



FIVE CASE STUDIES ON THE IMPACTS OF CLIMATE CHANGE ON EUROPEAN ISLANDS

**Annex II to the Final Report
'IMPACTS OF CLIMATE CHANGE ON ALL EUROPEAN ISLANDS'**

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1 MACARONESIA

Macaronesia is a diverse area, comprising 3 groups of islands with different characteristics: the Azores, Madeira, and the Canary Islands. Due to their different locations and specific topographies specific climate change impacts vary across the different islands. The water supply infrastructure and biodiversity are expected to come under increased pressure due to climate change. Tourism as key economic sector will be negatively affected. The flooding events in Madeira in February 2010 with damage costs of over € 1 billion showed the huge costs related to weather extremes that are likely to increase in the future.

1.1 Key features of the Macaronesian region

Macaronesia consists of three archipelagos: the Azores, Madeira (both belonging to Portugal), and the Canary Islands (belonging to Spain). These constitute the outermost regions of the European Union. Macaronesia also includes the Cap Verde archipelago, which is not considered in this study as it is not part of the EU territory. Figure 1 shows the location of these islands in the Atlantic Ocean.

Figure 1: Map of the Macaronesian region within the EU



Source: World Traveler.com (2013)¹

Although all Macaronesian islands are of volcanic origin and are therefore characterised by a unique landscape, they have fairly diverse features in terms of climatic conditions, biodiversity and economic structure. Due to their volcanic origin, these islands were never attached to any continent and feature therefore high levels of animal and plant endemism.ⁱ

The **Azores** archipelago comprises of nine islands and spans across 700 km (See Table 1 below). The archipelago is located at a third of the way between the Iberian Peninsula and Newfoundland in Canada. The Azores Islands are characterised by a relatively wet climate in which Northern European species (rather than Mediterranean ones) thrive. The topography, the climatic conditions and the rich soils provide an excellent basis for the development of the dairy industry, a major income generator in the Azores. The Azores' dairy sector

¹ <http://worldtraveler55.com/travelpage/macaronesia/macaronesia.html>

produces around a third of Portugal’s dairy products and provides employment for over a fifth of the islands’ inhabitants. In 2008, a number of 13,706 people, representing 12.8 per cent of the total employed population, worked in the primary sector.ⁱⁱ The tertiary sector, including the tourism industry, is of increasing importance, but is less developed than in Madeira or in the Canary Islands.

Table 1: Overview: Key features of Azores

Azores Islands	
Number of islands	9
Population	241,206 inhabitants (2005)
Area	2,332 km ²
Population density (inhabitants/km2)	104
GDP/inhabitant (EUR)	15,200
Unemployment rate	6.7 per cent
Economic activities	Agriculture, fishery, tourism

Source: European Parliament (2011)

Being situated at the transition between the tropics and the temperate zones, the Azores is an important breeding area for colonial nesting birds such as seabirds; however, their number has been declining after the introduction of rat populations.ⁱⁱⁱ The Azores do not have a national park, with 50% of its natural environment having been converted to dairy farming use over the last decade.^{iv}

Madeira is located further South and closer to the Portuguese mainland, between the archipelagos of Azores and the Canary Islands. Madeira consists of two inhabited islands (Madeira and Porto Santo), three small islands (Ilhéu Chão, Deserta Grande and Bugio), the small archipelago of Selvagens (with its two small islands: Selvagem Grande and Selvagem Pequena) and one islet (Ilhéu de Fora). Islands of volcanic origin, their climate are influenced by the Azores anticyclone and the rugged topography (eg steep slopes), which cause frequent extreme precipitation events.^v

Table 2: Overview: Key features of Madeira

Madeira Islands	
Number of islands	3 main islands
Population	244,098 inhabitants
Area	828 km ²
Population density (inhabitants/km2)	295
GDP/inhabitant (EUR)	21,400
Unemployment rate	7.6 per cent
Economic activities	Agriculture and tourism

Source: European Parliament (2011)

Subsistence agriculture is prevalent, while tourism accounts for 20 per cent of GDP, with 850,000 visitors a year (2005 estimate).^{vi} Tourism-related sectors, such as lodging and transportation, are amongst the most important sectors in Madeira, contributing with 14 per cent and 12 per cent, respectively, to the island’s gross value added.^{vii} Madeira hosts the largest area of laurel forest in the world, a species that is typical of the Macaronesian region. Moreover, it is exceptionally rich in endemics, with over 120 plant and animal

species having been identified so far.^{viii} A quarter of the plant species listed in Annex II of the Habitats Directive is accommodated in the region, which represents only 0.2 per cent of the EU territory. The region hosts 211 Sites of Community Importance, under the Habitats Directive, and 65 Special Protection Areas, under the Birds Directive.^{ix}

The **Canaries** comprises of seven islands and covers the largest area of the three island groups, while hosting most of the inhabitants. Due to their location, close to the African continent, the climate is warmer and drier here than in the Azores and Madeira. The Eastern Canary Islands (Lanzarote and Fuerteventura) are arid and rocky, and low lying, whereas the Western Canary Islands (Gran Canaria, Tenerife, La Gomera, La Palma, El Hierro) are more mountainous.^x

Table 3: Overview: Key features of the Canary Islands

Feature	
Number of islands	7 main islands
Population	2,025,951 inhabitants
Area	7,447 km ²
Population density (inhabitants/km ²)	272
GDP/inhabitant (EUR)	20,800
Unemployment rate	26.2 per cent
Economic activities	Tourism

Source: European Parliament (2011)

Tourism is the most important economic sector, accounting for up to 34 per cent of the Canaries' GDP². Traditional agriculture is rapidly declining after nearly three quarters of cultivated area is used for tropical and forced crops for export markets.^{xi}

1.2 Most relevant climate trends

1.2.1 Historical evidence

Since 1960 to 2012, the annual average temperature in the Macaronesian region has followed an increasing trend, with the highest temperature (18°C to 20°C) recorded in Madeira, while in the Canary Islands and the Azores, the temperatures ranged from 15°C to 18°C. The highest average temperature variability was identified in the Canary Islands.^{xii}

Data on precipitation patterns illustrates a higher frequency of rainfalls for Azores, with on average of 1,100 mm rainfalls per year, whereas in the Madeira and the Canary Islands around 600 mm per year were recorded -. The precipitations in the Canary Islands are also slightly decreasing, with frequent annual rainfalls lower than 500 mm after 1990.^{xiii}

Since the 1970s, the minimum and maximum temperatures have increased by 0.3°C per decade for Azores and by between 0.53°C and 0.66°C per decade for Madeira, predicting a path of future growth.^{xiv}

An analysis of data from 1981 until 2010 suggests that, during the summer season in the Canary Islands and Madeira, the temperature has increased from 0.40 to 0.46°C per decade^{xv}. This value is lower when annual values are considered, and the average

² Instituto Canario de Estadística

temperature increase ranges from 0.30 to 0.38°C per decade in all 3 archipelagos. This result is quite alarming since it exceeds global temperature rise by up to 0.10°C per decade. Looking at precipitation trends, no significant changes in historic trends were observed for the Macaronesia region; however, the Azores record a recent increase in average precipitation.^{xvi}

Between 1950 and 2010, a total number of 41 extreme weather events were recorded in the Canary Islands. More than half of these comprise heavy rainfall events, followed by severe wind storms and extreme temperatures. The intensity of the events has not changed, but their frequency has increased notably, from 1 event (1950-1960) to 8 events in each of the decades of the 80s and 90s, and ultimately to 20 events in the period from 2001 to 2010. Another significant trend that became more apparent in the Canary Islands (Tenerife) is the increase of cloudy days per decade.^{xvii}

1.2.2 Projected climate trends

Predictions for average temperature, precipitation, wind regime and sea level rise are summarized in Figure 2, until the year 2100.

Figure 2: IPCC predictions of climate change

Average for 21 global simulation models (scenario A1B). Margin of uncertainty in brackets (25/75% quartiles).

Climate indicator	Variation between 1980-1999 to 2080-2099
Air temperature	Increase of 2.1°C [+ 1.9 to +2.4]
Precipitation	Increase of 1% [-3% to +3%]
Wind regime	Decrease in the power of the north-westerly trade winds, increase in the prevailing eastern winds
Sea level	Average rise of 0.35 metres [+0.23 to +0.47]

Source: Petit and Prudent (2010)

The IPCC predicts an average sea level rise of 0.35 meters, with projections ranging from 0.23 to 0.47 meters until 2100. The north-west wind is also expected to decrease in intensity, giving more prominence to the eastern winds.^{xviii}

SIAM II, a study that assessed the impact of climate change in Portugal, reported in the 5th National Communication to UNFCCC the following results for Madeira and Azores (for the period up to 2070-2100). In the Azores, the temperature increase is expected to be in the order of 1°C to 2°C. During summer time, the average maximum temperature is expected to increase with between 1.2°C and 2.3°C, and the average minimum temperature during winter time is expected to raise with between 1°C and 2°C.^{xix} This milder increase in temperature (when compared to the same increase in the mainland or in Madeira) is due to the moderating effect of the sea on the temperature regime.^{xx} Changes are predicted in the annual rainfall cycle, but without substantial impact on the total amount of precipitation. Rainfall is expected to increase by 10 per cent during the winter period and to decrease by between 10 per cent and 20 per cent during the summer season.^{xxi} In Madeira, the overall increase in the average temperature is expected to range between 2°C to 3°C. The average maximum summer temperature is expected to raise by 1.6°C to 3°C, and the winter

minimum temperature is projected to increase by 1.5°C to 2.9°C. ^{xxii} A significant reduction (of about 30%) in the annual precipitation regime is projected, with a reduction of 20 per cent in rainfall during winter, and an increase of between 20 per cent and 40 per cent during summer. ^{xxiii}

For the Canary Islands, the average temperature is expected to increase by 1°C up to 2040, a smaller figure compared to the expected warming on the mainland. The average precipitation could decrease by between 10 per cent and 15 per cent for the same period. ^{xxiv} Until 2100, for the Canary Islands, the average maximum summer temperature is expected to increase by between 2°C to 4°C and the minimum winter temperature may increase by between 2°C and 3.5°C. Average precipitation is expected to decrease by between 20 per cent and 35 per cent. ^{xxv}

1.3 Consequences of climate change impacts on specific sectors

The consequences of climate change in the Macaronesian region are summarized in Table 4.

Table 4: Summary of Main climate change effects in the Macaronesian region

Macaronesian Region			
Section Indicator/Topic	Variable	Observed	Predicted
<i>Biodiversity</i>			
Marine-based	Species stocks	(-)	(-)
Land-based			
Land-based species	Species stock	(-)	-
Forest growth	Biomass		(±)
Forest fires	Area	(+)	+
<i>Agriculture</i>			
Productivity of agricultural crops	Productivity		(+)
Irrigation water requirement	Water requirement		+
Productivity of animal farming	Productivity		(-)
<i>Human health</i>			
Extreme temperatures and health	Mortality		+
Spreading of diseases	Events with epidemics	(+)	(+)
<i>Energy</i>			
Electricity Production	Electricity production		(-)
Electricity Demand	Electricity demand		(+)
<i>Water Resources</i>			
Water Availability	Availability of freshwater		-
Water Demand	Water Demand		+
Intrusion of Saltwater	Land water sources with saltwater intrusion	(+)	+
<i>Tourism</i>			
General tourism	Attractivity		±
Profitability	Tourism Revenues	(-)	-
<i>Physical Infrastructure</i>			

Destruction due to extreme events	Costs of Damage	+	+
LEGEND			
+	Increase in variable throughout (most of) the region		
-	Decrease in variable through (most of) the region		
±	Increases as well as decreases in the variable in the region		
°	Only small changes in variable		
()	Increase or decrease only in some parts of the region		
Green	Beneficial Change		
Red	Adverse Change		

Source: Adapted from EEA (2012)

1.3.1 Biodiversity

Climate change is already affecting biodiversity of the Macaronesia region. In the **Azores**, new and more aggressive invasive alien species such *Pittosporum undulatum* and *Acacia melanoxylon* have appeared, endangering the habitats of endemic species. Moreover, the quality of soils occupied by 'Turfeiras' (ground-water recharge areas) may be compromised due to water deficits and diminished water fluxes, which have a lower capacity to sustain nutrient recycling.^{xxvi}

Together with the Canary Islands, **Madeira** is a major hotspot of biodiversity of the Mediterranean area and of the world. However, the migration of these species is limited, which makes them more vulnerable towards climate change than continental species. Due to the increase in average temperature, *Laurissilva (Teucrium abutiloides)* forest species and invasive alien species could expand in altitude and occupy the areas that are currently home to other fauna and flora species. As such, species such as the *Urza's (Erica maderensis)* or the *Freira da Madeira (Pterodroma madeira)* could be under risk of becoming endangered.^{xxvii} A decrease in precipitation patterns could threaten Madeira's natural ecosystems, namely a large area of its protected humid forests, and the streams, aquifers and water tables that depend greatly of the storm water captured in high grounds.^{xxviii}

In Madeira, the change in sea current patterns could shift the traditional migrating routes of pelagic fish (between 0-200 m) such as tuna (*Thunnus sp*), and could affect the recruitment of young black scabbard fish (*Aphanopus carbo*, found between 600-1200m). These fish species account altogether for around 80% of the annual catch in Madeira. A temperature increase of coastal waters will shorten the reproduction period of temperate water fish species, decreasing the natural recruitment of young fish. This will result in a decrease of available and exploitable stock of several fish species in temperate waters for commercial purposes. Additionally, the loss of optimal air and water temperature might condition the growth of several groups of organisms and constituents of the food chain. The resulting fragile and less resilient marine environments could provide the adequate conditions for some invasive exotic fish species to thrive and for the proliferation of microalgae producing bioaccumulative toxins (eg recent episodes of ciguatera in the seas of the Autonomous Region of Madeira) to expand. Finally, heavier and more irregular rainfall might cause a greater water flow in the streams, resulting in high concentration of suspended sediments in coastal zones. This will decrease the primary production of phytoplankton and microalgae, with consequences such loss of food for most fish species in the larval stages, and also for

bivalve molluscs (eg limpets and snails), which serve for commercial purposes. Greater water flow may also cause deposition of sediments, which results in smothering of sessile organisms important to the food chain (eg microalgae, bryozoa), of organisms with limited mobility (eg limpets *Patella* sp. and snails *Osilinus atratus*).

In other islands, the weaker trade winds could force pine and eucalyptus forests to migrate downwards, occupying the land of Laurel forest that will not be able to migrate to lower altitudes since these have human settlements. The loss of Laurel forests represents a significant social loss for local livelihoods, their economy and well-being.^{xxix}

The main threats to biodiversity on the **Canary Islands** are direct destruction of habitats due to urbanisation, over-exploitation of resources caused by the increase in tourism industry, and biological invasions. The Canary Islands currently accommodate 550 endemic species, 171 of which are endangered.^{xxx} These negative effects are expected to worsen in the future as a consequence of climate change, also affecting the landscape and composition of ecosystems. Biodiversity is expected to be mostly affected by changes in the wind patterns. Cool, humid north-south winds are projected to shift to a east-west orientation, threatening humid coastal areas in the North of the islands, while the Southern coasts are likely to become more humid. The retreat of the north trade winds is deemed to lead to more inflow of warm air from the African continent. Changes in wind direction might result in migration of terrestrial plant species, including invasive species, and changes in the routes of bird species migration. Laurel forests are likely to be affected by climate change due to the change in direction of the trade winds. Pine forests might be affected more frequently by forest fires and spreading of disease due to higher temperatures and lower precipitation. For example, in the summer of 2007, a total of 35,000 hectares of forest were destroyed by fire on Gran Canaria Islands; nearly the entire habitat of the Blue chaffinch (*Fingilla teydea*) was decimated.^{xxxi}

In the **Canary Islands**, in Lanzarote, in 2004, 100 Million Pilgrim Crickets (*Desert Locusts*) landed on the coast. These crickets need high temperatures and strong droughts to expand their lifetime, and heavy rains for massive reproduction. In 2004, West Africa and the Canary Islands met these climate requirements and, due to the south-eastern winds, the crickets were brought to the coast of the Canary Islands. The crickets devoured around 1 per cent of crop land and a significant amount of pesticides was used against them, causing damage to endemic species. Although these plagues are rare, climate change could increase the number of occurrences of events such as the 2004 one. The same weather conditions (high water temperatures and different wind patterns: warm air from the Sahara bringing iron in the ocean) fostered the expansion of cyanobacteria, causing the red tides³. Consequences of these events include health problems related to ingestion caused by sea food, as well as deaths of fish and seabird species.^{xxxii}

Higher water temperatures have affected the coastal and marine ecosystems and fisheries on the Canary Islands and are expected to continue this in the future, especially for dark corals and algae. Certain fish stocks are likely to decrease, also due to higher probability of

³ Red tides are events in coastal areas characterized by large concentrations of algae, causing the water to be colored in red or brown, which endanger other marine species.

fish disease spreading.^{xxxiii} For instance, the predator of warm water ocean triggerfish (*Canthidermis suflamen*) was already observed around the Canary Islands indicating likely impacts on fish stocks in the region.^{xxxiv}

1.3.2 *Agriculture*

Animal farming is an important economic sector for **Azores**, especially the dairy industry, which accounts for almost 30 per cent of Portugal's total milk production⁴. If water supply is compromised due to lower average precipitation, and soils become drier and eroded due to extreme temperatures and heavy rainfall, the area available for grazing and its quality will decrease and the dairy production may be negatively impacted, affecting Azores' trade balance.

Climate change is expected to have significant impacts on **Madeira's** agricultural sector, both positive and negative ones. The main agricultural products of the island are bananas, wine and potatoes, but the island's rugged topography is not ideal for agriculture. making the installation of greenhouses difficult.^{xxxv} As the average temperature increases, it approaches the optimal value for the growth of these products and will most likely entail an increase in productivity and the potential production area of banana and potatoes, with uncertain effects in the wine production. However, with a decrease in water availability and expansion of production, water stress in agriculture is likely to increase. This will be the case especially in the Southern area and at high altitudes, and could possibly result in an increase in agriculture imports.^{xxxvi}

1.3.3 *Tourism*

Climate change is likely to affect the tourism industry in the Macaronesian region directly as a result of higher temperatures and weather extremes and indirectly as a consequence of damage to tourist attractions (eg biodiversity habitats) and health risks (eg vector borne diseases). The tourism industry is the most important economic sector for Madeira and for the Canary Islands. The various types of tourism that could be experienced on the islands (eg eco-/biodiversity tourism, littoral tourism) will be affected by climatic changes to a different extent.

Tourism in the **Azores** is a biodiversity-oriented tourism. If the summer temperatures will increase to a comfort level, the littoral tourism will benefit, while the biodiversity tourism could decrease due to the damage caused to the island's biodiversity. Earthquakes and other climate change related natural disasters (eg landslides) are relatively common in the Azores and this can heavily influence the attractiveness of Azores as a touristic destination (1998 earthquake).^{xxxvii} Nonetheless, the overall effect of climate change on the tourism industry in the Azores has not been quantified yet.

Besides the island's unique biodiversity, **Madeira's** most important economic sector, the tourism industry, is likely to be severely hit by climate change. Madeira hotels hosted around 995,000 visitors in 2012, a figure which has been declining since 2008, with an average stay of 5.5 days.^{xxxviii} Madeira's tourism is strongly motivated by landscape attractiveness, health and safety. Over the last decades, temperature increases above

⁴ http://www.ideassonline.org/public/pdf/br_42_98.pdf

global average, as well as decreased levels of precipitations and weather extremes have become more apparent. This increases the probability of spreading of epidemics and affects the landscape through erosion and fire hazards. Diseases spreading, human thermal comfort and natural disasters impact the feeling of security of tourists.^{xxxix} The presence of the mosquito *Aedes aegypti*, which was first reported in 2004 and explained by elevated temperatures, could seriously affect the influx of tourists. The mosquito is a vector species of dengue fever and yellow fever. Although the mosquito's population is not yet infected with viruses, there is a significant risk that this will happen in the future.^{xi} Moreover, as the majority of tourists in Madeira come from the UK and Germany, visitors during the summer period may shift preferences from the hot summer season to the milder temperatures in spring, winter and autumn.^{xii} In general, it is difficult to quantify the impacts on the tourism industry as it depends on many contextual factors (eg whether other tourist areas are affected by conflicts, advertising campaigns).

Erosion of the coastal infrastructure could have a negative impact of the number of tourists. Although less severe than in mainland Spain, climate change is expected to increase the probability of spreading epidemics, such as the dengue, Nilo virus and Leishmaniosis.^{xiii} Empirical evidence is however scarce. A study on the impact of climate change on tourism in Spain did not cover the Canary Islands due to lack of climate data, although the Canary Islands host around one fifth of foreign tourists in Spain.^{xiii}

1.3.4 Infrastructure

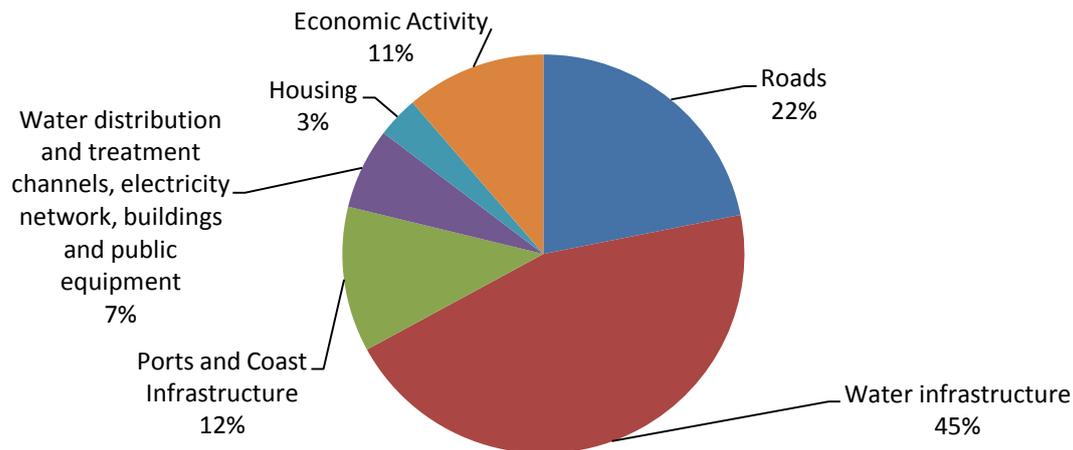
In **Azores**, a higher sea level will heavily affect areas by the coast, since 90 per cent of the population lives by the coast.

Hydroelectricity is an important energy resource for **Madeira**, harvested from small reservoirs with large waterfalls. Due to its orography, only small dams were built to produce electrical energy and only small amounts of water can be stored. In 2001, the production of electric energy in Madeira was 610 GWh, 15 per cent of which was generated in hydroelectric power plants.^{xiv} The robustness of the hydro energy sector could be put at risk should the precipitation decrease at it is expected.^{xiv} An increase of the average temperature has already stimulated energy demand, such as for air conditioning, as the peak electricity demand has already shifted from at night to lunch hours.

In **Madeira**, floods and mudslides due to heavy and sudden rainfall in February 2010 led to considerable destruction of transport infrastructure (roads), housing, electricity, port infrastructure, and tourist facilities^{xvi}. Costs of the flooding, as reported by the Regional Government to the European Commission, amounted to € 1,080 million, most of which was related to damages to the water and the road infrastructure (see Figure 3). These costs are material losses only and do not include human, natural biodiversity and habitats losses. The costs of around € 1 billion constitute about 20 per cent of Madeira's GDP, which was € 5.2 billion in 2010⁵.

Figure 3: Illustration of funds allocated following the flooding damage of 2010 in Madeira

⁵ Regional Statistical Office of Madeira (Direção Regional de Estatística da Madeira)



Source: Personal Communication (2013)

Moreover, natural disasters affect the tourists' perception of security and negatively affect the image of the region. The decrease in the number of tourists, especially of foreign tourists, was of 10.1 per cent which represented a fall of 14 per cent in revenues, while the number of available hotels in the tourism sector increased. This loss in the attractiveness of the region had significant impacts on the population employed by sectors related to tourism, ultimately affecting their employment (7 per cent increase in unemployment in touristic sectors in 2010 alone).^{xlvi, xlviii}

In August 2010 and in the summer of 2012, fire events caused significant loss of habitats and brought other costs. In 2010, an area of 8423 hectares was burnt, which represents 11 per cent of Madeira's territory. Endemic and high value species (*urzais*) were strongly affected. This affected the tourism sector, especially the tourism forms motivated by landscape attraction and the associated infrastructure, which was damaged and an required an investment of € 1.6 million.^{xliv} For 2012 alone, the material costs of fires in Madeira were more than € 1.2 million. This cost, however, covers only destroyed electric infrastructure and buildings and does not account for the costs of clean-up and restoration of the affected area. These costs are significant for the affected area of forest, which was 5720 hectares. It is estimated that the average cost for clean-up and re-plantation of trees are about € 15.000/hectare, resulting in a total cost of € 86 million from fires in 2012. Due to the current financial restraints, such a huge investment is not possible and only a few areas will be cleaned and re-planted.^l Current fire prevention expenditure (in projects that direct or indirectly aim at fire prevention in Madeira) for the year 2012 is only € 2.1 million.^{li, lii}

The **Canary Islands'** energy and transport infrastructure is, as for most islands, heavily dependent on fossil fuel imports. The relatively high energy consumption, including water desalination and the demand for kerosene for international flights and bunker fuels for maritime transport, is mainly (95 per cent) based on imported oil products. The Canary Islands have an oil refinery that serves most of the local needs, and oil storage capacities can cover 90 day of domestic consumption of the main oil products. Due to the absence of heavy industries, most energy consumption is linked to the residential, service (including tourism) and transport sectors. As a result of the strong role of the tourism sector in the local economy of the Canary Islands (as for Madeira and to a lesser extent the Azores), these

islands are even more vulnerable to oil supply disruptions as a result of weather extremes. Energy demand is expected to increase and, due to higher wind variability, wind power plants may suffer from disruptions and reduced output. At the same time, the potential generation from solar power increases.

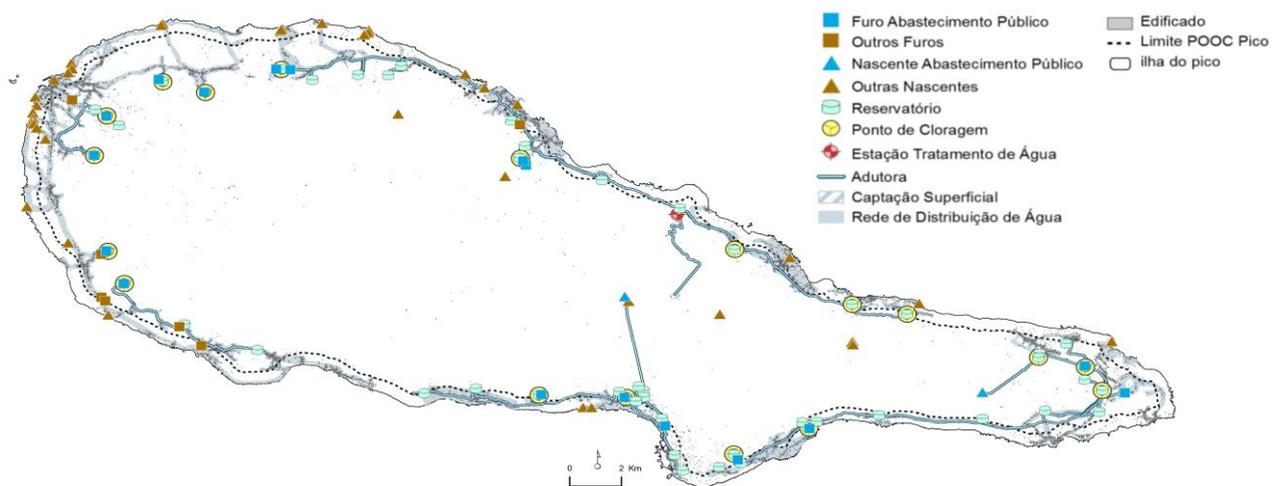
The water infrastructure will face particular challenges. In **Azores**, climate change and land-use changes may affect fresh water quantity availability due to higher frequency of droughts and flooding.^{liii} Currently, there are no major difficulties regarding water supply. There are no irrigation systems in place due to sufficient precipitation levels. Water needs in agriculture are related to drinking water for animals, less to irrigation. However, the high dependency of people on rainfall as their only source of drinking water combined with lower precipitation levels in summer increases the vulnerability for the population of Azores. Events of extreme weather would also disrupt transportation channels, affecting economic activity, and increasing the probability of landslides due to the more precipitation in the winter season.^{liv,lv} Sea level rise is expected to result in coastal erosion and flooding, while an increase in the intensity of storms would limit the functioning of port infrastructure.^{lvi} As the sea level rises and saltwater taints aquifers, a shortage in fresh water supply during the dry summer period is expected. Intrusion of saltwater in freshwater aquifers has already happened in two islands: Graciosa and Pico. Fortunately, regional awareness has increased and the regional watershed management strategy is being developed and implemented. More rainwater reservoirs or desalination plants could help to mitigate this negative impact. In addition, coastal developments of resorts are under threat due to coastal erosion and landslide hazards.^{lvii,lviii} The Government of Azores has commissioned a study to assess the impacts of climate change on water management and implement adaptation and mitigation measures.^{lix}

Effects of climate change are expected to be more prevalent in **Madeira** than in Azores as predicted increases in temperature are larger and precipitation decreases significantly. Although it is not the main issue, water shortage in Madeira will have major consequences. Firstly, flooding is a frequent phenomenon due to the steep slopes in Madeira's territory and small watersheds. The highest concentration of population is near the river floodplains, increasing their vulnerability to "flash flooding". Secondly, there may be a water quality issue regarding irrigation. "Levadas" are man-made channels, with an extension of around 1400km, which transport water from high (where fountains collect the water) to lower altitudes (below 600m) where the agricultural land is concentrated, thanks to the steep slopes that keep the water running. In this manner, water from locations with water surplus is brought to places where water demands are higher.^{lx} Decrease in precipitation may endanger this system and water pumping through these channels may become too costly. Furthermore, the sea level rise may increase the risk of sea water intrusion in watersheds and available drinkable water may decrease 30 per cent until 2050 and up to 50 per cent until 2100. Moreover, a discrepancy between water availability and necessity is expected, especially in the summer period.^{lxi}

For the island of Pico, in Azores, an assessment of the potential impacts of climate change was carried out. Sea level rise, that increases the probability of flooding and causes material damage, has already motivated the reinforcement of slopes ("taludes") at the coast to prevent infrastructure damage. The number of extreme weather events (droughts, heavy precipitation and intrusion by the sea) are likely to grow, putting at risk the quality of life of

the island's population mostly living nearby the coast.^{lxii} Figure 4 illustrates the extent to which the coastal water distribution network (grey lines) and other freshwater sources in the coastal area are under at risk as a result of raising sea levels and weather extremes. The island of Pico has already problems with contamination of underground water by saltwater sources, putting at risk freshwater quality for human consumption.^{lxiii}

Figure 4: Water distribution network in the island of Pico for the coastal area



Source: Costa and Melo (2011) Plano de ordenamento da orla costeira da Ilha do Pico, Volume 6, Avaliação ambiental estratégica, Relatório ambiental

Currently, a management plan has been developed, but not implemented. The plan takes into account, among other effects, climate change effects on the island of Pico and aims at promoting preventive measures instead of the current planning of solving problems as they appear.^{lxiv}

Due to heavy rainfalls (aggravated by loss of forest cover), more fires (loss of nutrients) and greater wind variability, soil erosion in the **Canary Islands** is expected to increase. This has major consequences: when the soil becomes saturated with water after many days of rain, landslides on slopes become more likely, increasing the probability of flooding.^{lxv} Additionally, water availability may decrease due to the intrusion of saltwater in coastal watersheds, as the sea level rises and landslides are more likely to occur.

1.4 Implications for trade, security and migration

1.4.1 Trade

Given the importance of the sector of tourism in the Macaronesian region, especially in Madeira and the Canary Islands, climate change will likely have adverse effects on the economy and subsistence of the local populations. Heat waves and desertification, among other aspects, will decrease attractiveness of the Macaronesia as a touristic destination. The most important factors that affect the attractiveness of Macaronesia as a touristic

destination are thermal comfort, risk of transmission of infectious diseases and risk of natural disasters, all of which may negatively impact the image of the Macaronesia region, decrease revenues in the economic sectors related with tourism (for example, transport and accommodation) and increasing unemployment in the region.^{lxvi}

Agriculture is a sector of great importance with its relative importance in Azores greater than in the mainland or Madeira. Climate change is expected to have negative impacts on trade and production, especially due to water shortage and problems in assuring water availability for irrigation in Madeira and for consumption in Azores. However, in the case of Madeira, higher temperatures will improve productivity and increase trade in certain products, as seen for the case of bananas and potatoes. New trade opportunities may appear, but this may be offset by very high costs for irrigation systems and hence lead to a reduced agricultural production.

Climate change is expected to have negative impacts on the fishing industry, as seen for the case of the Canary Islands and Madeira's biodiversity loss, decreasing trade in fishing products and worsening the trade balance. Aquaculture, a fairly recent activity in the archipelago, could be affected by a change in climate conditions.

1.4.2 Security

For the Canary Islands, food security may become an issue, especially in the supply of fish, as marine ecosystems change drastically. In the whole region, as water becomes a scarcer resource, agricultural production may be challenged and food security will become an issue.

The feeling of security of tourists is very important to ensure tourism revenues, economic development of these regions and employment of their population. In 2003, an exceptional heat wave increasing temperatures up to 46°C in Lanzarote (Canary Islands) led to the death of 13 people. A rise in temperatures, and other climate change effects, can also facilitate the spread of tropical diseases, especially insect-borne diseases.^{lxvii} In the case that more extreme weather events occur, and the feeling of security of tourists decreases as illustrated with the Canary Islands example, the tourism sector may be heavily damaged.

As energy demand increases due to extreme temperatures, energy production in the Canary Islands will be challenged, affecting energy security. Wind storms have been a frequent event in the last decades and greater wind variability compromises the production of wind energy. Moreover, the disruptions of distribution channels may compromise supply of oil imports. In Madeira, where part of the electricity is generated with hydroelectric power plants, variability of precipitation will affect electricity production, further affecting the energy security for the region.

Water security is a major issue for the Macaronesia region, especially concerning the irrigation of agricultural land. Less water availability and greater variability of supply will put at risk current systems of water management. Increase in water stress will impact all sectors of economic activity that are dependent on water as a raw resource, as well as drinkable water sources.

Finally, should climate change increase the frequency of extreme weather events that cause high infrastructure loss (e.g. roads, buildings), potential high costs for rebuilding are to be

expected, from seen examples in Madeira of natural disasters in 2010 and 2012 (fires and flooding).

1.4.3 Migration

No information on migration related to climate change could be identified.

1.5 Conclusions

The main impacts of climate change on the Macaronesian region differ from island to island, but they concentrate mostly on infrastructure damage due to extreme weather conditions, water availability for irrigation and consumption purposes and degradation of the touristic sector, of utmost importance due to the high dependency of the region in touristic activities. Animal farming may become an important issue in the Azores, biodiversity and agriculture are also affected in Madeira and the Canary Islands may face particular challenges meeting increasing energy demand.

2 THE GREEK ISLANDS

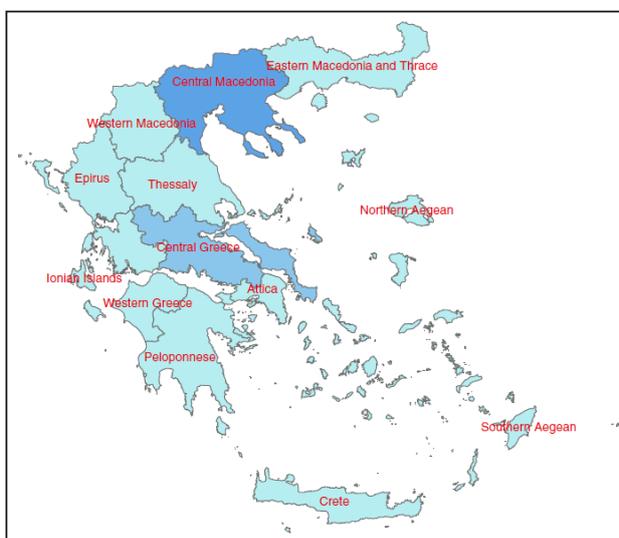
The Greek islands are situated in the Mediterranean Basin which is considered to be one of the geographic areas which is most vulnerable to climate change according to the Fourth IPCC Report.^{lxxviii} The main impacts of climate change in the Mediterranean region are expected to include decreased water availability, reduced crop yields, higher risks of drought, further biodiversity loss, higher incidence of forest fires, and increased frequency and intensity of heat waves.^{lxxix}

Additional stress on water resources is a critical challenge facing the Greek islands. Water scarcity is a key issue on many islands including those like the Cyclades that previously had sufficient water resources.^{lxxx} Several climate models, including that of the IPCC^{lxxxi}, predict that the Eastern Mediterranean will become dryer overall. Climate change will thus likely require adjustments to Greece's water resources management given the predicted 18 per cent decrease in the country's overall precipitation. Crete in particular is likely to face lower precipitation levels on average, as well as more extreme events and more frequent and severe droughts.^{lxxxii} Another expected impact of climate change is the increase in extreme summer temperatures^{lxxxiii}. This will not only affect the availability of water resources in the country, but is also likely to affect important sectors of the economy such as agriculture and tourism.^{lxxxiv}

2.1 Key features of the Greek Islands

The total population of Greece in 2010 was approximately 11.3 million^{lxxxv}. Greece has an area of 131,957 km², with most of the land mass (80 per cent) comprising of the mainland and 20 per cent spread over nearly 3,000 Greek islands^{lxxxvi}. Figure 5 provides an overview of the geographical regions of Greece. Approximately 25 per cent of Greece is lowland, particularly the coastal plains.^{lxxxvii} The surface is divided between forest (49.4 per cent), grassland/rangeland/pasture (13 per cent), and agricultural land (29.2 per cent).^{lxxxviii}

Figure 5: Geographical regions of Greece



Source: Nannos *et al* 2013: Geographical Regions of Greece

The climate in Greece is typical for the Mediterranean. The islands receive most of their rainfall during the winter months and experience a summer drought of between four to five months. Temperatures tend to be moderate with a relatively small range of changes between winter lows and summer highs.^{lxxxix}

There are 6,000 Greek islands and islets in the Aegean and Ionian Seas. Only 227 islands are inhabited.^{lxxx} Crete is the largest Greek island, located at the southern end of the Aegean Sea. It has an area of 8265 km², covering nearly 6.3 per cent of the area of Greece.^{lxxxii} The Greek Archipelago takes up 7,500 km (almost half) of the country's total 16,200 km coastline.^{lxxxii}

Most of the Greek islands are located in the Aegean Sea and can be divided into seven groups^{lxxxiii}:

- North-eastern Aegean islands: Agios Efstratios, Thasos, Ikaria, Lesbos, Limnos, Inouses, Samos, Samothrace, Chios, Psara.
- Sporades: Alonissos, Skiathos, Skopelos, Skyros
- Evia: The prefecture of Evia, which includes the island of Skiros.
- Argosaronic: Angistri, Aegena, Methana, Poros, Salamina, Spetses, Hydra.
- The Cyclades: A group of 56 islands including Amorgos, Anafi, Andros, Antiparos, Delos, Ios, Kea, Kimolos, Kythnos, Milos, Mykonos, Naxos, Paros, Santorini, Serifos, Sikinos, Sifnos, Syros, Tinos, Folegandros, and the 'Minor Cyclades - Donousa, Irakleia, Koufonisia and Schinousa.
- The Dodecanese: Astypalaia, Kalymnos, Karpathos, Kasos, Kastelorizo, Kos, Lipsi, Leros, Nisyros, Patmos, Rhodes, Symi, Tilos, Chalki.
- Crete: Divided into four prefectures - Chania, Rethymno, Heraklion and Lasithi.

In the Ionian Sea there are the Ionian Islands which include Zakynthos, Ithaca, Corfu, Kefallonia, Lefkada, Paxi, and Kythira. The biggest island in the Ionian Sea is Eptanissa. Antipaxi, Ereikoussa, Kalamos, Kastos, Mathraki, Meganissi, Othoni, Skorprios, Strofades are smaller islands.^{lxxxiv}

Around 33 per cent of the Greek population inhabits coastal areas located at a distance of 1-2 km from the coast, 85 per cent of the population inhabits areas up to 50km from the coast.^{lxxxv} It is estimated that around 80 per cent of industrial activities, 90 per cent of tourism and recreational activities, 35 per cent of agriculture, fisheries and aquaculture, as well as an important part of infrastructures (ports, airports, roads, electricity and telecommunications network etc.) are located in the coastal zone.^{lxxxvi}

Tourism and agriculture are the two biggest sectors of the Greek economy, with tourism representing about 16 per cent of GDP^{lxxxvii} and 20.8 per cent of total employment.^{lxxxviii} As noted by Giannakopoulos *et al.* (2011), tourism is concentrated in the Greek islands with the Dodecanese islands and Crete accounting for roughly 40 per cent of the country's total tourism output.^{lxxxix} Of the top ten tourist destinations in Greece, five of them are on islands.^{xc} In addition, 58.5% of Greece's hotels and 62.6% of its hotel beds are found on the islands.^{xc} The capacity utilisation rate in most regions is however low (with the exception of

the Dodecanese islands and Crete), indicating an under-utilised tourism stock due to inter alia over-investment, insufficient advertising and regional promotion etc.^{xcii} Agricultural activities are mostly concentrated on the mainland of Greece, although some important agricultural areas can be found on the island of Crete and Evia.^{xciii}

2.2 Most relevant climate trends

2.2.1 Historical evidence

For an overview of key observed and projected effects of climate change on the Mediterranean region see Table 1 below, adapted from a 2012 report by the EEA.^{xciv} The EEA report considers the Mediterranean region to be: most of Spain, Portugal, Croatia, Albania, Montenegro, Bosnia and Herzegovina; all of Italy and Greece; Southern France; and the coast of Romania and Bulgaria. The report finds that the region has been affected by major climate change impacts in recent decades primarily related to decreased precipitation and higher temperatures. Some of the main impacts include decreases in water availability and crop yields, increasing risks of droughts and biodiversity loss, forest fires and heat waves.^{xcv}

Table 5: Key observed and projected climate change and impacts for the Mediterranean region

Mediterranean Region			
Section Indicator/Topic	Variable	Observed	Predicted
<i>Changes in the Climate System</i>			
Key Climate variables			
Global and European Temperature	Temperature	+	+
Temperature extremes (warm)	Frequency	+	+
Temperature extremes (cold)	Frequency	-	-
Mean precipitation	Precipitation	-	-
Precipitation extremes (wet)	Duration/amount	(-)	+
Precipitation extremes (dry)	Duration	+	
Storms	Wind speed	°	(-)
<i>Climate impacts on environmental systems</i>			
Coastal Zones			
Sea-level rise	Mean sea level (excluding land movement)	(+)	(+)
Storm Surges	Surge height (in addition to mean sea level)	°	-
LEGEND			
+	Increase in variable throughout (most of) the region		
-	Decrease in variable through (most of) the region		
±	Increases as well as decreases in the variable in the region		
°	Only small changes in variable		
(l)	Increase or decrease only in some parts of the region		

Green	Beneficial Change
Red	Adverse Change

Source: Adapted from EEA (2012)

The Eastern Mediterranean Sea is warming substantially, particularly the Aegean and eastern Ionian seas.^{xcvi} Warming of the Mediterranean Sea is projected to be greater during the summer than the winter months.^{xcvii}

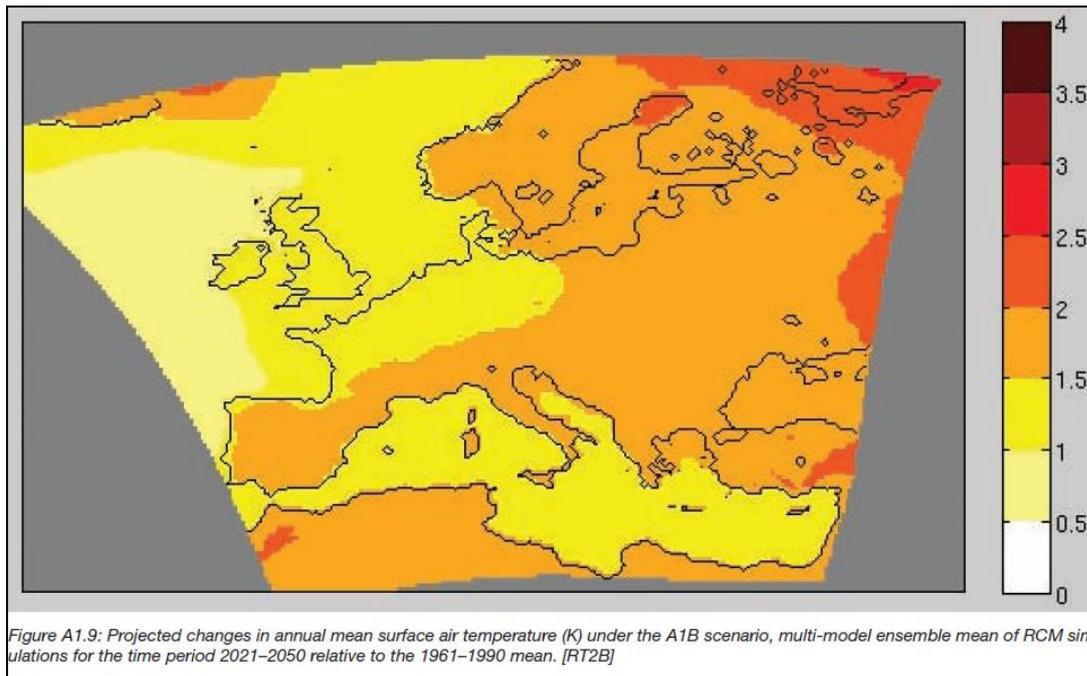
An issue related to the warming of the Mediterranean Sea is the introduction of invasive alien species which stands to threaten the islands' marine and land-based biodiversity.^{xcviii} Although warmer temperatures and human activity are jointly responsible for the "increased abundance and distribution" of invasive species, climate change is understood to be the enabling mechanism that allows human activity to have such significant impacts.^{xcix} As noted by the EEA, in the Mediterranean Sea, 'the observed invasion and survival of alien species has been correlated to the warming trend in sea surface temperature. Such invasions not only impact local ecosystems, they can also impact the activities of the international fishing fleet'.^c

Satellite data indicates that the Mediterranean sea level has risen by 2.6cm overall between 1992 and 2008. This is less than the global sea level rise of 3.0-3.5 mm/year, eg over 4cm, since 1992.^{ci} This rise in sea level has, among other factors contributed to one of the major problems facing the coastal zone in Greece which is the high rate of coastline erosion. Over 20 per cent of the total Greek coastline is threatened by coastal erosion. This erosion is expected to worsen in the future due to foreseen sea level rise, intensification of extreme wave phenomena and further reduction of river sediment inflows.^{cii}

2.2.2 Projected climate trends

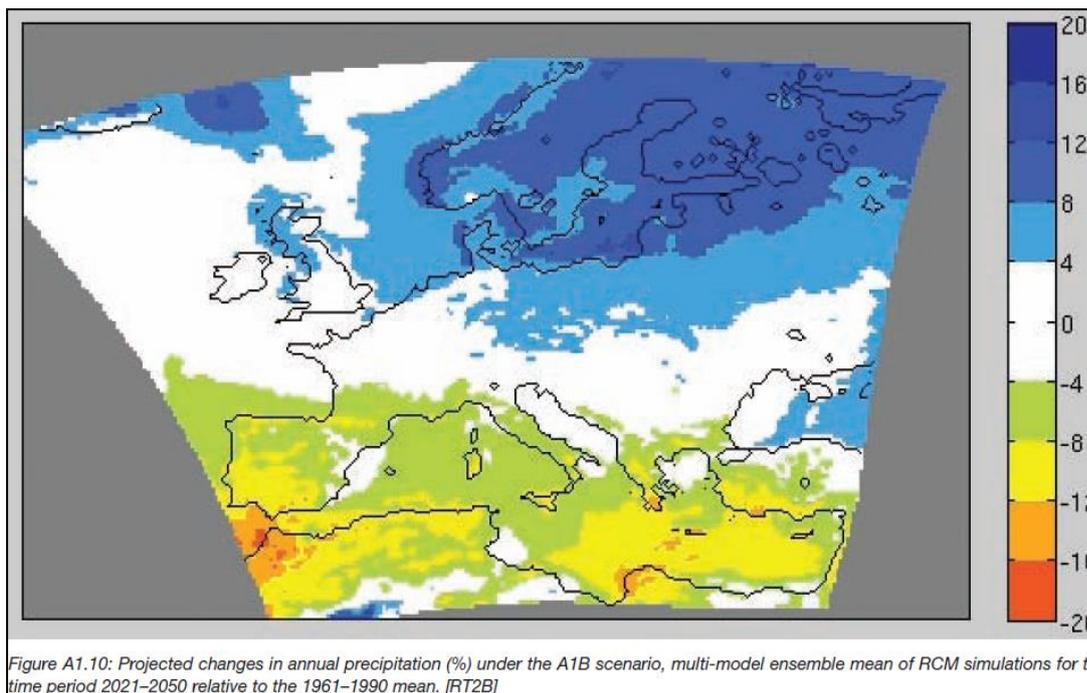
Projected changes in the region's annual mean surface temperature and annual precipitation are shown in Figure 6 and Figure 7 respectively. These maps were developed under the ENSEMBLES project (2004-2009), an integrated research study funded by the European Commission that projected climate change in Europe.^{ciii}

Figure 6: Projected changes in annual mean surface air temperature, 2021–2050



Source: van der Linden P., and J.F.B. Mitchell (eds.) (2009)

Figure 7: Projected changes in annual precipitation, 2021-2050



Source: van der Linden P., and J.F.B. Mitchell (eds.) (2009)

Giannakopoulos *et al* (2005) predicted the impacts of temperature changes under the IPCC’s A2 and B2 scenarios on the Mediterranean Basin between 2031 and 2060. The study found that with a predicted global temperature increase of 2°C, the corresponding warming in the Mediterranean Sea is expected to be between 1-3°C.^{civ}

A study by the Bank of Greece noted that an increase in mean annual air temperature in Greece between 2021-2050 and 2071-2100 is predicted to occur in the four IPCC scenarios (A2, A1B, B1, and B2).^{cv} Giannakopoulos *et al* (2011) predict that the number of days over 35°C (labelled as ‘heat wave days’) on some Greek islands will increase by about 10 between 2021 and 2050.^{cvi} Islands in the North Aegean Sea are expected to experience more heat waves (up to four weeks more) in the future.^{cvi} Previous estimates add an additional seven weeks of summer to the year for Crete (when temperature exceeds 25°C).^{cviii} Higher temperatures, including ‘tropical nights’ (when night-time temperature is over 20°C), are expected to affect coastal urban areas in particular adding to population heat stress.^{cix}

In the Mediterranean region, under both scenario A2 and B2, precipitation decreases substantially in the summer. This reduction in precipitation extends throughout the year in the south. Longer droughts are also expected while the number of dry days is shown to increase^{cx}. As noted by a 2011 report by the Bank of Greece, the period 2021-2050 is projected to see precipitation levels decrease across the country by between 3 per cent (Scenario B2) and 8 per cent (Scenario A2), while total water potential is expected to decrease by between 14 per cent (Scenario B2) and 22 per cent (Scenario A2).^{cx} Crete is predicted to have an overall decrease in precipitation between 1970 and 2100.^{cxii}

This decline in precipitation will have an impact on water resources - the Mediterranean basin is expected to experience a decrease in water resources due to climate change.^{cxiii} Water availability in the Mediterranean region may fall by 20-30 per cent under a 2°C increase global warming scenario and by 40-50 per cent under a 4°C warming scenario. Summer water flows in particular are expected to reduce substantially.^{cxiv}

An ocean temperature-driven sea level rise of between 3 and 61 cm is predicted over the entire Mediterranean Sea basin in the 21st Century. This needs to be combined with a salinity-driven sea level change of between – 22 and + 31 cm.^{cxv} As noted by Kontogianni *et al* (2012), local factors such as sediment supply and compaction, storm surges and in particular the role of tectonics should also be kept in mind as these may have an impact on estimated sea level rise, e.g. Crete has a tectonic uplift rate of between 0.7 and 4 mm/year and Rhodes an uplift rate of between 1.2 and 1.9 mm/year.^{cxvi} A report by the Bank of Greece (2011) noted that sea level rise is predicted to reach 0.25m (Scenario B2) and as much as 1m (Scenario A2) by 2100. The Greek islands likely to be most strongly affected include Lemnos, Samos, Rhodes, Crete and Corfu.^{cxvii}

2.3 Consequences of climate change impacts on specific sectors

An overview of some observed and projected climate change impacts on key socio-economic systems in the Mediterranean region are set out in Table 6 which is adapted from a 2012 report by the EEA.^{cxviii} More details on the consequences of climate change in specific sectors examined in this study are set out in the sections below.

Table 6: Key observed and projected climate change impacts on socio-economic systems in the Mediterranean region

Mediterranean Region			
Section Indicator/Topic	Variable	Observed	Predicted

<i>Agriculture</i>			
Growing season for agricultural crops	Duration	(+)	
Water-limited crop productivity	Yield	-	(-)
Irrigation water requirement	Water requirement	±	(+)
<i>Forests and forestry</i>			
Forest growth	Biomass		(-)
Forest fires	Area	(+)	
<i>Human health</i>			
Extreme temperatures and health	Mortality		+
Air pollution by ozone and health	Ozone levels	(+)	+
<i>Energy</i>			
Heating degree days	Heating demand	(-)	(-)
Electricity Demand	Electricity demand		+
Electricity Production	Electricity production		-
<i>Tourism</i>			
General tourism	Attractivity		(-)
LEGEND			
+	Increase in variable throughout (most of) the region		
-	Decrease in variable through (most of) the region		
±	Increases as well as decreases in the variable in the region		
°	Only small changes in variable		
()	Increase or decrease only in some parts of the region		
Green	Beneficial Change		
Red	Adverse Change		

Source: Adapted from EEA (2012)

2.3.1 Agriculture

Climate change is expected to result in adverse effects on natural conditions for crop cultivation in the Mediterranean region. For example, the crop growing season, timing of the cycle of agricultural crops and average yields are expected to be among the conditions affected.^{cxix} Increased frequency of weather extremes, such as dry spells and heat waves, will also potentially damage agricultural production, while pest outbreaks and the increased frequency in diseases induced by higher temperatures may pose additional risks for crop cultivation.^{cxx} At the same time, the changing weather conditions could also create new opportunities, for example the ability to cultivate certain crops (such as tomatoes) throughout the year^{cxxi}.

Iraklion on Crete is considered to be one of the most important agriculture areas in the country, employing close to 80,000 workers.^{cxxii} An overview of potential climate related changes on the island which will have an impact on the agriculture sector is set out in Table 7.

Table 7: Potential future changes in climate indices with particular relevance to agriculture

Area	Max dry spell length (days)	Days >35°C	Frost nights	Growing season (days)	Winter precip (%)	Autumn precip (%)
Iraklio	(+)15	(+)10	(-)5	(+)10	(-)15	(+)15

Source: Adapted from Giannakopoulos *et al* (2011)

The Mediterranean region is expected to face continuous periods of drought and hence suffer from rising water scarcity, declining crop yields and desertification.^{cxxiii} Kouroulis *et al* (2013) assessing a range of climate scenarios and their implications for water availability for the island of Crete for the period 2000-2050 point to a significant water insufficiency. Depending on the scenario the estimated deficit ranges from 10 per cent to 74 per cent. If it is assumed that all climate scenarios considered for this study are equally probable, 'average water availability is expected to drop from 93 per cent during 2000–2050 to a devastating 70 per cent of the observed average [...], which is already insufficient to cover current demand'^{cxxiv}.

For example, the length of the dry season (where precipitation is less than 1mm per day) is expected to increase to around 10 days in southern part of Iraklion in Crete and by 15-20 days in the northern part of Iraklion.^{cxxv} At the same time, water demand for agriculture is projected to continue, thus increasing competition between different water users.^{cxxvi} The decline in water resources will have implications for the cultivation of certain crops. For example Greece has seen its annual production of olive oil decline by half since 2001. Climate change is thought to be an important factor contributing to this decline as a result of higher temperatures drought and related water scarcity^{cxxvii}. The production of olive oil may not be possible in certain areas in the future or cultivation techniques will need to change (e.g. shifting farms to higher altitudes, changing planting patterns etc.)^{cxxviii}. Unfavourable weather conditions in summer 2013 affected the production of olive oil on Crete causing a decrease of up to 70 per cent. A combination of warm southern winds and increased temperatures over extended periods caused the olives to dehydrate and fall prematurely. The Cretan Association of Olive Oil Producers (SEDIK) estimated income losses of €150-200 million. SEDIK is currently seeking some form of support / assistance from the Greek Government and the EU^{cxxix}.

While the adoption of specific crop management techniques may help to reduce some of the negative effects on agricultural production, such options could require up to 40 per cent more water for irrigation which may not be available given expected pressures on water resources in the region^{cxxx}. The 2012 EEA report finds that while increasing the efficiency of irrigation in the agriculture sector can help to reduce water withdrawals, it will not be sufficient to compensate for expected climate change impacts on water stress in the Mediterranean region.^{cxxxi}

2.3.2 Biodiversity – land and marine based

Biodiversity and ecosystems in the Mediterranean region are vulnerable to climate change and are expected to suffer from predicted water scarcity and heat stress in the region. Furthermore predicted sea level rise may reduce the availability of habitats for certain bird species, while plant species losses of up to 62 per cent are projected for southern regions of Europe.^{cxxxii} Climate change is also expected to lead to shifts in the distributions and

abundances of species in the Mediterranean region, potentially increasing the risks of extinction of particular species.^{cxxxiii}

Biodiversity in Greek forests are also expected to be affected by climate change through for example the necrosis of fir trees, the invasion of coniferous to broadleaf forests, and forest fires.^{cxxxiv} The severity and frequency of forest fires is expected to increase with climate change as fires respond to the available moisture in the wood, which is dependent on the level of precipitation, relative humidity, air temperature, and wind speed.^{cxxxv} Thus, higher temperatures will increase vulnerability to forest fires.^{cxxxvi} For example, in Cephalonia, a significant increase in fire risk is predicted due to climate change, with an increase in the length of dry spells by fifteen or more days.^{cxxxvii} This is particularly pertinent in the wake of the devastating 2007 forest fires in western and southern Peloponnese and Euboea that resulted in a loss of human life, villages, healthy forest, and tourism revenue.^{cxxxviii} In Crete, a significant increase in the number of days with fire risk is expected (1-4 weeks).^{cxxxix} The increase in forest fires is expected to have a negative effect on *inter alia* the timber industry with a decline in production of between 27 per cent (B2) to 35 per cent (A2) predicted.^{cxl} Furthermore, forest fires are expected to increase the spread of invasive species which in turn may lead to more frequent and more forest fires.^{cxli}

Higher temperatures will also affect marine ecosystems as the rise in temperature is associated with ocean acidification and its negative consequences for marine biodiversity. In a study on the socio-economic effects of ocean acidification in the Mediterranean Sea, the main sectors which are expected to be impacted include tourism and recreation, the extraction of coral for jewellery production, and fisheries, including aquaculture.^{cxlii} In terms of impacts on the fisheries industry, a temperature increase of 3.3°C by 2100 is associated with a decrease in fishery landings of 3.6 per cent below the mean for benthic fish; 4.25 per cent of the mean for mesopelagic fish (but an increase of 1.7 per cent and 0.13 per cent for large and small pelagic fish catches).^{cxliii}

2.3.3 Tourism

The tourism sector in the Mediterranean region is expected to face less favourable conditions in summer given predicted increases in temperature. For example, the results of the CIRCE project ('Climate Change and Impact Research: the Mediterranean Environment') suggest that expected climate change will decrease tourism flows from the north of Europe to the south and increase flows within the north of Europe.^{cxliv} These impacts are likely to become increasingly important in the long-term.

A 2008 report by Deutsche Bank concluded that given the high ratio of international tourists and the high proportion of employment (20 per cent) from tourism, 'Greece will be one of the losers from climate change.'^{cxlv} For an overview of potential climate related changes of relevance to the tourism sector see Table 8.

Table 8: Potential future changes in climate indices with particular relevance to tourist areas

	No of heatwave days	No of tropical nights	Humidex above 38°C (days)	Max length of summer days	Heavy cooling demand (days)	Forest fire risk (days)
Rhodes	10	35	30	25	5	10
Attica	15	30	25	25	10	15
Iraklio	15	30	30	25	10	10
Chalkidiki	10	30	20	25	5	15
Cyclades	–	30	7	25	–	5
Corfu	10	30	25	20	5	10
Chania	10	30	20	30	5	10
Rethymno	10	30	25	30	5	10
Pieria	10	30	17	20	5	15
Zante/Cephalonia	5	30	25	25	–	5

Source: Giannakopoulos *et al* (2011). Note: Tourist areas listed which are located on islands are: Rhodes, Iraklio, Cyclades, Corfu, Chania, Rethymno and Zante/Cephalonia.

The Aegean islands and Crete in particular attract many tourists. In mid-summer many tourists are already finding the heat extreme and this is expected to increase by 2030.^{cxlvi} The number of so-called ‘hot days’ with temperatures above 35°C is expected to increase more significantly in certain areas, for example Iraklion, on Crete is expected to see a 10-15 day increase. Other tourist sites in Crete, namely Chania and Rethymno, as well as Rhodes have smaller increases of around 10 days.^{cxlvii} Smaller island sites which have a more pronounced sea influence are expected to experience smaller changes, for example Zante and Corfu are expected to see an increase of about 5-10 hot days. However these changes are still notable given that such temperatures have not been recorded in these areas.^{cxlviii} In contrast, the Cyclades islands are shown to retain much of their coolness with only negligible increases in hot days.^{cxlix} While the Ionian Islands (e.g. Corfu) should be able to cope better with increasing temperatures, they will also not escape the general trend.^{cl}

The number of ‘tropical nights’ with temperatures above 20°C is also expected to increase across Greece with island sites affected even more than continental areas. For example, Rhodos and the city of Chania on Crete are expected to experience a sum of 40 additional tropical nights in the future.^{cli} High temperatures coupled with increased humidity levels near the sea will add to the discomfort of tourists and may serve to discourage visitors, particularly during certain periods. Changes in the number of days with apparent temperature (humidity index) above 38°C can be used to assess the level of public comfort. The highest changes of such days of about 30 (±6) days are expected in Rhodes and Iraklio, whereas the lowest changes of about 7 (±2) days are expected in the Cyclades.^{clii} Together with the increase in hot days and tropical nights, the higher humidity will add to discomfort of tourists and may serve to deter potential visitors to the islands.^{cliii}

At the same time, more than 30 (±7) additional summer days are expected in coastal areas of Crete (Chania and Rethymno). This could lead to an extension in the tourism season by as much as one month per year in these areas with a ‘lengthening and a flattening’ of the Greek tourism season expected by 2030.^{cliv} Such a longer tourism season will help to spread demand (for energy, water etc.) more evenly and thus alleviate pressures on summer water supply and energy demand.^{clv}

The increased risk of forest fires can also deter tourists due to safety concerns, loss of scenic landscape and inaccessibility of certain regions. Forest fires in Greece in August 2007 were the worst for several decades and demonstrated the country’s vulnerability to fire as a

result of its dry climate.^{clvi} Extreme forest fire risk is expected to increase by around 10 days in Rhodes, Corfu, Iraklio, Chania, Rethymno, whereas the Cyclades islands and Zante/Cephalonia show negligible changes.^{clvii} Extensive forest fires can result in a considerable shortfall in tourist receipts.^{clviii}

2.3.4 Infrastructure

A 2004 study on the impacts of sea level rise on Crete, particularly the Hersonissos region, found that low lying areas will likely be permanently flooded, erosion of beaches will accelerate, and as a result flooding events will become more frequent. For the Hersonissos region on Crete alone the identified threats as a result of sea level rise mean that 470 ha and 520 ha for 50cm and 100cm of sea level rise respectively could disappear.^{clix}

The water supply infrastructure will be under increased pressure to maintain its functioning. For instance, on the island of Kalymnos, saltwater intrusion (related to sea level rise) is well above the legal limits in many water boreholes. This has led the majority of residents to consume bottled water for drinking and cooking purposes. It has been estimated that there may be a negative balance between the demand and available supply of water on the island, particularly in the summer months, with problems related to water storage, pressure on existing resources, increase of salinity, disruptions of the supply on the water network, etc.^{clx} On the island of Crete, the increasing salinity of groundwater reserves has implications for crop cultivation, especially along the coast^{clxi}.

Water supply is already an issue for many Greek islands, for example those in the Aegean Sea, where transfers of potable water are needed in certain periods. For example, water reservoirs on Greek islands were at their lowest level in July 2008 with imports of water resources via tankers costing €11 million that year, a 10 per cent increase over the amount of water imported in 2007.^{clxii} Water supply problems in tourist resorts are increasingly common and are expected to increase further as temperatures increase and the summer period lengthens. For example, the Aegean islands have more than 15 million overnight stays per year and on some islands the population over the summer period is 30 times greater. This leads to increased demands for water which are met through importation of water from the mainland by tankers and through desalination.^{clxiii}

Flooding is expected to become more frequent and severe, leading to infrastructure damage and biodiversity loss, if not the complete inundation of low-lying areas.^{clxiv} This is a particular problem for Greece as around 85 per cent of the population resides within 50km of the coastline.^{clxv} Table 9 sets out approximate values of flooded coastal areas and shoreline retreat triggered by a possible sea level rise of between 0.5m and 1m in high risk areas in Greece.

Table 9: Examples of shoreline retreat and inundated area for potential SLR of between 0.5-1m

Coastal area	SLR (m)	Inundated area (10 ³ m ²)	Length/Area of shoreline	Source
Hersonissos Crete	0.5	4,700	20 km	Doukakis, 2004
	1	5,200		
Lambi Kos	0.5	35	0.25 km	Papadopoulou & Doukakis, 2003
	1	52		
Kardamaina Kos	0.5	19	0.615 km	
	1	33		
Tigaki Kos	0.5	161	2.7 km	
	1	322		
Afantou Rhodes	0.5	375	3 km	
	1	439		
Vartholomio Ieias	0.5	190	2.65 km	
	1	300		

Source: Kontogianni *et al* (2012)

Kontogianni *et al* (2012) estimated the total long-term financial loss due to a sea level rise (SLR) of both 0.5m and 1m on different land uses in the Greek coastal zone. A summary of the results are presented in Table 10 and Table 11 below. For tourism and housing, the total area predicted to be lost in each scenario is multiplied by the market value of property in the area. Financial losses for the agriculture sector are calculated by multiplying lost area by a “specific base value” of the farmland, losses for wetlands are calculated by area lost multiplied by a unit value for wetlands (4.8 million €/km²). Similarly, forest area lost is multiplied by the unit value of Greek forests (89.25 €/ha) to arrive at the estimate for forestry. The total discounted SLR cost including long-term SLR, short-term SLR and non-use values (i.e. aesthetic, recreational and cultural/spiritual value loss) is estimated to equal 2 per cent of Greek GDP (in 2010 prices).^{clxvi}

Table 10: Present value of total financial loss for different land uses at a discount rate of 3 per cent

Land use	Total financial loss 2010 (10 ³ €)	
	SLR 0.5 m	SLR 1 m
Housing & Touristic	24,316,576	44,113,412
Wetlands	9,650	17,272
Forests	11	36
Agriculture	551,279	1,276,386
Total	24,877,517	45,407,106

Note: Figures do not include aesthetic/recreational/ storm surge damages

Source: Kontogianni *et al* (2012)

Table 11: Total long-term financial loss of SLR in Greek coastal zone under different discount rates

	SLR 0.5m	SLR 1m
NPV (0%)	355,760,113	649,342,831
NPV (1%)	145,289,294	265,185,888
NPV (3%)	24,877,517	45,407,106

Source: Kontogianni *et al* (2012). Note: Figures do not include aesthetic/recreational/ storm surge damages

Greek authorities' project that 0.5m SLR by 2100 will flood 15 per cent of the current total area of coastal wetlands in Greece with estimated economic losses exceeding €350 million.^{clxvii} Other estimates of land losses and associated costs of sea level rise are provided in Bosello *et al* (2012) which provide first-order approximations of the economic effects both with and without adaptation.^{clxviii} Key findings of the study for Greece are summarized in Table 12 and Table 13 below.

Table 12: A2 Scenario: High Sea-level Rise 2085 - Main macroeconomic Indicators (no adaptation)

	Land losses			GDP (*)	Investment (*)	Terms of trade (*)	Per Capita Utility (*)
	% of country total	Value (Million \$)	Value as% of GDP				
Greece	-3.542	203.04	0.032805	-0.0299	0.125	0.090	-0.008

(*) Values expressed as % changes wrt A2 2085 baseline

Source: Bosello *et al* (2012)

Table 13: A2 Scenario: High Sea-Level Rise 2085, Main macroeconomic indicators (with adaptation)

	Land losses (% of country total)	Coastal Protection Expenditure as% of GDP	Investment (induced by coastal protection)	Private Consumption	GDP	Terms of trade	Per Capita Utility
Greece	-0.056	0.0241	8.774	-0.181	0.086	1.571	0.654

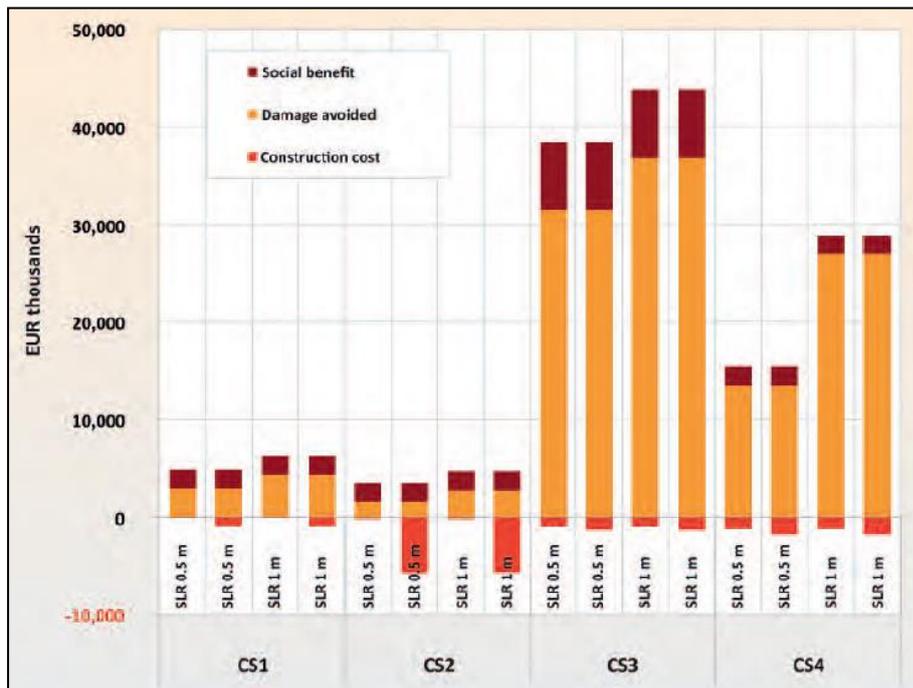
Source: Bosello *et al* (2012)

In a 2011 report by the Bank of Greece, four case studies were developed for a cost/benefit analysis of selected adaptation policies to the impacts of sea level rise. The case studies examined and adaptation measures considered were:

- Case Study 1 (CS1): Groynes in the Lambi area on the island of Kos.
- Case Study 2 (CS2): Artificial beach nourishment in the Kardamaina area on the island of Kos.
- Case Study 3 (CS3): Placement of riprap revetments and geotextile filter in the Afantou area on the island of Rhodes.
- Case Study 4 (CS4): Concrete seawall in the Tingaki area on the island of Kos.

An overview of the cost/benefit analysis using a 3 per cent discount rate in the case studies is presented in Figure 8 below. In the figure, ‘construction cost’ refers to the implementation cost of the adaptation measure for coastal protection, ‘damage avoided’ refers to the long-term sea level rise equal to the estimated value of the land area saved as a result of protection works, while ‘social benefit’ (measured in terms of willingness to pay) refers to the benefit for society arising from the adoption of measures to avoid short-term impacts such as storm surges.^{clxix}

Figure 8: Cost and benefits of adaptation measures considered in four case studies



Source: Bank of Greece (2011)

As part of an EU-funded project, CLIM-RUN^{clxx}, an interactive website has been developed to provide information on climate change impacts at the regional and local scale. The platform⁶ allows users to assess the impacts of climate change, in particular relating to temperature increase and forest fires, across different areas of Greece including groups of islands.

2.4 Implications for trade, security & migration

2.4.1 Trade

As noted by Giannakopoulos *et al* (2011), ‘agriculture and tourism are undoubtedly the most important economic sources for Greece and these may be more strongly affected by changing future climate conditions.’^{clxxi}

Agriculture is “highly sensitive” to long-term changes like a mean rises in temperature as well as short-term variations from year to year.^{clxxii} The adverse effects of climate change on agriculture including changes to natural conditions for crop cultivation as well as the

⁶ <http://www.meteo.noa.gr/oikoskopio/index.php?lng=en-US>

increased frequency of weather extremes, increase in pest outbreaks and frequency of diseases will impact the ability to trade agricultural products with the EU mainland. These changes will reduce the ability to trade certain agricultural products such as olive oil. Greece is the world's third largest producer of olive oil (after Spain and Italy) and the world's leading exporter of extra virgin olive oil.^{clxxiii} The majority of olive oil production is centred in three regions: Peloponnese (37 per cent), Crete (30 per cent) and the Ionian Islands (12 per cent) where the chief olive growing areas are Messinia and Ilia (Peloponnese), Iraklion and Chania (Crete) and Corfu (Ionian Islands). Thus climate change impacts on these islands can be expected to affect the main areas of olive oil production in Greece.

The changing climate may also potentially create new opportunities for trade in certain products, e.g. crops which are more suitable to changed climatic conditions such as tomatoes^{clxxiv}.

The tourism industry is also expected to be significantly affected by climate change. Warmer summers in northern Europe may encourage northern Europeans to take domestic holidays and thus reduce travel to the Mediterranean, while increasingly frequent and intense heat waves and periods of drought are expected to discourage holidays in the Mediterranean during the summer months.^{clxxv} The tourist season in the Mediterranean is expected to shift from the summer months to spring and autumn.^{clxxvi} The influence of climate change on local environmental conditions may also deter potential tourists. For example, following the devastating fires in the summer of 2000 in Greece, more than 50 per cent of tourist bookings for 2001 were cancelled.^{clxxvii}

2.4.2 Security

Given that the expected decline in the availability and distribution of freshwater resources (as noted above), *water security* is a major concern and may lead to potential conflict over water rights. This decrease in water resources may however be offset by an expected decline in the country's population.^{clxxviii}

Energy security is another important concern and increasing energy demands pose a particular challenge to energy infrastructure on the islands. The increase in mean annual air temperature predicted in the four IPCC scenarios^{clxxix} will lead to increased energy use for air conditioning during the summer months^{clxxx} and to reduced energy demand during colder months.^{clxxxi} The increase in annual electricity use due to climate change alone is between 3.6 – 5.5 per cent.^{clxxxii}

By 2050, more than 20 additional summer days (days with maximum temperature above 25°C) are expected across all tourist areas in Greece. This will lead to more days requiring cooling and thus an increased use of air conditioning. For instance, 15 extra days will require cooling in Pieria and 10 extra days in Athens, Iraklion and the north part of Rhodes.^{clxxxiii} The Cyclades islands and Zante/Cephalonia are two areas in which future changes in the number of days requiring heavy cooling are not expected.^{clxxxiv}

Energy demand is expected to peak during the dry season, which is expected to become even drier in the future due to reduced precipitation.^{clxxxv} For example, the ENSEMBLES model indicated a large increase in the cooling requirements for eastern Greece in

particular, with an estimated 20 more days of cooling annually needed, as a result of temperature changes between 2021 and 2050.^{clxxxvi}

At the same time, energy generation capacity will be affected by climate change. The 2012 EEA report finds that in the Mediterranean region, the hydropower sector will be increasingly affected by the lower availability of water as well as rising demand for energy.^{clxxxvii} In addition, the reduced water supply will also affect conventional power plants which use water for cooling and driving turbines. Consequently, energy demands may not be met in the summer months and additional capacity may need to be installed.^{clxxxviii} At the same time, conditions for renewable energy production, such as solar power, may improve as a result of climate change.^{clxxxix}

Another concern relates to potential *food security* issues. According to the IPCC (2007), small islands in particular may be challenged by food security in the future due to “anticipated land loss, soil salinization, and low water availability.”^{cxc} The expected impacts on agricultural production outlined above are expected to have important implications for food security in Greece and on the islands.

2.4.3 Migration

As noted in a 2011 report by the Bank of Greece, the country has already received large numbers of immigrants. These numbers are expected to increase significantly in the future as the flow of so-called ‘environmental refugees’ increases. At the same time, internal migration within Greece from low-lying coastal areas to higher altitudes is also expected to increase.^{cxc} With around 85 per cent of citizens living within 50 km of the coastline, sea level rise will have a significant effect on migration rates in the coming years as increasing numbers of people are displaced.^{cxcii}

The expected impacts of climate change on the key economic sectors of tourism and industry may also have an effect on migration. Given that Greece is highly reliant on the tourism industry, a decrease in tourist numbers may significantly affect overall migration rates as people seek employment outside peak seasons etc.^{cxciii} Agriculture can also expect changes to labour demands in the face of climate change. For example, the PESETA II study found that ‘in 2050, when the temperature increases 2°C, higher labour demand contractions are concentrated in the agricultural sector especially in Greece (-5.7 per cent)(...).’^{cxciv}

2.5 Conclusions

Overall, Greece is expected to be hit hard economically by climate change. It is estimated to be the most severely affected country in the EU, with predicted losses of between -1.76 per cent and 6.24 per cent of GDP in 2050 corresponding to 2°C and 4°C temperature increases, respectively.^{cxcv}

The main impacts of climate change on the Greek islands include decreased water availability with lower precipitation levels, higher land and sea temperatures, sea level rise,

reduced crop yields, increased risks of drought, biodiversity loss, higher incidence of forest fires, and increased frequency and intensity of heat waves. The expected additional stress on water resources in the face of climate change coupled with rising demand for water from multiple users (agriculture, tourism, households) is a critical challenge facing the Greek islands.

These climate change induced impacts are expected to have significant implications on the two main industries in Greece, namely agriculture and tourism, both of which are predicted to sustain some economic losses due to the impacts of climate change.

3 REUNION ISLAND

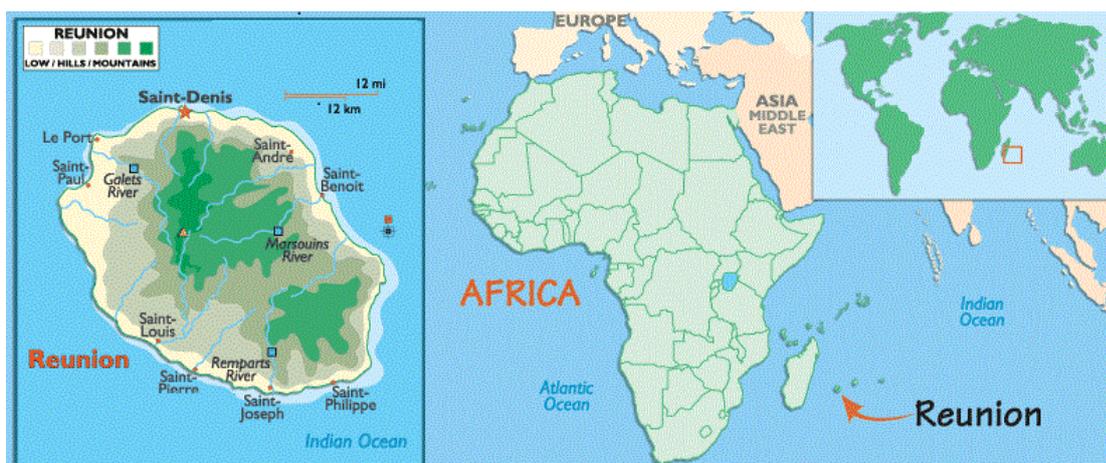
Reunion is one of the four European overseas entities in the Indian Ocean, it is a European outermost region (OR) and a French overseas department (OD). The island is a voluminous volcanic complex with the highest demographic growth of all European Union's regions.

Its confined territory, scarce natural resources and high demographic pressure, make it heavily reliant on the imports of products and more generally, on the dynamics of international trade and economy. The main projected climate impacts for the 2014-2100 time period are temperature increases between 1.5 and 2.8° C, an increase in sea levels and heavy rainfalls, together with a raise in drought periods at different sub-regional levels of the island, mostly in the Eastern areas of the island. The cumulated effects of these altered climatic conditions will harm the balance of land and marine-based ecosystems, potentially triggering an increase in forest fires, biological invasions, pests and diseases, along with modifications in soil and water quality, and the species' seasonal activities. As human installations, agricultural cultivations and infrastructural facilities are concentrated in the low-lying areas, an increase in sea-water levels and extreme weather occurrence will pose serious threats to human, food, water and energy security. This will ultimately affect trade from and to the island.

3.1 Key features of Reunion Island

The South Western Ocean accommodates a large number of islands that are either grouped in archipelagos (eg Seychelles, Comoros) or are isolated, as it is the case of Reunion Island. Reunion Island is situated in the Mascarene Basin, 750 km East of Madagascar and 170 km West/South-East of Mauritius island (see Figure 9). It is part of the highest oceanic volcanic system on Earth, and it displays a flattened cone morphology, with a large submarine part⁷ and two volcanoes, Piton des Neiges, 'Snow Peak', and Piton de la Fournaise, 'Furnace Peak'^{7,CXCVI}.

Figure 9: Physical and locator map of Reunion Island



Source: WorldAtlas.com, 2013⁸

⁷ 97per cent of Reunion's island volume is submerged.

⁸ <http://www.worldatlas.com/webimage/countrys/africa/re.htm>

Reunion Island is the most populous French overseas territory, with a population of 839,500 inhabitants (see Table 14). It experiences strong demographic growth with a population projection for 2030 of more than 1 million inhabitants^{cxvii}.

Table 14: Overview: Key features of La Reunion Island

La Reunion Island (France) OR	
Number of islands	1 island 
Latitude/Longitude	21° 06' S, 55° 36' E
Population	839,500 inhabitants (2011)
Population density	313 inhabitants/ m ²
GDP/capita	€17,520 (2010)
Unemployment rate	27 per cent (2009)
Main economic activities	Tourism, agro-food industry, agriculture, commerce, services ⁹
Land area	2,520 km ²
Maximum elevation	3,069 m (Peak Piton de Neige)
Lowest point	0 m (Indian Ocean)
Landscape character	Predominantly volcanic mountainous landscape, with fertile lowlands along the coastal area
Climate	Tropical, with variations in temperature moderate with altitude; many micro-climates

Source: Own compilation based on source cited in the text, Petit & Prudent pp. 15 (2010), and Lamy-Giner (2011)

Piton des Neiges is the largest and the highest volcano on the island, reaching to 3,069 m, and Piton de la Fournaise is one of the world's most active volcanoes. Both mountain massifs have forested slopes, with high plains and volcanic plateaus lying between them and descending towards the sea^{cxviii}. Due to their favourable geological composition, the surrounding low-lying lands in the coastal area are mostly used for agricultural cultivations. Characterised by altitude variations, rugged landscapes and pronounced ravines, the topology of the island is reflective of the acute erosion rates on its inland territory. Also, erosive action caused by waves and weather affects the coastal line, which is characterised by variable length, but is most developed on the Western side of the island. The Northern and Eastern coastal areas are frequented by cyclones (from November to April), while austral storms occur mostly in the Southern and South-Eastern low-lying areas of the island, from June to September^{cxix}. The high and steep mountain tops of Reunion attract abundant precipitation levels, which may amount to a maximum of 8,000 mm per year on the wind-exposed sides^{cc}.

Reunion Island is home to a remarkable reservoir of plants and animals of global significance, and represents one of the world's 25 biodiversity hotspots. Around 1.5 per cent of its territory hosts two third of all the known species^{cci}. Most of the species on the island are endemic of this part of the Indian Ocean, due to the geographic isolation that lead to the development of flora and fauna exclusively found in this region. Around 200 insect species, 835 native species of vascular plants (including 234 endemics), 18 native bird species (of

⁹ http://www.outre-mer.gouv.fr/?economie-la-reunion.html&artpage=2#outil_sommaire_3

which more than 50 per cent are endemic), and 965 fish species (including 25 Mascarene and 7 Reunion region endemics) are encountered in Reunion Island^{ccii}.

Natural ecosystems and habitats went through a series of drastic transformations in the period following the early 16th century, when human colonialisation started¹⁰. The overexploitation of natural resources and conversion of land for agricultural lots and human installations and urban sprawl lead to a loss of 60 per cent of the native ecosystems; however, the highland habitats remained well preserved due to their limited accessibility^{cciii}. At present, the cragged mountainous landscape still accommodates a belt of altimontane vegetation, which developed due the favourable moderate climatic conditions, and is unique among the world's tropical islands¹¹.

Coral formations on Reunion Island are relatively scarce and localised, being encountered mostly on the Western coast, where they form a discontinuous strip of roughly 25 km¹². As both a natural capital and a natural heritage rich in ecosystem services provision, coral reefs are posed in serious threat by rising sea surface temperatures, which cause coral bleaching.

The mountainous landscapes with lave cliffs and canyons, the cirques formed from the active collapsed calderas of Piton de la Fournaise, and the Reunion National Park are the primary attraction points for tourists. Adventure and sports tourism including surfing, snorkelling and scuba diving could be practiced off the island's West Coast, where the coral reef formations are most extended¹³.

The tertiary sector, including and services, such as administrative services, trade, concentrates three quarters of the active population in La Reunion. The construction and the industry sector account each for approximately 7 per cent of the regional gross domestic production¹⁴. In 2010, the agricultural sector employed 10 per cent of the active population in Reunion Island and generated 5 per cent of the regional GDP (DAAF, 2013)¹⁵. In 2011, tourism represented only 3.5 per cent of total private employment due to its seasonal character¹⁶; however, overall, the third sector including tourism and service industry accounted for around 70 per cent of the GDP¹⁷.

In the agri-food sector, the main added value is generated by sugarcane distillation, sugar derivatives and rum production. The agricultural land covers only 21 per cent of the island's surface, whilst the mountainous massifs and the UNESCO protected National Park occupy most of Reunion's territory^{18,cciv}. The agricultural sector is characterised by predominantly

¹⁰ The Portuguese were the first Europeans to discover the island, uninhabited in 1513, and named it Santa Apollonia. From the 17th to the 19th centuries, French immigration, supplemented by influxes of Africans, Chinese, Malays, and Malabar Indians, conferred the island its ethnic mix.

¹¹ http://www.azoresbioportal.angra.uac.pt/files/noticias_NetBiome_newsletter_2009_01.pdf

¹² <http://www.reunionisland.fr/geo.html>

¹³ <http://www.reunionisland.fr/geo.html>

¹⁴ http://www.insee.fr/fr/insee_regions/reunion/faitsetchiffres/presentation/presentation.pdf

¹⁵ <http://daaf974.agriculture.gouv.fr/Vue-d-ensemble>

¹⁶ http://www.insee.fr/fr/themes/document.asp?reg_id=24&ref_id=19309

¹⁷ <http://www.adreunion.com/Special-Trainings-Tourism-Agri.html>

¹⁸ Since 2010, the UNESCO World Heritage included 100,000 hectares of natural areas in the National Park of Reunion Island for their unique landscape and biodiversity conservation. Less than half of the area was already used by traditional agricultural activities, such as sugarcane cultivation, which needs to be preserved.

small-scale or subsistence farm holdings of less than 20 ha, and with an average of 5.8 ha, which are managed and run by an aging farming population¹⁹. As shown in Table 15, sugarcane cultivation takes up more than half of the total agricultural land, but was faced with a decreasing trend in land surface over the period 1989-2010. This pattern is also evident when analysing the evolution of Reunion department's total agricultural area, and could be explained by the increase in urbanization phenomena and adjacent infrastructural development at the expense of agricultural lots. After a continuous reduction of around -2% in 10 years, the agricultural surface used by farmers is reaching at present a stabilising level at around 43,000 hectares²⁰.

Table 15: Agricultural land cover: evolution in the period 1989-2010

Agricultural land cover type	1989 (ha)	2000 (ha)	2010 (ha)
Grains and oilseeds	1433	275	106
Sugarcane	30570	25923	24336
Aromatic plants	2573	736	493
Flowers and ornamental plants	113	120	168
Vegetable crops	2447	1611	1986
Tubers, roots, bulbs	426	224	296
Fresh vegetables	1748	1269	1671
Grain legumes/Pulses	273	118	19
Permanent fruit crops	1442	2066	1916
Citrus fruits	100	327	307
Semi-permanent fruit crops	760	564	865
Bananas	499	324	477
Others (pineapple, passion fruit)	261	240	388
Forage crops	811	1763	1896
Others: seeds	66	201	2
Family gardens of farmers	54	45	86
Family gardens of non-farmers	3800	4100	2500
Agricultural surface used by farmers	50235	43692	42813
Agricultural surface used by the department	54035	47792	45313
Department's total surface	252000	252000	252000

Source: Adapted from DAAF (2013)²¹

Managed pastures are encountered in the highlands, at approximately 800-1500m altitude. Fertile soil types that can be very productive for agriculture are predominantly found in the low-lying plains, up to 400m altitude^{ccv}. These differences in elevation and geographical settings lead to a diversified production of typical tropical climate crops, such as mango, sugarcane, vanilla, as well as of temperate-zone crops, such as potatoes. The annual agricultural yields are highly variable as a result of the climatic conditions and erratic weather events such as heavy rains, cyclones; however, domestic production usually covers up to 70 per cent of the local needs in terms of fresh vegetables and tubers, roots and bulbs.

¹⁹ <http://agreste.agriculture.gouv.fr/en-region/reunion/>

²⁰ http://www.insee.fr/fr/themes/document.asp?reg_id=24&ref_id=18847

²¹ http://www.daf974.agriculture.gouv.fr/IMG/pdf/cultures_RA-1_cle84b958.pdf

Sugarcane production, estimated at roughly 1.8 million tons annually²², is followed by vegetables and fruits (such as citrus fruits, pineapple, litchee, mango, bananas), livestock (mostly poultry, pork), forage production and vanilla. Around 30,000 tonnes of fresh produce are imported (eg garlic, onion, carrots, potatoes, fruits from temperate regions) and roughly 1,500 tonnes to 2,000 tonnes are exported, mostly consisting of Victoria pineapple, litchee, mango and passion fruits. Sugar and rum produced for exports are primarily traded with the European continent (DAAF, 2013)²³. Bagasse, the fibrous residue from the sugarcane crushing process, is used as a feedstock at two thermal power stations, and also for generating approximately 10 per cent of the island's electricity²⁴. In 2007, while the value of the agricultural production was €95 million for sugar cane production, €115.8 million for fruits and vegetables and €105.3 million for animal farming, the agricultural sector's gross added value was €178 million contributing 2.4 per cent to Reunion Island's GDP²⁵.

The variety of landscape forms is also a suitable base for harvesting different green energy sources, such as biomass, geothermal, wind, marine-energy and solar. Reunion Island has an efficient and well-developed energy strategy to climate mitigation, with renewables already contributing to 40 per cent of the total energy production. In 2011, the largest share of renewable energy consisted of bagasse production, which climbed to 58.7 per cent, and was followed by hydro-power (20.8 per cent) and solar thermal and photovoltaic energy, which accounted together for 16.65 per cent^{ccvi}. An ambitious greenhouse gas emissions reduction programme was set up for 2030 to make the island a pilot case for a low carbon energy system. Owing to its natural resources, Reunion Island aims to gain a resilient energy infrastructure based on 100 per cent renewable energy supply by 2025-2030, as well as clean transportation, with 50 per cent electric vehicles in use by 2020²⁶. Building up more sustainable domestic energy supply systems, independent from fossil fuel imports, is expected to foster long-term energy security in Reunion Island and contribute to mitigating climate change and reducing pollution and negative environmental and health impacts.

3.2 Most relevant climate trends

3.2.1 Historical evidence

In the period 1969-2008, the average temperature on Reunion Island has increased by 0.62°C, reflecting the climate change pattern at a global level; although this figure is lower than average temperature rise in the Northern hemisphere (+0.81°C), it is higher than the one recorded in the Southern hemisphere over the same period (+0.43°C)^{ccvii}.

Over the same period, a study carried out by METEO-France (2009)^{ccviii} shows that maximum extreme temperatures in Reunion Island were more prevalent than the minimum temperatures. Also, temperatures increased during all seasons during both day time and night time, with the most significant rise taking place over the austral autumn, in the months of March, April, and May. The number of storms during the summer season

²² ONERC (2012)

²³ <http://daaf974.agriculture.gouv.fr/Vue-d-ensemble>

²⁴ <http://www.reunion.chambagri.fr/spip.php?rubrique56>

²⁵ <http://daaf974.agriculture.gouv.fr/Vue-d-ensemble>

²⁶ <http://www.theclimategroup.org/who-we-are/our-members/the-region-of-la-reunion>

(December-January-February) augmented, while in the autumn period (March-April-May) fewer storms occurred (see Table 16) ²⁷.

Table 16: Empirical evidence on climate change in Reunion Island in the 1969-2008 period

Most relevant climate change	Historical evidence for the 1969-2008 time period
Temperature	An increase in temperature with 0.62°C. The 2012 updated figure is +1 per cent, according to SRCAE (2012) ^{ccix} . More maximum temperatures than minimum temperatures.
Precipitations	Large spatial-temporal variability of precipitation regimes. Visible differences between rainfall patterns in the East and West of the island that mirror the orientation of landscape forms in relation to the trade winds. As such, the Western and South Western and Southern areas were characterised by reduced precipitations and increased droughts, whereas the closer to the East, the higher the average precipitation rate. The austral winter recognized a general reduction in rainfalls. No clear tendency was observed with respect to the frequency of extreme precipitations.
Storms	The number of storms increased in the summer season, and decreased in the autumn period.
Cyclones	In the period 1967 to 2009, an annual average of 9.3 tropical systems was formed in the South-Western basin of the Indian Ocean, of which 4.8 reached the tropical cyclones stage. The high inter-annual variation was deemed to be caused the role that the El Niño-Southern Oscillation (ENSO) ²⁸ plays in the genesis of cyclone patterns.
Sea level	Between 1993 and 2011, the sea water level increased with 5 to 9 mm/year.

Source: Source cited in the text and METEO-France (2009)

3.2.2 Projected climate trends

According to the ARPEGE-Climate model developed by METEO-France (2009)^{ccx}, for Reunion Island an increase in temperature ranging from 1.0 to 3.2° C is projected for 2014-2070. This is slightly different to the average global figure, estimated at 1.8 to 3.2° C. It is also projected that the austral summer will register highest seasonal warming, whereas during winter the raise in temperature will be more moderate. As the most significant warming is expected to take place during the hottest months of the year, the effects of climate change will become even more apparent. Changes in the precipitation regimes will vary across sub-regions of the island.

The three climatic regions of the island, including tropical (present at <300 m altitude), subtropical (<1,800 m) and temperate (>1,800 m), confer the island a great number of microclimates, thus making the risks of climate changes on Reunion's territory more diverse

²⁷ The storms are characteristic to the autumn and summer season, when the hot and humid air accumulates in the low atmosphere strata.

²⁸ El Niño-Southern Oscillation (ENSO) is known to affect tropical cyclones in different ways around the globe. ENSO alters the global atmospheric circulation affecting tropical cyclone frequencies by changes in the lower troposphere vorticity sources and the vertical wind shear (differences in wind between upper and lower levels) (Landsea 2000).

and difficult to ascertain^{ccxi}. Being located on the transition line of the North of the austral zone, Reunion Island will be exposed to more prolonged dry periods over the winter season. An increase in drought events is also indicated in the regions exposed to wind (mostly Eastern areas), where rainfalls will diminish during the austral winter and increase from September to November^{ccxii}. A large inter-annual variation of precipitations is expected in the proximity of the coastal line and in the basins exposed to risk of cyclones. A total decrease in the quantity of annual precipitations on the island is projected, along with a higher number of extreme rainy events. One common point in all scenarios is the reduction of rainfalls in the austral winter. Similarly, it is difficult to provide accurate predictions on marine swells patterns, but studies indicate that their frequency has increased particularly over the past decades^{ccxiii}. Table 17 presents a summary of the main future climate change predictions in Reunion Island.

Table 17: Climate Change projections in Reunion Island for 2014-2070

Most relevant climate change	Predictions for the 2014-2070 time period
Temperature	An increase in temperature between 1.5 and 2.8 ° C. (METEO-France, 2009) ^{ccxiv}
Precipitations	Precipitation expected to be reduced by between 6 and 8 per cent by the end of the 21 st century. A decrease in precipitation during the austral winter. The heavy rainfalls will be more frequent. Drought periods will extend especially in the areas exposed to wind.
Cyclones	Not clear; projections show a decrease in the number of cyclones in conjunction with an increase in their associated intense precipitations.
Sea level	Sea level is expected to continue rising at variable rates, at ± 2 mm/year, or 20-60 cm in a century (according to IPCC projections).
Trade winds (Alizées)	Stronger trade winds will affect the North-East and South-West shores.

Source: Bastone and La Torre (2011) and METEO-France (2009)

3.3 Consequences of climate change impacts on specific sectors

3.3.1 Biodiversity – land and marine based

Biological invasions are a component of global environmental change and human activity, and represent the primary cause of biodiversity degradation in islands, after loss of habitats^{ccxv}. Invasive species, act as agents of habitat alteration and degradation, posing a considerable threat to endemic and native species. The diffusion of alien species also interacts strongly with land use change and, as illustrated in Box 1, the results of human-caused biological invasions have long-term effects. While competing with endemic species on shared resources or natural enemies, biological invasions contribute to loss of native habitats and species, along with their provision of ecosystem functions and services such as climate regulation, coastal protection, erosion limitation, pollination.

Box 1: Endemic species interaction with alien invasive species

At present, biological invasions represent the largest cause of endemic species decline in the Reunion island after anthropogenic land cover change. Although there are no studies that quantify the economic impacts of this issue, it is clear that the health of the native entamofauna in Reunion Island continues to be under threat because of the imported exotic insects, plants and animals. There are approximately 2,200 alien species in Reunion island, of which 700 have become naturalised and around 150 are invasive^{ccxvi}.

Four invasive ant species, part the most dangerous ones, reached in the lowland habitants, which, according to a study performed by Blard (2006)^{ccxvii}, have proved to be resilient. Nonetheless, new predators or competitors such as the Invasive Bramble (*Rubus alceifolius*)²⁹ and *Bufo gutturalis* toad, as well as the guppy fish, have been spreading extremely rapidly to the detriment of native and endemic species.

The evolution and reproduction of many endemic plants is strongly linked to specific pollinator populations which recognize them as their host-plant. A relevant example is the sturdy link between Salamid nymphalid (*Salamis augustina*), a critically endangered endemic butterfly of Reunion, and its unique host-plant, the Nettle tree (*Obetia ficifolia*). This strong plant-pollinator relationship is threatened by the land use changes that occur in native plains, where the plant grows. In the Mauritius island, the *Salamis augustina vinsoni* species went extinct in 1957, following the earlier disappearance of the Nettle tree^{ccxviii}.

In Reunion Island, biological invasions further affect the Nettle tree through the presence of the alien giant land snail. This snail, also called *Achatina*, eats the young shoots of the tree. The giant bramble (*Rubus alceifolius*) is also a species that has taken on worrying proportions by spreading over the island at an accelerated pace^{ccxix}. More recently, the evolution of native species in Reunion Island's local ecosystems is threatened by the increasing land-based and air transportation, which raises the probability of introduction and spread of alien species^{ccxx}.

Source: Own compilation based on Rochat (2008) and Petit & Prudent (2010)

Climate warming will exacerbate the expansion of biological invasions, as temperature increases will most likely lead to the migration of some species towards higher altitudes. This will entail a reconfiguration of mountainous habitats, which will seriously affect the equilibrium of ecosystems and the health of native and indigenous species. Also, the increase in the frequency and intensity of extreme weather events such as heavy marine swells and prolonged droughts (leading to more forest fire incidents) will pave the way for exotic species invasion in disturbed habitats or habitats with a weakened resilience^{ccxxi}. Wildfires are already a major problem on Reunion Island during the dry season, with the most severe event recorded in 2011, when a total of 1,200 hectares of forests were completely destroyed^{ccxxii}. Climate change is deemed to favour the accelerated spread of opportunistic and alien species, but the degree of such influence is still not clear and, in this respect, a better understanding of the biological limits of the species populations would be necessary.

Changes in marine species phenologies driven by environmental and climate disturbances, such as rising sea level and accelerated coral bleaching, will cause serious chain effects on the coastal areas of Reunion Island. Towards the end of the 20th century, the nesting activity of green turtles on the island has substantially decreased, with only 6 nests being identified in 2007^{ccxxiii}. A recent study by Dalleau *et al* (2012)^{ccxxiv} revealed that timing of seasonal activities of green turtles (*Chelonia mydas*) in South Western Indian Ocean was strongly affected by climatic disorders including changes in ocean temperature, biogeochemical configuration and sea water level. Although the paper did not analyse specific data on Reunion Island, the research findings demonstrate more generally that temperature change is the most crucial environmental factor that impacts food availability for species, their nesting seasonality and its peak date, as well as their migration patterns at a regional level^{ccxxv}. A IUCN paper (2010)^{ccxxvi} supports these results, specifying that shifts in temperature for turtle eggs will directly affect their reproduction in Reunion Island.

²⁹ Baret (2002), Available at: http://tel.archives-ouvertes.fr/docs/00/64/64/71/PDF/02_16_Baret.pdf

The increase in sea temperature has impacted fishing resources and coral reefs, which had already been exposed to pressures of anthropic nature related to urbanisation in the coastal area, overfishing, discharge of untreated sewage waters^{ccxxvii}, and nutrient run-off from intensive agricultural activities³⁰. In the last three decades, the recovery rate of coral reefs in Reunion Island has followed a decreasing trend, dropping from 41 per cent to 27 per cent in 2003, which qualified them as a species at high or very high risk. Taking into considerations the future scenarios of raise in global average air and ocean temperature and acidification, the coral reefs are projected to face a critical risk of degradation by 2050^{ccxxviii}.

The economic damages produced by the bleaching of coral reef communities in 1998 were estimated between US\$ 608 million (€450 million) and US\$ 8,026 million (€5,922 million) for the entire Indian Ocean region^{ccxxix}. An earlier bleaching event took place in 1983, and was succeeded by recurring events in 2001³¹, 2003³², 2004³³ and 2005³⁴. IPCC estimated that a 2.8°C increase in tropical sea water will take effect until 2100, which entails that similar coral bleaching incidents could become apparent annually or every other year in 2030-2050^{ccxxx}. Depending on the duration and intensity of thermal stress, coral reefs can survive or die bleaching, but even the most resilient ones will suffer from reduced growth and reproduction rates and will become more prone to diseases. Some scientists argue that a high coral mortality rate at the global level will already be observed by 2050^{ccxxxi}.

Although the strip of coral reefs on Reunion Island is not extended, its degradation could be inductive to negative chain effects on marine ecosystems, including the proliferation of more robust but less diverse species (eg herbivorous fish), or even damaging micro-organisms such as toxic algae (eg *Gambierdiscus toxicus*) that cause food poisoning^{ccxxxii}.

3.3.2 Agriculture

The landscape of Reunion island is pierced through by rivers and streams that form an East-West longitudinal pattern, of which the biggest are Galets River (in Noth-West), Remparts River (in South) and Marsouins River (in the East). Large-scale water supply conveyance pipelines are used to transfer water from the Eastern areas to the Western, more water scarce parts of the islands, to serve for agricultural irrigation and other utility purposes. Nonetheless, access to and availability of reliable water sources in all the regions of the island remains a challenge, especially during the hot seasons, when protracted dry periods occur^{ccxxxiii}.

Landslides and erosion risks are high in some areas along the rivers, on escarpments and ravines, where the soil is sensitive to intense rainfalls and water exposure, conditions under which landslides occur. As illustrated in Figure 10 below, the regions most prone to natural disasters are situated on the Northern and North-Eastern Coast, where precipitations increased significantly over the last decades.

Figure 10: Map of landslides Reunion Island and their degree of risk

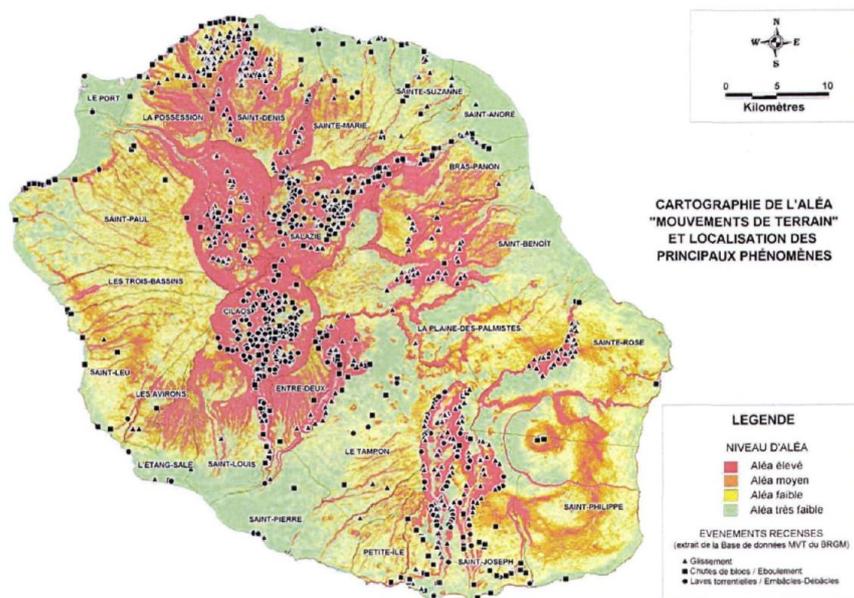
³⁰ Sedimentation and nutrient pollution from the land, as well as eutrophication have significantly affected coral reefs.

³¹ Turquet *et al* (2002)

³² Turquet *et al* (2003)

³³ Nicet and Turquet (2004)

³⁴ *Ibid.*



Source: Bastone and La Torre (2011)

In the rugged landscapes of ravines or river banks, healthy tropical forests are crucial in maintaining ecosystems regulating services such as the stability of soils and land cover, as well as preventing natural disasters^{CCXXXIV}. On Reunion Island, loss of soil from agricultural land on slopes was already signalled in 1993 by Perret, who estimated that around 20 t of soil matter per hectare and per year was washed away after heavy rainfalls. This phenomenon is even more accentuated on the Western coast of Reunion Island, where the use of tree fallows was abandoned to make space for agricultural cultivations, thus discouraging erosion control and macrofauna restoration^{CCXXXV}. Sub-regional climatic changes, including the greater rainfalls in the Northern and North Eastern coastal areas, further impaired fragile and unstable soils, impacting agricultural production. In the past 50 years, the increased number of droughts in the Western and South-Western coastal zones harmed crops and caused a decline in yields; however, although no studies were performed on the economic impacts of climatic changes on agricultural production, it is clear that the incomes of farmers continue to be unstable because of natural calamities.

Changes in annual temperature regimes and major raises in temperature on the coastal strips of Reunion Island will also alter certain insect prey-predator interactions and the dynamics of the insect population^{CCXXXVI}. This will result in less competitive capacity and lack of biological control under the form of natural enemies, which could make possible outbreaks of pests. As many weeds, pests and fungi thrive under higher temperatures, crop development will be disturbed and endemic species will be harmed. Heat waves on the Eastern areas of the island could both directly and indirectly threaten livestock such as cattle by escalating the likelihood of disease, declining their fertility rates and diminishing milk yields.

Saltwater intrusion was already observed in the low-lying plains of the Western Coast^{CCXXXVII}, and the forecasted increase in sea level will further accelerate this process in certain cultivated areas, potentially leading to the contamination of soil, landward groundwater and

drinking water sources. The overall reduced precipitations regime projected across the island will play a part in intensifying porewater salinities, with negative effects on crop yields, especially for species less tolerant to saline conditions.

Elevated water temperature is expected to affect the lifecycle for many fish and shellfish species and cause their reproduction and migration timing to shift. This will make them more susceptible to diseases, and poses a stress factor to the health of marine environments.

3.4 Implications for trade, security and migration

3.4.1 Trade

Domestic industrial production and agricultural yields are not sufficient to fulfil the needs of the population, and they are also often times more costly than imported commodities due to lack of economies of scale and a small market outlet. Thus, commodities exchange plays a significant role for Reunion Island, maritime trade accounting on its own for two thirds of imports. The largest trade partner of Reunion Island is Europe, which accounts for one third of its maritime traffic, but Africa and Asia also remain important contributors. India is the primary provider of rice, whereas Latin American countries exports vegetable oil and cereals to the island^{ccxxxviii}.

A highly productive business for both fishers and merchants is the trade of reef food fish, which had an economic value of \$810 million (€600 million) in 2002, and of ornamental species, which is valued between \$200 million (€148 million) to \$330 million (€244 million) per year globally. Although the exporting countries were traditionally from the South Eastern Asia block, the exports from the Indian Ocean and Pacific islands have increased significantly over time^{ccxxxix}.

Climate change will add up to the socio-economic factors that underpin agricultural trade, by determining food crop yield variations, price shifts and alteration of comparative advantage of products. The domestic vegetable and fruit production, which is currently estimated to cover more than 70% of the island's demand, is particularly vulnerable to parasites and diseases which are expected to increase also due to climate change^{ccxli}. The sugarcane cultivation, which occupies the largest portion of the total agricultural surface, is also a sensitive crop to climatic change impacts such as warmer temperatures and decreased precipitations. Under these conditions, sugarcane production is deemed to be particularly vulnerable, especially in the non-irrigated agricultural areas, and a reduction in yields would impact on domestic economy and trade, putting under risk the jobs of dozens of thousands of Reunionese employees^{ccxlii}; however, considerable steps have been made in the direction of enhancing the resilience of sugarcane production, such as cultivating sugarcane species that are more adapted to warmer and tougher climate conditions^{ccxliii}.

The effects of climate change on the entire agricultural production will result in a reduced contribution to the island's gross added value (currently around 2 per cent) and in turn require more imports of food produce (eg fresh fruit and vegetable) in order to respond to the needs of a growing population. At the same time, a lower agricultural production will result in substantially decreased rates of exports including exotic fruits and increased burden on foreign exchange earnings. Moreover, Reunion Island's dependence on imports

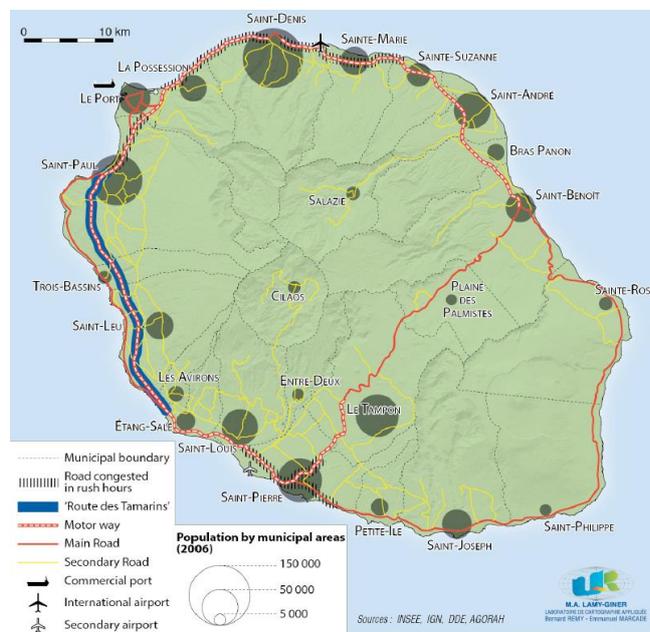
implies also that farmers of small agricultural holdings will be affected by the increase in prices of agricultural inputs such as fertilisers and pesticides on the global market.

Although the tourism industry does not rely heavily on the quality of beaches and the coral reefs, but rather on the natural landscapes of the Reunion National Park under UNESCO patrimony and of the two volcanic mountains, a degradation of the coastal areas and marine habitats will diminish substantially the volume of adventure and sub-aquatic sports tourism that is currently practiced off the Western Coast of the island. It will also affect fish stocks and reduce the cultural and aesthetic amenities of the islands. Moreover, the increased intensity of weather events associated to cyclones could damage the natural capital and its adjacent infrastructure, thus reducing the attractiveness of Reunion Island as a tourist destination.

3.4.2 Security

As many other islands, Reunion’s low-lying areas concentrate 82 per cent of the population and have a per capita density that is three to four times bigger as compared to the island average^{ccxliii}. This constitutes a major security risk in view of projected sea-rise and more frequent extreme weather events. Vital infrastructure (eg road, maritime, air transport as shown in Figure 11), installations and facilities that support local communities will be at severe risk. Furthermore, certain industry sites are located in the near-shore, and with the projected elevated intensity of weather extremes, a great threat in terms of industrial pollution is posed to the surrounding human settlements and marine environments^{ccxliv}. The capacity to respond to such climatic challenges is limited due to the island’s territorial confinement, as well as its restrained economic and technical resources^{ccxlv}.

Figure 11: Transport infrastructure in Reunion Island



Source: Lamy-Giner (2011)³⁵

³⁵ <http://shimajournal.org/issues/v5n2/h.%20Lamy-Giner%20v5n2%2086-105.pdf>

In addition, the risk of degradation of coral reefs means also that large urban settlement will be exempt from shoreline protection and will get directly exposed to heavy ocean swells, which will cause severe damages to beaches. As such, altering coral communities has further ramifications to human health and well-being, as well as the tourism, fishing and trade industry.

Although future climate scenarios on the evolution of cyclones on Reunion Island indicate roughly that their number will decrease, they also predict that the intensity of cyclone-associated phenomena will escalate, thus the risks posed on human and economic security would remain present. A series of cyclones with dramatic effects were recorded over the last decades on Reunion Island, such as the Hyacinthe cyclone in 1980, which resulted in the loss of 25 human lives. In the aftermath of the event, a total of 7,500 human displacements took place, and the damage costs reached €85 million, including settlements, roads and infrastructural networks. Nine years later, Firinga, a cyclone of a lower intensity, hit the island and caused the death of 4 people, entailing a damage bill of €25 million. The most recent cyclone, Dina, reported in 2002, destroyed 500 buildings and had an estimated cost of 95 million Euro damages in human installations, roads and infrastructural networks, as well as cultural amenities^{ccxlvii}.

Increased recurrence of extreme climatic events and associated natural disasters will affect physical security, as inundations and flooding could have a domino effect and destroy larger populated and agricultural areas. The projected reduced precipitations and prolonged drought periods, especially in the regions of the island exposed to wind, will pose a significant threat to water security and availability of fresh and irrigation water, increasing the competition between its different uses (eg human consumption, agriculture, tourism activities) and users. Via water, climate change will subsequently impact on the Reunionese society, its economy and ecosystems. The energy infrastructure will also be affected, and although certain types of energy such as marine and geothermal energy are fairly robust in the light of climate change, hydro and bio-energy production could be less secure due to their dependence on air temperature and water levels^{ccxlviii}. As of 2011, a great drop in hydro-energy production has already been recorded^{ccxlviii}. Bagasse, which represents 10% of total energy production on the island, is entirely reliant on sugarcane, whose growth and development could be impeded by higher temperatures and protracted droughts. Moreover, around 60 per cent of the power distribution network comprises of above ground transmission cables which are particularly vulnerable to weather extremes and heat waves^{ccxlix}.

More frequent extreme weather events caused climate change may pose serious concerns for food security and the ability to feed the nation's rapidly growing population. The projected decrease in annual rainfalls and prolonged drought periods are likely to result in reduced crop yields and livestock production. As a large portion of the available agricultural lands are located in the lowlands and coastal plains, sea level rise entailing land loss, soil erosion and salinisation will put a high pressure on mainland fertile land. Accentuated droughts will increase the already high risk of forest fires, whereas extreme weather events will disrupt the availability of food crops and compromise agricultural yields, entailing a heavier reliance on imports. Prolonged periods of water scarcity will deteriorate soil fertility and its cover, with direct effects on food security. The migration pattern and the depth of fish stocks distribution and availability of fish stocks will also be impacted by changes in

climatic conditions^{cc1}. Increased sea temperatures and the degradation of coral reefs create conducive conditions for the proliferation of toxic micro-algae and poses a threat for marine ecosystems as well as for human health.

Public health concerns rise with environmental degradation, as extreme weather events, such as heat waves, droughts, and strong storms, cause damages in terms of loss of human lives, health and economic growth. There are also vector-borne viruses such as malaria and dengue fever which proliferate when dramatic changes in temperature and precipitation patterns occur^{cc1i}. Warmer air temperatures could act as a vehicle for spreading tropical diseases, and an illustrative example in this case is the chikungunya crisis reported in Reunion between 2005 and 2006. The mosquito-borne infection touched 35% of the population and led to a dramatic drop in tourist numbers^{cc1ii}. The consequences of the fall in influx of visitors was however not confined to the local economy but affected also global tour operators and international aviation companies^{cc1iii}. A warmer climate increases the likelihood of proliferation of such epidemics. In 2004 the dengue disease infected 119 inhabitants^{cc1iv}.

3.4.3 Migration

During the 1900s, the variation in population was high due to the strong immigration movement, but this pattern has diminished substantially over time³⁶. Today, Reunion Island is the only French department Outre Mer (DOM) that registers a positive migratory rate. This amounts to 0.6 inhabitants for 10,000 existent inhabitants due to internal migration. In 2009, a number of 15,000 people immigrated in Reunion Island, representing 1.8 per cent of the total population of the island. Three thirds of the immigrants come from the South-West of the Indian Ocean, mostly from Madagascar, followed by Mauritius and Comores Islands (INSEE, 2009)³⁷. Almost one third of the emigrants are young people, with an age range between 18 and 24 years, whereas more than 60 per cent of the immigrants are situated within the age group of active persons, namely 25-59 years. This temporary migration of the young population is explained by their aspiration to seek for better educational and employment opportunities overseas (INSEE, 2009)³⁸.

In small islands, the damages of physical infrastructure and human installations caused by climate change pose a significant threat to human security and health. Additionally, environmental degradation and higher number of extreme weather events may temporarily drive human migration; however, there is little room for internal migration, as the innermost mountainous and rugged landscapes the island are inhabitable. The spread of vector-borne diseases and micro-algae in marine environments will jeopardise tourism opportunities and could potentially lead to increased economic and poverty-driven migration, especially for the categories that already experience high emigration rates (eg young and active people).

3.5 Conclusions

Reunion is a small island characterised by physical, economic and social fragility in the light of future climate changes. The island is a reservoir of delicate flora and fauna, unique for its

³⁶ <http://www.outre-mer.gouv.fr/?presentation-la-reunion.html>

³⁷ http://www.insee.fr/fr/themes/document.asp?reg_id=24&ref_id=19106#p0

³⁸ *Ibid.*

exceptional importance of biodiversity on the global scale. La Reunion's physical characteristics, such its topography and geological composition, as well as its fragile and discontinuous strip of coral reefs, make it particularly exposed to higher temperatures and raising sea levels. Reunion Island is already faced with damaging biological invasions that threaten the health of endemic species and balance of native ecosystems and species.

Reunion Island's agricultural sector has a confined territory of 21 per cent of the total territorial surface, with no possibilities for expansion, and has to cope with the pressure of urban and demographic growth, the price volatility of the global trade market and the threats of natural calamities and variable climate conditions. The elevated population density in the lowlands around the coasts increases the vulnerability of the island in the face of climatic changes. The projected increase in the erosion of shores, water scarcity, rising sea levels, and in the intensity of extreme weather could threaten the security of a significant number of inhabitants. The unfavourable weather events (eg forest fires, heat waves) could also reduce economic growth and affect energy production and consumption, the construction industry, tourism, forestry and agriculture, as well as unmanaged ecosystems.

4 THE NETHERLANDS ANTILLES

The Netherlands Antilles are representative for the Caribbean area as a whole in the challenges the archipelago faces in terms of diminished trade and tourism and other economic and social erosion due to increased weather extremes and a general change in temperature as well as sea level rise.

A large share of the islands' economies revolves around tourism. The islands, especially Aruba, Bonaire and Curacao, are considered biodiversity hotspots for their quite unique natural make-ups, especially their particularly vulnerable mangrove wetlands and coral reefs which host a variety of species. The tourism is expected to be hardly hit by climate change impacts also as a result of damages to the marine biodiversity the latter being an important motivation for tourists to travel to the Netherlands Antilles. Coral reefs showed dramatic decline rates in the last decades which is expected to even worsen as a result of climate change.

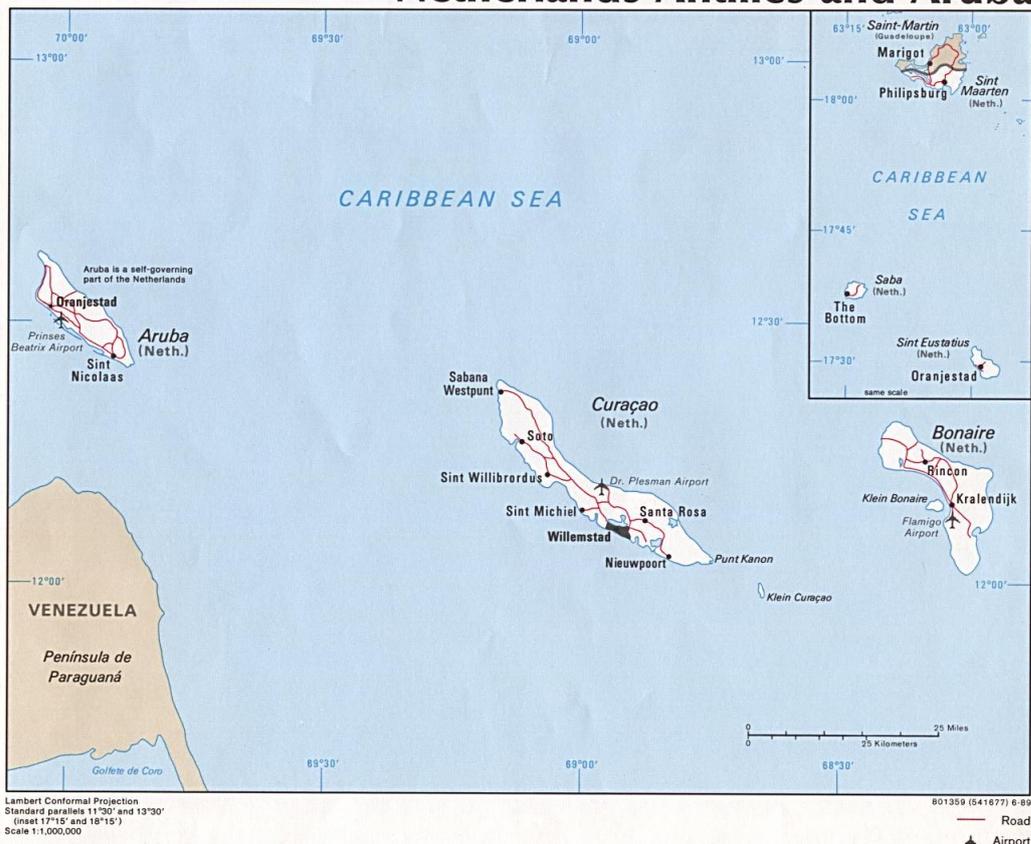
4.1 Key features of the Netherlands Antilles

The Netherlands Antilles are a group of islands consisting of two archipelagos in the Caribbean Sea: the ABC islands, which constitute of Aruba, Bonaire and Curacao and the SSS-islands of Saba, St. Maarten and St. Eustatius. While the islands no longer officially form one nation, all islands are still under differing forms of protection of the Netherlands, which colonized the now dissolved country in the 17th century.

The ABC-islands are also often signified as the leeward Netherlands Antilles for their location beneath the wind streams, close to Venezuela (see Figure 12). The SSS-islands are in the windward zone of the Caribbean, about 900 kilometres to the Northeast, east of Puerto Rico. Because of the relatively large distance between the two archipelagos, the ecosystems and circumstances of both are quite different. In this case study, we will cover both island groups separately, with a special emphasis on the ABC-islands, which are significantly larger and more populated as well as more unique in their ecosystem and general natural make up.

Figure 12: Map of the Netherlands Antilles and Aruba

Netherlands Antilles and Aruba



Source: Maps of the World.com, 2013³⁹

Aruba, Bonaire and Curacao are the largest and more populated islands of the Netherlands Antilles, the group further consists of the small, uninhabited islands of Little Curacao and Little Bonaire. Particularly Curacao is large, its capital Willemstad has a population of approximately 140,000, and is the most densely populated island in the former island state. Bonaire, instead, has the least inhabitants per square meter, at 46/km² of the Netherlands Antilles.

The ABC-islands are among the more affluent in the Caribbean region, with Curacao the 50th ranked nation in the world (the island was officially granted country-status in 2010, but still belongs to the Kingdom of the Netherlands). The economies of the islands are centred on tourism; particularly Aruba and Curacao draw many tourists (see Figure 13). The islands are particularly suited for litoral tourism, as well as diving and other forms of sea recreation. The development of seaports more accessible for cruise ships is expected to increase the importance of this sector. The Dutch Ministry of Public Health notes that tourists choose the islands of the Netherlands Antilles as a destination because of their natural attractions^{cciv}. This might be a crucial step towards turning the double-edged sword of tourism into a positive, which might aid the process of preservation.

The SSS-islands are significantly smaller than the ABC-islands and are more similar in nature to the typical northern rim Caribbean islands, green, mountainous and covered in forest.

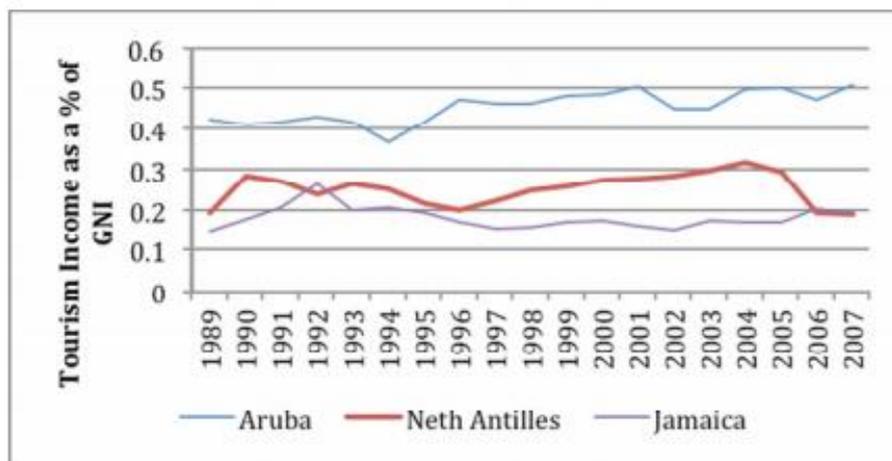
³⁹ <http://www.vidiani.com/?p=6149>

Where the ABC-islands are largely out of the trail of cyclones and hurricanes, the SSS-islands are regularly hit by these tropical storms, where, on average, hurricanes occur once every 4-5 years^{cclvi}.

The SSS-islands are small and have relatively few inhabitants, with the exception of Saint Maarten. The islands are focused on tourism as well, but due to their smaller size receive far fewer visitors. Saba, for example, is still quite undeveloped, and due to its natural and still mostly unspoiled beauty seen as a prime location for the development of ecotourism^{cclvii}. Around 25.000 tourists visit the island annually.

As illustrated in Figure 13, in the period 1989 to 2007, tourism income in the Netherlands Antilles had a substantial contribution to the domestic economy, amounting to 19-31 per cent of the gross national income^{cclviii}. Also, the petroleum industry is important; Curacao produces and refines oil of its own, and forms an important transit harbour for oil that enters the country from Venezuela. Offshore financial industry also plays an important role on the islands. The islands are not well suited for agriculture, as the soil is too arid and infertile –the sector only makes up 1 per cent of total GDP. The ABC-islands are therefore largely dependent on imports of food and water, mostly from the United States, the EU and Venezuela.

Figure 13: Tourism income as a percentage of Gross National Income (GNI) for selected Caribbean countries



Source: ECLAC pp. 1, 2010b

The islands are located in the tropical zone and have a semi-arid climate; temperature stays fairly constant over the year at an average hovering around 28 degrees Celsius. Precipitation on the ABC-islands is low, this in combination with constant winds on the islands, leave the islands with a rather atypically landscape of low growth bushes, dunes and large sand plains.

The marine environment hosts 13 km² of salt marshes and mangroves, which act as a protection barrier for the low-lying coastal areas against extreme weather events and erosion process. They also serve as a nursery habitat of exceptional biodiversity importance for pink flamingos and reef fish species, with more than 340 species of fish accommodated only in the National Marine Park of Bonaire^{cclix}.

4.2 Most relevant climate trends

4.2.1 Historical evidence

A 2007 UNFCCC paper on climate change vulnerability of Small Island Developing States (SIDS) shows that, since the late 1950s to 2000, the frequency of days and night with very warm temperature has been dramatically increasing. Also, in the Caribbean Sea, an unprecedented raise in sea water temperatures by 1.5°C was recorded over the last century^{cclx}. Despite the volatility in weather over the past decades, an overall trend of reduction in precipitation regimes and protracted dry periods has been experienced in the Caribbean region^{cclxi}. The ABC-islands are slightly different in nature; their southern, leeward position protects the islands from the brunt of tropical storm and has also left the islands relatively drier than the more northern Caribbean states. The SSS-islands follow the more typical trends.

4.2.2 Projected climate trends

According to most predictions, temperatures on the ABC-islands are expected to rise over the coming decades. In the Caribbean, the air temperature by 2080 is projected to raise with 2°C following a low scenario and 3.3°C following a high scenario^{cclxii}. It is expected that this rise in temperature will be accompanied by decreased rainfall in the -rainy season (-6.9 per cent for 2050 and -8.2 per cent for 2080), which will become shorter, and precipitation increase during the summer months, June-August (+5.9 per cent for 2050 and +8.2 per cent for 2080)^{cclxiii}. Overall, a larger number of intense precipitation events are expected in the Caribbean, conducting to more severe and frequent flash flood episodes^{cclxiv}.

The IPCC (2007)^{cclxv} concluded that, because of higher sea levels and storm surges, climate change will impact more heavily on the social and economic prospects of small island states. Roughly 70 per cent of the beaches in the entire Caribbean region are already exposed to high erosion rates amounting to 0.25 and 9 meters per year^{cclxvi}. As sea levels will rise with about 0.16 to 0.87 meters by 2100, coastal erosion or the engulfment of certain coastal areas into the sea will be further encouraged, heightening this particular risk for tourism (a climate-sensitive economic sector) on the Antilles^{cclxvii,cclxviii}. The dynamics of tropical storms and hurricanes over the following decades is difficult to ascertain, but their intensity will most likely increase^{cclxix}. The Meteorological Department of Curacao^{cclxx} carried out a study on more specific regional projections on expected climate change in Curacao. The results confirm an expected increase in air temperature, associated with warm spells and heat waves. Also, a raise in rainfall intensity is very likely, with an expected upsurge in extreme precipitation events.

Soil salination and the tainting of aquifers will result from this drier climate. However, since the islands rely so little on agricultural development, these problems will not have very profound effects on the livelihood of people or the economy as a whole.

4.3 Consequences of climate change impacts on specific sectors

Small islands are particularly vulnerable to the threats of climate change. The most important threats for the Netherlands Antilles are decreased precipitation in combination with more intense wet seasons, which could come accompanied with more frequent

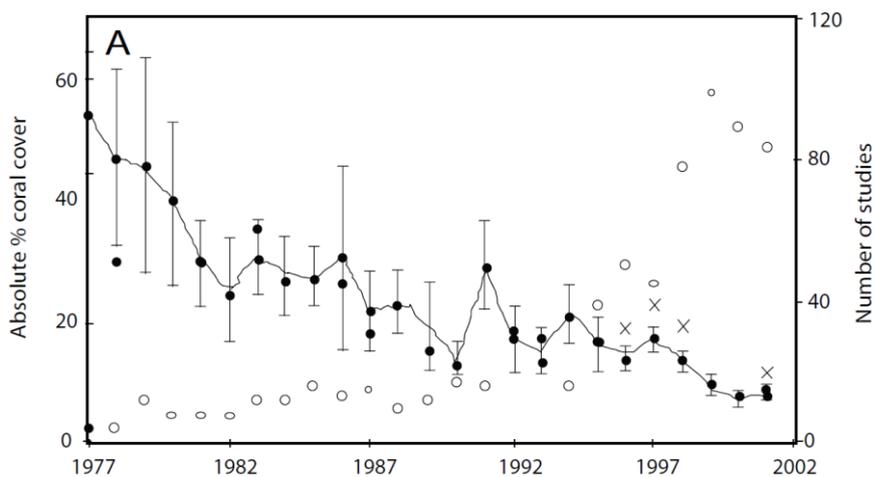
extreme weather events like hurricanes. The rich marine biodiversity is under severe risk as a result of ocean acidification and increasing water temperature.

4.3.1 Biodiversity

Ocean acidification will do much damage to the coral reefs of the islands. Hoegh-Guldberg *et al* (2007)^{cclxxi} examined the impact of rapid climate change and ocean acidification on coral reefs and found that temperature increases of 1-2°C for a period of two to four weeks can cause coral bleaching. Human-induced environmental degradation under the form of coastal development has long been affecting the mangroves in the Netherlands Antilles, whereas the sea grass has been exposed to pollution and discharges of untreated effluents (eg point source pollution in the proximity of the Curacao refinery). Moreover, two thirds of the 210 km² band of coral reefs is already under threat^{cclxxii}. All these fragile terrestrial and marine habitats will be even more exposed to risks of degradation in the light of climate change.

A study by Gardner *et al* (2003)^{cclxxiii} on reef communities in the Caribbean Basin reveals that that there have already been many instances of coral bleaching and that, in the period 1977 to 2002, almost 80 per cent of the living coral reef population were lost (see Figure 14).

Figure 14: Absolute percentage of coral cover between 1977 and 2001 in the Caribbean Basin



Source: UNEP (2008) based on Gardner *et al* (2003). Note: Absolute percentage reef coral cover represents the average difference between the estimated per cent live coral at the start and at the end of each study period. It was estimated that the high mortality rate and the overall decline of coral reefs population could cost the Caribbean region between US\$350m to US\$870m (€258m to €642m) per year by 2050 (CARSEA, 2006).

There is no doubt that coral reefs are a key resource for Caribbean nations. They provide protection along the coastline for many Caribbean countries and they represent a significant source of biodiversity for the region. They are also a very important tourism resource in the region^{cclxxiv}. In Curacao, the coral reefs have been valued at \$1.6 million (€1.2 million) per kilometre, revenue which they generate annually from the tourism industry, fishing activities and coastal protection alone^{cclxxv}.

In Curacao, between 1980 and 2010, the coral reef cover has declined by 42 per cent. Also, between 1975 and 2005, a decrease by 54.7 per cent in juvenile coral reefs was observed.

This alarming decline rate, observed only over three decades, poses serious risks for the population growth and the resilience of the reef ecosystems, as well as the health of the wider marine environments. Due to strong thermal stress caused by the warmer tropical Atlantic and Caribbean waters, severe mass bleaching events were recorded in 2005 and 2010 in the Southern Caribbean basin. As a result of the 2010 event, around 1 per cent of the living corals in Curacao were completely destroyed and 12 per cent of the deep-sea reef-building corals (30 per cent in certain areas) bleached^{cclxxvi}.

Increased sea-levels are also a direct threat to the islands' coastal ecosystems, in particular for Bonaire and Curacao, which are situated at low altitude. Wetlands and habitats accommodating the nesting sites for marine turtles (an already endangered species) are expected to be the most affected^{cclxxvii}. The potential loss of nesting area in Bonaire is estimated at between 23 and 52 per cent, depending on the level of sea level rise^{cclxxviii}. Also, biological invaders, such as the beetle palm, already threaten the fragile endemic and native terrestrial species, and this risk is expected to escalate in the light of climate disturbances^{cclxxix}.

The predicted raise in sea level and surface temperatures, ocean acidification and the resulting growth in poisonous organisms (eg turf algae^{cclxxx}) will also affect the health of corals and of a large number of fish species that are important for the local fishing industry. This was the case in 1983, when an epidemics decimated the Curacao's Long-spined urchins (*Diadema antillarum*), then spreading though the Caribbean basin, reducing the population down to 5 per cent of its original number^{cclxxxi}. This disease outbreak led to almost complete destruction of shallow coral reefs in certain marine environments, as there is a symbiotic relationship between sea urchins and coral reefs.

4.3.2 Tourism

Climate change having a negative impact on biodiversity will also affect other sectors, most notably tourism. Many visitors come to the Netherlands Antilles specifically for the diving and reef-watching experience^{cclxxxii}.

The costs of climate change in the Netherlands Antilles related to the tourism sector in the period 2020 to 2050 have been estimated to be as high as US\$4 billion (€3 billion) already in 2020 and increase to between US\$9.2 (€6.8) and 11.7 (€8.6) billion in 2050^{cclxxxiii}. The cost estimates take account of changes in temperature and precipitation but also extreme events (frequency and intensity), sea level rise and the destruction of ecosystems (particularly coral reef loss) due to ocean acidification. The cost of extreme weather events are assessed in terms of the potential damage to tourism industry. The cost of sea level rise is examined with respect to loss of beach and tourism infrastructure along the coast and combined with the costs of coral reef loss due to rising sea levels and ocean temperatures.⁴⁰ The cost estimates are summarised in Table 18.

Table 18: Costs of Climate Change to the tourism sector in the Netherlands Antilles (2008 US\$ millions and € millions in brackets)

⁴⁰ The latter is calculated on the assumption that tourists spend around 30 per cent of their total expenditure on sea related activities and that this expenditure will not occur anymore as a result of sea level rise, loss of beach and coastal tourism infrastructure as well as coral reef destruction (ECLAC, 2010b).

	2020		2030		2040		2050	
<i>Climate scenario*</i>	A2	B2	A2	B2	A2	B2	A2	B2
Costs for temperature and precipitation changes	9 (7)	8 (6)	15 (11)	16 (12)	19 (14)	22 (16)	22 (16)	27 (20)
Costs for extreme weather events	1,622 (1,197)	1,958 (1,445)	2,628 (1,939)	3,253 (2,400)	3,311 (2,443)	4,145 (3,058)	3,788 (2,795)	4,770 (3,519)
Costs of sea level rise and destruction of ecosystems	2,254 (1,663)	2,720 (2,007)	3,650 (2,693)	4,519 (3,334)	4,598 (3,392)	5,757 (4,248)	5,261 (3,882)	6,626 (4,889)
Total costs incurred	3,967 (2,927)	4,762 (3,513)	6,428 (4,743)	7,931 (5,851)	8,102 (5,978)	10,123 (7,469)	9,270 (6,839)	11,670 (8,610)

Source: Own compilation based on ECLAC, 2010b. Note: Total costs incurred are reported from the referenced report and do not reflect the sum of the individual costs reported in the table; *International Panel on Climate Change's A2 and B2 scenarios (see section 2 of the main report for further details)

These huge costs point to the relevance of adaptation measures that could reduce future costs as a result of climate change. A cost-benefit analysis for several adaptation options showed that incentives to retrofit tourism facilities to limit the impact of increased wind speeds, catastrophe insurance for those government buildings that are used by tourists, and flood drainage protection for hotels would generate net benefits. Although the implementation of these measures would be beneficial to the Netherlands Antilles, the upfront cost for these measures are considerable, ranging from US\$844,208 (€622,848) for retrofit measures to US\$7.4 million (€5.5 million) for catastrophe insurance and US\$8.8 million (€6.5 million) for flood drainage protection.

4.3.3 Infrastructure

As most infrastructure and residential construction is located close to the coast, rising sea levels, coastal erosion and greater incidence of extreme weather events will cause severe damage. Although Saba and Saint-Eustatius are considered to be less vulnerable to climate change due to their elevated topography, the impacts of coastal erosion and threats to harbour facilities from higher hurricane risks remain prevalent in these islands^{cclxxxiv}. Already significant damages were caused by hurricanes and an increase in their frequency or intensity will have a direct and visible impact on the infrastructure and the cultural heritage along the coastline.

Replacement costs for buildings and other infrastructure due to sea level rise in the Caribbean region were estimated to be between US\$960 million (€708 million) to US\$6.1 billion (€4.5 billion) on an annual basis.^{cclxxxv} The Netherlands Antilles has about 245 hotel/resorts/guest houses and most of these lie close to or very near to the coastline^{cclxxxvi}. The airport and the main roads lie also close to the coast, as well as the largest cities. A destructed coast line will discourage future tourists from visiting the islands, and may prevent potential investors. Table 19 below illustrates the predicted value of the land loss in the Netherlands Antilles due to rising sea levels:

Table 19: Predicted value of land loss in the Netherlands Antilles due to sea level rise

<i>Country</i>	<i>A2 Scenario</i>	<i>B2 Scenario</i>
Curaçao		
Total Land Area (km ²)	444	444
Land Loss (km ²)	8.8	4.4
Value of Land Loss (US\$ million)	616	308
Bonaire		
Total Land Area (km ²)	294	294
Land Loss (km ²)	5.8	2.9
Value of Land Loss (US\$ million)	406	203
St. Maarten		
Total Land Area (km ²)	34	34
Land Loss (km ²)	0.68	0.34
Value of Land Loss (US\$ million)	47.6	23.8
St. Eustatius		
Total Land Area (km ²)	21	21
Land Loss (km ²)	0.42	0.21
Value of Land Loss (US\$ million)	29.4	14.7
Saba		
Total Land Area (km ²)	13	13
Land Loss (km ²)	0.26	0.13
Value of Land Loss (US\$ million)	18.2	9.1

Source: ECLAC pp. 15, 2010b

Damage to construction also hurts transport lines. The Netherlands Antilles are already heavily reliant on imports of basic commodities like water and nearly all other consumption goods^{cclxxxvii}. Disruptions in this process could lead to demand shocks in the short run, and even higher prices and dependency in the medium to long run.

Hurricane events are often associated with coastal flooding, which impacts on capital investment assets and infrastructural facilities. The estimated damage and losses incurred by hurricanes in the SSS-islands over the period 1950 to 2008 are considerable and summarised in Table 20. These unfavourable weather events that result in major economic losses, extensive destruction of property and livelihoods, as well as ecosystems, have put the SSS-islands region's natural and capital resources, as well as socio-economic systems at great risk.

Table 20: The economic impacts of the most important hurricanes in the SSS-islands (1950-2008)

Hurricane(Year)	Damage bill	Damages
Dog (1950)	US\$ 70.000 (€52.000) ⁴¹	Major damage to infrastructure, loss of internal communication for several days
Hugo (1989)	US\$ 10 million (€7.4 million)	Extensive environmental and physical damages, the islands of St. Eustatius and Saba remained nearly bare of all vegetation. Considerable material damage, including buildings, energy networks and infrastructure, harbour facilities.
Luis (1995)	US\$1 billion(€0.74 billion) (direct	Devastated 90 per cent of all construction, transport and communication networks were disrupted, major damage was caused to the coast and coastal installations

⁴¹ The 1 October 2013 currency exchange rate was used (US\$1.3554/€), Source: European Central Bank, <http://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-usd.en.htm>.

	and indirect costs)	
Georges (1998)	US\$70 - 80 million (€52 - 59 million)	Buildings, energy and communication infrastructure were severely damaged.
José (1999)	7.5 - 8.5 million US\$ (€5.5 - 6.3 million)	The hurricane was associated with a heavy rainfall, which triggered a severe flooding in the low-lying areas of the island and caused extensive material damage.
Lenny (1999)	n.a.	Hurricane associated with mud slides and severe flooding, as well as swells that caused severe beach erosion and coastal damage to port facilities.
Omar (2008)	n.a.	Severe coastal flooding devastated coastal facilities, buildings and infrastructure. The storm surge hit strongly Saint Nevis largest tourism resort, hurting the island's economy and employment rate ⁴² .

Source: Own compilation based mainly on MDNA&A (2010)^{cclxxxviii} and source cited in the text

The water supply infrastructure will be affected by climate change to a a higher degree in Saint Kitts and Nevis and to a lesser extent in Curacao. Presently, in Curacao, the production of water is dependent on the desalination and reverse osmosis technological processes, both of which are cost and energy intensive^{ccclxxxix}. Nonetheless, the projected increase in sea water level will lead to saline intrusion in aquifers, the water table and across water bodies, and this phenomenon has already been observed in Saint Kitts and Nevis island. This puts under threat the habitats with evergreen vegetation, such as those in Southern area of Bonaire island^{ccxc,ccxci}. Reduced groundwater recharge capacity during the summer period will further accentuate droughts and severe water stress, which is projected in Saint Kitts and Nevis. The island is already classified as a 'water-scarce' territory, as available water supply for the population represents roughly 621 m³ per capita, a value lower than the international limit of 1,000 m³ per capita^{ccxcii}. In this respect, water supply will become a bottleneck for economic activities and a serious concern for health, and the disrupted distribution of water could lead to the proliferation of water-borne diseases, such as schistosomiasis, cryptosporidium and cholera^{ccxciii,ccxciv}.

Willemstad, the vibrant port and capital city of the Netherlands Antilles, is a UNESCO heritage site and constitutes a major tourist attraction for visitors. Although Curacao is situated outside the hurricane belt, certain areas of its coastline lie at less than 1 m above the sea level, which expose it to strong storms, swells and sea level rise^{ccxcv}. As 40 per cent of the workforce and economic activity in the city is concentrated on the shoreline, human displacement in the case of coastal damages would have direct impact the city's aesthetical resources, economy and the service and tourism sector, as well as on transport, energy and communication systems^{ccxcvi}.

⁴² <http://www.imf.org/external/pubs/ft/scr/2009/cr09180.pdf>

4.4 Implications for trade, security and migration

4.4.1 Trade

As mentioned before, the Netherlands Antilles are a service economy: they rely on imports of goods and on inflow of tourists to bring capital to the country. Damages to the transport system will hurt the flow of these imports, likely causing prices to rise domestically. The ABC-islands' position as transit harbour and oil refinery will suffer from damage to infrastructure and investor confidence. The review of available data has shown that damage to the tourism industry, a key economic sector for the Netherlands Antilles, will most likely be significant. The potential decrease in tourists visiting the Netherlands Antilles will have an important impact on the islands' trade balance.

4.4.2 Security

The Netherlands Antilles are already dependent on food and water imports, only a single digit share of total food consumed on the islands is produced domestically. A key threat to food security is disruptions in the transport system that may hinder imports at certain times. A change in precipitation levels and temperature patterns will affect the availability of the already scarce water resources especially in the low-lying areas islands, ultimately leading to lower freshwater supply. Combined with saline intrusion and reduced groundwater recharge capacity during the summer period droughts and severe water stress are likely to become more frequent and put water security at risk. This would have important consequences for the local economy and constitute a serious concern for health and lead to the proliferation of water-borne diseases.

As for energy security, the Netherlands Antilles are also not energy independent. While Curacao used to produce oil, focus has shifted, and most energy is imported. A switch to renewable energy sources, such as solar and wind energy (to effectively utilize the strong winds on the islands) could therefore increase energy security. On the plain of Hato, an uninhabited desert-like nature reserve on the north-side of Curacao, a wind-energy park is already in place and functioning. The country has been utilising wind energy for electricity generation since 1993^{ccxcvii}. An increase in air temperature, would lead to the energy (eg air conditioning systems), which would entail more energy consumption.

Sea level rise constitutes a major threat for the entire infrastructure located near to the coast.

4.4.3 Migration

The special relationship between the Netherlands and Netherlands Antilles still allows for a free exchange between the islanders and Dutch citizens to move overseas. There are currently around a 100,000 immigrants of Antilles origin in the Netherlands - the majority of which are originally from Curacao^{ccxcviii}. Because of the ease of migration and the absence of a language barrier, many of these migrants tend to move back and forth. Due to extreme weather events (eg earthquakes, hurricanes) and loss of agricultural land, an influx of environmental refugees from neighbouring regions such as Haiti has been observed, most of which have already settled as part of the Curacao's population^{ccxcix}.

With the effects of climate change, it is expected that this immigration will become more frequent. With the economy dwindling, and particularly the tourism industry being negatively affected, many islanders can be expected to seek new opportunities in the Netherlands or elsewhere. There is no data available to quantify these predictions. The decision to immigrate is a difficult one, dependent on a lot of variables. Deteriorating living and economic circumstances due to climate change (such as greater frequency of coastal flooding associated with the occurrence of hurricanes on the SSS-islands, increased regularity of damages to sanitation, transport, energy and communication networks) will indubitably increase the likelihood of people leaving the islands.

4.5 Conclusions

Because of the islands' reliance on tourism and the service industry in general, damage to the land will have less direct effects than in many other islands that are more reliant on agriculture. However, tourism in the Netherlands Antilles is centred around biodiversity and natural attractions, damage to the former will thus consequently also hurt these important industries.

Based on the data available it can be concluded that there are significant risks and economic losses that will affect the Netherlands Antilles as a result of climate change impacts. Losses are mainly related to damage to the tourism industry, a key pillar of the local economy, as well as damage to infrastructure located close to the sea.

5 FRENCH POLYNESIA AND NEW CALEDONIA

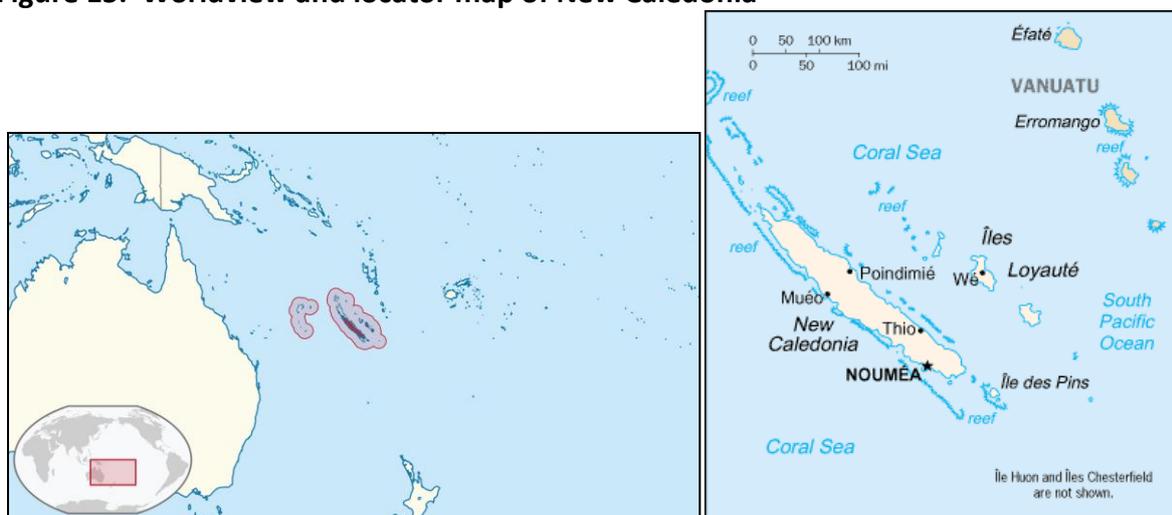
New Caledonia's main vulnerabilities to climate change lie in the areas of the constant increase of pressures on its water resources and the unique character of its biodiversity and its coral reef. Other risks include the bush fires and dengue fever epidemics. The foremost impact of climate change on the marine environment is without doubt the degradation of the coral reefs as a result of successive bleaching events and particularly intense tropical cyclones. Additionally, tourism, which is a vital component of New Caledonia's economy, might be adversely affected by the degradation of the coral reefs as a result from rising temperatures and acidification of oceans.

French Polynesia is one of the territories most at risk from rising sea levels. A large number of islands are at very low altitude and therefore particularly vulnerable to rising waters. The limited size of most islands that are part of the different archipelagos that form French Polynesia as well as the overall lack of territorial continuity prevent populations and plant and animal species to migrate inland in case of sea level rise, in particular in the atolls that are only a few meters above sea level. The well-preserved, endemic species-rich subalpine ecosystems are the terrestrial habitats most at risk from variations in temperature and rainfall patterns. The economy of French Polynesia heavily depends on natural resources through sectors like tourism, the production of pearls, fisheries and agriculture – all sectors that depend on resources that are directly at threat from climate change. Whilst it is clear that French Polynesia is particularly vulnerable, there is only a limited amount of data on the potential impacts of climate change on French Polynesia.

5.1 Key features of French Polynesia and New Caledonia

New Caledonia is an overseas collectivity of France, located in the South Pacific Ocean (see Figure 15). It consists of a main island (one of the largest in the Pacific Ocean), the archipelago of Iles Loyaute, and numerous small, sparsely populated islands and atolls. New Caledonia has a land area of 18,576 square kilometres. The population (Jan. 2012 estimate) is 256,000^{CCC}. The capital of the territory is Nouméa.

Figure 15: Worldview and locator map of New Caledonia



Source: CIA World Factbook (2013)

New Caledonia has a hot and humid tropical climate, which is modified by southeast trade winds. New Caledonia experiences cyclones, most frequently from November to March, which could potentially be exacerbated by the impacts of climate change^{ccc1}. Mean temperature is approximately 23 degrees Celsius^{ccc2}. Rainfall in New Caledonia varies from 2000 mm in the east to 1000 mm in the west per year^{ccc3}. The terrain consists of coastal plains with interior mountains^{ccc4}. The east coast of New Caledonia, which is exposed to prevailing winds, is characterized by tropical humid landscapes. The dense humid rainforest covers 21 per cent of the territory and still occupies a single block of thousands of hectares. Conversely, the west coast, which is sheltered from the wind by a central mountain chain, was once covered by dry forest. Today, the landscape is covered by herbaceous vegetation and savannahs - only 1 per cent of the original surface area of dry forest remains on the west of the island. This is because New Caledonia experienced massive deforestation during the 19th century, due to wood production, agriculture, livestock rearing and poorly managed bush fires^{ccc5}. The islands have experienced erosion caused by mining exploitation and forest fires^{ccc6}.

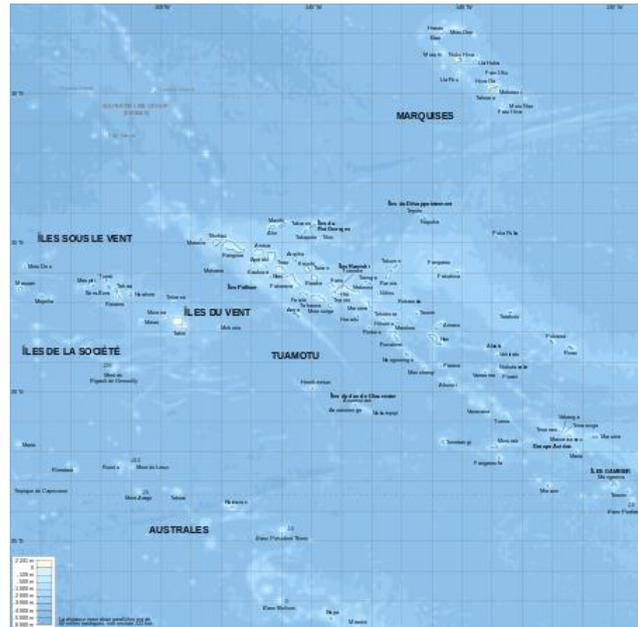
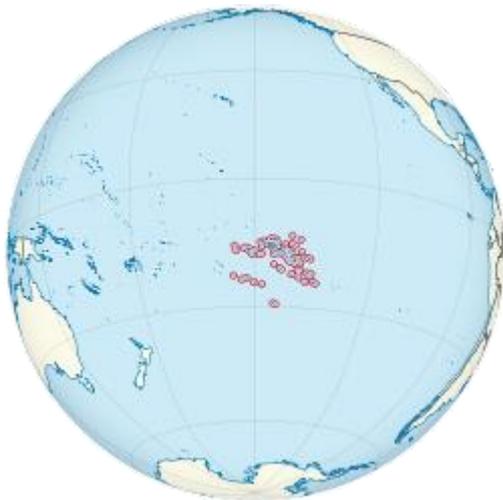
Only a small amount of land is suitable for cultivation, and food accounts for about 20 per cent of imports. Agriculture and livestock are poorly developed and have declined steadily over the last few years, contributing 1 per cent to the added value in 2011^{ccc7}. However, subsistence agriculture and fishing for personal consumption still occupy an important place in the Caledonian economy^{ccc8}.

New Caledonia is home to an extremely rich terrestrial and marine biodiversity. It has one of the highest observed rates of endemism in the world for terrestrial flora. The territory is a global biodiversity hotspot^{ccc9}. It is the smallest single biodiversity hotspot in the world. New Caledonia displays remarkable plant diversity. There are 3,261 species of indigenous flora (74 per cent of which are strictly endemic), almost as many as on the whole of continental Europe (3,500 species). New Caledonia is also host to 106 species of endemic reptile, including the world's largest gecko (*Rhacodactylus leachianus*), as well as six species of endemic bat and 4,500 species of invertebrates, of which 90 per cent are endemic. The bird life of New Caledonia includes 23 species of endemic birds, among them the Kagu (*Rhynochetos jubatus*), an iconic crested bird and the last remaining survivor of the species family, and the Giant imperial pigeon (*Ducla goliath*), the largest arboreal pigeon in the world^{ccc10}.

French Polynesia is a French overseas territory in the South Pacific (see Figure 16). It consists of 119 islands spread over a maritime area of 2.5 million km² (an area the size of continental Europe). The territory is made up of five archipelagos. The island groups are:

- Marquesas Islands
- Society Islands
- Tuamotu Archipelago
- Gambier Islands, often considered part of the Tuamotu Archipelago
- Austral Islands
- Bass Islands, often considered part of the Austral Islands

Figure 16: Worldview and locator map of French Polynesia



Source: Claudel (2008) Topographic map with French names of French Polynesia

It has 34 volcanic islands and 84 atolls. With a population of 270,000 (2010) (ISPF, 2011) spread over an area of 3,660 km² of emerged lands, French Polynesia's population density is relatively low (73.8 inhabitants/km²), and very unequal depending on the islands. Tahiti has approximately 178,000 inhabitants, of whom 132,000 are in the capital Papeete^{cccxix}.

Fishing and coprah cultivation (dried coconut pulp) are the two principal traditional economic activities of French Polynesia. In 2001, the territory exported 2,400 tonnes of fish and 25,000 tonnes of coprah⁴³. Recently, pearl farming has begun to occupy an important place on the territory's commercial balance sheet, and is now the primary export. Tourism is also an important industry; today, with some 210,000 visitors a year, it accounts for 20 to 25 per cent of the territory's GDP.

Because of their isolation, the Polynesian islands have a rather low biological diversity as regards the number of species for a tropical region, but are also extremely rich in terms of terrestrial endemism^{cccxii}. The species that have reached those islands have evolved over several thousands of years in isolation to adapt through specialisation to the unoccupied ecological niches. The islands of French Polynesia are part of the "Polynesia-Micronesia" biodiversity hotspot that includes Polynesia, Micronesia and Fiji^{cccxiii}. These islands include inter alia 880 species of indigenous vascular plants of which 68 per cent are endemic, 31 species of terrestrial birds (of which 22 are endemic), over 320 species of snails and slugs which are all endemic, and a fauna of remarkable arthropods (insects, arachnids and crustaceans) that are often endemic^{cccxiv}.

Amongst the different types of natural plant formations of the high island of French Polynesia, the altitude rainforests (or cloud forests) are the richest in endemic plant and animal species and are relatively well preserved. The coral islands, on the other hand, have poorer terrestrial ecosystems due to their limestone soil, of the strong sunshine and the

⁴³ http://archive.iwlearn.net/www.sprep.org/att/IRC/eCOPIES/Countries/French_Polynesia/40.pdf

high salinity of their air to which they are exposed. While they have less than a hundred indigenous species, the marine birdlife of those islands is very varied.

French Polynesia has one of the largest variety of formations of coral reefs in the world. The 12,800 km² of reefs of the country have 176 coral species, 1024 fish species and 1160 mollusc species^{cccxv}. Five of the seven existing sea turtle species are present in French Polynesia, including the Green sea turtle, which lays its eggs on a large number of islands and atolls of the country. Marine biodiversity is threatened in some areas by overfishing, hypersedimentation of terrestrial material due to erosion of water basins, the pollution through wastewater or embankments on reefs and dredging^{cccxvi}.

French Polynesia's terrestrial biodiversity is confronted with a large number of invasive plant and animal species that threaten the endemic species. For example, the small tree *Miconia calvescens* today covers over 70,000 hectares in Tahiti, which amounts to about two thirds of the island. In French Polynesia, there are about two times more introduced vascular plants (1,700 species) than indigenous species (893 species)^{cccxvii}.

5.2 Most relevant climate trends

5.2.1 Historical evidence

The climate in **New Caledonia** has become warmer within the last forty years. It has been estimated that within the last 40 years the minimal temperatures have increased by 1.2°C and that the maximal temperatures have increased by +0,9°C^{cccxviii}. In Noumea temperature increased by 1.3 °C over the period 1970-2009^{cccxi}. No other major climate change impacts have been observed for New Caledonia in the past.

The historical evidence on climate change impacts for **French Polynesia** are summarised in Table 21.

Table 21: Historical evidence of climate change impacts on French Polynesia

Most relevant climate change	
Air temperature	In French Polynesia, in Tahiti Faaa, the observed heating was of 0.39C higher each decade, which is equivalent to about 1.05C over this period (1976-2003) ^{cccxx} . The general trend has been a decrease in cool days and nights and an increase in the number of hot night and days in all archipelagos ^{cccxxi} .
Changes in rainfall/precipitations	Since the mid of the 1970s annual rainfall has increased by 50 to 100 per cent depending on the measurement posts in the Marqueses islands. This change in the rainfall regime goes in the same direction as the changes predicted by the IPCC (2007) ^{cccxxii} projections. A significant increase in average rainfall was also observed in Moruroa (in the Tuamotu) and in Pueu (Tahiti) since the 1970s ^{cccxxiii} . In other areas of French Polynesia no significant variation of rainfall has been observed.

Intensification of cyclones	From 1878 to 1969, 29 cyclones and strong tropical depressions (STD) have been recorded, while 44 cyclones and STD have been observed between 1969 and 2007. ⁴⁴
Sea level rise	In French Polynesia an increase of about 7.5 cm has been observed in Tahiti between 1975 and 2005. The observed increase which was relatively steady, was of about 0.25 cm a year over that period. ⁴⁵

Source: Sources cited in the text.

5.2.2 Projections

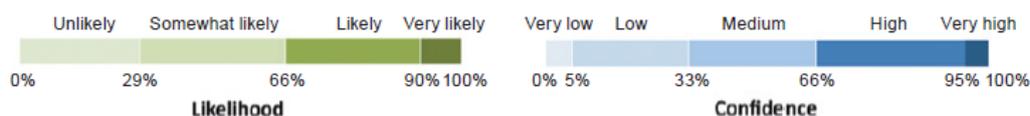
5.2.3 Impacts of climate in the pacific region

According to a study performed by the Secretariat of the Pacific Community (2011), the regime of precipitations in New Caledonia by 2035 is projected to change and to reduce overall, and diminish over the winter period, while increasing in the summer season (see Table 22 **Error! Reference source not found.**). Over the same period of time, a raise in sea surface temperature (SST) water level is also expected along with elevated ocean acidification levels^{cccxxiv}.

Table 22: Main climate projections in New Caledonia for the 2035 and 2100 time frame

Climate feature ^a	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	23.5 (Noumea)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1066 (Noumea)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	2.3	<ul style="list-style-type: none"> ➤ Total number of tropical cyclones may decrease ➤ Cyclones are likely to be more intense 			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the southern subtropical Pacific, see www.cawcr.gov.au/projects/PCCSP.



Source: SPC (2011)

Table 23: Most relevant projected climate change impacts on New Caledonia

Most relevant climate change	Projections for the 2014–2070 time period
Air temperature	The minimal and maximal temperatures could increase between +1,4 °C and +2,7 °C depending on the different scenarios regarding global greenhouse gas

⁴⁴ It is however difficult to say for sure whether this represents an increase in frequency as the first exploitable satellite images date from 1969 – the data from before that date come from historical records and the accounts of sailors.

⁴⁵ As far as the Southern Pacific is concerned, observations of the rise of the sea level have been very variable depending on the sub-region and the year. This variability is mostly due to changes in ocean circulation associated with the ENSO phenomenon.

	emissions ^{cccxxv} .
Changes in rainfall/precipitations	The regime of precipitations in New Caledonia by 2035 is projected to change and to reduce overall, and diminish over the winter period, while increasing in the summer season ^{cccxxvi} . By 2080, the reduction in precipitations is likely to lie in the range of -5 to -8 per cent ^{cccxxvii} . The frequency of extreme rains as well as droughts and bush fires are likely to increase.
Intensification of cyclones	While the occurrence of cyclones will not necessarily increase these are likely to intensify ^{cccxxviii} .
Sea level rise	In the region of the Southern Pacific, the increase in the sea level by the end of the century is in the same range than the global average (0.35 meters) (Church, 2006). However, as seen for the observations, variations between sub-regions are important and the level of uncertainty is still high.

Source: Sources cited in the text.

Table 24: Most relevant climate change impacts in French Polynesia

Most relevant climate change	Projections for the 2014-2070 time period
Air temperature	In the South Pacific, IPCC projects an average increase in surface temperatures of 1.8C by 2100 (+1.4C to +3.1C). This increase is slightly less important than the global projected rise (of +2.8C) and is relatively uniform across seasons. ⁴⁶ Most of the models project a slightly higher temperature increase in the area of the equatorial pacific, north of the Marqueses (+2.5C), and lower South of the Austral Islands (+1.5C) ^{cccxxix,cccxxx,cccxxxi} .
Changes in rainfall/precipitations	A slight increase in rainfall is projected by the IPCC in the Southern Pacific area by 2100, with an increase an annual averages of 3% [+3 to +6] for the whole area. But regional and seasonal variation might be important. The projected increase is usually stronger in equatorial pacific in the North (+10% to +30%) and weaker, if not negative, in the South (from 0% to -30%) ^{cccxxxii} . There are no specific rainfall projections for the different archipelagos of French Polynesia but a zoom into the global projections until 2100 suggests increases in the range of 5-15% for most islands, with the exception to those at the East of Tuamotu, where an important fall of rainfall in the range of -5 to -50% is projected in the humid season. Thus, IPCC's projections for French Polynesia are overall quite variable depending on the archipelago and the season. In addition, these changes are very influenced by the Pacific Decadal Oscillation (PDO) ⁴⁷ and the El Niño Southern Oscillation (ENSO) phenomenon.
Intensification of cyclones	Building on all its models, the IPCC projects an intensification of cyclones in all tropical regions, with stronger maximum winds and more abundant punctual rainfall ^{cccxxxiii} .
Sea level rise	IPCC foresees an increase in the sea level of about 35 cm [+23 to +47cm] on average by the end of the century ^{cccxxxiv} . This does however not include the thermic expansion of the oceans nor the melting of the ice caps.

Source: Sources cited in the text.

Acidification of oceans

⁴⁶ The geographical area for which these projections have been done is very vast (ranges from Mexico to New Zealand) and the interregional variations are certainly important.

⁴⁷ The PDO is a pattern of change in the Pacific Ocean's climate (see climate change). The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N. During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs. It shifts phases on at least inter-decadal time scale, usually about 20 to 30 years.

The increase in the concentration of carbon produced by human activities since 1750 has led to a general acidification of oceans. An average global decrease of the pH by 0.1 unit has been measured. Simulations of IPCC project an additional reduction of pH in the surface of the world's oceans in the range of 0.14 and 0.35 on average by the end of the century^{cccxxxv}. No more detailed projections for the South Pacific, French Polynesia or New Caledonia exist.

5.3 Consequences of climate change impacts on Biodiversity

The assessment of consequences of climate change impacts in New Caledonia and French Polynesia focuses on biodiversity as this is the area where the impacts will be most significant and damaging for the region, with strong ramifications for Europe and the rest of the world. We will discuss first the impacts on marine biodiversity, mainly coral bleaching, and then the impacts on terrestrial biodiversity, in particular invasive species. Economic and social implications of these biodiversity impacts on are also highlighted whenever these are important.

5.3.1 Marine biodiversity

In **New Caledonia**, the foremost impact on the marine environment is without doubt the degradation of the coral reefs as a result of successive bleaching events. Between January and March 1996, following unusually warm water temperatures, the corals of New Caledonia suffered a bleaching episode. Around Nouméa, the rate of coral mortality was as high as 80 per cent, reaching as high as 90 per cent on some shallow reefs^{cccxxxvi}. However, the affected areas were very limited in size. The coral reefs were also damaged by the tropical storms which battered the territory.

The hurricane Erica in 2003 had a significant impact on the reef formations and the fish populations in the park. The fragile coral formations diminished significantly, resulting in a loss of habitat for the fish populations. The wealth of commercially-exploited fish and butterfly fish was seriously affected. Twenty months after the hurricane, the reefs had not regenerated; the broken corals had turned into debris and were being colonized by algae. The medium-term impacts of the hurricane turned out to be even more damaging than the short-term impacts. Twenty months after the storm, the richness and density of the fish were even lower than before the storm, and lower still than those recorded a few days after the storm. Furthermore, a different species composition was observed in the medium term. Herbivorous fish, associated with debris and benthic species that feed on micro-invertebrates, had replaced the fish usually associated with corals. The corals of New Caledonia are not adapted to tropical storms of such intensity; the immediate impacts of these events on the reefs are very serious and profoundly degrade the reefs in the short and medium term. Intensification of tropical storms in the region, as predicted by the IPCC, could irreversibly modify the coral formations and the species' composition of New Caledonia.^{cccxxxvii}

Another study has demonstrated that a warmer and more humid climate, with an increase in levels of precipitation and runoff, could affect the size of the reef fish^{cccxxxviii}. Indeed, the leaching of soil nutrients as they are carried towards the lagoon increases the turbidity of the water, thereby reducing the amount of light entering the water and changing the habitat structure and food resources of the reef fish^{cccxxxix}.

At the same time, a rise in sea levels threatens the beaches and coastal ecosystems of **New Caledonia**. Estuaries and low-lying islands are likely to be particularly affected, especially during tropical storms. The Island of Ouvéa seems to be the most threatened, along with some coastal plains and mangrove-lined estuaries on the west coast. The degradation of the beaches could also perturb the turtle populations that depend upon these habitats for their reproduction^{cccxi}.

French Polynesia has experienced seven coral bleaching episodes in the last 20 years. In 1991, a bleaching episode resulted in 20 per cent mortality among the coral colonies on the outer slopes of Moorea^{cccxi}. In 1994, a similar bleaching episode affected the region, but most of the colonies were able to regenerate without suffering excessive losses. Finally, in 1999 a last episode of bleaching affected Polynesia; mortality rates varied from one island to another^{cccxiii}. Successive bleaching episodes lead to a decline in the number of lagoon fish and thus of the entire tropical marine food chain. Erosion of the beaches could also affect the turtle populations that depend upon these habitats to reproduce.

An increasing number of dead corals help the spreading of ciguatera which is a common form of food poisoning in tropical regions. It is caused by the ingestion of lagoon fish infected by dinoflagellates – photosynthetic micro-algae that form on coral debris. These dinoflagellates produce powerful neurotoxins, which accumulate in herbivorous marine animals and are subsequently transmitted up the food chain by carnivorous fish^{cccxiii}. Dinoflagellates occur naturally on coral reefs but become a problem when their density hits critical levels. Ciguatera is caused by the ingestion of a large quantity of these neurotoxins. It is often referred to in the Pacific as the “itching illness” because it causes serious bouts of itching. Throughout French Polynesia there are on average 800 to 1,000 cases of the disease per year^{cccxiv}. A high rate of mortality among the corals caused by bleaching could lead to a spread of ciguatera^{cccxiv}. The surface of dead corals is an ideal breeding ground for algae and thus for the proliferation of related epiphytes like dinoflagellates^{cccxvi}. Further studies are however needed in French Polynesia and elsewhere to establish with certainty the link between coral bleaching and an increase in ciguatera.

The degradation of the corals as a result of bleaching and acidification could also destroy the physical barrier which shelters Atolls from heavy ocean swell. Atolls are among the most complex and fascinating geological structures of the planet. These ring-shaped tropical islands, which sometimes exceed 10 kilometres in diameter, enclose a lagoon in their centre and are home to an exceptional diversity of marine life. It takes 30 million years for an atoll to form. Atolls are made of coral; if the latter disappear, these islands too will vanish. Furthermore, rising sea levels are likely to accelerate the deterioration of these islands. Atolls never rise more than 2 or 3 metres above sea level. They are therefore particularly vulnerable to both temporary and permanent changes in sea level. If the rise is gradual, healthy corals could continue to grow and possibly follow the water level, but degraded corals would be incapable of doing so.

5.3.2 Terrestrial biodiversity

In **French Polynesia**, the well-preserved, endemic species-rich subalpine ecosystems are without doubt the terrestrial habitats most at risk from variations in temperature and rainfall patterns. Climate change could cause plant species to migrate towards higher

altitudes and result in a general degradation of the ecosystemic equilibrium. These changes will take place to the detriment of the fragile indigenous species and will likely lead to the expansion of invasive species into hitherto uninfested areas. The *Euglandina* carnivore snail, for example, cannot develop above a certain altitude (about 1,400 metres). This threshold is likely to rise with increasing temperatures.

Terrestrial gastropods (snails and slugs) are one of the jewels of Polynesian fauna. More than 320 species were inventoried and 100 per cent of native species are endemic^{cccxlvi}. These species are of major interest for the general study of natural evolution and speciation (evolutionary process through which new species develop). However, most of these species are under severe threat (IUCN Red List), especially from a predatory snail introduced from Florida (*Euglandina rosea*). The latter was originally introduced to combat *Achatina fulica*, another species of invasive snail which was wreaking devastation among local crops. The *Euglandina* has already caused the extinction of 57 endemic species of the *Partula* family, including all the species from the Island of Moorea^{cccxlviii}. The remaining species of French Polynesian snails are now mostly confined to high altitude areas where neither *Euglandina*, whose altitudinal threshold is believed to be between 1,300 and 1,500 metres^{cccxlix}, nor the invasive *Miconia* plant, which does not grow above 1,400 metres, have been able to evolve. As a result, the spatial distribution of indigenous French Polynesian gastropods is extremely limited. An increase in temperatures brought about by climate change could critically endanger the last remnants of endemic species. Rising isotherms would both decrease the gastropods' area of occupancy and lead to the upward migration of the predatory snail towards higher altitudes^{ccccl}.

The upward migration of invasive species towards higher altitudes will have a major impact on the indigenous fauna and flora; especially on the remarkable French Polynesian malacofauna which is mostly limited to the last remaining zones of preserved mountain forests. Tahiti is the only island in the South Pacific to possess tropical subalpine forests. These habitats are limited to three summits above 2,000 metres and do not exceed a total area of 125 hectares. Subalpine zones are characterized by extreme climatic conditions, with low average temperatures (<14°C), a wide range of temperature variations, and inferior rates of rainfall than lower altitude mountain zones. The characteristic vegetation of these ecosystems, known as orophile or mountain vegetation is very rigid with small, tough leaves. Almost entirely devoid of direct human-induced degradation, subalpine forests are of tremendous biological importance. Inaccessibility and climate have limited the destruction of these habitats and the spread of the many of the invasive species found at sea level. These habitats therefore have a remarkable flora and fauna, which are rich in endemic species. However, these subalpine regions are also vulnerable to a rise in temperatures. A recent study has shown that an average rise in global temperatures of 3°C between now and the end of the century would destroy 80 per cent of alpine forests, and lead to the disappearance of one-third to one-half of all alpine plants in the world^{ccccli}.

There are no observations or projections of the impacts of climate change on terrestrial ecosystems of **New Caledonia**. Impacts on the already seriously degraded dry forests) are very likely. In the past, the dry forests of New Caledonia covered the entire west coast of the island up to an altitude of 300 metres, or about one-quarter of the territory. Today, only a few dispersed fragments of these habitats remain (253 in total); their total area is 50 km², or 1% of their original area^{cccclii}. These last remaining vestiges of dry forest are a conservation

priority. They are home to 262 species of endemic plants, of which about 60 are only found in these habitats. These are species that are particularly well adapted to the dry conditions, such as, for example, the dry forest *Gardenia (Gardenia urvillei)*. These forests are also home to specialized fauna including reptiles, birds and invertebrates, and 33 species of butterfly that occur only in these ecosystems. The already severely degraded dry forests have a very limited resilience in the face of the pressures with which they are currently confronted. They are further threatened by human impacts such as bush fires, invasive species (deer and wild pigs) and extensive cattle farming. Climate change will likely further diminish the resilience of these habitats. There are no observation data or projections about the impacts of climate change are likely to be significant^{cccliii}.

The high level of species endemism in New Caledonia is the result of strong specialisation caused by the evolution of species in environments or ecosystems with a limited surface area^{cccliv}. A change in climate, even minimal, could affect the micro-climatic conditions in these environments and imperil the survival of the ecosystems (freshwater ecosystems, high altitude forests, etc.). The functioning of the wetlands in the south (lakes region) is as yet poorly known but a change in rainfall levels could influence these environments and their associated fauna and flora.^{ccclv}

A study has assessed the consequences of a sea level rise between 25 and 50 cm. This would most impact estuaries and low islands, in particular during cyclones. The island of Ouvéa is particularly threatened, as are some coastal areas. In addition, the areas exposed to flooding are likely to increase as sea level rise will make drainage of river water more difficult in the event of important rainfall^{ccclvi}.

5.4 Implications for trade, security and migration

As far as French Polynesia is concerned, its insular character and the absence of territorial continuity prevent the movement of population and species more inland in case of sea level rise, in particular in the atolls that are only a few meters above the level of the sea. The infrastructures in these territories are not always prepared to resist to an intensification of cyclone. In addition, the economy of French Polynesia is largely dependent on natural resources, in particular through tourism, the culture of pearls, fisheries and agriculture; and these resources are directly at threat from climate change^{ccclvii}.

5.4.1 Trade between island and EU mainland and tourism

Both in **French Polynesia and New Caledonia** sea level rise, increasing ocean temperatures and ocean acidification could adversely affect the tourism industry. Sea level rise could lead to the loss of beaches and put the existing tourism infrastructure at risk (eg in French Polynesia, almost all hotels are on the coastline)^{ccclviii}. In addition, much of the tourism also depends on the health of the coral reefs, which are under particular stress from increasing ocean temperatures and ocean acidification as well as the intensification of cyclones. While New Caledonia's economy might be more resilient to adverse trends in its tourism industry given the relative importance of its Nickel reserves as a source of income for the territory⁴⁸, French Polynesia's economy would be very much affected by a contraction of its tourism sector: the tourism sector generates revenues equivalent to a hundred times of fisheries

⁴⁸ Institut de la statistique et des études économiques, ISEE (2013)

export and five times the size of the pearl culture sector. It contributes to 6 per cent of the GDP of French Polynesia^{ccclix}.

In **New Caledonia** repeated droughts caused by climate change could damage subsistence agriculture and livestock farming, which still play an important role today. Some agricultural production will be more affected than others. Litchis and mangoes are difficult to grow in the absence of a cool season. Subsistence fishing also plays an important role. A reduction in fish stocks, caused by the degradation of the reefs, would adversely affect populations whose livelihoods depend on fisheries. The resulting deficits could force the populations to purchase certain foodstuffs from abroad. This could increase the cost of living and lead to a drop in the standard of living^{ccclx}.

In **French Polynesia**, pearl farming, a very delicate process with a high value added, would also be disrupted by a change in the environment. Within 20 years, the local pearl oyster (*Pinctada margaritifera*) has become one of the main economic resources for French Polynesia thanks to its black pearl. In 2008, pearl cultivation provided over three quarters of Polynesian export revenues (in 2012, this was equivalent to about 6,888 million FCFP (EUR 58 million))⁴⁹ and employed about 5000 people, in particular in the remote archipelagos, thus contributing to re-establishing the demographic equilibrium of the country^{ccclxi}.

Climate change could undermine the profitability of this industry through an increased mortality and more frequent damages to material^{ccclxii}. By increasing the temperature and the acidity of the ocean, climate change could have serious consequences for pearl production in Polynesia. The actual impact of climate change on pearl farming in the region is still largely unknown; however several studies have confirmed the existence of potential impacts^{ccclxiii,ccclxiv}. In 2000, the Cook Islands in New Zealand experienced exceptionally dry conditions, with an absence of wind and important increases in temperature. These conditions reduced the level of oxygen in the lagoons and led to an increase in diseases affecting oysters; the result was massive mortality among the pearl-producing oysters. The resulting economic losses for the region have been estimated at EUR 22 million in lost revenue. The oysters could also be vulnerable to increasing acidification of the oceans, caused by a rise in the concentration of CO₂ in the water. It has been demonstrated that calcification of the Pacific Oyster (*Crassostera gigas*) diminishes in direct proportion to the increase in the acidity of the sea water.^{ccclxv}

5.4.2 Security

In **New Caledonia** variations in temperature and precipitation could have an impact on public health by facilitating the spread of certain vector-borne diseases such as dengue fever or malaria. Malaria is currently absent from New Caledonia, but present in Vanuatu. With a rise in temperatures, the risk of this disease being introduced would increase^{ccclxvi}. In **French Polynesia**, climate change presents a risk to public health through, for instance, a rise in the number of vector-borne infectious diseases such as dengue fever, or the proliferation of the micro-algae responsible for ciguatera, food poisoning caused by ingesting infected fish^{ccclxvii}.

⁴⁹ ISPF (2013) Bilan commerce extérieur 2012, http://www.ispf.pf/Libraries/Publi/PF/Bilans_et_Etudes/PF_2013_03_comext_2012.sflb.ashx

A large majority of the population of **French Polynesia** lives in the narrow coastal strips and urbanisation is particularly concentrated on the limited number of flat areas located along the seashores. A rise in sea levels could therefore have disastrous consequences on these urban settlements and hence on the economy of the territory. A simulation of rising sea levels carried out on the site of Tahiti international airport illustrated their potential impacts. Tahiti airport, like many in French Polynesia, has been built on a coral reef. A rise of 88 centimetres in the sea's level (the top end of IPCC projections) would result in the complete submersion of the airport and of part of the surrounding town of Faa where it is situated. In addition to sea level rise the intensification of cyclones could result in concrete risks for such infrastructures and related populations. Increased rainfall in specific periods in the year can increase the risks of landslides and floods, threatening housing that is at risk. Economic impacts could be very serious for the territory

Also in New Caledonia a large majority of the inhabitants live along the coast, in low-lying urban areas that are highly vulnerable to rising sea levels but there is more scope for inland migration.

5.4.3 Migration

The consequences of climate change in terms of migration of insular populations are very context specific and no generalisations can be drawn for all islands^{ccclxviii}.

For **French Polynesia**, the threat that costal erosion leads to the disappearing of parts of some islands and obliges to displace some populations and relocate them to new islands is real. The islands that are most urbanised, in which population no longer depends on the ecosystems, technical solutions to adapt to climate change and prevent migration could be considered, such as the building of dams or placing houses on piles. Where population are still very much dependent on their environment this is unlikely to work and populations might have to be re-located to other (French) islands^{ccclxix,ccclxx}. In addition, the threats to the culture of pearls from increased temperatures, intensification of cyclones and acidification on of oceans might make this sector less profitable due to increased mortality, material damage and decreased productivity^{ccclxxi}. Given this activity is the reason why those employed in the sector settle in certain islands (the industry is based in Tuamotu Gambier and is a keystone of the economic development of the remote archipelagos. It also helps curb population exodus towards Tahiti), a contraction of the sector is likely to result the migration of the affected populations to other islands.

With 84 atolls, Polynesia is home to 20% of the world's atolls. The human populations who inhabit these islands are at risk from climate change. They could be forced leave their atolls and seek refuge on islands or continents located at higher levels. In the neighbouring islands of Tuvalu, there is already talk of "climate refugees". Since 1993 these islands have experienced a rise in sea levels of approximately 2 millimetres a year, caused by the El Niño weather system^{ccclxxii}. They have lost 3 metres of beach front, their crops are inundated for five months of the year, and salt water has seeped into the water tables. The impact of tropical storms on the coast is becoming more and more violent, and whole populations have already had to be temporarily evacuated from their islands during very high tides.

As far as **New Caledonia** is concerned, the size of the territory makes inland migration more practicable, as the territory of the mainland is not only large, but much of it is located high

above the sea level (the mainland - island of Grande Terre) is divided in length by a central mountain range whose highest peak, Mont Panié, culminates at 1,629 meters.

5.5 Conclusions

Climate risks for **New Caledonia** are mainly related to the constant increase of pressures on its water resources and the unique character of its biodiversity and its coral reef (sensitive to changes in temperatures). Other risks include the bush fires and dengue fever epidemics. The foremost impact of climate change on the marine environment is without doubt the degradation of the coral reefs as a result of successive bleaching events and particularly intense tropical cyclones. These have also taken their toll on the small agricultural sector causing socio-economic impacts that are likely to increase in the future as cyclones are projected to become more intense as a result of climate change. While this may not have tremendous impacts on the territory's trade balance (agriculture and fisheries do not account for an important share in export revenues) this might in particular be a problem for subsistence farmers that might have to migrate from rural to urban areas and buy relatively expensive foodstuffs produced abroad, thus experiencing a reduction in their living standard. Additionally, tourism, which is a vital component of New Caledonia's economy, might be adversely affected by the degradation of the coral reefs as a result from rising temperatures and acidification of oceans.

The geomorphology of most of the Islands that are part of **French Polynesia** means that they are at a very high risk related to climate change. Although it is difficult to predict the impacts across all of French Polynesia which is a very large territory in which effects of climate change might play out very differently, it seems quite likely that French Polynesia will have to face a higher frequency of extreme weather events such as cyclones, that rainfall might fall in larger quantities but less regularly in some islands, increasing risks of landslides and that specific islands, in particular atolls, might become inhospitable because of sea level rise. As in many islands, much of the infrastructure in islands across French Polynesia concentrates on flat land along the shores, exposing populations to the risks associated with extreme weather events combined with sea level rise.

Some of the most important economic sectors in **French Polynesia** (tourism, the culture of pearls, fisheries and agriculture) are also vulnerable to the risks of climate change as they all heavily depend on natural resources that might suffer from climate change. This includes the forest ecosystems in some of the islands that host a high share of endemic species as well as the marine biodiversity that is in particular at risk because of coral bleaching.

ANNEX

People contacted for further information:

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Frédérique Lehoux	SOPAC
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José Simas	AZORINA S.A.
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Mathieu Fichtner	European Commission, DG REGIO
Nikos Zografakis	Regional Energy Agency of Crete
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Interviews conducted

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Macaronesia	
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Greek islands	
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La Réunion	
Amélie Navaro	Service Déchets et Energie, Direction de l'Environnement, Depart. De la Reunion
Netherlands Antilles	
Lloyd Narain	Friends of the Earth Curacao

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