links between the different components of climate risks (according to AR5 concepts: hazards, exposure, vulnerability, risks, step 1)). For each of these components of the theoretical IC, several indicators are selected and collected (step 3). Data are then normalised to be able to be aggregated (steps 4 and 5) with different weights. The final objective (step 6) is to achieve a standardised risk score that, according to the spatial scale of the analysis can allow comparison and decision making on adaptation, including hierarchization of resource allocation or identification of adaptation options to mitigate climate risk.

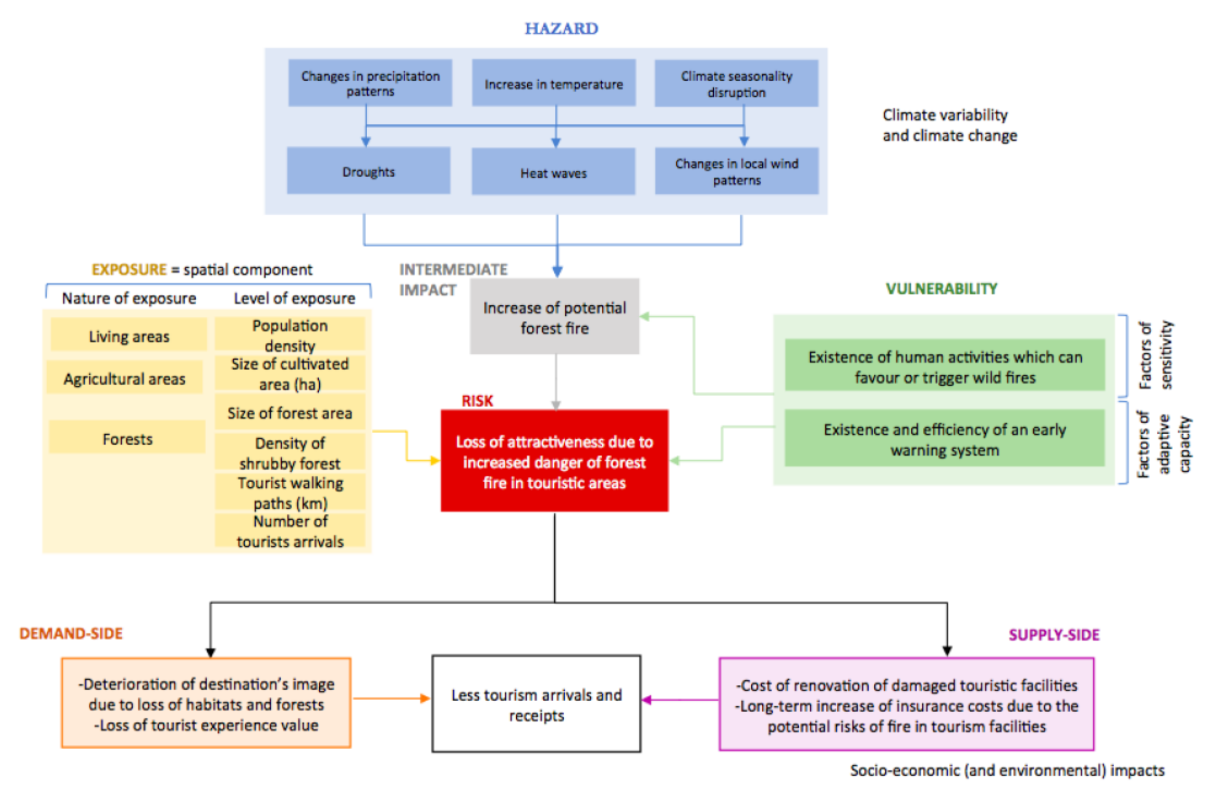

Figure 1: Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.2

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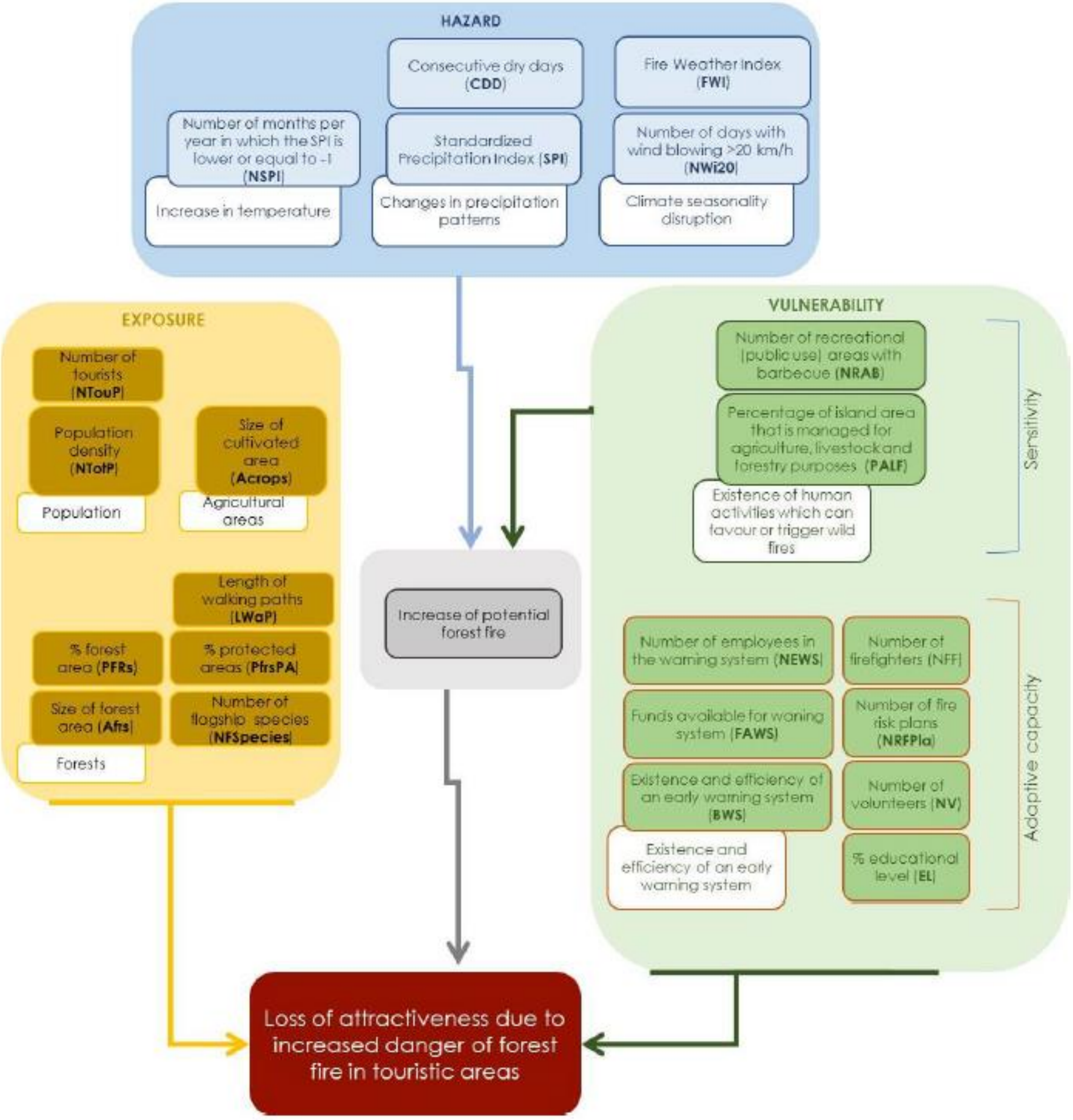

Figure 2: Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.3

Many indicators were formulated in a very broad 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.

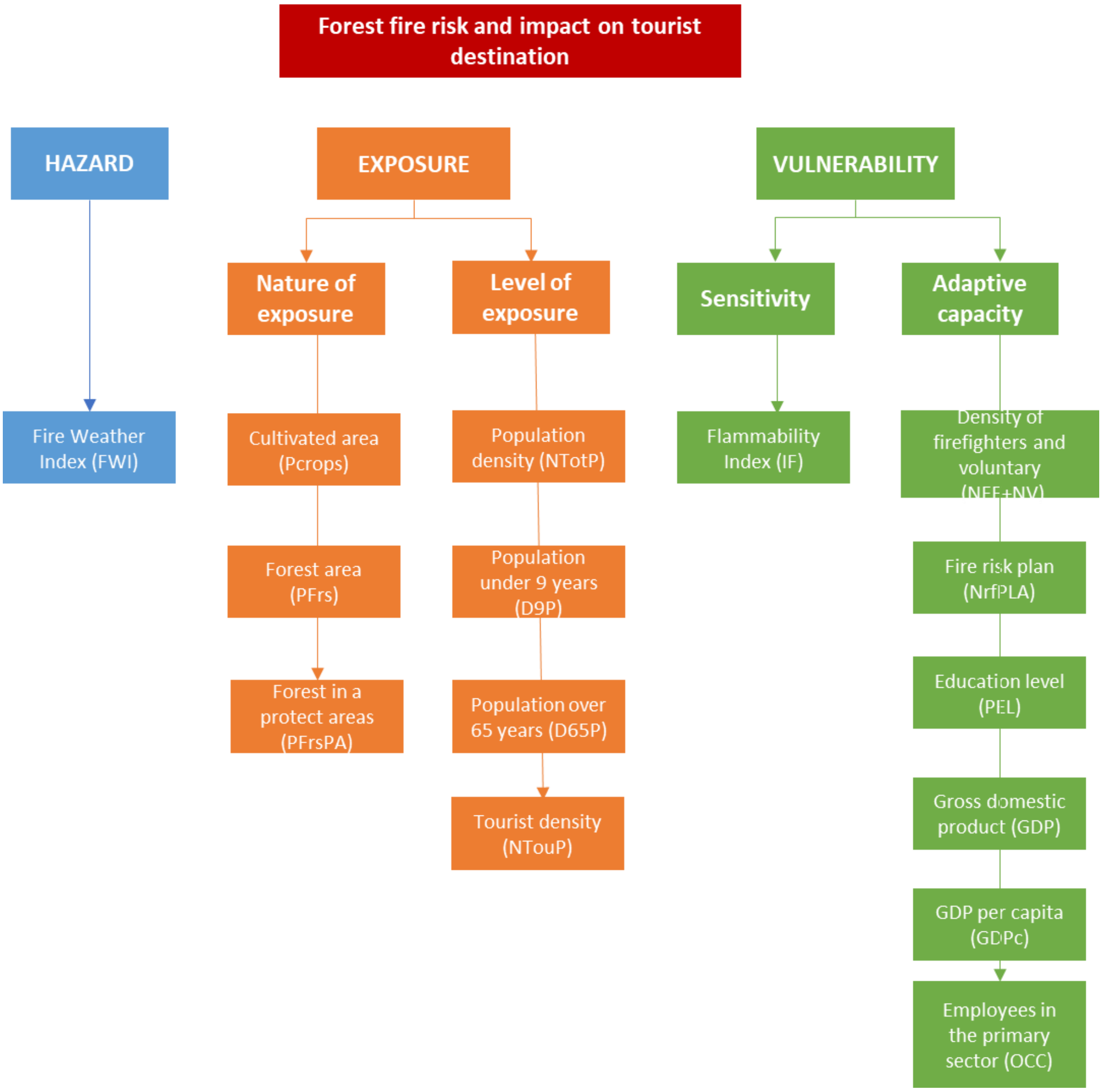

Figure 3: Final Impact Chain Model
Source: Soclimpact deliverable D4.5

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. Afterwards, the normalized index was categorized into five equal interval classes representing values from "Very low" to "Very high".

Considering the weighing, an assessment of GIZ methodology has been developed for this impact chain including interviews with various types of stakeholders (cf. dedicated 4.5 to forest fires).

The indicators previously normalized have been aggregated to elaborate three sub-component indices (hazard, exposure, vulnerability) and the final risk index. The result is included in a comparison for the 9 other islands studied for the risk linked to forest fires.

Hazard scores

The main findings are:

- Scores for fire danger 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 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

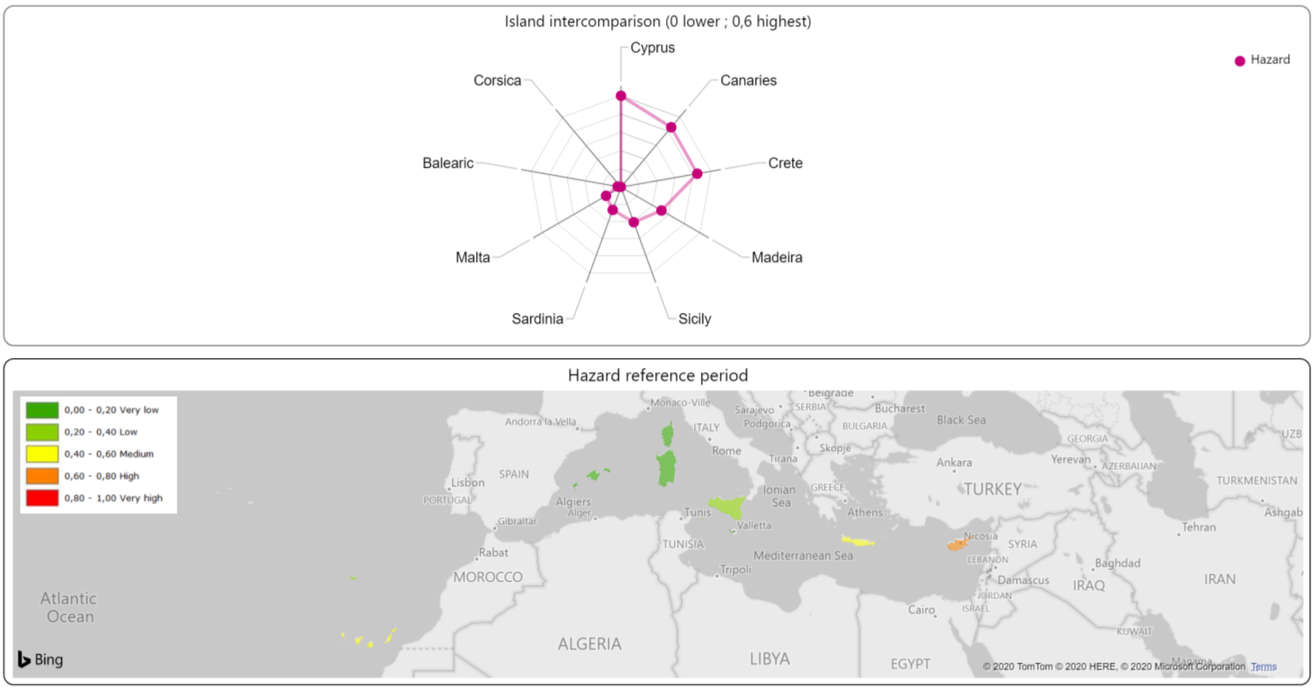

Figure 4: Hazard score (Fire Weather Index) per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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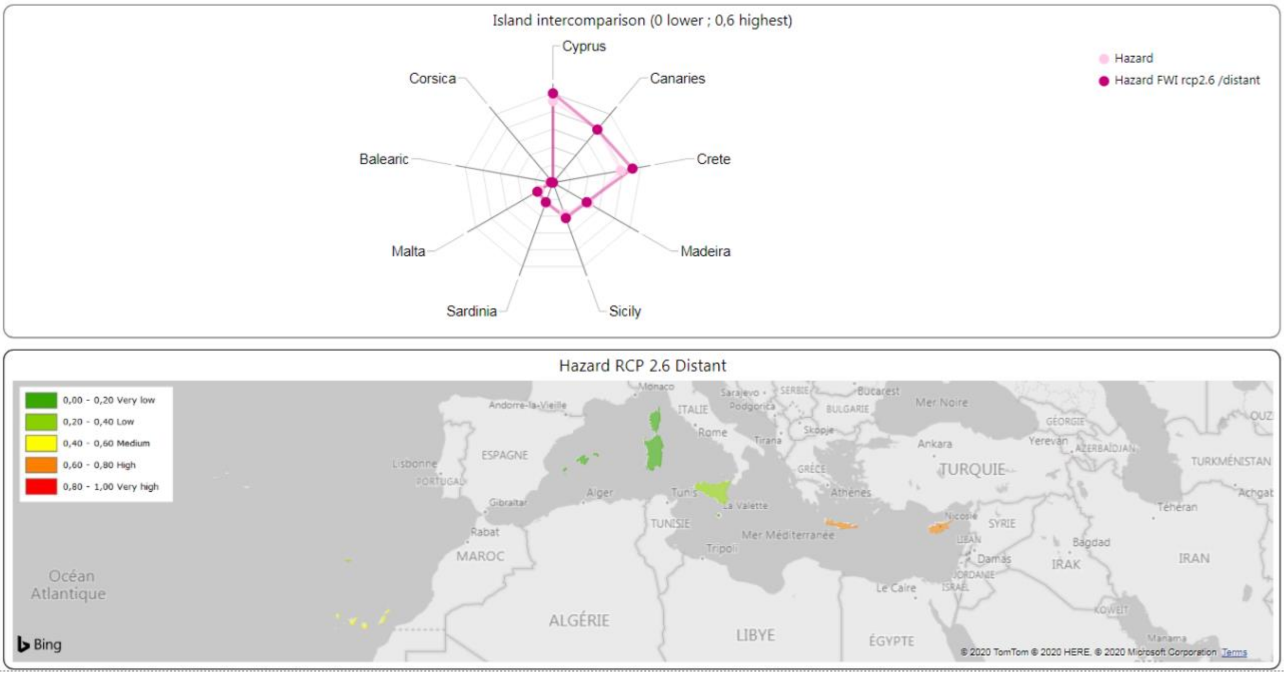

Figure 5: Hazard score (Fire Weather Index) per island at the end of the century (2081-2100) under RCP2.6 (Ambitious Mitigation Policies)
Source: Soclimpact deliverable D4.5

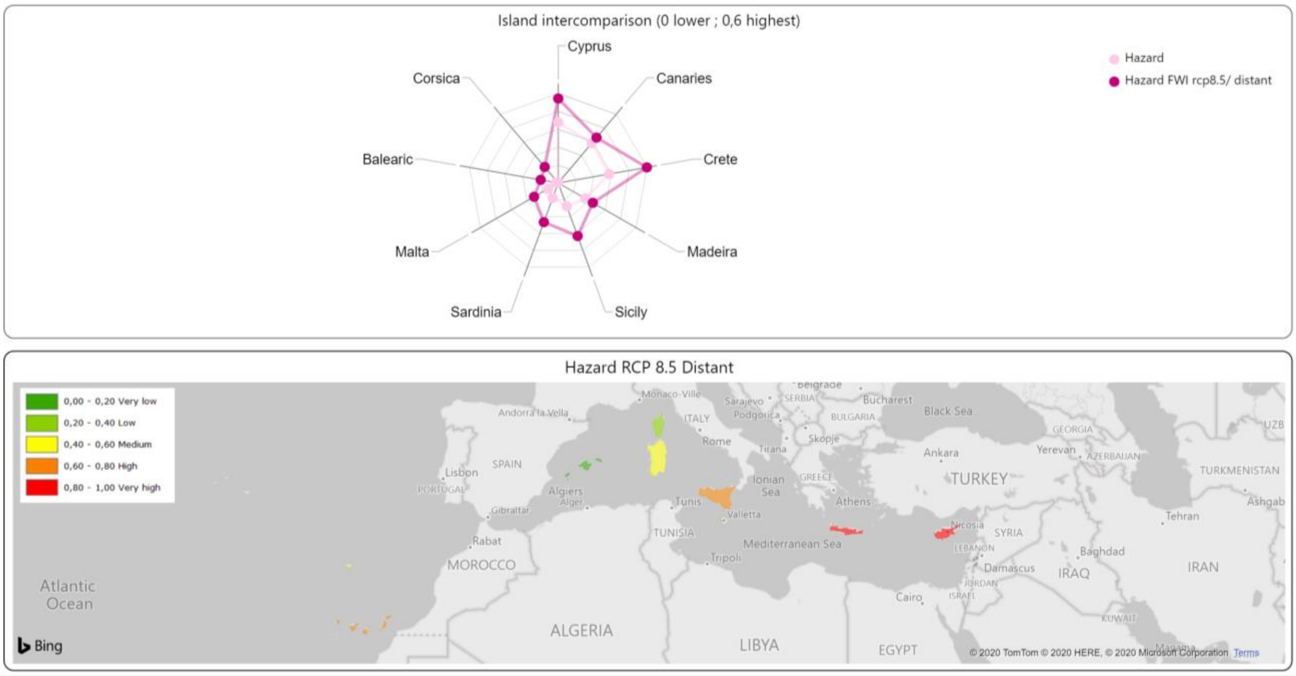

Figure 6: Hazard score (Fire Weather Index) at the end of the century (2081-2100) under RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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Exposure

The results show that:

- Atlantic Islands (Madeira and Canary Islands) are more exposed than Mediterranean Islands (from low to medium score). We can see an increase as we move from North to South in the Mediterranean area.
- Atlantics Islands higher scores 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.

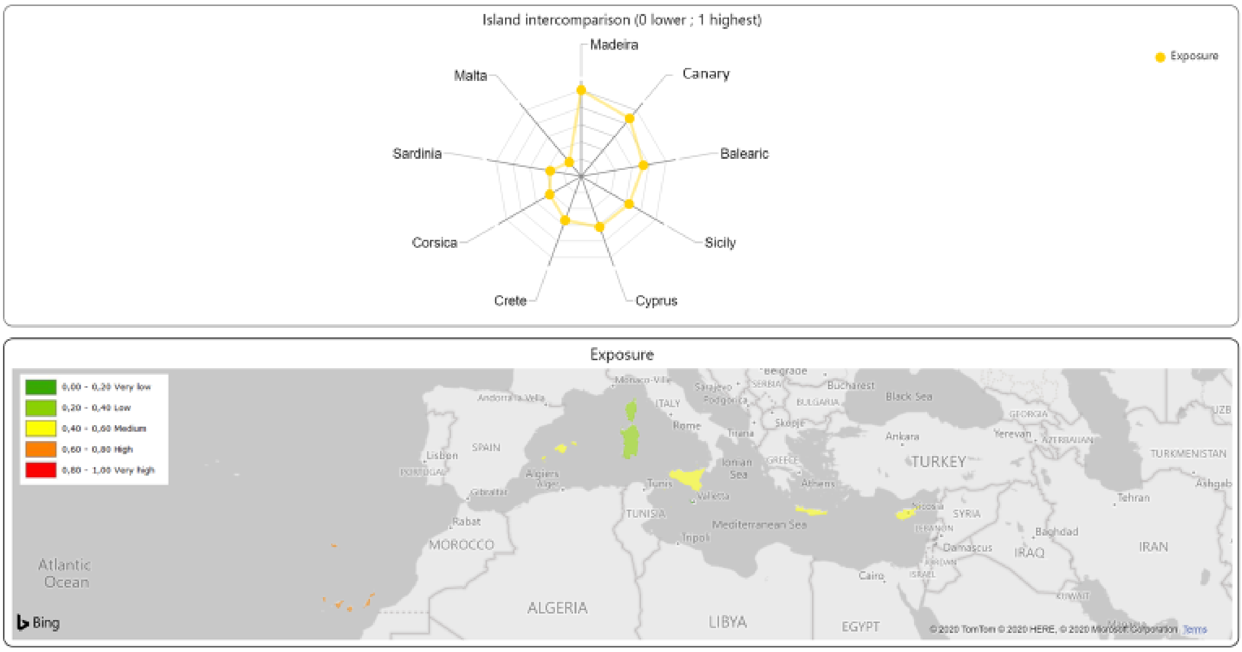

Figure 7: Exposure score (current period) per island
Source: Soclimpact deliverable D4.5

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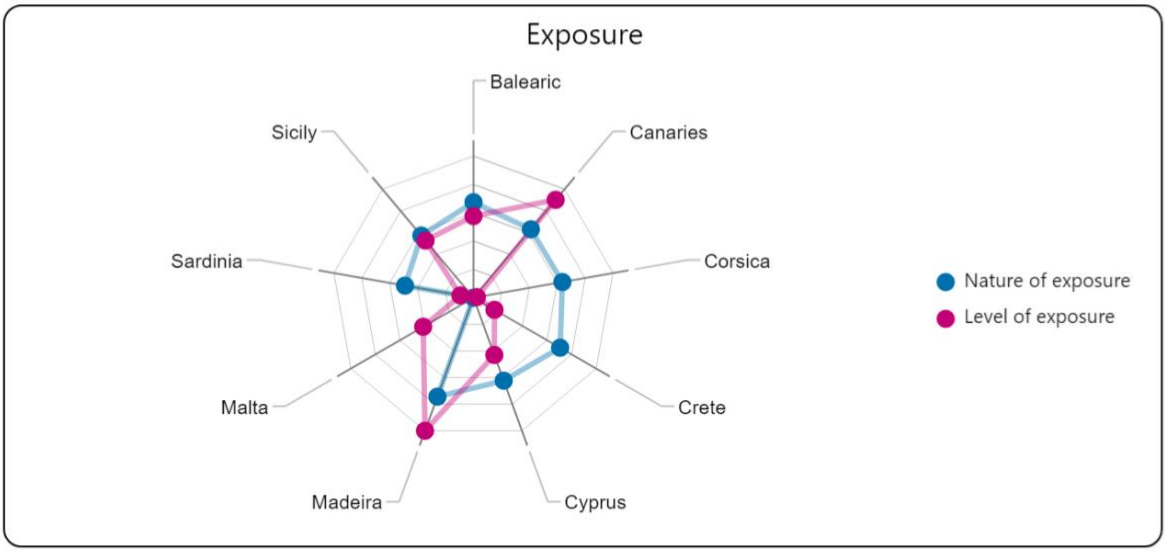

Figure 8: Subcomponents of exposure and related score (current period) per island
Source: Soclimpact deliverable D4.5

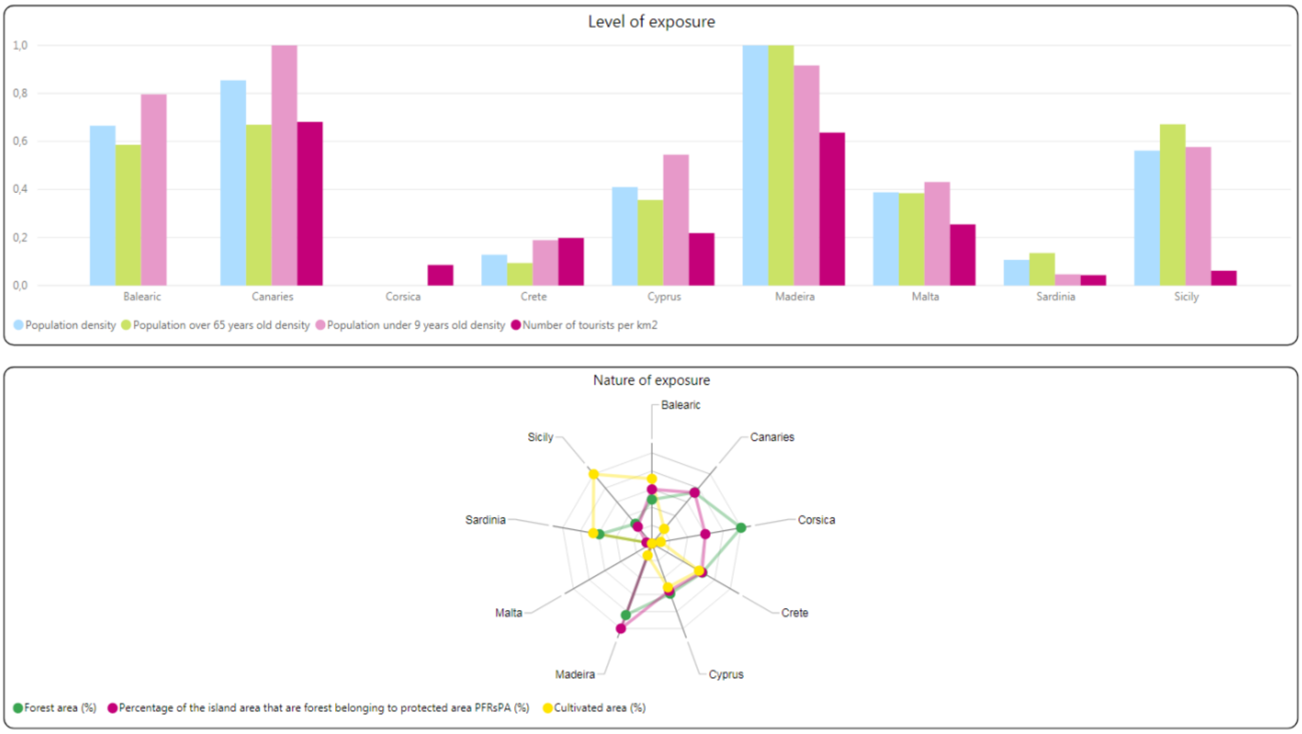

Figure 9: Breakdown by exposure subcomponent
Source: Soclimpact deliverable D4.5

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Vulnerability

The main findings are:

- Results show large disparity across EU Islands in terms of vulnerability. The vulnerability score for Corsica is very high followed by Sardinia (high), Madeira, Balearic Islands and Cyprus. Malta, Canary Islands and Crete scores are low and Sicilia very low.
- Breakdown by component 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, Corsica and Sardinia have the highest score, **Malta**, Sicilia and Canary Islands, the lowest one.
- Looking at the adaptative capacity subcomponent, 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.

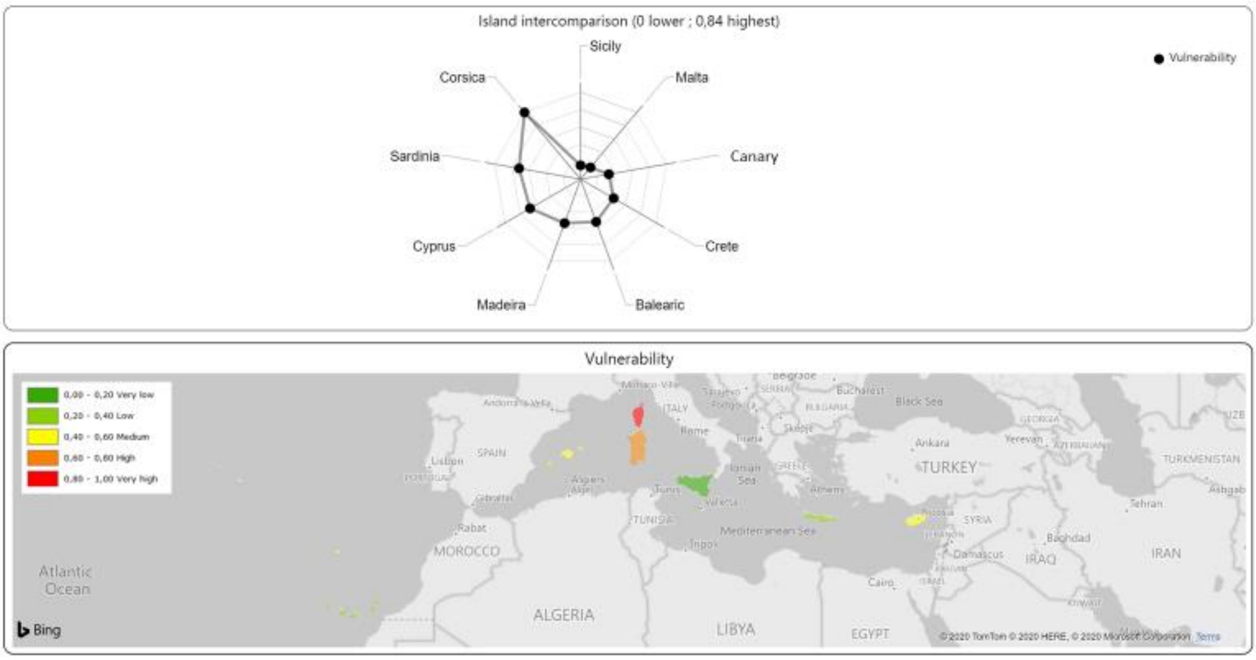

Figure 10: Vulnerability score per island
Source: Soclimpact deliverable D4.5

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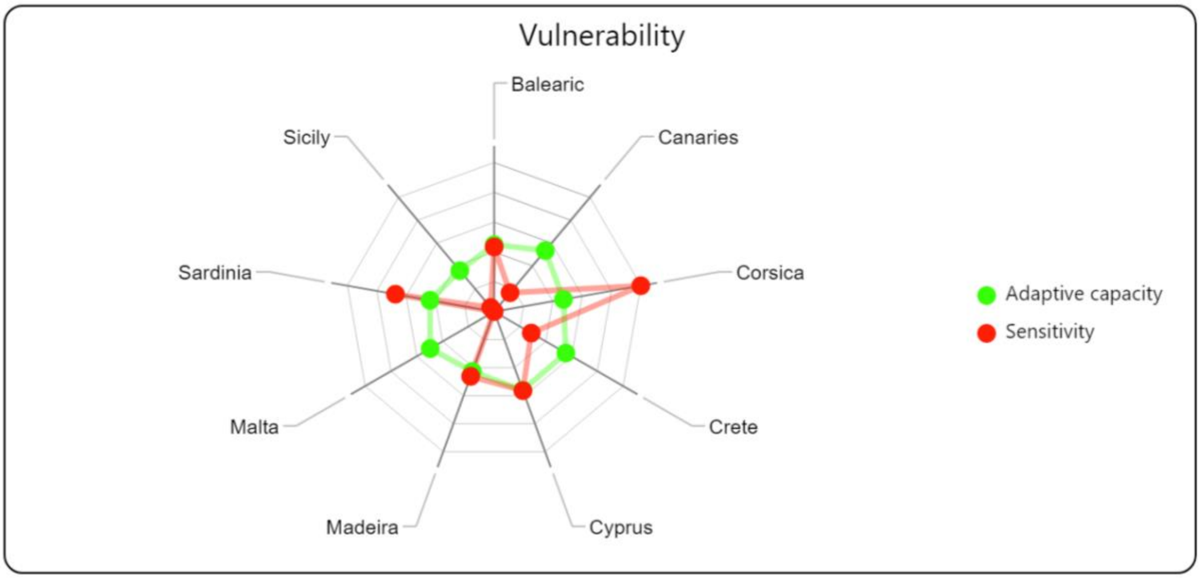

Figure 11: Subcomponents of vulnerability and related score (current period) per island
Source: Soclimpact deliverable D4.5

Figure 12: Details and scores of the two subcomponents (adaptive capacity and sensitivity) per island
Source: Soclimpact deliverable D4.5

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Risk

- For the reference period, the overall risk 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, the structure is quite similar for 3 groups:
    - Madeira, Canary Islands, Sicilia and Balearic Islands: Predominance of exposure component (around 50% of the score);
    - Crete and Cyprus: Predominance of the hazard component (around 40% of the score);
    - Corsica and Sardinia: Predominance of the vulnerability component (around 60-70%);
    - 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 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 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. Even under this RCP8.5 risk remains constant for Canary Islands and Madeira (Medium) and Sicily (Low).

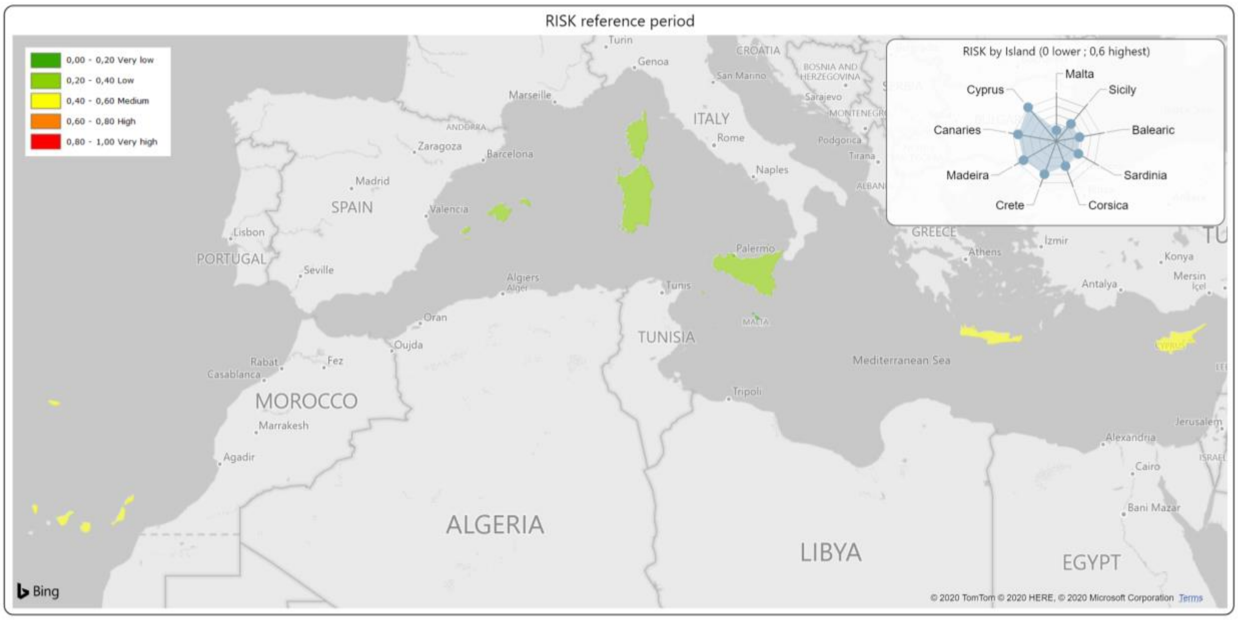

Figure 13: Risk score per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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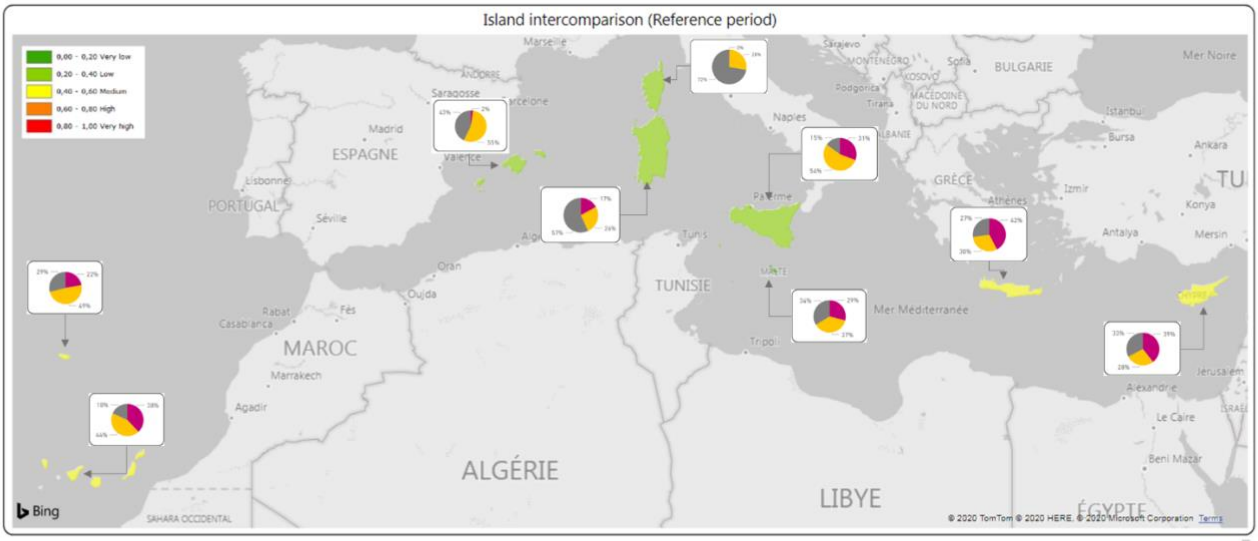

Figure 14: Risk breakdown by island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

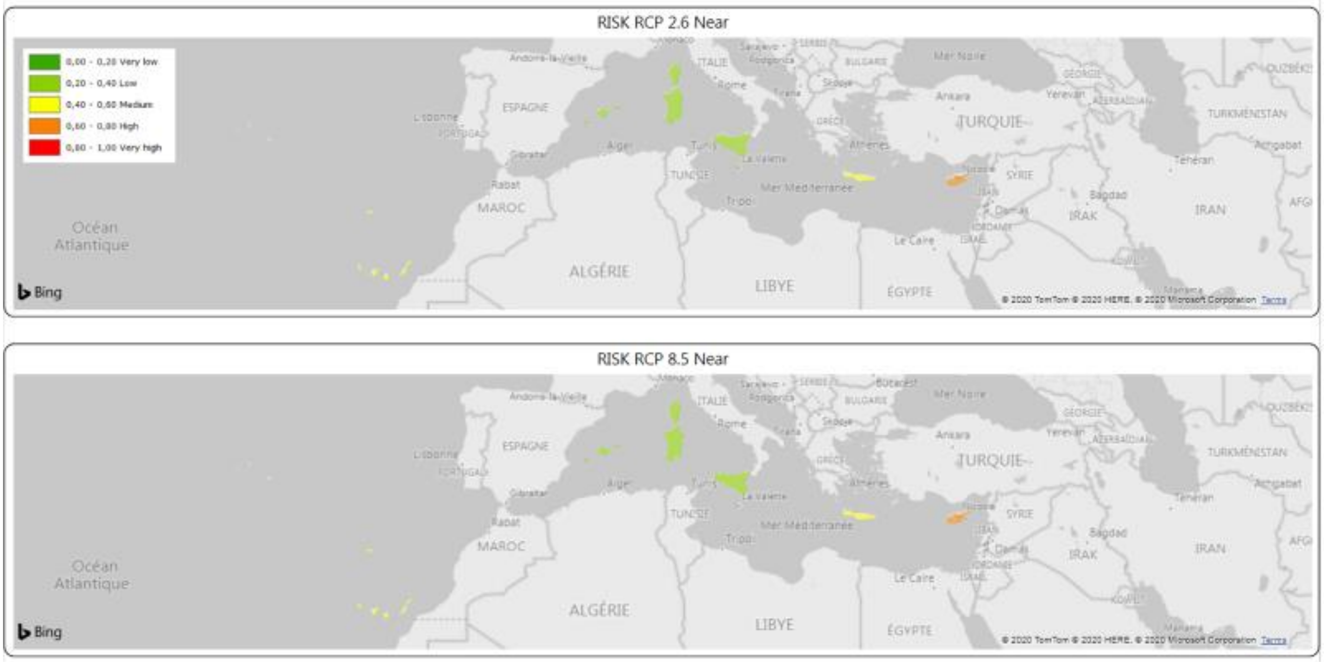

Figure 15: Risk score per island in the near future (2046-2065) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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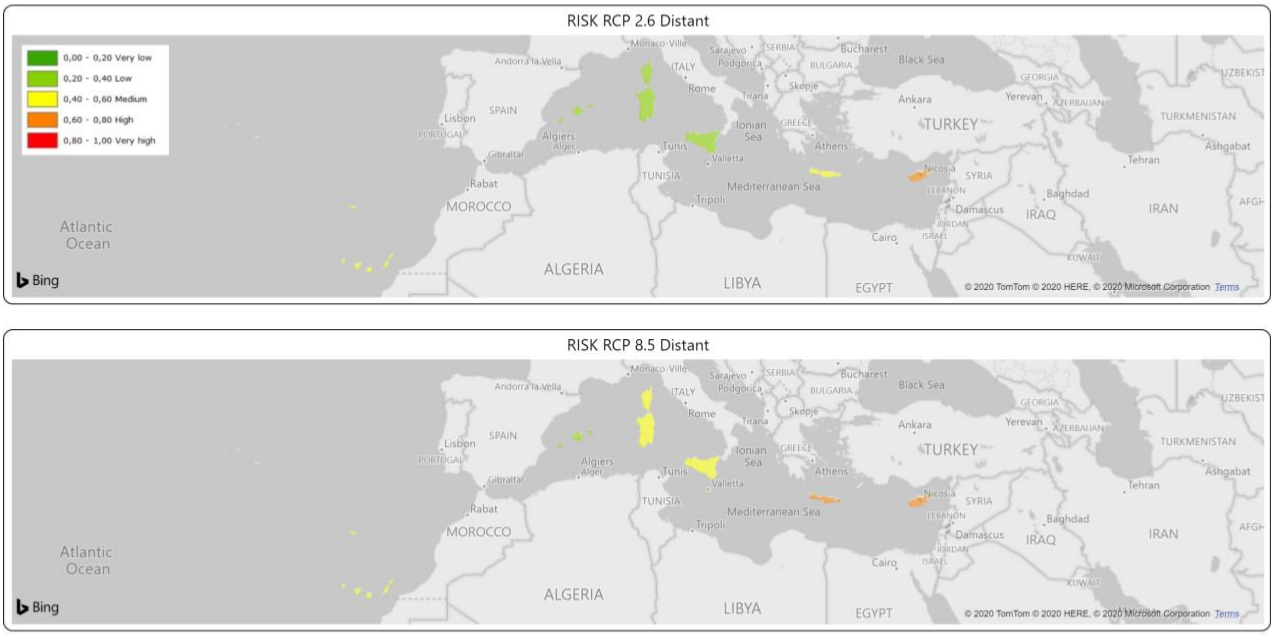

Figure 16: Risk score per island at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

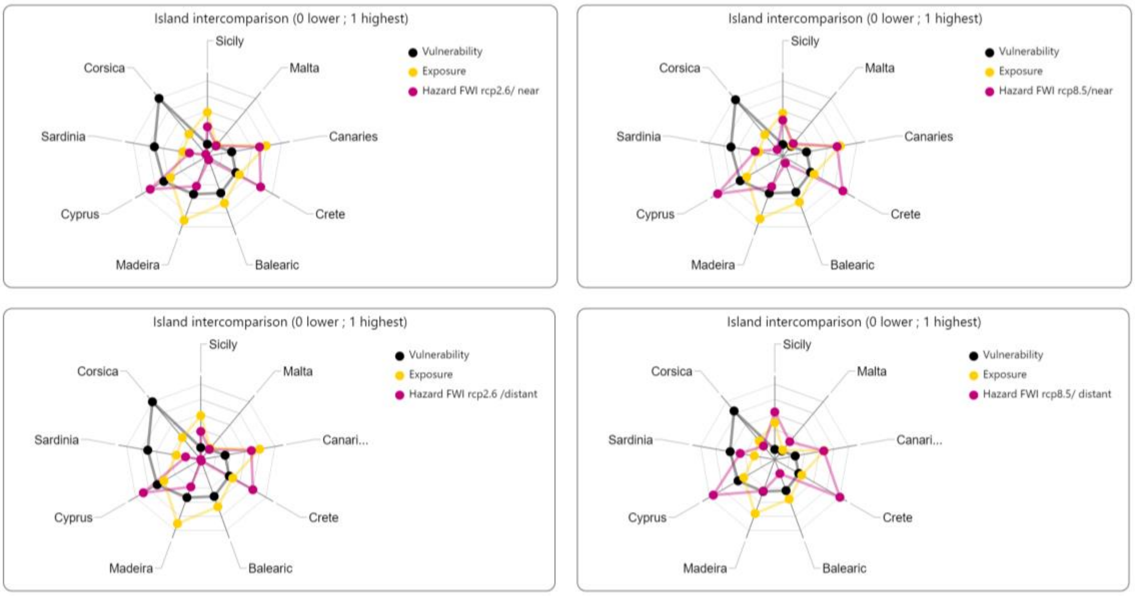

Figure 17: Score per component and per island in the near (2046-2065) and the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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Malta island results

Considering, the reference period, the risk for Malta is very low and the three components are balanced. The future risk will change from very low to low under RCP 8.5 at the end of century.

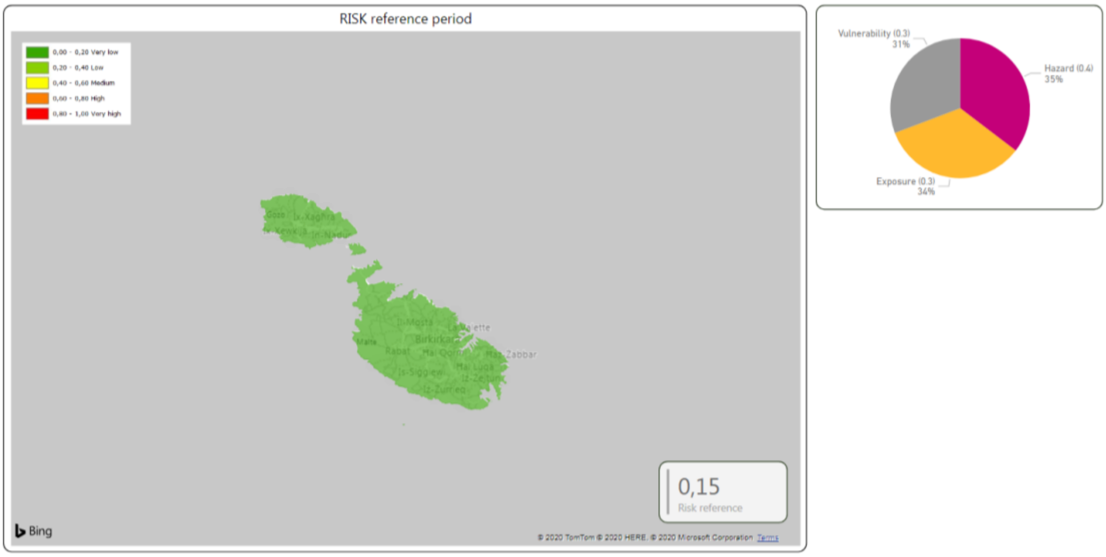

Figure 18: Risk score and components of the risk for the reference period
Source: Soclimpact deliverable D4.5

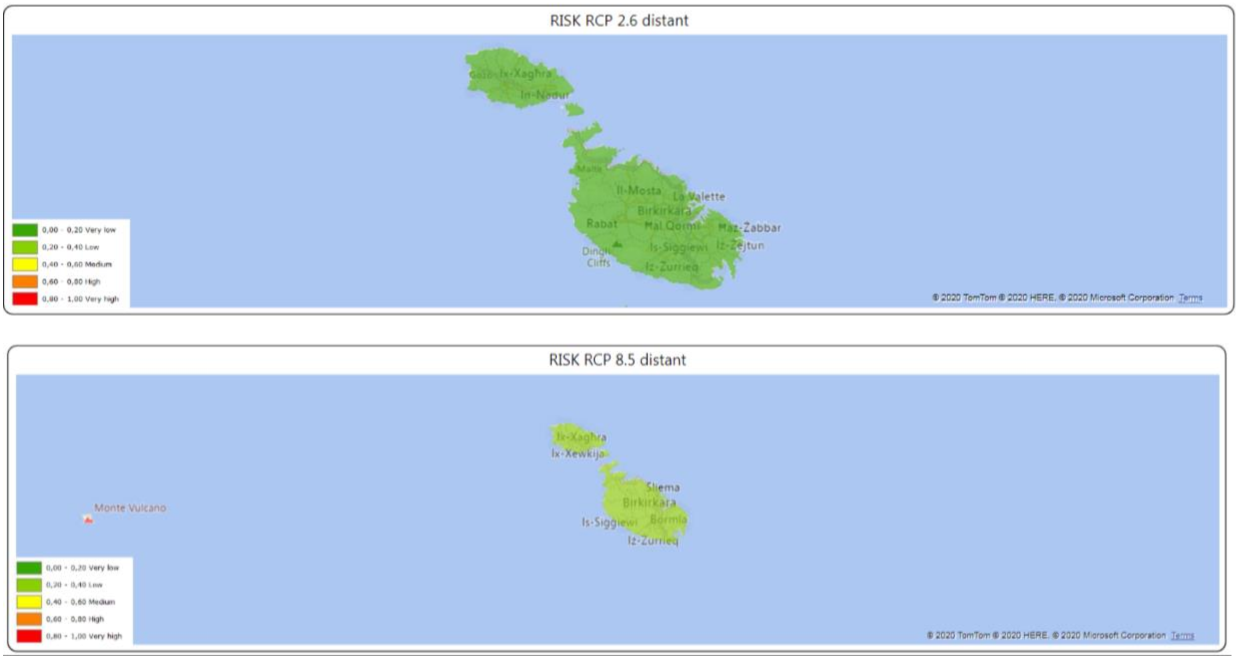

Figure 19: Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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Considering the exposure component, only the level of exposure is represented in the calculation of the final risk scores.

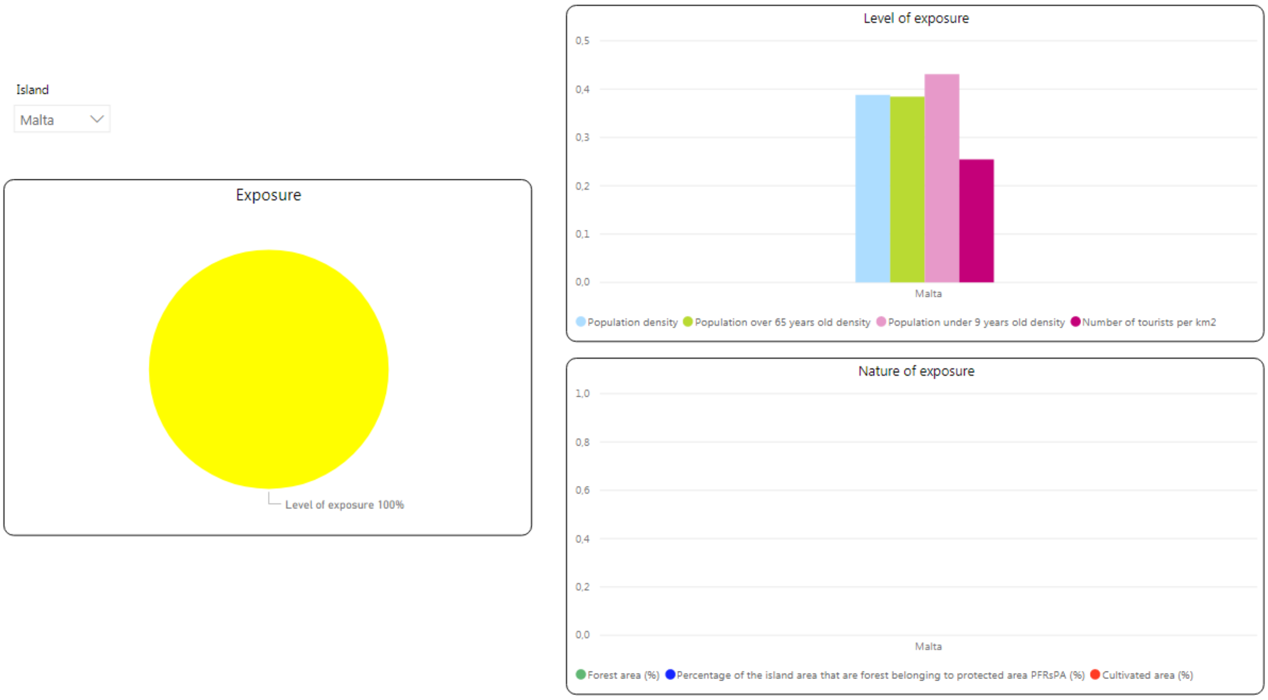

Figure 20: Details and scores of the two subcomponents of exposure (nature and level of exposure)
Source: Soclimpact deliverable D4.5

Considering the vulnerability component, only the adaptive capacity is represented: indeed, the flammability index as indicator of the sub-component of sensitivity is almost 0. The indicators of numbers of firefighters (+volunteers) and the occupation rate (%) are the most representative within the adaptive capacity sub-component.

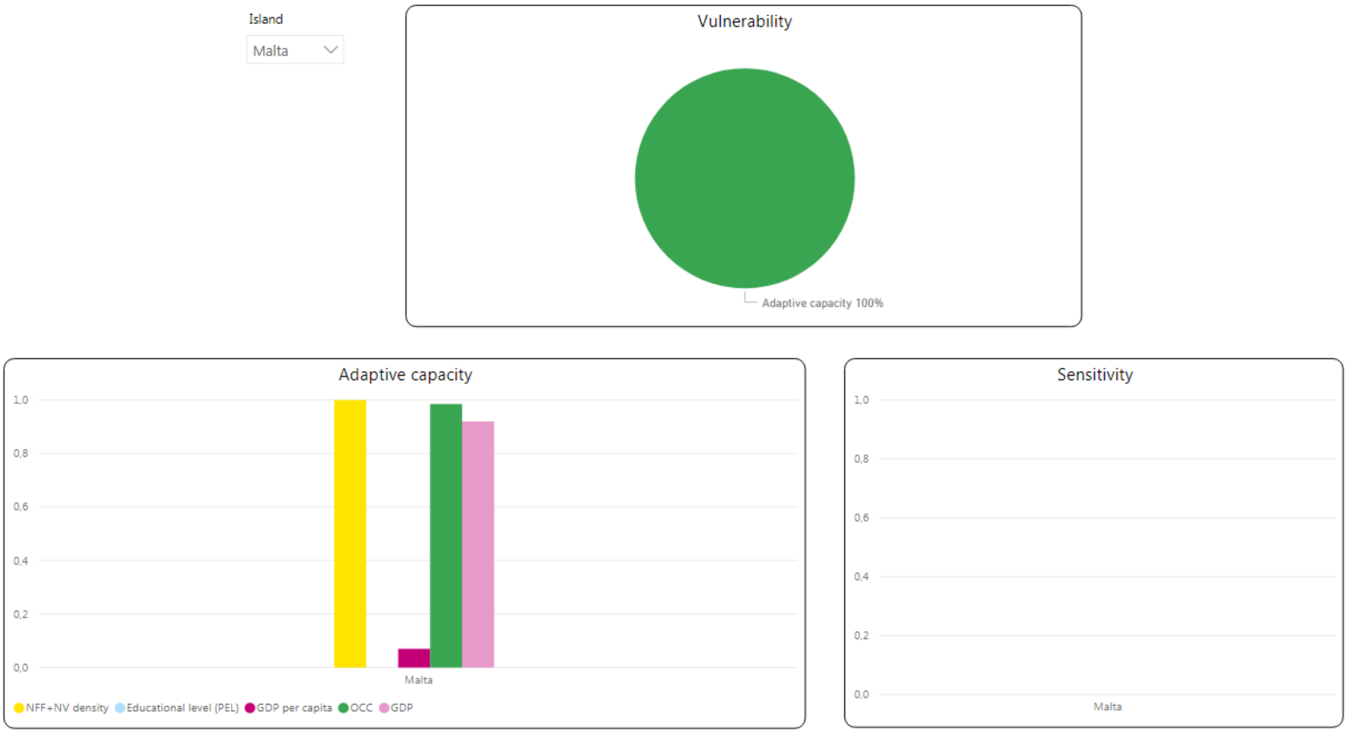

Figure 21: Details and scores of the two subcomponents of vulnerability (adaptative capacity and sensitivity)
Source: Soclimpact deliverable D4.5

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Loss of attractiveness due to marine habitats degradation

Climate change is expected to impact tourism activities through direct impacts on comfort and health of tourists, on the infrastructures and facilities that provide basic services to visitors and on the natural ecosystems that hold a big part of the attractions of the coastal and marine tourism destinations. The analysis of those impacts was decomposed into a single impact chain.

Specifically, it 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 next figure shows the theoretical impact chain. 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; also seawater acidification 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;
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.

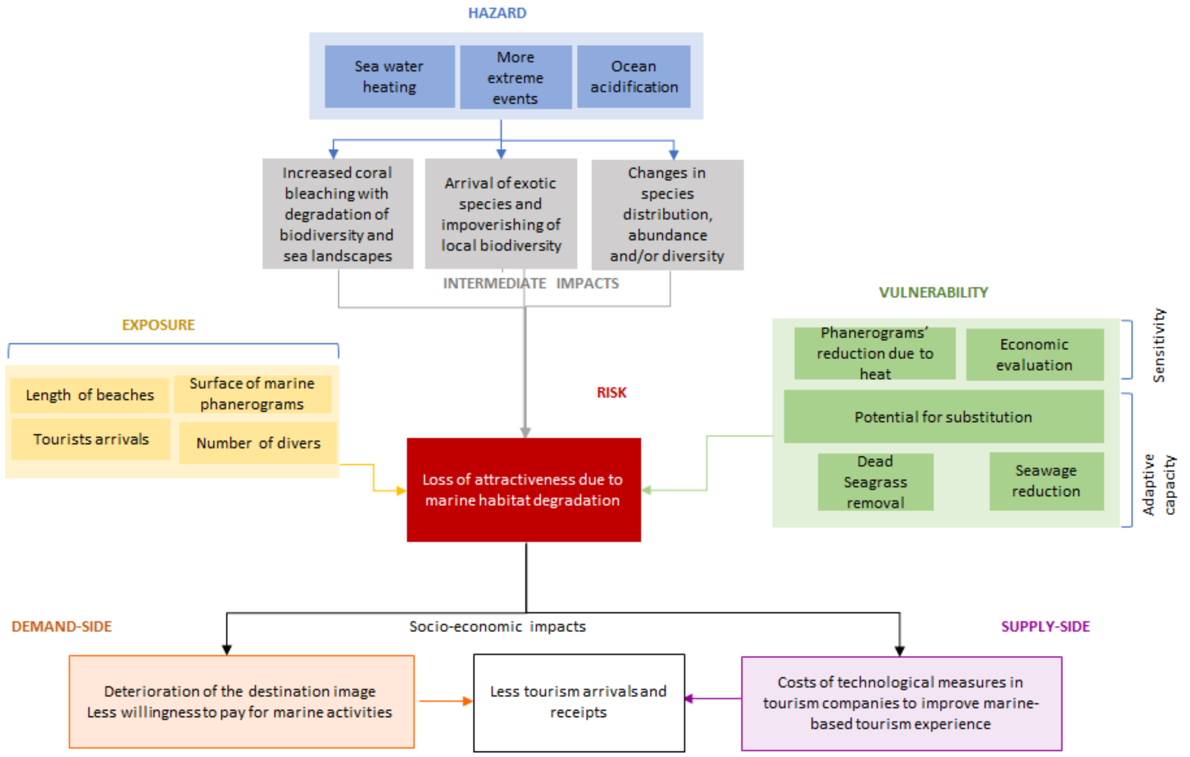

Figure 1: Loss of destination attractiveness due to marine environment degradation as a result of climate change hazards.
Source: *SOCLIMPACT Deliverable Report – D3.2. Definition of complex impact chains and input-output matrix for each islands and sectors*

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 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 the degradation of the marine environment.

Application of the AHP methodology

The problem to be solved along through the expert decision process was comparing the risk of the 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, 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. The next figure shows the basic structure, or hierarchy tree, of the decision making process that was presented to the experts.

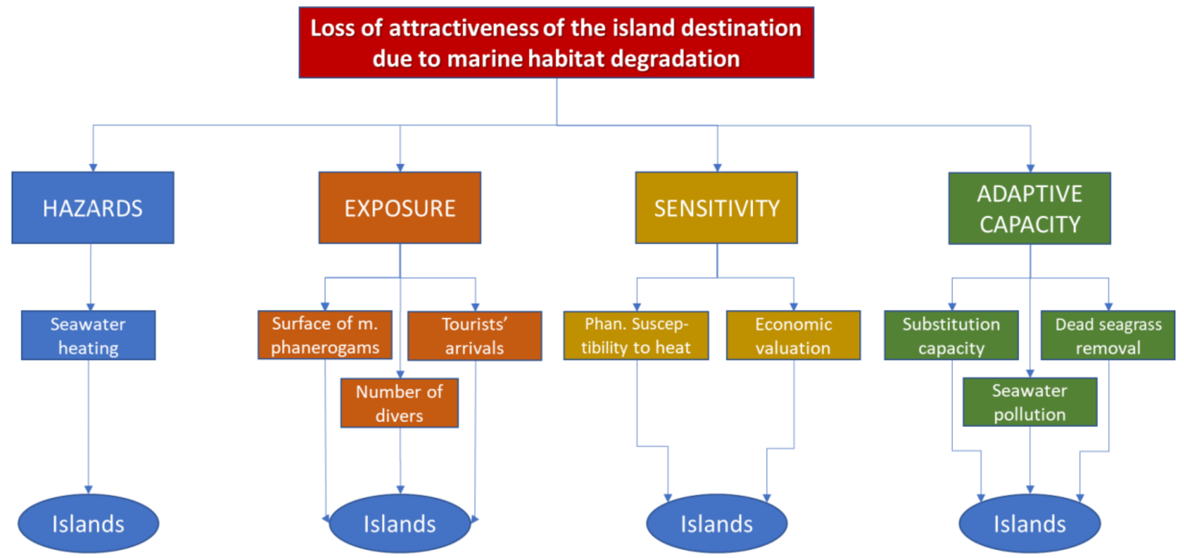

Figure 2: Hierarchy tree for marine habitats impact chain.

Source: SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public

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 phanerogams 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 theses uses and the selected indicator was the number of divers per year. It was assumed that other sea watching activities like snorkelling and bottom-glass boating evolve 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 tourists' welfare.
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 the tourists' willingness to pay for the preservation of marine ecosystems[1]. Thus, ecosystems' and social's 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 habitats dependent ones, and two concerning 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.

<u>Results and islands' ranking</u>

The table below shows the final results of the operationalization process. In particular, it summarizes 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.

[1] This information was delivered by Soclimpact researchers who are in charge of the work package WP5. More information at: *SOCLIMPACT Deliverable Report – D5.5. Report on market and non-market economic values for environmental services of marine and coastal ecosystems related to the activities of the blue economy.*

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Table 1. 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
	Tourists' arrivals	0.013	0.013	0.002	0.001	0.006
	Total	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
	Total	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
	Total	0.079 *(35.3%)*	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.

Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public*

<u>The risk: from Eastern to Western and viceversa</u>

The relative risk for marine habitat-based tourism demand due to the heating of seawaters surrounding the 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:

- From the perspective of the intensity of the hazard, threats diminish from Eastern to Western. Effectively, episodes of water heating threating the integrity of marine ecosystems will we 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.

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.

Analysis of 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 its cultural attributes and 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 shows lesser uncertainties than those showed by the Italian island.

The mentioned advantages and disadvantages of **Malta** are depicted in the next figures. The further the criteria or sub-criteria is located from the centre of the graph, the more it affects the risk.

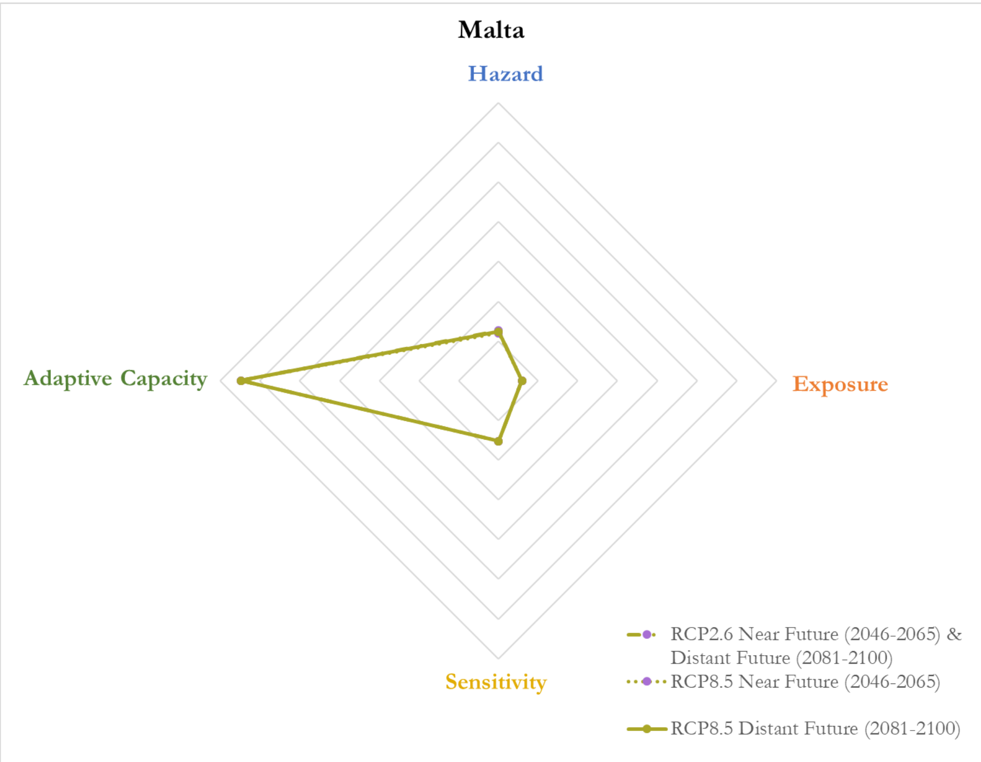

Figure 3: Global weights of each criteria and sub-criteria in the final score.
Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public*

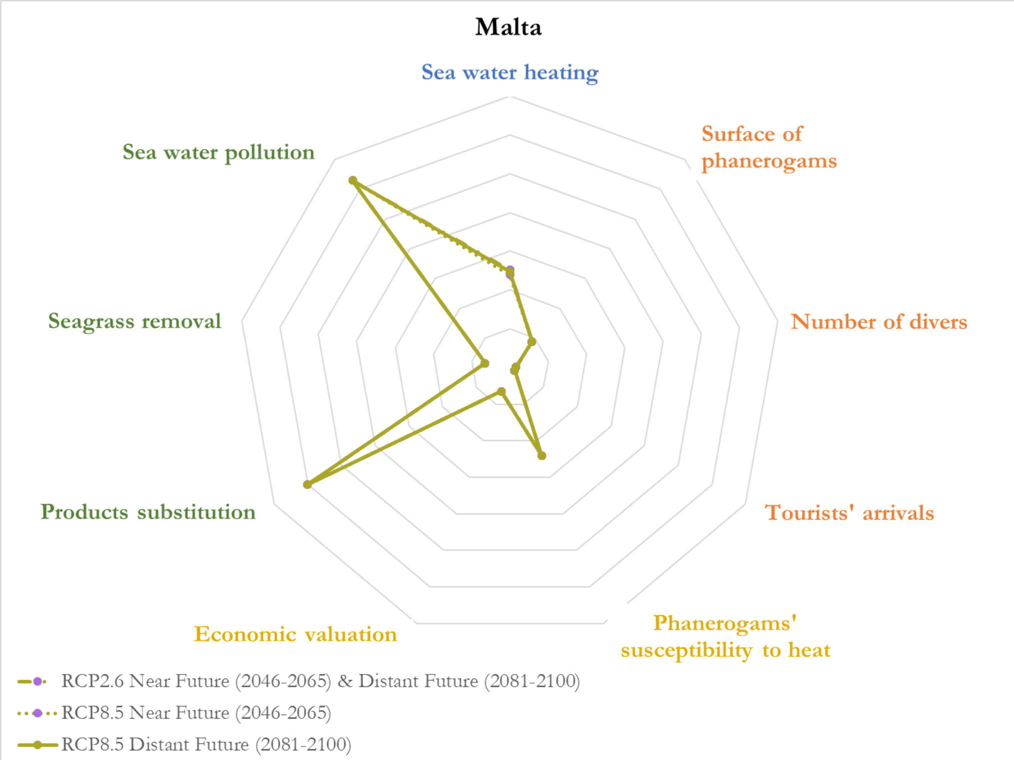

Figure 4: Global weights of each criteria and sub-criteria in the final score.
Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general publi*

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.

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Loss of competitiveness of destinations due to a decrease in thermal comfort

This section describes the work carried out for the operationalization of the impact chain "*Loss of competitiveness of destinations due to a decrease in thermal comfort*"[1]. It provides details on the method applied for the operationalization, the island data used, and the results obtained. 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.

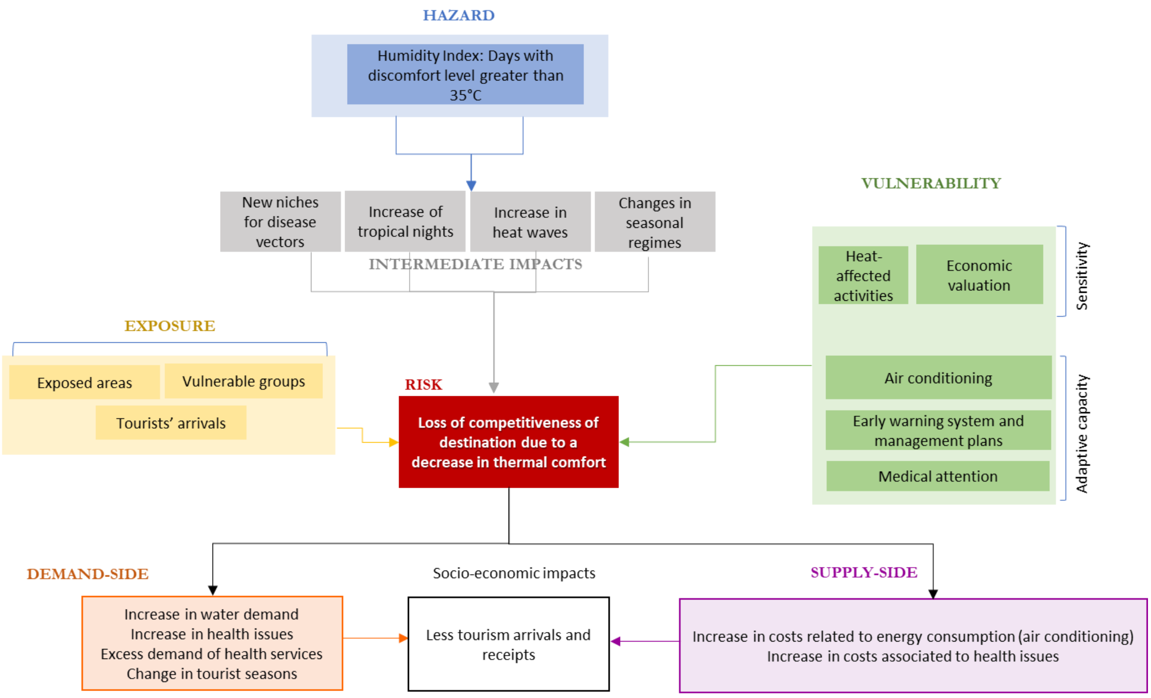

Figure 1: Loss of competitiveness of destinations due to a decrease in thermal comfort
Source: *SOCLIMPACT Deliverable Report – D3.2. Definition of complex impact chains and input-output matrix for each islands and sectors*

For the purposes of the operationalization it was decided by the team to retitle 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.

[1] Detailed information about the methodology used and the results obtained is available at: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public.*

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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 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.

Application of the AHP methodology

The problem to be solved along through the expert decision process was comparing the risk of the European islands of losing tourist attractiveness due to a decrease in thermal comfort as consequence of climate change. The hierarchy tree for this decision problem was built underpinning on the impact chain elements. Some refinements were necessary regarding the indicators (at sub-criteria level) that were to be used for comparing the islands.

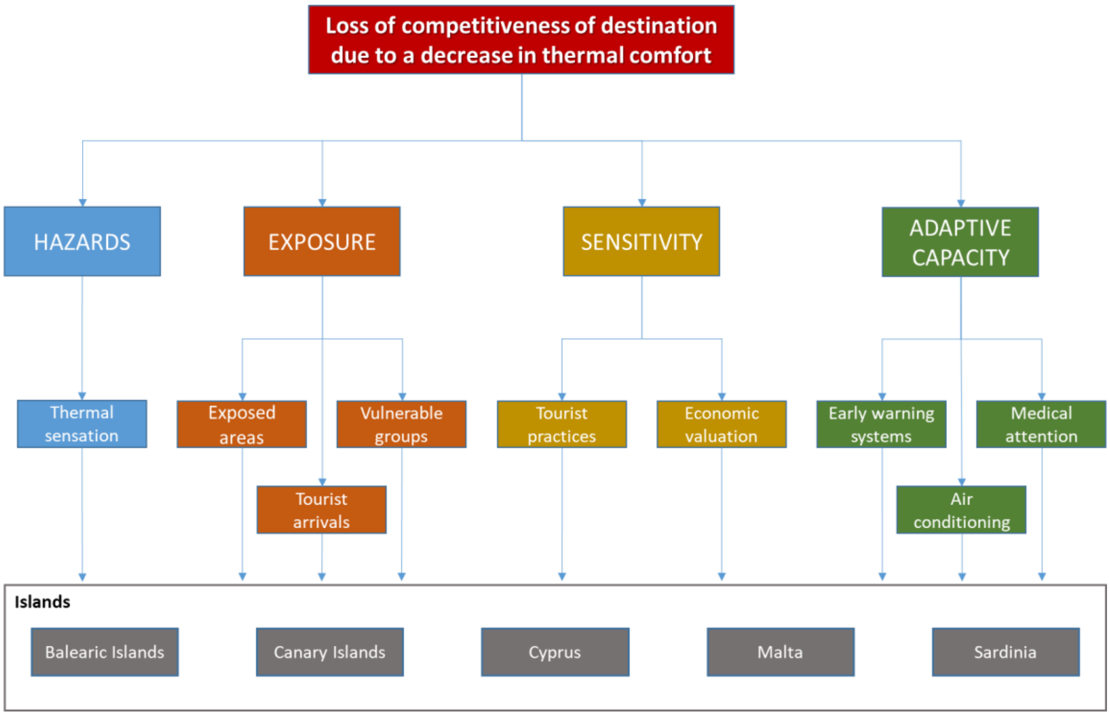

Figure 2: Hierarchy tree for thermal comfort impact chain.
Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public*

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 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

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measured by much money tourists are willing to pay to avoid a heatwave during their vacation time[2].

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 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.

Results and islands' ranking

The table below shows the final results of the operationalization process. In particular, it summarizes 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.

Table 1. Final scores and islands' ranking (under RCP8.5 distant future).

Criteria	Sub-criteria	Balearic	Canary	Cyprus	Malta	Sardinia
Hazards	**Humidex RCP8.5 (2081-2100)**	0.024 *(12.1%)*	0.008 *(4.6%)*	0.088 *(34.6%)*	0.023 *(11.7%)*	0.023 *(13.1%)*
Exposure	**Exposed areas**	0.007	0.002	0.007	0.007	0.007
	Vulnerable groups	0.007	0.017	0.016	0.017	0.038
	Tourists' arrivals	0.050	0.008	0.029	0.018	0.065
	Total	*0.064 (32.2%)*	*0.027 (15.5%)*	*0.053 (20.9%)*	*0.042 (21.3%)*	*0.110 (62.9%)*
Sensitivity	**Heat-sensitive activities**	0.074	0.073	0.074	0.074	0.012
	Economic valuation	0.004	0.004	0.015	0.028	0.010

[2] Further information available at: *SOCLIMPACT Deliverable Report – D5.5. Report on market and non-market economic values for environmental services of marine and coastal ecosystems related to the activities of the blue economy.*

	Total	*0.079 (39.7%)*	*0.078 (44.8%)*	*0.089 (35.0%)*	*0.103 (52.3%)*	*0.021 (12.0%)*
Adaptive capacity	**Early-warning systems**	0.007	0.007	0.007	0.007	0.003
	Air conditioning	0.011	0.048	0.011	0.021	0.012
	Medical attention	0.014	0.006	0.005	0.002	0.005
	Total	*0.032 (16.1%)*	*0.061 (35.1%)*	*0.024 (9.4%)*	*0.030 (15.2%)*	*0.020 (11.4%)*
Total		**0.199**	**0.174**	**0.254**	**0.197**	**0.175**
Rank		2	5	1	**3**	4

Note: Total contribution of the criterion to the final score of the island in parenthesis.
Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public*

Cyprus is at most 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 and average in Adaptive capacity.

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: 0.199 for the Balearic Islands and 0.1970 for **Malta** in the RCP8.5 distant future scenario. They score relatively high in Exposure and Sensitivity (the most important criteria for the risk) and average in Hazard and Adaptive capacity.

Sardinia and the Canary Islands are the lowest at risk of loss of competitiveness. Even though Sardinia scores the highest for Exposure, 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.

Analysis of Malta

The island shows some disadvantage in the criterion Sensitivity, contributing 52.3% to the final score. In particular, it is due to the heat-sensitive activities that tourists carry out when visiting the destination, given that Maltese tourism is attracted by its cultural attributes. On the other hand, Malta scores average in the Hazard, in Exposure and in Adaptive Capacity, being especially favourable the medical attention in the latter case.

The mentioned advantages and disadvantages of **Malta** are depicted in the next figure. The further the criteria or sub-criteria is located from the centre of the graph, the more it affects the risk.

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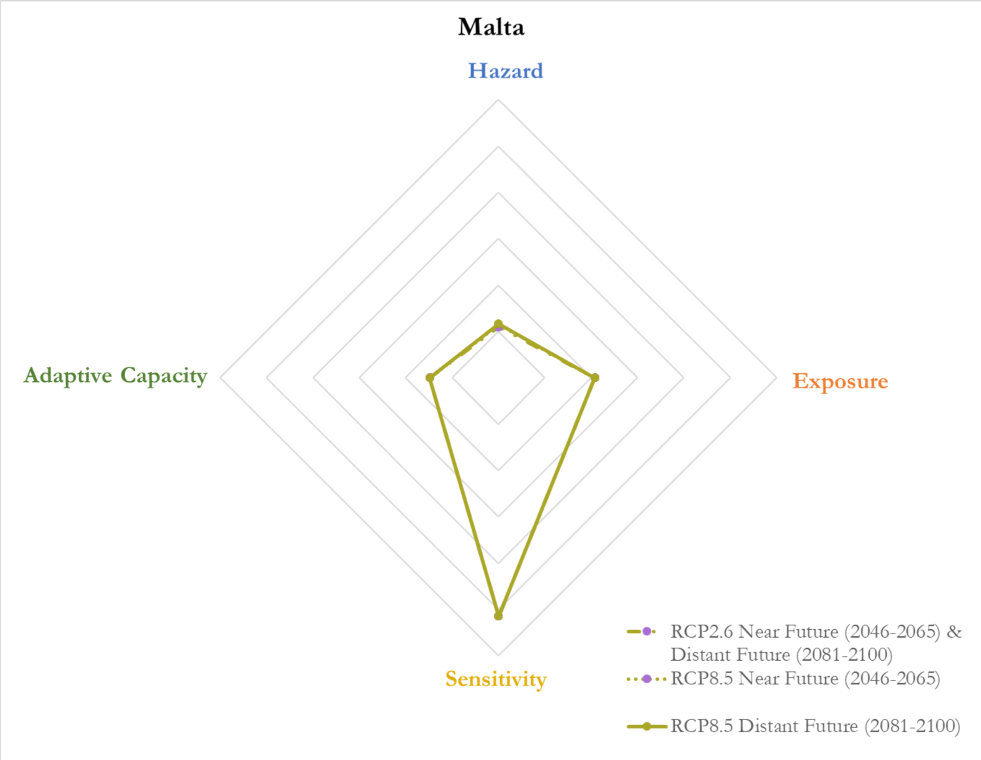

Figure 3: Global weights of each criteria and sub-criteria in the final score.
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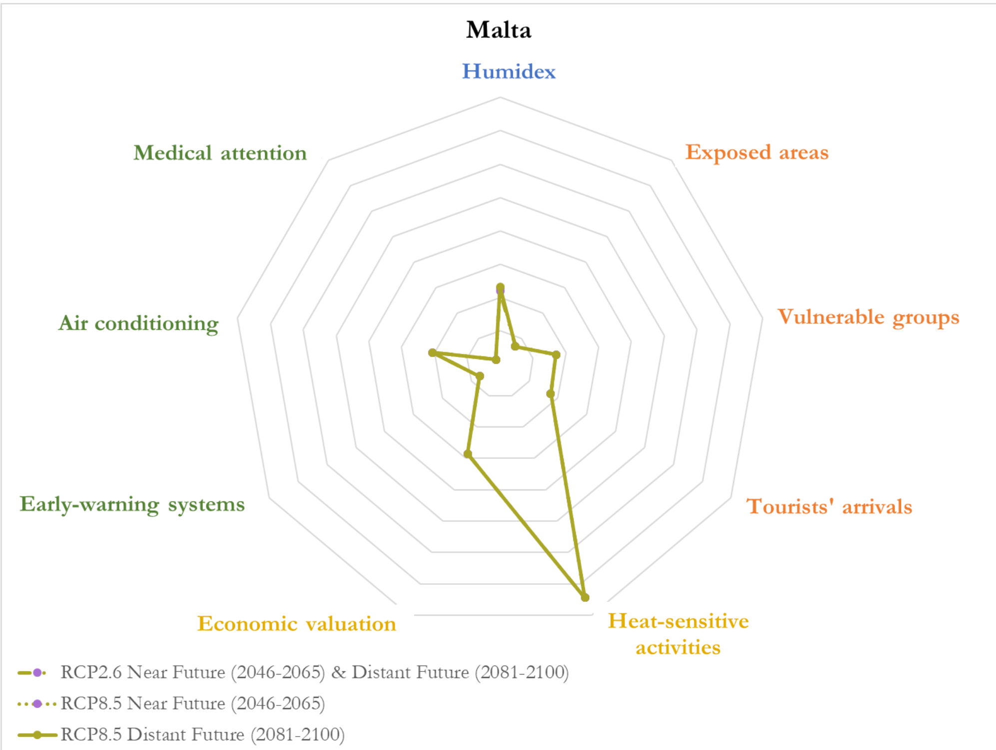

Figure 4: Global weights of each criteria and sub-criteria in the final score.
Source: *SOCLIMPACT Deliverable Report – D4.5. Design of a comprehensive approach to climate and climate-related risk information to policy makers and the general public*

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The operationalization of the impact chain for the "*Loss of attractiveness of a destination due to a decrease in 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.

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Increased fragility of aquaculture activity due to an increase of sea temperature and extreme weather

Malta

In the framework of Soclimpact, the following impacts were more closely studied:

1) Increased fragility of the aquaculture activity due to an increase of extreme weather.

Increased frequency and intensity of extreme weather events result in higher waves and storm surges and changes in salinity. These events result in loss of stock and damages to infrastructure and require adaptation in species selection, site selection and technologies.

2) Decrease in production due to an increase in surface water temperature

Changes in water temperature can directly affect the growth rate and Food Conversion Ratio of the fish. Temperature also affects the oxygen levels and can cause harmful algae blooms, reduce water quality and an increase in occurrence of diseases and parasites which can than affect the fish or other culture species. A change in temperature can ultimately change the ranges of suitable species for a certain area but can also have positive impacts such as increased growth (mainly in tropical and sub-tropical regions) and a longer growing season. Primary productivity can also increase with increasing temperature, which may be beneficial for filter feeders such as mussels.

The concept of Impact Chain (Schneiderbauer *et al.* 2013; Fritzsche *et al.* 2014) is also applied as a climate risk assessment method (with 7 steps for aquaculture, present risk and future risk are calculated separately) for research of decision making. The goal of this method is to use collected data for certain indicators of the impact chains for different islands to assess the risks of each island's aquaculture sector to be affected by the hazard displayed in the impact chain. Therefore, data for all indicators were collected from all islands. After reviewing the data, selecting indicators and islands, the indicators were normalized, and different risk components were weighted. Using these values, the risks for present and future conditions under different Representative Concentration Pathway (RCP) scenarios were calculated for the different island and compared between each other. For the aquaculture impact chains, RCP 4.5 and 8.5 were compared since for the hazard models RCP 2.6 was not always available.

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 operationalization 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.

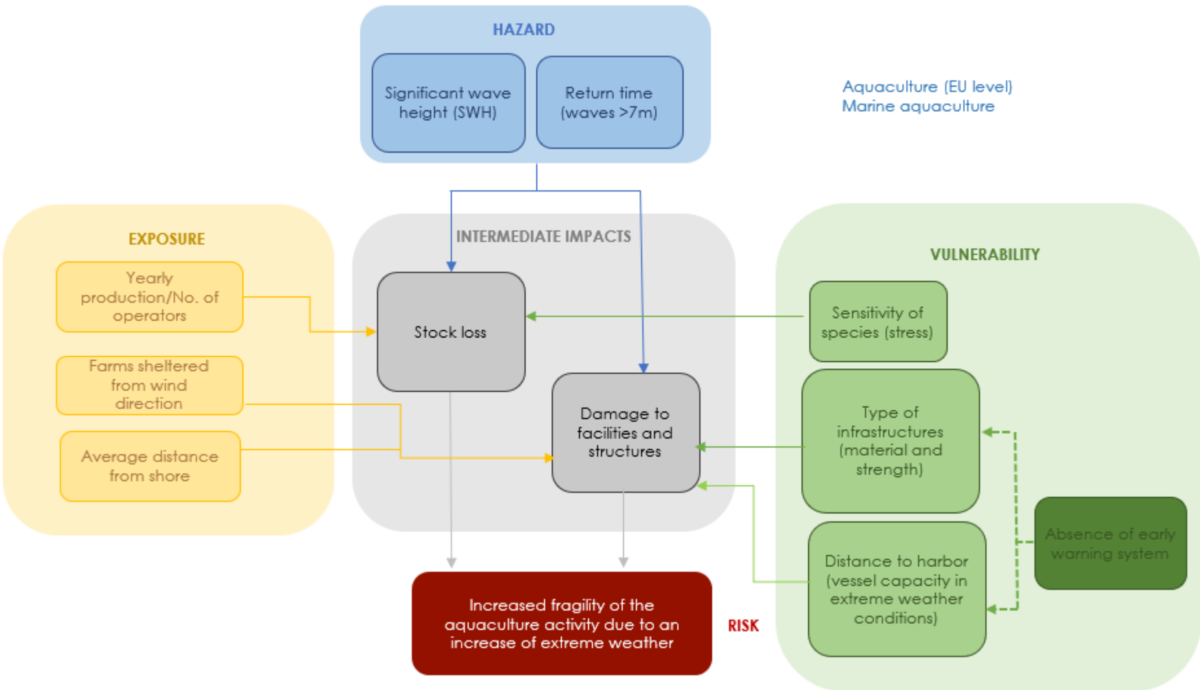

Figure:1: Impact chain on Increased fragility of the aquaculture activity due to an increase of extreme weather adjusted depending on data availability and used for the operationalisation.

Source: Soclimpact project deliverable 3.2

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: 1: Proportions of aquaculture species farmed per island.

	Proportion of species production			
Species	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

Source: Soclimpact project deliverable 4.5

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.

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Table: 2: Estimated vulnerability factors for the sensitivity of species to wave stress

Sensitivity of species for wave stress threshold				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.55	0.65	0.3	0.9

1= very vulnerable to stress: 0=very resilient to stress.

Source: Soclimpact project deliverable 4.5

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 3: Estimated vulnerability values for the vulnerability of infrastructure in case of an extreme weather event.

Vulnerability of aquaculture infrastructure in case of an extreme weather event			
Infrastructure for species	Sea bream & Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.4	0.3	0.6

1= very vulnerable to stress: 0=very resilient to stress.

Source: Soclimpact project deliverable 4.5

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: Increased 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 4: Temperature threshold per species.

Temperature thresholds for different species				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Threshold (°C)	24	25	24	20.5

Source: Soclimpact project deliverable 4.5

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.

<u>Exposure</u>

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.

<u>Sensitivity (vulnerability)</u>

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:5: Estimated vulnerability factors for the sensitivity of species to temperature stress

Sensitivity of species for temperature stress threshold				
Species	Sea bream	Sea bass	Tuna	Mussels & Clams
Estimated vulnerability factor	0.6	0.6	0.3	1

1= very vulnerable to stress: 0=very resilient to stress.

Source: Soclimpact project deliverable 4.5

<u>Adaptive capacity (vulnerability)</u>

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.
There are two different ways of normalizing the indicator values:

- Minimum/maximum normalization;
- Expert judgement.

Fraction of maximum normalization
This normalization method was used for 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 de 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 was used for indicators which were expressed by real data and not by expert judgement. The minimum and the maximum value of that indicator of all islands was calculated and the following formula was applied to normalize all indicator values to the scale between 0 and 1:

$$x_{normalized} = \frac{(x - x_{min})}{(x_{max} - x_{min})}$$

For both impact chains, the hazard values were normalised using the min and max method. However, in these cases the minimum and maximum values were not automatically the minimum and maximum values of the entire dataset but rather treated differently for every hazard indicator. This handling of the normalisation of the hazard indicators arose from the different nature of the indicator itself and the fact that data were available for different RCPs and periods of time. Therefore, the hazard indicators were normalised as following:

The sea surface temperature values were normalised separately for each temperature data set. This means that all values for all RCPs and time periods of one "longest event over a certain temperature" were taken into account when determining the minimum and maximum values. For Madeira, RCP 4.5 data was not available, therefore RCP 2.6 data was used and doubled.

Wave amplitude (significant wave height)

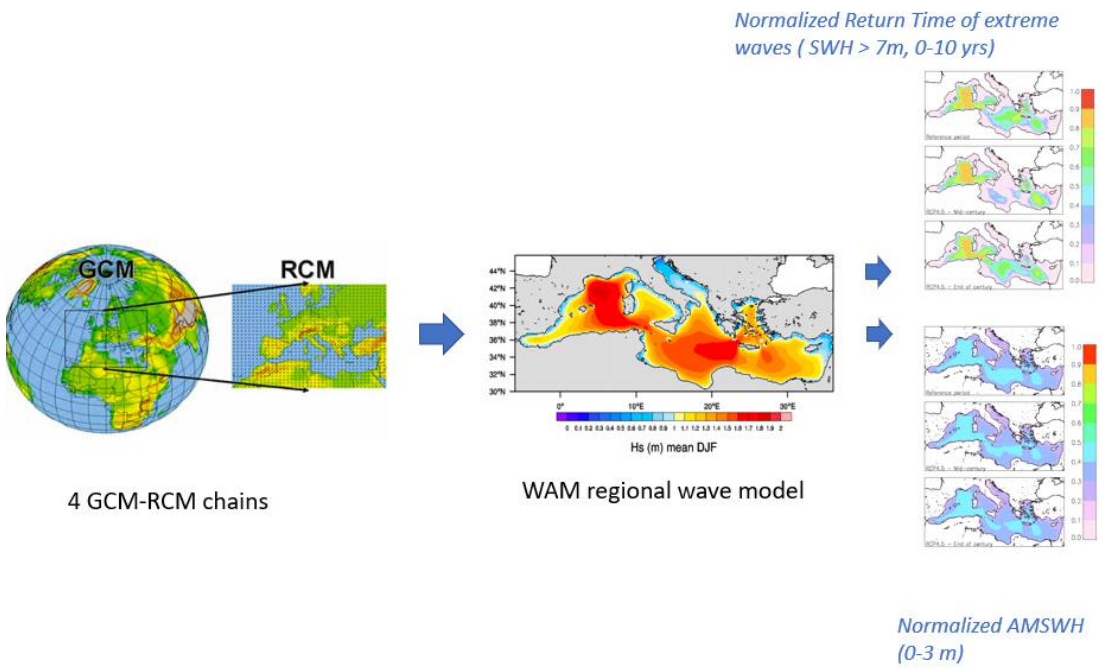

Figure 2: Modelling indicators for sea-state hazards, return time and significant wave height starting with 4 Global Circulation-Regional Circulation Model chains, which a fed into the WAM regional wave model. Results are then normalized.

Source: Soclimpact project deliverable 4.5

The return time was normalised as following; all values equal or greater that 10 are set to 0, all values between 0 and 10 are linearly mapped to the interval 1-0, so that 0 gives risk 1, 10 gives risk 0. It was assumed that a time period of 10 or more years allowed to repay investments is a reasonable threshold.

Since, as described in D4.4 of Soclimpact, that the probability of having at least one event exceeding the return level 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), and that the return level cannot be considered a "no-risk" safety level in evaluating the survivability and sustainability of structures or plants.

Table 6: Probability of occurrence of at least one event exceeding the return level associated with a given return period (blue) in a given time window (green), according to the formula

*RL,T=1-(1-1/T)**L, where L=length of time window, T=Return Period.*

Return Period [years]	Probability of occurrence				
	1 years	2 years	5 years	10 years	20 years
5	20%	36%	67%	89%	99%
10	10%	19%	41%	65%	88%
20	5%	10%	23%	40%	64%

Source: Soclimpact project deliverable 4.5

Therefore, using a combination of the normalised values and the probability of occurance, experts transformed these values into risk classes such all "low", "moderate", "medium", "high", "very high", or the like, on a qualitative basis.

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: 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

Source: Soclimpact project deliverable 4.5

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 indicators:

$$s_{comp} = \frac{(ind_1 + ind_2 + \cdots + ind_n)}{n}$$

s – *score*

comp – *component or subcomponent*

ind – *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.

Results

Impact chain: extreme weather events

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Table 8: Exposure and vulnerability indicators each island

Component	Exposure						Vulnerability						
Component Weight	**0.2**						**0.2**						
Sub-component Sub-component weight							Factor of sensitivity 0.75			Factors of adaptive capacity 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 distance from shore (m)		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		Normalised	Normalised		Data	Normalised	Normalised	
Corsica	*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

Source: Soclimpact project deliverable 4.5

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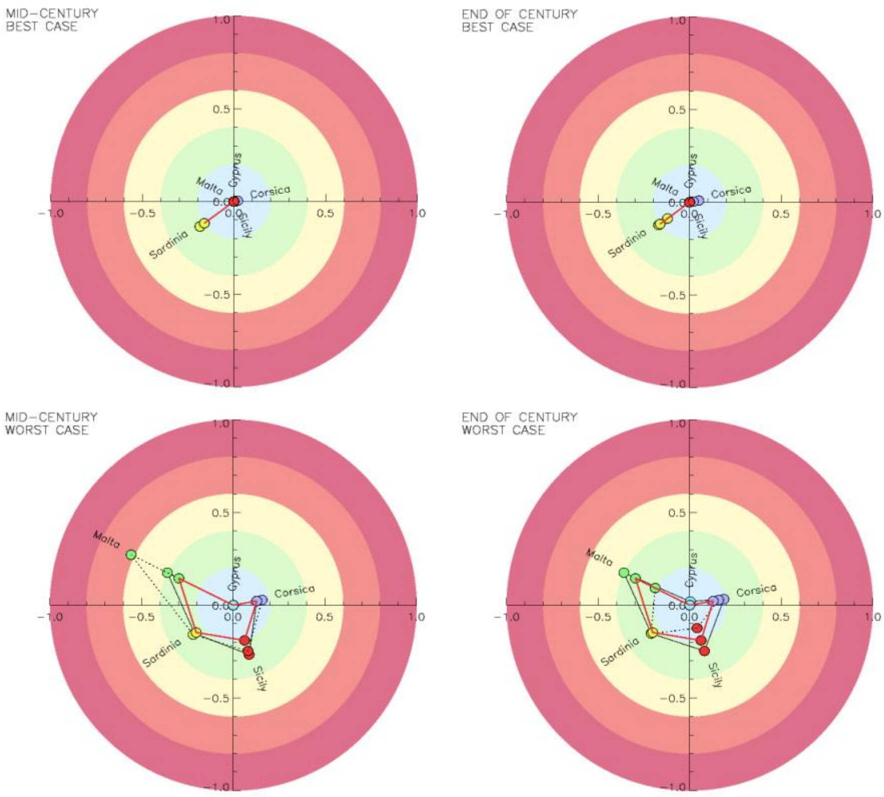
Mediterranean islands

Hazards

Statistics of extreme events can significantly differ across the four model realizations

The hazard data for return time was derived from 3 different models; CMCC, CNRM and GUF. Since the data varies highly between models a best- and worst case scenario was executed where in the best-case scenario the lowest value (showing the lowest risk) between the models was used and in the worst case scenario the highest value was used. Distance between the best and the worst projection, give an estimate of uncertainty

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



Return time

Figure 3: Results for return time in best- and worst-case scenarios for Mediterranean islands for reference period (red line), RCP 4.5 (dotted line) and RCP 8.5 (black line).

Source: Soclimpact project deliverable 4.5

"Worst" and "best" cases respectively refer to the least and most favorable projection in the set of models. For example return time, you will find that there is at least one model predicting no hazard for all islands except 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 hazard going from moderate (reference period, red) to medium (RCP8.5, solid black), to high (RCP4.5, dotted black) for Malta, while for Cyprus the hazard is irrelevant even for the most negative projection.
This means that
a) the result for Sardinia and Cyprus is 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 and best cases do not necessarily come from the same model for all islands, that is, one model can predict the lowest hazard for Sicily and another one for Sardinia, and each of these projections is represented in the plot for the corresponding island.

Risk- Best-case scenario

Table 9: Risk results for best-case scenario for impact chain Extreme weather events

	Reference period	Mid century		End century	
Risk	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

Source: Soclimpact project deliverable 4.5

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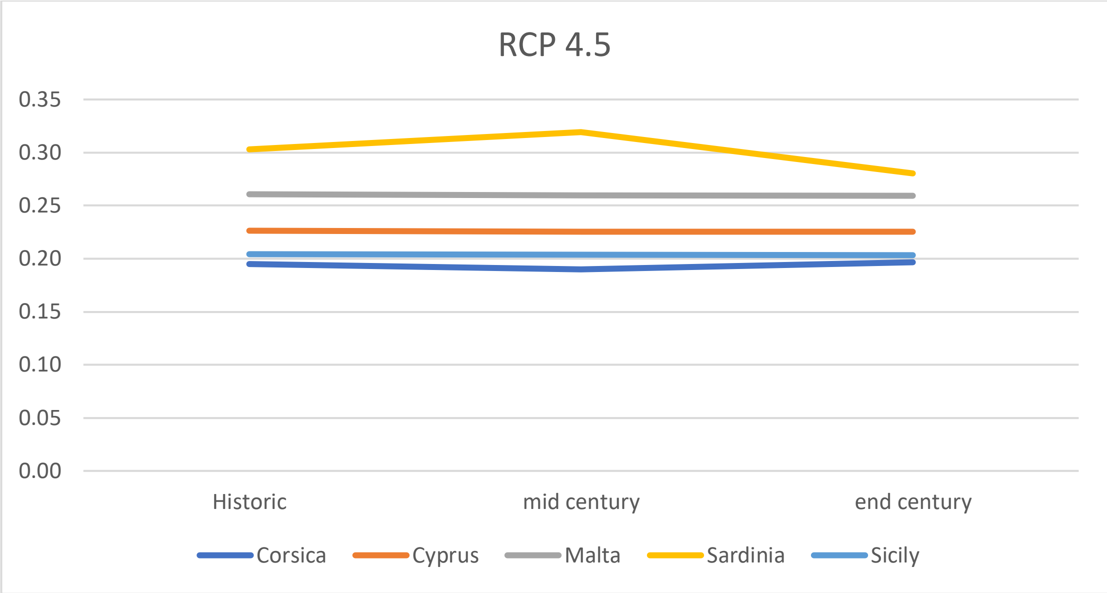

Figure: 4: Risk results for best-case scenario for impact chain Extreme weather events under RCP 4.5

Source: Soclimpact project deliverable 4.5

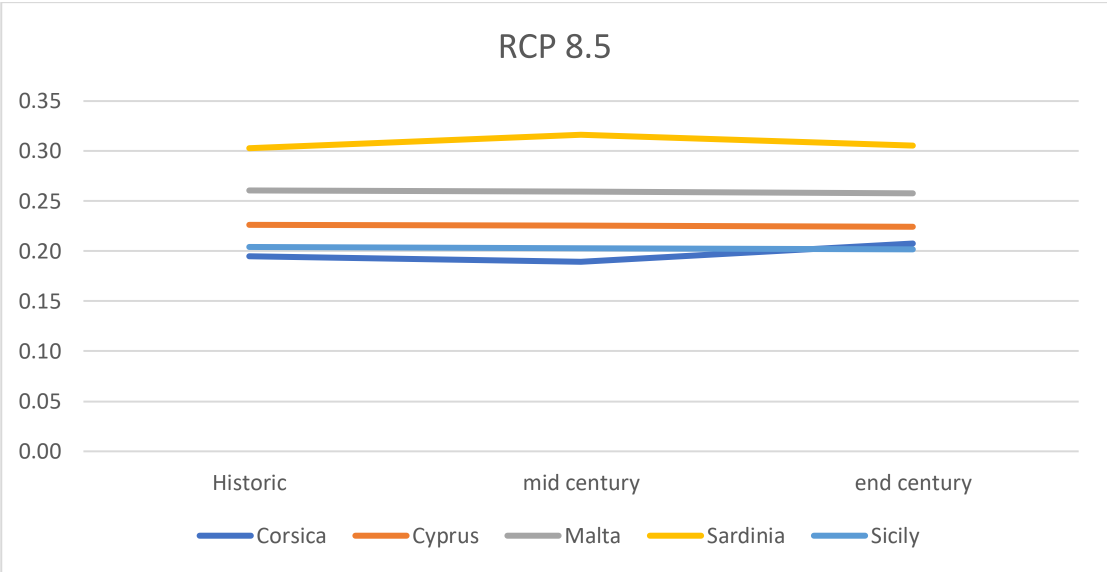

Figure: 5: Risk results for best-case scenario for impact chain Extreme weather events under RCP 8.5

Source: Soclimpact project deliverable 4.5

Risk- Worst-case scenario

Table: 10: Risk results for worst-case scenario for impact chain Extreme weather events

	Reference period	Mid century		End century	
Risk	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

Source: Soclimpact project deliverable 4.5

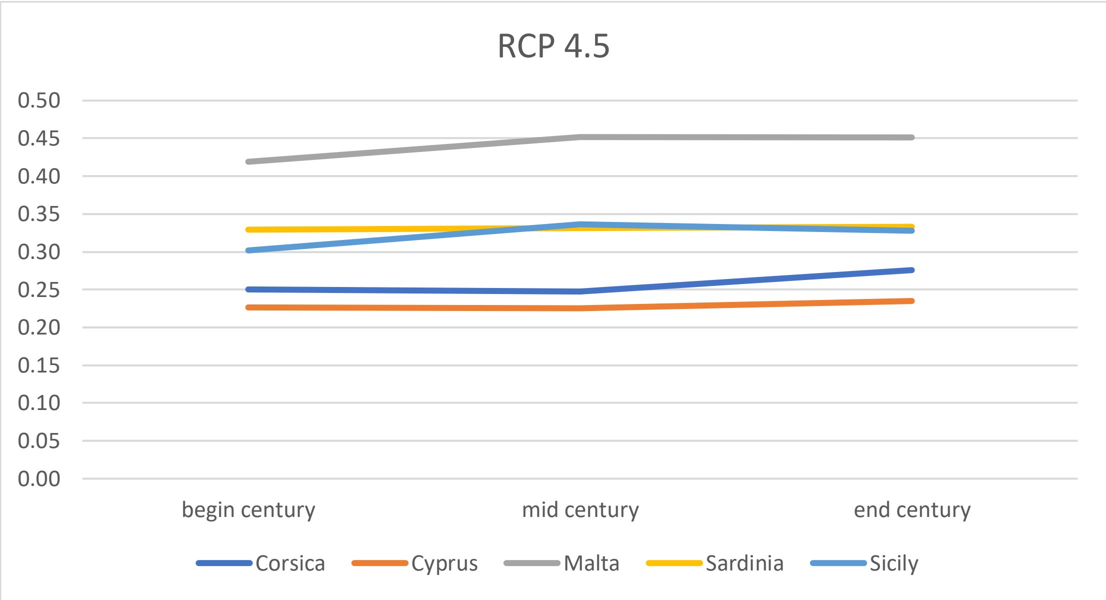

Figure: 6: Risk results for worst-case scenario for impact chain Extreme weather events under RCP 4.5

Source: Soclimpact project deliverable 4.5

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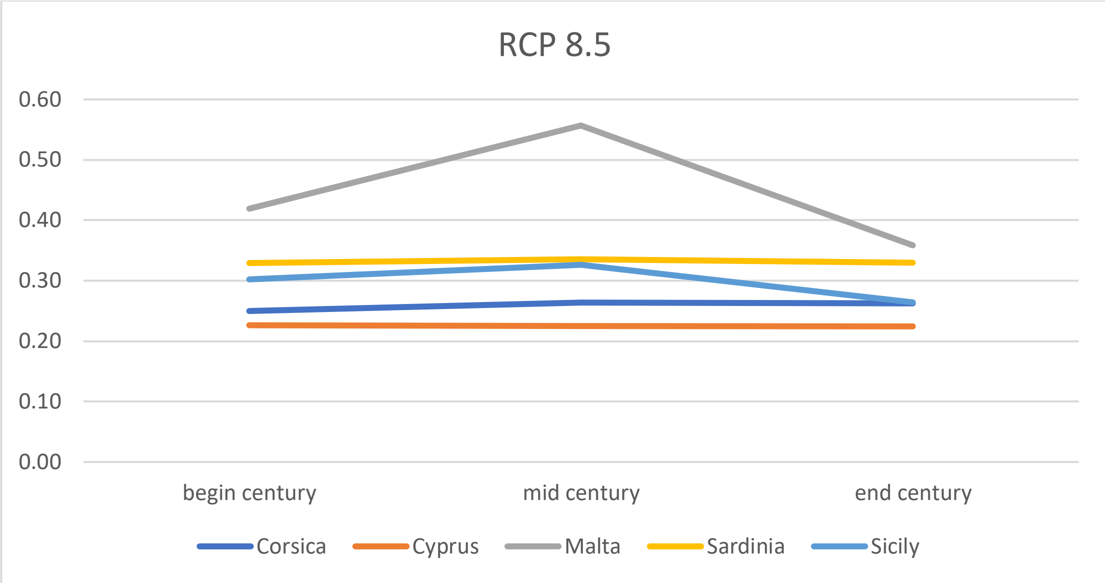

Figure 7: Risk results for worst-case scenario for impact chain Extreme weather events under RCP 8.

Source: Soclimpact project deliverable 4.5

Bigger islands were separated in areas since conditions can vary greatly in different parts of the island.

Table: 11: Risk results for impact chain Extreme weather events for the Mediterranean islands with large islands analysed on a local level using the worst-case scenario.

Worst case	Historic	RCP 4.5		RCP 8.5	
		mid century	end century	mid century	end century
Malta	0.37	0.45	0.45	0.56	0.36
Sicily North	0.34	0.39	0.39	0.36	0.30
Sicily East	0.17	0.20	0.20	0.20	0.20
Sicily South	0.41	0.42	0.40	0.42	0.30
Corsica West	0.37	0.32	0.37	0.34	0.34
Corsica East	0.18	0.18	0.18	0.18	0.19
Sardinia West	0.40	0.46	0.47	0.47	0.44
Sardinia East	0.39	0.20	0.20	0.20	0.18
Cyprus	0.23	0.23	0.23	0.23	0.22

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**

Source: Soclimpact project deliverable 4.5

For all islands and all RCPs, it can be concluded that there is no significant change in risk, even in the worst-case scenario, between the reference period, middle and end of the century. Malta, Sicily

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south and Sardinia west are found to be the most vulnerable with risk exceeding 0.45 due to a higher hazard risk. Malta also has the highest exposure of all islands. Malta has an increased risk mid-century in the worst case scenario, due to an increase in hazard.

Impact chain: sea surface temperature

Hazard

Model projections are 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.

Exposure and vulnerability indicators

Table: 13: Expose and vulnerability indicators, the data for each island and the normalized values.

Component	**Exposure**			**Vulnerability**				
Component weight	**0.4**			**0.3**				
Sub-component Sub-component weight				**Factor of sensitivity** **0.75**		**Factors of adaptive capacity** **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

Source: Soclimpact project deliverable 4.5

Risk

The values in this analysis is not an estimate of the risk but rather a ranking between islands since a lot of the data was normalised based on a min-max or fraction of the maximum of the islands.

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A proper risk assessment would need additional data from farmers and a detailed model of farming results as a function of temperature. Malta has a much higher risk than the other islands due to the high exposure, Malta's farm produce on average 3.5 to 22 times more than the farms on other islands.

Table: 14: Risk results for impact chain Sea Surface temperature

	Historic	Mid century		End century	
Risk	Hist.	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Corsica	0.30	0.34	0.41	0.38	0.42
Cyprus	0.40	0.48	0.48	0.50	0.59
Malta	0.68	0.73	0.74	0.75	0.80
Madeira	0.19	0.26	0.23	0.24	0.35
Sardinia	0.37	0.42	0.43	0.44	0.49
Sicily	0.38	0.43	0.43	0.45	0.48

Source: Soclimpact project deliverable 4.5

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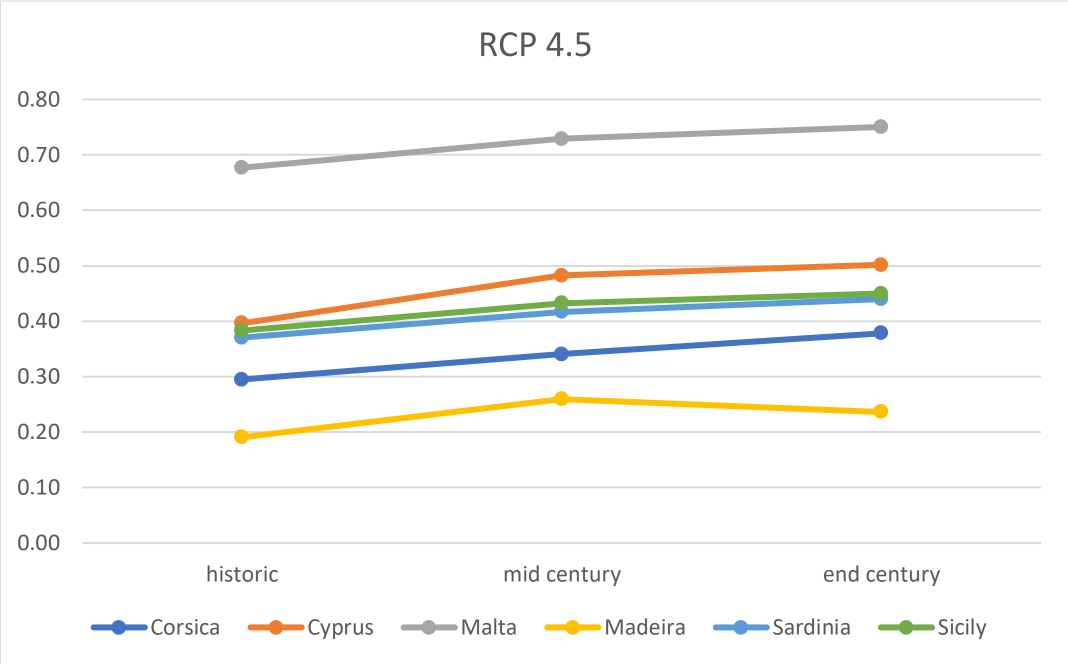

Figure: 8: Risk results for impact chain Sea Surface temperature under RCP 4.5

Source: Soclimpact project deliverable 4.5

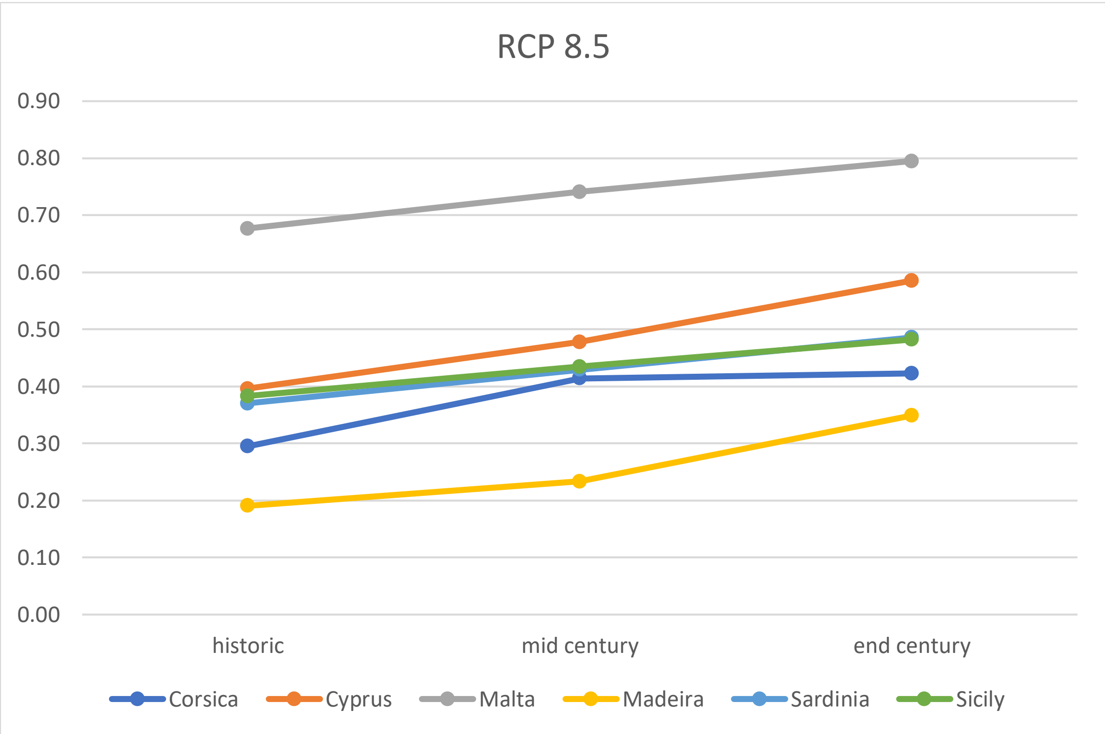

Figure 9: Risk results for impact chain Sea Surface temperature under RCP 8.5

Source: Soclimpact project deliverable 4.5

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Risk of increased energy demand due to increased cooling demand and desalination/pumping needs

There are more than 2200 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.

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 specifically 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.

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.

Most RES (renewable energy sources) 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 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.

For the energy sector, three theoretical impact chains (IC) have been proposed in the SOCLIMPACT project:

i) risk of changes in power generation due to long term climate change and variability,
ii) risk of changes in energy demand due to changes in precipitation and temperatures,
iii) risk of damages to transmission grids due to extreme events.

Only the second IC, i.e., the one related to changes in energy demand was selected to be operationalized, mainly due to data availability constraints. The quality of IC operationalization depends strongly on data availability over long periods. Data for cooling energy demand are still scarce and difficult to obtain, despite the requirements of the European Commission for information regarding the national energy efficiency targets. The availability and quality of cooling demand data should improve in the future due to the need for tracking the advances towards energy efficiency targets. Desalination demand data should also improve strongly, including data about the energy efficiency of the desalination processes used.

This demand-side IC has been deployed into 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 risk assessment was carried through and expert assisted process.

The diagrams of the two operationalized impact chains are presented below

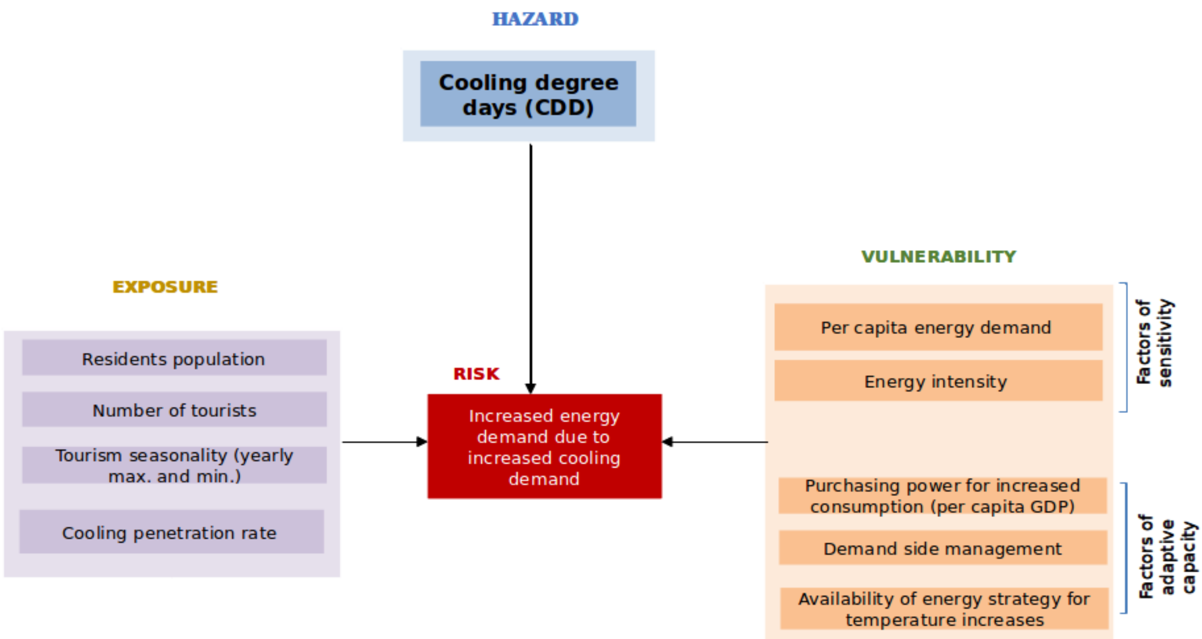

Figure 1: Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased cooling demand
Source: Soclimpact project Deliverable 4.5-Comprehensive approach for policy makers

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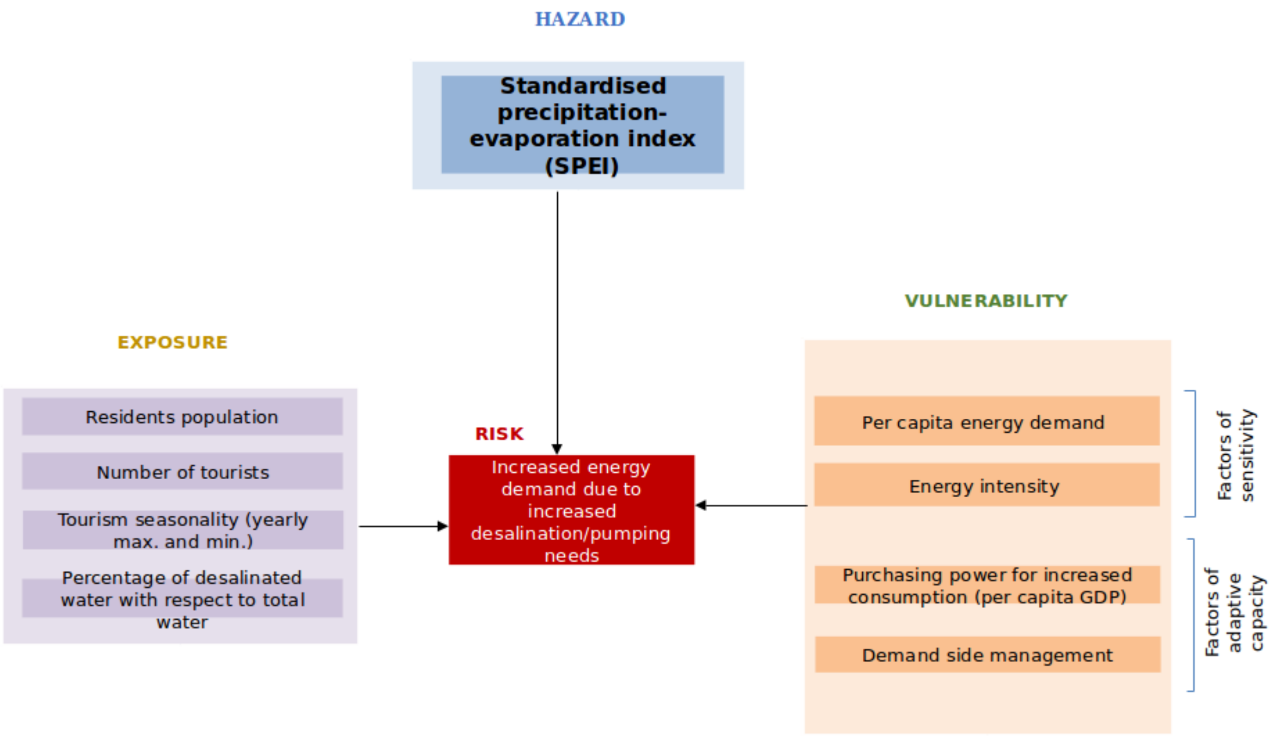

Figure 2. Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased desalination demand

Source: Soclimpact project Deliverable 4.5-Comprenhensive approach for policy makers

Hazard scores for energy demand **(Cooling Degree Days -CDD, Standardized Precipitation-Evapotranspiration Index - SPEI)**, and supply indicators (wind energy, solar PV and combined productivity and droughts) were analysed. 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.

Regarding the normalization of these hazards, 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 clearly a normalized score like the one use 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.

CDD and SPEI scores are normalized with respect to a maximum projected value previously identified. Renewable energy productivity indicators in present climate are normalized using global thresholds (5th and 95th percentiles of the respective technologies). The same normalization method is used for projected changes of **renewable energy droughts**. Thus, energy drought indicators are normalized comparing them to a maximum upper limit, taken among all the islands and renewable energy technologies.

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.

This method, based on correlations between observed energy demand and observed data for the indicators, points 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, for periods of 10 years, performed as part of the EU Energy Efficiency Directive. A consequence of this is the relatively low weights assigned to the climate hazards in the operationalization.

For the operationalization of the full impact chains, the exposure and vulnerability indicators were also weighted utilizing different criteria. 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 components and the dependent variable (in this case, energy demand due to desalination or energy demand due to cooling). The detailed weight calculation for the risk components (hazards, exposure and vulnerability) can be found in the Soclimpact Project deliverables 4.5.

Hereafter we only present the results of the operationalization of the IC, this is, the final risk scores for increased cooling and desalination energy demand, joint to a general conclusion:

Table 1. Final risk scores for Malta: cooling and desalination energy demand, for the historical and future periods.

Risk scores	Hist. ref.	RCP2.6 (2046-2065)	RCP2.6 (2081-2100)	RCP8.5 (2046-2065)	RCP8.5 (2081-2100)
Cooling	0.49	0.51	0.51	0.53	0.57
Desalination	0.47	0.54	0.55	0.61	0.67

Categorization:

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

Source: Soclimpact project Deliverable 4.5-Comprenhensive approach for policy makers

According to the risk analysis, it is expected a large cooling energy demand increase. Besides, desalination demand, which is already high, should also 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. 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

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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.

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.

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, 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.

*** Energy demand:**

- Certain data illustrate the strong impact that demand-side management options can have on energy demand. In the case of Malta, water losses in the distribution network were tackled through a leak management strategy during several years in such a way that the water losses were nearly halved from 2004 to 2009. This factor has been decisive in the evolution of the desalination energy demand, which has decreased 20% from 2004 to 2018 at the same time that GDP has grown 80%, the number of tourists has doubled and drought conditions have worsened.
- A clear demand management option for reducing cooling demand is the improvement of the energy efficiency of buildings. The energy efficiency directive of the EU sets binding targets for all European countries, but the data about the efficiency classes of buildings are

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rather limited and difficult to access. The scarce data available indicate that there is much room for improvement in this respect. A consequent implementation of energy efficiency measures in buildings could reduce clearly the effect of increasing temperatures on energy demand.

- Digitalisation is key in EU strategies. In this respect, demand side management options for adaptation to generation peaks and troughs should be developed as much as possible through digitalisation, prioritising automatic instead of manual adaptation.

* Energy supply:

- The frame for energy supply in the islands 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 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).
- New financing possibilities linked to the recently approved EU COVID-19 recovery fund, and over a 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.
- Interconnections to mainland are very important for supply safety. Excessive dependency on interconnections to mainland should be nevertheless avoided, due to 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.

Read more: *Hazard indicator computation and normalization*

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. For the indicator weight calculation, the observed values of CDD (EUROSTAT) have been used, and compare to the hazard of the island. 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 (CDD=1183.49 ºC· days/year, corresponding to Cyprus for RCP8.5 scenario, end of century period).

Standardised Precipitation-Evapotranspiration Index (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 indicator weight calculation was done using data from ECA&D (European Climate Assessment & Dataset). 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).

The indicator **Wind energy 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 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). 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 (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 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. 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.

Renewable energy productivity droughts 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. 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.

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 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.

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Risk of isolation due to transport disruption

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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 CO_2 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 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 it. 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).

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,
(c) risk of isolation due to transport disruption.

We selected to operationalize the third one which in terms of hazards and impacts can be considered as a combination of the other two. The hazard risk component indicators considered for the operationalization were: 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). 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. The conceptualization framework of the operationalization is summarized in the next Figure.

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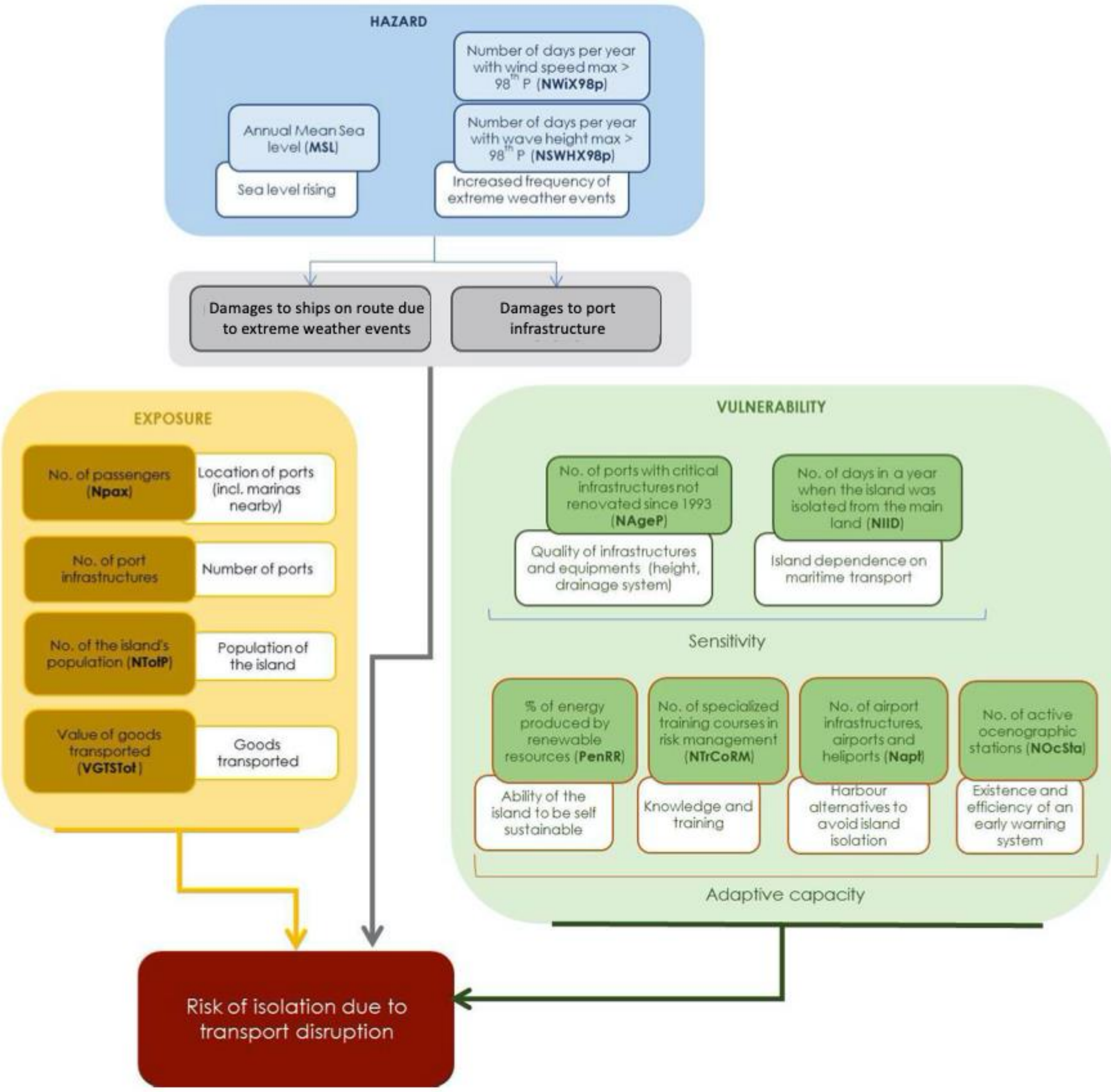

Figure 1. Conceptualization framework for the operationalization of the Maritime Transport Impact Chain: Risk of Transport Disruption.
Source: Soclimpac project deliverable 4.5

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, 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.

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, we have 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 have 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 have assigned a weight of 0.25 for the Factors of Sensitivity and a weight of 0.75 for the Factors of Adaptive Capacity.

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 low risk for all investigated islands. 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 in 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.

Table 1. 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

Categorization:

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

Source: Soclimpact project deliverable 4.5

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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 small number of ports and 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.

READ MORE about the risk indicator computation: normalization of sub-component indicators o**n Deliverable 4.5 Soclimpact project HERE**