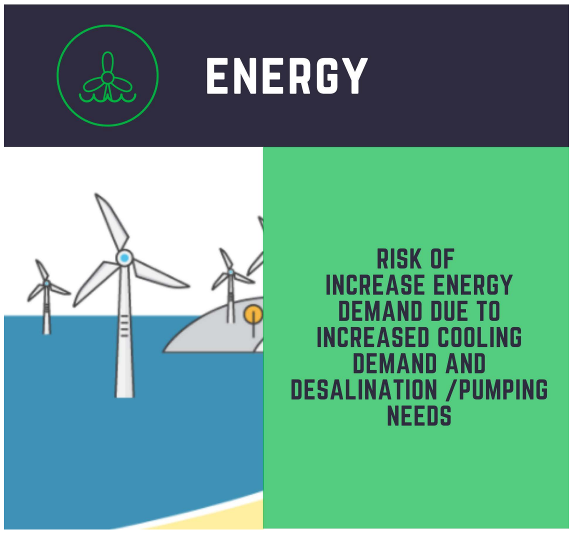
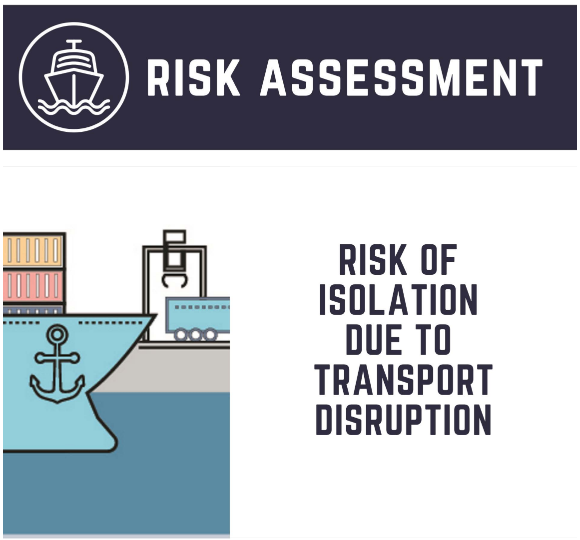
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No776661

CLICK ON THE IMAGE TO READ THE REPORT OF YOUR TOPIC INTEREST





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

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.

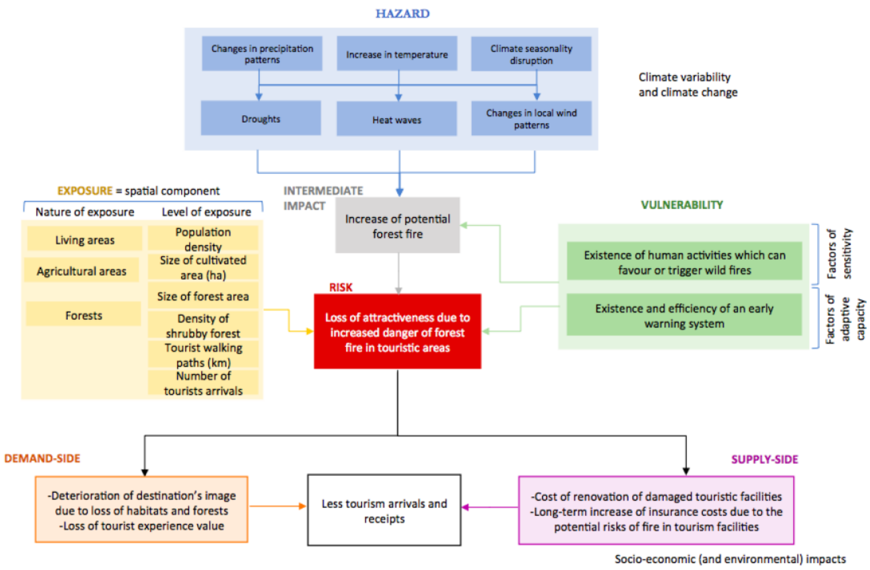


Figure 1: Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.2

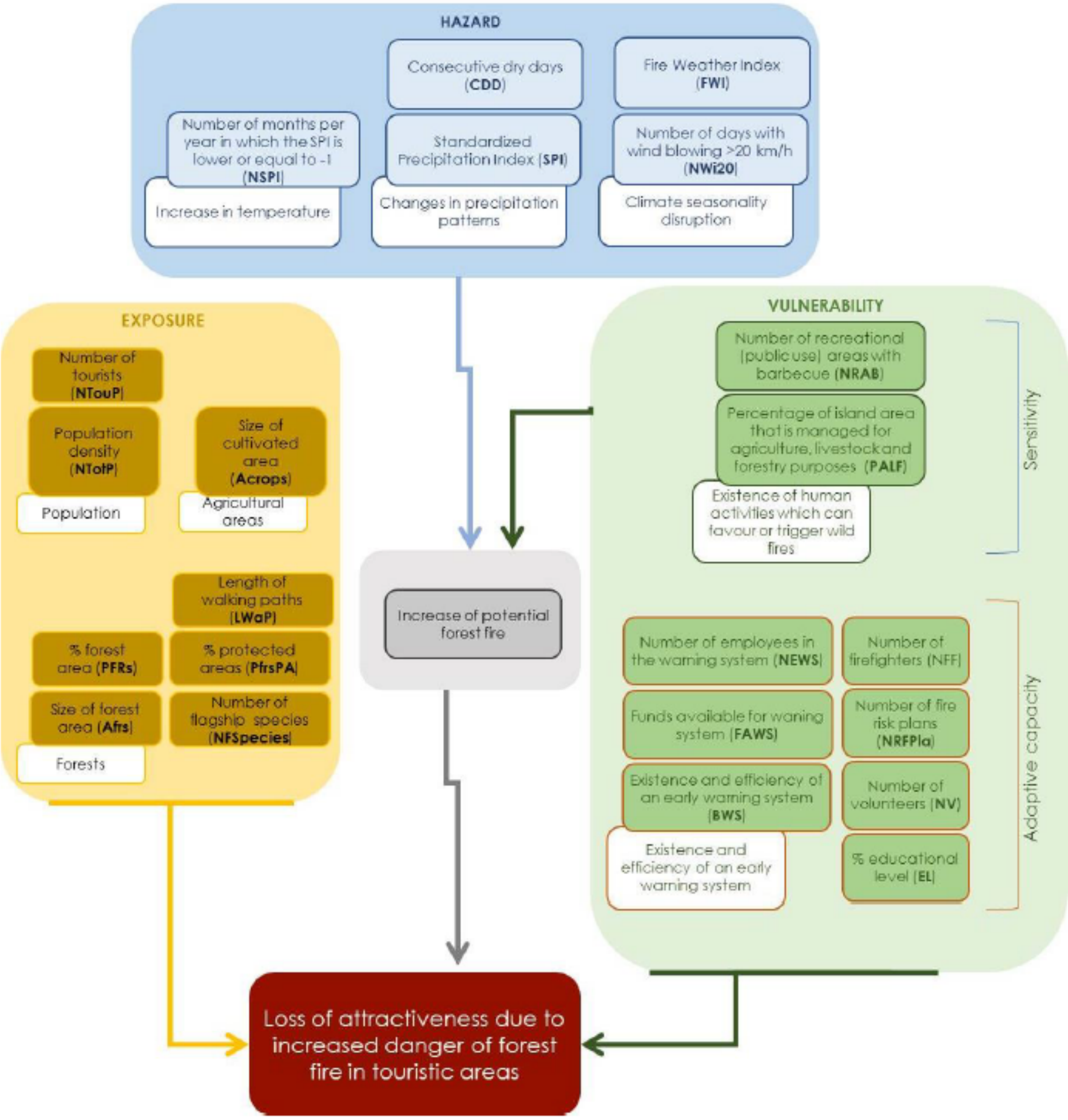


Figure 2 : Loss of attractiveness due to increased danger of forest fire in touristic areas
Source: Soclimpact deliverable D3.3

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.

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

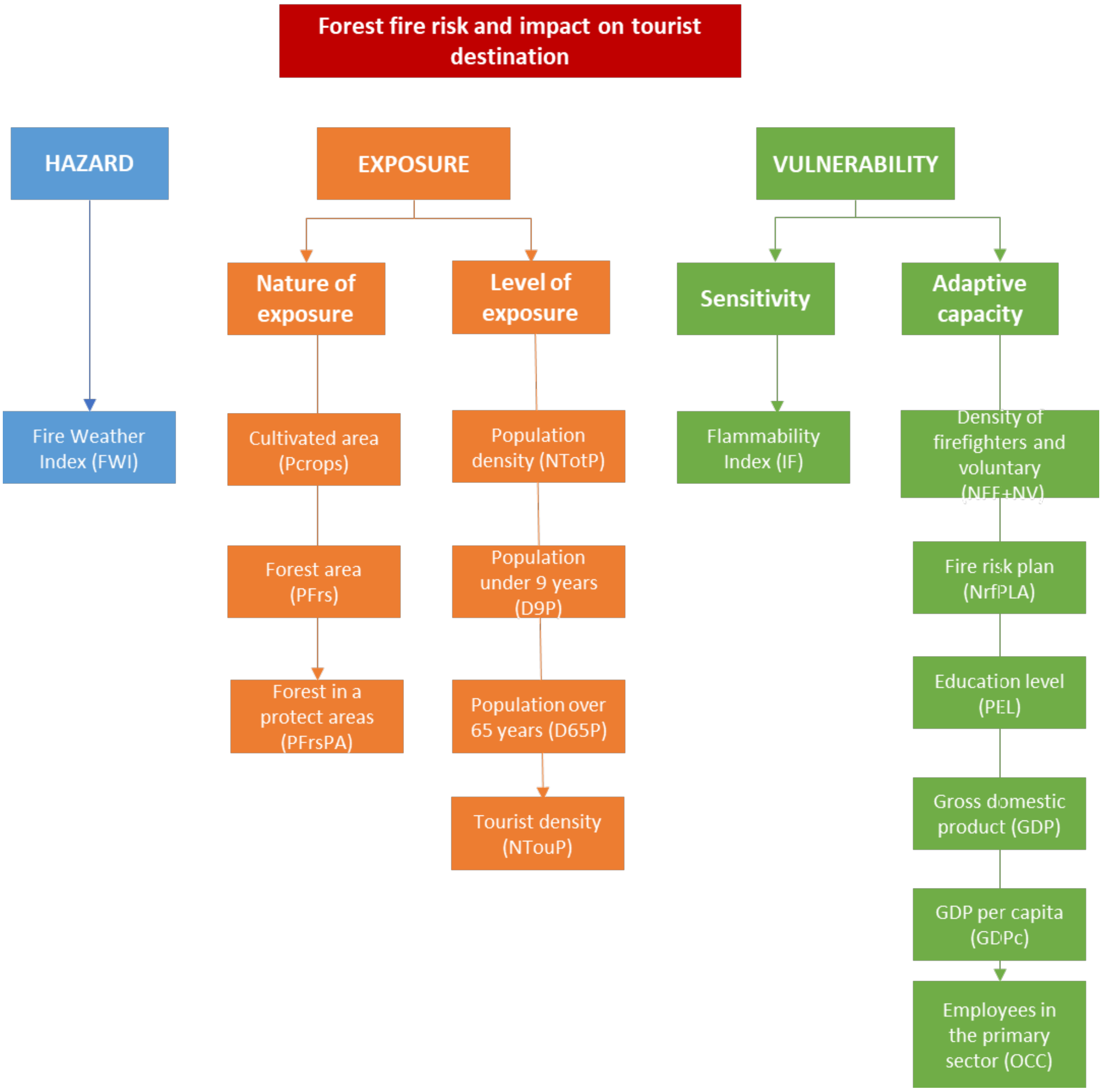


Figure 3: Final Impact Chain Model
Source: Soclimpact deliverable D4.5

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).

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

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>Comparative study</u>

Hazard

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.

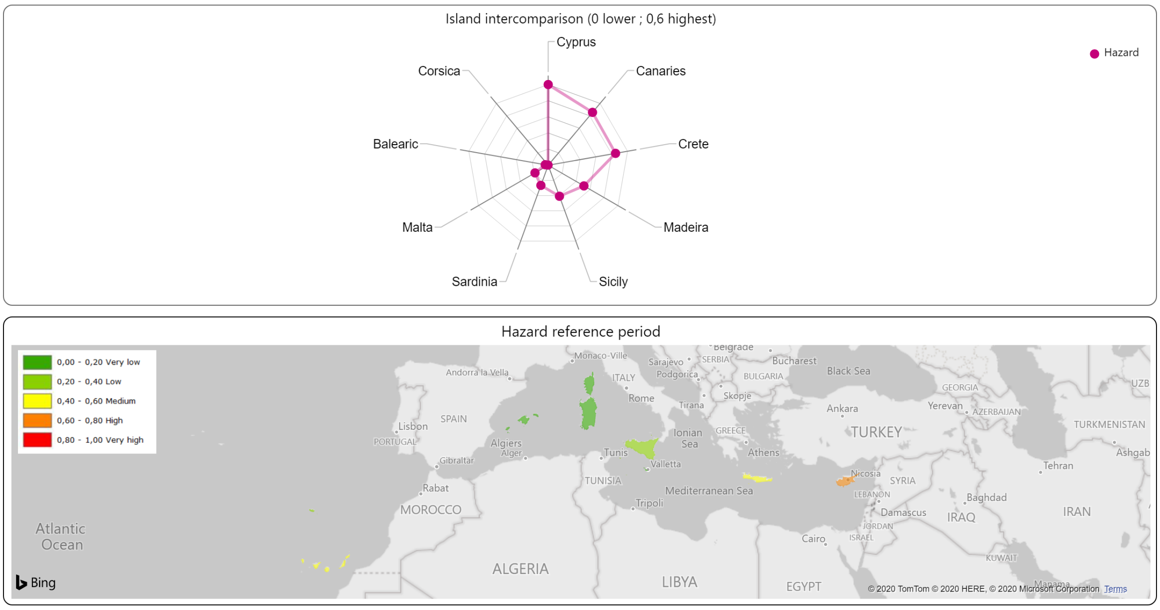


Figure 4: Hazard score (Fire Weather Index) per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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

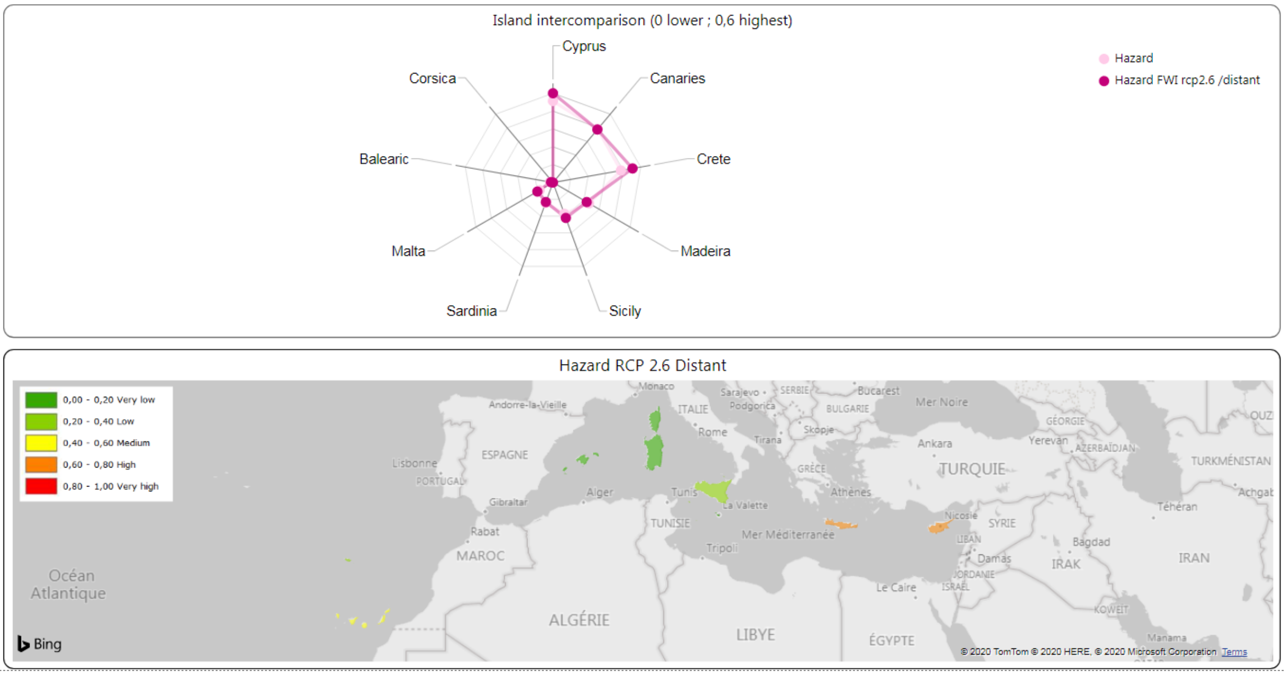


Figure 5: Hazard score (Fire Weather Index) per island at the end of the century (2081-2100) under RCP2.6 (Ambitious Mitigation Policies)
Source: Soclimpact deliverable D4.5

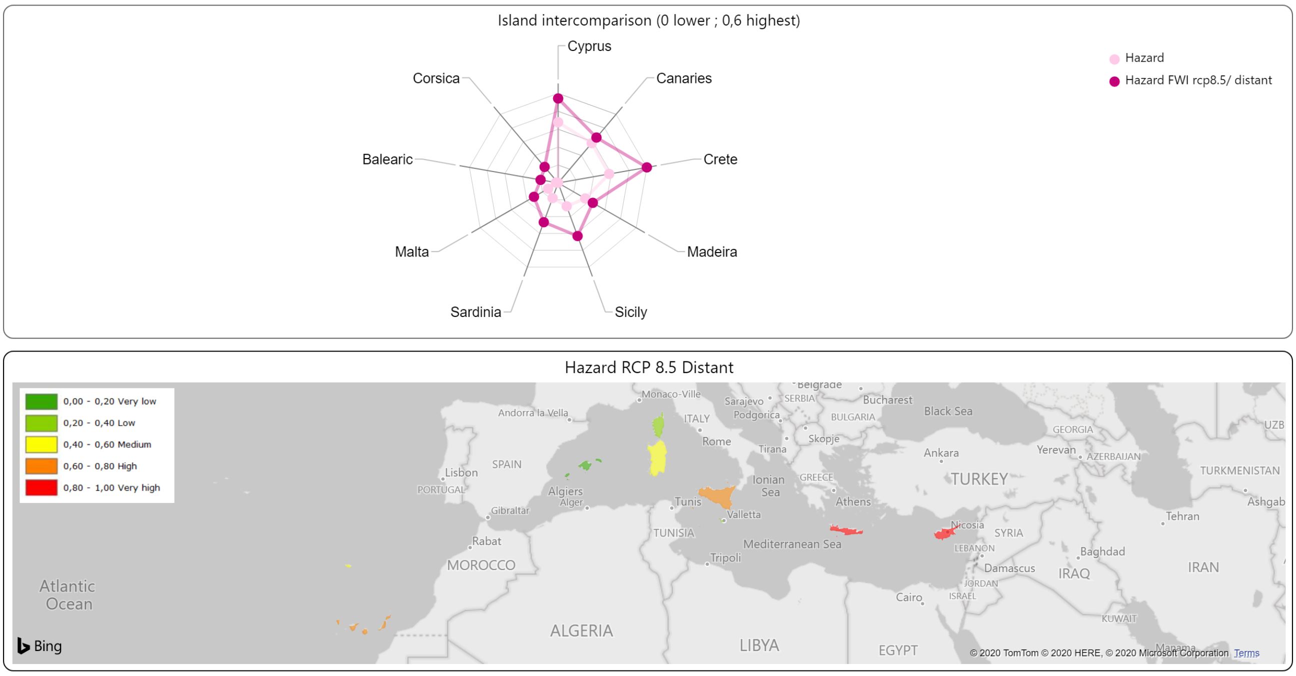


Figure 6: Hazard score (Fire Weather Index) at the end of the century (2081-2100) under RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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

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.

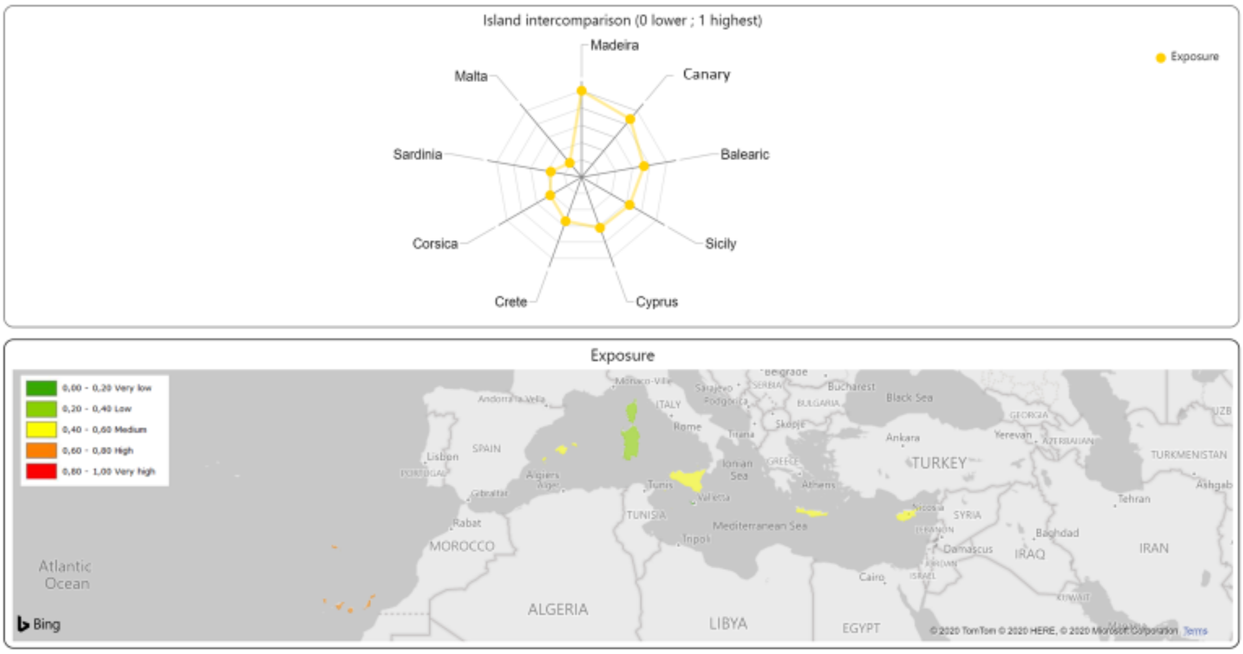


Figure 7: Exposure score (current period) per island
Source: Soclimpact deliverable D4.5

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

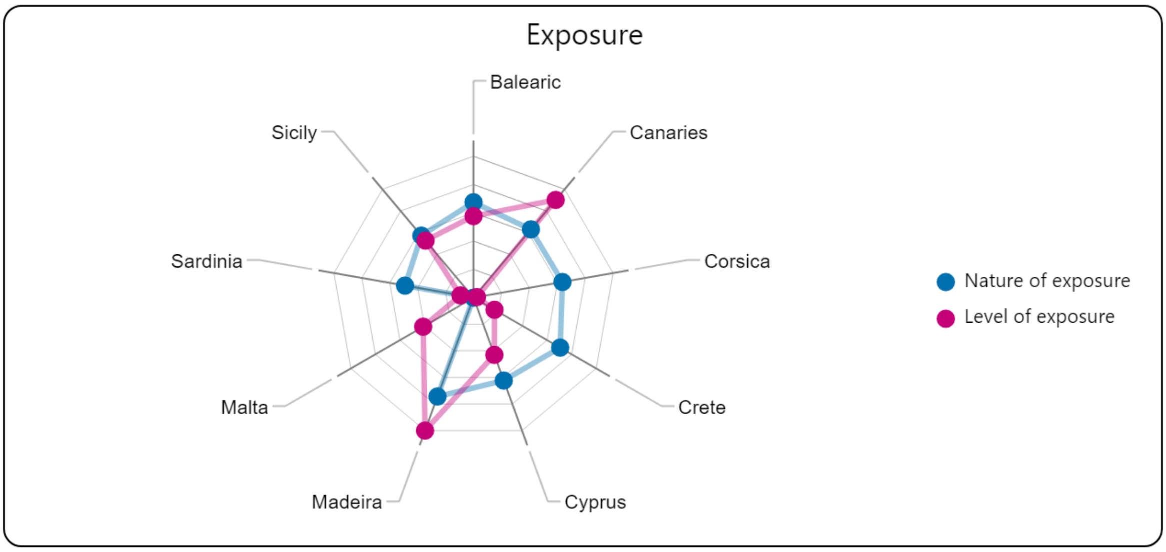


Figure 8: Subcomponents of exposure and related score (current period) per island
Source: Soclimpact deliverable D4.5

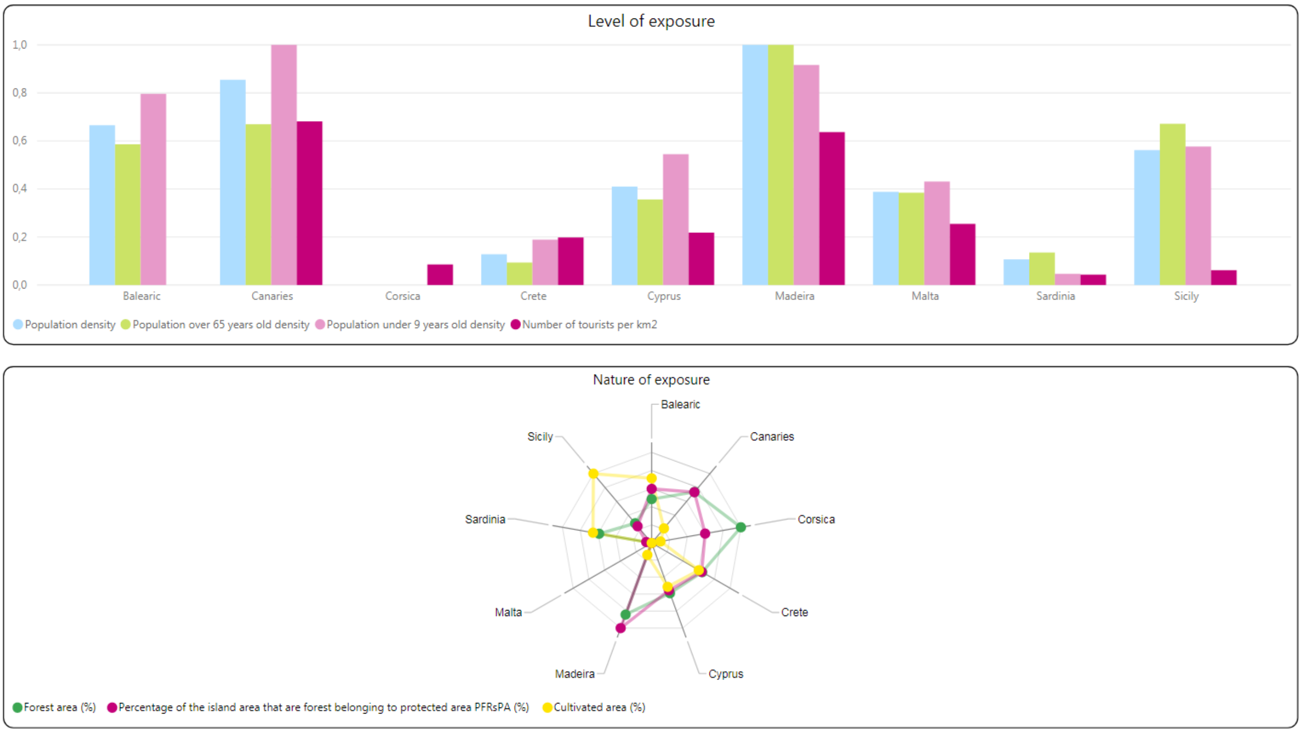


Figure 9: Breakdown by exposure subcomponent
Source: Soclimpact deliverable D4.5

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

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:
    - o high score for employees in the primary sector, apart from Sardinia and Sicily;
    - o scores for density of firefighters and volunteers are important for all the islands except for Cyprus;
    - o GDP per capita and level of education are the most heterogeneous factors of influence;
    - o GDP per capita score is very high for **Crete**, very low for Corsica, Malta and Balearic Islands.
    - o Scores for education level is important for Cyprus and low for Madeira, Malta and Corsica.

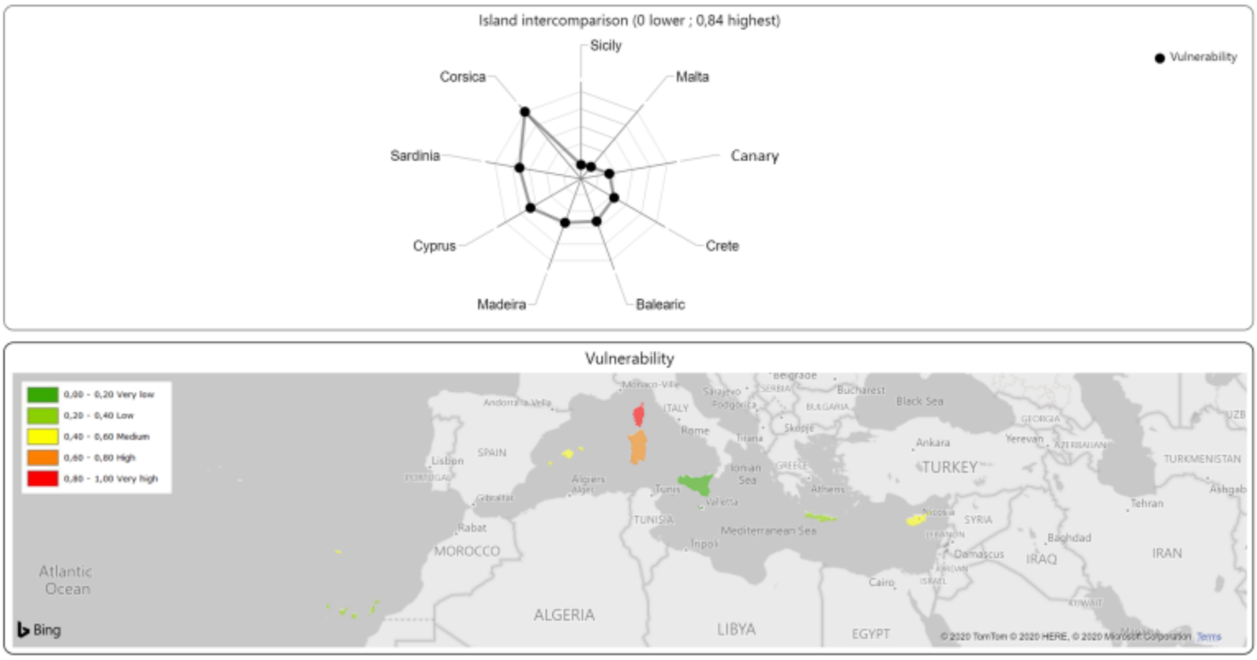


Figure 10: Vulnerability score per island
Source: Soclimpact deliverable D4.5

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

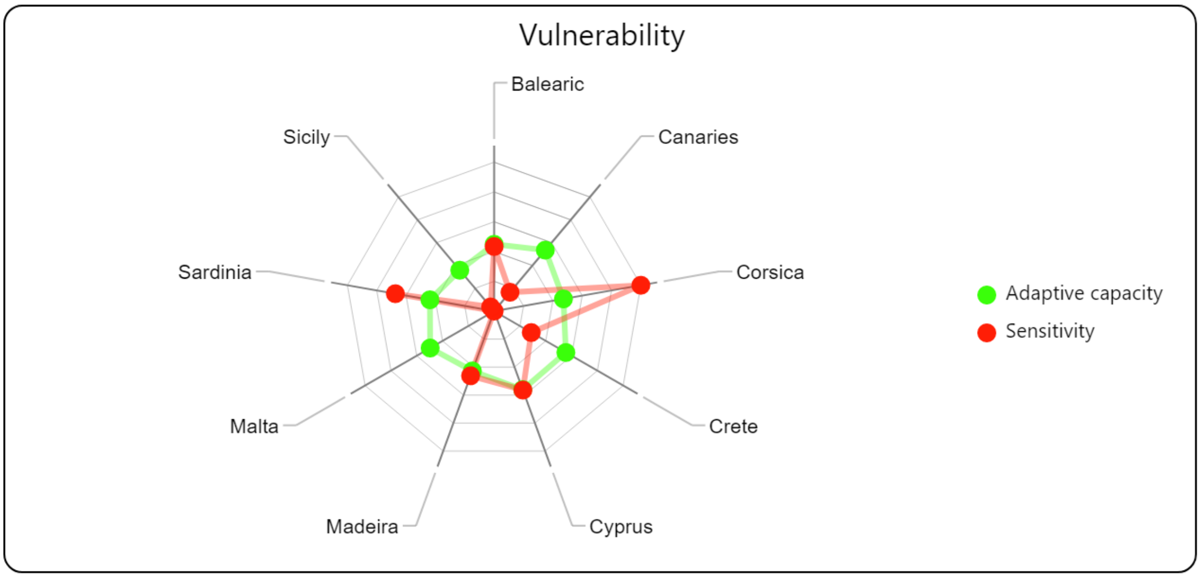
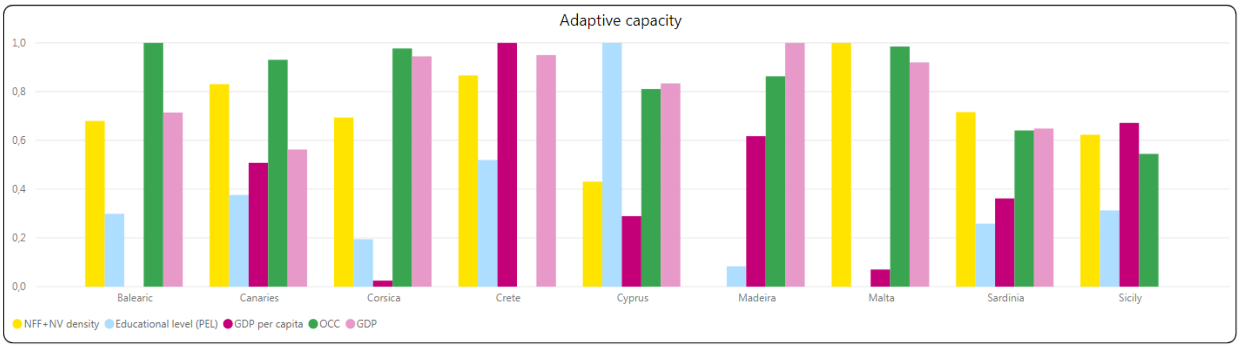


Figure 11: Subcomponents of vulnerability and related score (current period) per island
Source: Soclimpact deliverable D4.5



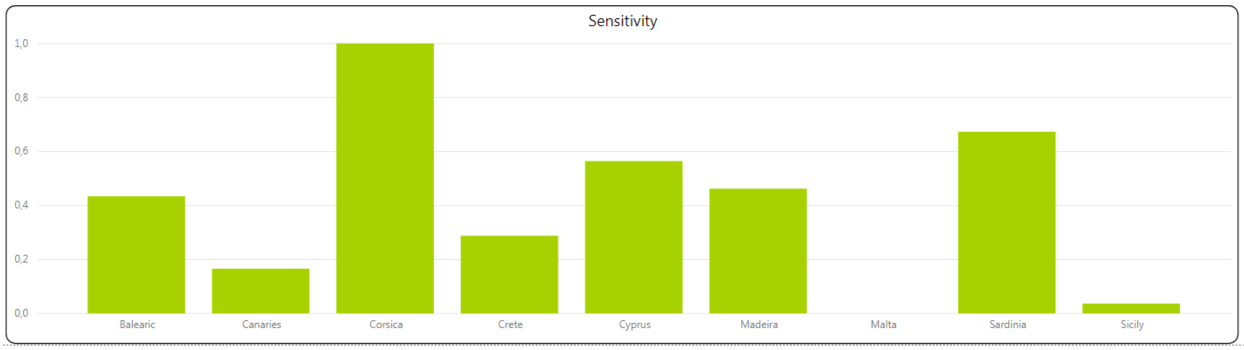


Figure 12: Details and scores of the two subcomponents (adaptive capacity and sensitivity) per island
Source: Soclimpact deliverable D4.5

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

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:
    - o Madeira, Canary Islands, Sicilia and Balearic Islands: Predominance of exposure component (around 50% of the score);
    - o **Crete** and Cyprus: Predominance of the hazard component (around 40% of the score);
    - o Corsica and Sardinia: Predominance of the vulnerability component (around 60-70%);
    - o Only Malta has a quite balanced distribution across the components.

- In this exercise, only the hazard component is changing in the future. In the near future 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).

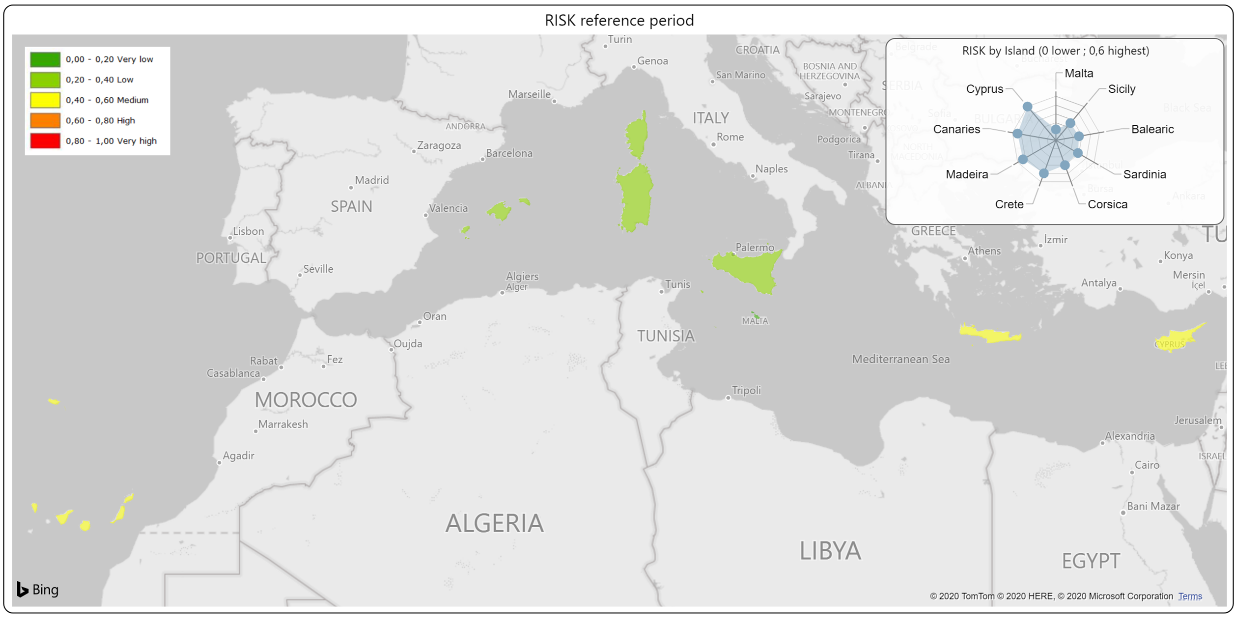


Figure 13: Risk score per island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

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

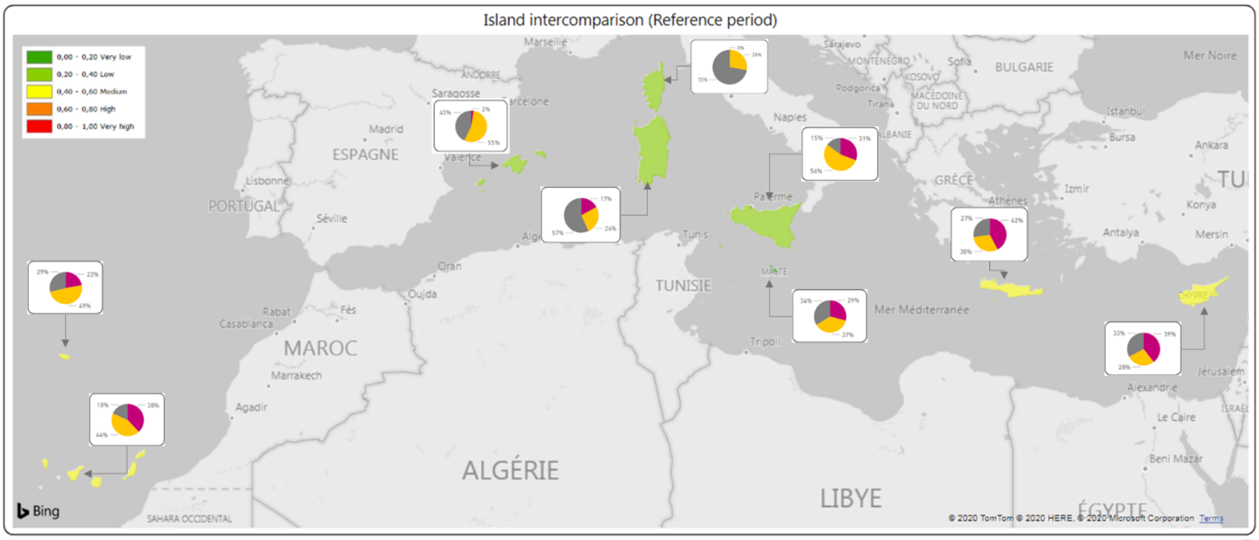


Figure 14: Risk breakdown by island for the reference period (1986-2005)
Source: Soclimpact deliverable D4.5

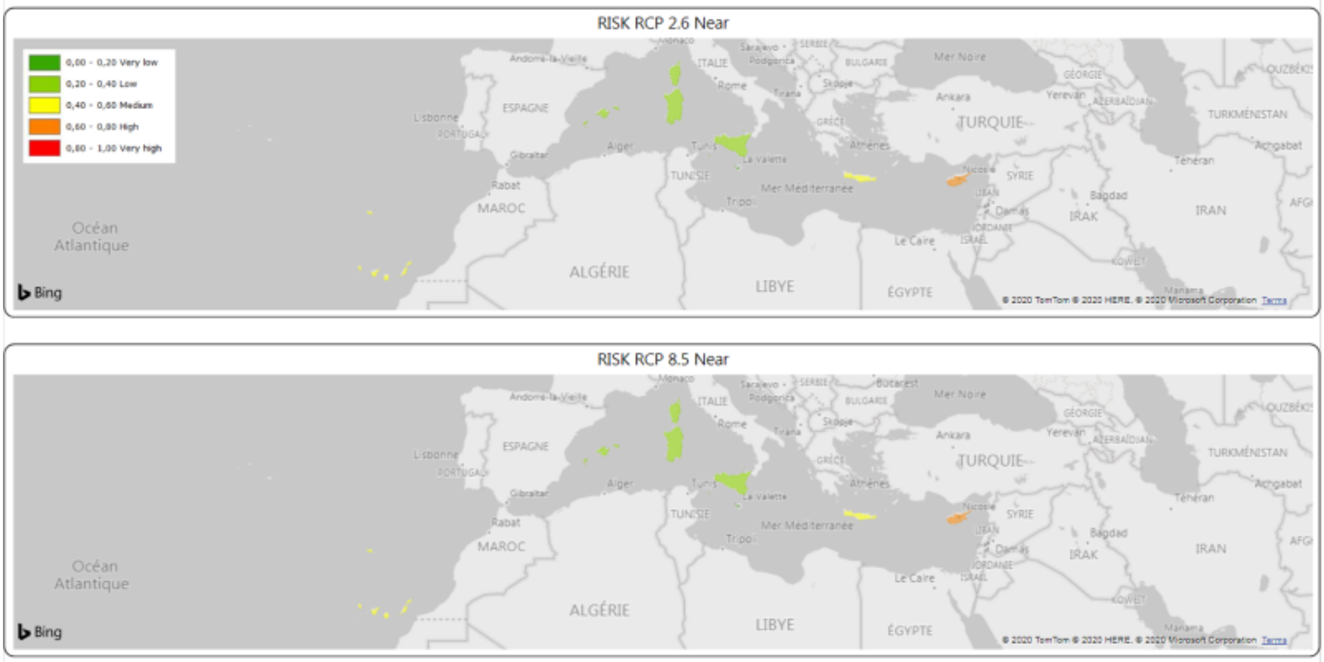


Figure 15: Risk score per island in the near future (2046-2065) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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

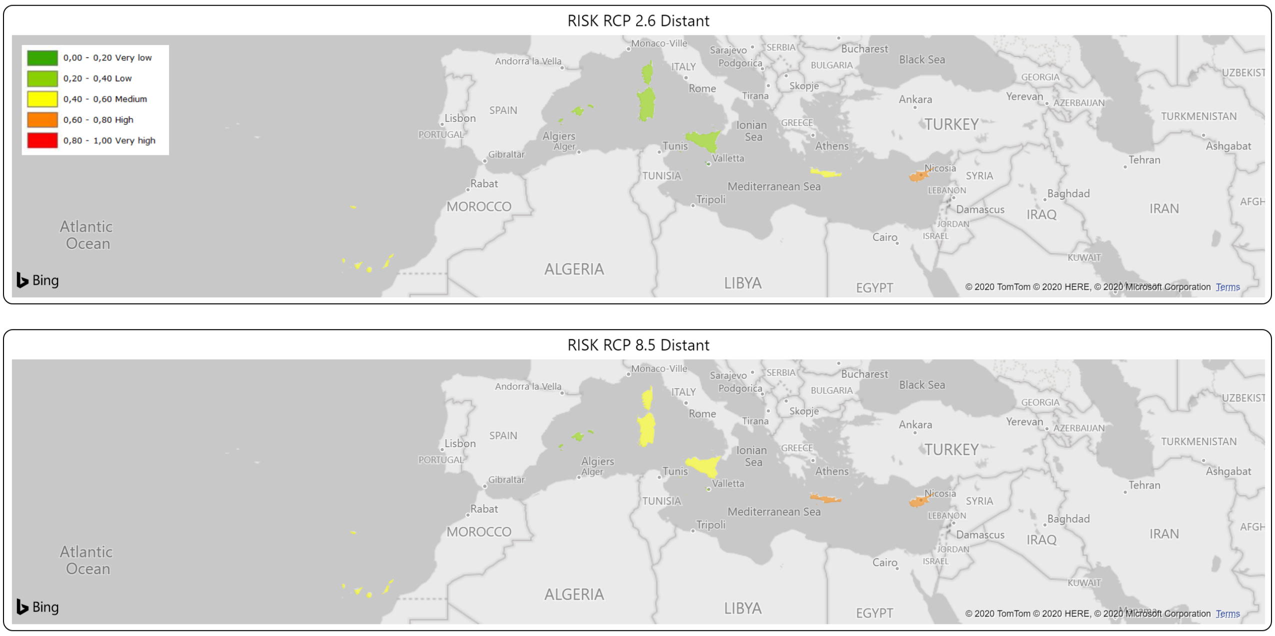


Figure 16: Risk score per island at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

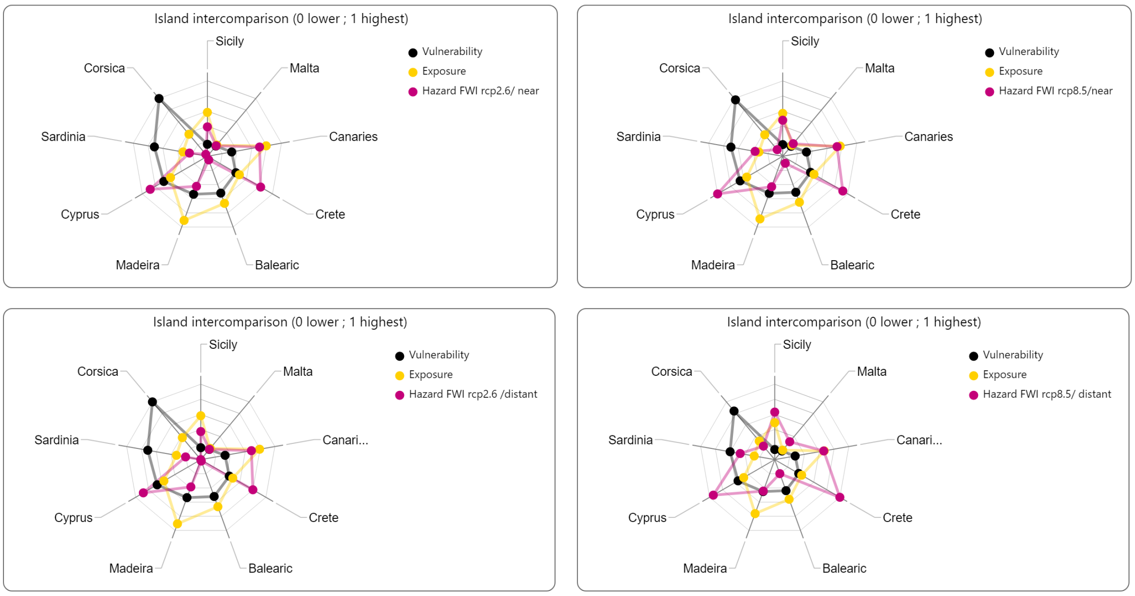


Figure 17: Score per component and per island in the near (2046-2065) and the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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

Crete island results

The component of hazard is predominant (50%) and the risk is medium under reference period and under RCP 2.6. (end of century). The risk is high under RCP 8.5. (end of century).

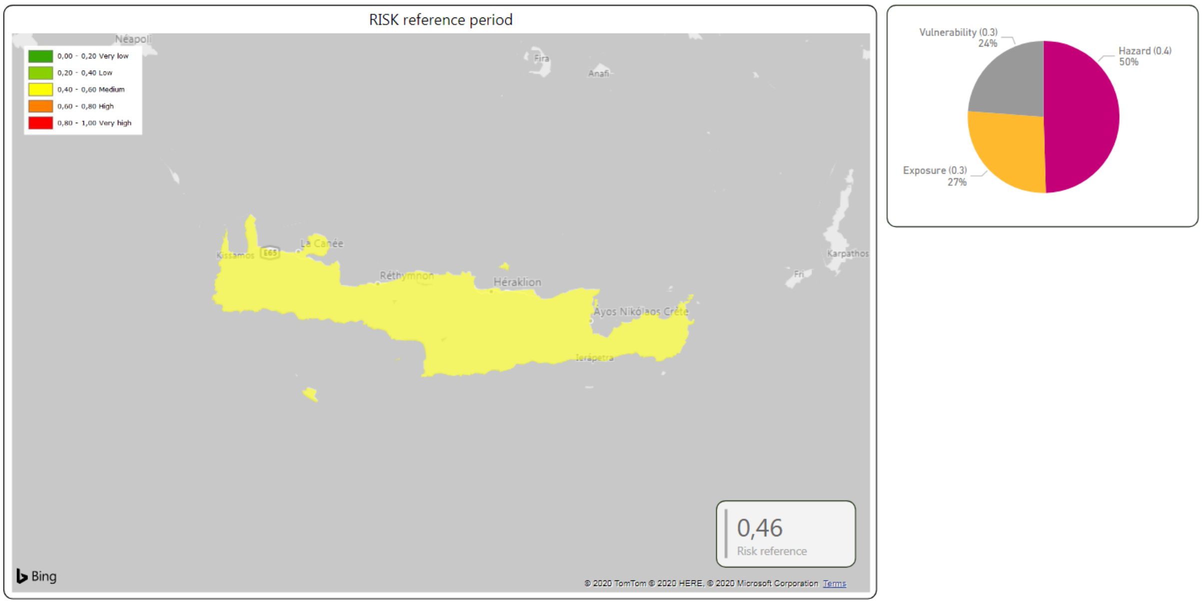


Figure 18: Risk score and components of the risk for the reference period
Source: Soclimpact deliverable D4.5

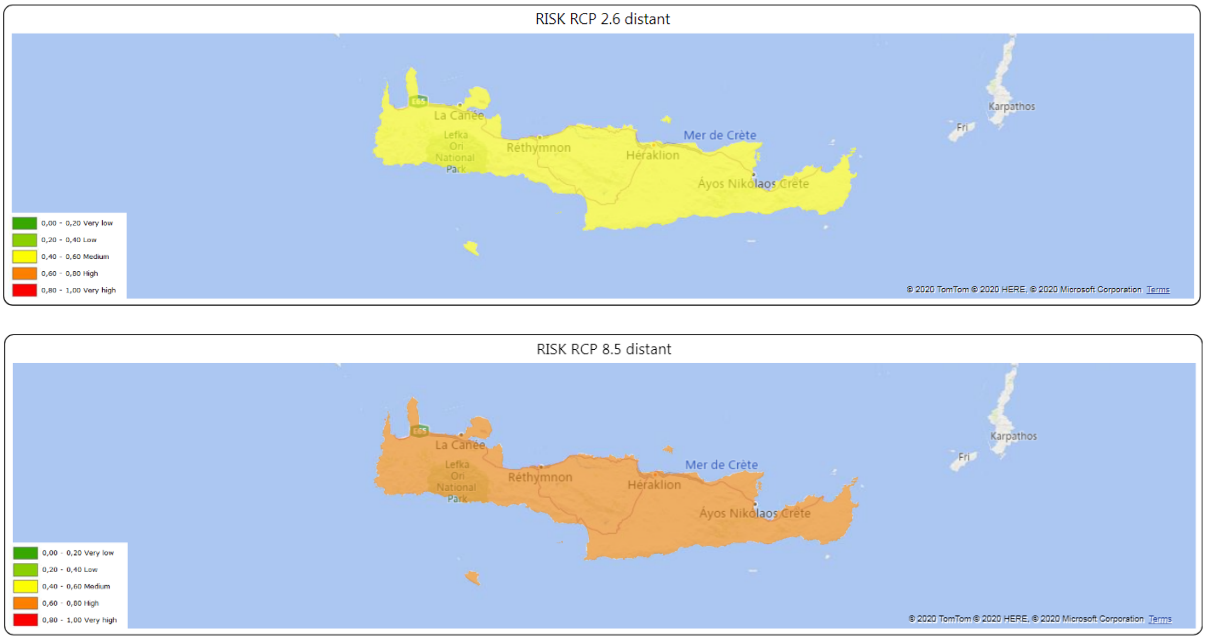


Figure 19: Risk score at the end in the distant future (2081-2100) under RCP2.6 (Ambitious Mitigation Policies) and RCP8.5 (Business as usual)
Source: Soclimpact deliverable D4.5

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

The component of exposure is represented in majority by the nature of exposure (80%).

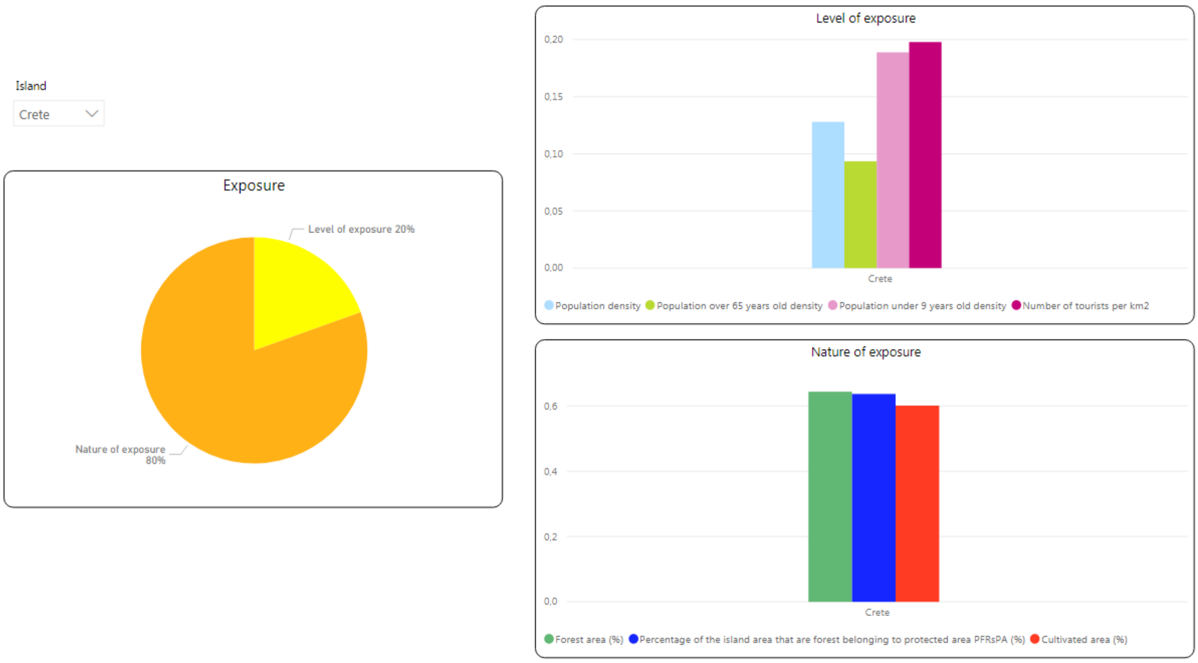


Figure 20: Details and scores of the two subcomponents of exposure (nature and level of exposure)
Source: Soclimpact deliverable D4.5

Considering the vulnerability component, the sub-component of adaptative capacity is the most represented (66%).

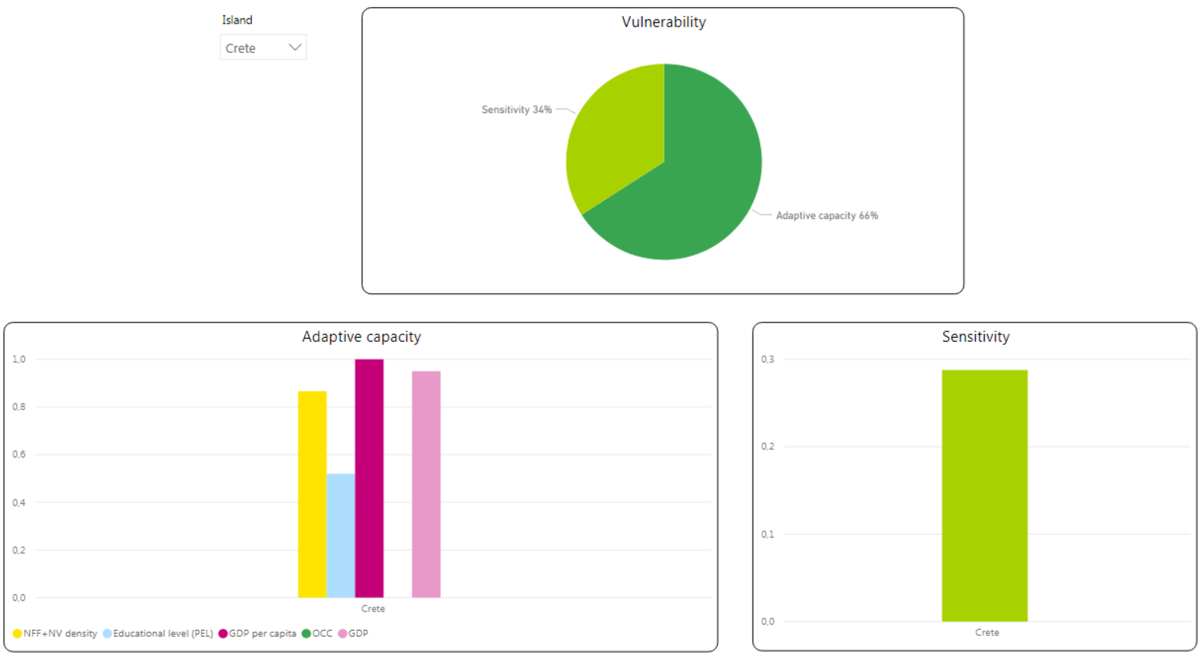


Figure 21: Details and scores of the two subcomponents of vulnerability (adaptative capacity and sensitivity)
Source: Soclimpact deliverable D4.5

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

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

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

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.

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

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

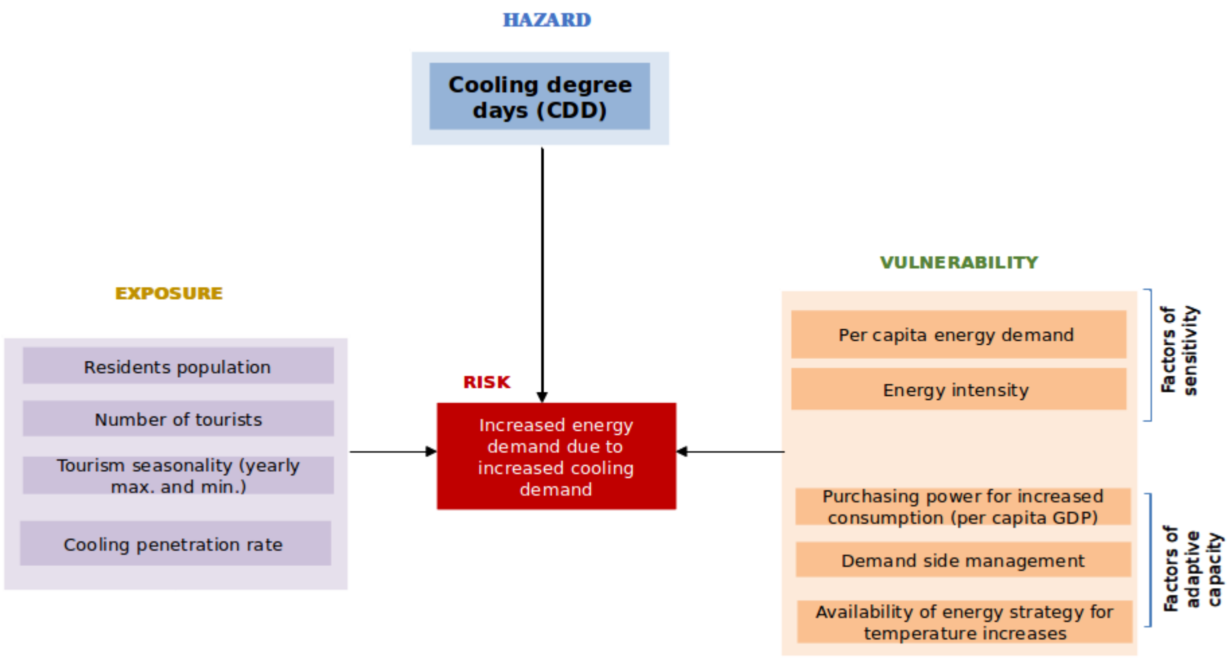


Figure 1. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased cooling demand*

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

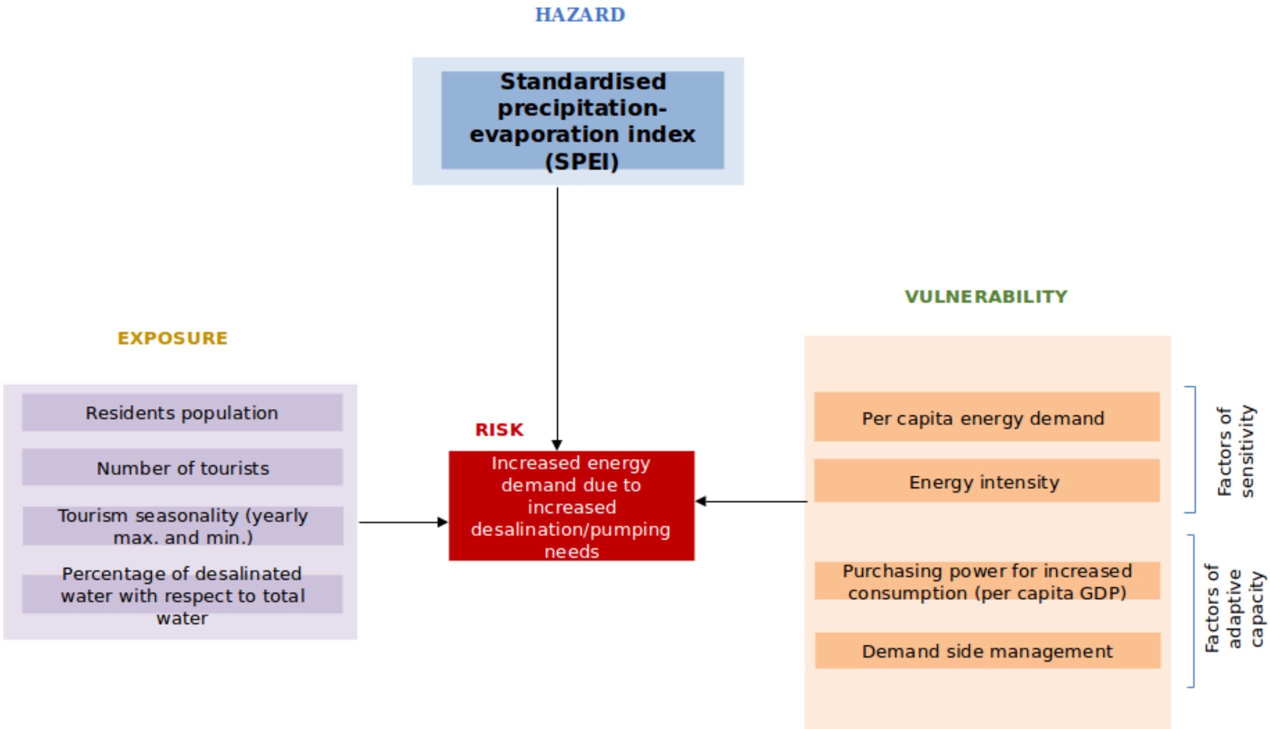


Figure 2. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased desalination demand*

Source: Soclimpact project Deliverable 4.5-Comprehensive 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.

SOCLIMPACT

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

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 Crete.. The criteria for the selection of the islands have been: (a) availability of data for the computation of the exposure and vulnerability indicators of the demand-side ICs, (b) modeling constraints of the hazard component. In the next tables we present the normalized hazard scores for the island.

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

Histori-cal ref.(1986-2005)

Demand	
CDD	**0.20**
SPEI	**0.00**

Supply:	Productivity Land	Productivity Sea	Droughts
Wind	**0.63**	**0.00**	**0.84**
Solar PV	**0.19**	**0.21**	**0.16**
Combined			**0.41**

RCP2.6 (2046-2065)

Demand	
CDD	**0.29**
SPEI	**0.32**

Supply:	Productivity change		Droughts change
Wind	**0.1**	**0.3**	**0.2**
Solar PV	**0.4**	**0.6**	**0.1**
Combined			**0.3**

RCP8.5 (2046-2065)

Demand	
CDD	**0.42**
SPEI	**0.68**

Supply:	Productivity change		Droughts change
Wind	**0.2**	**0.3**	**0.3**
Solar PV	**0.6**	**0.7**	**0.4**
Combined			**0.5**

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

RCP2.6 (2081-2100)

Demand	
CDD	**0.28**
SPEI	**0.32**

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

RCP8.5 (2081-2100)

Demand	
CDD	**0.66**
SPEI	**0.96**

Supply:	Productivity change		Droughts change
Wind	**0.2**	**0.5**	**0.4**
Solar PV	**0.6**	**0.7**	**0.1**
Combined			**0.7**

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-Comprehensive approach for policy makers

The low present CDD score would not increase much under RCP2.6 scenario, pointing to a limited cooling energy demand in this case. The increase of Etesian winds in summer would help to moderate this demand. In contrast, under RCP8.5 this score would reach high values by the end of the century. Regarding the hydrological drought conditions, some increase during the first half of the century is expected under RCP2.6. Under RCP8.5, a strong and sustained worsening is projected, which would imply a high pressure on desalination energy demand. The possibility of using large quantities of brackish water instead of seawater can lower the cost of desalination (Zotalis et al., 2014).

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

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

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

- 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.

- 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.

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

- 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.

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

Risk of isolation due to transport disruption

SOCLIMPACT

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

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.

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

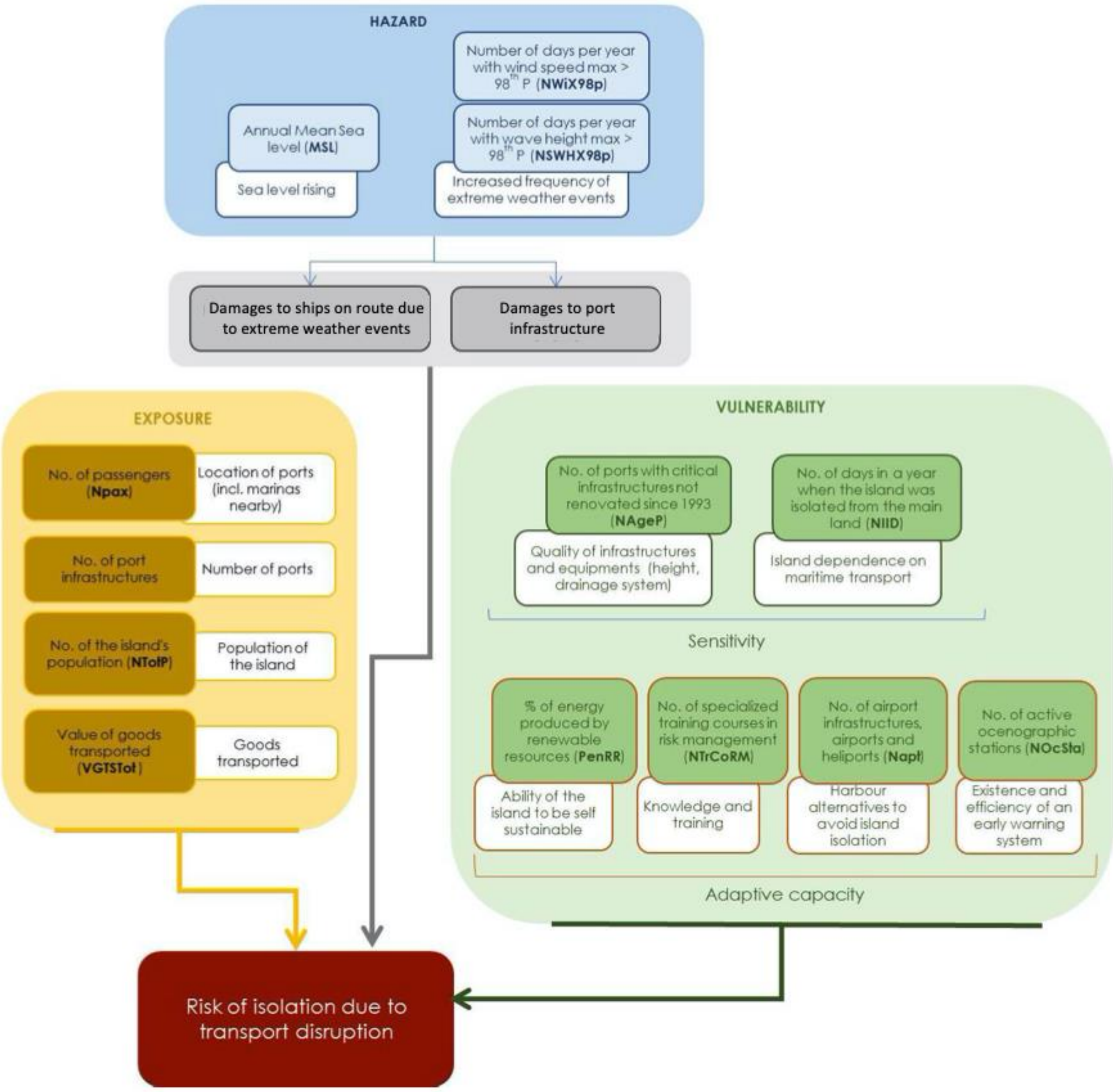


Figure 1. Conceptualization framework for the operationalization of the Maritime Transport Impact Chain: Risk of Transport Disruption.
Source: Soclimpac project deliverable 4.5

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.

SOCLIMPACT

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

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

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

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

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