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

SOCLIMPACT

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Work Package 5:

Measuring market and non-market costs of Climate Change and benefits of climate actions for Europe

Deliverable 5.1. Report on the bibliography.

Coordinated by ULPGC (Carmen García Galindo and Yen E. Lam González) with the participation of Soclimpact partners (UNIBO, AquaBioTech, CYI, CETECIMA) and reviewed by Elias Giannakis (CyI) and Paolo Figini (UNIBO), according to the quality review internal process.

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	Coastal and Maritime Tourism
	Aquaculture
	Marine Energy
	Maritime transport

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1. Introduction

The Environmental Services are the analytical interface between Climate Change (CC) impacts on oceans, atmosphere and coasts and the effects of those impacts on the functional activities of the Blue Economy. Previous effort (WP4) was addressed to determine the environmental functions (climate hazards) considered relevant to evaluate the Climate Change impacts on the key Blue Economy sectors studied in SOCLIMPACT (Coastal and Maritime Tourism; Fisheries, Maritime Transport; Marine Energy). The aim of WP5 is to measure the economic value of the alterations of the Environmental Services (quality and quantity), caused by these Climate Change impacts and risks.

The Impact Chains conceptual framework, developed previously within the SOCLIMPACT project, serves as a theoretical guide to analyze the relationships between different climate hazards, ecosystem services and risks. The potential risks have further impacts on the economy, both on the specific sectors studied (WP5) and on the whole economy through the interdependence of the sectors (WP6). In addition, the exposure and sensitivity of the ecosystems and societies are taken into account within this specification, using the Impact Chains as a reference.

At sectorial level, Climate Change risks can impact the market either from the supply side (the costs of providing the service or the activity) or from the demand side (changes in the quantities demanded), or both. In this project, the climate impact on the Aquaculture and Maritime Transport sectors will be studied from the supply side, analyzing changes in the production functions or in the costs supported by providers. Regarding the Marine Energy sector, impacts on both the supply and on the demand side will be considered. In this case, not only providers could face higher costs of production due to weather conditions, but also consumers may alter their demand for cooling or heating provisions, for instance. Finally, the Coastal and Maritime Tourism sector will be analyzed through changes in the demand side. Tourists' valuation of Environmental Services will be analyzed, together with their behaviour when these services experiment changes due to Climate Change.

The Climate Change impact on the four specified sectors will be analyzed through its direct effect on the markets. However, in the case of the tourism sector, a non-market valuation assessment will be needed in order to identify how the tourist experience value is altered when Environmental Services are damaged.

This deliverable reviews the existing literature regarding the economic valuation of the risks proposed in the sectoral Impact Chains. The aim is to summarize the methodologies used to estimate the impact of Climate Change on the risks considered for the Blue Economy Sectors, and the results obtained. The analysis is organized by sector and risk.

2. Theoretical framework

Market goods are defined as the goods in a market economy that are sold for prices which reflect the equilibrium between supply and demand. For these goods, the market price is observable. Analogously, the concept of non-market goods refers to those that are not bought or sold directly in the market (in other words, goods that are not traded in the market). Thus, non-market goods do not have observable monetary values. Since there is no market price for non-market goods, valuation of non-market goods involves assigning monetary values to those goods. Non-market goods valuation methods rely on information from the markets for related goods (revealed preference methods) or on direct information on people's preference (stated preference methods). For instance, in the tourism sector, many ecosystem services are traded embedded in the service packages that tourists pay for. Therefore, the environmental services have an implicit market value that can be elicited through different direct and indirect methods. Even if these environmental services are not being valuated directly by markets, complementary or related markets posse values for it.

The impact of Climate Change could be reflected in market goods, which is usually the case in the Aquaculture, Marine Energy and Maritime Transport Sectors, or in Environmental Services, which affect Tourism sector and belong to the category of non-market goods. Therefore, as hinted in the introduction, when analyzing the sectors we will focus on changes in the demand and supply of market goods, and also identify non-market effects that can be subject to the non –market valuation.

The cost assessment of intangible effects of natural hazards is following the main principles of welfare economics. One of the central themes in the field of welfare economics is to consider all categories of total economic value in decision- making. This includes also the value of environment or human health. According to welfare economics, individuals derive values from non-market goods, especially environmental and health assets, through many more ways than just direct consumption (Pearce and Turner, 1990).

More specifically, they refer to the importance of considering the Total Economic Value (TEV) of a non-market asset (of natural goods or environmental services). TEV recognizes two basic distinctions between the value that individuals derive from using environmental goods and services, i.e. use values, and the value that individuals derive from the environmental resource even if they themselves do not use it, i.e. non-use values. In this context, the concept of total economic value (TEV) helps to identify the different market and non-market values that might be damaged in a natural hazard event (OECD, 2000)

Figure 1 summarizes the classification of total economic value and commonly used valuation methods. An exhaustive list of valuation methods for environmental goods and services will be discussed in the next deliverables.

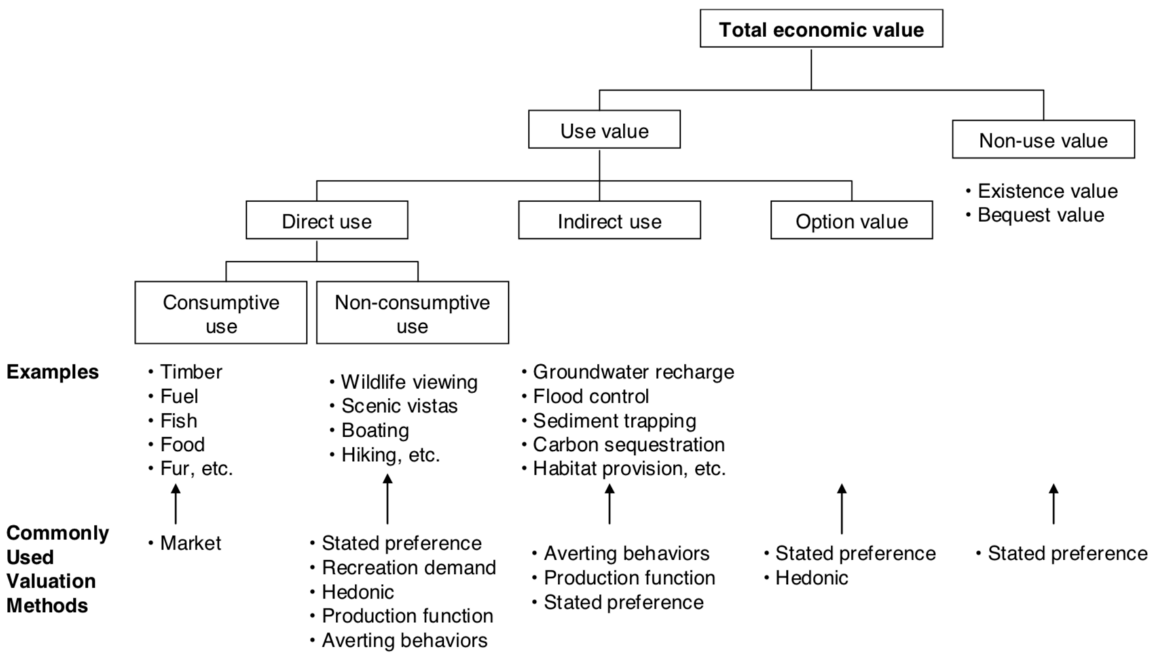

Figure 1. Classification of total economic value and commonly used valuation methods. Source: Lee et al. (2010)

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3. Methodology

The review of the literature was conducted in four steps, and has taken place from August 2018 to February 2019. The first step consisted on establishing criteria to select the relevant papers. Partners were asked to find articles that study the economic values and economic impact from Climate Change, in the four selected Blue Economy sectors. Therefore, these analyses would relate measures of impact on Climate Change on risks with the economic value of risk occurrence and its effect on the economy. It was decided to collect recent papers, and to provide a list of the most relevant articles studying the effect of interest (around 10 articles per impact considered). The articles referenced have been published in scientific journals with high impact, indexed in the database of Journal Citation Reports and Scopus. The main search source used has been Google Scholar.

The second step of the process was the collection of papers. In order to do so, partners were asked to fill in the template used as guide, which was homogenized across sectors. The collection of papers was done per sector, per Impact Chain and per risk. Once the risk was identified, the general impact studied in the article was determined, together with the distinction between demand or supply effect. The keywords used for the search depended on the sector and the risk. An example and non-exhaustive list of keywords is the following: Climate Change, tourists' perceptions, ecosystem shifts, benefit transfer, risk perception, environment management, Mediterranean aquaculture, environmental technical change, impact assessment, port resiliency, thermoelectric generation, wind energy, renewable energy, etc.

The third step corresponds with the validation of references. It was checked that the impacts considered were in line with the Impact Chains' definition and the aim of WP5. Once the references were validated, partners generated a text where the main references were confronted, with the aim to create the present meta-analysis, where the variables analyzed and the corresponding results are presented.

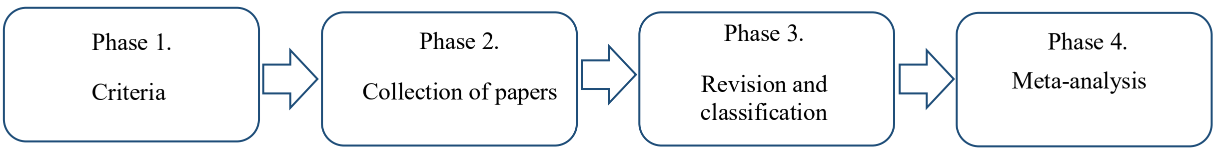

Figure 2. Process for collection and review of existing literature regarding the economic valuation of the Climate Change risks and policies on Tourism, Aquaculture, Energy and Maritime Transport

Sector leaders were key partners contributing to this deliverable. UNIBO was in charge of collecting the literature corresponding to the Coastal and Maritime Tourism sector. AquaBioTech was responsible for the Aquaculture sector, while CETECIMA reviewed the literature of the Maritime Transport sector. Finally, CYI was in charge of the part related to the Maritime Energy sector.

The aim of this deliverable is to present the state of the art with respect to the economic valuation of the risks identified in the Impact Chains framework (WP3). The next sections are dedicated to summarize the more relevant findings that will be useful for the next stages of this WP5, transfer economic values and the fieldwork.

4. Literature Review

4.1. Tourism

There is no doubt that tourism industry is vulnerable to various Climate Change hazards. Impact chains analysis can help in defining several dimensions that would be affected and that can be generally classified in: environmental attributes, human being comfort, and the organization and quality of infrastructure and facilities.

4.1.1. Changes in environmental attributes

Beach availability and impacts on infrastructures due to sea level rise

The most important effects of Climate Change on coastal and maritime areas come from the sea level rise (SLR), the changes in water and air temperatures, the increased frequency of extreme events (rainstorms, windstorms, heat waves, etc.) and other climatic features. They all have both direct and indirect effects, contributing to environmental physical impacts, such as shifts in biodiversity both in marine and land environments, beach surface reduction and increased risks of forest fires. These risks could have impacts on the demand of the destination or its image and attractiveness, and on the supply of experiences, touristic activities or facilities.

An obvious and immediate consequence of SLR is beach erosion and damage to coastal infrastructure. On the demand side, beach surface reduction was found to negatively impact the destination image in various locations. For instance, in Martinique, a 25cm SLR was estimated to pose a risk on 87% of beaches used for tourism (Schleupner, 2008). In Barbados, 77% of tourists declared unwillingness to return in case of beach surface reduction. This would translate into tourism revenues decreasing by as much as 46% (Uyarra et al., 2005). In Australia, where under different beach erosion scenarios the share of tourists opting for alternative destinations is estimated to be 17-23%, the drop of revenues would be as large as $20-$56 million p.a. (Raybould, 2013). However, many tourists claim to reconsider their choice if coastal protection measures are taken (Atzori et a., 2018). Buzinde et al. (2010) investigate the case of Playacar, Mexico, that was hit by severe beach erosion and undertook some protective measures, which were expected to have a strictly negative impact on tourists' perception. The analysis revealed that tourists adapt their views and attitudes: some express positive sentiment towards the changed image of the beaches while others, although expressing concerns from aesthetical points of view, are still aware of the necessity of protection measures, and are willing to accept them in the light of Climate Change.

On the supply side, beach erosion affects properties and infrastructures, and, consequently, contribute to increased costs. A vulnerability assessment on the consequences of SLR and flooding on the Moroccan coasts (Snoussi et al., 2008), estimates 24% of land loss in the "*best case*" scenario of 2m inundation, and 59% of land loss in "*worst case*" scenario of 7m inundation, with severe damage to housing, leisure and agricultural sectors as well as to the natural environment. Another recent study by Antonioli et al., (2017) on Climate Change-induced SLR in the Italian regions of North Adriatic, the

Gulf of Taranto and Sardinia (Oristano and Cagliari) reports that the expected projections of SLR by 2100 (516-1010 mm for the IPCC scenarios and up to about 1430 cm for the Rahmstorf scenario) will have a dramatic impact on the Italian coastal plains, with about 5500 km^2 inundated, resulting in land loss, damage to environment and infrastructures, as well as inland migration. In Sardinia, the maximum sea-level rise by 2100 is estimated to be about 1.35 m, leading to partial flooding of several areas located at 1 m a.s.l. Such changes cannot leave intact tourist facilities and infrastructures. Sagoe-Addy & Addo (2013), having studied the enhanced sea level rise (ESLR) impacts on tourism infrastructure on coastal Accra (Ghana), indicate that 13 tourism facilities may suffer from SLR impacts, with 31% likely to be fully damaged. Scott et al., (2012a) studied potential impacts of one meter SLR in the Caribbean islands, suggesting that 29% of the resort properties would be partially or fully inundated, whereas indirectly, through beach erosion, a one-metre sea level rise would affect 60% of resort properties. The projected losses are expected to be spread unevenly across the Caribbean region, with 50% of the loss burden lying on 5 countries.

While most of the studies tend to project severe consequences of SLR on coastal infrastructures, some suggest that the overall impact on the tourism industry would be moderate. Bigano et al. (2008) estimate the impacts of SLR on tourists' flows. The results suggest that 25 cm of sea level rise projected by 2050 would lead to a GDP loss ranging from 0.1% in South East Asia to almost no loss in Canada, while redistribution of tourist flows would correspond to GDP losses ranging from 0.5% in Small Island States to 0.0004% in Canada. Therefore, the study also highlights that both SLR and the redistribution of tourism flows would have different impacts in different parts of the world.

Consequently, some countries have begun to invest in a variety of adaptation initiatives such as beach protection and artificial beach nourishment (Mycoo & Chadwick, 2012). Such measures are obviously costly, but ignoring mitigation and adaptation strategies may lead to much higher losses. Darwin & Tol (2001) estimate that if no protection measures take place, a 0.5 meters SLR in 2100 would have the annualised total cost of about US$43 billions, with severe differences across regions: US$7 billions in Europe and US$36 billions in the Asian region. However, adopting an optimal protection package would reduce total cost, thus resulting in US$10.5 billions for the whole world. Importantly, the authors find that international trade is going to smoothen disparities in losses by redistributing from regions with relatively high to regions with low damages.

Extreme weather events, such as storms and hurricanes, can produce immediate detrimental impacts, which could be even more profound that those from SLR, although the literature is biased towards the latter. A recent study of the 2015-2016 El Niño events (Barnard et al., 2017) revealed that the shoreline retreat among the six regions of the US West Coast in the winter of 2015-2016 was 76% above the normal winter erosion rates. Similarly, the stormy winter of 2013-2014 along the Atlantic coast of Europe was found to have changed dramatically the equilibrium state (beach gradient, coastal alignment, and nearshore bar position) of the beaches (Masselink et al., 2016). The effects were found to vary depending on obliqueness of the waves, and lead not only to beach erosion, but also to beach rotation (Burvingt et al., 2016). The immediate economic impacts of events such as El Niño can be quite considerable, reaching US$11.5 billion globally (NOAA, 2016).

Regarding the impacts of extreme events on the demand side, the literature consistently finds a negative impact on tourist arrivals. Results from a study in Jamaica show that increased number of hurricanes may cause a fall in the exchange rate and a decrease in tourism arrivals in the short term, and a negative impact on tourists' expenditures in the long-run (Ghartey, 2013). Increased greenhouse gases may change the frequency and intensity of events such as heat waves, drought and fire in the Mediterranean region, leading to a less economically and environmentally sustainable tourism with criticalities for tourists' safety and adaptability (Perry 2006).

Literature findings on the past dynamics of different types of extreme events generally indicate that their frequency and intensity has been increasing. Wave height and other parameters of storminess, which are found to have risen over the last decades, are of particular interest for the marine sector. Specifically, for the Atlantic coast of Europe an increasing trend in significant wave height of up to 0.02 m yr^{-1} was documented (Bertin et al., 2013), and elevated levels of storminess measures have also been observed since 1871 in many parts of central, western and northern Europe (Donat et al., 2011). However, regarding projections of extreme events occurrence, intensity and frequency, there is little consensus in the literature. An extensive review by Seneviratne et al. (2012) reveals that there is low confidence for the abovementioned wave height projections, as well as for the El Niño episodes, while there is high confidence in projections of heat waves and temperature extremes in general. Therefore, it is crucial to account for occurrence and intensity of extreme events and for the uncertainty in their projections when modelling and measuring the socio-economic impacts of Climate Change.

Threat to Biodiversity

Shifts in climatic attributes may result in spreading of invasive and dangerous species, affecting tourists' well-being and their destination choice (Nilsson & Gössling, 2013), but also in losses of land, marine and coastal habitats, which are amongst the indirect environmental effects of Climate Change and may have profound implications on the destination's attractiveness, especially if wildlife is the main reason for traveling.

Special attention has been paid to coral reefs (Hall, 2001; Marshall et al., 2011; Coghlan & Prideaux, 2009), as they represent an important attraction for tourists but are also very delicate ecosystems that can be deeply affected by Climate Change. Indeed, the increase of oceanic waters temperature causes mass coral bleaching that damages the reefs, while acidification of the oceans endangers their flora and fauna (Marshall et al., 2011). Coral bleaching refers to '(…) the whitening of corals due to stress-induced expulsion or death of their symbiotic protozoa, or to loss of pigmentation within the protozoa' (Scott et al., 2012b, p. 220) and is mainly due to temperature change and ocean acidification. This last phenomenon is due to the presence of high percentages (about 30%) of total emitted anthropogenic CO_2 in the ocean waters (IPCC, 2014), thus impacting the reproductive and physiological activity of numerous marine creatures (Scott et al., 2012b) and increasing their vulnerability. With high confidence, IPCC AR5 (2014) states that numerous species may extinguish because of Climate Change and the other modifications that are affecting their environment. Coral reefs are also at risk because of the increased intensity and frequency of extreme events. Although it is acknowledged that corals are endowed with high level of resilience and can naturally recover successfully from cyclones, hurricanes or typhoons (Bythell et al., 2000), when these extreme events become more frequent, the reefs are not able to fully rebuild themselves, especially if other climatic changes are at place, making the environment less favourable for the corals. Furthermore, destruction of corals due to the storms may trigger the succession of algae (Welsh, 1983), which may affect tourist demand, as shown in Nilsson & Gössling (2013). Note also that coral reefs are not only an important part of marine ecosystem and a tourist attraction, but also a shield that protects the beaches and coasts from erosion (Cuttler et al., 2018). Jordà et al. (2012) conclude that warming will lead to the functional extinction of *Posidonia oceanica* meadows by the middle of this century, even under a relatively mid greenhouse-gas emissions scenario.

A study by Hongo et al. (2018) has incorporated projections of both SLR and tropical cyclones to simulate impacts on beach erosion under two scenarios: a degraded reef and a healthy reef. Results show that healthy reefs can reduce the significant wave heights by up to 0.44 m, while a reduction by only 0.1 m would already be sufficient to decrease the risks of coastal and infrastructural damages.

Therefore, these studies show that there is also a tight interconnection between different physical impacts.

Other species of marine and coastal habitat are also at risk. Assuming 2°C global warming and consequent inundation of low-lying coasts for shorebirds in the US, the projected loss of habitat ranges from 20 to 70%, with most vulnerable sites being those where the current coastline is unable to move inland because of steep topography or coastal defence structures such as sea walls. (Galbraith et al., 2002). For certain species, however, the impact may be both positive and negative depending on the exact Climate Change scenario and on specific physical impacts: SLR and increased intensity of storms would have a negative impact on turtle nesting beaches, while seawater temperature rise may result in increased food availability for the same animals (Poloczanska et al., 2009). Such changes would have impacts on tourism industries, particularly for the islands where these natural features are of high value for tourists. Regarding coral reefs, the literature generally finds that biodiversity loss results in a lower probability of revisiting the destination (Uyarra et al., 2005; Parsons & Thur, 2008), with consequent economic losses. Payet & Obura (2004, in Scott et al. 2012b) estimate that in the western Indian Ocean, where 30% of corals loss led to a considerable decrease in visitors, economic losses amount to almost US$18 million. Parsons & Thur (2008) support that the drop in the quality of the reefs in Bonaire results in per-capita spending decrease of $45-$192. At the same time, this result is also case-specific of massive coral bleaching in Mu Ko Surin National Park, Thailand. Despite of the strong agreement of surveyed tourists that coral has been severely degraded, more than a half of respondents were willing to revisit the park, and two-thirds of the respondents were satisfied with the overall quality of tourism activities (Cheablam et al., 2013).

It follows that Climate Change impacts necessitate the increase of awareness of both tourists and businesses (Zeppel, 2012), which will lead to increased costs of preservation and restoration of marine and coastal flora and fauna. Bayraktarov et al. (2013) have constructed a comprehensive database of restoration or rehabilitation projects of the last 40 years for five main marine coastal ecosystems: coral reefs, seagrass, mangroves, saltmarshes, and oyster reefs, mostly in Europe, US and Australia. The results suggest that the cost vary significantly over many dimensions: depending on the location, type of ecosystem to restore and executing actor. Projects in developing countries were found to be up to 30 times less expensive, while coral reefs and seagrass were among the most expensive ecosystems to restore, and community- or volunteer-based projects usually associated with lower costs. Regarding costs estimates, the average reported costs for restoration of one hectare of marine coastal habitat were between US$80,000 and US$1,600,000 (2010), respectively, while the authors suggest that the real median cost was about two times higher.

Forest fires

Climate Change may also impacts destinations through the probability of wildfire occurrence. Wildfire outbreaks are particularly likely when humidity is extremely (unusually) low while the temperatures are extremely high. For example, extreme summer heat in Moscow in 2010 fuelled wildfires in vast areas around the city, resulting not only in physical damage to the forests, but also to severe increase in pollution, leading to 11.000 excess deaths over only 6 weeks (Shaposhnikov et al., 2014).

The impact chains analysis highlights the importance of wildlife fires in affecting the attractiveness of the destination for tourist purposes. Despite the fact that wildfires often result in large losses of forests and even human lives, this chain is among the least represented in the current literature, with much more emphasis on losses and recovery strategies (Lynch, 2004) than on tourists' behaviour. Concerning the demand side, there is mixed evidence on the attitudes of tourists towards fires. While the immediate effects of fires can be negative, in the long-run tourist behaviour does not alter (Hystad

& Keller, 2008). Moreover, a considerable share of tourists can be somewhow insensitive to fire risks and do not intend to change their travel plans even when informed about wildfires present in the destination. For instance, in Florida, where wildfires happen almost on a yearly basis, about 33% of tourists are not at all discouraged by this risk factor, while 42% would change their behaviour only if the risk is very high (Thapa et al., 2013). Regarding the supply side, a somewhat similar picture appears: businesses report being affected in the short-run, but not in the long-run (Hystad & Keller, 2008). However, in some cases indirect impacts of increased probability of wildfires, such as increase in insurance costs, can be even more considerable than the direct ones, especially for small businesses (Cioccio & Michael, 2007). Thus, even if the impact of forest fires on tourism demand vanishes in the long-run, an increase in the frequency of fires can make short-run decisions more relevant for the tourism demand. In other words, tourism demand could be permanently affect by short-run impact-based decisions.

4.1.2. Changes in human being comfort

The relationship between weather and climate variables and tourists' comfort is complex and is the focus of numerous studies. To measure the suitability of climate for tourism sector, the literature resorts to different variations of the Tourism Climatic Index (TCI), originally proposed by Mieczkowski (1985). This index allows to incorporate several weather variables (e.g. mean temperature, humidity, precipitation, etc) and has an easy interpretation. Mieczkowski's original index has been modified and adapted, leading to alternative versions (de Freitas et al., 2008), creation of indices for specific types of tourism (Moreno & Amelung, 2009), or area-specific modifications, with a focus on Europe and the Mediterranean region (Amelung & Viner, 2006; Moreno & Amelung, 2009; Perch-Nielsen et al., 2010), Australia (Amelung & Nicholls, 2014), or at global scale (Amelung et al., 2007). This unified tourist comfort measure is then used to obtain projections of seasonality changes in various regions. Amelung & Viner (2006) and Amelung et al. (2007) use TCI to predict shifts in seasonality for the Mediterranean region for IPCC-2000 Climate Change scenarios. The results suggest that due to Climate Change the Mediterranean region will become too hot in summer but a more pleasant destination in the shoulder seasons. For the case of Balearic Islands the studies predict that, while these changes may be even favourable from resource management and biodiversity point of view, the effects from an economic and social perspective are likely to be detrimental.

Abundant literature provides evidence of tourism being a highly weather-sensitive activity (Maddison, 2001; Scott et al., 2008; Becken, 2010). This relationship stems, in particular, from the effect on human being comfort. On the extensive margin, weather and climate directly affect tourism industry through tourists' destination choice (Gössling et al., 2006), the type of activities and their timing (Cavallaro et al., 2017; Gómez-Martín et al., 2014). Additionally, tourists' comfort may be indirectly affected when Climate Change result in a decrease of water availability (itself also a consequence of extra-demand of water generated by tourism), or an increase in health risks. These indirect effects receive less attention in the literature. Gómez-Martín et al. (2014) studied the case of a heat wave in Spain in 2003 and inquired respondents on their perceptions of the extreme weather they had to face and on the changes in their habits and activities. According to the results, many tourists switched to indoor activities and 25% reported a substantial increase in water consumption. The study also highlights that perceptions are heterogeneous across respondents of different age: younger generations are less susceptible to extreme weather conditions than the elderly. Indeed, while high temperatures are generally associated with higher risks of dying from cardiovascular, respiratory, and cerebrovascular diseases, these risks are substantially more pronounced for young children and people older than 65 (Basu, 2009).

Climate and weather change will therefore inevitably lead to increased health costs. As shown in Toloo et al. (2015) for the case of Brisbane, Australia, projected increased temperatures can have a considerable impact on Emergency Department admissions: the excess number of visits in 2030 is estimated to range between 98–336 and 42–127 for younger and older groups, respectively, with the associated costs of AU$51,000–184,000 and AU$27,000–84,000. By 2060, these projections reach 229–2300 and 145–1188 at a cost of between AU$120,000–1,200,000 and AU$96,000–786,000 for the respective age groups.

Apart from the direct effect on health outcomes, Climate Change is expected to have pronounced indirect effects via disease spreading. In light of globalization and increased population mobility, the geography of certain diseases is changing rapidly, urging to be seriously considered in the process of diagnosing. Tourists are a particularly vulnerable population subgroup, especially when they choose a destination with environmental features which are drastically different from those of their country of origin. The health and medical literature, however, generally does not focus on tourists, and more often considers increased risk for various demographic groups of the indigenous population. One of the exceptions is the analysis of Lau et al. (2010 a; b). The authors examine potential effects of Climate Change on the spread of leptospirosis and conclude that increased temperatures, extreme weather events and particularly flooding will result in increased incidence and magnitude of the outbreaks of this disease. Results reveal that travellers are at particularly high risk even if initially they are in good health because the disease is often under-diagnosed in their home countries. Importantly, the paper highlights adventure-seeking tourism activities as most susceptible to leptospirosis. Therefore, it should be noted that different types of tourism exhibit different exposure to health risks (e.g. cruise tourism is one of the most vulnerable (Liu & Pennington-Gray, (2017).

Although the likelihood of tourists being infected by malaria, dengue, the Wst Nile virus or other infectious diseases while visiting European islands is very low, it is well known that overreactions to low probabilities of being affected are the expected behaviour. The European Centre for Diseases Prevention and Control has reported cases of local transmission of malaria in Greece in 2018; some cases of West Nile virus have also been reported the same year for Italy (19), Greece (2) and Cyprus (1). In October 2018, the French and Spanish authorities reported some cases of autochthonous dengue. In 2016, some European countries reported 2.418 confirmed cases of dengue, 106 in Italy and 199 in Spain. In 2015, the number of confirmed cases of malaria in European countries was 6.199 (France with 2.500, Spain with 713, and Portugal with 194 cases). Italy is the only country, of the ones studied within the SOCLIMPACT Project, that reported West Nile virus cases in 2015 (61 cases). Chikungunya fever cases reported in 2016 took place in France (45), Italy (17), Spain (97), Portugal (3) and Greece (2). The prevalence of those vector-borne diseases depend on the mosquitoes surviving and the potential for disease transmission, in turn depending of temperatures. The increasing of autochthonous contagion is due to both the augment of stablished colonies and the spreading the climate conditions that allow mosquitoes for longer surviving time. In the islands analysed in this Project some cases have been report: a dengue outbreak in Madeira was reported in 2012, while the ECDC has reported new settlements of Aedes aegypti, potential transmitter of dengue, in the island of Fuerteventura in the Canary Islands; and Cyprus registered 1 case of WNF disease.

From an economic perspective, disease spreading can have significant economic impacts, both directly and through affecting tourism arrivals, on the destination. Developing countries are likely to be the most vulnerable to these impacts, since they are often highly dependent on the tourism industry, but also have lower levels of health care services and hygienic conditions. Mavalankar et al. (2009) estimated the potential losses for the tourism industry in a hypothetical scenario of the chikungunya and dengue epidemics in Gujarat (an economically important state of India), Malaysia, and Thailand. Under the assumption of 4% annual decline in the number of international tourists from non-endemic countries, the estimated losses of tourism revenues are at least US$ 8 million for Gujarat, US$ 65 million for Malaysia, and US$ 363 million for Thailand. To have an idea of the relative importance of these values, the authors provide comparison with the estimated immediate annual cost of chikungunya and dengue to these economies: US$ 90 million, US$ 133 million, and approximately US$ 127 million respectively, thus revealing that highly tourism-dependent Thailand would incur extremely high losses.

4.1.3. *Quality of infrastructures and facilities*

Infrastructure and facilities play an important role in providing tourism services. Apart from accommodation per se, a wide range of amenities contributes to the attractiveness of a destination: transportation (Della Corte et al., 2015), restaurant services (Szende et al., 2018), recreation facilities and amusement parks (Zopiatis et al., 2017), etc. Climate Change can have both direct and indirect effect on these features.

The quantity and intensity of precipitation was found to have an effect on transport demand through its influence on the choice of transportation mode, trip postponement or cancellation (Koetse & Rietveld, 2007, Koetse & Rietveld, 2009). For the aviation sector the crucial factors are wind speed and direction; however, the potential impacts of Climate Change are viewed as ambiguous, since the impacts may affect transport infrastructure in different directions (Koetse & Rietveld, 2009). A study of Climate Change impacts on road and railway systems at EU27 aggregated level by Nemry & Demirel (2012) suggests that normal degradation rates of road transport infrastructures will only slightly increase in the future (according to A1B scenarios for 2040-2100). However, more frequent extreme weather events may induce additional cost of 50-192 million €/yr. In contrast, softer winter conditions are projected to reduce the costs by 170-508 million €/yr.

Regarding restaurants, hotels and other facilities, they are also directly influenced by weather and Climate Change. In particular, extreme events are the most damaging and may have severe consequences, especially for small and less productive businesses that face financial constraints. These effects can be even more pronounced in the long-run, if the area is characterized by high levels of competition (Basker & Miranda, 2014), which is often the case for coastal areas. It is important to note that infrastructural damages resulting from the increased probability of extreme events are often much higher than those from gradual Climate Change processes. Using the case of Barbados and scenarios for land loss, inundation and flooding due to SLR and hurricanes until 2100, Moore et al. (2010) have shown that when only SLR is accounted for, the projected losses in revenues are $15.6-$150.3 mln, while if hurricanes scenarios are also incorporated, the projected losses rocket up to $267-$1477 mln. On the demand side, damages to different infrastructures were found to have a negative impact on the destination image, especially for tourists who have never visited the destination before (Pearlman & Melnik, 2008).

Climate Change can also impact the quality of the facilities indirectly, for instance, by affecting water availability, and this aspect receives plenty of attention from the literature. While globally tourism-related direct water consumption was estimated to be less than 1% and is expected to remain marginal even taking into account tourism growth projections (Gössling et al., 2012), in fact, for heavily tourism-dependent countries tourism sector is one of the major water consumers. In Barbados, for instance, the average per capita consumption associated with tourism is three times higher than the one of domestic consumers, and water demand by the tourism sector is projected to rise from the current 12% to 18% of total consumption by 2050 (Cashman et al., 2012). Given that most of the Climate Change projections predict a decrease of precipitation levels for Barbados (Cashman et al., 2010), freshwater scarcity is expected to be a serious issue affecting all economic sectors, including tourism, resulting in increased operating costs, and consequently, increased prices (Cashman et al., 2012). This may lead to significant changes in the market, giving a comparative advantage to larger hotels and resorts, since they are more efficient in water consumption due to economies of scale (Gabarda-Mallorquí et al., 2017). Furthermore, for countries where tourism is a major sector providing jobs and generating revenues, needs of tourists might be prioritised over the needs of local population, creating potential for local conflicts, instability and marginalization (LaVanchy, 2017). It is important to note that developing countries are not the only focus of the literature: in the context of the Mediterranean region, for instance, it addresses concerns about the impacts of decreasing rainfall on water supply availability (Philandras et al., 2011) and costs (Martínez-Ibarra, 2015). The literature also tackles important methodological aspects of measuring the water footprints, such as taking into account both direct and indirect water consumption: although the latter is often overlooked, it may account for much larger share of water consumption by tourists than its direct counterpart (Hadjikakou et al., 2013).

Finally, Climate Change may also have an impact on those segments of a destination's infrastructure that are the very purpose of the trip: monuments, architecture, and other cultural heritage. Existing studies provide evidence that Climate Change will lead to damage of different types of cultural heritage (Hall et al., 2016), and result in increased conservation-restoration costs (Grøntoft, 2017). While the literature on the impacts of tourism on the cultural sites is very vast, there is very scarce research investigating the reverse relationship. A notable exception is the study of Alberini & Longo (2009), who apply contingent valuation to investigate the cost-efficiency of a hypothetical conservation program for heritage sites in Armenia. Their analysis revealed that uncertainty about what would happen to monuments in the absence of the program results in decreased willingness to pay. However, the study was conducted using data from surveying local population rather than tourists.

To summarize, there is abundant literature on the effects of Climate Change on tourist flows. However, relatively few studies aim to pin down particular channels of transmission: in fact, they focus on either the environmental (intermediate) impacts of Climate Change, or on the effects of these intermediate impacts on the tourism industry, but not on the full chain of interconnections, something that SOCLIMPACT project aims to do. Finally, with respect to the focus of the literature on the effects of Climate Change on the tourism sector, relatively more studies are interested in tourism demand, rather than in the supply side.

A summary of case studies with relevant findings for Tourism sector is presented in Tables 4.1a & 4.1b, especially those papers in which there is a clearer measure of the interlinkages among physical impacts and market and non-market costs of Climate Change and related policies. In most cases, the economic impact was not possible to be quantified in a macroeconomic way (and in alignment with input-output sectoral matrices), which is precisely the objective of the next deliverable 5.2, in order to identify possible value transfer.

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Table 4.1a. Tourism summary - Market and non-market effects of different CC impacts on demand side

Hazard	Case study / CC scenario	Method / Model	Environmental services / Non-market effects	Economic impact	Source
Seal level rise (SLR)	1. Martinica - 25cm SLR 2. Morocco 2m inundation 7m inundation	Spatial analysis based - GIS model.	1. ↓ 87% of beaches availability 2. 24% of land loss 59% of land loss		Schleupne, 2008 Snoussi et al., 2008
	Bonaire and Barbados Reduced beach area	Survey data analysis	↓ Destination image ↓ 77% willingness to re-visit	↓ 46% tourism receipts	Uyarra et al., 2005
	Australia 1.Beach erosion (different scenarios) 2.Adaptation measures	Online survey data analysis.	1. ↑ 17-23% tourists opting for alternative destinations 2. no change	1. ↓ 17-23% tourism arrivals 2. no decrease	Raybould, 2013
	Global data (16 macro regions) 25 cm SLR rise projected by 2050	Computable General Eq. (CGE) GTAP-EF (Global Trade Analysis Project) model.	Redistribution of tourism flows	GDP loss ranging from 0.1% in South East Asia to almost no loss in Canada	Bigano et al., 2008
Increased temperature	2°C global warming and consequent inundation in the US	stated preference method, applying a random utility framework, estimated via mixed logit model.	loss of habitat ranges from 20% to 70% coral reefs biodiversity and quality loss ↓ turtle nesting beaches ↓ prob. of revisit the destination	↓ expenditure per-capita $45-$192 economic losses amount to almost US$18 million	Uyarra et al., 2005; Parsons & Thur, 2008
	Brisbane (Australia) Climate Change projections (from CSIRO).	Forecasts of population growth	↑ Health costs 1. By 2030 (AU$) 2. By 2060 (AU$)	1.≥ $27000 ≤ $184000 2.≥ $ 96000 ≤ $ 1 200 000	Toloo et al.,2015
	Gujarat (India), Malaysia and Thailand. Chikungunya and dengue epidemics	Data analysis: tourist arrivals, expenditures, length of stay.	↓ tourism receipts (US$)	Gujara: ↓ 8 mill. Malaysia: ↓ 65 mill. Thailand:↓363 mill.	Mavalankar et al. (2009
	British tourists are attracted to climates with an average daytime maximum of 30.7 C.	Quarterly data on international travel - Theoretical Pooled Travel Cost Model, semi-log regression estimation of the demand equation	↓ low-cost destinations attractiveness		Maddison, 2001
Forest fires	Florida (USA) Victoria (Australia) ↑ risk of occurrence of forest fires	Interviews of managers of individual tourism firms. Survey data analysis; K-means cluster method.	33% of tourists are not at all discouraged by this risk factor	↓42% tourism arrivals only under very high risk scenario	Thapa et al., 2013; Hystad & Keller, 2008; Cioccio & Michael,2007
Heat waves	Spain, 2003.	Survey data analysis.	↑ demand for indoor activities ↑ 25% of water consumption		Gómez-Martín et al., 2014

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Table 4.1b. Tourism summary - Market and non-market effects of different CC impacts on supply side

Hazard	Case study	Method	Environmental services / Non-market effects	Economic impact	Source
Seal level rise (SLR)	Historical orthophotos and topographic maps of Accra, Ghana; IPCC projections of SLR.	Scenario analysis, GIS analysis	Beaches will lose on average GHC 227,500 per year ↓ 2000 visitors per beach facility per holiday 31% of tourism facilities likely to be fully damaged		Sagoe-Addy & Addo, 2013
	19 Caribbean Community (CARICOM) countries. 1. 1-meter SLR scenario on beach 2. Beach erosion due to 1-meter SLR	Geo-referenced database	1. ↑ 29% prob. of inundations in resort properties 2. 60% of resort properties affected		Scott et al. 2012
Increased temperature	Evidence of 954 intervention/restoration projects of coastal habitats in Europe, US and Australia.	Systemic review of literature, reports, and data-bases	↑ no. of coral reefs, seagrass, mangroves, saltmarshes, and oyster reefs	Average cost for marine habitat restoration = US$80 000-$1,600,000 /1 hectare (2010)	Bayraktarov et al., 2013
	Armenian nationals living in Armenia, 2004. Hypothetic conservation program for heritage sites in Armenia	survey-eliciting WTP; Bayesian updating model	↑ WTP with the proposed programme	Benefits of the program = US $6.2-6.8 mill. or US $0.9 mill annually, which is roughly equal to annual costs.	Alberini & Longo , 2009
	Climate and air pollution data and projections (IPCC) for the city of Krakow.	Corrosion eq.derived from dose-response functions	↑ conservation- restoration costs of limestone façades.	↑3% weathering costs	Grøntoft., 2017
Forest fires	Moscow, 2010 ↑ wildfires in vast areas	Systemic review	- physical damage to the forests severe increase in pollution -↓attractiveness of the destination -businesses report being affected in the short-run, but not in the long-run	11.000 excess deaths over only 6 weeks	Shaposhnikov et al., 2014 Lynch, 2004; Hystad & Keller, 2008
Extreme events	Impact of Hurricane Katrina on Mississippi business owners. Data from Census Bureau's Longitudinal Business Database (LBD)	Linear probability models	↑ short-term damage for all businesses. Even more pronounced for small firms in the long-run due to high competition in the coastal zone.	↑ losses $267-$1477 mill	Moore et al., 2010
Precipitation	Barbados ↓ precipitation		↑ operating costs ↑increased prices		Cashman et al., 2010, 2012

4.2. Aquaculture

The world's dependence on capture fisheries and the aquaculture sector is threatened not only by inadequate management of these aquatic resources but also by factors external to the sector such as Climate Change. Fisheries stakeholders in coastal and inland areas are particularly vulnerable to the direct and indirect impacts of Climate Change. From early stages (2000-2008) important conferences were held in order to increase awareness of the issue (example FAO Conference 'High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy', held in Rome, Italy, 3-5 June 2008 and similar early workshops). Hence, policy options and activities to minimize the negative impacts, improve mitigation and prevention and build adaptive capacity in aquatic resource-dependent communities were identified and suggested. However, governments neglected the issues brought forward and postponed mitigation actions, which now have led already to their inability to act pro-actively (Barange et al., 2018; Soto & Brugere, 2008).

Practically it has been recognized that Climate Change will affect aquaculture indirectly through the changes that will be brought to the ecosystem, its productivity and behaviour (hydrology, etc.). It has also been recognized that the effects of Climate Change on the ecosystem will be highly unpredictable, random and extremely localized (as localized is an ecosystem) and therefore, any mitigation or pro-active action needs to be locally adapted. Hence, the reluctance of governments and agencies to act is due to the large variety of ecosystems, the vast amount of resources required and their thin-spreading influence. This policy so far has been supported by scientists who advocate that there is a limited evidence on the impacts on aquaculture that can be attributed to Climate Change (Gubbins et al., 2013; Mohanty et al., 2010).

The basic effects of Climate Change on aquaculture are (Soto & Brugere, 2008):

1. Change in biophysical characteristics of coastal areas.
2. Increased invasions from alien species.
3. Increased spread of diseases.
4. Changes in the physiology of the cultivated species by changing temperature, salinity, oxygen availability and other important physical water parameters.
5. Changes of the differences between sea and air temperature which will alter the seasonality, frequency and severity of storms, cyclones and other extreme events (already experienced this in the Mediterranean for the first time in 2018 - South Italy to North Greece and Turkey 'Medicane'), affect the stability of the coastal resources and potentially increase the damages in infrastructure.
6. Sea level rise, acidification, changes in precipitation and other effects will also add to the changes in coastal ecosystems and environment, thus affecting production and infrastructure (=investments)

In addition to the above, stakeholders and their livelihood will also be directly and indirectly affected by Climate Change. The subsequent sections will highlight major findings on Climate Change impacts on aquaculture activity, the socio-economic implications, as well as policy recommendations. The sections are organized according to the different socio-economic aspects for which these studies contributed to the literature.

4.2.1. Changes in sales and profits as a result of Climate Change

Climate change is expected to cause an increase of coastal temperature affecting the physiology of the cultivated fish all over the EU countries (Lorentzen, 2006; McCauley and Beitinger, 1992) as different species are cultivated in the different EU waters. Lorentzen (2006) used a Gross Present Value function (GPV) of salmon farming in North European waters, which was designed to include market data and the logistic growth function of the cultivated fish in weight. The function was implemented based on different scenarios. The first scenario was based on the increase of temperature amplitude between ±0.5 and ±2.5 °C (increase in higher maximum and lower minimum temperatures, average temperature remains as is). Results showed that amplitudes up to ±2.5 °C based on the current average temperature may not affect the growth of the fish, except in the case when temperature falls below +1 °C (amplitude > -3.1 °C), which will result into the death of the fish because the temperature will fall in the zero growth-high mortality levels for the species.

The second scenario was based on the increase of the average temperature by +0.5 to +3 °C. Due to the fact that salmon and similar species are cold-blooded, such an increase in temperature will result in the increase of the growth of the cultivated fish gaining around 2-4 months in the total production period. The third scenario was based on the change of both amplitude and average temperature. Increase of average temperature by 3-4 °C and increase of amplitude by +3 to +4 °C will create an environment which is similar to 1 °C increase in average temperature alone (similar to the change expected in the next 20-50 years) and will be negative for the fish. Below these levels, production cycle can be reduced by 3-4 months and even more. The sales and profit increases with a ratio of 0.8% per 1% increase of the average temperature. On the other hand, in the case of simultaneous change of temperature amplitude and the average temperature, the results showed that for every 1 °C increase, gross production value increases on average by 17% (12-21% based on country region). However, when changes above these levels occur, GPV drops substantially.

On a global scale, the adaptation of proactive and adaptive management in the fisheries sector may lead to 154% increase in profits, half of which will be produced from aquaculture, as aquaculture contributes about 53% of the total global fisheries production (FAO, 2018). In terms of EU aquaculture production, this value may reach 1 billion € (McCausland et al., 2006). In a similar study, it was reported that an increase in average sea temperature of 2°C resulted in enhanced growth and recruitment of cod and herring, increased annual catches, increased local employment and profitability in Barents Sea fisheries (Eide and Heen, 2002).

Other models which have been used in order to examine the effects of Climate Change on aquaculture include forecasting ocean temperatures based on a coupled ocean–atmosphere forecast model (in this case the Australian POAMA[1]) (Spillman and Hobday, 2014). The application of this model was based on the measurement of sea temperature around operating fish farms and then subtract the long-term monthly mean ocean temperatures for 1991–2010 for each farm estimated by POAMA, in order to create temperature anomalies. Spillman and Hobday (2014) actually proposed a generalised meteorology forecasting model of ocean conditions which can be used to improve preparating salmon farm managers for expected environmental conditions and can increase their resilience to extremes. As for many other primary industries, aquaculture farm managers need to know the likelihood of particular conditions in the upcoming season, and see this as more relevant than climate projections for the upcoming decades. As for the prediction capacity of the model, predictions of salmon farm temperatures, using regional ocean forecasts from POAMA and a simple statistical analysis, have been shown to be accurate at up to 3 months lead-time.

In another econometric approach using the Data Envelopment Method based on the Malmquist

[1] *POAMA is a global ocean–atmosphere ensemble seasonal forecast system run operationally at the Australian Bureau of Meteorology since 2002. It comprises a coupled ocean–atmosphere model and data assimilation systems for the initialization of the ocean, land and atmosphere*

bilateral economy comparison index, the traditional Malmquist productivity index was used to analyse the changes of economic efficiency for cage culture and pond culture (Hamdan et al., 2015). Under the Climate Change risks and challenges, the environmental technical efficiency component was important to promote efficient aquaculture farms. The technology usage in fish breeding and aquaculture practice will allow the increase of aquaculture activities efficiency in producing quality fishes and resist climate variability and risks. The authors find out that high levels of technology used in aquaculture may increase the capacity of farmers to overcome Climate Change effects. Moreover, species thermal tolerances are important biological parameters for the site selection for aquaculture (Beitinger, Bennett, & McCauley, 2000; Madeira, Narciso, Cabral, & Vinagre, 2012). Climate Change effects on the coastal area temperature may lead to changes in the diversity of species suitable for aquaculture. It is, therefore, essential to obtain accurate temperature forecasts and ocean-air models in order to at least forecast weather events and provide enough time for actions (Heim, 2015).

4.2.2. Effects of extreme weather events

One of the major indirect effect of Climate Change is the increase of frequency of extreme weather events especially along the shallow coasts, which is expected to have negative effects on the aquaculture infrastructure resulting to increased production costs, reduced gross income and increased requirements for insurance costs and services (IAIS, 2018). The global insurance sector plays a cornerstone role in the management of climate-related risks and opportunities for individuals, households, firms, other financial institutions, and public authorities. A 2016 analysis found that nearly 60% of the 116 insurers surveyed recognise climate risk as an issue; however two fifths of these insurers took no action to adjust their portfolios (IAIS, 2018). The term "*aquaculture insurance*" describes all the various types of insurance that would normally be used to protect an aquaculture business operation. For a reasonably large aquaculture company, this would include insurance protection for buildings and equipment, employees, stock, livestock, liabilities, motor vehicles, vessels and divers, goods in transit, and other insurable interests. The insurance market offers two types of aquaculture livestock policies: **All Risks** and **Named Perils** policies.

The difference between the two policies is as follows:

(a) **All Risks** policies cover every risk and then exclude certain perils that underwriters do not wish to cover

(b) **Named Perils** policies only cover specific risks, adding and defining where necessary any extra risks for which cover is offered[2]. Among the key perils that aquaculture owners are interested are temperature fluctuations and natural hazards such as drought, storm and floods all of which are potentially Climate Change-related hazards.

A number of important lessons have been learned since the establishment of the aquaculture insurance market (Secretan et al., 2007):

- First, risk management practice is the key to reducing loss and wastage in the industry, and a vital tool for both producers and their insurers. It has to be constantly applied at every level of the industry. Aquaculture is not an industry in which corners can be cut.
- The second lesson is that for small to medium-sized producers and family operations in less developed countries, access to insurance is, at best, very difficult, and at worst, completely unobtainable. The insurance industry cannot be expected to change this situation. It is up to

[2] *https://www.worldfishing.net/news101/financeinsurance/an-introduction-to-aquaculture-insurance*

governments to provide the right legal, educational and other support frameworks to help raise the operating standards of small producers to levels at which they can be insured, if not individually, then in cooperative or coordinated groups.

- The third lesson is particularly important: the surveyors and survey skills of the insurance industry are not exclusively reserved for the use of insurers and their clients. They are available to anyone, including governments. Governments in particular need to appreciate that the specialist aquaculture insurance industry has more practical all-round experience in what can go wrong in aquaculture than any other body or collective group.

So far, most of the costs associated with extreme climatic events have been covered by public and private insurance systems or absorbed by the private sector. The economic impact of these natural catastrophes is growing quickly, with total losses increasing five-fold since the 1980s to around $170bn today. Over the same period, the average annual protection gap has widened quickly from $23bn to $100bn today[3]. With a continued increase in reimbursement claims under Climate Change, one indirect effect may be an increase in insurance premiums to cover an estimated cost of 170 billion € of damages and which may make insurance simply unaffordable[4]. Alternatively, insurance companies may simply refuse to insure certain areas (e.g., flood zones), or demand compensation from municipalities if damages are incurred because regulations were not followed (O'Brien et al., 2006). The potential increase of premiums has not been estimated yet and is expected to depend on existing policies, proactive management and in general, the level of Climate Change mitigation polices applied in each case. Pricing of physical climate risks (e.g. weather-related extremes) is difficult due to lack of hazard/vulnerability/exposure data in many regions, the complexities of disasters and volatility of losses (Golnaraghi, 2018). To set the big picture, currently, total assets under insurance management exceed 4.1 trillion € for which the premiums held by insurance sector is 0.48 trillion € (= 8.4%) (Golnaraghi, 2018).

4.2.3. Repair/replacement and upgrade costs for infrastructure

There is an emerging view that planning for Climate Change adaptation should begin as soon as possible because anticipatory and precautionary adaptation is more effective and less costly than forced, last minute, emergency adaptation or retrofitting (Watkiss et al., 2005). The ability of human systems to adapt to and cope with Climate Change depends on factors such as wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities.

Developing countries have less of these attributes and, as a result, have a lesser capacity to adapt and are more vulnerable to Climate Change impacts. Reviews of Climate Change adaptation work[5] have shown that Climate Change costing studies often pay little attention to adaptation costs and further research would increase the reliability of adaptation cost estimates. Moreover, infrastructure related issues include other neglected but very important issues and mainly working safety for the aquaculture personnel and marine safety from damaged infrastructure, which may interfere with transportation.

As an example from Norway, deaths in the aquaculture sector average 9.13 per 100,000 work years as related to other industries which ranges 0.53 per 100,000 work years (Myers & Durborow, 2012). Climate related disasters contribute 17% in damages on infrastructure and 31% in losses of capital (FAO, 2016). World Bank's global study estimated that the price tag between 2010 and 2050 for adapting to an approximately 2 °C warmer world by 2050 will be in the range of $70 billion to $100

[3] *ClimateWise network*

[4] *estimate by Lloyds London*

[5] *http://adaptation.nrcan.gc.ca/perspective/profile_e.asp*

billion a year (World Bank, 2010). Individual country studies suggest that costs could be even higher, once cross-sectoral impacts are taken into account (expected domino effect on the primary and secondary industries). This sum is the same order of magnitude as the foreign aid that developed countries now give developing countries each year. The costs vary by climate scenario and whether benefits from Climate Change are used to offset adaptation costs. According to the World Bank (2010), the contribution of coastal area adaptation costs can reach 35% of the total adaptation costs.

4.2.4. *Farming of non-native species and alien invasions*

Increased temperatures along the coasts, as well as changes in temperature oscillation amplitude throughout the year could, potentially, allow new species to be cultured (Bergh et al., 2007) in the region where the current temperature maximums and minimums are marginal for the species, such as sea bass, sea bream, turbot, hake, tunas and Manilla clams. Although it should be recognised that with higher temperature regimes, most bacterial infections may be predicted to progress faster once the host is infected, preventing these opportunities of species diversification being realized (Gubbins et al., 2013).

Aquatic non-native invasive species are already causing significant economic impacts in the EU and especially in the Mediterranean, due to the equalization of the temperature barriers between the Mediterranean, the Red Sea and the Atlantic as well as increased maritime transportation, which allows alien species to invade the region and in many cases establish viable populations (Mannino et al., 2017). In terms of numbers, there are recorded 1071 marine flora and fauna species in EU waters from which 171 (16.1%) show ecological impact and 1276 species (16.4%) show economic impacts (Vilà et al., 2010). Most literature cover specific case studies and therefore, upscaling to Europe level is rather difficult. As an example of annual costs (indicative order of magnitude), we have:

- US, UK, Australia, South Africa and India (all invasive species) 276 billion €/year
- Ireland (all invasive species) 202 million €
- UK (marine invasive species) 8 million €/year
- Germany (marine invasive species) 14 million €
- Canada (marine invasive species) 45.7 million €/year
- USA (only fish and molluscs) 2.3 million €/year
- EU (all invasive species) 125 billion €/year

At the same time, the estimated cost for proactive management and mitigation in EU, is estimated at 190 million € (maximum; from 40-190 million €) i.e. 0.15%.
Some studies suggest that the rate of invasions is likely to increase under Climate Change and increasing temperature regimes (Byers et al., 2002; Stachowicz et al., 2002). There is currently little evidence of impact on aquaculture from non-native species in the UK and Ireland. However, examples from beyond the region suggest Climate Change could increase the rate of invasions, particularly in marine habitats at higher latitudes (Gubbins et al., 2013) as species ranges expand further north.

4.2.5. *Clean-up processes*

Cultivated bivalves may play an important role in remediating the negative impacts of land-derived nutrient loading which is expected to increase due to Climate Change (increased flooding, increase of precipitation within the micro-catchment area, coastal erosion, increased riverine outputs etc.), based on a spatially-explicit coupled hydrodynamic-biogeochemical model to address the issues of production and ecological carrying capacity and the potential for mussel culture to mitigate the effects of nutrient inputs. Climate Change may lead to increases in production and ecological carrying capacity as long as the cultivated species can tolerate warmer summer conditions (Guyondet et al., 2015). However, the benefits from shellfish aquaculture in nutrient sequestration should be balanced with the environmental output of shellfish farming in the form of suspended particles through filtration, ingestion and digestion (Cranford et al., 2009, 2007).

Coastal ecosystems offer important ecosystem goods and services (such as flood prevention and control, seawater barriers, nutrient recycling and sequestration, food, job/income security, recreation and many others) creating balance (Sipkay et al., 2010). In addition to the offering of services, these ecosystems also regulate micro-climate (Kontogianni et al., 2009). Climate Change accentuates these pressures while it makes mean sea level rise (SLR) one of the most predictable and alarming impacts globally. SLR is known to be rather inelastic against the reduction of greenhouse gas emissions, a phenomenon known as '*commitment to SLR*'. That is, even if drastic reduction policies globally succeed in stabilizing the climate, SLR and the accompanying phenomena of coastal erosion and storm surges will continue to occur for centuries, creating possible tipping points for some ecosystems.

The chemical imbalance of coastal formations such as lagoons and wetlands, caused by Climate Change is expected to reduce the amount and value of ecosystem services offered by these ecosystems (Summers et al., 2018). Protection and restoration of the capacity of these ecosystems to produce goods and services should be top priority in the management agenda. The community, may not pay directly for these ecosystem services but do pay significantly for their loss through infrastructure and policy costs (e.g., construction and operation of wastewater treatment facilities, increased illness, losses in soil fertility and reductions in basic human well-being) and which all form parts of the clean-up costs (Summers et al., 2018). In terms of policy costs (adaptation costs), the value for the coastal infrastructure varies between 0.5-0.9 billion € per year for the EU Member States from the sea level rise hazard alone (for 2015 the value of 0.65 billion €) (Policy Research Corporation and MRAG, 2000). The same authors point out that every Member State has different budget requirements. For example, The Netherlands alone will require more than 1 billion € per year in the period 2010-2100 (to maintain flooding sea barriers and freshwater resources. The economic valuation of these costs is difficult since it depends on the level of coastal development. For example,

- for UK this value is 440 million € (source: IPCC at http://www.ipcc.ch)
- for the Japanese ports is 97 billion € for just 1-m SLR (source: IPCC at http://www.ipcc.ch)
- for Australia, the value of endangered infrastructure (replacement value) is 142 billion € for 1-m SLR

4.2.6. Employment and job security

Employment is a very difficult issue to address since it needs to be addressed on a local basis based on the dependency to the fisheries and aquaculture sector. In addition, the effects of Climate Change on employment is highly related to the national economy and level of country development. Most literature is focused on local and regional case studies and hence, have limited value for a global review of the issue. Fisheries and aquaculture contribute in a significant way to food security and to the livelihoods of millions of people, as a creator of employment, supplier of nutritious food, generator of income and economic growth through harvesting, processing and marketing (Barange et al., 2018). There have been identified 388 fisheries-dependent communities that together play host to 54 percent of total fishery employment in Europe (Natale et al., 2013).

4.2.7. Policy recommendations

For the Mediterranean Sea, it is expected to observe: (i) an increase in air temperature of between 2.2 and 5.1 °C; (ii) a decrease in rainfall of between 4% and 27%; (iii) an increase in drought periods related to a high frequency of days during which the temperature would exceed 30 °C; and (iv) an increase of the sea level of around 35 cm and saline intrusion (IPCC 2017, scenario A1B in Rosa et al., 2012). Moreover, extreme events, such as heat waves, droughts or floods, are likely to be more frequent and violent. Rosa et al. 2012 makes a review of the present status of Mediterranean aquaculture (e.g. production trends, main farmed species, production systems, major producing countries), and the most relevant impacts of Climate Change on this sector (temperature, eutrophication, harmful algae blooms, water stress, sea level rise, acidification and diseases). In this work they propose a wide range of adaptation and mitigation strategies that might be implemented to minimize impacts. Mitigation measures per potential hazard are summarized in Table 4.2a (adapted from Rosa et al., 2012).

Table 4.2a. Climate Change impacts in Mediterranean aquaculture and potential adaptive measures

CC Impact	Adaptation/mitigation measures
Temperature rise (above optimal range of tolerance)	Use better feeds Use selective breeding and genetic improvements Use short-cycle aquaculture
Enhanced growth/production	Increase feed input
Sea level rise/salt water intrusion	Changing farmed species Moving operations away from the shore
Increase in eutrophication	Improve monitoring and early warning systems. Implement waste water treatment with cost-effective and environmental friendly techniques
Limitations on seafood meal and fish oil supplies	Shift to non-carnivorous, bivalve and seaweed species Genetic improvement for alternative feeds
Less wild seed stocks	Use of hatchery seed Protect nursery habitats Improve seed quality and production efficiency Close the species life cycle
Water quality	Implement waste water treatment with cost-effective and environmental friendly techniques Shift to faster growing seafood species Use agro or multi-trophic aquaculture
Loss of stocks	Improve site and design to prevent losses and escapes Encourage use of indigenous or non-reproducing species
Increase resistance to diseases (increase use of veterinary drugs)	Replace veterinary synthetic drugs by natural control of diseases (e.g. probiotics, green water technique. natural immunostimulants, vaccines) Implement genetic improvements for higher resistance

Finally, table 4.2b presents a summary of the above findings, with special attention to the works that provide a quantification of market and non-market effects of Climate Change impacts and related policies.

Table 4.2b. Aquaculture summary - Market and non-market effects of different CC impacts and policies on supply side

Hazard	Case study	Method	Environmental services / Non-market effects	Economic impact	Source
Increased temperature	Salmon farming in North European waters 1. Temp. amplitude > -3.1 °C 2. Temp. average ↑ +0.5 to +3 °C. 3. Temp. amplitude ↑ +3 to +4 °C, and average ↑ 3-4 °C	Gross-Present Value function(GPV)	1. death of the fish 2. ↑ production cycle around 2-4 months in the total production period 3. Negative. But below these levels, for every 1 °C increase, the production cycle ↓ by 3-4 months	3. every 1 °C increase ↑ gross production value on average by 17%	Lorentzen, 2006
	Barents Sea fisheries ↑ 2°C average sea temperature with adaptation measures		↑ recruitment of cod and herring, ↑ annual catches, ↑ local employment	↑154% in fisheries profits ↑77% aquaculture profits	Eide and Heen, 2002; McCausland et al., 2006
	Macrobrachium rosenbergii farmers in Bangladesh CC scenarios of water salinity, cyclones, sea level rise, coastal flooding, water temperature, drought and rainfall on the prawn production are discussed	primary data collection, including (1) questionnaire interviews, (2) focus groups and (3) interviews. Supported by analytical hierarchy process (AHP)	biophysical resources, feed availability, marketing, availability of fry, eco-friendly practices→ ↑resilience capacities inadequate fry supply, diseases, low technical knowledge, high costs, low production → ↓resilience capacities		Ahmed, N., Diana, J.S. 2016
Extreme events	1. Norway 2. Global scale		1. 9.13 deaths per 100,000 work years	2. ↑ 17% damages to infrastructure ↑ 31% capital losses	Myers & Durborow, 2012 FAO, 2016
	Sizewell, Bradwell, Lilstock, and Seascale coastal towns Mapping water inundation/ flooding on specific UK coast	ARCoES DST GIS-based decision support system paired with a vulnerability model	- Effects of appropriate and timely intervention and adaptation to ↓vulnerability to coastal flooding - Net Present Value of the investments that are required for coastal defenses.	↑ infrastructure damages ↑ maintenance and repair costs	Brown, J.M. et al., 2018
	Ghana INTENSE STORMS Coastal runoffs; increased river outflows due to rainfalls; deterioration of coastal water quality from increased runoff pollution	Questionnaires and national account data on temperature, rainfall, and humidity	Stakeholders adaptation solutions: - 32% planted trees around ponds to serve as shade to reduce evaporation. - 20% raised the banks of ponds to prevent loss of fish. - 16% dug boreholes near ponds to serve as a water source - 12% constructed ponds close to water bodies and stocked favorable species.		Asiedu, B., et al., 2017

4.3. Energy

4.3.1. Risk of changes in power generation due to long term Climate Change and variability

Understanding the impacts of climate variability and change on electricity systems is paramount for operators preparing for weather-related disruptions, policymakers deciding on future directions of energy policies and European decision makers shaping research programs.

Stanton et al. (2016) reviewed the impacts of Climate Change on electricity systems across Europe and indicated that in the absence of adaptation, the thermal electricity generation will decrease for both the near term to mid-21st century (NT-MC) and the end of the 21st century (EC). In contrast, the renewable electricity generation will increase for hydroelectricity in Northern Europe (NT-MC and EC), for solar electricity in Germany (NT-MC), the United Kingdom and Spain (NT-MC and EC) and for wind electricity in the Iberian Peninsula (NT-MC) and over the Baltic and Aegean Sea (NT-MC and EC).

Rübbelke and Vögele (2013) found strong negative effects of Climate Change on the European power sector. By assuming a reduction in the runoff of rivers of up to 10%, the authors estimated that electricity prices will rise significantly in some European countries, e.g., in Switzerland by more than 80 % and in France by more than 30 %, implying welfare losses for consumers throughout Europe.

Weber et al. (2018) analysed the impact of the change of the temporal characteristics of the wind power generation in a strong (RCP8.5) and a medium Climate Change scenario (RCP4.5) and found that backup and storage needs increase in most of Central, Northern and North-Western Europe and decrease over the Iberian Peninsula, Greece and Croatia. Tobin et al. (2016) found that, under two Greenhouse Gas (GHG) concentration scenarios, the annual energy yield of the European wind farms as a whole, as projected to be installed by 2050, will remain stable across the 21st century. However from country to local scale, wind farm yields will undergo changes up to 15% in magnitude, according to the large majority of models, but smaller than 5% in magnitude for most regions. More precisely, the Iberian Peninsula power production is likely to be the most affected, with a robust reduction projection of yield by 5%–10% at the annual scale, and by 15% in autumn, by the end of the century under the RCP8.5 scenario. The Italian fleet is also likely to experience similar yield reduction. This is partly due to a decrease in geostrophic winds, i.e., a change in large-scale circulation patterns. By contrast, the Poland-Baltic fleet energy yield may benefit from Climate Change, which may be due to sea ice melting. The authors however note that the projected changes are assessed at the century scale; at the time horizon relevant for wind power investors, which is 10–20 years, changes will be much smaller. Therefore, these Climate Change effects will not jeopardize the development of wind energy in Europe.

François et al. (2017) found that the increase of the wind power capacity in Mid-Norway can reduce the energy balance deficit. The deficit becomes almost nil during high consumption/price period, i.e., in winter. Generation from new wind power plants is almost totally used for reducing the deficit and only 2% of the additional wind generation is exported during the whole year. The authors conclude that coupling effects from both Climate Change and increasing wind power and transmission lines capacities appear to lead to a win-win situation: Mid-Norway average energy balance deficit is reduced and would become positive in the next decades allowing the region to increase its exportation, especially during winter season when prices are high.

Miu (2015) assessed the magnitude of the vulnerability of wind resource to Climate Change using two Scottish wind farms in Gordonbush and Dun Law. Climate-forced changes in atmospheric circulation patterns were predicted to increase the wind resource availability on Gordonbush and decrease on Dun Law, leading to corresponding changes in net annual electricity production: a 31.7% increase at Gordonbush and a 31.8% decrease at Dun Law by the year 2040. In economic terms, these

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deviations were equivalent to an increase of annual gross profit of £95,284 at Gordonbush, and a decrease of £22,742 at Dun Law. The findings of the study also shows that the turbine design plays an important role in determining the sensitivity of the two sites to changes in the wind resource, with higher, more powerful wind turbines being more sensitive to changes in mean wind speed.

Davy et al. (2017) showed that overall the northern and western parts of the Black Sea region are very suitable for the development of new wind farms with respect to an increase in the extractable wind potential. The seasonality of the wind resources fits well to the seasonality of energy demand in the region, and the wind resources in the Black Sea have been shown to be unaffected by the projected Climate Change of the 21st century, unlike the wind resources in much of the European domain. Van Vliet et al. (2012) assessed the impact of Climate Change on thermoelectric power production in Europe and United States, especially during summer by applying a physically based hydrological and water temperature modelling framework combined with an electricity production model. Model results revealed a summer average decrease in the capacity of power plants of 6.3-19% for Europe and 4.4-16% for the United States depending on cooling system type and climate scenario for 2031-2060. In addition, probabilities of extreme (>90%) reductions in thermoelectric power production will on average increase by a factor of three. The power plants with once-through cooling will be the most severely affected by future water temperature rises and reductions in summer flows.

Behrens et al. (2016) quantified the effects of policy mechanisms (e.g., feed-in tariffs) for promoting renewable energy in Portugal in the period 2000-2010. Their findings show that in this period, these mechanisms led to a cumulative net reduction of GHG by 7.2 million tonnes of CO2 equivalent (MtCO2eq), an increase of GDP by 1,557 M€ and a creation of 160 thousand job-years. The same author in 2017 studied the combined impacts of changes in water availability and temperature due to CC, and sectoral water use changes on thermoelectric generation for 1,326 individual thermoelectric plants and 818 water basins across EU. They found that the number of regions experiencing reduction in power availability due to water stress rises from 47 basins to 54 basins between 2014 and 2030. The majority of vulnerable basins lie in the Mediterranean region.

Wagner et al. (2017) estimated that the average annual electricity generation of run-of-river plants for the time period 2031–2050 compared to 1961–1990 for the whole Alpine region is estimated to decrease slightly for all climate scenarios considered (up to -8%). These findings highlight the need for an integrated, basin-level approach in energy and water policy. However, the major barriers for the uptake of adaptation strategies include the cost of implementation and the fragmentation of energy and water policy frameworks (Behrens et al., 2017). Solaun and Cerdá (2017) combined physical, technical and economic information to analyse to what extent a decrease in average rainfall and changes in temperature, as a consequence of Climate Change, could affect the long-term profit margins and operations of three hydroelectric plants in Southern Spain. The study has shown that the reduction in availability of water resources linked to Climate Change will significantly reduce the hydroelectric production in Southern Spain between 30%-49% (under the IPCC Scenario A2) and between 10%-31% (under the IPCC Scenario B2) by the end of the century, thus substantially affecting the operating margins of the plants. Under the Scenario A2 two of the three plants would have negative operating margins (-6% & -27%) and under the Scenario B2 one plant would cease to have positive margin (-16%). This reduction in water resources would also affect new investments in the sector as the results show positive values in only one of the plants in a hypothetical investment from scratch.

Crook et al. (2011) explored the impact of Climate Change on future photovoltaic (PV) and concentrated solar power (CSP) energy output. Their estimates revealed that PV output is likely to increase by a few percent in Europe and China, little change in Algeria and Australia, and decrease by a few percent in western USA and Saudi Arabia, while CSP output is likely to increase by more than 10% in Europe. These findings demonstrate that CSP is usually more sensitive to Climate Change than PV photovoltaic, although there are strong regional differences. Panagea et al. (2014) analysed the effect of projected changes in temperature and irradiance on the performance of photovoltaic systems in Greece and they found that the PV output is projected to have an increasing trend for all regions of Greece during the 21st century. Using the IPCC A1B Climate Change scenarios and the DOE-2 energy building simulation program.

Lu et al. (2010) showed that by mid-century, building yearly energy consumption and the peak load will increase in the Southwest US and Canada. The results of the study suggest an increasing need for the industry to implement new technology to increase the efficiency of the temperature-sensitive loads and apply proper protection and control to prevent the increasingly adverse impacts of a/c motor loads. Reeve et al. (2011) studied the impact of Climate Change on wave energy generation in UK (Cornwall) and they found that the available wave power will increase 2-3% for the A1B scenario, with more energy available in waves with greater steepness. In contrast, the available wave power for B1 scenario will be 4-6% smaller than that for the A1B scenario. The energy yield from the wave energy converter (WEC) is found to decrease by 2-3% for both A1B and B1 scenarios, mainly due to the upper-limit of exploitable energy from steep waves.

Linnerud et al. (2011) explored the impact of a warmer climate on nuclear power supply and they found that a 1ºC rise in ambient temperature will reduce output by about 0.7% at low temperatures (around 0ºC) and by about 2.3% at high temperatures (around 20ºC) as a result of decreased thermal efficiency. It has been reported that during droughts and heat waves near to 40% of the nuclear power plants in Europe have already experienced loss of electricity production which may exceed 2% per degree Celsius due to refrigerating problems (Linnerud et al., 2011; Rübbelke and Vögele, 2011). Similarly, model simulations have shown that power production in central Europe could decrease near to 12% representing losses for a single power plant around 80 million € (Förster and Lilliestam, 2010).

According to Rademaekers et al. (2011) the annual monetary costs of power plants in the EU for adapting to Climate Change in 2080 have been estimated around €400 million. Solutions such as the diversification of supply sources, e.g., by including the possibility of using off-grid small generation facilities for backup (e.g., solar photovoltaic), compensation via energy storage and/or interregional transmission and, increasing demand management options can reduce the risk of power supply disruptions (Bardt et al., 2013). Incorporating possible Climate Change impacts into planning processes could strengthen energy production and distribution system infrastructures, especially regarding water resource management. The adaptation of energy use to Climate Change may focus on increased demands for space cooling in areas affected by warming and associated increases in the total energy consumption costs (Wilbanks et al., 2008). Finally, one way for addressing the risk of energy supply disruptions is through the application of supranational legislation and action plans (Linnerud et al., 2011).

4.3.2. Risk of changes in energy demand due to changes in precipitations and temperatures

Cian and Wing (2014) evaluated future impacts of climate on energy demand at the global scale and they showed that the cooling effect, as revealed by an increase in electricity demand, is larger in temperate regions for the residential and commercial sectors. The heating effect mostly shows up as changes in fuel oil and natural gas, with a generally larger and more significant marginal effect in tropical regions. Concerning industry, they found a significant response of electricity for cooling in tropical countries and of fuel oil for heating in temperate countries. Labriet et al. (2013) indicated that the impacts of Climate Change on the global energy system can be large at different territorial levels, with a decrease of energy uses (mostly fossil fuels and biomass) for heating, and an increase of electricity for cooling. The impacts on electricity generation may reach up to several gigawatt (GW) in some regions, often supplied by coal, resulting in additional greenhouse emissions. However, the climate feedback would be negligible, given the small share of heating and cooling in the total final energy use and also the balancing, at the global level, of the increased emissions from the additional electricity supply and the decrease of emissions associated to space heating.

Global warming will significantly affect the demand side of the European energy system (Mima and Criqui, 2015). Damm et al. (2017) examined the impacts of +2 ºC global warming on electricity demand in Europe. Their findings indicate a temperature induced reduction in electricity demand for most European countries, i.e., the decrease in heating electricity demand more than outweigh the increase in cooling electricity demand. By far the highest absolute net-decrease in mean electricity consumption is found for France that can be explained by the French energy policy formulation, where electric heating has been strongly promoted since the 1970s for reducing energy dependency and fostering CO2-savings compared to conventional heating fuels. Norway shows the highest relative net decrease in mean electricity consumption. Expressing the electricity demand changes in monetary terms at current prices (excluding taxes, which are very heterogeneous amongst EU member states), the effects for e.g. France correspond to a reduction in consumer spending for electricity between €976 million and €1,713 million, whereas for Italy results suggest an increase in consumer spending for electricity by €68 million to €246 million. Overall, the effect results in a decrease by €3.8 billion to €6.6 billion for the European countries, although these effects are unevenly distributed.

Töglhofer et al. (2012) conducted a cross-country analysis for the impact of Climate Change on electricity demand in Continental Europe and they concluded that climate is not the main driver for the amount of electricity used for heating and cooling purposes, but that it is rather the energy policy mix. Current cooling electricity demand was estimated to be relatively small compared to heating electricity demand for most of the countries, and Climate Change will lead to a reduction of electricity consumption. While in several countries with comparatively warm summer temperatures (e.g., Spain, Hungary, Croatia) the size and seasonal distribution of the climate change signal might determine the direction of the effect, for Italy the increase in cooling electricity demand is predicted to be stronger than the decrease in heating electricity demand for all climate scenarios. The authors highlight that if not considering electricity only, the total effects of Climate Change on energy demand in Austria as well as in Europe are positive. In Austria, consumer expenditures for heating energy carriers other than electricity are approximately 10 times higher than heating and cooling electricity costs. Thus, total consumer savings for energy until 2050 could be around €500 million per year.

Kitous and Despres (2017) showed that the total residential final energy needs for heating and cooling decrease by 5% in the short-term and 22% in the long-term (-26% in 2100) due to the increase in the average temperature in Europe, compared to a scenario without Climate Change. Similarly, future projections of potential Climate Change impacts in urban regions of Greece revealed an increase in the energy demand for cooling in summer and a decrease in demand for heating in winter (Giannakopoulos et al., 2011). More specifically, 15 (±8) fewer days requiring heavy heating per year are expected in almost all urban areas in Greece. However, the winter and summer loads do not counterbalance each other, as the energy consumption required for cooling in summer is greater at specific days and times of the day. Taseska et al. (2012) found that the projected increase in summer space cooling demand in Macedonia dominate over the reduction in winter heating demand, and the net increase though relatively small grows larger over time. Harrison and Wallace (2005) indicated that expected changes in the wind and wave patterns will affect offshore wind and wave energy conversion in Western Scotland leading to severe losses in the production and economic performance. A 20% decrease in the mean wind speed would lower available wave power levels by 67%, while unit electricity costs would increase by 35%. Mima and Criqui (2015) estimated the costs of the impacts of Climate Change on the EU-27 energy system. Energy expenditure on the demand side will decrease by $140 billion by 2100 under the

A1B scenario for heating and it will increase by $136 billion for space cooling. Households would benefit from such lower spending on heating energy, which could decrease the incentives to invest into dwelling insulation. However, these estimates vary widely by region. In relatively mild countries, like Italy, higher demand for electricity during summer is compensated by lower demand for gas, oil products and coal in winter and spring, while in warm countries, such as Spain, the cooling effect increases energy demand.

Park et al. (2018) estimated that the economic impacts of Climate Change are largely affected by socioeconomic assumptions. The study estimated that the global GDP change rates will range from +0.21% to -2.01% in 2100 under a 4ºC change in the global mean temperature, depending on the socioeconomic conditions. On its side, Golombek et al. (2012) explored the equilibrium consequences of three partial effects, namely, price, quantity, and trade effects, of Climate Change on electricity markets in Western Europe. The results of the study revealed that the total effect of a change in climate on the producer price of electricity in Western Europe would be an increase of only 1%, while the total production of electricity would decrease by 4%, mainly reflecting the demand effect. Since the reported effects on electricity production were in general small, trade did not change much. However, there is a significant effect on electricity trade in Northern Europe: without Climate Change, all Nordic countries are net exporters of electricity; with all climate effects, Nordic exports doubles, reflecting that the electricity transmission capacity at the border of the Nordic countries and the continental Europe will be increased by around 80%.

Auffhammer et al. (2017) assessed the cost implications of the increased intensity and frequency of extreme events driving peak demand in the US by parameterizing the relationship between average or peak electricity demand and temperature. Their findings indicate that peak load is impacted by Climate Change far more than is average load (consumption). The results revealed moderate and heterogeneous changes in consumption, with an average increase of 2.8% by the end of the century. Peak load simulations suggest significant increases in the intensity and frequency of peak events throughout the US. As the electricity grid is built to endure maximum load, these findings have significant implications for the construction of costly peak generating capacity, suggesting additional peak capacity costs of up to 180 billion dollars by the end of the century under business-as-usual scenario, thus highlighting that adaptation would require additional expenses in terms of capacity or storage or transmission investments and not simply generation costs. Advances in batteries or the use of electric vehicles for storage could mitigate the peak load effects estimated in the study. Similarly, a widespread adoption of time-varying prices, such as real-time prices, could smooth the distribution of demand, with customers finding the optimal way to shift some of their demand from peak to off-peak hours.

Jaglom et al. (2014) assessed the impact of temperature change on US electric power sector and they found that without mitigation, the total annual electricity production costs in 2050 are projected to increase by 14% ($51billion) because of greater cooling demand as compared to a control scenario without future temperature changes. Similarly, Reyna and Chester (2017) showed that without policy intervention, the residential electricity demand could increase in Los Angeles by as much as 41-87% between 2020 and 2060. However, aggressive policies aiming at upgrading heating/cooling systems and appliances could result in electricity use increases as low as 28%. Emodi et al. (2018) assessed the impact of future temperature changes on electricity demand of six Australia states and they found a gradual increase in electricity consumption due to warmer temperatures with a possibility of peak demand in winter. However, demand tends to decrease in the middle of the 21 century across the RCPs, while the summer peak load increases by the end of the century. Shourav et al. (2018) assessed the impacts of Climate Change on residential energy consumption in Dhaka city of Bangladesh. The results revealed that the daily total residential energy consumption, particularly the daily peak energy consumption in Dhaka city is highly sensitive to temperature. More precisely, the daily total residential energy demand

and peak energy demand in Dhaka city will increase up to 5.9-15.6% and 5.1-16.7%, respectively, under four RCP scenarios.

Giuntoli et al. (2016) assessed the potential of bioenergy power plants fuelled by three different types of biomass residues, namely, forest logging residues, cereal straw and dairy cattle slurry, to mitigate global warming. Their findings indicate that power generation from cereal straws and cattle slurry can provide global warming mitigation by 2100 compared to current or even future decarbonized European electricity mix in all of the systems and scenarios considered. Literature findings highlight the need for regulators, power companies and regional transmission organizations to account for future temperature changes in demand forecasts and investment planning decisions (Jaglom et al., 2014). Ignoring the influence of future temperature changes may lead power sector planners and decision-makers to underestimate future electricity demand, particularly during periods of peak load (Jaglom et al., 2014).

4.3.3. Risk of damages to transmission grids due to extreme events

The warmer and more frequent hot days will increase the peak load in summer-peaking regions stressing at the same time the power system components (Kezunovic et al., 2008). Bartos et al. (2016) found that by mid-century (2040-2060), increases in air temperature may reduce average summertime transmission capacity over the continental US by 1.9%-5.8% relative to the 1990-2010 reference period. At the same time, peak per-capita summertime loads may rise by 4.2%-15% on average due to increases in ambient air temperature. In absence of energy efficiency gains, demand-side management programs and transmission infrastructure upgrades, these load increases may question the current assumptions about future electricity supply adequacy.

Karagiannis et al. (2017) explored the disruptions of the critical electricity infrastructure by floods in Europe. Erosion due to the floodwaters and landslides triggered by floods undermine the foundations of transmission towers. Early warning is possible, and enables electric utilities to shut off power to facilities in flood zones, therefore minimizing damage. On average the blackout lasts from less than 24 hours to more than one month. The authors suggest that although burying electrical equipment (such as distribution substations and power lines) has been considered an efficient measure to reduce building density, improve security, and protect against weather-related hazards, this option is rather expensive and time-consuming. For example, it was estimated that the replacement of all existing overhead distribution lines with underground cables in the State of North Carolina would cost US$ 41 million, nearly six times the net books value of the distribution assets of all State Distribution Systems Operators, and would require 25 years to complete (Staff, 2003).

Since 1980, the US has sustained 144 weather disasters whose damage cost reached or exceeded $1 billion, while the total cost of these 144 events exceeds $1 trillion (Executive Office of the President, Council of Economic Advisers, 2013). The annual cost of weather-related power outages in the US ranged between $25 and $70 billion (Campbell, 2012). Similarly, the 2008 heatwave in South Australian regions caused severe problems to maintain the electricity supply on the transmission grid (WattClarity, 2008). It reduced the instantaneous reserve margin up to 7%, which led to rocketing electricity market prices. The cumulative increase of price was over AU$150,000 and forced the electricity market operator to set a price cap. The heat wave was claimed to have allowed electricity companies to obtain extra revenues of nearly AU$200 million and caused financial losses estimated at AU$800 million, mainly resulting from power outages, interruptions in transport service and response costs.

Energy policy-making and planning need to assess disaster risks such as storms, floods, droughts and sea-level rise at both national and local level. Feasibility studies for power plants should include an evaluation of future disasters risks to determine whether a site is adequate or not for a new power plant, while environmental impact assessments should consider the dynamic nature of disaster risks in a changing climate and should include an assessment of future disaster risks for new power plants (Urban and Mitchell, 2011). Structural and topology measures can increase the resistance and resourcefulness of the system to extreme weather events, while smart grid solutions can also be applied for providing flexibility and advanced monitoring, protection and control strategies to mitigate the effect of severe weather (Panteli and Mancarella, 2015).

Jufri et al. (2018) highlight that the assessment of grid resilience (determined by the extreme weather event intensity, the grid exposure, and the grid vulnerability) and grid capability, can provide valuable information about the existing condition of the grid in order to provide early awareness about the impact caused by an upcoming extreme weather event and help designing and prioritizing grid resilience improvement strategies.

See tables 4.3a, 4.3b and 4.3c for a summary of those works that provide clear insights for the subsequent economic modelling phases.

Table 4.3 a. Energy summary - Market and non-market effects in energy demand due to changes in precipitations and temperatures

Hazard	Case study / CC scenario	Method / Model	Demand	Economic impact	Source
Extreme events	US Cost implications for Driving peak demand	Multiyear data from 166 load balancing authorities in the US were analysed using statistical models.	↑ 2.8% peak demand by end of century ↑ costs of up to 180 billion dollars by the end of the century		Auffhammer, et al 2017
	Global scale Impact on building operation and performance	Typical and extreme meteorological weather data were created for 25 locations (20 climate regions range of predicted heat island scenarios for building simulation	In cold climates ↓ 10% energy use tropical climates ↑ 20% energy use mid-latitude climates: ↓ 25% heating energy- ↑ 15% cooling energy Low-energy buildings will be the least affected, with impacts in the range of 5–10%.		Crawley, D. B., 2008
Wind	Western Scotland	Sensitivity study ↓ 20% in the mean wind and wave patterns on marine energy	↓ 67% available wave power levels	↑35%unit electricity costs.	Harrison, G. P., & Wallace, A. R.,2005
Increased temperature	Impacts on the European energy system A1B scenarios	Prospective Outlook for Long-term Energy Systems (POLES) model, partial equilibrium model from the present day till 2100	↑ energy demand for air-conditioning by 2100 ≥50 Mtoe ≤ 65 Mtoe ↓ output by thermal, nuclear and hydro-power plants	Expenditure(2100: heating - ↓$140 billion space cooling- ↑ $136 billion Loss= 200 TWh (2070)	Mima, S., & Criqui,2015
	Switzerland Impact of a changing climate on the energy demand and supply system.	CGE model (GEMINI-E3)	↓ population requirements for heating purposes. ↑ energy demand for cooling ↓ efficiency and the load at which thermal power plants are operated	↓ prices	Gonseth, C., & Vielle, M., 2012
	Western Europe Impact on electricity demand and hydropower supply	The numerical model LIBEMOD	total production of electricity ↓ 4%	↑ 1% producer price	Golombek, R., et al 2012

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Hazard	Case study / CC scenario	Method / Model	Demand	Economic impact	Source
Increased temperature	Continental Europe	non-linear relationship between temp. and electricity demand with the use of smooth transition regression models	↓ electricity demand ↑ heating energy expenditure carriers other than electricity	consumer savings for energy until 2050 = €500 million per year.	Töglhofer, C., et al 2012
	Singapore equatorial climate- Impact on electricity demand	Model the effect of GDP, temperature, humidity and lagged demand variables on the hourly electricity	↑ electricity demand ↑ humidity - ↑electricity demand. impact marginally higher during the warmer months of the year		Joutz, F., et al 2013
	Europe Impact of +2 oC global warming on electricity demand	Construction of national temperature indices. Correction of national electricity consumption for non-climatic effects.	↓ heating electricity demand > ↑ in cooling electricity demand France: ↓ consumer spending between €976 million and €1,713 million Italy: ↑ consumer spending by €68 million to €246 million. Overall: ↓ €3.8 billion to €6.6 billion in EU		Damm, A., et al 2017
	Global scale	Asia-Pacific Integrated Model/Computable GeneralEquilibrium [AIM/CGE]) coupled with an end-use model	global GDP change rates will range from +0.21% to -2.01% in 2100 under 4oC change in the global mean temperature.		Park, C., et al., 2018
	Impact on residential energy demand for heating and cooling in Europe	The study estimated bias-corrected near-surface air temperature transmitted by GCMs.	↓ heating needs compared Long-term : -27% (2070-2100). Short-term : -5% (2020-2050). ↑ air cooling 44% - short-term and multiplied by a factor of 3 in the long-term,		Kitous, A., & Despres, J. 2017
	Dhaka city, Bangladesh Impact on residential energy consumption	six global circulation model (GCM) simulations of coupled model intercomparison RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios	↑ 5.9–15.6 daily total residential energy demand ↑ 5.1–16.7%, peak energy demand		Shourav, M. et al 2018

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Table 4.3b. Energy summary - Market and non-market effects in power generation due to long term Climate Change and variability

Hazard	Case study	Method/Model	Production	Economic impact	Source
Increased temperature	Cornwall, UK Impacts on wave energy generation	Global Climate Model and Regional Climate Models as well as a third generation wave model (WW3)	A1B scenario: ↑ wave power 2-3% B1 scenario ↓ 4-6% respect to A1B scenario WEC energy yield ↓ by 2-3% for both A1B and B1 scenarios		Reeve, D et al., 2011
	Europe Impacts on supply of nuclear power and the national effects of induced changes in the exchange of power via the European grid	Power stations' freshwater demand equations	↓ power plant capacity	France: ↓ net-exports 10,595 MW to 9545 MW	Rübbelke, D., & Vögele, S, 2011
	Europe ↑1°C ambient temp. Impact on nuclear power supply	Regression models	↓ thermal efficiency and load	↓ 0.4% - 2.3% output	Linnerud, K., et al., 2011
	Europe Impacts on electricity systems - in the absence of adaptation Scenarios for mid-21st century and the end of 21st century	Literature review	↓ thermal electricity generation ↑ RES production: - Hydroelectricity - Northern Europe - solar electricity – Germany, UK and Spain wind electricity- Iberian peninsula, Baltic and Aegean Sea		Stanton et al., 2016
	European power sector ↓ runoff of rivers ≥ 10%	Cooling water demand functions of thermal power plants	↑ electricity prices: ≥80%-Switzerland ≥ 30 %-France ↓ welfare for consumers		Rübbelke & Vögele, 2013
	Scottish wind resource availability under the forcing of the SRES A1B GCC scenario	The HadCM3 General Circulation Model (GCM)	Gordonbush: ↑ 31.7% the net annual elect.production Dun Law: ↓ 31.8% (2040)	Gordonbush: ↑ annual gross profit of £95,284 Dun Law: ↓£22,742	Miu, 2015
	USA Impact of CC on energy production, supply and consumption	Literature review	↓ energy demand for space heating ↑ energy demand for space cooling ↓ overall thermoelectric power generation efficiency.		Wilbanks et al., 2008
	Greece: Impact of changes in irradiance and temperature on the performance of photovoltaic systems	RCM temperature and irradiance outputs for their biases. ENSEMBLES database-special report on emissions scenarios (SRES) A1B emission scenario IPCC.	(2011–2050) ↑ av. temp. up to 1.5∘C ↑ irradiance projections 2-3W/m2 (2061–2100) ↑ av. temp 3∘C to 3.5∘C () ↑ irradiance projections 5W/m2 ↑ PV output western mainland and Peloponnese, ↓ PV output Central Macedonia		Panagea, I. et al 2014

Hazard	Case study	Method/Model	Production / Economic impact	Source
Water	South Europe Southeastern US Impacts of reduced river flows in thermoelectric power	Physically based hydrological and water temperature modelling framework with an electricity production mode	Summer capacity of power plants: South Europe ↓6.3–19% Southeastern US ↓4.4–16%	Van Vliet et al., 2012
	Europe Impact of changes in water availability, temperature and sectoral water use on thermoelectric power plant generation	Energy-water-climate model using power plant data set, a water quantity data set (both availability and demand), and a water temperature data set.	47 basins to 54 basins ↓ in power availability due to water stress rises (2014- 2030) the majority of vulnerable basins lie in the Mediterranean region, with further basins in France, Germany and Poland.	Behrens, P. et al 2017
	1. Alpine region 2. Austria Changes in river discharge characteristics and the power generation of run-of-river hydro power plants up to 2050.	lumped-parameter rainfall-runoff model at a monthly time step SRES greenhouse gas emission scenario pathway A1B	1. ↓ up to -8% annual electricity generation of run-of-river plants (2031–2050) 2. Austria: +5% to - 5% depending on the technical parameters of the power plants	Wagner, T., et al 2017
Rainfall decreased	Three hydroelectric power plants in Southern Spain. ↓ rainfall and changes in temperature	Hydroclim model combining climatological, technical and economic data and projections	Southern: ↓ 30%-49% hydroelectric production (IPCC Scenario A2) ↓ 10%-31% (IPCC Scenario B2) by the end of the century This reduction would also affect new investments.	Solaun, K., & Cerdá, E, 2017
Wind	Changes in temporal characteristics of the wind power generation in scenarios RCP8.5 and RCP4.5	- five state-of-the-art global circulation models (GCMs). - Coupled Model Intercomparison based on circulation weather types. - Coarse-grained model of the electric power system	↑ backup and storage needs in Central, Northern and North-Western Europe ↓ backup and storage needs in Iberian Peninsula, Greece and Croatia	Weber et al., 2018
	Europe Annual energy yield of the wind farms under two GHG concentration scenarios	Multi-model of EURO-CORDEX ensemble. Nine GCM-RCM combinations comprise the ensemble.	Europe: annual energy yield stable across the 21st century Iberian Peninsula: ↓power production of yield by 5%–10%/year, ↓15% in autumn under the RCP8.5 Poland-Baltic fleet energy yield ↑ due to sea ice melting	Tobin et al.,2016

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Table 4.3c. Energy summary -Risk of damages to transmission grids due to extreme events

Hazard	Case study	Method/ Model	Economic impact	Source
Extreme events	North Carolina State	Feasibility study	the replacement of all existing overhead distribution lines with underground cables in the State of North Carolina would cost US$ 41 million, nearly six times the net books value of the distribution assets of all State Distribution Systems Operators, and would require 25 years to complete.	Staff, 2003
	South Australian region	Review	The 2008 heatwave reduced the instantaneous reserve margin up to 7%, which led to rocketing electricity market prices. The cumulative increase of price was over AU$150,000. The electricity companies obtained extra revenues of nearly AU$200 million.	WattClarity, 2008
	US	Review	Weather-related power outages and electric system resiliency: The annual cost of weather-related power outages in the US ranged between $25 and $70 billion	Campbell, R.J., 2012
	US	Thermal models of representative conductors to estimate climate-attributable capacity reductions to aerial transmission lines.	The results of the study indicate that by mid-century (2040–2060), increases in ambient air temperature may reduce average summertime transmission capacity by 1.9%-5.8% relative to the 1990-2010 reference period. At the same time, peak per-capita summertime loads may rise by 4.2%-15% on average due to increases in ambient air temperature.	Bartos, M., et al., 2016
	Europe	data-driven approach, using an inductive approach based on the analysis of power grid disruptions due to earthquakes, space weather and floods.	Floods are commonly associated with power outages. Erosion due to the floodwaters and landslides triggered by floods undermine the foundations of transmission towers. Serious, and often explosive, damage may occur when electrified equipment comes in contact with water, while moisture and dirt intrusion require time-consuming repairs of inundated equipment. Early warning is possible, and enables electric utilities to shut off power to facilities in flood zones, therefore minimizing damage.	Karagiannis, G. M., et al 2017

4.4. Maritime Transport

More than 80% of globally traded goods are carried by maritime transport (Xiao et al., 2015), which means that seaports provide crucial linkages in global supply-chains and are essential for the ability of all countries to access global markets. The different elements of the maritime transport sector are likely to be affected directly and indirectly by climatic changes, with broader implications for international trade and development (Becker et al., 2013). Therefore, it is crucial to analyze the socio-economic impact of the risks identified in the Impact Chains. Most of the literature focuses on the damages to seaports infrastructures and the emergence of new transportation routes.

4.4.1. Damages to ports' infrastructures and equipment due to floods and waves

Seaports are located in vulnerable areas to Climate Change impacts: on coasts susceptible to sea-level rise and storms or at mouths of rivers susceptible to flooding. They serve a vital function within the local, regional, and global economy. Their locations in the heart of sensitive estuarine environments make it an imperative to minimize the impacts of natural hazards (Becker et al., 2012).

Hallegatte et al. (2011) propose a simplified approach of catastrophe risk assessment, coupled to an economic input-output model, in order to assess the economic impacts of Climate Change at a city scale and benefits of adaptation, taking the case of sea level rise and storm surge risk in the city of Copenhagen. The city has been chosen as a case study of port cities. The analysis concludes that Copenhagen is not highly vulnerable to coastal flooding due to its high standards of defence. However, in absence of adaptation, sea level rise would significantly increase flood risks, and the potential losses would increase over time. For instance, the total losses (direct and indirect) caused by a present-day 100-year storm surge event, at 150 cm above normal sea level, are estimated to reach EUR 3 billion with no protection. In the aftermath of such an event, thousands of jobs would be lost and thousands would be created in the construction sector. In the absence of protection, future sea level rise would significantly increase flood risks beyond this level. For instance, with 25 cm of mean sea level rise (SLR) total losses caused by a future 100-year event would rise from EUR 3 billion to EUR 4 billion, to EUR 5 billion with 50 cm of mean SLR, and to almost EUR 8 billion with 100 cm of SLR. Indeed, in the most optimistic scenarios (low emission, low climate sensitivity, low response of sea level), SLR should not exceed 25 cm by the end of this century. In the most pessimistic IPCC scenario, SLR would reach 25 cm in 2050 and up to 60 cm in 2100. In the particular case of the city of Copenhagen, extreme sea level events (referred to as "storm surge events") are not particularly high, so the city is relatively easy to protect with dykes and sea walls and the residual risk is low. While annual mean losses[6] can reach several billions of Euros with protection of less than 1 m, they decrease very rapidly with protection height. They are lower than 100,000 Euros per year for 180 cm protection, and null for protection higher than 2 m.

Hanson et al. (2011) present a first estimate of the exposure of the world's large port cities to coastal flooding due to sea-level rise and storm surge now and in 2070s, taking into account scenarios of socio-economic and Climate Changes. The analysis suggests that about 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population in the cities considered) are currently exposed to a 1 in 100 year coastal flood event. For assets, the total value exposed in 2005 across all cities considered is estimated to be US$3,000 billion; corresponding to around 5% of global GDP in 2005 (both measured in international USD) with USA, Japan and the Netherlands being the countries

[6] A typical measure of the risk level is the *mean annual loss*, which is calculated as the sum of the occurrence probability of all possible events multiplied by the total losses they would cause and is equal to the expected value of annual flood losses.

with the highest values. By the 2070s, total population exposed could grow more than threefold due to the combined effects of sea-level rise, subsidence, population growth and urbanisation with asset exposure increasing to more than ten times current levels or approximately 9% of projected global GDP in this period. Additionally, this research shows the high potential benefits from risk-reduction planning and policies at the city scale to address the issues raised by the possible growth in exposure.

Becker et al. (2012) summarizes the economic impact caused to ports by SLR, storms and flooding. The Hurricane Katrina caused $1.7B of damage to southern Louisiana ports (Santella et al., 2010) while the Hurricane Ike caused $2.4B of damage to Texas ports and waterways (FEMA, 2008). Some studies found that the Port in Grenada incurred indirect losses of EC$670,000 due to Hurricane Ivan (OECS, 2004). Moreover, in recent years an average of 130 ports were hit or brushed by a tropical cyclone each year. Hallegatte (2007) found that just a 10% increase in storm intensity would increase annual hurricane damages in the US by 54%, from $8 billion to $12 billion per year. Simpson et al. (2010) found that surrounding port lands at 35 of 44 Caribbean ports will be inundated by 1m of SLR, unless protected by new coastal structures. Hurricane Katrina caused $100 million to Mississippi's ports (PEER, 2006). Between 1990 and 2012, tsunami-related casualties in Small Islands Developing States (SIDS) included more than 2,500 deaths; estimated asset and infrastructure damages amounted to nearly $660 million. In 2004, the Maldives ($470 million) and Samoa ($150 million) suffered the highest damages (UNCTAD, 2014). The Rapid Damage and Impact Assessment (RDIA, 2015) of Tropical Storm Erika for the Commonwealth of Dominica showed that transport sector damages were estimated at about US$303 million, or about 54 per cent of Dominica's GDP.

The literature highlights the importance of the economic investment that will be needed in the future to cope with the Climate Change impacts. Ports are highly vulnerable to climate risks in terms of both their facilities and operations. There have been carried out analyses in different ports to demonstrate the interaction between cost and risk, offering a useful analytical tool for assessing Climate Change risk to ports and selecting the most cost-effective adaptation measures in uncertain conditions (Yang et al., 2018). The climatic variables (mean sea level, significant wave height, peak wind speed, wave agitation) affect the harbour engineering, exploitation and operability (Sánchez-Arcilla et al., 2016; Sierra et al., 2017), as suggested in the IC. In this sense, Becker et al. (2012) state that climate impacts, like a projected SLR of 0.6m to 2m and doubling of category 4 and 5 hurricanes by 2100, will result in more extreme events at many seaports. When asked, administrators and the port community felt relative uninformed about potential climate impacts and agreed that this issue needs to be addressed. This information is relevant for the scientific community and port practitioners, given that adaptation measures should be considered as ports construct new infrastructure that may still be in use at the end of the century.

Damage caused by disasters can be prevented or alleviated if sufficient investments are made in a timely manner. This issue remains a challenging task, as immediate investment is optimal for disasters with very high probability, while investment should be postponed if such a probability is very low (Xiao et al., 2015). In the same line, Nursey-Bray et al. (2013) show evidence regarding variable vulnerability in ports in the short and the long term in relation to their exposure to Climate Change. However, this is offset by inherent adaptive capacity both in current Climate Change initiatives driven by ports, and in the self-confidence of the industry to be able to adapt.

As ports are nodal points along supply chains, it is extremely important to ensure they can develop effective adaptation strategies (Ng et al., 2013). Besides, it has been proposed a new conceptual framework for evaluating how ports currently strategize against the risk associated with climatic-related events and how they plan to ensure port resiliency (Gharehgozli et al., 2017).The port resiliency also includes a port's ability to maintain normal operations and performance over a long period of disruptive adverse change. It is also of interest how port stakeholders' planning and policy-making address these concerns. Stakeholders play a key role in planning and policy making for seaports, as they are the population potentially vulnerable to Climate Change induced events and also the complex network of stakeholder that depend on their functionality (Becker et al., 2015).

In order to ensure the sustainability of port development plans, a comparative methodology has been developed to assess port long-term management plan on the level of sustainable port development and to verify the realised impacts related to social, economic and environmental aspects (Schipper et al., 2017). The adaptive capacity building to respond to Climate Change is a key issue, taking as starting point the port sector. Planning for adaptation takes the form of multi-disciplinary teams developing and delivering innovative solutions through adaptive strategies and technologies. The implementation of adaptive actions involves practical steps to reduce vulnerability including engineering solutions, technical changes to port operations, and planning measures. Disruptions to supply-chain for an islands nation need to be highlighted, to enable ports and businesses to compete globally (O'Keeffe et al., 2016). Furthermore, the United Nations Conference on Trade and Development (UNCTAD) provided a structured way for organizations in small islands developing states to approach Climate Change adaptation (UNCTAD, 2017).

UNCTAD has also provided a platform to help advance the debate on how best move forward on Climate Change and adaptation, and a forum to discuss the latest developments and emerging challenges in international transport (UNCTAD, 2011b). The changes in market tendencies were also identified as a specific impact. It was found that there are essays that present an analysis on the challenges for ports and global society and the strategies for port resilience, although adaptation requires the development of organizational ability to respond effectively (Becker et al., 2013). The UNCTAD identified that port operations may be severely affected by climate-related impacts, with broader implications for trade, tourism and the economic development prospects (UNCTAD, 2011b).

4.4.2. Damages to ships on route (open water and near coast) due to extreme weather events

The majority of the literature focuses on the one hand, on the environmental impact of ships and ports, which represent a significant contribution to the global anthropogenic emissions. Shipping emissions are currently increasing and will most likely continue to do so in the future due to the increase of global-scale trade (Viana et al., 2014). On the other hand, the literature focuses on the study of factors affecting the degradation and corrosion ships and marine infrastructures (Yamamoto & Ikegami, 1998; Gardiner & Melchers, 2001; Guedes Soares et al., 2008).

However, not many studies take into consideration the impact of Climate Change on this process. One of the exceptions is Guedes Soares et al. (2009), who focus on the effects of relative humidity, chlorides, and temperature on the corrosion behavior of ship steel structures subjected to marine atmospheres. The authors propose a new corrosion wastage model, where different environmental factors contained in the marine atmosphere are accounted for. This way, the model distinguishes between ships that are subjected to harder or to more benign corrosion environments. It was demonstrated that corrosion in marine atmosphere is primarily influenced by moisture and is accentuated by contaminants. Additionally, the chemical composition of the water film is important.

Kubat and Timco (2003) analyzed 125 Ice Regime System database events that caused damage to vessels in Arctic waters. The analysis showed that there was multi-year ice present in the ice regime in 73% of the damage events. For Canadian Arctic Class (CAC) vessels, designed to operate in severe ice conditions, there are few damage events, but virtually all those that did occur had ice regimes with multi-year ice present. The ice regime represents a region consisting of the same ice conditions, i.e. ice type and ice concentration. For Type vessels, designed to operate in more moderate first-year ice conditions, 66% of the damage events occurred in ice regimes which contained multi-year ice. The data also showed that damage is more severe in ice regimes that contain multi-year ice.

Ventikos et al. (2018) present a comprehensive statistical analysis of navigational ship accidents in the presence of severe/adverse weather conditions that might be related to manoeuvrability issues, focusing on navigational/limited waters. They find out that about 54% of the accident sample consists of grounding and collision/contact accidents that occurred while the vessel was within port limits or limited areas. Most grounding accidents (about 20% of the accident sample) involved Tankers, Bulk Carriers and General Cargo Ships that were en-route at the time of the accident. The analysis generally indicated that smaller cargo ships seem to be more vulnerable to this type of accident. The time-series analysis of the accident sample revealed a statistically significant increasing trend approximately during the period from 2005 to 2007, while the years after and up to 2013 seem to mark a decline in the number of adverse weather accidents. This trend may correlate very closely to the rapid growth of the maritime industry up to 2008 and the subsequent recession. The IMO 2013 Interim Guidelines determine the limits for adverse weather conditions as a function of ship size, regardless of ship type, while the limits for significant wave height range from 4.0 m to 5.5 m and the limits for mean wind speed range from 15.7 m/s to 19.0 m/s (IMO, 2013a). This analysis has demonstrated that most navigational accidents in the presence of adverse weather conditions happened at much lower significant wave heights and wind speeds, namely in conditions that cannot be defined as adverse, while the accidents happened in limited (coastal) waters.

4.4.3. Risk of isolation due to transport disruption

Suffering from activity disruption, or isolation, due to extreme events is a relevant issue, especially for islands. Zhang & Lam (2015) estimate the economic losses of port disruptions induced by extreme wind events, in two selected ports (Ningbo and Shanghai). The authors estimate first the likelihood of port disruption from a climate analysis based on the historic record, and then calculate the total economic loss, which is split into four parts: reputational loss, loss to the shippers, loss to the carriers and loss to the ports. The highest number of expected disruption days per month is 2.67 for Shanghai, and 1.17 for Ningbo. The highest economic losses are estimated to be 117.6million Chinese RMB[7] and 23.1million RMB, respectively. The total estimated economic loss per year is 292.6m RMB in Shanghai and 109.0m RMB in Ningbo. Moreover, the loss to the ports contributed most among the total economic loss (>80%). The economic losses should be considered a lower bound of the total loss, because other factors such as social and environmental ones are not considered.

Esteban et al. (2012) studied the increase in port downtime and damage in Vietnam due to a potential increase in tropical cyclone intensity. The paper attempts to indicate what are the likely economic effects by using a Monte Carlo simulation that magnifies the intensity of historical tropical cyclones between the years 1978 and 2008. This tropical cyclone model is then coupled with a socioeconomic model that attempts to provide a projection of the likely development course of the Vietnamese economy and society. The simulation shows how annual downtime from tropical cyclones could increase from 0.23 to 0.37% by 2085 which could cause the loss of between 0.015 and 0.035% of GDP growth per year (between 600 bn and 1,400 m USD after factoring in the likely growth in the Vietnamese economy by this time). The effect that this could have on port operations and a preliminary assessment on the potential for increases in direct damage due to high winds are also made, showing a typical 33 to 65% increase for the centre and north of the country.

[7] 6.23 RMB=1.0 US dollar

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Koetse & Rietveld (2009) studied this problem from a more general point of view, considering the effects of Climate Change and weather conditions on the transport sector. It is emphasized that the predicted rise in sea levels and the associated increase in frequency and intensity of storm surges and flooding incidences may be the most worrying consequences of Climate Change, especially in coastal areas. Changes in temperature and precipitation have consequences for riverine water levels. Lower water levels will force inland waterway vessels to use only part of their capacity, which will have a negative impact on this transport mode due to the increase in transportation costs in the future.

Extreme events constitute a relevant risk regarding transport disruption. For instance, a major iron ore exporting port was hit by five cyclones in six weeks and had to suspend operations which led to increased ship queuing, costing A$3bn to the Australian economy (Ng et al., 2013). Hurricane 'Sandy' crippled the New York region, leading to a week-long shut-down of one of the largest container ports in the US and generating economic damages which could reach $50 billion (EQECAT, 2012). Another example is the five-day shutdown of the Port of Houston after Hurricane Ike. It is estimated every day the Port of Houston is closed, it costs $322 million (Gharehgozli et al., 2017).

On the other hand, with global warming a new route has opened up due to the shrinking of Artic ice, the Northern Sea Route (NSR). Hong (2012) assesses the impact of the ice-free Arctic on the development of marine transport industry in China. Verny & Grigentin (2009) verifies the technical and economic feasibility of regular container transport along the NSR. They conclude that while shipping through the Suez Canal is still by far the least expensive option, the NSR and Trans-Siberian Railway appear to be roughly equivalent second-tier alternatives. Another study, carried out by Liu & Kronbak (2010), finds out that shipping through the Arctic Ocean via de NSR could save about 40% of the sailing distance from Asia (Yokohama) to Europe (Rotterdam) compared to the traditional route via the Suez Canal. However, a 40% reduction in distance does not mean a corresponding 40% in cost savings due to many factors, including: higher building costs for ice-classed ships, non-regularity and slower speeds, navigation difficulties and greater risks, as well as the need for extra ice breaker service.

Therefore, there might be a more intensive use of airplane, as well as new routes for transport and changes to navigation routes, due to Climate Change impacts (Nursey-Bray et al., 2013).

Finally, table 4.4 presents a summary of the above findings. While some non-market effects are presented, most findings refer to the economic impact of Climate Change on the Maritime Transport sector.

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Table 4.4. Maritime Transport summary - Market and non-market effects of different CC impacts on supply side

Hazard	Case study	Method	Environmental services / Non-market effects	Economic impact	Source
Sea level rise, storms and flooding	City of Copenhagen	Catastrophe risk assessment coupled to economic input-output model	Most optimistic scenario: SLR not exceed 25cm by end of century. Most pessimistic IPCC scenario: SLR would reach 25cm in 2050 and 60cm in 2100.	Total loss: No protection=3bil.€ 25cm SLR=4bill. € 50cm SLR=5bill. € 100cm SLR=8bil.€ Mean annual loss: 100,000€ if 180cm protection Null if >2m protect.	Hallegatte et al. (2011)
	Exposure of world's large port cities to coastal flooding, SLR & storm surge	Geographical Information Systems	40mill. People (0.6% of global population) exposed. ↑>3 times population exposed by 2070.	Total value exposed in 2005= US$3,000b. (5% global GDP) By 2070=9% global GDP	Hanson et al. (2011)
	Southern Louisiana ports. Texas ports. Port in Grenada. Maldives Samoa	Projected SLR of 0.6m to 2m and doubling of category 4 & 5 hurricanes by 2100.	- 130 ports hit by tropical cyclone every year. - 35 of 44 Caribbean ports inundated by 1m SLR unless protected. - Tsunami-related casualties in SIDS: >2,500 deaths.	Hurricane Katrina: $1.7b to southern Louisiana ports. Hurricane Ike: $2.4b to Texas ports. Hurricane Ivan: $670,000 to Port in Grenada. Tsunamis: in SIDS= $660m; Maldives=$470m; Samoa=$150m.	Becker et al. (2012); Simpson et al. (2010); UNCTAD (2014)
	USA		10% increase in storm intensity would ↑ damages by 54%.	Loss= $8b to $12b per year	Hallegatte (2007)
Adverse weather conditions	125 Ice Regime System database events		Multi-year ice present in 73% of damage events to vessels in Arctic waters.		Kubat & Timco (2003)
	Accident information: HIS/Sea-Web & GISIS	Statistical analysis	54% of accidents: grounding & collision while vessel was within port limits. Smaller cargo ships more vulnerable. Accidents happen at lower significant wave heights & wind speeds than limits for adverse weather.		Ventikos et al. (2018)
Extreme events	Shanghai Ningbo	Regression Estimation	2.67 disruption days/month for Shanghai port; 1.17 for Ningbo	Economic loss per year: 292.6m RMB for Shanghai; 109.0m RMB for Ningbo (>80% loss to ports)	Zhang & Lam (2015)
	Vietnam	Tropical cyclone & socioeconomic model	Annual downtime ↑ from 0.23 to 0.37% by 2085	Loss: 0.015-0.035% of GDP growth/year (600-1400m.US$)	Esteban et al. (2012)
	Australia New York Texas		5 cyclones in 6 weeks: A$3b. to Australia Hurricante Sandy: $50b. to New York. 5-day shutdown in Port of Houston due to Hurricane Ike: $322m.		Ng et al. (2013); EQECAT (2012); Gharehgozli et al. (2017)
Ice Shrinking	4300 TEU container ship	Comparison Suez Canal & NSR routes.	Shipping through NSR saves 40% sailing distance (Asia-Europe)	<40% cost savings	Liu & Kronbak (2010)

5. Concluding Remarks and Next Steps

The present deliverable aims at reviewing and summarizing the existing publications addressing the topic of socio-economic and non-market assessment of Climate Change impacts and related policies. This analysis has been performed sector by sector putting special emphasis on the risks and impacts considered in the different Impact Chains.

The methodologies and results presented in this report will be analyzed and used in two ways. On the one hand, part of information will be used to construct the valuation scenarios that will presented in the surveys that will be done with tourists, in the task 5.4. The purpose of these surveys is to understand how tourists valuate the changes in Environmental Services, how this fact affects their behavior and how they would react to potential policies regarding mitigation and adaptation strategies. Therefore, these plausible scenarios will come from the literature. On the other hand, some results could be used directly or through transfer values or functions to the models aiming at analyzing the economic impact that WP6 will develop.

In order to be able to use the information present in the literature, it is necessary to employ the benefit transfer methodology, which will be explained in the Deliverable 5.2 of the SOCLIMPACT Project. The benefit transfer method is defined as the use of research results from pre-existing primary studies at one or more sites or policy contexts to predict wellbeing estimates and tipping points (willingness to pay) or related information for other, typically unstudied sites or policy contexts. The two main approaches are: unit value transfers and benefit function transfers. While the former involves the transfer of a single number or set of numbers from preexisting studies; the latter derive information using an estimated function derived from the original research, a meta-analysis that synthesizes results from multiple prior studies, or preference calibration that constructs a structural utility model using results from two or more prior studies.

Therefore, the studies summarized in the present deliverable (especially the economic valuation part), will serve as inputs for the generation of values or information of interest regarding the Blue Economy of the European islands studied within the project, through the benefit transfer methodology.

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