**Title:**

Climate change and their impacts in the Balearic Islands. A guide for policy design in Mediterranean regions

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**Abstract:**

Understanding the local effects of global warming-derived impacts is important to island systems due to their fragile environmental conditions. This is especially true when it comes to Mediterranean insular regions as they are climate change (CC) hotspots where adaptation and mitigation policy design is an urgent matter. Looking at 2030 as a time horizon for climate action and focusing on the Balearic Islands, this paper reviews the physical changes projected for the coming decades as a result of CC and analyses their impacts on regional environmental, economic and social variables. Mitigation and adaptation measures are also proposed based on the identified priority impacts. The fact the Balearics are a top world holiday destination allows the analysis to serve as a guide to other Mediterranean islands with tourism-based economies facing similar CC scenarios.

Results show the projected rise of temperature and sea level, the reduction of the average precipitation and increase in evapotranspiration, the droughts, and the increase in ocean acidification and deoxygenation are the main threats faced by the Balearics, this putting their economy at risk due to the high tourism’s vulnerability to CC. Mitigation and adaptation action on terrestrial and marine ecosystems, water resources, energy, infrastructure and urban planning, human health, economy, law and education is recommended. Sustainable mobility and waste managing are also viewed as important fields for mitigation action. Conclusions show that diversifying the current socioeconomic model is needed to increase the community and territory resilience.

**Keywords:**

Climate change, Mediterranean islands, impacts, mitigation, adaptation.

**Length of the manuscript:**

Number of words counting from the top of the title page, including abstract, keywords, acknowledgements and conflicts of interest to the end of text (before the reference list (3.849)): **7.932** words

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**1. Introduction**

Since the beginning of the 20th century, the increase in human-induced concentrations of greenhouse gases (GHG) in the atmosphere has risen the planet’s mean temperature (IPCC 2018). In this context, understanding the local effects of global warming-derived impacts is especially important to islands due to their fragile environment. This is particularly true in the Mediterranean Basin as it is a climate change (CC) hotspot (Giorgi et al. 2006; MedECC, 2020). Accordingly, both the review of CC-related current and projected physical changes and the analysis of their derived impacts on environmental, economic and social variables represent the starting point for developing adequate policies in insular territories. Though these changes will be most noticeable in the second half of the 21st century (Klausmeyer and Shaw 2009; Lelieveld et al. 2012; Cramer et al. 2018; Kaniewskia et al. 2020), designing measures to mitigate and adapt to CC becomes today an urgent task since the islands especially need preparedness given their vulnerabilities.

In 2018, responding to the interest of the regional government to assess the economic, social and environmental prospects for the Balearic Islands by 2030, the Economic and Social Council (ESC) requested to the Interdisciplinary Lab on Climate Change of the University of the Balearic Islands (LINCC UIB) a study about climate change (CC). In particular, the ESC commissioned the LINCC UIB to evaluate the CC impacts on the insular territory and give guidance on the implementation of mitigation and adaptation policies to address them. This resulted in chapter 5 of the “Study on the Economic, Social and Environmental Prospects for the Balearic Islands for the 2030 Horizon” report. This chapter attempted to assist the government in the identification of all the relevant CC-related issues to be included in mitigation and adaptation plans before 2030 (De Vílchez et al. 2019). This paper upgrades and extends the research undertaken in such a report. However, for space limitations, it only presents the CC impacts considered of priority for the Balearic Islands[[1]](#footnote-1) and briefly discusses the importance of designing mitigation and adaptation measures. The fact the Balearics are a world top holiday destination makes relevant this discussion as it can serve to give guidance to other Mediterranean territories with tourism-based economies facing similar CC threats. The high vulnerability of tourism to CC (Simpson et al. 2008; Bujosa et al. 2015; Factor CO2 Ideas 2015; Lee et al. 2018; González et al. 2019; Arabadzhyan et al. 2020) makes these regions even more fragile thus calling for an urgent change of their socioeconomic model The analysis presented here also wants to serve as a wake-up call for initiating such a change.

The paper is structured as follows. Next section describes the methodology used to evaluate the CC-related physical changes and their derived impacts, which is based on an ad-hoc expert opinion elicitation procedure. Sections 3 and 4 discuss the priority physical changes and expected impacts on ecosystems, respectively, while section 5 revolves around the priority impacts on human systems. Section 6 comments on the importance of mitigation and adaptation and recommends a series of policies within each field. A Conclusions section ends the paper.

**2. Methodology**

To evaluate the CC-related physical changes and impacts (both referred to as hazards from now on) in the Balearic Islands, a LINCC dedicated working group was created including nine experts from different academic disciplines such as physics, engineering, biology, oceanography, economics and law. Based on their expertise, they reviewed existing research on hazards in both the Balearics Islands and other Mediterranean regions sharing similar environmental and/or socioeconomic characteristics, thus facing analogous CC threats. In cases where information on hazards was scarce for the region of interest, the experts reviewed related research focusing on other places elsewhere[[2]](#footnote-2). Regarding the identified impacts, they were classified into two groups: i) impacts on ecosystems, divided into the categories ‘terrestrial’ and ‘aquatic’; and ii) impacts on human systems, divided into the categories ’water resources, energy and infrastructure’, ‘human health’, ‘economy’, and ‘human rights, society and the political system’. Impacts on terrestrial ecosystems were further divided into ‘natural’ and ‘agricultural and livestock’ systems, and those on aquatic ecosystems were classified into ‘marine’ and ‘freshwater’. Likewise, economic impacts distinguished between ‘general impacts’ and ‘sectoral impacts’ (including tourism, agriculture, livestock, fishing, construction, real estate and public sector).

An expert opinion-based assessment was conducted according to an ad-hoc methodology based on a qualitative informal knowledge elicitation (Gavrilova and Andreeva 2012; O’Hagan 2019)[[3]](#footnote-3). Considering the nature of and the available time for the exercise, a round table-focused collective knowledge elicitation was carried on where all of the experts had equal rights to answer. A consensus combination of collective elicited judgements was adopted after a facilitated discussion among experts during a series of meetings to determine the relevance of each identified hazard and the available documented evidences. For each hazard, the experts were asked to answer the following questions: 1) “Is there any chance the hazard will occur in the Balearic Islands during the 2050-2100 period?” and, if so 2) “Which is the expected variation in its magnitude and the associated probability of occurrence for this period?” Such a time frame was chosen because changes due to CC were expected to be exacerbated in the second half of the 21st century and hence easily distinguishable from changes related to the natural (in case of physical changes and ecosystem impacts) or usual (in case of human system impacts) variability. Three different levels of magnitude variation were defined according to the comparison between the expected change in the intensity, duration and/or frequency of the hazard due to CC and the variation registered during the last 30 years. So if the CC-related expected change in magnitude was much larger or larger than the variation occurring due to natural/usual variability, it was assigned the levels high or medium, respectively. In contrast, if the expected magnitude change was slightly above the natural/usual variation, it was considered low. The probability of occurrence (i.e. the confidence on the projection) was also assigned the levels low, medium or high depending on the extent to which the expected magnitude variation was likely to happen[[4]](#footnote-4).

To evaluate the expected magnitude and associated probability of occurrence for each hazard, the experts reviewed literature published from 2003 onwards and considered different criteria depending on whether they were assessing a physical change, an ecosystem impact or a human system impact. Thus, to determine the expected variation in the magnitude of a physical change and its probability of occurrence, they considered information on the observed and projected climate at regional scale. For the impacts on natural and human systems, they took into consideration the expected magnitude variation of physical changes and its probability of occurrence, the environmental and socioeconomic conditions of the islands and their expert knowledge on both the system and its resilience in terms of vulnerability[[5]](#footnote-5). For the human system impacts, they also considered the expected magnitude variation of ecosystem impacts and its probability of occurrence.

As a final step for the elicitation, the experts defined different categories for the hazards being likely to happen in the Balearic Islands. Hazards were considered of priority when both their expected magnitude variation and its probability of occurrence were medium or high. In contrast, they were considered of no priority when either i) their expected magnitude variation was low and its probability of occurrence was medium/high or ii) their expected magnitude variation was medium/high and its probability of occurrence was low. When both the expected magnitude variation and its probability of occurrence were low, the hazards were assumed to be of no concern for the islands[[6]](#footnote-6)

(Insert Table 1)

When the existing research was not enough to draw conclusions about whether the hazard would occur or not due to CC, it was classified into a “not enough information” category. This category was also applied to hazards being likely to happen but whose expected variation in its magnitude and/or its probability of occurrence were difficult to determine according to existing data (e.g. decrease of the market value of coastal properties due to a loss of aesthetics caused by beach erosion)[[7]](#footnote-7).

Once the different types of hazards being likely to happen in the Balearic Islands had been identified, the experts proposed a series of mitigation and adaptation measures which could be implemented.

**3. Physical changes**

From 1975 to 2015, maximum and minimum air temperatures have risen at a rate of 0.44 and 0.37ºC/decade, respectively (Herrera et al. 2016). The winter-summer transition has become more abrupt (0.86ºC/decade) due the spring warming (Jansà et al. 2017). Since 1970, the Western Mediterranean sea temperatures have also increased at a rate of 0.25ºC/decade in the upper 80m of the water column (Vargas et al. 2008). Sea level records also show an upward trend of 1.3 cm/decade for the 20th century (similar to the global one).

Climate projections suggest temperatures will increase by 3-5ºC by the end of the 21st century compared to 2010 if GHG emissions follow current trends (Adaptecca 2018), and by 1.75-2ºC under a moderate scenario. This will lead to longer and more intense heat waves. Mean precipitation will decrease by 20% in 2100 under a pessimistic GHG emissions scenario and by 10% under a moderate one and the severity of droughts will be enhanced. There are some results projecting a slight increase of extreme precipitation but there is little consensus among models. Also, wind intensity and the number of cyclones will likely decrease on average, while the intensity of the intense events could slightly increase.

Depending on the GHG scenario, the mean sea level will increase between 37-90cm (MedECC 2020). The intensity and frequency of marine storms will slightly decrease, although their impact will increase due to the rise of the mean sea level. The sea temperature will also rise between 2-4ºC in the upper layers (Soto-Navarro et al. 2020), leading to stronger marine heat waves. Also the vertical stratification will be enhanced and the available dissolved oxygen reduced, thus diminishing the ventilation of intermediate and deep layers. Though there are not robust estimates for this yet, more atmospheric CO2 might provoke higher ocean CO2 absorption and ocean acidification.

**4. From physical changes to impacts on ecosystems**

**4.1 Impacts on plant and animal biodiversity**

Terrestrial ecosystems are suffering from rising temperatures and reduced rainfall derived impacts. Both factors combined will lead to an increase in evapotranspiration that will reduce the area occupied by forests of *Quercus ilex* (holm oaks), which will not be able to subsist in the spaces that currently represent their climatic limit. In turn, there will be an increase in the forests and maquis of *Olea europea* var. *sylvestris* (olive tree) and *Pinus halepensis* (pine tree). On the other hand, forest fires risk will be higher due to a greater number of days with high temperatures and low humidity. All these factors combined can lead to forest decline and make them more sensitive to pests and pathogens. Consequently, their capacity to sequester carbon will be reduced.

It is also expected that some threatened plant species may become extinct when their habitat disappears such as plants living in fountains, torrents or simply wet soils. *Naufraga balearica*, a critically threatened endemic monotypic plant genus, is paradigmatic in this sense (Cursach et al. 2018). In contrast, some exotic species are becoming dangerous invaders by finding a more favourable climate, such as some cultivated plants natives from dry tropical zones (*Lantana camara*, *Opuntia* spp., *Agave* spp., etc.). Finally, changes in phenology of flowering and fruiting could result in ruptures of mutualisms, for instance with their pollinator and dispersant animals. On other hand, sea level rise and extreme meteorological events will have an important impact as well, since beaches and coastal dunes will reduce its extension and in some places, they may disappear. Likely some rare psammophilous plants and animals could extinct at the local level. Also, coastal wetlands will suffer salinization, with dramatic changes in these ecosystems. It is also expected that temporary ponds and torrents will reduce the time they are flooded, even some could disappear. It could also threat some plants and animals which live in this habitat, for instance, the endemic and endangered amphibian *Alytes muletensis* or the very rare fern *Marsilea strigosa*.

Even if there are not specific studies in the Balearic Islands about the CC effect on animals, it is expected that animal biodiversity and populations are also affected by alteration of distribution, seasonality, growth, reproduction, migration and synchrony of life cycles among animals and/or plants. Temperature increase is currently changing distribution of birds, insects and mammals to northern latitudes (Feehan et al. 2009) as well contributing to the extinction of some species of mammals (Thomas et al. 2004). CC effects are expected to be more severe on those species with a restricted distribution, such as the endemic ones (i.e. *A. muletensis* in the Balearic Islands). On the contrary, invasive species (i.e. insects such as *Aedes albopictus* and *Rhynchophorus ferrugineus*) will be favoured by higher temperatures this increasing its distribution. There are also evidences of global insect decline due to CC (Habel et al. 2019; Harris et al. 2019; Powney et al. 2019). Indeed, indicators of decline in lepidoptera populations were found in Menorca and attributed to changes in the phenology of host plants (Colom et al. 2019).

**4.2 Impacts on wild plant and animal health**

CC is expected to cause a weakening of trees and a reduction of their defences against phytophagous insects and pathogens that will experience favourable periods for proliferation. Currently, severe outbreaks of bark beetle species (*Tomicus destruens* and *Orthotomicus erosus*) and pine processionary (*Thaumetopoea pityocampa*) on the populations of *P. halepensis* have been observed in the Mediterranean region (Spathelf et al. 2014). Meanwhile, *Q. ilex* forests are increasingly affected by high abundance of the lepidopteran pest *Lymantria* dispar. Thus, holm oaks weakened by insects or unfavourable weather are more vulnerable to the spread of pathogenic fungi, such as *Botryosphaeria corticola* and *Biscogniauxia mediterranea* (Moralejo, 2010, unpublished work).

Recent emerging plant vector borne diseases such as the bacterium *Xylella fastidiosa* found in the Balearics in 2016 (Olmo et al. 2017) will increase its distribution in Europe because of the temperature rise according to model scenarios for 2050 and 2100 (Bosso et al. 2016). CC will also affect the wild animals’ health by favouring reproduction and distribution of parasites (i.e. gastrointestinal nematodes) and increasing the presence of emerging diseases (Altizer et al. 2013). In the Balearics, some introduced parasites are affecting key endemic species (i.e. chrytidiomycosis in *A. muletensis*) (Fisher et al. 2012). The effect of tropical parasites species (e.g. Angiostrongilasis in the hedgehodge *Atelerix algirus*) on some vertebrates are also an example (Paredes-Esquivel et al. 2019). Pollinators (bees) are a key group of animals affected by CC. Indeed, it directly impacts their life cycles and indirectly affects them via diseases and parasites such as fungi *Nosema* spp., the mite *Varroa destructor* and the coleopteran *Aethina tumida* (EFSA 2015)*.*

**4.3 Impacts on marine ecosystems**

Global warming has multiple effects on marine ecosystems, including biodiversity loss, changes in ecosystem functioning and proliferation of invasive species.

The coastal ecosystems of the Balearic Islands are dominated by the endemic seagrass *Posidonia oceanica*, which is a key species providing multiple services thanks to its high productivity: it increases water transparency and biodiversity; produces oxygen; acts as an important carbon sink, absorbing 7% of carbon emissions of the islands (Marbà, personal communication). However, these meadows are very sensitive to global warming as it produces physiological stress, stimulates bacterial activity, changes ecosystem biodiversity, and increases flowering events and plant mortality (Marbà and Duarte 2010). As a result, both the seagrass and its services could disappear by 2040-2060 in the shallowest areas (Jordà et al. 2012), this shaping the future of Mediterranean coastal ecosystems.

Benthic filters are another Mediterranean sensitive community to global warming. During summer, high temperatures enhance stratification, reducing food-supply to bottom waters, and benthic filtering communities die of starvation. This phenomenon has already caused mass mortality events of different invertebrate groups, such as gorgonians and corals (Garrabou et al. 2019).

Migration and distribution of fish communities can also suffer from CC impacts. Since 1960 global warming produced a migration of ocean isotherms of 50 km/decade in the Mediterranean Sea (Burrows et al. 2011) altering distribution of fish species, with some species migrating northwards seeking for refugee in colder waters.

The proliferation of tropical species is leading to the Mediterranean tropicalization (Bianchi and Morri 2003). Some invasive species will benefit from warmer waters (Raitsos et al. 2010). The invasive macroalgae *Halimeda incrassata* has rapidly colonized sandy habitats since 2011 (Alós et al. 2016) leading to changes in abundances and distribution of fishes (Vivo-Pons et al. 2020). Another invasive species that could benefit from CC are the rabbitfish (*Siganus luridus* and *S. rivulatus*). These species negatively affect rocky ecosystems leading to deforestation, due to their highly herbivore rates (Vergés et al. 2014a). At the moment, thermic tolerance of these species limits their distribution to the Eastern Mediterranean, but CC might allow to broad its distribution western-wards with isotherms migration (Vergés et al. 2014b).

CC can also alter trophic interactions as a consequence of the presence of new species with warmer thermal windows and due to changes in the nature or strength of existing interactions due to warming responses. Species interactions can dramatically alter species responses to CC. The exact consequences for focal species are unknown and dependent on multiple interacting factors (Gilman et al. 2010; Zarnetske et al. 2012).

CC also impacts marine biogeochemical cycles and organisms’ metabolic rates. Temperature rises both respiration (oxygen consumption) and photosynthetic (oxygen production) rates although respiration increases faster than primary production (Brown et al. 2004; Vaquer-Sunyer and Duarte 2013). This could lead to a decrease in oxygen content in coastal waters with negative consequences for marine benthic communities, very sensitive to deoxygenation (Díaz and Roseberg 2008; Vaquer-Sunyer and Duarte 2008). This situation has been already reported for a Balearic enclosed bay (Vaquer-Sunyer et al. 2012). CC will also aggravate negative effects of deoxygenation as organisms increase their oxygen requirements at warmer waters at the time that warming accelerates oxygen depletion (Vaquer-Sunyer and Duarte 2011).

Ocean acidification decreases survival, calcification, growth, development and abundance of a broad range of marine organisms. However, the magnitude of these responses varies among taxonomic groups. Molluscs larvae are specially sensitive to acidification, whereas in other taxonomic groups it is not clear that early stages are more sensitive than adults. The variability in the species' responses is enhanced when multi-species assemblages are assessed. Elevated water temperature enhances organisms’ sensitivity to acidification (Kroeker et al. 2013).

**4.4 Impacts on agricultural and livestock systems**

Climate prediction models indicate warming will cause substantial changes in global agriculture (IPCC 2014) which will be of particular importance in Mediterranean regions (del Pozo et al. 2019; Santillán et al. 2020; Varotsos et al. 2021). Temperature increase, changes in precipitation distribution and more intense and frequent extreme events (e.g. severe drought periods, heat waves) can cause important quantifiable impacts on agriculture. On the one hand, crop productivity can be reduced due to prolonged drought (Fraga et al. 2020). Evaporative demand and plant transpiration rates can also raise this leading to greater direct evaporation of soil water and reduction of availability of water for crops, respectively (López-Urrera et al. 2012). In addition, modification of phenology of cultivated species (advance of budburst, lengthening of phenologic cycles, delays in dormancy of buds) can happen (Ramos 2017; Lorite et al. 2020;) and a reduction of chill hours can affect physiology, such as flowering (Ashebir et al. 2010), dormancy, and latent periods. The severity and frequency of heat waves will also influence the physiology of plants causing a loss of production (DaMatta et al. 2010). Changes in chemical composition of crop products and its derivates due to light spectrum modification (greenhouse effect) and high temperatures will be another CC impact on agriculture. Such changes will have negative effects on products’ taste and nutritional properties (Lorite et al. 2018; del Pozo et al 2019). Finally, new pests might cause significant economic costs, and even the infeasibility of certain crops. Milder winter periods will also intensify local pests-derived impacts due to more annual generations and favour the emergence of new invasive plant pest and diseases (Civantos et al. 2012).

Extreme heat waves are considered the most important CC direct impact on livestock production (Thornton et al. 2009), while the loss in the quality of pastures due to rainfall reduction would be the main indirect impact. New vector borne diseases are also expected as shown by those having occurred in Europe in recent years such as Lumpky Skin Disease in Greece and East Europe. Diseases transmitted by *Culicoides* spp*.*, such as bluetongue (Miranda et al. 2003) have also occurred in Spain and the Balearics Islands. Though bluetongue was initially considered to be restricted to southern latitudes, it has surprisingly reached North European countries, such as Germany, Deutschland and United Kingdom. This is viewed as an example of the global warming-derived effect on the insect vector competence (Purse et al. 2014).

(Insert Table 2)

**5. From physical changes to impacts on human systems**

**5.1 Impacts on water resources, energy and infrastructures**

CC is expected to reduce the fresh water resources due to a reduction of precipitation and an increase in evapotranspiration. Specifically, the more pessimistic emission scenarios show reductions greater than 55% (Pulido-Velazquez et al. 2015). In addition, a significant increase of water demand by the residential, service and industrial sectors (Milano et al. 2013) would lead to future lower water availability. The Balearic Islands’ water reservoirs get their minimum levels during summer, in particular in August due to the tourism activity, which is one of the biggest contributors to local water demand (García and Servera 2003). The monthly mean water demand by the region’s population is 1.7 hm3, which almost doubles during the peak season when an increase between 0.9-1.4 hm3 is produced. This will undoubtedly impact water distribution and collection systems (Loftus et al. 2011). Increased water demand will also contribute to raise the pollutant concentrations in the water reservoirs and aquifers’ salinity (Fader et al. 2020).

Such a water scarcity scenario will also lead to raise the demand for desalination which will increase energy consumption. The Balearic Islands have 8 desalination plants (3 in Mallorca, 3 in Eivissa, 1 in Menorca and 1 in Formentera) based on reverse osmosis. Although this is said to be an efficient technology, it requires at least 5 kWh to desalt 1m3 of sea water (Shemer and Semiat 2017). Energy consumption from water desalination rose by 37.4% during the 1999-2017 period (GOIB 2016; ABAQUA 2019; Vaquer-Sunyer et al. 2021)[[8]](#footnote-8).

As water demand, energy demand will be higher in summer (Valor et al. 2001), especially at nights (Papakostas and Slini 2017), while it is expected to be lower in winter (Giannakopoulos et al. 2009). Thus the annual average demand might remain unchanged at current energy consumption levels. However, as peaks of summer demand will be higher due to cooling systems, polices oriented to either increase the power generation capacity or implement energy saving will have to be undertaken, which will involve higher generation costs (Elimelech and Phillip 2011).

Action on infrastructures will also be needed in the face of global warming. Higher temperatures might also deteriorate the infrastructures due to dilatations/thermal contractions and induce acceleration of corrosion processes. More CO2 concentration involves a higher carbonation rate, this deteriorating existing concrete infrastructures (Stewart et al. 2011; Ekolu 2020). Although corrosion might be viewed as a minor issue, current estimates indicate that the global cost of corrosion represents the 3-4% of the GDP in industrialized countries, or equivalently $US 1.8 trillion (Schmitt 2009). The huge magnitude of the direct and indirect corrosion costs allows anticipating that a slight CC-derived acceleration of this process could lead to important global economic costs.

On the other side, the expected rise in the sea level will reduce the height of the coronation level of the breakwaters in harbours and other maritime infrastructures, increasing the risk of failure under the occurrence of potential high waves. In addition, extreme rainfall episodes may increase which would lead to more floods, and therefore larger drainage requirements such as slopes, elements of transverse drainage on roads or bridges, among others, may be needed locally to avoid aggravating the flooding effect at certain points (CEDEX 2013; Cramer et al. 2018).

**5.2 Impacts on human health and the economy**

Although at the global level it is expected CC will cause deaths due to heat stress, poor nutrition and malaria between 2030 and 2050 (WHO 2014), heat waves will represent the major direct CC human health impact in Western societies. The one occurring in Europe in 2003 was estimated to increase the probability of death between 20 to 70% in large cities (Mitchell et al. 2016). In the Balearic Islands, elder suffering from cardiovascular or respiratory diseases as well as out-door workers are expected to be the most vulnerable population segments. On the other side, the most important indirect CC human health impacts will be vector borne diseases and the rise of allergy episodes. Invasive species of vectors (i.e. *Aedes albopictus*) and imported diseases (i.e. dengue) will also increase the transmission risk, as already confirmed in Spain in 2018 (ECDC 2018). In addition, higher temperatures may modify the transmission capacity of autochthonous vectors, such as *Culex pipiens* and West Nile virus, as confirmed in the recent epidemic in Andalusia (ECDC 2020). Higher pollen concentrations will also provoke allergy-related respiratory problems.

CC is also expected to substantially affect the economy, thus leading to a decrease in social welfare (IPCC 2014). On the one side, production costs of all sectors will be affected by some physical changes. Indeed, higher temperatures and more frequent heat wave episodes will lead to a lower labor productivity mainly affecting the most vulnerable people and the employees’ mental and physical health (Kjellstrom et al. 2016). In addition, the capacity of facilities and infrastructures can also be reduced by increased temperatures, which can lead to a growing risk of fires affecting infrastructures’ logistics. The electricity generation and/or distribution systems will also experience more pressure due to the potential rise in summer energy demand. Utilities of provision and treatment of water for consumption can suffer from overload not only due to higher water demand but also due to lower precipitation. Some facilities might also have to be repaired or forced to close due to the sea level rise ([Linnenluecke](https://www.sciencedirect.com/science/article/abs/pii/S0959378010000944?via%3Dihub#!) et al. 2011; Factor CO2 Ideas 2015)[[9]](#footnote-9). Production costs will further increase because of a potential rise in water prices due to both the increase in the demand of water and its use rivalry between sectors (e.g. tourism, agriculture, industry). The agro-products prices might also increase due to a reduction of agro-systems productivity which, together with insularity costs, can increase imports of agro-products and their price (MedECC 2020). A higher energy demand can also lead to a rise in the energy prices which could be further exacerbated due to the peak oil, gas and coal phenomena.

On the other side, CC will also impact ecosystems’ capacity to provide goods and services (Torres and Hanley 2017) especially affecting tourism, livestock and agriculture sectors. Warming and frequent heat waves are expected to affect the Balearic Islands’ attractiveness (Bujosa et al. 2018) leading to a seasonal and geographical redistribution of tourists’ flows, which will look for higher latitude, cooler regions (Bujosa et al. 2015). They are also expected to cause a loss of environmental quality, this making the islands even less attractive. Indeed, higher temperatures will increase the risk of fires (Fernández-González et al. 2005) and provoke the loss of seagrass *Posidonia oceanica* (Marbà and Duarte 2010) affecting two recreational services provided by this plant: i) the quality and transparency of coastal waters (Torres et al. 2009) and ii) the recreational fishing of species which the plant serves as habitat to[[10]](#footnote-10). Warming can also lead to a higher frequency of jellyfish outbreaks (Canepa et al. 2014) and a loss of landscape values due to the further spread of the plant pathogen *Xylella fastidiosa*. New pathogens could also affect the destination attractiveness through vector-borne diseases or pandemics caused by other types of viruses like Covid-19[[11]](#footnote-11). On the other side, the sea level rise will also affect the environmental quality through the reduction of beaches’ width (Enríquez and Bujosa 2020). Warming and lower precipitation will also impact the livestock and agricultural sectors’ benefits (Factor CO2 Ideas 2015; Institut d’Estudis Catalans and Generalitat de Catalunya 2016) as they will lead to a lower availability of fodder and grasses, this causing a reduction in milk and cheese production, lower yields and increased irrigation costs.

As a result of general and sectoral impacts, a rise in governments’ budget deficit is expected due to the potential growth in public spending associated to energy and health systems, fighting against pests, port infrastructures and water collecting and distribution utilities[[12]](#footnote-12). The expected economic losses will also lead to an income reduction and hence less public revenues, this further contributing to raising the deficit.

**5.3 Impacts on human rights and socio-political systems**

CC can also lead to serious consequences upon citizens, society and the democratic institutions. Even from a legal perspective the interdependence between nature and human beings is becoming increasingly clear. Since the 1972 Stockholm Declaration on the Human Environment, there has been a growing awareness that a clean and healthy environment is indispensable to the enjoyment of human rights. This has been clearly stated by the most recent reports of David R. Boyd, the current Special Rapporteur on Human Rights and the Environment,[[13]](#footnote-13) and recognized by an increasing number of courts, both at the domestic[[14]](#footnote-14) and international level[[15]](#footnote-15).

Accordingly, it is expected that CC will affect the human right to life, health, private and family life, property, food, water, and housing, which have been established in several international instruments to which Spain is Party[[16]](#footnote-16) and according to which Spain is obliged to interpret the fundamental rights set forth in its own Constitution[[17]](#footnote-17). This is especially true when it comes to consider the CC impacts on the most vulnerable, lower-income and marginalized sectors of society which are expected to be the most affected ones (O’Brien and [Leichenko](https://www.researchgate.net/profile/Robin-Leichenko) 2000; MedECC 2020). The encroachment of legally established human rights is likely to produce a surge in legal actions directed either against public authorities or private actors contributing to global warming, as is already happening in many countries (UNEP 2020).

Moreover, the dire CC impacts, together with a probable increase in the flux of migrants from Northern Africa (Cramer et al. 2019) will also likely deteriorate social stability and increase an already growing disaffection towards the democratic institutions that has fuelled the surge of a xenophobic and extreme-right party in the 2019 local, regional and nation-wide elections[[18]](#footnote-18).

(Insert Table 3 and Table 4)

**6. Climate policy for the Balearic Islands**

Given CC cannot be avoided, prevention is not seen as a policy option and climate policy usually revolves around two types of action: mitigation and adaptation. While adaptation is oriented to enhance the resilience of the ecosystem and society for them to better cope with the expected CC impacts, mitigation pursues to diminish GHG concentrations in the atmosphere to reduce the global temperature increase and hence its derived impacts. The IPCC strongly recommends reaching net zero emissions by 2050 to limit the temperature increase to 1.5ºC (IPCC 2018). On the other side, the EU has reached an agreement on the European Commission’s proposal for the first European Climate Law, which aims to write into law the goals of the European Green Deal, establishing a GHG emissions reduction target of at least 55% by 2030. This is consistent not only with the Paris Agreement’s recommendation to reach net zero emissions by 2050 but also with some studies pointing to the need to raise the ambition level up to a 55%-65% reduction in an attempt to ensure the net zero emissions objective (ECF 2018).

Mitigation is urgently needed to avoid the further exacerbation of the economic and social costs linked to emissions reduction within a shorter time period. Starting mitigation now can also avoid a reduction of both the set of feasible emissions reduction options and the social capacity for response.

**6.1 Mitigation policy recommendations**

Mitigation policies can be viewed as an opportunity to diversify the Balearic Islands economy as they can lead to create new job opportunities in high value-added technological sectors requiring skilled labour and being hard to delocalize. Mitigation can also help to strengthen local economic sectors such as agriculture, fishing, arts and crafts and natural resource management. In a CC context, diversification becomes a necessity for a tourism-based economy due to the intensive use of fossil fuel energy and materials by the tourism sector which converts it into a big contributor to CC (Simpson et al. 2008; Torres and Moranta, 2021). Indeed, tourism carbon footprint rose from 3,9 to 4,5 GtCO2e at the planetary level between 2009 and 2013 accounting for the 8% of global emissions (Lenzen et al. 2018). As stated by Cadarso et al. (2015; 2016), tourism is responsible not only for direct, indirect and imported emissions but also for emissions associated with the capital investments required to supply tourism goods and services, which are mostly linked to the construction sector (e.g. hotels, restaurants, transport infrastructures).

Accordingly, it is highly recommendable to design a Plan for Mitigation to reach by 2030 the emissions reductions targets set by the Climate Change and Energy Transition Law launched by the Balearic Islands Government at the beginning of 2019[[19]](#footnote-19) in accordance with EU goals. Although mitigation in a broad set of areas is required, it is worth noting the importance of acting on the energy and transport sectors as they represent almost 80% of total direct emissions in the territory (40% and 37%, respectively, in 2016). Implicitly, this involves reducing the mass tourism-induced human pressure which an economy’s diversification built on promoting activities having a lower carbon footprint will undoubtedly contribute to. Within a framework of a more diversified economy, the tourism sector’s strategies aimed at reducing its emissions are also necessary. In this sense, some airlines, cruise liners and establishments are already committed to achieve carbon neutrality by putting emphasis on reducing energy consumption through efficiency improvements and a rise in renewable energy use. The case of Artiem Hotels in Menorca is outstanding in this regard. This family enterprise has reduced by 14% the CO2 emissions of all its establishments in five years and pursues to reduce them by 80% in an eight year time period.[[20]](#footnote-20) However, technological innovation will not be sufficient to effectively decarbonise tourism as behavioural and structural changes at a large scale are required (Simpson et al. 2008; Becken 2019). In line with this, latest debates on tourism, which have been intensified by the Covid-19 pandemic, interestingly advocate for relocating tourism in search of other alternatives involving a reduction of the ecological and social conflicts associated with the exponential growth of the sector (Cañada 2014). Labelled as “proximity”, “low-carbon” or “slow” tourism, such alternatives aim to rethink tourism to make it more sustainable (Becken 2017; Lee et al. 2018; Gössling and Higham 2020; Romagosa 2020).

In this context, both designing an R&D&I Plan oriented to acquire knowledge on potential mitigation strategies and developing a system to measure emissions also become essential to achieve mitigation targets.

Table 5 reports the mitigation policies which are recommended to effectively address all the impacts considered of concern:

(Insert Table 5)

**6.2 Adaptation policy recommendations**

Adaptation policies should serve to make more resilient the ecosystems, the economy and the society of the Balearic Islands as well as to acquire knowledge oriented to keep or even increase social welfare. Such policies have to be adequate to cope with the expected priority CC impacts by 2030. So the design of a Plan for Adaptation based on specialized research on both the CC effects on natural and human systems and the vulnerability of the different socioeconomic sectors is highly recommendable. The plan should be focused on the impacts requiring most urgent action such as temperature increase, sea level rise, threats to biodiversity, human health, water resources and risks related to infrastructures-, and be built on an in-depth analysis about which activities can better adapt to CC.

In this sense, the high vulnerability of tourism to global warming emerges as another argument in favour of the economy’s diversification. Put it another way, diversifying the economy also represents a necessary adaptation strategy for the Balearic Islands to become more resilient. Even more, basing diversification on the promotion of activities with a lower carbon footprint (as explained in section 6.1) can further increase the destination’s resilience. In parallel with such a diversification process, it is also recommendable the different sectors engage in adaptation strategies to better cope with CC. And tourism is not an exception. Accordingly, retreat measures or relocating coastal firms, infrastructures and facilities and even residential populations from one area to another one are examples of adaptive responses to CC (Wall and Badke 1994; [Linnenluecke](https://www.sciencedirect.com/science/article/abs/pii/S0959378010000944?via%3Dihub#!) et al. 2011; [Mycoo](https://onlinelibrary.wiley.com/action/doSearch?ContribAuthorStored=Mycoo%2C+Michelle) 2013; Fatorić et al. 2017) which become interesting strategies to follow in “sun & beach” tourism destinations. Creating shadow areas to counteract the expected tourists' thermal discomfort due to the increase in the temperature (e.g. designing green environments surrounding the buildings) or diversifying the tourism product in favour of less climate-dependent activities (e.g. conservation strategies of natural assets or improvement of the cultural offer) are other examples of adaptation strategies which could also be undertaken (Bujosa et al. 2018).

Undoubtedly, creating an Observatory of CC Impacts to better forecast the expected impacts and closely monitor the actual ones upon all relevant sectors would be very helpful. Such an Observatory would provide essential data to devise efficient policies to prevent and address the deleterious CC effects. Designing an R&D&I Plan allowing for the development of adaptation policies being suitable for the Balearic Islands would also be recommendable.

The adaptation policies recommended to cope with CC are reported in Table 6:

(Insert Table 6)

**7. Conclusions**

For the Balearic Islands, this paper discusses the observed and projected changes in the most relevant atmospheric and marine variables due to the higher GHG emissions concentrations in the atmosphere. It also analyses the derived priority impacts on natural and agricultural and livestock systems, water resources, energy and infrastructures, as well as on human health, the economy, human rights and the socio-political system. Though all these hazards are expected to be more intense in the second half of the 21st century, it is argued a fragile territory such as the islands should design mitigation and adaptation plans before 2030 on the basis of the priority impacts identified in this paper for them to better cope with CC.

The analysis presented here shows higher temperatures, heat waves, the reduction of the average precipitation, the increase in evapotranspiration, the droughts, the sea level rise, and the increase in ocean acidification and marine deoxygenation as the main CC-associated threats. The high vulnerability of the islands’ ecosystems and the human systems depending on them calls for an urgent set up of CC policies if welfare of current and future generations is to be ensured. We identify important threats for the insular economy as it strongly depends on mass tourism, which is not only highly vulnerable to CC and pandemics but also a big contributor to the planetary environmental problems due to its high ecological footprint. This can put into risk the islanders’ wellbeing if the economy is not diversified in an attempt to make it more resilient and lesser emitter of GHGs. CC will have an important impact on biodiversity and the supply of services by terrestrial and marine ecosystems which importantly contribute to the current “sun & beach” tourism model of the Balearic Islands (e.g. landscapes, forests, sandy beaches, *Posidonia* *oceanica* meadows).

Under recognition that ecosystems provide the society with goods and services that are not only economically valuable but especially crucial for life reproduction, the economy’s diversification should be oriented to promoting an economic system which is environmentally-friendly and protects the islands’ heritage and idiosyncrasy. Diversification of the current socioeconomic model will facilitate the implementation of the needed adaptation and mitigation measures. In this sense, we identify ten areas which should be object of mitigation action related to terrestrial and marine ecosystems, water resources, energy, infrastructure and urban planning, sustainable mobility, human health, economy, waste, law and education. Terrestrial and marine ecosystems, infrastructure and urban planning, energy, human health, economy and education have also been identified as major areas for adaptation action.

Though the analysis has been focused on the Balearic Islands, their Mediterranean environmental conditions, and hence the particular CC threats they face, also make it interesting to other Mediterranean insular regions, and in particular, to those that also have a mass-tourism based economy. So, the conclusions drawn here can serve as a guide for them when it comes to design CC mitigation and adaptation policies.

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**9. Conflicts of interest**

The authors declare that they have no conflict of interest

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1. All the identified CC impacts are reported in the Table I provided as Supplementary Material (Online Resource 1). [↑](#footnote-ref-1)
2. This was especially true for some expected impacts on human systems. [↑](#footnote-ref-2)
3. Expert opinion elicitation has been frequently used to predict the effect of CC on ecosystems, technology or management, among others (Barons et al., 2018; Dessai et al., 2018; Few et al., 2018; Verdolini et al., 2018; Wilcox et al., 2018; Reside et al., 2019; Abad et al., 2020). [↑](#footnote-ref-3)
4. The level was assigned depending on the robustness of the projections. [↑](#footnote-ref-4)
5. Vulnerability was related to the sensitiveness and capacity of the system to cope with CC as well as its dependency on other systems. [↑](#footnote-ref-5)
6. The values of the expected magnitude variation and its probability of occurrence for all the identified hazards are reported in Table I provided as Supplementary Material (Online Resource 1). [↑](#footnote-ref-6)
7. The very few impacts classified into these categories are reported in Table I provided as Supplementary Material (Online Resource 1). [↑](#footnote-ref-7)
8. As an example, this consumption represented the 2.6% of the archipelago’s annual electricity demand during the last drought period experienced by the region in 2016. [↑](#footnote-ref-8)
9. Fossil fuel burning emissions are also expected to reduce both labour productivity and the facilities and infrastructures’ capacity due to health impacts and the acceleration of corrosion processes, respectively. [↑](#footnote-ref-9)
10. It is worth noting the economic value of recreational fishing is five times higher than that of commercial fishing in Mallorca (Morales-Nin et al. 2015). [↑](#footnote-ref-10)
11. Together with CC, the Covid-19 pandemic represents another global environmental effect from the expansion of human activities (Perkins et al. 2020). [↑](#footnote-ref-11)
12. Impacts on health and port infrastructures due to more atmospheric CO2 can also increase public expenditure. [↑](#footnote-ref-12)
13. See, for instance, the 2019 Report on a safe climate, A/74/161, and the pioneering report on Human Rights and the Environment submitted by Fatma Zohra Ksentini to the Commission on Human Rights in 1994, UN Doc E/CN.4/Sub.2/1994/9. [↑](#footnote-ref-13)
14. See the ruling by the Supreme Court of the Philippines in the Minors Oposa case, in 1993 (G.R. No. 101083 July 30, 1993). More recently, Juliana et al. v The United States of America et al., Opinion and Order, 10 November 2016, p. 32., or Friends of the Irish Environment et al. v. Fingal County Council et al., High Court of Ireland, Judgment, 2017 No. 201 JR, 21 November 2017, §264. [↑](#footnote-ref-14)
15. See, among others, Taskin c. Turquie, 46117/99, [2004] ECHR 621, and Corte Interamericana de Derechos Humanos, Opinión Consultiva OC-23/17 de 15 de noviembre de 2017. [↑](#footnote-ref-15)
16. Among others, the 1948 Universal Declaration of Human Rights, the 1966 Covenant on Civil and Political Rights, the 1989 Convention on the Rights of the Child or the 1950 European Convention on Human Rights. [↑](#footnote-ref-16)
17. As established by Article 10.2 of the 1978 Spanish Constitution. [↑](#footnote-ref-17)
18. The extreme right party Vox obtained 11,30% of the ballots in April 2019 and rose to 17,08% in November 2019, up from 1,53% in the 2014 European elections. Source: http://www.infoelectoral.mir.es/. [↑](#footnote-ref-18)
19. 10/2019 Law of Climate Change and Energy Transition, 22nd February (https://www.caib.es/sites/institutestudisautonomics/ca/n/llei\_102019\_de\_22\_de\_febrer\_de\_canvi\_climatic\_i\_transicio\_energetica/) [↑](#footnote-ref-19)
20. Artiem Hotels presented both its mitigation strategy and its Sustainability Artiem 8/80 project at the 2018 First Conference on CC in the Balearic Islands organized by the LINCC UIB. It also showed the case of the Hotel Artiem Audax which has reduced its emissions by 44% since 1999 (<http://lincc.uib.eu/conferencies-jornades/primeres-jornades-sobre-canvi-climatic-a-les-illes-balears/resum-i-conclusions-de-les-jornades/#section4>. Accessed 13 May 2021). [↑](#footnote-ref-20)