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

Fehmarn

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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.

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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

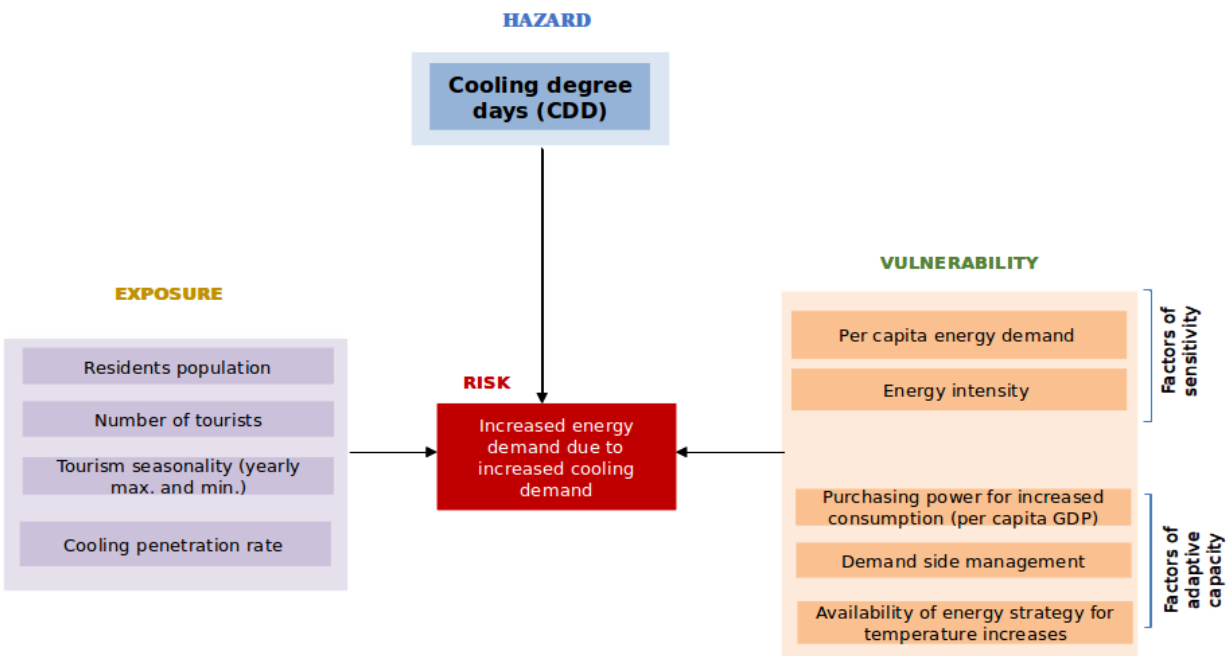

Figure 1. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased cooling demand*

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

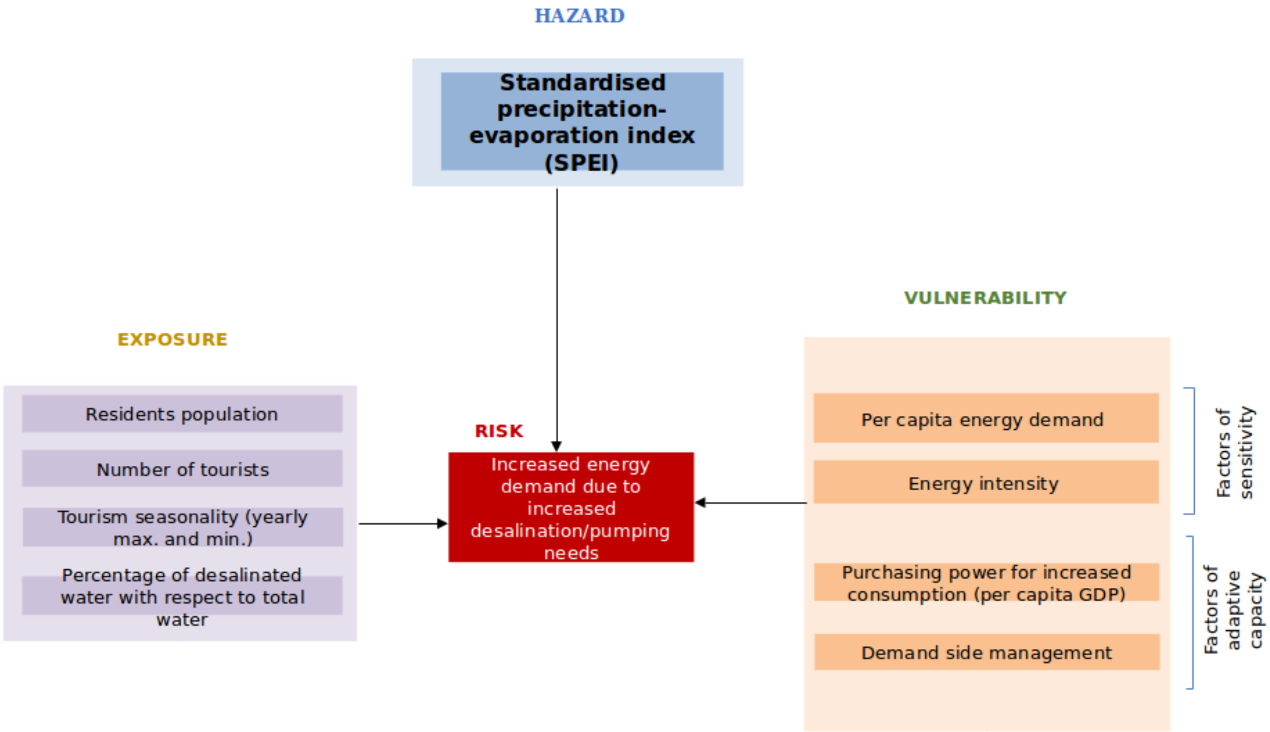

Figure 2. *Conceptualization framework for the operationalization of the energy impact chain: Risk of increased energy demand due to increased desalination demand*

Source: Soclimpact project Deliverable 4.5-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 Fehmarn.. 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 Fehmarn*

Historical ref.(1986-2005)	***Demand***	
	CDD	**0.00**
	SPEI	**0.00**

Supply:	Productivity Land	Productivity Sea	Droughts
Wind	**0.55**	**0.00**	**0.79**
Solar PV	**0.69**	**0.67**	**0.43**
Combined			**0.40**

RCP2.6 (2046-2065)	***Demand***	
	CDD	**0.00**
	SPEI	**0.20**

Supply:	Productivity change		Droughts change
Wind	**0.7**	**0.7**	**0.6**
Solar PV	**0.7**	**0.7**	**0.7**
Combined			**0.9**

RCP8.5 (2046-2065)	***Demand***	
	CDD	**0.01**
	SPEI	**0.28**

Supply:	Productivity change		Droughts change
Wind	**0.5**	**0.3**	**0.4**
Solar PV	**0.8**	**0.8**	**1.0**
Combined			**0.8**

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RCP2.6 (2081-2100)	***Demand***	
	CDD	**0.00**
	SPEI	**0.12**

Supply:	Productivity change		Droughts change
Wind	**0.8**	**0.8**	**0.8**
Solar PV	**0.6**	**0.6**	**0.7**
Combined			**1.0**

RCP8.5 (2081-2100)	***Demand***	
	CDD	**0.03**
	SPEI	**0.36**

Supply:	Productivity change		Droughts change
Wind	**0.4**	**0.4**	**0.5**
Solar PV	**1.0**	**1.0**	**1.0**
Combined			**0.9**

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

As could be expected due to its high latitude, hazard scores for Fehmarn are very different to most other islands. CDD is zero for present conditions and under RCP2.6 scenario, and it increases very little under RCP8.5. Cooling energy demand will not be a problem here. SPEI shows some tendency to increase, particularly under RCP8.5, but it should be taken into account that this score is relative to the present climate SPEI which defines the minimum threshold, and the climate in the area is wet. Therefore, no significant problems should be expected regarding water availability.

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

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

**** 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

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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.

- 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

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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.