Second Report
on Climate Change in Catalonia

Generalitat de Catalunya

Institut d'Estudis Catalans

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Executive summary

The present synthesis reports the main findings of the second assessment of climate change in Catalonia. Using extensive data from the period 1950-2008, it has been found that the maximum temperature increased during this time at an approximate average of +0.25°C / decade, while the minimum temperature rose by +0.17°C / decade. In Catalonia as a whole the temperature increased at +0.21°C / decade. The geographical distribution of this increase was fairly uniform, although observatories in the north-east show less marked rising temperature trends. Studies of the evolution of rainfall in Catalonia show no significant trends of variation over the past century. In the period 1990-2007, greenhouse gas (GHG) emissions in Catalonia increased by 43.2% (40.5 to 58.1 Mt CO_2 eq.). Taking 1990 as the baseline year, such emissions accounted for 14% of those in Spain, where an increase of 52.6% (289.8 to 442.3 Mt CO_2 eq) was recorded in 2007. In Catalonia, emissions rose from 6.57 tonnes of CO_2 equivalent per capita for the base year 1990 to 8.05 in 2007. Such emissions were higher in Spain as a whole, rising from 7.26 tonnes of CO_2 eq per person in 1990 to 9.79 tonnes in 2007.

Short term projections in Catalonia indicate that in the coming years (to 2020) temperature will tend to rise, which could lead to a temperature 0.5°C higher than the average of the late 20th century. Annual average rainfall could decrease by up to 10%, especially in spring and autumn, and more markedly in the Pyrenees. Several studies suggest that by the middle of the 21st century temperature could rise by up to almost 2°C compared with that of the late 20th century. These increases would probably be higher in summer than in winter, and slightly lower in spring. The increases would be evenly distributed throughout Catalonia territory, albeit somewhat lower along the coastal areas.

Simulations for the year 2080 show increases in the annual growth period of Catalan forests from 1-2 months with respect to the length of such periods in 1990. The lengthening of vegetative activity will also result in a longer water demand period, a process which will also interact with other projected trends such as reduced rainfall, reduced soil water reserves (by up to 35%) and an increase in the respiration of the system (by up to 23 %). The overall effect is that by the end of this century a drastic decline in the already low sink capacity of the Catalan forests is expected. Carbon sequestration in Catalan forests accounts for 8% of annual CO_2 emissions in Catalonia.

Among the observed phenomena in Catalonia that potentially can be linked to climate change are the occurrence of exceptionally high temperatures, including higher frequency of heat waves, and the increase of long periods without rain. However, no increase has been found in the number of days with heavy rain or in the trend of maximum flash rains in 24 hours. Results from the models reviewed indicate that this trend is likely to increase, although the uncertainties in this regard are still very high. While there has been no significantly increasing trend in the occurrence of extraordinary floods, they are likely to produce higher negative impacts, as they tend to occur near the coast where most of the population is concentrated (Figure 8). This is also likely to happen with snow avalanches, due to higher exposure. No other significant trends concerning other natural hazards, such as tornadoes, or violent thunder, wind or hail storms, have been observed.

Future scenarios for the 21st century in Catalonia indicate a trend toward decreasing water availability combined with increased demand for water. Climate change is likely to alter the hydrological cycle. Lower river flows, decreased groundwater recharge and changes in various biogeochemical processes all affect water quality. Several interventions, including artificial recharge of groundwater, investment in water infrastructures for water treatment, efficient interconnection of existing water networks and dam regulation could reduce territorial vulnerability to climate change and ensure the performance of expected water system functions in the future.

Global warming is apparent in the Mediterranean with a rise in sea level over the last century and, in particular during the past 30 years, an increase in surface water temperature of about 0.7°C, gradual salinization of medium and deep sea water levels, and greater stratification. Catalan sea waters have also been affected by these processes which include: (a) an increase in thermopile marine species and a negative impact on species needing more temperate water, with its potential effects on commercial fisheries; (b) mass mortality of sessile coral invertebrates, (c) enhanced growth rate of phytoplankton and smaller herbivores, and gelatinous carnivores such as jellyfish, (d) a decrease in the ability of the Mediterranean to capture atmospheric CO_2. Further research and observation, the setting up a network of marine conservation areas, and integrated measures inland to prevent over-exploitation of groundwater resources and pollution are required. Climate change is also likely to affect coastal dynamics and exacerbate coastal erosion and water quality due to changes in the direction and intensity of waves as well as other closely intertwined processes. The end result could lead to serious consequences, especially in the areas most subject to human pressure and infrastructures.

In regard to terrestrial ecosystems and biodiversity, it has been estimated that in Catalonia spring now arrives earlier and winter arrives later, with the result that the growing season has lengthened by four days per decade over the past fifty years. This has important implications for biodiversity and the environment, e.g., some species have shifted to higher latitudes and altitudes. These changes affect the species composition of plant, animal, and microbial communities and therefore also provoke numerous functional changes such as the following: lower levels of soil enzymatic activity, nutrient recycling, phosphorus accumulation in plant tissues and forests, and the CO_2 sequestration capacity of plants and forests.

In Catalonia, nearly 80% of agricultural land (the layer of soil at a depth of between 0 and 30 cm) contains carbon concentrations of between 0.6% and 2.3%, while in soils with higher irrigation (76% of the samples) these figures rise to 1.2-2.3%. Despite the limitations of the available information, stocks of organic carbon in the soils of the agricultural provinces of Lleida and Tarragona show concentrations of 90-100 mg / ha down to a depth of one meter, although approximately half of it is located within the first 30 cm (45-56 mg / ha). Any alteration that favours degradation of this layer of soil can result in significant emissions of CO_2. Overall, the addition of organic waste into the soil in Catalonia represents an input of about 100,000 mg of nitrogen per year. The nitrogen used in fertilisers leads to a direct and indirect increase in GHG emissions, although it also augments biomass production and therefore CO_2 sequestration. It is important to bear in mind that the overall goal of fertilising soils should be that of maintaining or increasing the amount of organic matter in the soil. The use of organic waste is one of the best alternatives for doing so, provided appropriate measures are also adopted to maximize the beneficial effects and mitigate GHG emissions. It is worth noting that the reforestation of abandoned cultivation terraces (over a period of over 50 years) in wet mountain areas in Catalonia has allowed the gradual recovery of nearly half of the original carbon content of these soils.

During the last two decades several new institutional arrangements to cope with climate change have been made at the EU, Spanish and Catalan levels. Climate policy in Catalonia is now designed and co-ordinated by the newly created Interdepartmental Climate Change Commission and the Catalan Climate Change Office. While the former is composed of the different regional ministries of the Catalan Government and has a more strategic function, the latter focuses on the actual implementation of the Catalan Mitigation Plan, which highlights and supports the application of key strategic, cross-sectoral emission reduction actions during the period 2008-2012. In Catalonia, active participation in the EU Emission Trading Scheme (EU STS) has been limited to large companies, mainly from the power sector. Overall, the emissions of EU STS-regulated industries have fallen steadily as a result of the global economic crisis, except in the case of sectors to do with energy production.

Agro-food systems also play an important role in both climate mitigation and adaptation. In Catalonia, the existence of a great diversity of landscapes and production processes creates a situation whereby climate change can lead to certain beneficial effects in terms of production processes in some territories, but may be detrimental in others. Changing rainfall regimes and rising temperatures could negatively affect the production of certain crops, especially in the drier areas where irrigation systems are not in place – or will require a more intense use of water and resources where these systems already exist. Climate variability may increase the risk of late frost as well as the occurrence of extreme events, impinging negatively on the production of vegetables in the irrigated areas. However, the fact that Catalonia has a great diversity of vegetables and processes constitutes a potential opportunity for its adaptation to changing climatic conditions. Integrated responses that take into account all the cycles related to the agro-food production and consumption, as well as their associated ecosystem functions are required in order to deal with the emerging risks and opportunities posed by climate change.

Nevertheless, Catalonia is very dependent on foreign energy sources. Such dependency is likely to be intensified in the near future due to increased internal demand for energy as well as dwindling internal energy production capacity. Transport and electric power generation are the two sectors which, according to the Catalan Energy Plan 2006-2015, are likely to produce most GHG emissions. The predicted increase in the average temperature of Catalonia will result in the loss of efficiency in many energy systems, an increase in energy demand for cooling (not offset by decreased demand for heating), increased demand for water and a reduction in the transport capacity of existing power lines.

Catalan industry has made an important effort to reduce GHG emissions, to the extent that it has met its obligations in terms of GHG emission allowances as laid down in the European Emission Trade System Directive. For instance, major investment in the cement sector has improved the overall energy efficiency of this sector by about 40 per cent in recent years. Measures aimed at improving efficiency are perceived to be the most effective in curtailing GHG as they also result in the reduction of economic costs. Electric power generation is the only sector which has surpassed its allowed emissions, although it is also true that this sector has reduced its overall emissions. Diffuse emissions have also decreased. Altogether 2.7 Mt CO_2 equivalent of waste-related GHG emissions were generated in 2005, representing 4.55 % of the total, of which 2.87 % was generated by landfills and 1.34% by wastewater treatment. Reducing GHG emissions from waste will require, above all, a decrease in waste flows where waste is produced, especially in construction, livestock farming, urban solid waste, industrial waste and urban and industrial wastewater. This should be complemented with a reduction of secondary waste, which is the type of waste that has increased most in recent years. Reducing GHG emissions from the inter-municipal transport of waste will become increasingly important in terms of climate mitigation. Improving the efficiency of biogas collection at landfills could contribute notably to GHG reduction in this sector.

Climate change is bound to affect tourism in Catalonia in different ways depending on the different types of tourism and the possible choices and actions taken to adapt to these changes. Traditional sun and beach tourism will not be much affected by global warming, as the seasonal periods in which tourism services are provided may be changed or extended. Additional climate pressures on coastal tourism, such as reduced freshwater availability or a rise in sea level, may be dealt with to some extent by technological solutions such as desalination plants or sea defence infrastructures. However, energy availability (e.g. for water desalination, air conditioning) will be a key limiting factor for the further development of this sector in Catalonia. On the one hand, winter ski tourism appears to be the most vulnerable modality to climate change, but on the other, it is also the sector which is already taking the most decisive actions to adapt to the new situation. Climate change may affect other minority types of tourism in Catalonia, such as those focused on rural locations, or the cultural and natural heritage, in so far as global warming generates additional negative impacts such as forest fires, new plagues or other disturbances to the natural systems.

The effects of climate change on health depend on a number of geographical, social, and economic factors. However, it is likely that climate change will impinge negatively on the atmospheric conditions that have to do with non-infectious diseases. Patients with chronic or acute respiratory problems and blood circulation conditions as well as older population may be especially vulnerable to climatic changes. All in all, the most notable phenomenon which is likely to have the biggest impact on the Catalan population is the greater frequency of extreme heat events due to rising temperatures. The increasing frequency and severity of heat waves may result in a generalised increase in the aggressiveness of urban pollutants and, in turn, provoke or intensify heart and respiratory diseases and allergies.

Climate change impacts and responses are also closely intertwined with the processes and policies concerning urban planning and transport. It has been estimated that the movement of people and goods by road in Catalonia generates 103.12 million vehicle-km / day, involving overall consumption of 3,173.45 billion litres of fuel and 11.3 million tonnes CO_2. When other forms of transport are included (air, maritime, railway), transport-related emissions in Catalonia amounted to a total of 15,029.790 tonnes in 2005, which makes this sector the largest GHG emitter (about a quarter of all GHG emissions). In this regard, climate change mitigation and adaptation requires the consideration of different scales, at both the city and regional levels, but also on the scale of neighbourhoods and houses. Current estimates show that integral construction could provide building solutions that would reduce the current energy consumption of conventional buildings by up to 50 % with only 4-7% of additional costs and a return period of 10 years.

A review of existing public opinion polls and the evolution of the print media in Catalonia indicates that climate change has been mainly framed as a mitigation problem, rather than one of adaptation. Yet, until recently, climate change has also mainly been seen as a risk to economic growth rather than as an opportunity for such growth and for investment, although this perception appears to be changing. In this sense, while the economic crisis has lessened the sense of urgency in regard to climate issues, it has also led to the view that dealing with climate change can also be a major factor in helping to resolve the economic crisis. An analysis of the evolution of the number of articles dealing with climate change in the Catalan daily press can be used as a proxy for tracking the development of public opinion and in Catalonia this trend experienced a very marked increase during the period of 1990-2007. A selection of 19 experts' views also reveals notable contrasts between experts and the public in respect of the possibility of successfully dealing with climate change in time. They also express their concerns as to whether Catalan policy-makers and society are taking enough incentives, sufficiently reforming institutions or deploying enough resources to deal with climate change, despite having many options for doing so.

Last but not least, examination of the current state and evolution of climate research production and capacities in Catalonia shows that the number of scientific publications produced by Catalan researchers on climate change cited by Social Citation Index journals increased by 3.5 during the period 2000-2008. In particular, in 2008 a total of 134 scientific articles on climate issues were produced and 46 doctoral theses were submitted on a very wide range of topics. However, little attention is devoted to the study of mitigation and adaptation, or to the analysis of climate change policies. Furthermore, the overall institutional structure that supports scientific climate research in general in Catalonia is still quite fragile and fragmented.

Preface

The First Report on Climate Change in Catalonia was produced in 2005. At that time it was a pioneering experience in Spain, a result of the work of the newly created Expert Group on Climate Change in Catalonia (GECCC). This second report was commissioned by the Interdepartmental Commission on Climate Change (CICC) of the Catalan Government (Generalitat of Catalonia) and, like the first report, it has received the support and encouragement of the Catalan Advisory Board for Sustainable Development (CADS). At a meeting on 18th June 2007, the Commission decided to set up an interdisciplinary working group composed of the CADS, the Catalan Climate Change Office (OCCC), the Meteorological Service of Catalonia and the Institute of Catalan Studies (IEC), which enabled the project to be carried out successfully. This benchmark report, drawn up in 2009-2010, was made possible thanks to the financial collaboration of 'Fundació La Caixa' and the professional support of the Institute of Catalan Studies.

1. Introduction

This report follows, extends, and updates the work carried out in the First Report on Climate Change in Catalonia. Is organized into four major areas:

1) *The scientific basis of climate change*: past climate change trends in Catalonia, assessment of climate balances, regional carbon sinks, and future projections.
2) *Impacts and vulnerability of the biophysical environment*: climate-related risks, impacts and interactions with water resources, coastal and terrestrial ecosystems, soils, biodiversity, and marine ecosystems.
3) *Assessment of different policy and social domains, and economic sectors*: This includes an analysis of mitigation and adaptation policy instruments as well as of the relevant legal framework. The sectors covered include agriculture, energy, industry, waste, health, public perception, transport and mobility, and land use, urban planning and housing.
4) *Analysis of the status of climate change research in Catalonia:* this section highlights the main climate research areas and identifies the leading institutions and possibilities for cross-fertilisation between Catalan institutions and disciplines.

This Second Report follows a methodological approach akin to the one used for the IPCC and it is based on downscaling future scenarios and producing relevant quantitative and qualitative insights on a regional scale. The latest available data for most chapters is for the year 2008. Each chapter has been anonymously reviewed by two independent reviewers. A total of 91 people participated in the production of texts and 50 more were part of the reviewers' team. The present synthesis follows the same structure as the original report (which contains 1152 pages), although some sections contain material from more than one chapter. References to the original chapters are provided at the beginning of each chapter.

II. The scientific basis

II.1. Climate in Catalonia. Past and recent trends[1]

The planet's climatic history has been linked to variations in concentrations of atmospheric CO_2. Although these changes in CO_2 concentration do not seem to have been the original cause behind initial climate variability, different records and models indicate that they were key amplifiers of the intensity of climate changes and in most of the major climate transitions. Changes in atmospheric CO_2 concentration are well quantified over the past glacial-interglacial cycles. There is strong evidence now supporting the thesis that the origin of these changes was in the ocean, in particular in the oceanographic changes which altered the flow of CO_2 between the ocean and atmosphere.

Catalonia, along with the rest of the Mediterranean region, has been very sensitive to such climate changes in the past. It even appears to be the case that the temperature variations during these changes have been more intense than the global average. During the Holocene (the current interglacial period), the most significant changes had to do with variations in the rainfall regime and an intense increase in the aridity of the landscape during the mid-Holocene (7000-4000 years ago). Rapid climatic oscillations also occurred during the Holocene with significant changes in humidity and/or temperature. In general, despite the limitations of existing records, it seems that periods of reduced intensity of circulation in the deep North Atlantic have been associated with relatively cold and arid periods in Catalonia. However, the specific regional characterisation of the changes and the related drivers and components of such long-term palaeoclimatic dynamics needs further research.

At present, Catalonia has a very wide range of average temperatures: from 17°C near the mouth of the Ebro in the south to below zero values in the highest peaks of the Pyrenees. Rainfall also varies widely, with annual averages ranging from less than 400 mm in the dry lowlands of Lleida, to more than 1,250 mm in certain parts of the Pyrenees. In the period 1950-2008, the average annual temperature in Catalonia rose at a rate between +0.18°C / decade and +0.23°C / decade (Figure 1) according to data verified and homogenized from the 13 best temperature series (see Figure 2). The geographical distribution of these changes is fairly uniform, although the observatories in the north-east show less marked increases. The increase per decade for the whole Catalonia was +0.21°C. Using extensive data from the period 1950-2008, it was found that maximum temperatures increased at an approximate average of +0.25°C / decade, while minimum temperatures increased by +0.17°C / decade. Both the maximum and minimum temperature increases are statistically significant in all cases. An analysis of seasonal variations indicated that the increase was more marked in summer (+0.35°C / decade) while autumn is the only season for which the increase was not statistically significant (+0.13°C / decade).

Studies of the evolution of rainfall show no clear variation trends in Catalonia to be sufficiently significant over the past century as a whole or in the second half of the century taken separately. The only clearly distinctive feature is a significant decrease in overall March rainfall during the second half of the 20th century. Analysis of the evolution of the annual and seasonal rainfall at the Southern Ebro Observatory (Roquetes; with data from 1905) and the Fabra Observatory in Barcelona (with a series dating back to 1914), shows no clear trend in the last cen-

1. This section is based on the following two chapters: Cacho, I. 'Els Climes a Catalunya: El Passat' [Climate in Catalonia: the Past]; and Martin-Vide, J., Brunet, M., Prohom, M. and Rius, A. 'Present i tendències recents' [The present and recent trends].

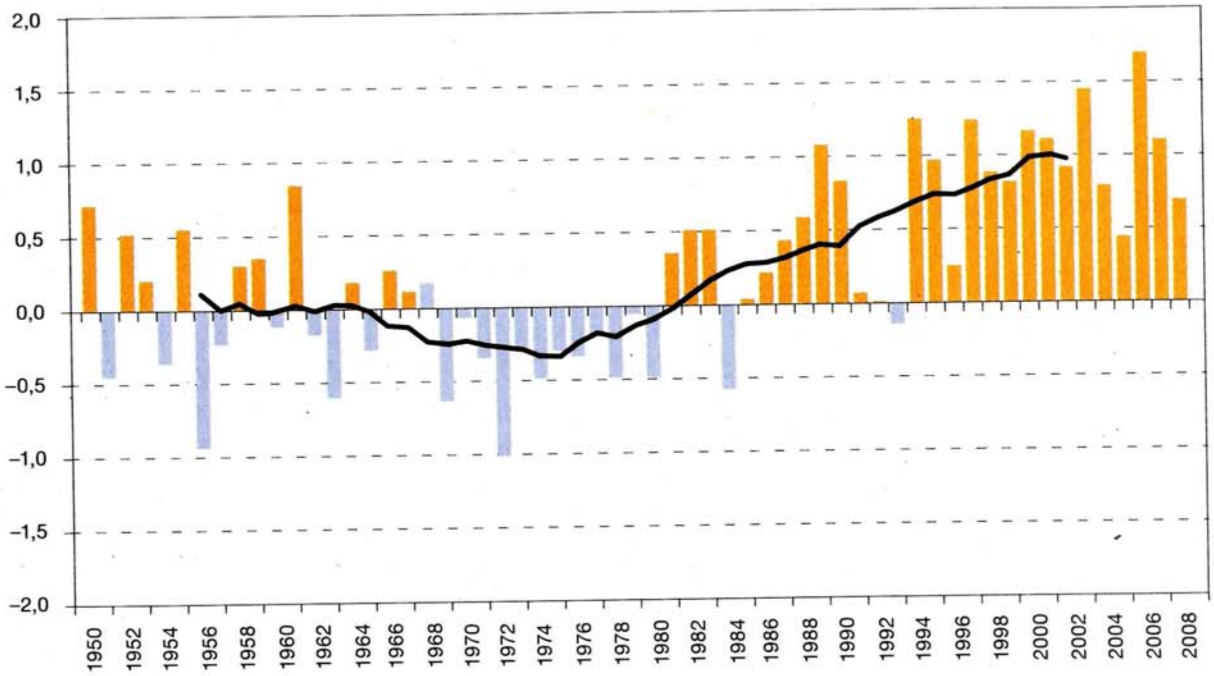

Figure 1. Evolution of the average annual temperature (°C) for the whole of Catalonia during the period 1950-2008, expressed as anomalies with respect to the reference period 1961-1990. The black curve shows the moving average of the thirteen-year period.

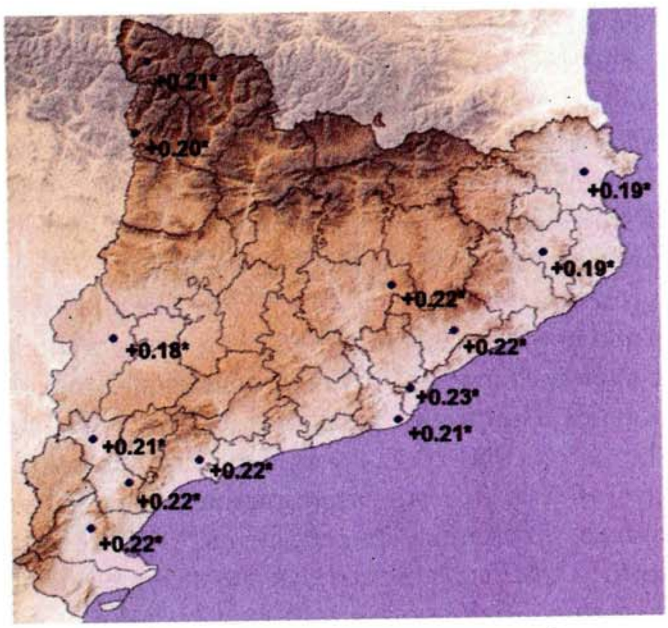

Figure 2. Annual average temperature for the period 1950-2008, expressed as temperature increase per decade (* = statistically significant; source: Servei Meteorològic de Catalunya).

tury. Furthermore, an analysis of data from 121 Catalan observatories reveals that annual rainfall has fallen by 1% (–6.6 mm with respect to the Catalan average for the period 1961-1990, the most remarkable variation being a 22% decrease in spring). However, the variations found are not statistically significant.

The series of average annual hours of sunshine of Catalonia from 6 measurement points during the period 1951-2004, show two clearly contrasting periods: on the one hand, 1951-1983, which displayed a clear drop in sunlight and marked the end to the *global dimming* period, followed by a sharp rise in the *brightening period* of 1984-2004. The partial trends for both sub-periods are significant: –50.2 hours / decade and +109.4 hours / decade respectively. Seasonally, spring sunshine has increased more clearly since the 1980s, and especially in March.

Analysis of the indices of climate extremes at the Ebro (1905-2008) and Fabra (1914-2008) observatories shows a decrease in the frequency and duration of cold periods, an increase in the frequency, intensity, and duration of warm periods, and a certain increase in the intensity of rainfall. Annual rainfall is concentrated into fewer days, although this does not mean that there is less accumulated rain annually. Overall, the results of the trends in climatic variables in Catalonia are consistent with those in the IPCC Fourth Assessment Report.

II.2. Carbon balances[2]

Carbon dioxide (CO_2), the main gas creating human disturbance in the climate system, has increased globally by 38% since the industrial revolution and contributed two thirds of the overall observed warming during the last 100 years (0.8°C). Since 2000 the growth rates of emissions have been unprecedented and have surpassed the United Nations' most pessimistic projections. Taking 2°C as the upper threshold on global warming needed to prevent dangerous interference with the climate system, some studies state that in order to have a 50% certainty that this limit is not exceeded, emissions must be kept to no more than 500 Pg C. This requires a global reduction rate of CO_2 emissions of 6 % per year.

Sector/GHG emissions (Kt CO_2 eq)	Baseline year	1990	1995	2000	2005	2006	2007
Energy production	26,169	26,169	31,698	34,714	43,946	42,298	42,556
Non-energy industrial processes	7,169	5,019	7,472	9,706	5,991	5,914	5,935
Use of solvent and other products	245,000	245,000	226,000	285,000	265,000	270,000	296,000
Agriculture	5,061	5,061	5,254	5,956	5,591	5,509	5,584
Waste treatment	1,869	1,869	2,587	3,078	3,405	3,531	3,646
Total	**40,513**	**38,363**	**47,236**	**53,739**	**59,198**	**57,523**	**58,017**
Percent with respect to baseline year	0 %	– 5 %	17 %	33 %	46 %	42 %	43 %

Table 1. Estimated total GHG emissions by sectors in Catalonia.

In the period 1990-2007, greenhouse gases (GHG) emissions in Catalonia increased by 43.2% (40.5 to 58.1 Mt CO_2 eq.). Taking 1990 as the baseline year, these emissions account for 14% of those in Spain, where an increase of 52.6% in 2007 (289.8 to 442.3 Mt CO2 eq) was recorded. In Catalonia, emissions grew from 6.57 tonnes of CO_2 equivalent per capita for the base year 1990 to 8.05 in 2007. The corresponding figures for Spain were higher: 7.26 and 9.79 t CO_2 eq per capita, respectively. (Figure 3).

In Catalonia, the sector contributing most to GHG was power production and processing (73.7% of total emissions in 2007). This sector includes transport (28.1%), manufacturing and construction (21.2%), as well as energy (14.4%). In particular, emissions from the energy production and processing sector increased by 62.8% during the period 1990-2007.

2. This section is based on: Canadell, J. 'El Balanç global de carboni antropogenic' [The global anthropogenic carbon balance] and Baldasano, J. M. & Soret, A. Balanços de Carboni. Emissions [Carbon Balances. Emissions].

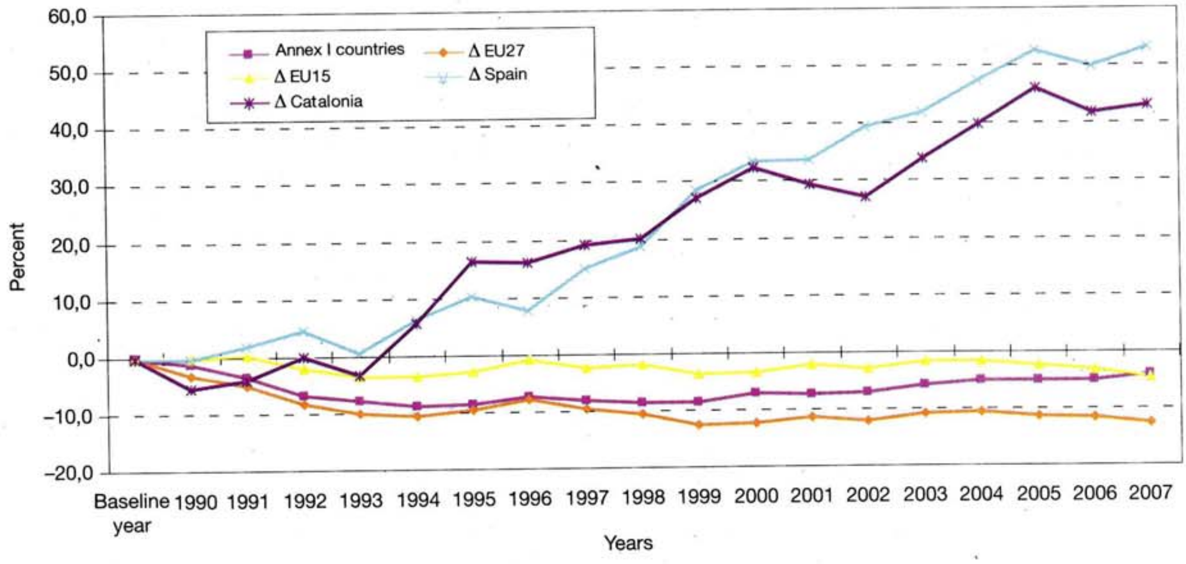

Figure 3. Evolution of GHG emissions in Catalonia, Spain, UE-15, UE-25 and Annex I countries (Source: UNFCC, 2009 and OCCC, 2009).

II.3. Carbon Sinks[3]

Catalonia's forests contain approximately 95 Mm³ of timber, amounting to 97.5 Mt of biomass, 70% of which is in the aerial part and 30% in the ground (coarse roots), equivalent to 49.2 Mt C (1.34 Mt C/ year). Some 21% is oak (*Quercus ilex*), 19% Scots pine (*Pinus sylvestris*) and 13% white pine (*Pinus halepensis*). These three species account for more than 50% of total forest carbon in Catalonia. The species with the highest sequestration capacity in Catalonia is *Pinus radiata*, estimated at 5.42 tC/ha/year, while the species with lowest sequestration capacity is *Quercus suber*, 1.34 t/C/ha/year. In particular, carbon sequestration in Catalan forests absorbs up to 8% of annual CO_2 emissions in Catalonia. (Figures 4 & 5).

The results of process-based models simulations also indicate that forest growth in the foreseeable future of drier and warmer atmospheric conditions will result in reduced fixed carbon rates and increased rates of respiration, which in turn will lead to the reduction of sink capacities of the Catalan forests. As for future projections, comparing the length of the growing vegetative season in 1990 with estimates for 2020, 2050 and 2080, the growing season will begin to lengthen in the southern coastal zone (2020), and increase progressively after that. In particular, simulation results for the year 2080 show increases from one to two months with respect to those periods in 1990. The lengthening of the vegetative activity will also result in a longer period of water demand, a process which will also interact with other projected trends such as reduced rainfall, reduced soil water reserves (up to 35%), and an increase in the respiration of the system (up to 23 %). The overall effect is that by the end of this century a drastic decline in the already low sink capacity of the Catalan forests is expected. To offset their emissions, the inhabitants of Catalonia would require a surface area of about 14.2 million hectares of forest, 12.5 times higher than the currently existing 1.13 million hectares.

Other terrestrial sinks include mountain grasslands and pastures as well as agricultural ecosystems. In the Catalan Pyrenees, the average aerial biomass at the peak of the vegetative cycle in the mountain grasslands is 400 $g \cdot m^{-2}$. In the ground, the accumulated biomass down to a soil depth of

3. Based on: Gracia, C. 'Embornals' [Sinks], with contributions by S. Sabaté, J. Vayreda, T. Sebastià, R. Savé, M. Alonso, and M. Vidal.

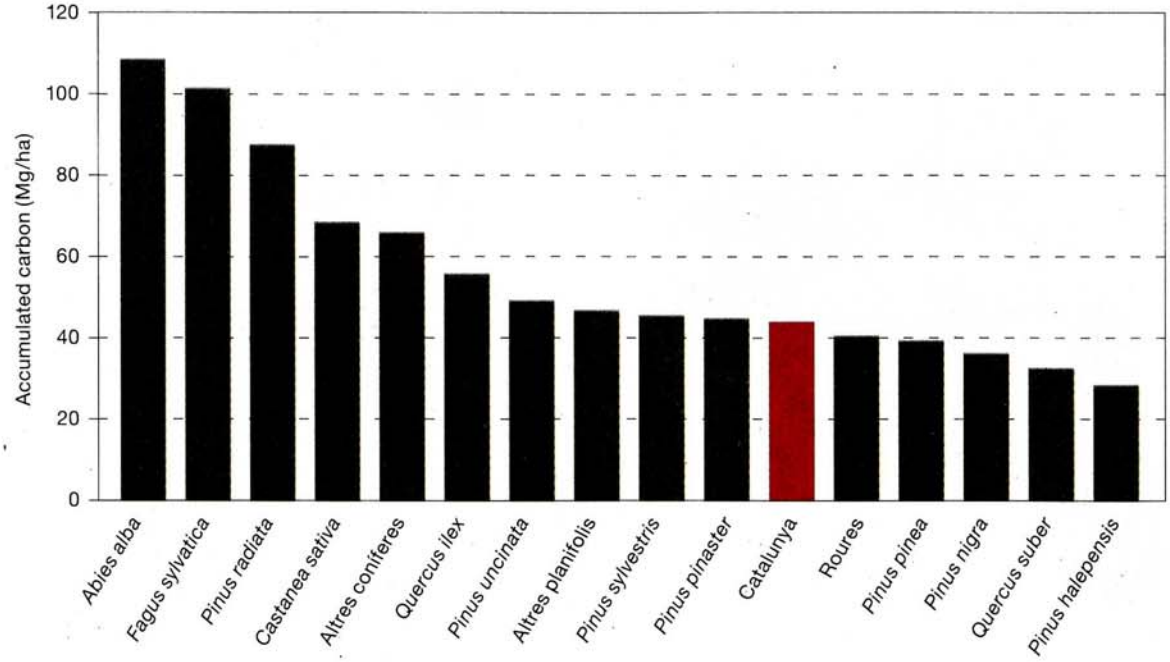

Figure 4. Accumulated carbon per forest area unit in Catalonia of different tree species. Average in Catalonia.

10 cm is 2,000 g, and 3,000 $g \cdot m^{-2}$ to a depth of 20 cm. A study carried out in the Pyrenean meadows at altitudes above 1850 m found between 6 and 30 $kg \cdot m^{-2}$ of organic carbon. The sink capacity of agricultural ecosystems is however extremely dependent on the type of soil management.. The sink capacity of pastures appears to increase as cattle-raising activities increase, but only in areas where the slopes are not too steep.

Finally, the deep ocean waters and coastal sediments are major marine carbon sinks in the sea off Catalonia. Deep water and coastal sediments sequestrate approximately 1.5 Mt/year. The western Mediterranean contains one of the few regions in the world where there is open sea deep convection. This occurs in an area between 41.5° and 42.5° north and 4° and 6° east. The deep ocean waters and coastal sediments constitute the main marine carbon sinks. In the sea off Catalonia, the transport of carbon reservoirs within this site follows three unique mechanisms: winter convection in the open sea, sea cascades of dense coastal waters, and organic matter deposition in *Posidonia oceanica* marine meadows. The Gulf of Lion is a paradigmatic region insofar as these three mechanisms occur there. However, there is much variability in terms of the volume of different water masses sunk year by year, the extent of the convection area and the resulting carbon export rates. Considering the entire area of the Gulf of Lion, the annual transport of carbon due to deep convection in the open sea and dense coastal waterfalls is estimated at 0.5 to 0.8 and 0.6 Mt C, respectively. Taking into account that about 10 per cent of the coastal marine beds are covered by these plants, deposition of coastal sediments is estimated to be about 0.1 Mt C per year.

II.4. Projections and future scenarios[4]

Short term projections in Catalonia indicate that in the coming years (to 2020) temperature will tend to rise, and this could lead to a temperature 0.5°C higher than the average of the late 20th

4. Based on: Calbó, J., Sánchez-Lorenzo, A. Cunillera, J. Barrera-Escoda. A. 'Projeccions i escenaris de futur' [Projections and future scenarios].

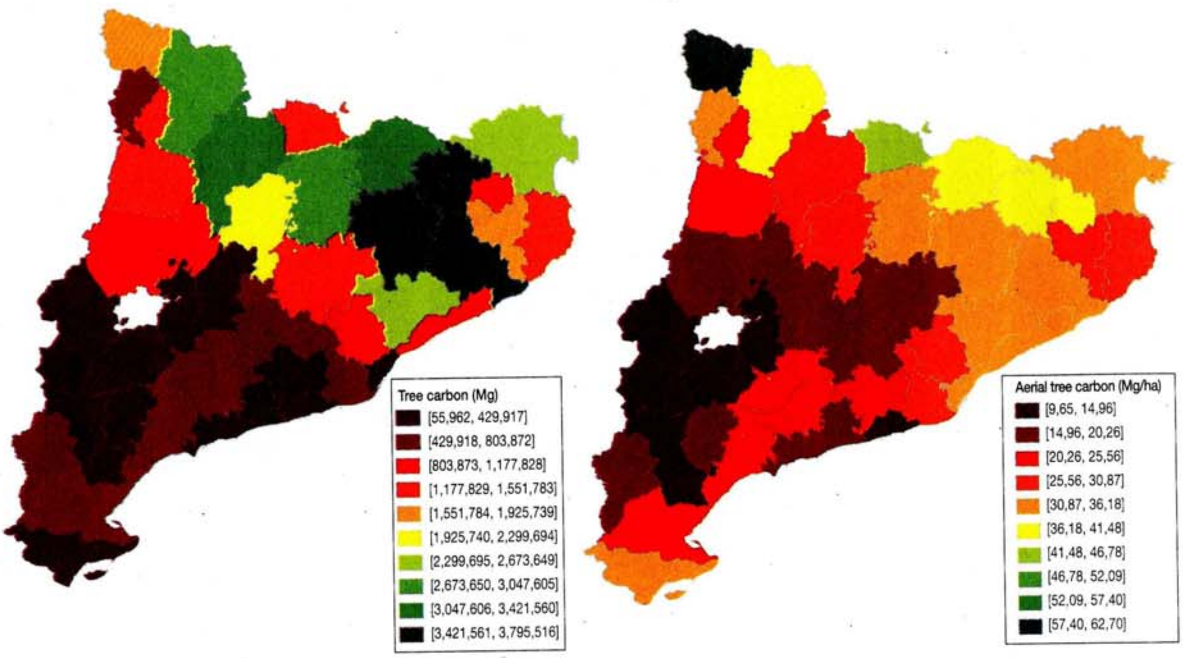

Figure 5. Distribution by *comarques* (administrative districts) of the total carbon stored in trees (in Mg) in Catalonia. The figure on the left shows total carbon accumulated by all species, while the one on the right shows only the aerial carbon accumulated by trees. The difference between north and south reflects the limiting factor of water availability in the process of carbon sequestration and accumulation.

century. Annual average rainfall could decrease by up to 10%, especially in spring and autumn, and somewhat more markedly in the Pyrenees. By the middle of the 21st century, several studies (by the ENSEMBLE project at the Spanish Meteorological Agency, AEMET, and those carried out by the Meteorological Service of Catalonia) indicate that temperature could rise by almost 2°C compared with that of the late 20th century. These increases would probably be higher in the summer than in the winter, and slightly lower in spring. Such temperature increases would be evenly distributed across Catalonia, though they would be somewhat lower along the coastal areas. The seasonal and spatial distributions of rainfall changes are still quite uncertain for the mid-century scenario; different techniques give different results, although the overall rainfall regime is not expected to change very much.

By the late 21st century temperature may be up to 5°C higher than last century, while average rainfall may have decreased by more than 10% (Figures 6 and 7). Increases in temperature would also be higher in summer and affect areas farther from the coast. Rainfall is expected to diminish, especially during the summer, while rainfall may even increase in winter in the Pyrenees.

Several findings and simulations carried out by the Catalan Meteorological Service suggest a possible intensification of the temporal variability of temperature and rainfall. It is difficult to provide a conclusive assessment of extreme events, given the uncertainties reflected in the existing results –some of which are even contradictory. However, there appears to be clear trend towards an increase in heat waves – both in frequency and intensity – and periods of droughts. More intense rainfall that may produce flash floods is a possibility, but no conclusive, unanimous assessment can be provided in this regard for Catalonia. (Figures 6 & 7).

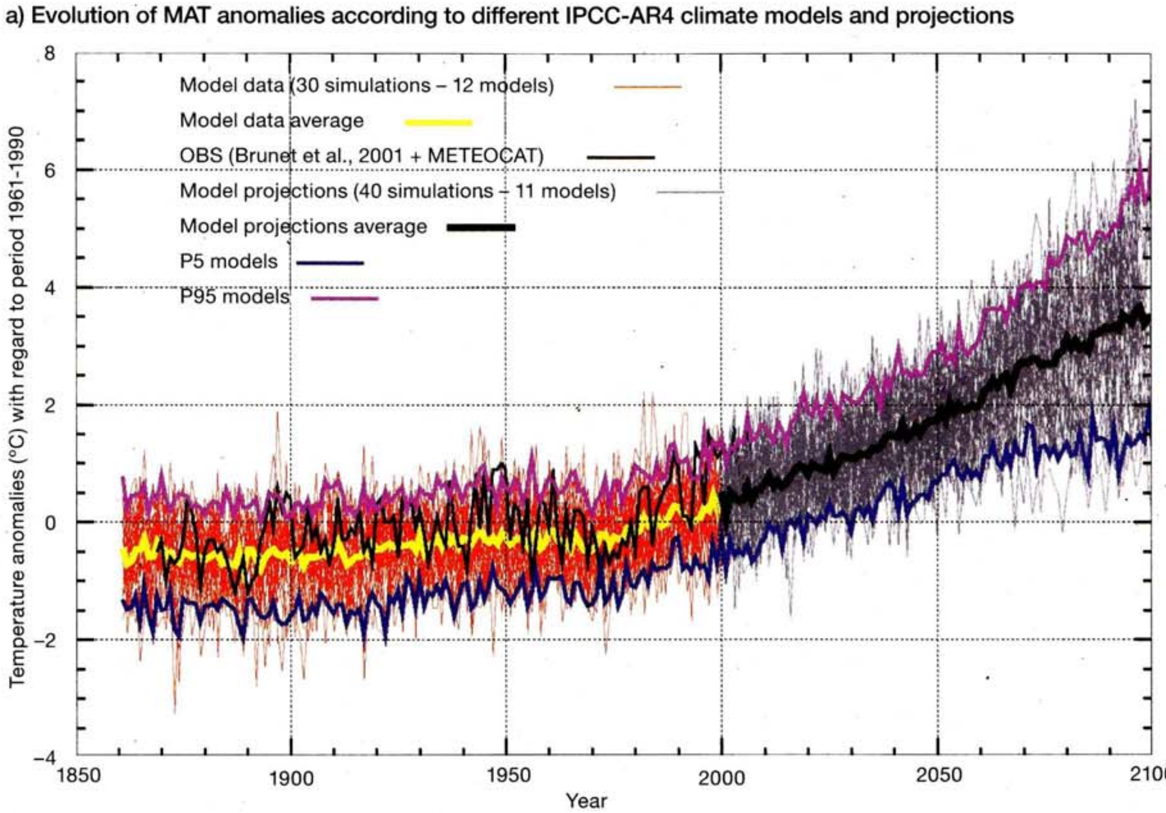

Figure 6. Evolution of annual mean temperature anomalies for the whole of Catalonia for the period 1860-2100 obtained from simulations of different global climate models developed within the fourth IPCC report. The anomalies are calculated with respect to the reference period 1961-1990. (OBS: observed; MAT: mean annual temperature).

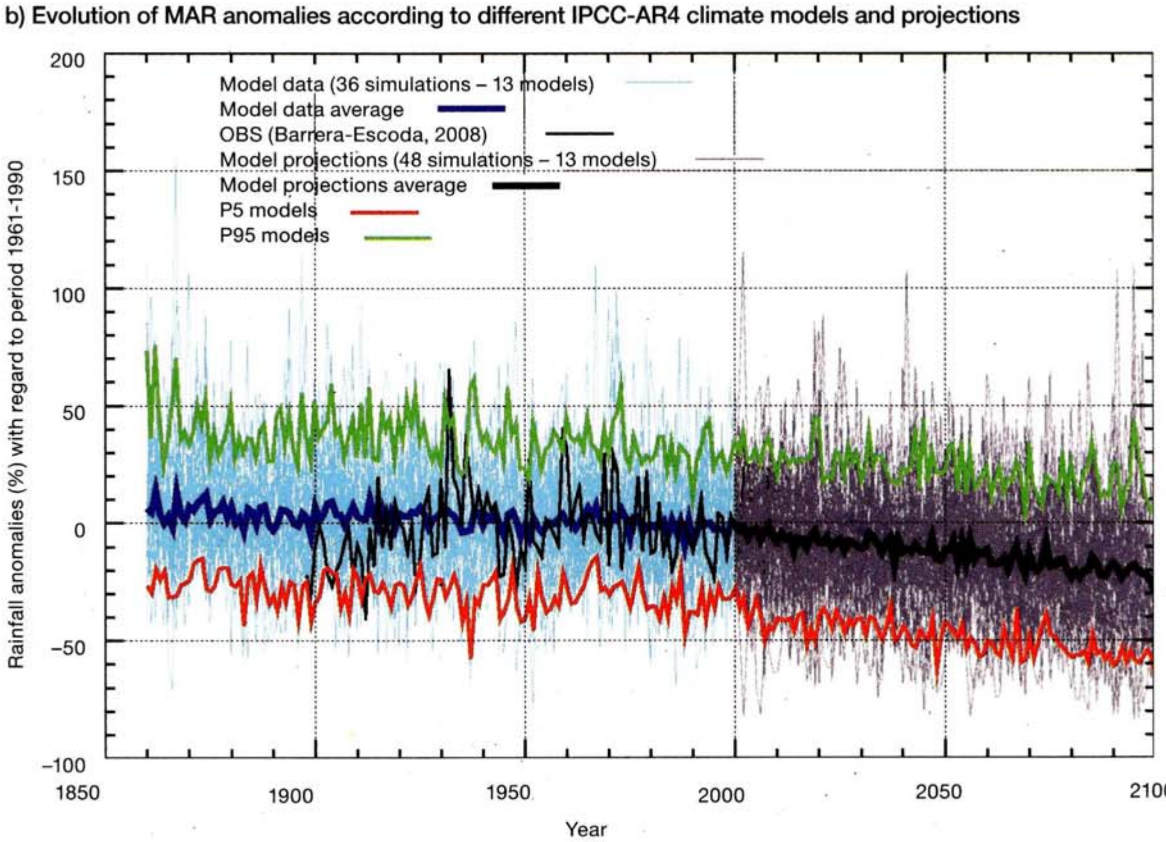

Figure 7. Evolution of annual mean temperature anomalies (a) and precipitation (b) for the whole of Catalonia for the period 1860-2100 obtained from simulations of different global climate models developed within the fourth IPCC report. The anomalies are calculated with respect to the reference period 1961-1990. OBS, observations; MAR, mean annual rainfall).

III. Impacts and vulnerabilities of the biophysical environment

III.1. Risks associated with climate change. Recent trends[5]

Among the observed phenomena in Catalonia that can potentially be associated with climate change are the occurrences of exceptionally high temperatures, including a higher frequency of heat waves, and more long periods without rain. Nevertheless, there has not been an increase in the number of days with heavy rain or in the trend of maximum flash rains in 24 hours. Results from the models reviewed indicate that these dynamics are likely to increase, although the existing uncertainties are still very high. The rise in the number of exceptional flash floods, especially along the coast, is often not so much related to an increased intensity in the amount of rainfall, as to changes in land use and the growth of the urban sprawl. There has not been a significant overall increase in forest fires in Catalonia since 1970, although they did increase in the period 1970-1994, but not afterwards. As forest fires are complex phenomena, they are contingent on many human and biophysical factors, both of which are closely intertwined. Human intervention can trigger forest fires in the first place, but other processes such as the abandonment of farmland and changes in crops and forest structure and distribution, are all crucial to understanding their evolution, regardless of the direct or indirect effects of climate change. This includes the implementation of effective mitigation and preventative measures which may counteract and reduce the likelihood of fires. However, it is obvious that higher temperatures amplify and intensify the drought conditions which are favourable to the occurrence of forest fires.

In particular, it has been found, based on several time series (the longest from 1951 to 2002), that 30% of the area of Catalonia has experienced an increase in the drier annual period of two days per decade. Spring is the season with the biggest increase in the duration of dry spells. From the IPCC A2 scenario it is possible to expect for Catalonia a reduction of between 5-10 per cent of the average rainfall, with a more marked descent along the coast. The rate of increase of very hot days is 4% per decade, being more marked in the *comarques* of El Baix Ebre and El Montsià. The number of tropical nights has also been growing rapidly since the eighties, with an average change across Catalonia of 1.7 days per decade, although on the coast it can be as high as 5 days per decade. The number of consecutive days per year with maximum temperatures exceeding 25°C shows an average trend of 1.9 days / decade, while the number of days exceeding the threshold temperature shows a trend of 2.7 days / decade. However, there is no such significant positive trend in the Pyrenees regions show. Although the number of extraordinary floods has not grown significantly (they occurred throughout the whole of the last century), it is likely that they may produce higher negative impacts, as they tend to occur near the coast, where most of the population is concentrated (Figure 8). This is also likely to happen with snow avalanches, due to higher exposure. No other significant trends have been observed regarding other natural hazards, such as tornadoes, or violent thunder, wind or hail storms.

5. Based on: Llasat, M.C and Corominas, J. 'Riscos associats al clima' [Risks associated with climate change].

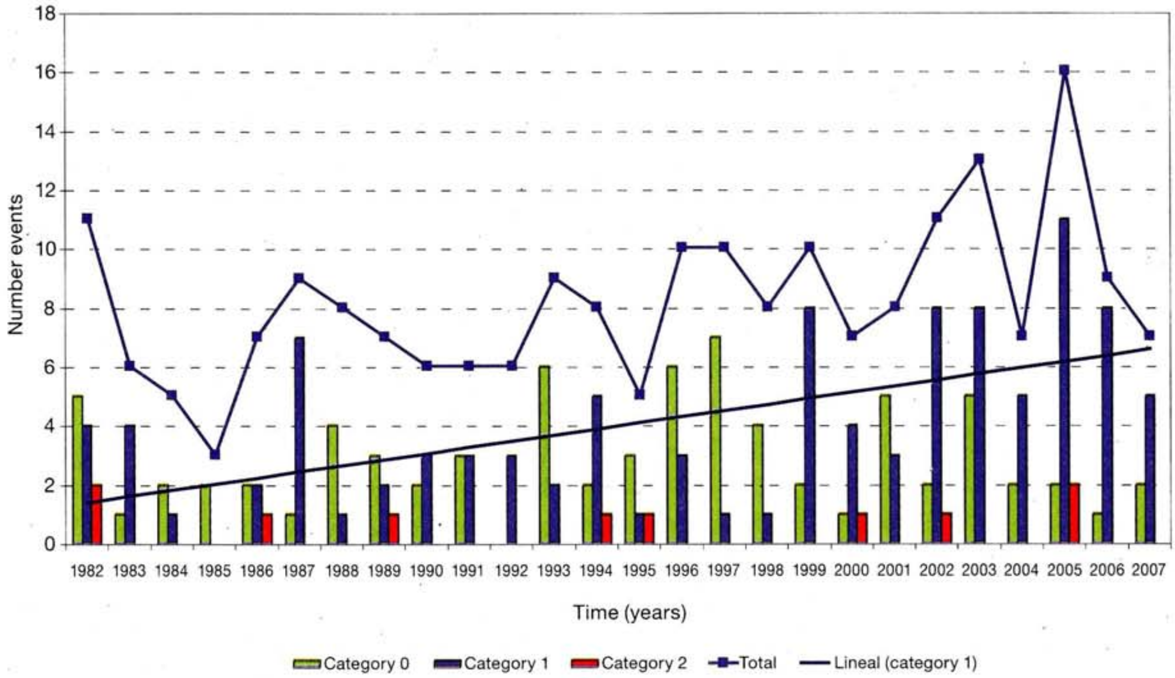

Figure 8. Evolution of floods in Catalonia in the period 1982-2007. (0: ordinary, 1: exceptional, and 2: catastrophic).

III.2. Territorial vulnerability of water resources to climate change[6]

Catalonia's vulnerability to climate change with regard to water resources was analysed taking into account both anthropic pressures, such as increased levels of water exploitation and pollution, and climatic changes, such as variations in temperature and rainfall. This was combined with an assessment of the actual and potential sensitivities and responses of the different parts of the territory to these changes and for water systems to perform their expected human and eco-hydrological functions.

Future scenarios for the 21st century in Catalonia indicate a trend toward decreasing water availability combined with increasing demand for water. Climate change is likely to alter the hydrological cycle. Lower river flows, a decrease in groundwater recharge, and a modification of different biogeochemical processes all affect water quality. The bodies of water most vulnerable to climate change are those which are now employed to supply water for human use and the production of hydroelectric power. These bodies of water are in the upper system catchments of the Llobregat and Ter rivers.

Regarding water quality, loss of the dilution capacity of rivers is likely to be more severe in those stretches of the river system with intense urban and industrial discharges, in particular, those of the lower and middle sections of the Llobregat, Ter, Fluvià, Tordera, and Francolí river basins and the lower reaches of the Ebro. In these cases, adapting to the new scenarios will require greater investment in water treatment plants and stricter control of discharges. The new climatic conditions may also dissolve and affect the current composition of pollutants now present in a solid form in sediments and transfer them to the surrounding hydrological environment.

Climate change may also increase the vulnerability of groundwater masses. However, in Catalonia, the possibility of artificially recharging groundwater may reduce the vulnerability of the aqui-

6. Based on Pla, J. M. 'Vulnerabilitat territorial dels recursos hidrològics al canvi climatic [Territorial vulnerability of water resources to climate change].

fers which are most dependent on direct recharge from rainfall. In some cases, the interconnection of water network infrastructures for the supply and regulation of existing dams might ensure the performance of water system functions in the near future. Furthermore, it is expected that in the second period of implementation of the Water Framework Directive (beginning in 2017), climate considerations will be increasingly incorporated into the drawing up of water river basin management plans.

III.3. Marine ecosystems, climate variability and the Catalan coast[7]

Despite the limited data available, present records indicate that global warming is reflected in the Mediterranean by a sea level rise over the last century and, in particular during the past 30 years, by an increase in surface water temperature of about 0.7°C (Figure 9), gradual salinification of the medium and deep levels of sea water, and enhanced stratification.

The models predict that these trends will be maintained. In fact, it is expected that the Mediterranean will follow changes found in periods of the prolonged positive phase of the North Atlantic Oscillation (NAO) represented by a noticeable decrease in rainfall and wind, a warming of surface water and a lengthening of the period of stratification. Visible effects of these changes on the Medi-

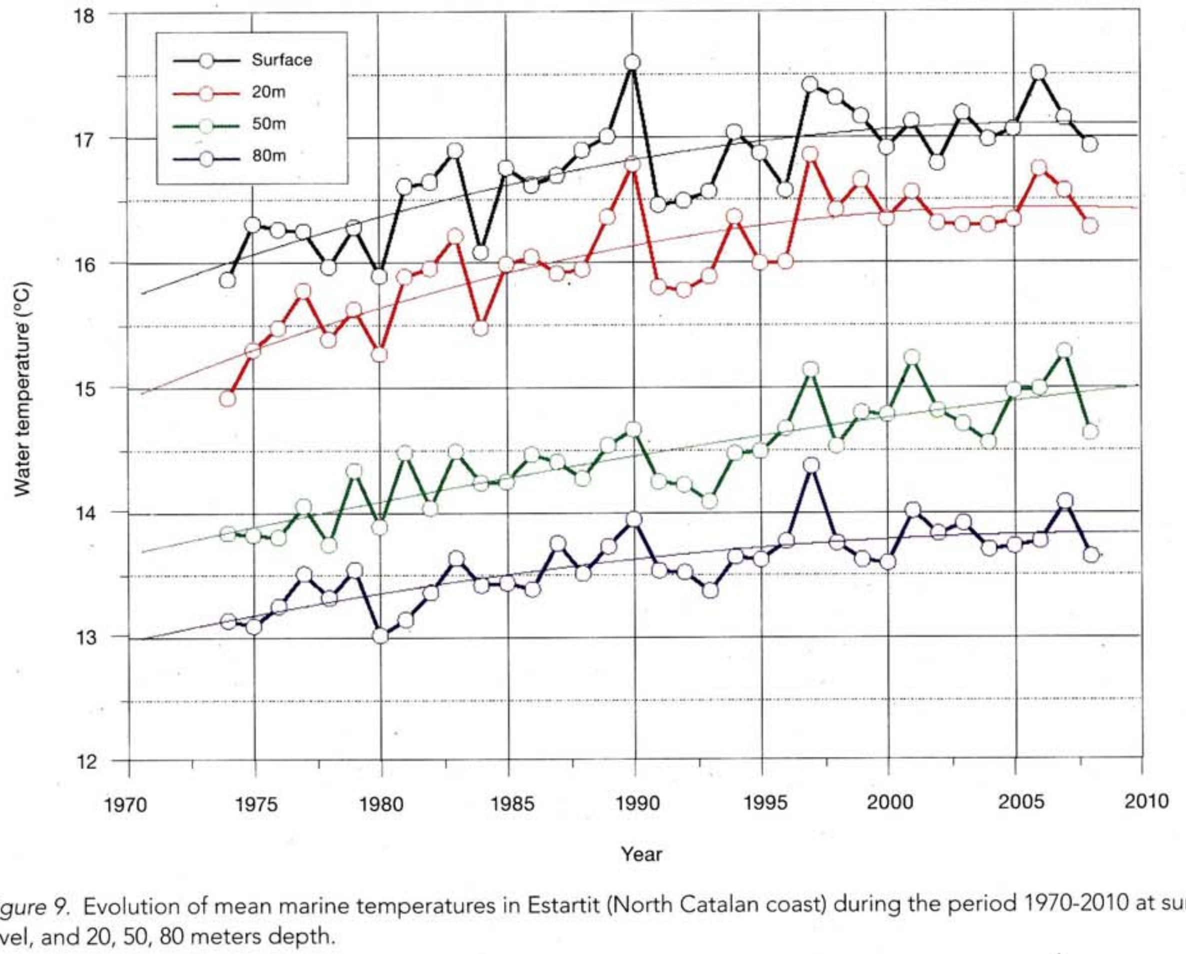

Figure 9. Evolution of mean marine temperatures in Estartit (North Catalan coast) during the period 1970-2010 at surface level, and 20, 50, 80 meters depth.

7. Based on: Simó, R., Calvo, E., Ribes, M., Pelejero, C., Coma, R., Pascual, J. 'Ecosistemes marins' [Marine ecosystems] and Sánchez-Arcilla, A., Mösso, C., Sierra, J. P., Casas, M. 'La variabilitat climàtica i la costa catalana' [Climate variability and the Catalan coast].

terranean ecosystems include: (a) an increase of tropical species of algae, invertebrates and vertebrates, favouring more thermophile species in contrast to those which are more characteristic of temperate seas. This also applies to fish of commercial interest, especially those populations which are already in a critical situation; (b) episodes of mass mortality of sessile coral invertebrates due to periods of anomalous warm waters at the time when food is scarce; (c) heightened growth of phytoplankton and smaller herbivores as a result of the lengthening of the period of water stratification, and gelatinous carnivores such as jellyfish. Increased water temperature will favour their reproduction in the same way that the lack of rainfall increases the likelihood of their being pushed towards the coast by sea breezes; (d) a decrease in the ability of the Mediterranean to capture atmospheric CO_2 as a result of previous changes and the diminution of the solubility of this gas with higher temperatures in the sea water. The policy options recommended to cope with these changes include: 1) furthering research and observation, 2) establishing marine conservation areas which can serve as indicators of ongoing climate changes and act as buffers to reduce the synergies that accelerate these changes, including over-fishing, and the destruction and transformation of habitats, and 3) combining the above with other integrated measures inland, such as preventing the over-exploitation of ground waters resources and pollution.

In addition to a rise in temperature, there has been an increase in the frequency of meteorological tidal surges in Catalan coastal waters. Available results show an increase in this erosive tendency, already present on Catalonia's shores, together with the risk of progressive deterioration in the quality of coastal waters. However, while available records of wave height and sea level do not indicate a significant trend in the medium and long term, simulated wave dynamics point to changes in the directional frequency of storms. These changes are likely to lead to further coastal erosion as well as to changes in the water quality of coastal areas. Nevertheless, these findings should be interpreted with caution, as they are derived from extrapolations from a limited set of data.

In particular, the average duration of moderate storms on the Catalan coast remains relatively constant, while the corresponding value for severe storms has shown a growing trend (+2/decade) during the recorded period (Figure 9). The directional distribution of incident waves shows a large variation along the Spanish Mediterranean coast. The resulting impact on the Catalan coast, subject to storms of more than one direction, would be an increase in erosion and flooding, thus affecting a coast that is already vulnerable. Based on simulated data, there are signs of change in the direction of the waves. If such a trend is confirmed, this could also affect the configuration and dynamics of some Catalan beaches as well as the dredging operations of some Catalan harbours. This would be the result of changing patterns in longitudinal transportation –decreased from north to south, and of storms in the north–, especially in the northern and southern parts of the Catalan coast.

The relative sea level rise would also mean an increase in coastal erosion in Catalonia, particularly in areas with low subsidence, such as deltas and wetlands. Coastal erosion would also be affected by the shift to the north of the storms paths. This would entail a reduction in wave height, but also a change in the direction of the approaching waves. Furthermore, sea water surface temperature shows a marked increasing trend (Figure 10) resulting in lower levels of oxygen being dissolved. The overall combined effect of all these processes, together with a decrease in rainfall and a concentration of rain events in shorter periods, may lead to lower quality of coastal waters and could have serious consequences for the Catalan coast, especially in the areas with most anthropic pressure. An anticipatory, multi-sectorial, multi-scale, precautionary approach is required to cope with such changes.

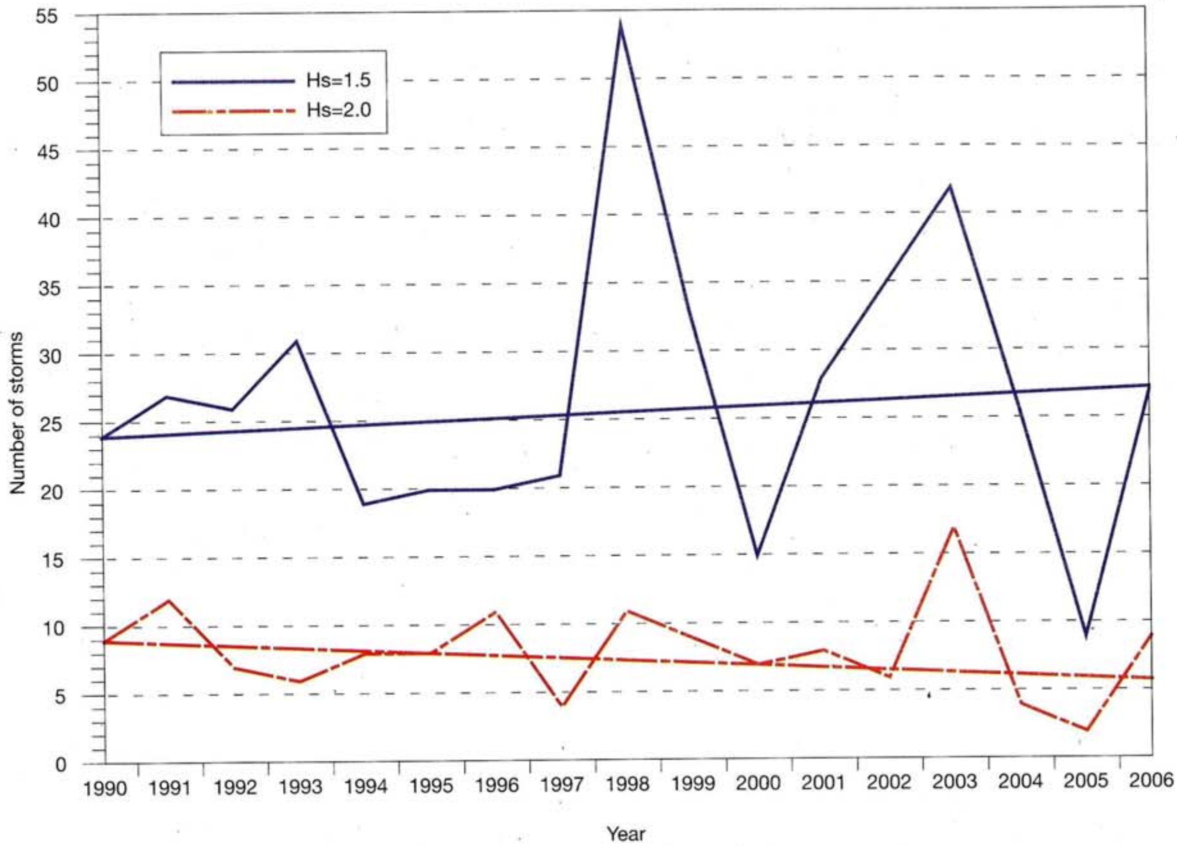

Figure 10. Annual number of moderate storms (Hs> 1.5 m) and severe storms (Hs> 2 m) in the Ebro Delta.

III.4. Terrestrial ecosystems, soils and biodiversity[8]

A substantial amount of observational and experimental evidence is now available with regard to the first biological effects of climate change in Catalonia. While spring now arrives earlier, winter also arrives later, with the result that the growing season has lengthened by four days per decade over the past fifty years. This has important implications for biodiversity and the environment, e.g., some species have shifted to higher latitudes and altitudes. In severe cases, some populations are now threatened, mostly due to the synergy between the stress caused by climate change, which makes their habitats unsuitable, and the modification of their habitats due to changes in land use. Land fragmentation also impedes the migration of certain species to habitats that would otherwise provide better conditions for their survival. In addition, in recent decades, while vegetation has made more efficient use of available water, given the enduring drought, the new conditions have resulted in increasing defoliation and reduced vegetative growth of many species of trees.

As some species are more affected than others by global warming, climate change can also alter their relative competitive ability and, ultimately, the composition of the different communities. (Figure 11). For instance, a diminution of the species richness of Catalan shrubs has been observed

8. Based on: Peñuelas, J., Filella, I., Estiarte, M. Ogaya, R., Llusià, J., Sardans, J., Jump, A., Curiel, J., Carnicer, J., Rutishauser, T., Rico, L., Keenan, T., Garbulsky, M., Coll, M., Diaz de Quijano, M., Seco, R., Rivas-Ubach, A., Silva, J., Boada, M., Stefanescu, C., Lloret F. and Terradas J. 'Impactes, vulnerabilitat i retroalimentacions climàtiques als ecosistemes terrestres catalans' [Climate impacts, vulnerabilities and feedbacks in the Catalan terrestrial ecosystems]. Alcañiz, J. M., Boixadera, J., Felipó, M. T., Ortiz, J. O., Poch R. M. 'Sistemes naturals i diversitat biològica: sols.' [Natural systems and biological diversity: soils].

in experimental settings that simulate increased heat and drought conditions, as projected in the coming decades. However, Mediterranean post-Pliocene genera appear to be better able to respond to an environment which is not easily predictable and characterised by a high seasonal and yearly variability, and thus subject to frequent disturbances. These experimental studies also show that the increasingly drier conditions which are expected in the coming decades have a negative effect on the diversity of soil bacteria, which in turn slows down the decomposition of organic matter and its ability to respond to increased temperature.

These changes in the species composition of plant, animal, and microbial communities are accompanied by numerous functional changes, including lower levels of soil enzymatic activity, nutrient recycling, the accumulation of phosphorus in plant tissues and forests, and their capacity for CO_2 sequestration due to drought. This also leads to an increased loss of nutrients in lixiviated components after rains and increased emissions of biogenic volatile organic compounds (VOC) in response to warming. These increases in VOC also have other cascading effects as they modify the communication between organisms and affect atmospheric chemistry and climate. Thus feedbacks between biogeochemical processes and climate include changes in the dynamics of carbon sinks and carbon sequestration processes as well as changes in the albedo, turbulence, and latent and sensible heat.

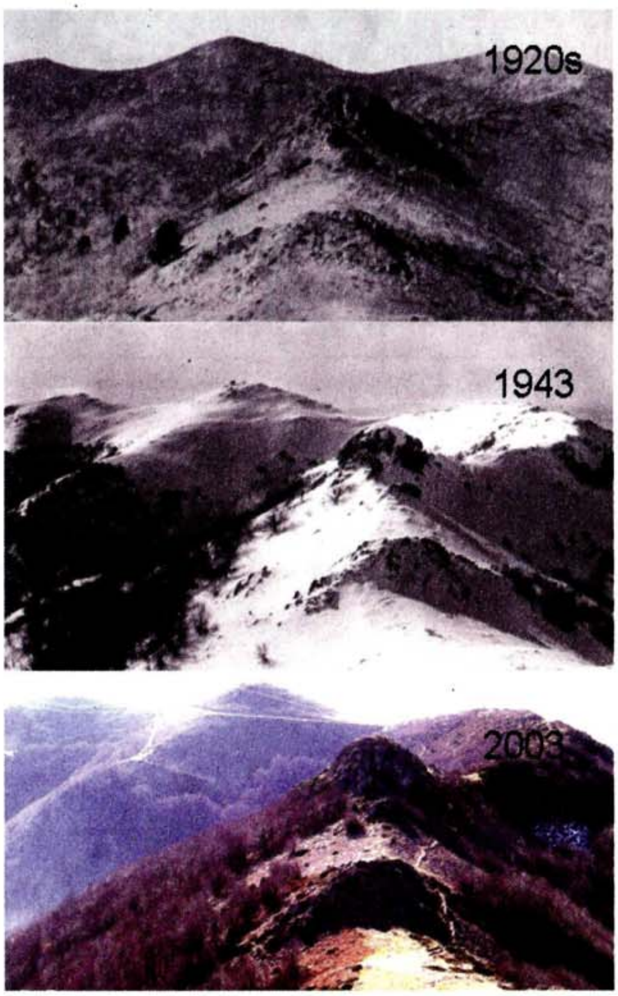

Figure 11. Growth of beech altitudinal extension in El Montseny Natural Park. Beech forest have become denser in some higher parts and moved above the tree line with the establishment of new and vigorous individuals. The new situation is the result of warmer and drier conditions combined with land use change. In particular, and with regard to the latter, the abandonment of traditional practices such as fires associated to cattle farming -which are now banned in the park.

Soils, therefore, are also subject to the effects of climate change. Soils constitute one of the largest reservoirs of carbon in the biosphere, although processes of soil degradation such as erosion, salinization, loss of organic matter and biodiversity are now under way. In Catalonia, nearly 80% of agricultural land (the layer of soil down to a depth of 30 cm) contains concentrations of between 0.6% and 2.3% of carbon, while in soils with higher irrigation (76% of the samples) these figures rise to 1.2-2.3%. Despite the limitations of the available information, stocks of organic carbon in the soils of the agricultural provinces of Lleida and Tarragona show concentrations of 90-100 Mg / ha, down to a depth of one meter, although approximately half of it is located within the first 30 cm (45-56 Mg / ha). Any alteration heightening the degradation of this layer of soil may result in significant emissions of CO_2.

The stock of inorganic carbon (carbonates) in the south-west of Catalonia is estimated at 300 Mg / ha per 50 cm of soil, excluding solidified limestone carbonates. The soil's ability to sequester organic carbon depends on its saturation capacity, a property which is externally determined by climatic and land use conditions. And in this respect, as already mentioned, global warming could change soils' carbon saturation capacity.

The main input of carbon to soils is provided by plant debris, including organic waste from harvesting, and organic fertilizers. Today in Catalonia the overall quantity of organic matter which potentially could be applied to the soil is estimated to be around 19 million Mg of wet matter (e.g. manure) and 173,000 Mg of dry matter (e.g. compost and treated sludge). In Catalonia, the consumption of nitrogenous mineral fertilizers has declined in recent years and it is now estimated at less than 50,000 Mg / year, while the use of organic fertilizers has been maintained and its territorial distribution improved. Overall, the input of organic waste into Catalan soils represents an incorporation of nitrogen of about 100,000 Mg / year. The nitrogen used as fertiliser leads to a direct and indirect increase in GHG emissions (the production of fertilisers is also a source of GHG emissions; in the case of compost this is 30-60 Kg CO2 eq/Mg) although it also increases biomass production and therefore CO_2 sequestration.

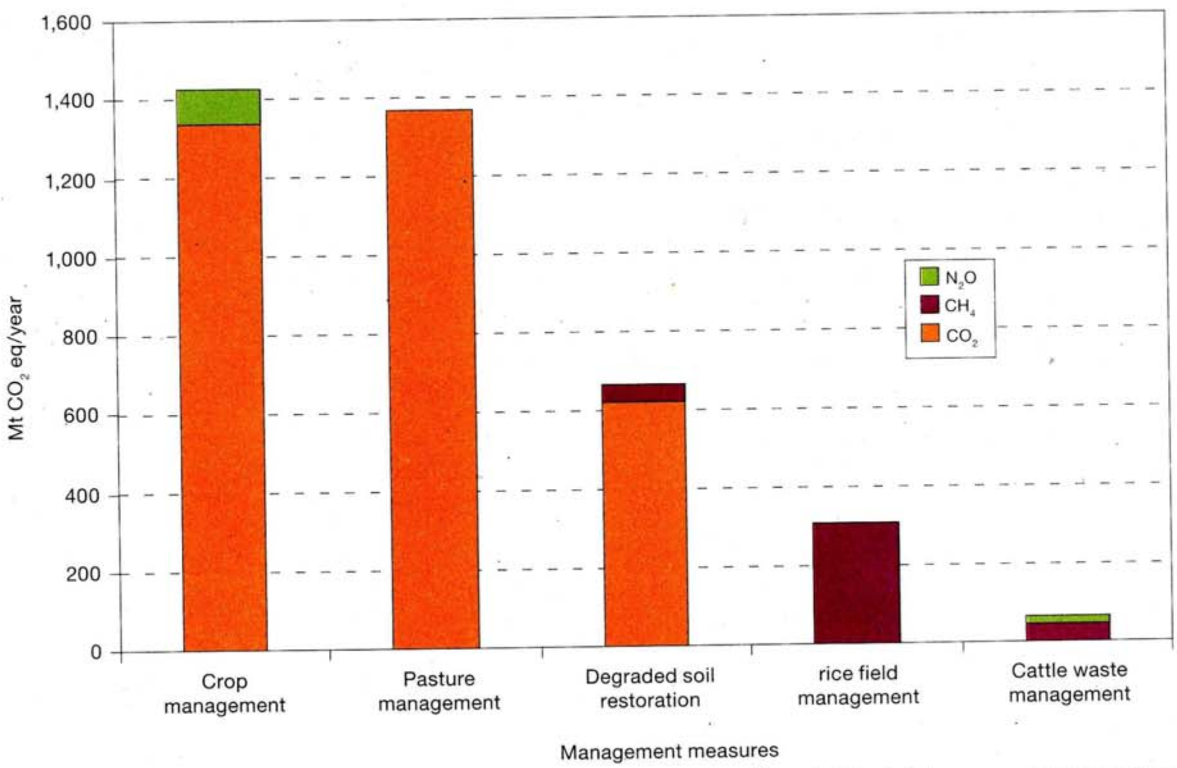

Figure 12. GHG mitigation potential of various soil management measures (from left to right: crop management, pasture management, degraded soil restoration, rice field management, cattle waste management)

With regard to policy options and possible management interventions, it is important to underline that the overall goal of fertilising soils should be to maintain or increase organic matter in the soil. Using organic waste is one of the best ways of doing this, provided appropriate measures are also adopted to maximize their beneficial effects and mitigate GHG emissions. Reforestation of abandoned cultivation terraces (during a period of over 50 years) in wet mountains areas in Catalonia has allowed the gradual recovery of nearly half of the original carbon content of these soils. Energy recovery of organic waste in the form of biochar is an interesting alternative due to its stability and high potential for sequestering CO_2, as it can retain up to 50% of the initial carbon in it. The incorporation of this option could help to mitigate diffuse GHG emissions and increase the carbon sink function of Catalan soils, albeit only on a limited scale (further assessments are necessary both in terms of GHG sequestration and agricultural production benefits). In any case, despite the general EU Directive on Soil Protection and the Common Agricultural Policy regulations, there is no effective integrated framework at the Catalan, Spanish or European level that appropriately considers the soil's potential for carbon sequestration. (Figure 12).

IV. Sector analysis: management, mitigation and adaptation

IV.1. Legal and policy instruments[9]

Since the start of international negotiations on climate change in the late 1980s a large number of international policy organisations, networks and instruments have been developed to address global warming. It is noteworthy that despite the fact that most countries in the world are now signatories to the United Nations Framework Convention on Climate Change (UNFCCC), Andorra, part of the cultural area of the Catalan(-speaking) countries (*els Països Catalans*), is one of the only two countries not to have ratified it (December 2009).

In Spain and Catalonia, several new institutional arrangements have been put in place recently. In 2008 the Spanish Environment Ministry and the Agriculture and Fisheries Ministry were merged, thus facilitating the integration of climate change-related policies. The creation of the Spanish Commission for Climate Change Policy Coordination (CCPPC), which includes a Working Group on Mitigation and GHG Inventories, and the development of the Spanish Strategy for Climate Change and Clean Energy (ECCCEL), are also worth highlighting. This strategy re-emphasises the country's commitment to the Kyoto Protocol of not exceeding the 37% GHG emissions threshold for the period 2008-2012. The strategy has been accompanied by an Energy Efficiency Plan, a National Adaptation Plan and a GHG National Allocation Plan. This new legal framework has opened up opportunities for regional autonomous communities to develop their own climate-related strategies and action plans.

Climate policy in Catalonia is now articulated by the newly created Interdepartmental Climate Change Commission and the Catalan Climate Change Office. While the former is composed by the various ministries of the Catalan government (Generalitat de Catalunya) and has a more strategic function, the latter is focused on the actual implementation of the Catalan Mitigation Plan, which highlights and supports the development of key strategic, cross-sectorial emission reduction actions during the period 2008-2012. In Catalonia, active participation in the EU Emission Trading Scheme (EUETS) has been limited to large companies, mainly from the power sector. Overall, emissions of EUETS regulated industries have fallen steadily as a result of the global economic crisis, except for sectors to do with energy production. The adoption of voluntary measures by diffuse sectors has been scant in comparison with other European countries, although the Catalan Mitigation Plan is likely to result in significant reductions. Adaptation policy and actions in Catalonia appear to be in line with those implemented at the EU and Spanish levels. A series of studies have begun to assess various vulnerabilities and climate risks under different scenarios, but the adoption of risk management measures across the public and private sectors remains anecdotal.

9. Based on: Muñoz, M. 'La negociació internacional del canvi climàtic' [The international negotiation of climate change]; Pont, I., Campins, M., Nieto, J. E. 'Els aspectes legals de la lluita contra el canvi climàtic' [The legal aspects of the fight against climate change]; and Corbera, E., Romeo, I. 'Eines de gestió del canvi climàtic' [Instruments for the management of climate change].

IV.2. Agriculture, livestock farming and forestry

Agriculture
is the profession
of wise people,
it agrees with the unaffected
and it is the worthiest ocupation
for all free men.

Although the current economic value of agricultural, farming, and forestry activities in Catalonia is relatively low, their strategic and territorial value is very high, as they provide numerous direct and indirect ecosystem services, and, taken as whole, they account for more than 90% of land use. These activities perform crucial functions in terms of soil conservation and fertility, climate regulation (including carbon sinks), adequate maintenance of the water cycle and water quality, biodiversity, recreation and landscape benefits. However, in considering both the potential impacts and the possible mitigation and adaptation options, it is important to bear in mind that agro-food systems are made up of several closely interlinked processes that include plant production (for food, feedstock, timber, fibres and others), animal farming, food processing, and human consumption. Each of these processes has its own specificities in terms of impacts and potential responses to adapt to or mitigate its effects on global warming. In Catalonia, the existence of a great diversity of landscapes, production processes, human practices and interactions makes the overall assessment of these sectors a particularly difficult task. Particular analyses and measures are required for each of sub-sector and area. It is worth noting in this connection that livestock production is responsible for a high proportion of GHG emissions in this sector in Catalonia.

For instance, climate change may lead to certain beneficial effects on production processes in some parts Catalonia, but may be detrimental in others. Changing rainfall patterns or decreasing rainfall and rising temperatures could negatively affect the production of certain crops, especially in the drier areas where irrigation systems are not in place – or will require a more intense use of water and resources where these systems already exist. Climate variability may increase the risk of late frost and extreme events, thus impinging negatively on the production of vegetables in irrigated areas. However, the fact that Catalonia has a great diversity of vegetables and production processes constitutes a potential opportunity for this sector to adapt to changing climatic conditions.

Although the effects of rising temperature may be very different depending on the type of produce and how such increases actually occur, it is estimated that an increase of temperature will reduce the production cycles of some crops (e.g. wheat, oats and barley) and, if these changes occur in winter, this will likely lead to lower yields. Nevertheless, wheat shows a greater response capacity to increased CO_2, provided production is supplemented by nutrients and water. Under such conditions, increased production has been predicted for this crop. Climate change can also intensify the flow of invasive species, as well as the emergence of certain pests and diseases, and can lead to an intensification of forest fires and soil erosion. Grasslands are among the ecosystems most threatened by climate change and deserve special attention from the standpoint of biodiversity. Despite the existing uncertainties, a precautionary approach is required: agro-food production and consumption systems should move towards ensuring and increasing the energy efficiency of their manufacturing processes, improve product quality, and guarantee and contribute in integrated ways to the aforementioned functions and services provided by farming ecosystems.

IV.3. Energy, industry and waste[10]

According to the forecasts of the Catalan Energy Plan for 2006-2015, the consumption of all sorts of energy was expected to increase until 2010 and only in 2015 decrease in certain sectors and energy types. Despite the review of the Plan carried out in 2009, which lowered the energy consumption forecast in the original plan, this reduction is the result of the diminution in the use of non-renewable energies. The overall consequence of this is that GHG emissions in Catalonia will be higher than those allowed by existing policies and energy cogeneration and use of renewable energies will not fulfil the commitments of either the Spanish Renewable Energy Plan or other EU programmes. It will also further exacerbate foreign energy dependency and intensify the need for energy imports.

In particular, Catalan dependency on foreign energy sources will result from increasing internal demand for energy and reduced internal energy production capacity. Transport and electric power production are the two sectors which, according to the Catalan Energy Plan 2006-2015, are likely to produce most GHG emissions. This will also have economic consequences, as it will also require the need for offsetting emissions and buying emission rights outside the country.

The predicted increase in the average temperature of Catalonia will result in a loss of efficiency in many energy systems, increase demand for energy for cooling (not offset by a decreased demand for heating) and for water, as well as a loss of the transport capacity of existing power lines. At the local level, the emission of heat from thermoelectric power plants will also add to the increase in the air temperature due to climate change. Climate mitigation and energy policies require integrated and decisive policies at different levels of governance. In this regard, adaptive policies are needed to update the requirements to be fulfilled by power stations in the light of the current climate situation and go beyond the original licences that allowed them to function in the first place. Electric vehicles may be a way to deal with both environmental and energy commitments, provided the electricity needed to power them is produced from renewable sources.

Industries operating in Catalonia have made a big effort to reduce their GHG emissions and have been able to meet their obligations in terms of GHG emission allowances in accordance with the European Emission Trade System Directive. Diffuse emissions have also decreased. However,

Sector	2005	2006	2007	2008
Electric power	5,816,725	5,033,612	5,180,189	5,052,680
Cog/Combustion	3,002,840	3,655,861	3,811,286	4,398,003
Refineries	2,832,719	2,784,072	2,836,669	2,620,212
Limestone	286,602	326,489	317,826	301,063
Steel	266,720	277,375	286,915	263,837
Cement	6,314,544	6,168,807	6,025,335	4,905,729
Glass	412,088	413,854	377,593	363,462
Ceramics	573,656	550,017	564,320	372,173
Paper	555,936	548,441	537,989	536,676
Total	**20,061,830**	**19,758,528**	**19,938,124**	**18,813,835**

Table 2. Evolution of industrial emissions 2005-2008.

10. Based on the following chapters: Corominas, J. 'Energia' [Energy], Garriga, R. 'Indústria' [Industry], and Gabarrell, X., Escaler, I. Font, X., Massagué, A. and Rieradevall, J. 'Residus' [Waste].

Sector	Number of facilities	Emissions 2008	GHG allocation 2008	Allocation minus '08 emissions	Statements with GHG > than allocated
Electric power	8	5,052,680	2,487,798	2,564,882	8
Cogeneration	49	3,877,915	4,463,468	–585,553	16
Other ind., combustion facilities	41	520,088	687,333	–167,245	7
Refineries	2	2,620,212	2,803,148	–182,936	0
Steel	1	263,837	321,117	–57,280	0
Limestone	4	301,063	344,042	–42,979	1
Cement	6	4,905,729	6,200,610	–1,294,881	0
Glass	9	363,462	409,498	–46,036	2
Ceramics	37	372,173	555,636	–183,463	4
Paper	28	536,676	685,591	–148,915	3
Total	**185**	**18,813,835**	**18,958,241**	**–144,407**	**41**

Table 3. Summary of GHG statements and comparison of actual GHG vs GHG allocations per industrial sector in Catalonia.

taking into account the major reductions that need to be achieved in the coming years, special attention still needs to be paid to improving energy efficiency, which has made the biggest contribution to curtailing GHG emissions in recent years. These measures need also to be combined with the use of the best available technologies and alternative fuels.

Tables 1-3 show that, on the one hand, energy production is the main source of GHG in Catalonia, with electric power, COG combustion and refineries the main sources of such emissions. On the other hand, cement production is also an important contributor to GHG in Catalonia. Major investments in this last-mentioned sector have improved its overall energy efficiency by 40%, from consumption of more than 4.500 MJ per tonne of cement to just over 3000 MJ at the present. If we look at the evolution of GHG allocations and compare them with actual emissions, we can see that electric power generation is the only sector which has exceeded its allowed emissions, although it is also true that this sector has reduced its overall emissions.

In short, the promotion and development of adequate R&D&I incentives and policies oriented towards this end is essential, as such innovations can result in significantly reduced economic costs as well as lower emissions. This needs to be tackled in conjunction with growing awareness by both industry and the general public in these matters. In this regard, some prevailing paradigms need to be changed, particularly those to do with construction, in order to mainstream sustainability aspects in the processes involved. Meeting the EU 20/20/20 policy targets will also entail a major collaborative restructuring effort by industry, governmental agencies and research institutions.

It is important to note that GHG emissions from waste are produced throughout the entire process of collection, transport and treatment, including processes aimed at recovery and recycling or ensuring adequate disposal. The amount of GHG emissions generated by waste in Catalonia in 2005 was of 2.7 Mt CO_2 equivalent, representing 4.55 % of the total, with 2.87 % generated by landfills and 1.34% by wastewater treatment. In comparison with the baseline year, waste emissions rose by a factor of 1.47. Reducing GHG emissions from this sector will require, above all, a decrease in the flows of waste at origin. i.e. where they are produced, especially in building, livestock farming, urban solid waste, industrial waste, urban and industrial wastewater. This should be complemented with a reduction of secondary waste, as this is the flow that has increased most in recent years in Catalonia. Reducing GHG emissions from the inter-municipal transport of waste will be an increasingly important source for climate mitigation: without considering emissions from the transport of industrial and secondary waste, GHG from transport waste was 260 kt CO2eq. Improving the efficiency of biogas collection at landfills could also contribute notably to GHG reduction in this sector.

IV.4. Tourism[11]

While Spain is the second most popular destination of international tourism worldwide, Catalonia is the biggest destination of this type of tourism in Spain. Tourism continues to be the foremost economic activity in Catalonia accounting for up to 10-12% of GDP and employing around 10% of the population. This sector is characterized by its high diversity and excellent ability to adapt to new challenges. However, accommodation capacity in Catalonia did not change significantly during the period 2002-2007 and most services are concentrated in about a quarter of the *comarques*, where most hotels and campsites are located.

Climate change is bound to affect tourism in Catalonia in different ways depending on the different types of tourism and the possible choices made and actions taken to adapt to these changes. Despite the fact that there has not been much research specifically carried out in this field, traditional sun and beach tourism is unlikely to be much affected by global warming, as the seasonal periods in which tourism services are provided may be changed or extended. Extreme events such as the European heat wave of 2003 do not seem to have entailed any loss of tourists using Catalan beaches. Additional climate pressures on coastal tourism, such as reduced freshwater availability or a rise in sea level, may be dealt with to some extent by technological solutions such as desalination plans or sea defence infrastructures. However, energy availability (e.g. for water desalination, air conditioning) will be a key limiting factor for the further development of this sector in Catalonia.

On the one hand, winter ski tourism appears to be the most vulnerable modality to climate change, but on the other, it is also the sector which is already taking the most decisive actions to adapt to the new situation. Climate change may affect other minority types of tourism in Catalonia, such as those focused on rural locations, or the cultural and natural heritage, in so far as global

11. Based on: Saurí, D. & Llurdés, J. C. 'El turisme' [Tourism]

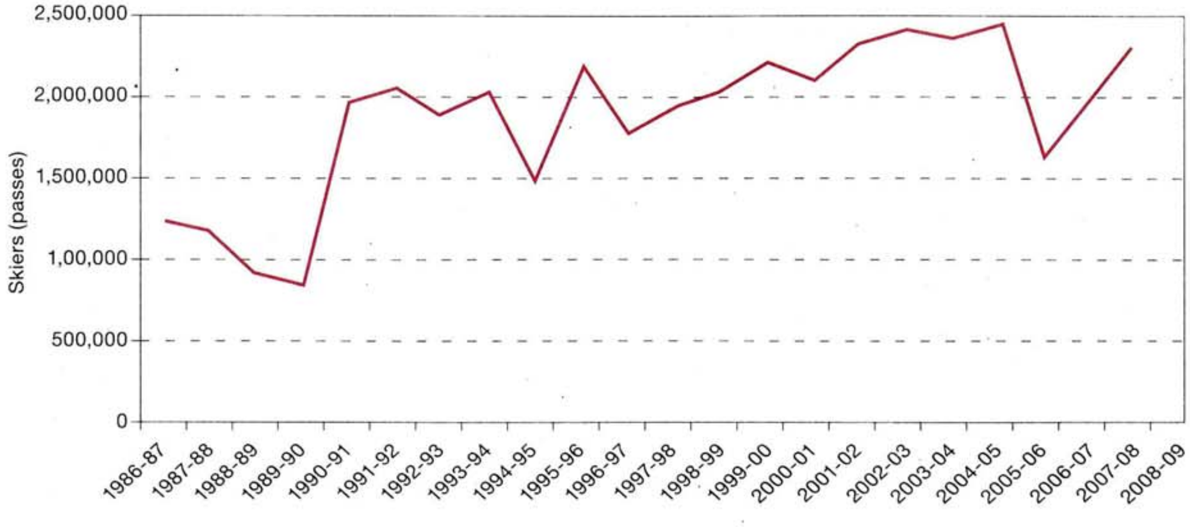

Figure 13. Evolution of skiers at the Catalan ski resorts 1986-2007.

warming generates additional negative impacts such as forest fires, new plagues or other disturbances to the natural systems.

On the one hand, winter ski tourism appears to be the most vulnerable modality to climate change, but on the other, it is also the modality which is already taking the most decisive actions to adapt to the new situation. In 2009 a total of 2200 artificial snow cannons were available in the Catalan ski resorts while at the same time many resorts have already began to diversify their supply outside the winter season (figure 13). Climate change may affect other minority types of tourism in Catalonia, such as those focused on rural locations, or the cultural and natural heritage, in so far as global warming generates additional negative impacts such as forest fires, new plagues, or other disturbances to the natural systems.

IV.5. Health[12]

A major difficulty in assessing and predicting the effects of climate change on health has to do with the fact that such changes are now occurring at a very fast pace and their impacts also are very dependent on geographical, social, and economic conditions – which are also quite diverse in Catalonia. Since the possibilities for experimentation are rather limited, assessments have to be based on past and existing observations, and thus are also subject to a high degree of uncertainty.

The effects of climate change on health depend on a number of geographical, social, and economic conditions. However, it is likely that climate change will impinge negatively on those atmospheric conditions that have to do with non-infectious diseases. Patients with chronic or acute respiratory problems and blood circulation conditions as well as the older population may be especially vulnerable to climatic changes.

The most notable phenomenon which is likely to have an impact on the Catalan population is the greater frequency of extreme heat events due to rising temperatures. The heat wave of 2003 caused a significant increase in mortality in the country, particularly in the Barcelona metropolitan area. Moreover, the increasing frequency and severity of heat waves may result in a generalised increase in the aggressiveness of urban pollutants, and in turn, provoke or intensify heart and respiratory diseases and allergies (see figure 14).

12. Based on Raso, J. M. 'Salut' [Health]

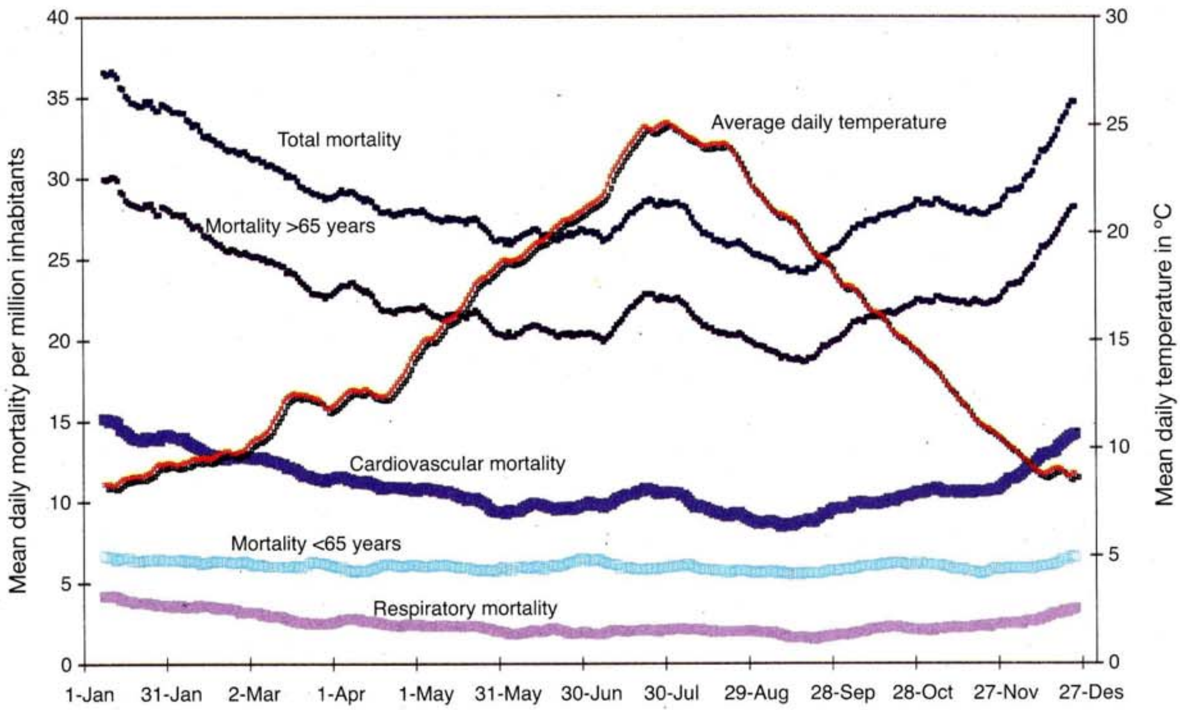

Figure 14. Death per million inhabitants in Barcelona with respect to mean daily temperature 1990-1997 (red line). Note the increase in mortality when the temperature first reaches 30 °C.

A less serious risk, at least for now, comes from biogenetic pollutants which are essentially constituted by pollen and plant components. The generation of such pollutants might be altered by climate change as a result of rising temperatures (e.g. by extending the period of pollen production by native species), as well a greater presence of non-native plants and species. Although a relatively a minor consideration at present, greater amounts of sand dust from the Sahara also exacerbate respiratory diseases and might be intensified by climate change.

IV.6. Transport, mobility, land use planning and construction[13]

Greenhouse emissions from transport in a particular geographical region also depend on a variety factors such as the amount of vehicle kilometres, the type of transport or vehicles used, the number of people per vehicle, and their energy efficiency. In recent times, the more comprehensive concept of *mobility* has been used to refer to an approach which has more in keeping with a demand-based and social orientation, but which also includes other modes of transportation (either of goods or people) by non-motorised means (e.g. bicycle or walking). It has been estimated that the mobility by road of people and goods is 103.12 million vehicle-kilometres per day, with an overall consumption of 3,173.45 billion litres of fuel and emissions of 11.3 Mt of CO_2. Taking into account other forms of transport (air, sea, rail), emissions in Catalonia reached a total of 15.03 Mt in 2005, this being the sector which emitted the largest amount of GHG (about a quarter of all GHG emissions). Therefore, both households and transport are key contributors to the growth of GHG emissions in Catalonia. (Figures 15 & 16).

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13. Based on: Robusté & Estrada, M. A. 'Transport, mobilitat i logística' [Transport, mobility and logistics], and Gausa, M. (Coord.), Rueda, S., Muñiz, I., Muñoz, F., Calatayud, D., Sabaté, J., Pérez, M. and Gorostiza, S. 'Canvi climàtic: territori, urbanisme i edificació. Nous models (més) sostenibles' [Climate change: territory, urban planning and construction. New (more) sustainable models]

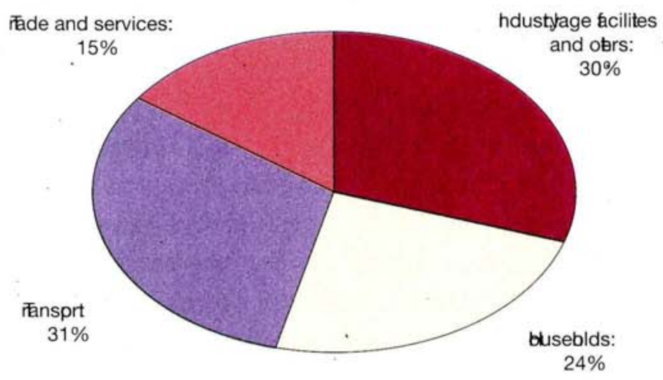

Figure 15. Distribution of GHG emissions in Barcelona by sectors (2004).

Despite this, Catalonia has made considerable progress in certain areas regarding mobility, particularly those to do with the promotion of rail and interurban bus networks, the building of logistics platforms, the implementation of regulations for the distribution of urban goods and increased car occupancy, with positive effects on climate change mitigation. If hydrogen batteries and transport electrification take off in the coming years, GHG emissions derived from transport could be drastically reduced by 2025. If this happens, challenges regarding transport will have more to do with energy consumption and other negative social externalities such as traffic congestion and road accidents rather than GHG emissions.

Different urban configurations also have different impacts on GHG emissions and may respond differently to potential climate change impacts. A debate is now going on as to whether distinct city and urban structure models – compact, diffuse and new ones – and modes of articulation between municipal networks have different consequences for overall sustainability. Taking the ecological footprint as an indicator of sustainability, a compact city such as Barcelona may yield more optimal results in terms of the use of natural resources, efficient management of natural cycles and greater opportunities for social interaction, connectivity, and functional diversity. Hence climate change requires the consideration of different scales, at the city and regional levels, but also on the scale of neighbourhoods and houses. Planning and construction play a central role in mainstreaming concerns about saving and appropriate use of natural resources. An innovative and integral conception of the management of materials, water and waste – all with positive co-benefits in terms of health, comfort and quality of life – is required. In this respect, current estimations show that integral construction could provide building solutions that would cut the current energy consumption of conventional buildings by up to 50 % with only 4-7 % of additional costs and a return period of 10 years. (Figures 15 & 16).

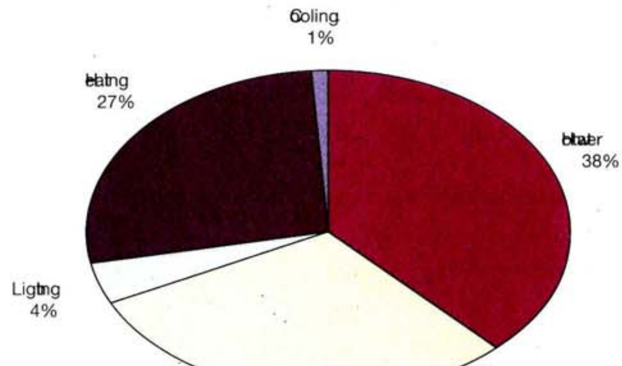

Figure 16. Distribution of GHG emissions by Catalan households, by energy use (2006)

IV.7. Public perception and communication[14]

A review of existing public opinion polls and of the evolution of the print media in Catalonia indicates that so far climate change has been mainly framed as a mitigation problem, rather than one of adaptation. Furthermore, climate change has been seen mainly as a risk or economic cost, rather than as an opportunity for economic growth or investment. The economic crisis has affected the way the Catalan public perceives climate change: on the one hand, it has reduced the sense of urgency, but on the other, it has also increased the perception that dealing with climate change could be an important factor helping to overcome the economic crisis.

Over the last two decades there has been a marked trend towards greater coverage of climate change issues in the Catalan daily press (Figure 17), as well as the emergence of a number of interpretative frameworks, sometimes in conflict.

An analysis of the views of 19 experts and relevant agents dealing with climate change in Catalonia reveals that they tend to be less optimistic than the general public with regard to the possibilities of dealing with climate change. They also tend to be concerned that Catalan politicians do not seem to be doing enough on these matters and think Catalan society is not generating enough incentives or disincentives to mitigate or adapt to climate change, and not enough reforms are made in institutions or resources invested for such purposes, although Catalonia has many viable options for doing so.

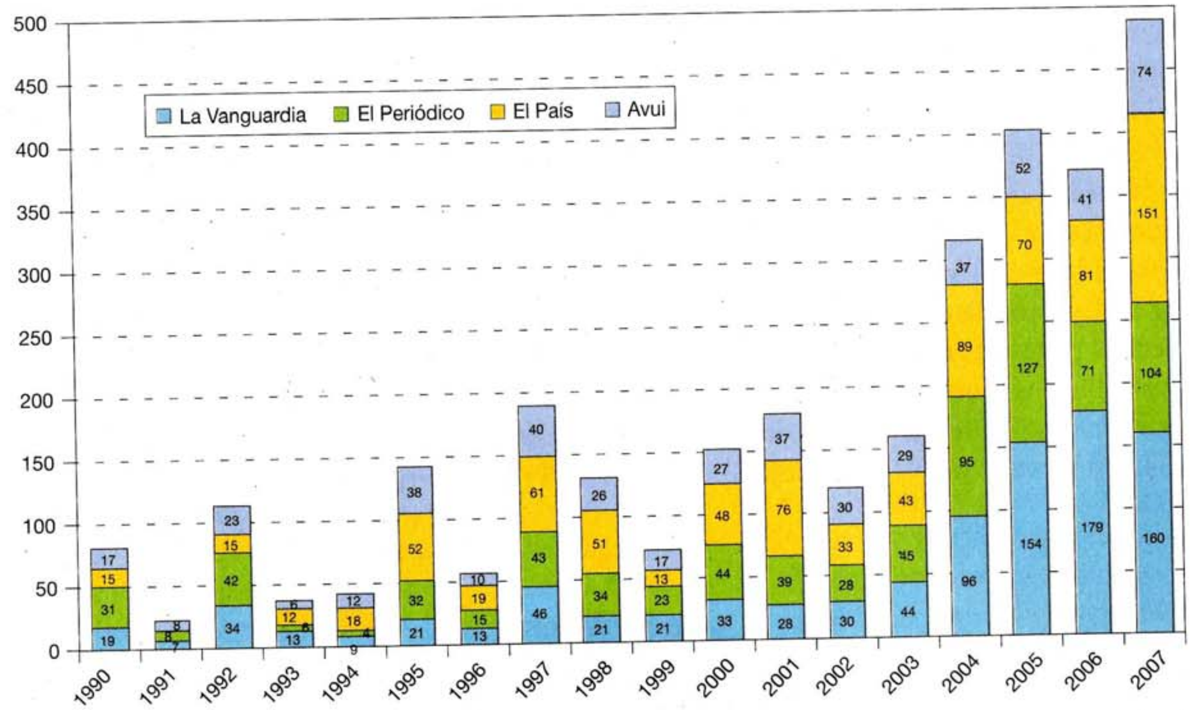

Figure 17. Evolution of the coverage and number of articles on climate change in four major newspapers in Catalonia (1990-2007).

14. Based on Tàbara, J. D. 'Percepció i comunicación del canvi climàtic a Catalunya' [Perception and communication of climate change in Catalonia].

V. Research on climate change in Catalonia

An examination of the current state and evolution of climate research production and capacities in Catalonia shows that the number of scientific publications produced by Catalan researchers on climate change cited in Social Citation Index journals increased by 3.5 during the period 2000-2008. In particular, in 2008, a total of 134 scientific articles on climate issues were produced and 46 doctoral theses were submitted during the whole period. Moreover, a very wide range of topics is dealt with in this domain. (Figure 18).

However, the institutional structure supporting scientific research on climate change in Catalonia is still quite fragile. Most researchers working on these issues work in departments and institutes where climate change is not the main strategic line, or their work appears under traditional disciplinary classifications.

Furthermore, over fifty percent of the competitive climate projects in which Catalan researchers take part have to do with the analysis of climate change observations, GHG emissions and the study of biogeochemical cycles. Palaeo-climate research has been particularly active in recent years. This is also the case with research on climate impacts and their relation to natural risks, as shown by the rise in the number of competitive projects in this area and the work carried out by the Centre for Ecological Research and Forestry Applications (CREAF) and the Institute of Agro-Food Research and Technology (IRTA). In this regard, half of the research projects on climate impacts were devoted to the study of the impacts of global warming on plants. Little attention has been given to the study of mitigation and adaptation or analysis of climate change policies.

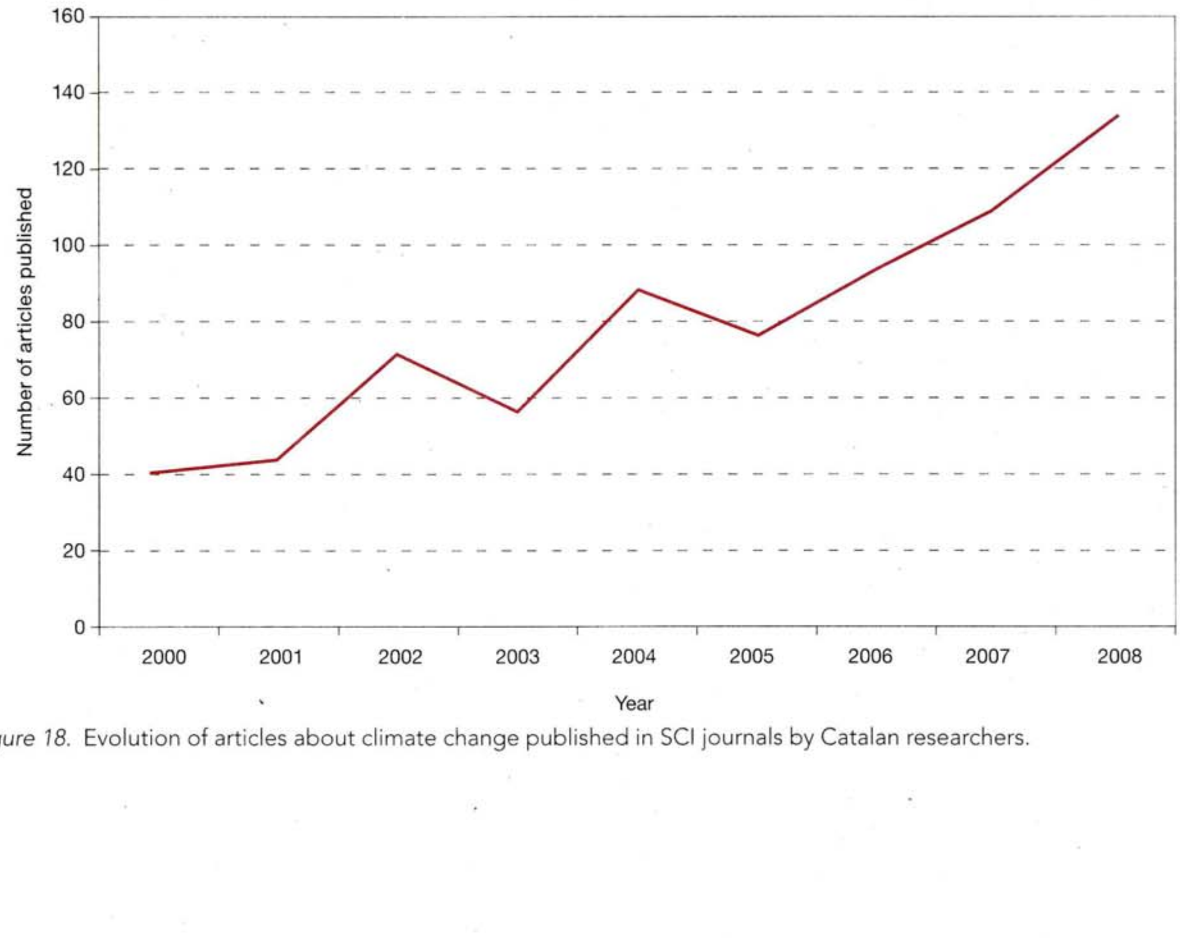

Figure 18. Evolution of articles about climate change published in SCI journals by Catalan researchers.

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