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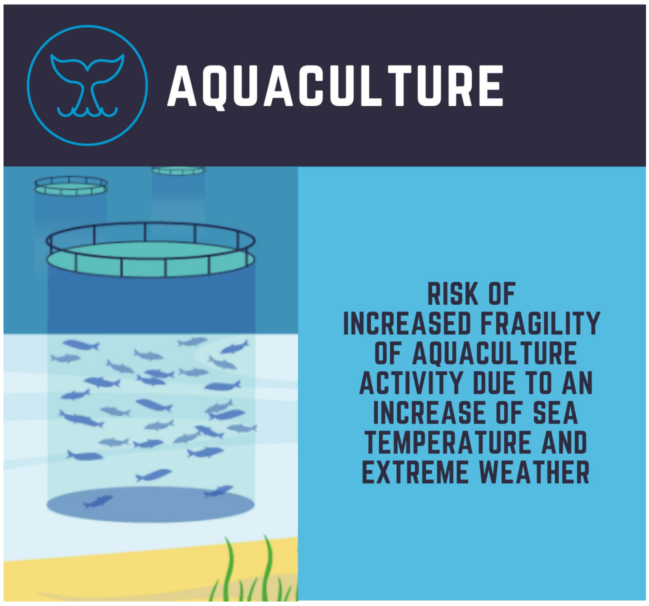

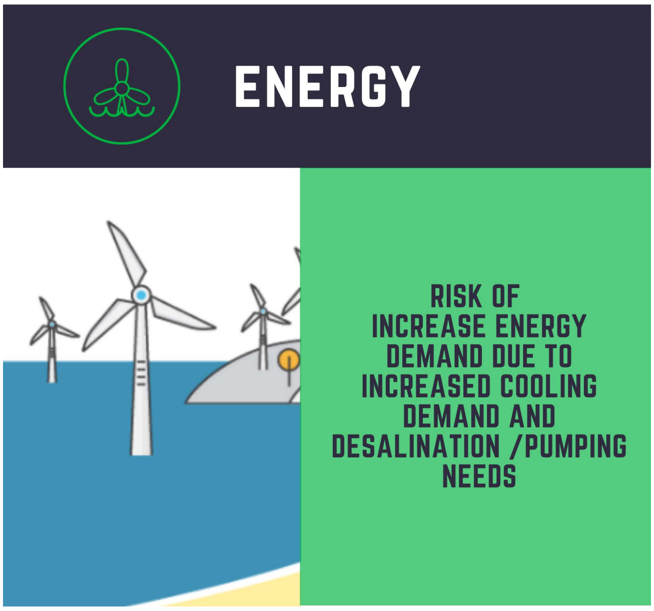

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Loss of attractiveness due to increased danger of forest fires in touristic areas

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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 normalized to be able to be aggregated (steps 4 and 5) with different weights. The final objective (step 6) is to achieve a standardized 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.

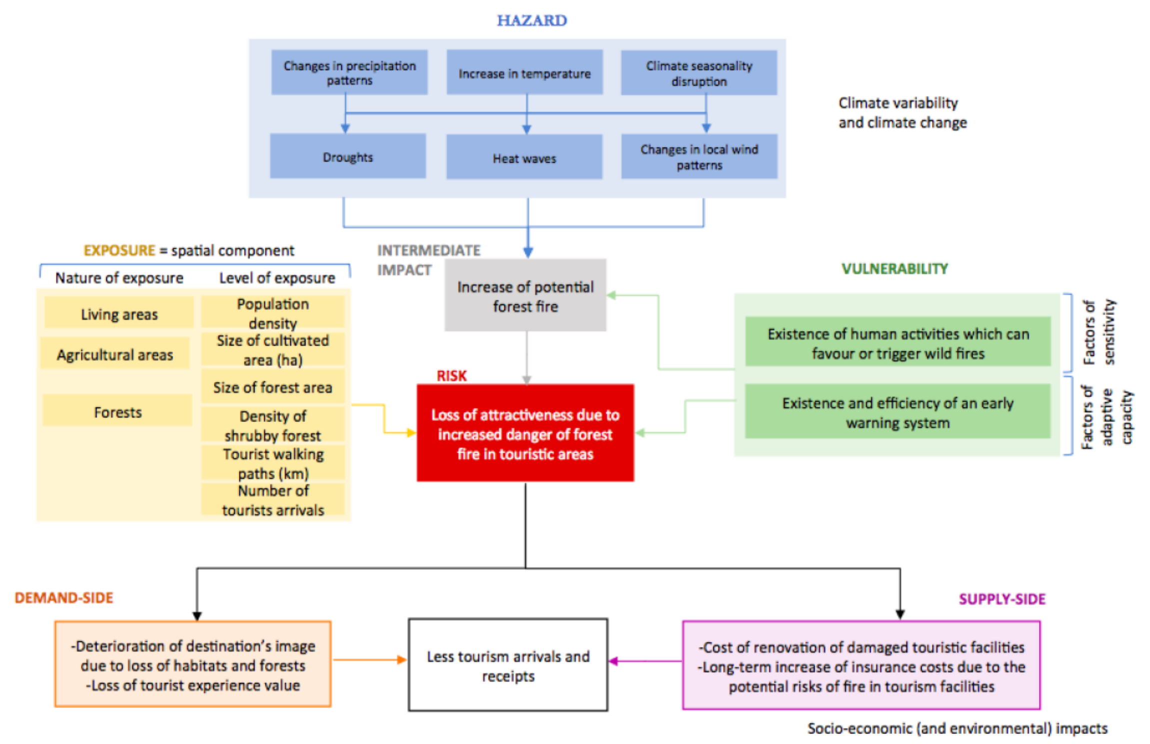

Figure1: Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.2

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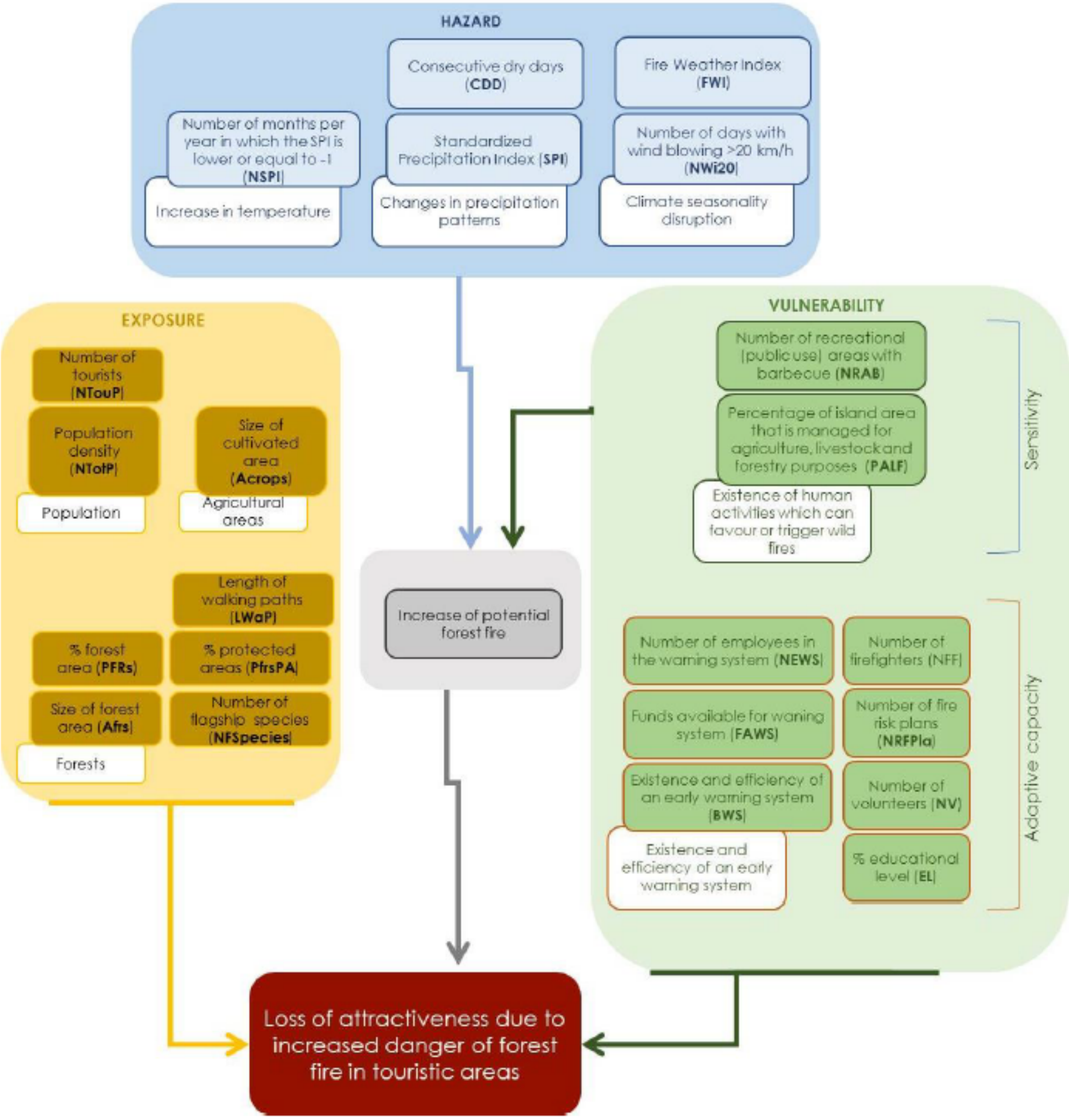

Figure 2: Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.3

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.

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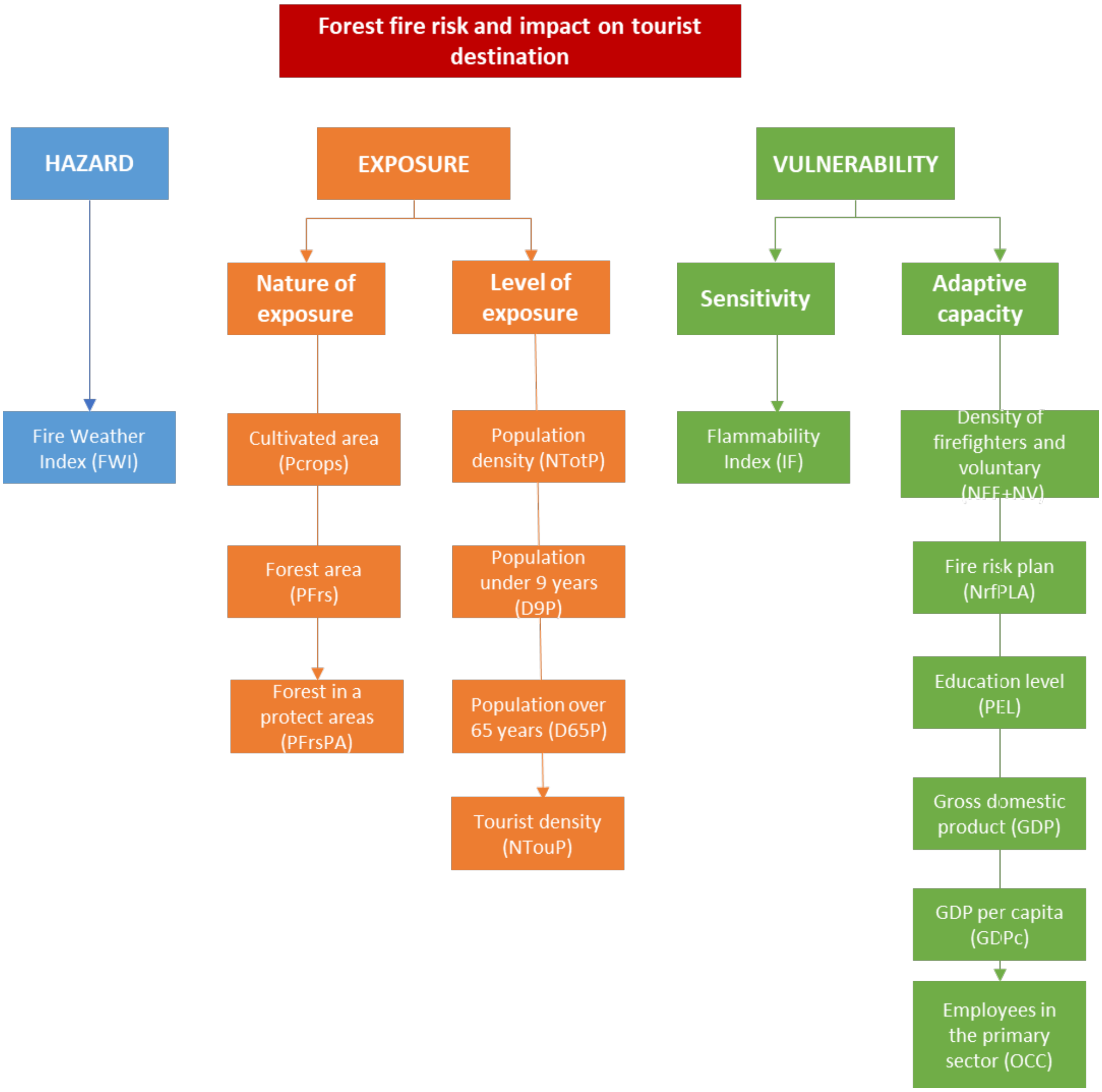

Figure 3: Final Impact Chain Model
Source: Soclimpact deliverable D4.5

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".

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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.

<u>Hazard scores</u>

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

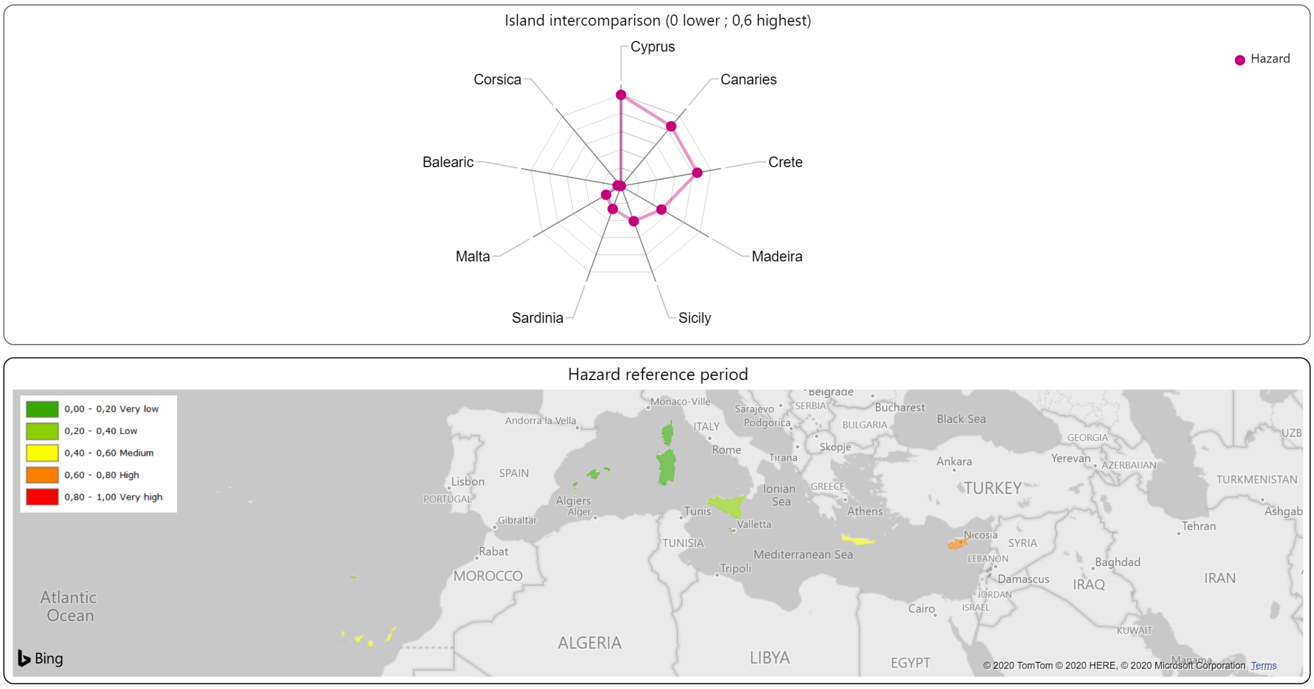

Figure 4: Hazard score (Fire Weather Index) per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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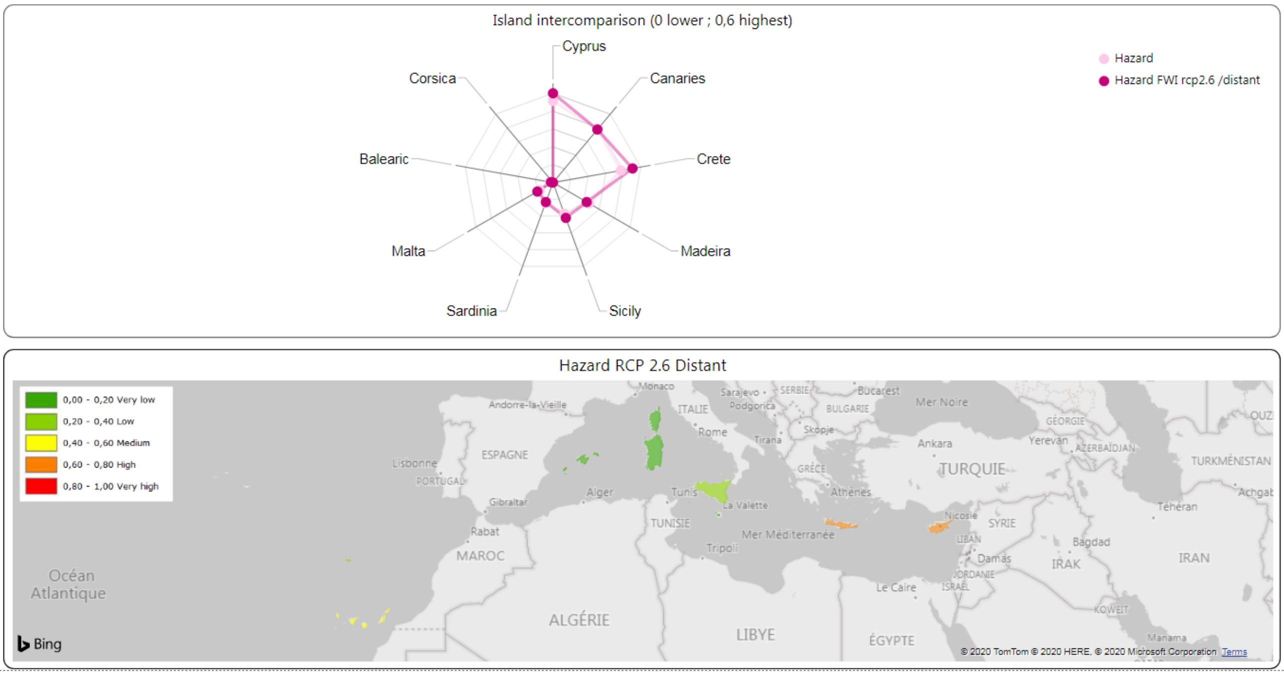

Figure 5: Hazard score (Fire Weather Index) per island at the end of the century (2081-2100) under RCP2.6 (Ambitious Mitigation Policies)
Source: Soclimpact deliverable D4.5

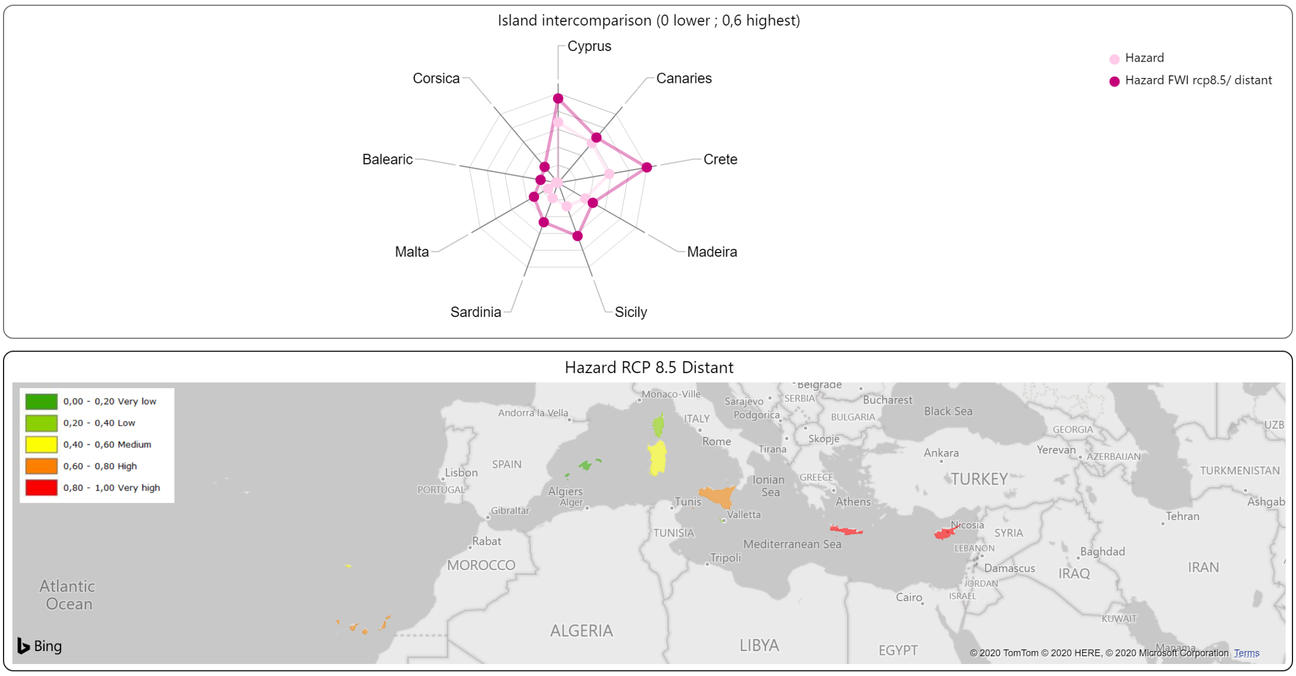

Figure 6: Hazard score (Fire Weather Index) at the end of the century (2081-2100) under RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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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.

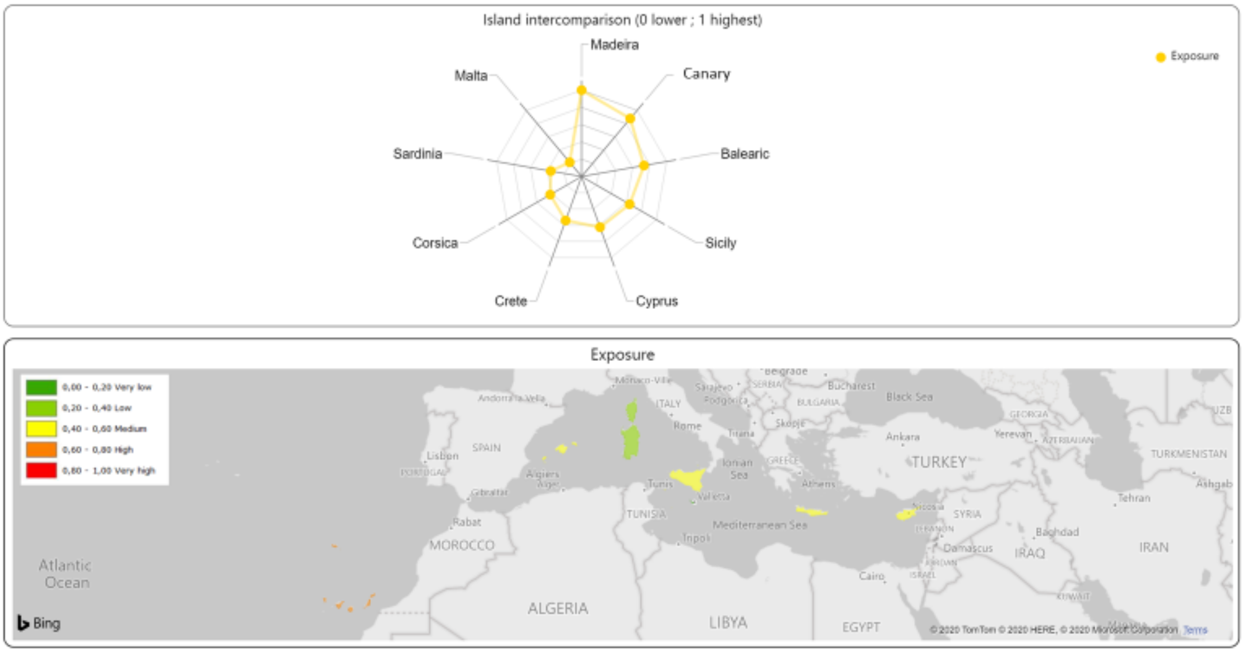

Figure 7: Exposure score (current period) per island
Source: Soclimpact deliverable D4.5

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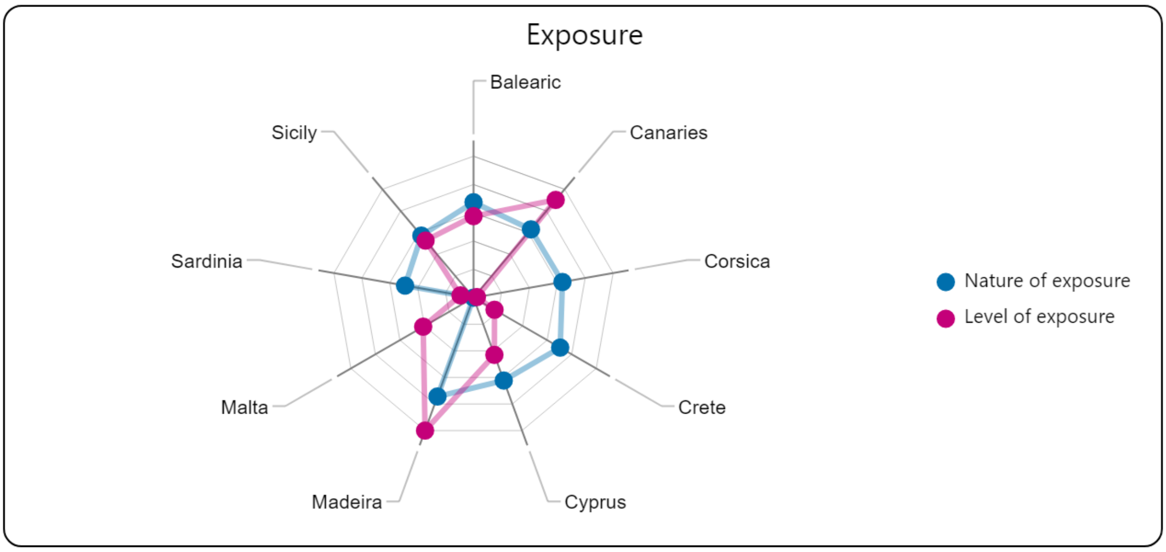

Figure 8: Subcomponents of exposure and related score (current period) per island
Source: Soclimpact deliverable D4.5

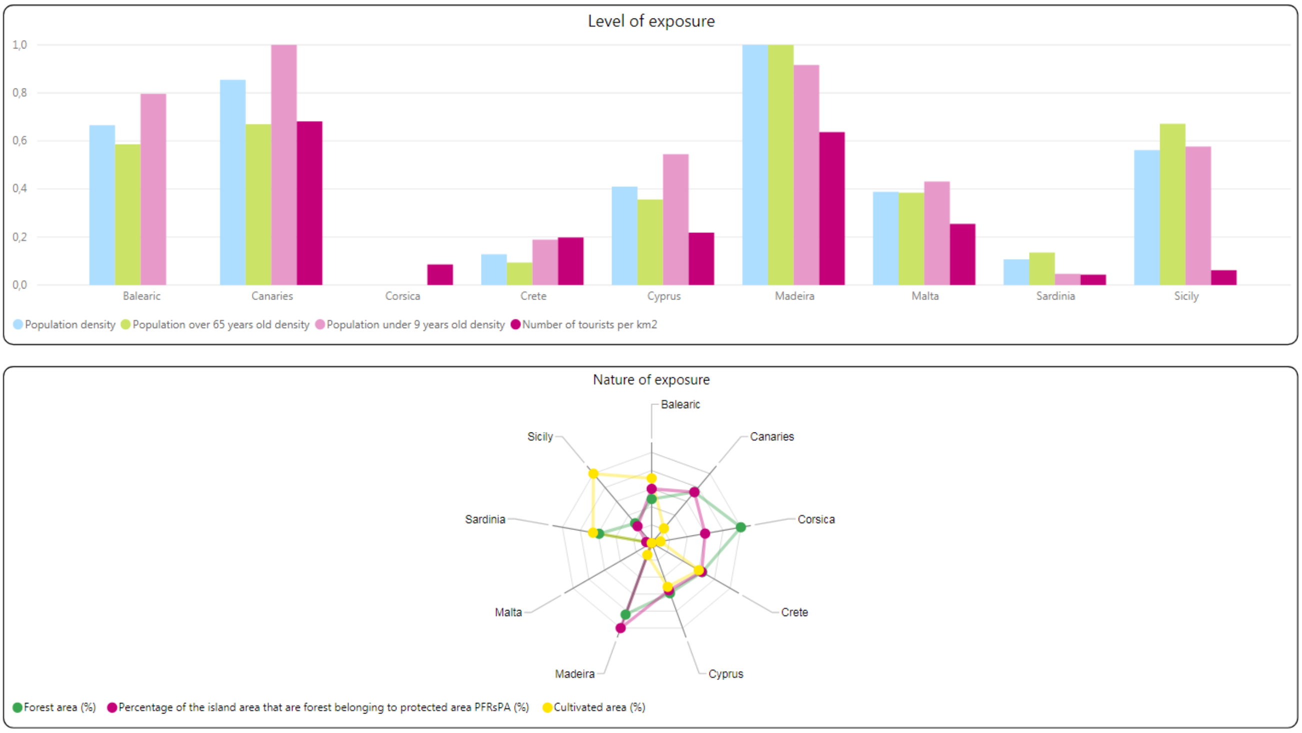

Figure 9: Breakdown by exposure subcomponent
Source: Soclimpact deliverable D4.5

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.

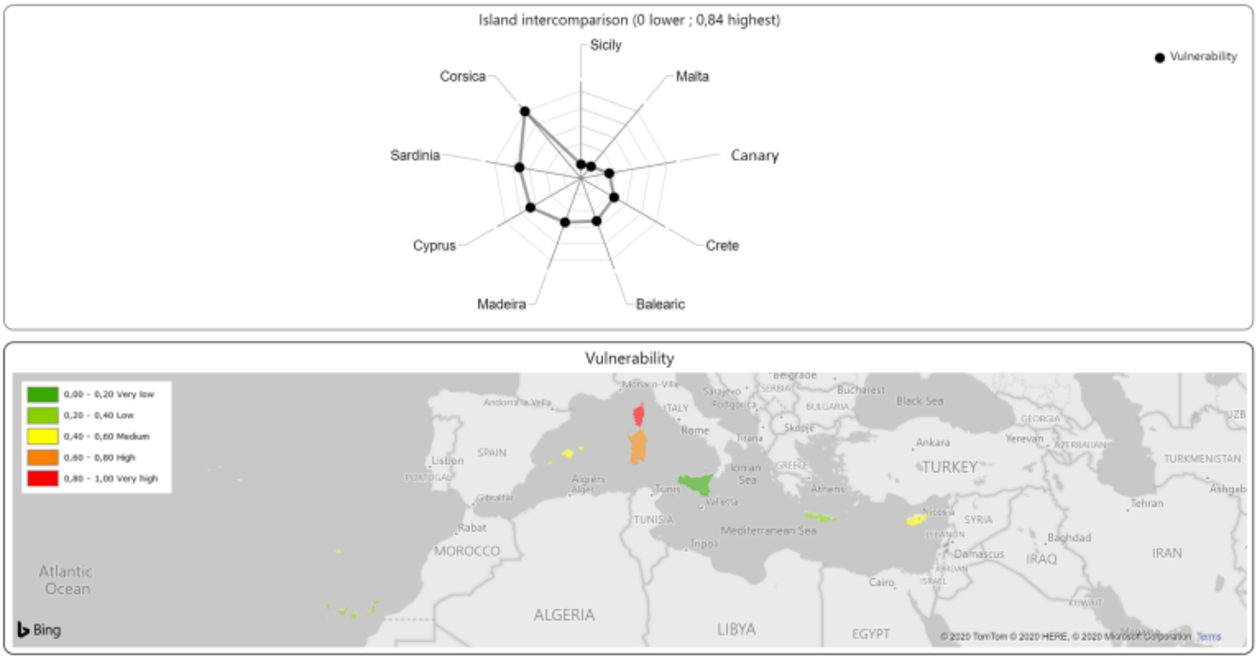

Figure 10: Vulnerability score per island
Source: Soclimpact deliverable D4.5

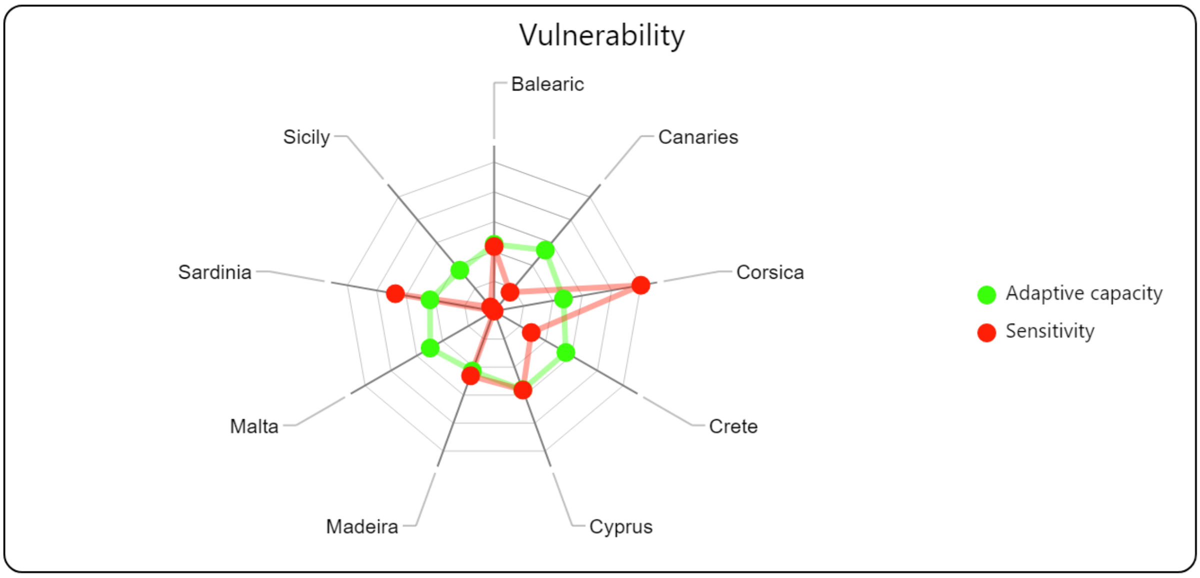

Figure 11: Subcomponents of vulnerability and related score (current period) per island
Source: Soclimpact deliverable D4.5

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).

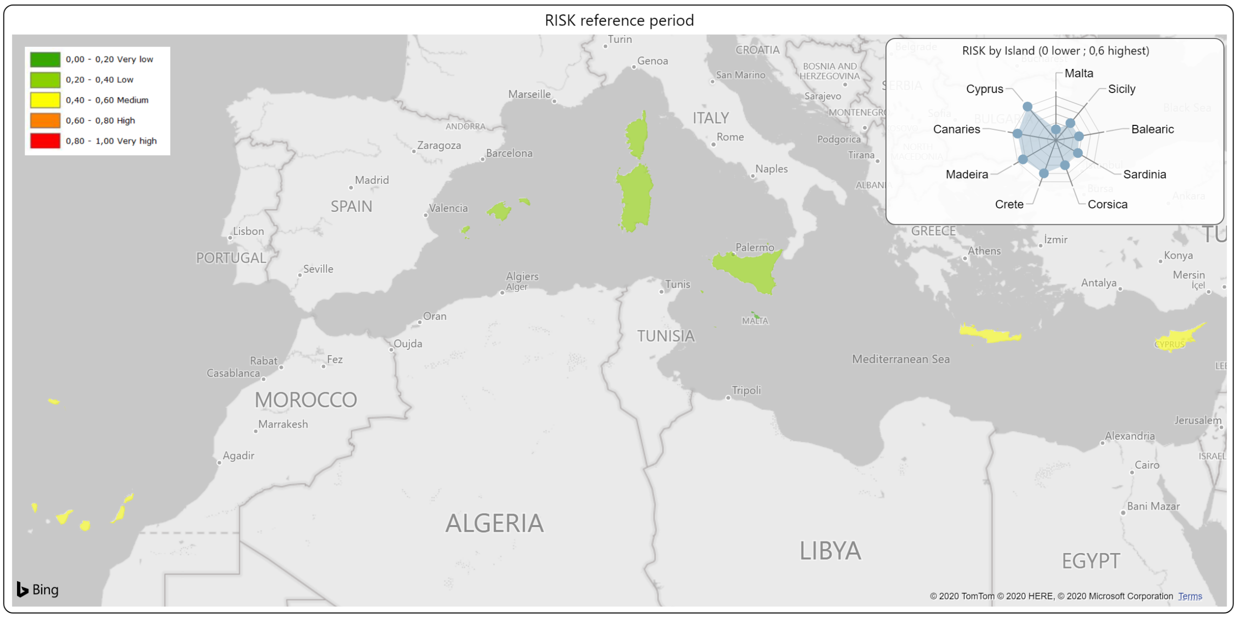

Figure 13: Risk score per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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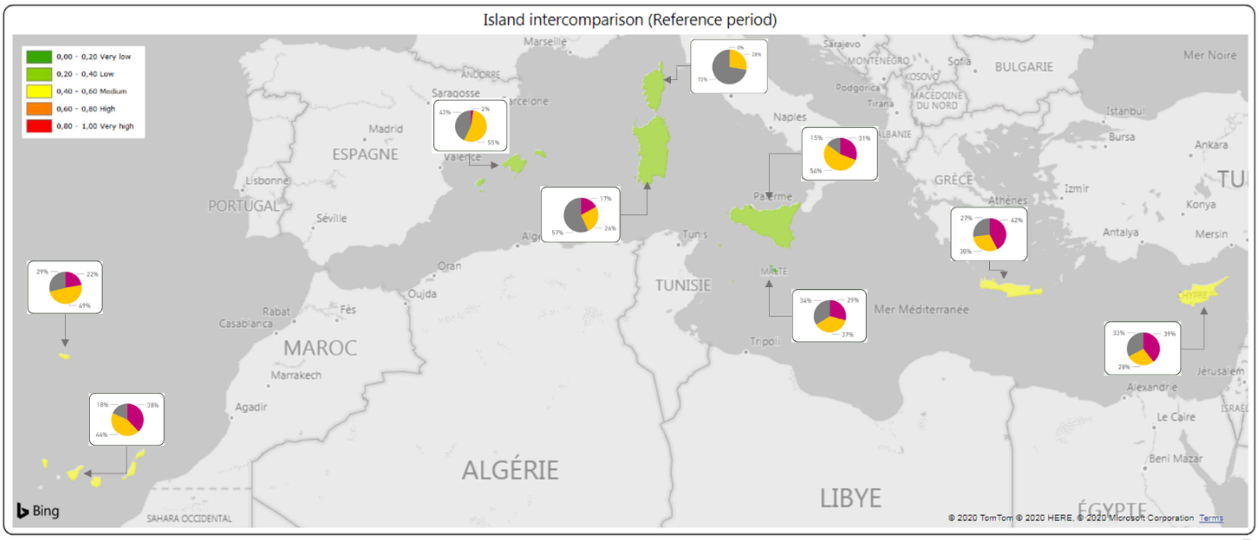

Figure 14: Risk breakdown by island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

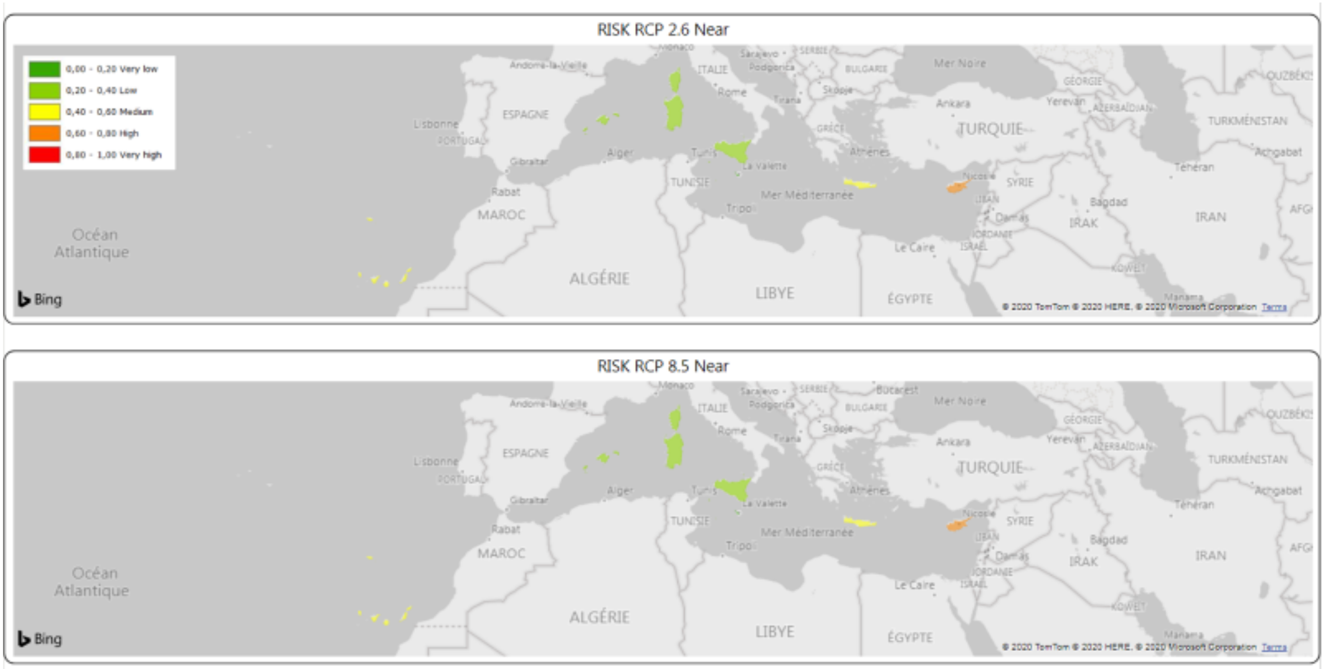

Figure 15: Risk score per island in the near future (2046-2065) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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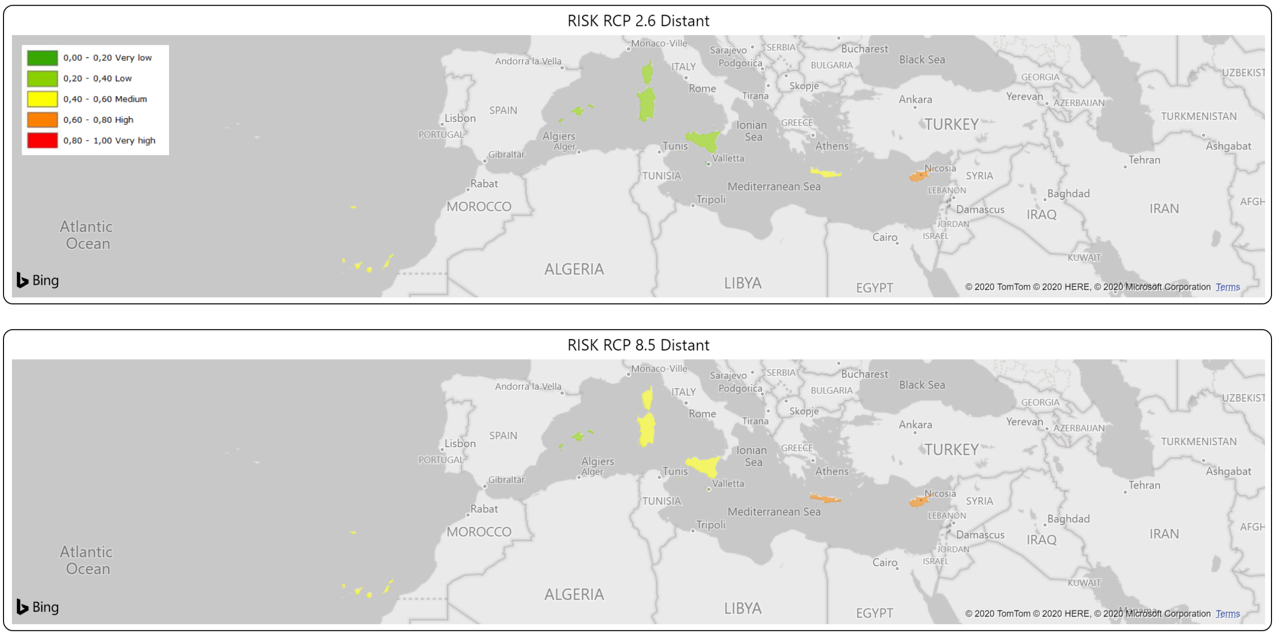

Figure 16: Risk score per island at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

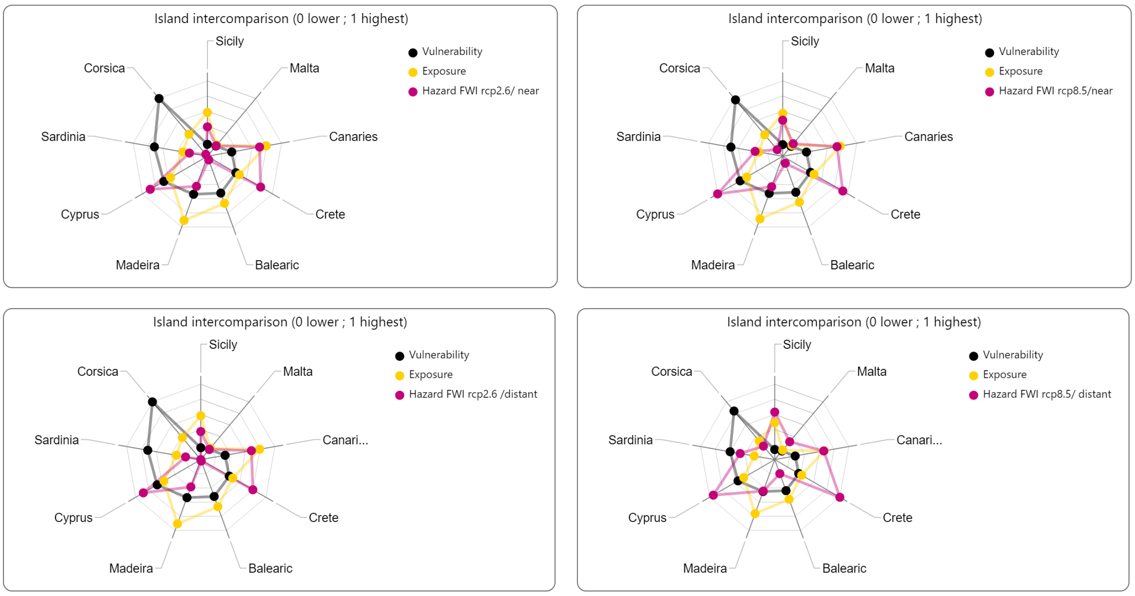

Figure 17: Score per component and per island in the near (2046-2065) and the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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Madeira island results

Considering, the reference period, the risk for Malta is medium and the component of exposure is the most represented. There is no change in the future for the category of risk.

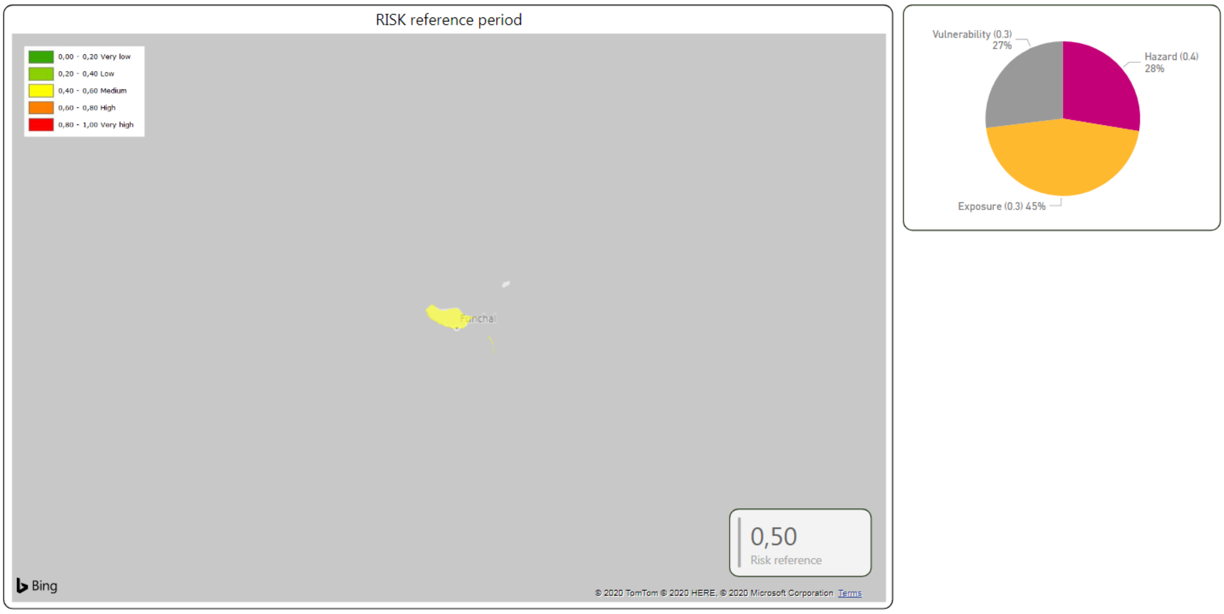

Figure:18: Risk score and components of the risk for the reference period
Source: Soclimpact deliverable D4.5

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, the level of exposure is the most represented in the calculation of the final risk scores.

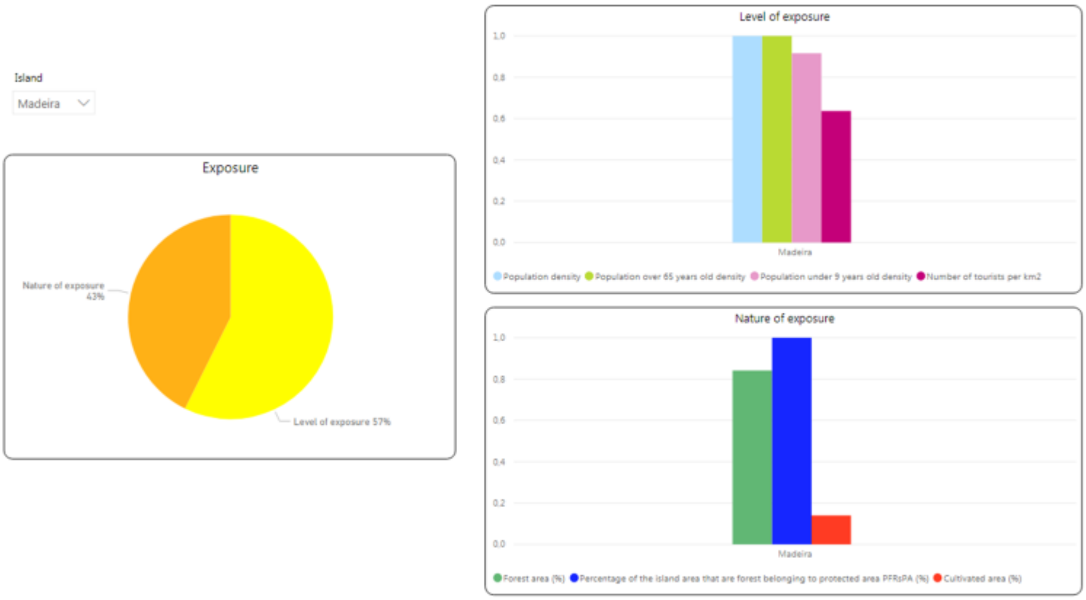

Figure 20: Details and scores of the two subcomponents of exposure (nature and level of exposure) per island
Source: Soclimpact deliverable D4.5

Considering the vulnerability component, the sensitivity is the most represented.

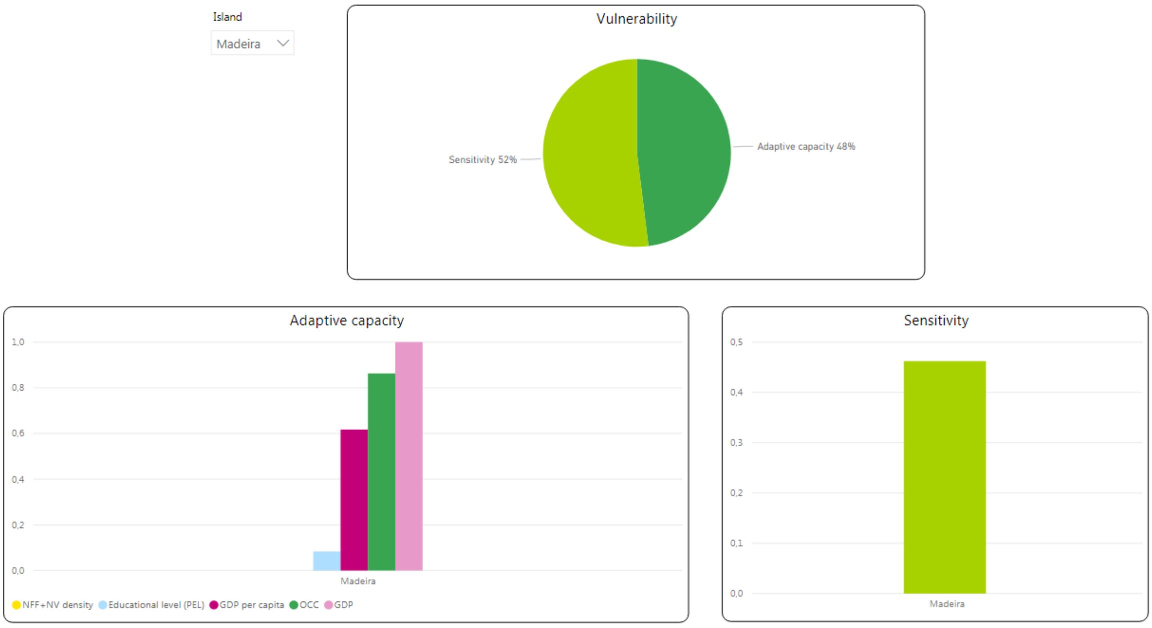

Figure 21: Details and scores of the two subcomponents of vulnerability (adaptative capacity and sensitivity)
Source: Soclimpact deliverable D4.5

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

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

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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.

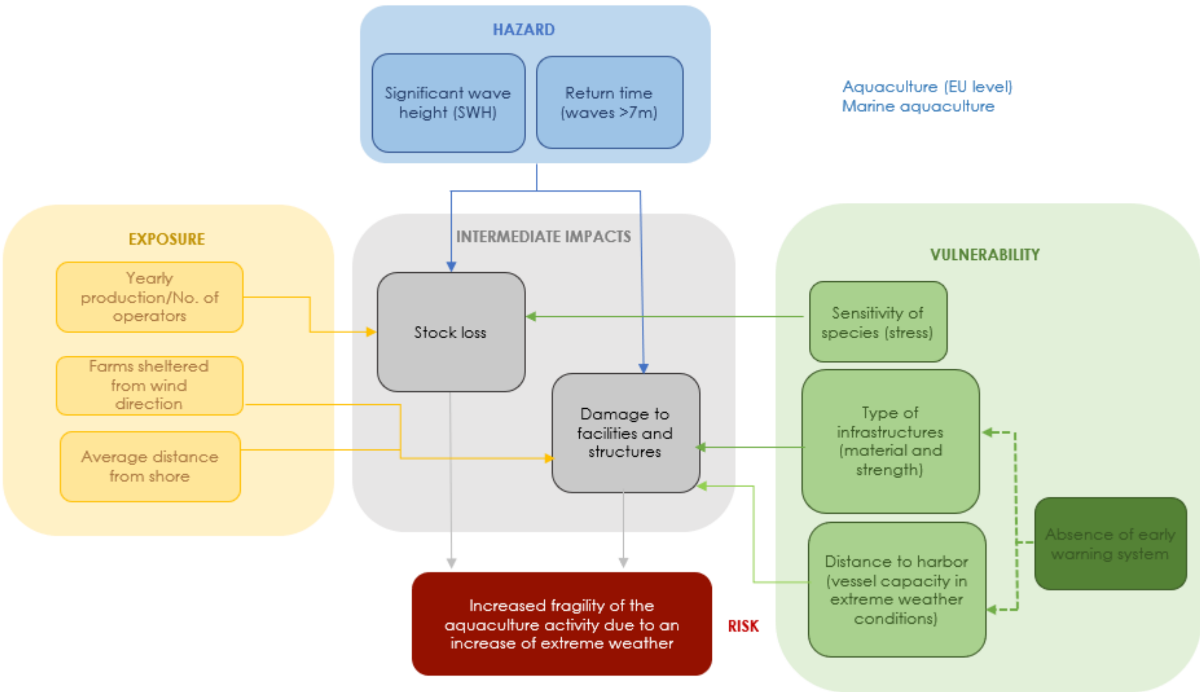

Figure:1: Impact chain on Increased fragility of the aquaculture activity due to an increase of extreme weather adjusted depending on data availability and used for the operationalisation.

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.

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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.

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

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

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

<u>Hazard</u>

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

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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

Adaptive capacity (vulnerability)

Two out of four indicators from the impact chain were utilized for the operationalization. The monitoring early warning systems were included and show all the same values for all islands as there is a sea surface temperature forecast available for each island. The capacity to change species was included with all the islands displaying the same value as well. The risk value is high in this case, as it would be quite difficult to change species farmed on the islands in general as this would result in high economic expenditures. For the indicator of the impact chain know-how of recognizing and treating diseases/parasites there is no data available for any island. As this could vary a lot between the islands, the indicator was removed instead of making assumptions, to not negatively influence the risk values. A similar case arises from the indicator availability of alternative place for farming. There is no data available to make correct assumptions regarding the occurrence of alternative areas on the islands and therefore the indicator was not used for the operationalization.

Step 4: Normalization of indicator data for all islands

In order to come up with one final risk value per island and to be able to compare these values between islands, the indicator values were transferred into unit-less values on a common scale. The normalized values range between 0 and 1 with 0 being low risk and 1 being very high risk.
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:

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- 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)

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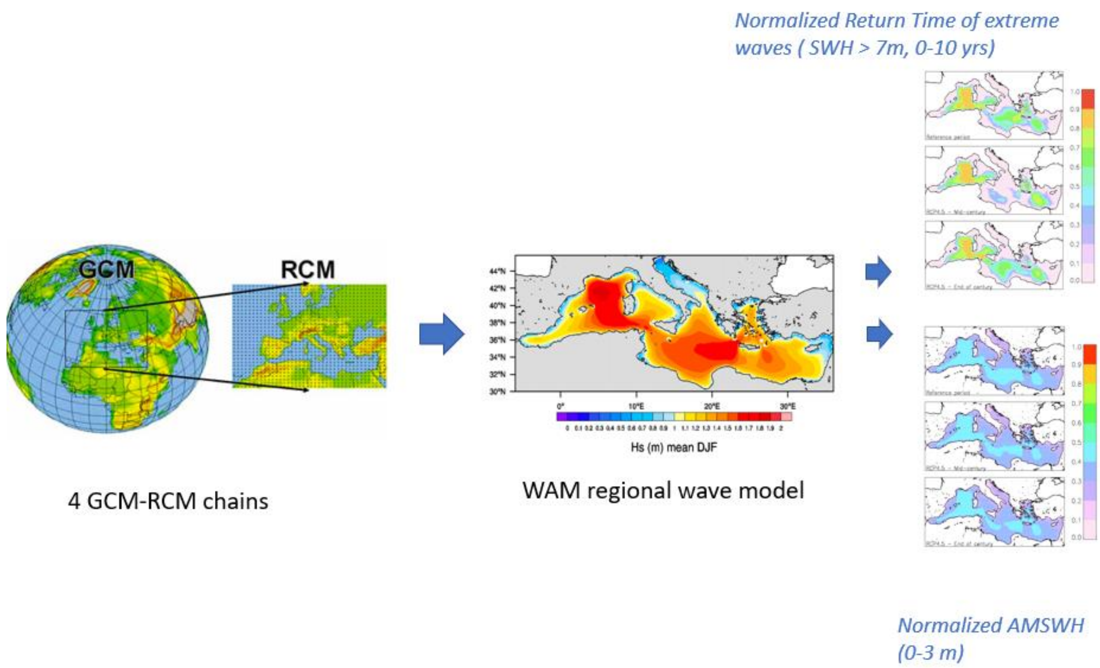

Figure 2: Modelling indicators for sea-state hazards, return time and significant wave height starting with 4 Global Circulation-Regional Circulation Model chains, which a fed into the WAM regional wave model. Results are then normalized.

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.

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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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Table8: 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

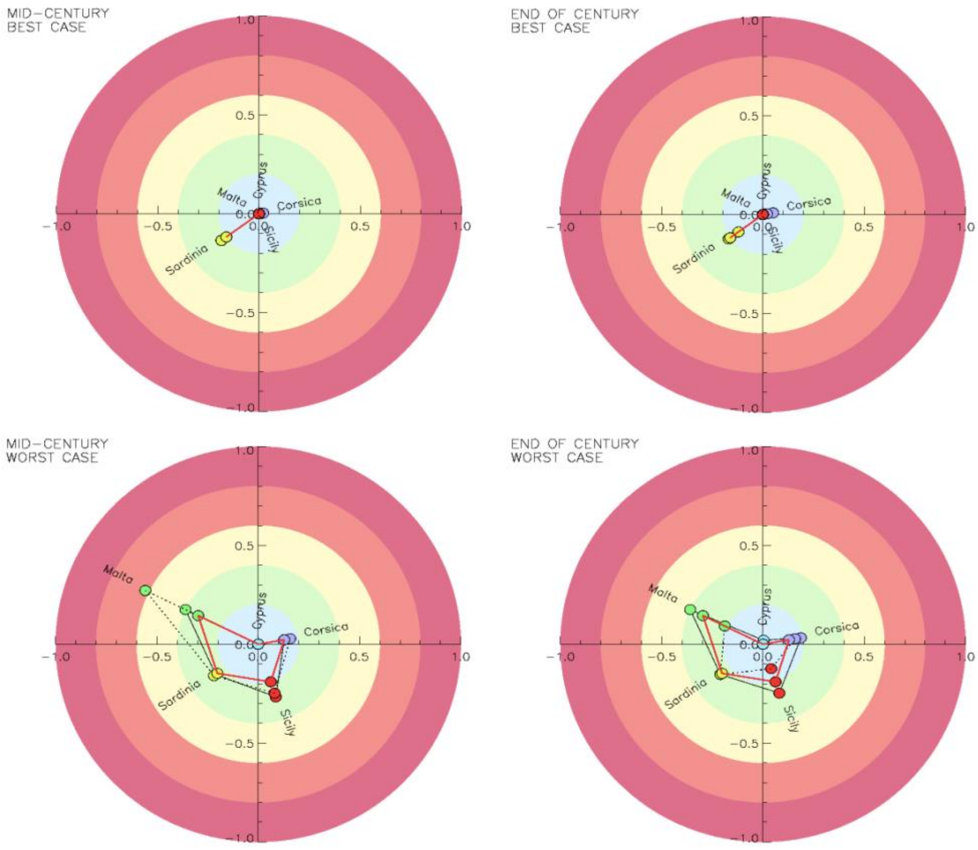
Mediterranean islands

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.

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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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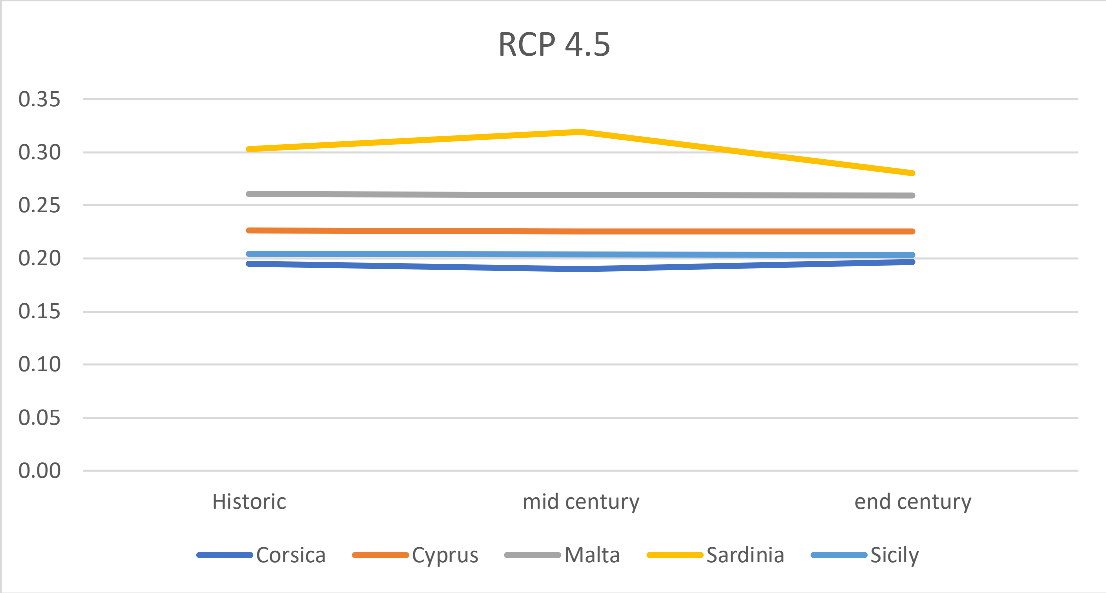

Figure: 4: Risk results for best-case scenario for impact chain Extreme weather events under RCP 4.5

Source: Soclimpact project deliverable 4.5

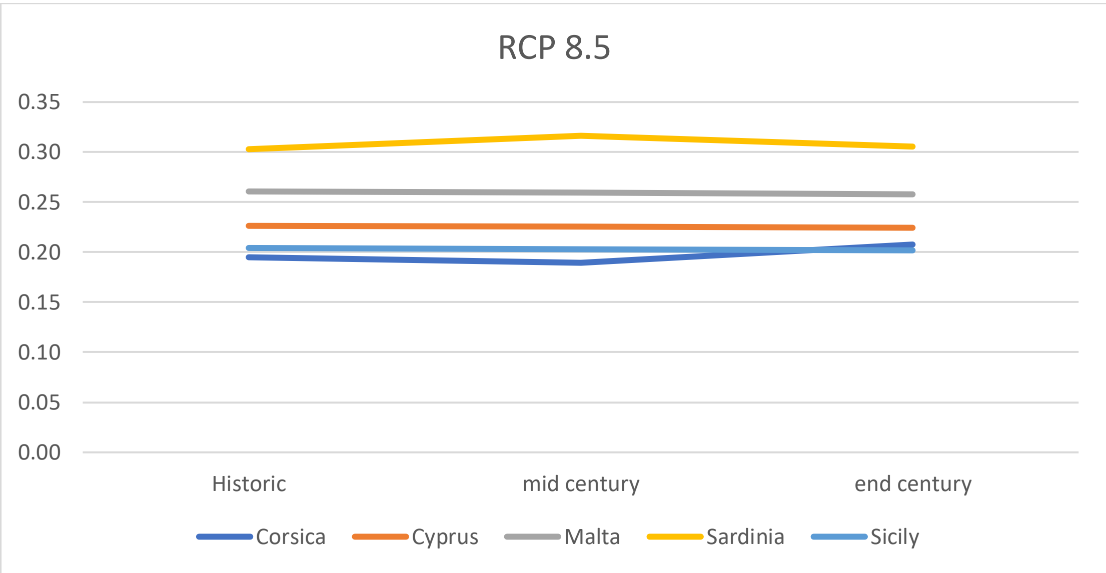

Figure: 5: Risk results for best-case scenario for impact chain Extreme weather events under RCP 8.5

Source: Soclimpact project deliverable 4.5

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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

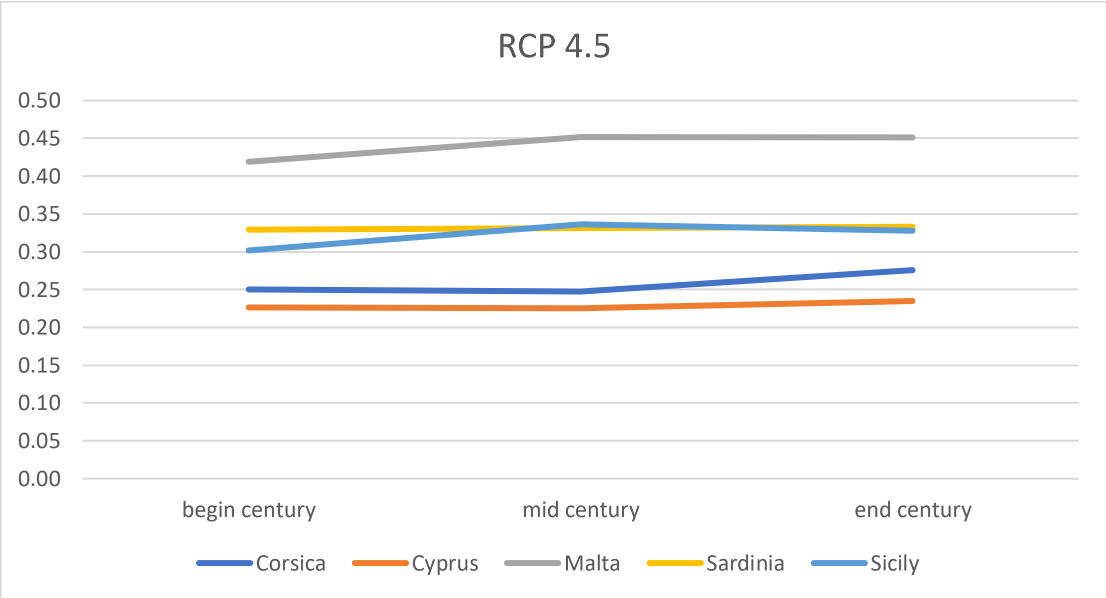

Figure: 6: Risk results for worst-case scenario for impact chain Extreme weather events under RCP 4.5

Source: Soclimpact project deliverable 4.5

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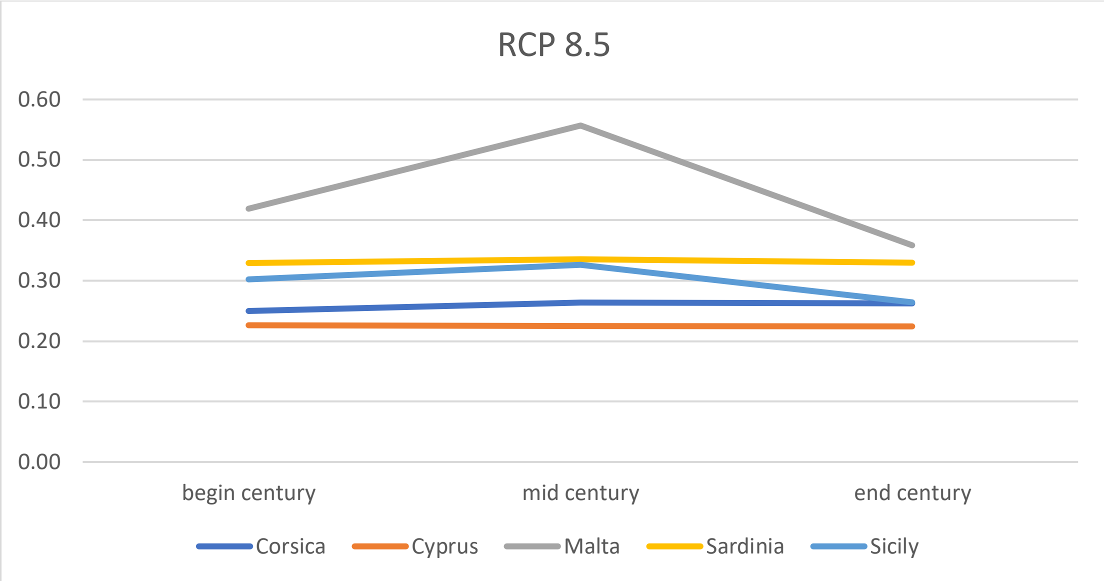

Figure 7: Risk results for worst-case scenario for impact chain Extreme weather events under RCP 8.

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	0.20 – 0.40	0.40 – 0.60	0.60 – 0.80	0.80 – 1.00
Very low	Low	Medium	High	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 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.

Atlantic islands

Table: 12: Risk results for impact chain Extreme weather events for the Atlantic Islands

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

Source: Soclimpact project deliverable 4.5

For the Atlantic islands, 2 models are available (Hadley Centre and ACCESS) for data on return time. The results of these models are highly variable. For the Azores even the change of the risk is different, where the Hadley riley model shows a decrease in risk while ACCESS shows a significant increase in risk. Therefore, no conclusion can be made. For Madeira, the risk in the future will be nihil. Not considering probability, it could be concluded that climate change has no or a positive effect on the occurrence on extreme events in Madeira. However, since this data is not accurate, more work needs to be done.

<u>Impact chain: sea surface temperature</u>

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

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

Component Component weight	Exposure 0.4			Vulnerability 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. 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

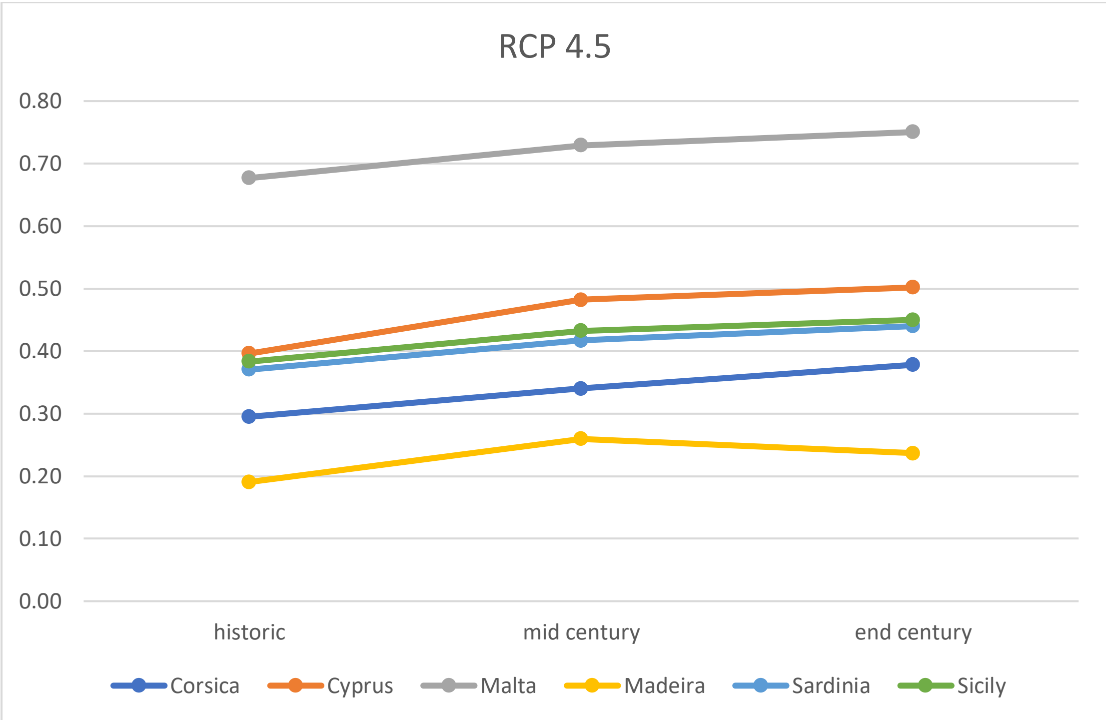

Figure: 8: Risk results for impact chain Sea Surface temperature under RCP 4.5

Source: Soclimpact project deliverable 4.5

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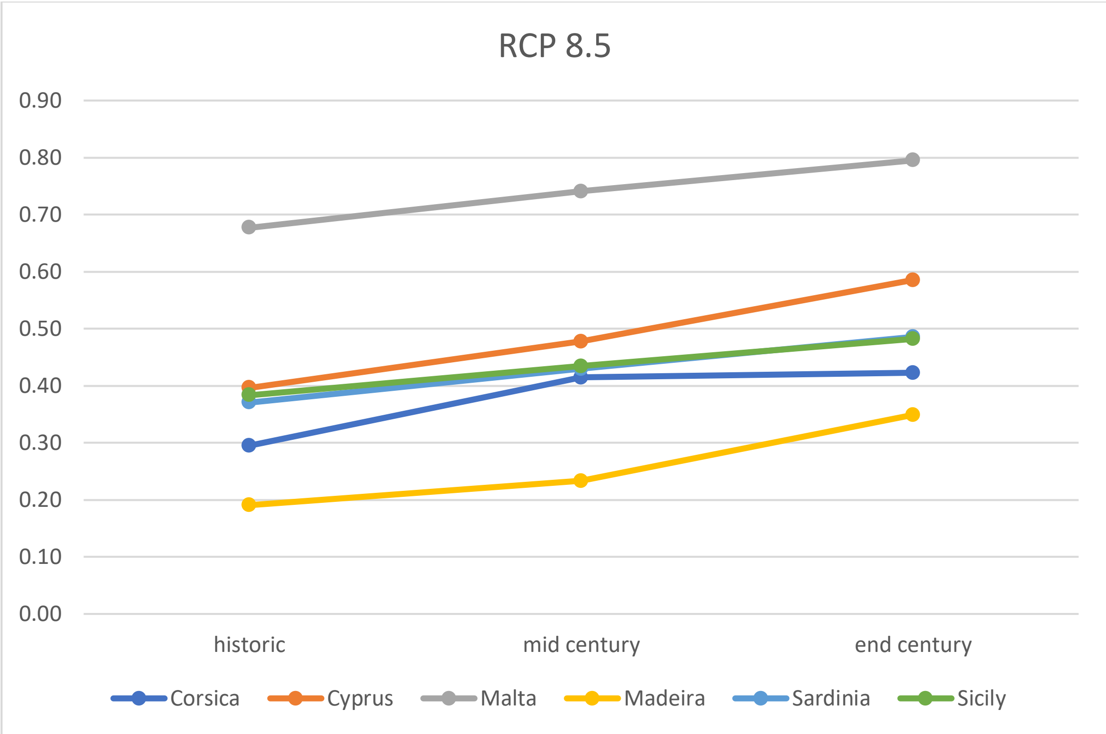

Figure 9: Risk results for impact chain Sea Surface temperature under RCP 8.5

Source: Soclimpact project deliverable 4.5

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

Madeira

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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

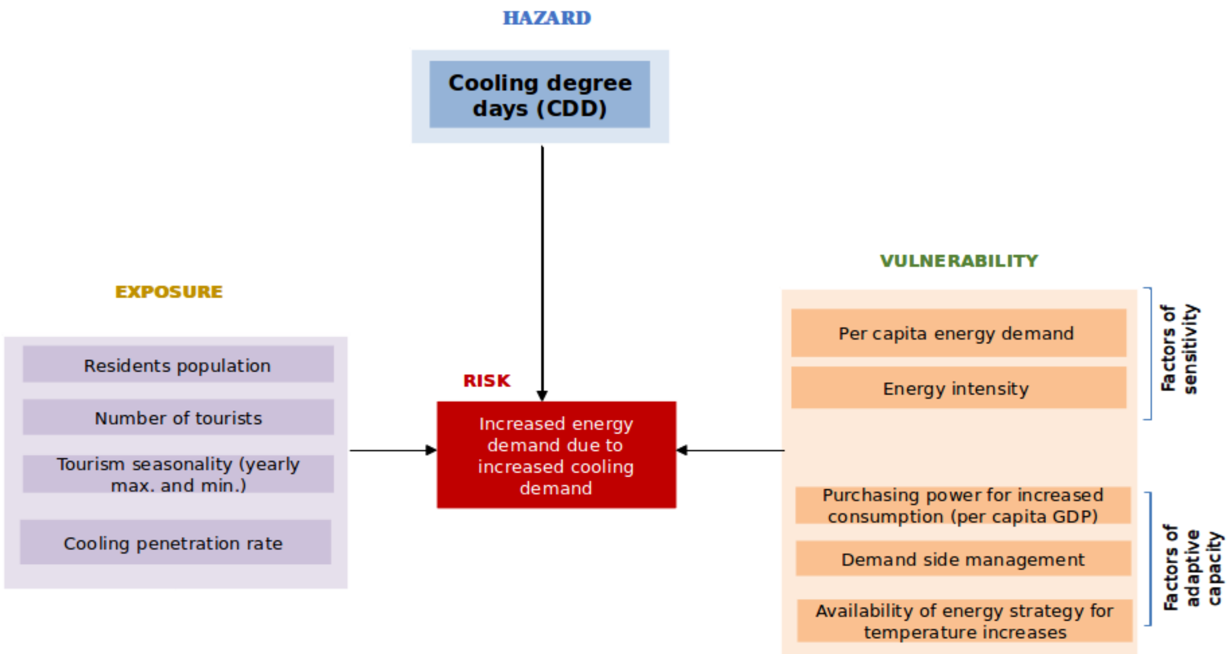

Figure 1. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased cooling demand*
Source: Soclimpact project Deliverable 4.5-Comprehensive approach for policy makers

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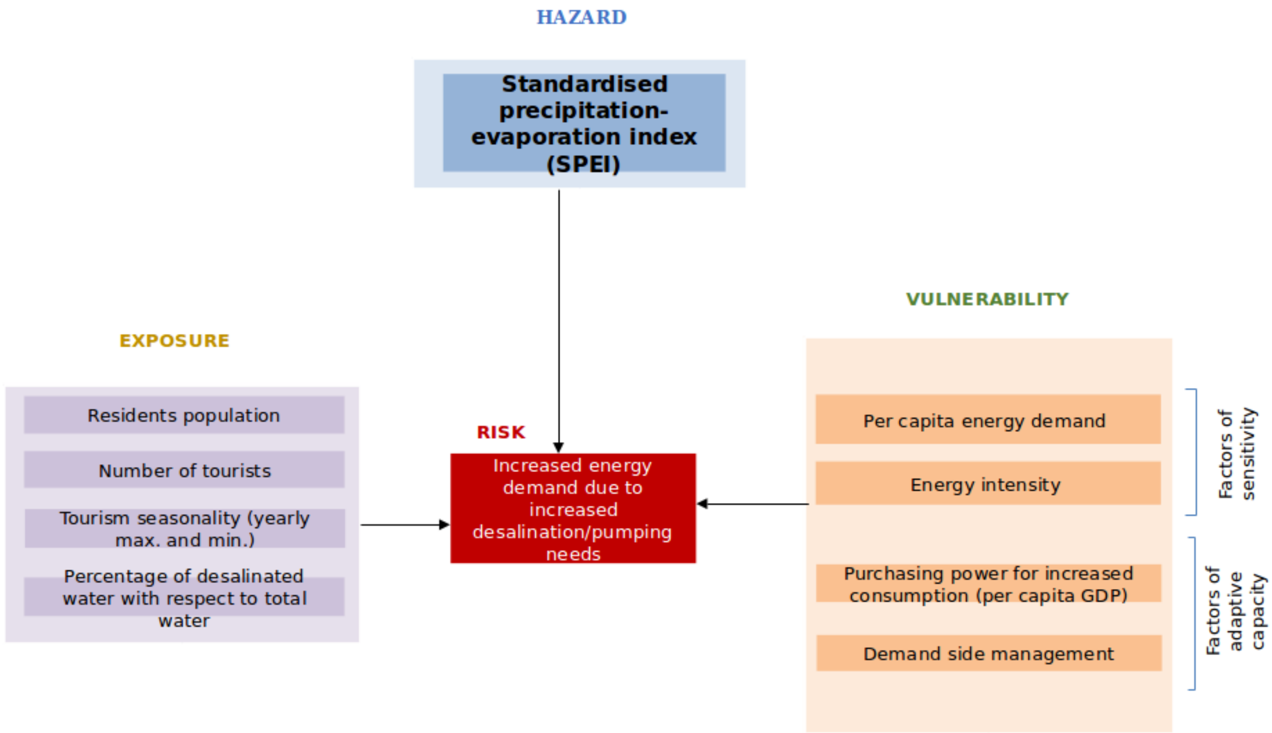

Figure 2. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased desalination demand*

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.

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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.

It was not possible to conduct a full operationalization of the IC for the case of Madeira. The criteria for the exclusion of the island was: (a) availability of data for the computation of the exposure and vulnerability indicators of the demand-side ICs, (b) modeling constraints of the hazard component. In the next tables we present the normalized hazard scores for the island. In this regard, the assessment was carried out on the normalized hazard indicators

Table 1. *Energy demand and supply hazard scores for Madeira*

Histori-cal ref.(1986-2005)	***Demand***		***Supply:***	Productivity Land	Productivity Sea	Droughts
	CDD	**0.01 (2.6)** **0.06 (8.5)**	Wind	**0.20**	**0.00**	**0.67**
	SPEI	**0.00**	Solar PV	**0.54**	**0.52**	**0.20**
			Combined			**0.47**

RCP2.6 (2046-2065)	***Demand***		***Supply:***	Productivity change		Droughts change
	CDD	**0.04**	Wind	**0.7**	**0.7**	**0.8**
	SPEI	**0.32**	Solar PV	**0.6**	**0.6**	**0.9**
			Combined			**1.0**

RCP8.5 (2046-2065)	***Demand***		***Supply:***	Productivity change		Droughts change
	CDD	**0.18**	Wind	**0.6**	**0.5**	**0.5**

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SPEI	0.60

Solar PV	0.4	0.6	0.1
Combined			0.6

RCP2.6 (2081-2100)

	Demand
CDD	0.04
SPEI	0.28

Supply:	Productivity change		Droughts change
Wind	0.8	0.7	0.8
Solar PV	0.7	0.7	0.9
Combined			1.0

RCP8.5 (2081-2100)

	Demand
CDD	0.35
SPEI	0.96

Supply:	Productivity change		Droughts change
Wind	0.6	0.5	0.5
Solar PV	0.3	0.6	0.0
Combined			0.5

Categorization:

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

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

For Madeira, CDD scores are presently very low, and should remain in this category except under RCP8.5 scenario by the end of the century. This implies only limited increases in cooling energy demand at least until mid-century. The projected evolution of SPEI scores is clearly worse. Under RCP2.6, this score increases to 0.32 by mid-century, stabilising thereafter. Under the high-emissions scenario, SPEI increase is already strong by mid-century, reaching almost the maximum score by the end of the century. This could imply a substantial pressure on water resources. Presently, there is only a desalination plant in the smallest island, Porto Santo. The observed time-series from this desalination plant show nevertheless the positive impact of efficiency measures, as the specific consumption has decreased from 5.5 kWh/m^3 in 2006 to 4 kWh/m^3, and the yearly maximum desalination consumption has also decreased from the highest value attained in August 2007 (807 MWh) to a clearly lower value of 626 MWh in August 2017 (this is the highest value in the last decade).

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

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

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

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

**** Islands' comparison and challenges***

- The contrast between the mitigation scenario (RCP2.6) and the high-emissions scenario is drastic. Not only are the hazard scores much lower for RCP2.6, but they even tend to decrease slightly during the second half of the century, while for RCP8.5 the hazard scores tend to rise in a sustained way.

- The Atlantic islands show a more contained increase of CDD than the Mediterranean islands, while the SPEI decrease is similar in both basins. One reason for this different behaviour can be the higher sea surface temperatures of the Mediterranean Sea in summer. Another factor may be the different wind regimes in summer, as trade winds are strong and persistent over Canary Islands and Madeira, contributing to moderate temperatures, while over the Mediterranean Sea winds are generally low in summer.

- 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 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.

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- 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.

- 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 future change of wind energy and PV productivity should be rather small in general: around 5% or less with respect to the reference period in many cases, with maximum changes of about 10% for some islands at the end of the century under RCP8.5 scenario (particularly for wind energy productivity over land). A 10% productivity change could have a significant impact on a planned or existing plant if it occurs over the lifetime of the power plant, but in this case such a change would extend over many decades, which will facilitate adaptation and efficiency measures.

- In general, projections show a decreasing tendency of wind energy productivity over the Mediterranean region, with a more important decrease for the RCP8.5 scenario. The main exception is Crete, which shows a consistent increasing tendency.

- Projected PV productivity changes are generally smaller than wind energy changes. In most cases PV productivity remains constant or decreases slightly. The main exception is Fehmarn, which shows a clear decreasing tendency in PV productivity under RCP8.5 scenario, reaching a 10% decrease by end of the century.

- There is a specific uncertainty source in the photovoltaic projections. Most regional climate model simulations, including the ones used here, do not include a projected evolution of aerosols in future climate runs. The missed effect of the likely evolution of aerosols would likely increase to some degree the future surface solar radiation and PV productivity over most of the islands (Gutiérrez et al., 2020).

- Renewable energy productivity droughts are a measure of the variability of the resource. Wind droughts are much more frequent (around 50% of the days for most islands) than PV droughts (10% or less of the days). This agrees with results from the study of Raynaud et al. (2018), and highlights the stable character of the solar productivity in comparison to wind productivity over time.

- Wind energy droughts are more frequent in the Mediterranean islands than in the Atlantic islands or Fehmarn. The best quality resources in terms of stability are found for Canary Islands, which show the minimum values of both wind energy and PV droughts among all islands. Fehmarn shows by far the worse PV drought score, corresponding a drought frequency of 23% of the days.

- Projected changes in the frequency of droughts are small, with future variations that generally do not attain a magnitude greater than 5% of the days. This indicates that the time-variability characteristics of wind and PV energy are a robust feature, which is relevant for planning the amount of storage or backup needed.

- The combination of PV and wind energy has generally a very positive impact on the frequency of droughts as a result of the complementarity of both sources. This impact also exists but is less clear for islands with substantial summer wind energy resources (Canary Islands, Madeira and Crete).

- As part of the pathway towards very high or 100% RES shares, offshore wind energy should play a very relevant role. Solutions to overcome the obstacle posed by the deep bathymetry surrounding most of the islands are beginning to near commercial deployment, so that floating offshore wind plants are already planned near Gran Canaria and Sicily.

- Offshore PV could be an interesting option for some islands, particularly when land surface limitations are large. There is growing interest in this option, as shown by the test plants being installed and the references made to this technology in the Roadmap for the Offshore Renewable Energy Strategy of the European Commission or in the report of Monitor Deloitte and Endesa (2020) about the accelerated decarbonization of Canary and Balearic Islands.

- The combination of different types of offshore renewable energy sources in the same platform is also attracting interest, as the different sources can exhibit complementarity in time and the combined output can thus be more stable and reliable. The different RES can also share part of the installations, like the connection to land, reducing their cost (Pisacane et al., 2018; MarineEnergy, 2019a). The European Union is trying to promote such combinations, through projects like MUSICA (Multiple Use of Space for Island Clean Autonomy) which will design and test a floating offshore platform integrating wind, PV and wave energy for use on islands (MarineEnergy, 2019b), and plans to develop roadmaps for its deployment in three case study islands, among them Malta and the Canaries (MaREI, 2020).

- 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.