# CLIMATE CHANGE IN CATALONIA

## Executive summary of the Third Report on Climate Change in Catalonia

Generalitat de Catalunya

Institut d'Estudis Catalans

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Barcelona, 2017

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# Contents

# Introduction

Climate change is a fact. This is apparent from the data that is now available, and has been confirmed by the scientific community working in the field under the auspices of the Intergovernmental Panel on Climate Change (IPCC).

Sixteen of the seventeen warmest years since records began have been recorded since 2000, and the planet's average global temperature (the air above the surface of the land and sea) exceeded pre-industrial levels by 1°C for the first time ever in 2015. Finally, permanent atmospheric concentration levels of carbon dioxide ($CO_2$) now exceed 400 parts per million for the first time in eight hundred thousand years.

This warming will have numerous effects, and will clearly determine our collective future. Catalonia is also subject to climate change and its effects. The average annual air temperature for Catalonia as a whole has risen by 0.23°C/decade, and this figure is slightly higher than the global levels for the period between 1950 and 2014.

The projections point to a rise in temperatures and a slight reduction in rainfall in the coming decades. This will be more pronounced by the middle of this century, with a greater likelihood of more intense rainfall and an increase in the amount and duration of droughts.

Decision-making requires relevant and high-quality information, as well as dialogue and partnership between public and private decision-makers and scientists. For this reason, in 2005 the Government of Catalonia and the Institute of Catalan Studies published the *First Report on Climate Change in Catalonia*. This report analysed the conditions and evolution of climate in Catalonia, from the perspective of the scientific foundations and based on its relationship with natural and human systems.

This initial project to place the international and European analysis and projections made by institutions such as the United Nations Intergovernmental Panel on Climate Change and the European Environment Agency on a regional scale for Catalonia led to a second edition, which was published in 2010. The *Third Report on Climate Change in Catalonia* (TICCC), which updates the previous two editions, was presented on 30 January 2017.

## What is the TICCC?

The *Third Report on Climate Change in Catalonia* is an independent report from the scientific perspective, covering Catalonia (with the necessary references to the global and European situation) on the state of the climate and how it is evolving as regards natural and human systems. The report aims to provide the broadest possible thematic and service-based coverage for the country's various stakeholders.

## What does it aim to achieve?

The objective of the TICCC is to analyse the situation and recent and future developments relating to climate in Catalonia, the effects of climate change on natural and human systems, the contribution of those systems to greenhouse gas emissions (GHG), and adaptation to climate change.

## Who has produced it?

The TICCC is produced by:

1) The Advisory Council for Sustainable Development, which is the Government of Catalonia's advisory body on sustainability issues, affiliated with the Ministry of Transparency and Foreign and Institutional Relations and Affairs.
2) The Catalan Office for Climate Change, affiliated with the Directorate-General for Environmental Quality and Climate Change of the Ministry of Territory and Sustainability.
3) The Meteorological Service of Catalonia.
4) The Institute of Catalan Studies.

## Who has participated in it?

More than one hundred and forty authors and forty reviewers have participated in the TICCC. They are all important scientific and technical experts in their field, based at leading research centres and universities in Catalonia, and in technical units of various government bodies (a full list of the authors and reviewers is provided at the end of the dossier).

The scientific coordinator of the TICCC was Dr Javier Martín-Vide, Professor of Physical Geography at the University of Barcelona, and he was helped by the Catalan Panel on Climate Change (GECCC). The publication was also supported by Obra Social "la Caixa".

## Why this executive summary?

The institutions organising the project would like readers interested in the results of the TICCC to have access to this executive summary. However, it is not a summary of the report in the strictest sense, but instead a document that has been prepared from scratch, for information purposes, which contains the most important messages included in the TICCC.

For this reason, the executive summary does not follow the report's division into chapters, and is structured based on the four main parts of the TICCC.

## How is the executive summary structured?

The executive summary is structured as follows:

1) **The scientific foundations for climate change**, which describes the scientific consensus on global warming, recent developments in the gas emissions that cause it, and measures to mitigate its effects. This section also outlines the natural systems that increase carbon sequestration, highlights variations in Catalonia's climate since 1950, and examines changes in climate during the first half of the twenty-first century.
2) **Natural systems: impact, vulnerability and adaptation**, which focuses on natural systems, and examines the climate risks and impact on water resources, the coastline and terrestrial, aquatic and marine ecosystems. This section also considers the specific characteristics of soils.
3) **Human systems: impact, vulnerability, adaptation and mitigation**, which presents the impact, vulnerability and proposals for adaptation to and mitigation of climate change in various areas and human systems in Catalonia (agriculture, livestock farming and fishing; energy; industry; tourism; health; waste and resources; transport, mobility and logistics; territory and the urban space; and the interaction between human and natural systems in high mountain areas).
4) **Governance and management of climate change**, which addresses the policies and instruments required, the importance of public opinion, the state of research in Catalonia and the process between signing the Kyoto Protocol and the Paris Summit.

We hope that this publication is interesting and useful for taking climate change into account in the actions and decisions that have to be taken, thereby making Catalonia a country that is committed and resilient in the face of one of the most important issues facing mankind in this century.

# PART 1

# Scientific foundations for climate change

## 1.1. Climate change—an obvious fact

There is no room for doubt: there is an unmistakable rise in temperatures all over the planet, and human activity has been the primary cause since the second half of the twentieth century, according to the IPCC's *Fifth Assessment Report*, which was completed in 2014.

Since then, further data have corroborated that there is a trend towards warming: the planet's average global temperature exceeded pre-industrial levels by 1°C in 2015, for the first time since records began. Meanwhile, the concentration of $CO_2$ in the atmosphere now exceeds 400 parts per million, for the first time in eight hundred thousand years.

It is safe to say that the scientific consensus is now virtually complete. There are some doubts about the speed of this change in the future, its consequences on a regional scale, and about the acceleration or slowdown that variations in some conditions could cause, e.g. changes in the area covered by ice, which reflects solar radiation, and the effects of policies reducing emissions. However, there is no doubt about human responsibility for global warming (Figure 1), or the severity of its effects.

Rising temperatures are not the only sign of climate change: other changes associated with this increase have been observed, including a reduction in the amount of snow and ice, warming and acidification of the oceans, and rising sea levels.

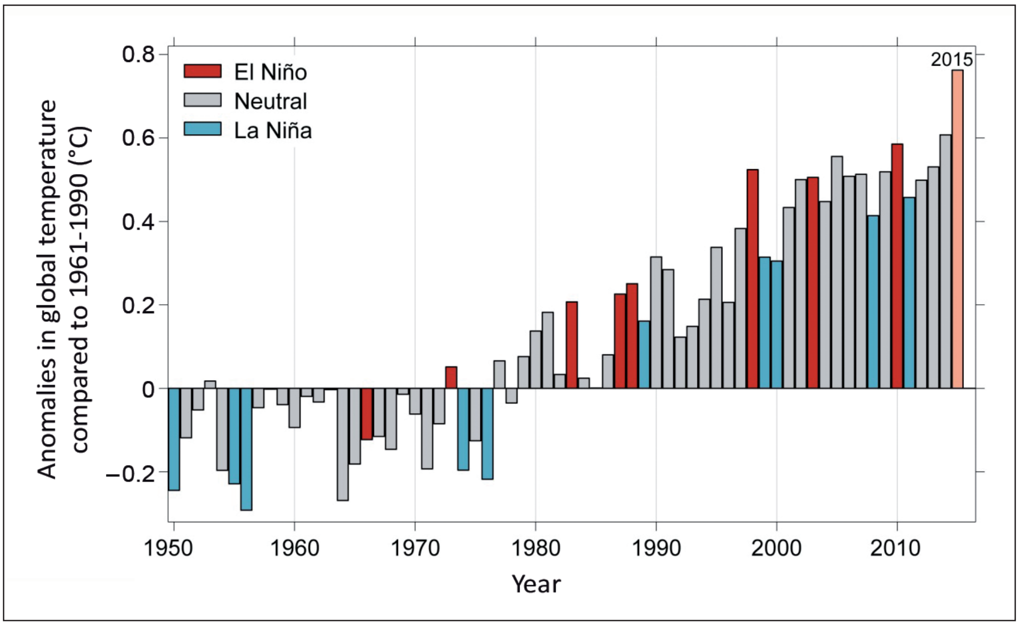



Figure 1. Anomalies in global temperature (1961-1990). The 2015 average is based on temperatures from January to October. The red columns are the years in which the El Niño phenomenon took place; the blue columns are the years in which the La Niña phenomenon occurred; and the grey columns are neutral years. The values have an uncertainty of around 0.1 °C.

Source: HadCRUT.4.4.0.0, GISTEMP and NOAAGlobalTemp for the period 1950-2014. (Graph adapted from https://www.wmo.int.)

An increase in extreme weather and climate events has also been recorded since 1950.

An agreement was signed in Paris in December 2015. As part of the United Nations Framework Convention on Climate Change, it established a target of limiting the increase in average global temperature to 2°C compared to the temperature before the Industrial Revolution (and to pursue efforts to limit this increase in temperature to 1.5°C). Unfortunately, scientists suggest that more than two-thirds of all the carbon that could be discharged into the atmosphere without the increase in global temperature exceeding 2°C has already been emitted.

Many experts believe that exceeding this threshold of an increase of 2°C would have severe social, economic and environmental consequences. The only alternative to avoid this is to reduce GHG emissions, and as such the governments that signed the Paris Agreement resolved both not to increase their production of GHG, and also that human activities must not be able to generate more GHG than it is possible to remove from the atmosphere by natural processes, such as carbon sequestration by forests, or artificial $CO_2$ uptake methods.

According to the Paris Agreement, all the world's countries must reduce their GHG emissions, taking into account their respective socio-economic situations.

For this reason, the Agreement states that a voluntary fund will be established in 2020, which will be endowed with 100 billion dollars every year. The objective of this green fund is to help the poorest countries to develop while adopting a low carbon intensity economic model (involving the use of clean energies) which is resilient, i.e. adapted to the impacts of climate change.

However, reducing emissions will not be a quick process, and when the effects are achieved they will not be immediately apparent, because $CO_2$ is a gas with a very long residence time in the atmosphere. Indeed, estimates suggest 40% of the emissions produced today will remain in the atmosphere for a hundred years, and that 20% will still be there in a thousand years' time.

So what are the prospects of achieving a truly significant reduction in GHG emissions? The *Fifth Assessment Report* of the IPCC considers various scenarios. In a globalised world that very quickly stops using the current energy system, which is based above all on fossil fuels, the average temperature at the end of the century will be only 1°C higher than pre-industrial levels.

However, if most economies continue to be based on fossil fuels, and high levels of energy consumption and use of materials persist, the average global temper-

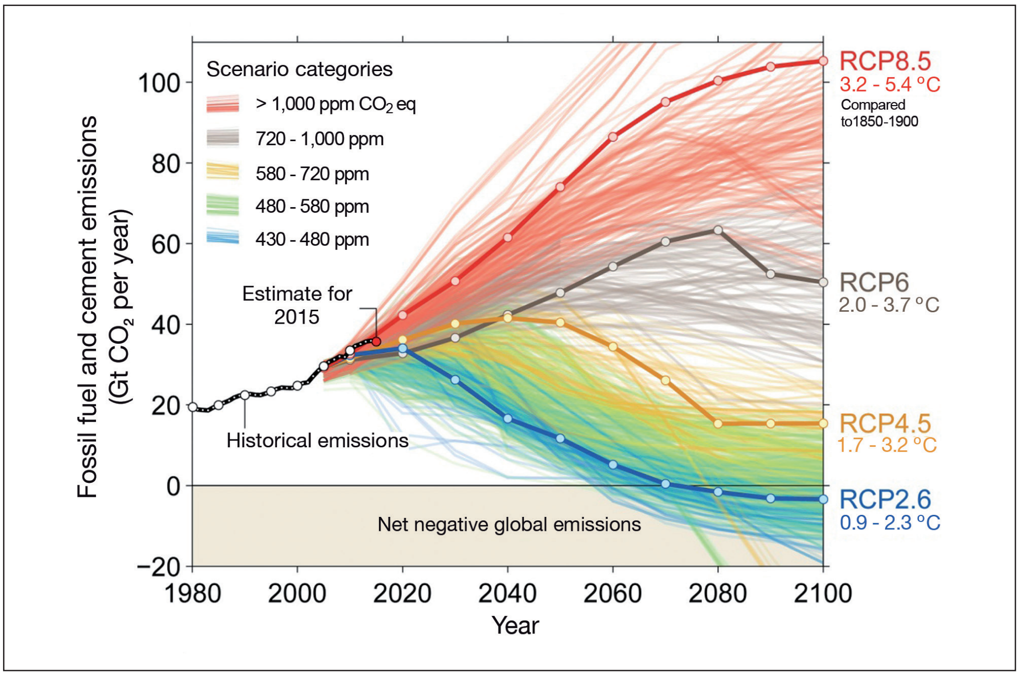



Figure 2. Trends in $CO_2$ emissions used in the IPCC's *Fifth Assessment Report* (2013-2014). The bold lines show the four possible representative concentrations used by Working Group I of the IPCC to create projections for climate change, and the more blurred lines show the scenarios used by Working Group III of the IPCC to evaluate the mitigation alternatives. The black line showing historical emissions is based on data from the Carbon Dioxide Information Analysis Center and the Global Carbon Project.

Source: *Third Report on Climate Change in Catalonia*, 2016.

ature at the end of the century could be about 5°C above pre-industrial levels. The report by the IPCC contains extreme scenarios which are very pessimistic, shown in Figure 2.

What seems clear is that any action taken must be firm and begin soon. The likelihood of remaining below 2°C will decline swiftly if these measures are not implemented in the next few years.

## 1.2. Recent developments in greenhouse gas emissions

$CO_2$ is the primary greenhouse gas (GHG), although there are others: methane ($CH_4$), nitrous oxide ($N_2O$) and other gases with a long atmospheric lifetime containing halogens (hydrofluorocarbons or HFCs, perfluorocarbons or PFCs, and sulphur hexafluoride or $SF_6$). Carbon dioxide ($CO_2$) equivalent emissions are often used to simplify calculations and comparisons. These are the results obtained from calculating how many tons of this gas would produce the overall greenhouse effect of all the GHG.

### *A sustained increase over two and a half centuries*

The Industrial Revolution, which began in the mid-nineteenth century, led to a large increase in $CO_2$ emissions, and the production of GHG worldwide has increased exponentially since then. If we consider the planet in overall terms, nearly two-thirds of these emissions come from the energy sector—a percentage that reaches 75% in developed countries.

The problem has worsened in the last half century: since 1970, the total amount of GHG discharged into the atmosphere due to human activities has increased by 80%, and in the decade between 2000 and 2010, it increased more rapidly than in the three previous decades. This means that in 2015, the concentration of $CO_2$ in the atmosphere exceeded 400 parts per million for the first time in eight hundred thousand years. If no action is taken and this rate persists, by 2100 the average temperature could have risen by between 3.7°C and 4.8°C above preindustrial levels.

In international terms, based on data from 2014, the leading emitters of $CO_2$ in absolute terms were China (which accounted for 27% of the world's total), the United States (15%), the European Union (10%) and India (7%). However, the leaders in emissions per capita are the oil-rich Arab countries such as Qatar, with high levels of emissions and a small population, and the United States and Australia, with 16-17 tonnes per person per year.

These figures are more than double the figure for China (6.26 tonnes per person per year) and the average figure for European countries. They are eight times higher than the levels for India, and more than fifty times higher than many of the less developed countries in sub-Saharan Africa.

Nevertheless, China's industrial growth means that it now has the same level of emissions per capita as the European Union (which means that it is a key player in global policies to fight climate change), and approximately a quarter of its emissions are the result of producing goods that are exported and consumed abroad. This means that in the recipient countries, the emissions levels are not an accurate reflection of their habits and consumption levels.

These figures show that, in recent years, emissions have not been reduced as much as is necessary. In fact, the opposite has happened. However, there are some figures that show that it is possible to reduce GHG emissions without economic development suffering as a result: for example, in 2014, GHG emissions by the European Union and Iceland were 24.4% lower than the levels in 1990, while their population and gross domestic product (GDP) per capita had increased.

This trend has not been uniform across the European Union. There was continued growth in emissions in Spain between 1990 and 2007. This was followed by three years—2008, 2009 and 2010—which saw a marked decline. This should mainly be attributed to the economic downturn and, to a large extent, to changes in fuels used in electricity generation. The European Union has established measures that should enable GHG emissions to be reduced by 20% by 2020.

$CO_2$ emissions in Catalonia increased continuously between 1990 and 2005. In 2006 and 2007 they fell slightly, and the values stabilised. Finally, between 2008 and 2013 they fell by 19.4% compared to the base year (1990). Figure 3 shows GHG emissions per capita in Catalonia and Spain.

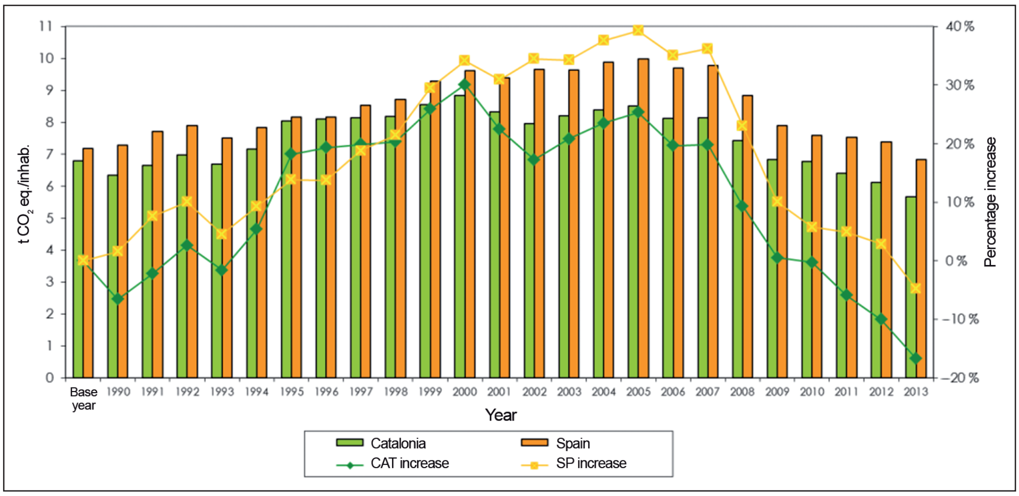



Figure 3. GHG emissions per capita in Catalonia and Spain.
Source: *Third Report on Climate Change in Catalonia*, 2016.

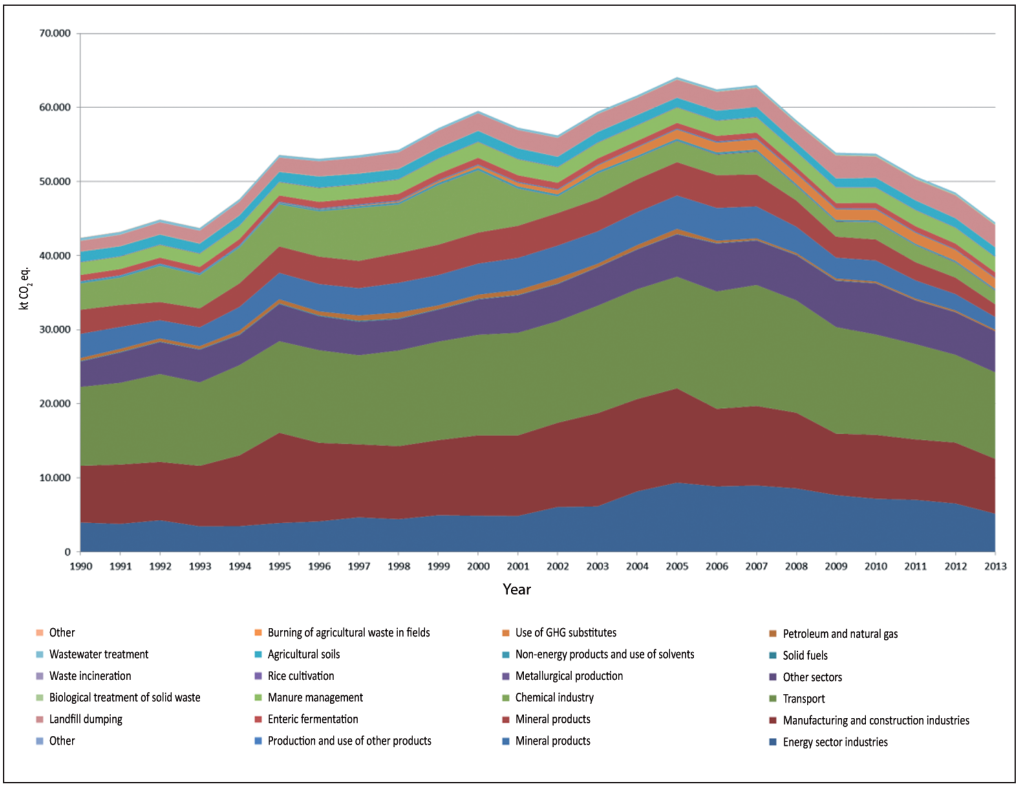



Figure 4. Equivalent emissions of $CO_2$ by sector in Catalonia between 1990 and 2013.

Source: *Third Report on Climate Change in Catalonia*, 2016.

Despite these variations, GHG emissions increased by 9.2 % between 1990 and 2013. Last year, the emissions generated in Catalonia accounted for 13.3% of the figure for Spain as a whole.

Bearing in mind that the population of Catalonia accounts for 16% of Spain's population and 19% of its GDP, the conclusion is that the emissions it produces are lower in percentage terms than would be expected for its population and generation of wealth. Figure 4 shows emissions in Catalonia, broken down by sectors.

### *GHG emissions and economic activity: an inseparable partnership?*

The fact that in 2014 the European Union and Iceland produced fewer emissions than in 1990 despite the rise in population and GDP, along with Catalonia's lower percentage of emissions within Spain as a whole than would be expected from its population and generation of GDP, shows that more GHG emissions are not essential for increasing economic activity.

*Energy intensity* is used to measure energy efficiency (the energy required for each production unit, calculated using GDP). Based on the emissions generated

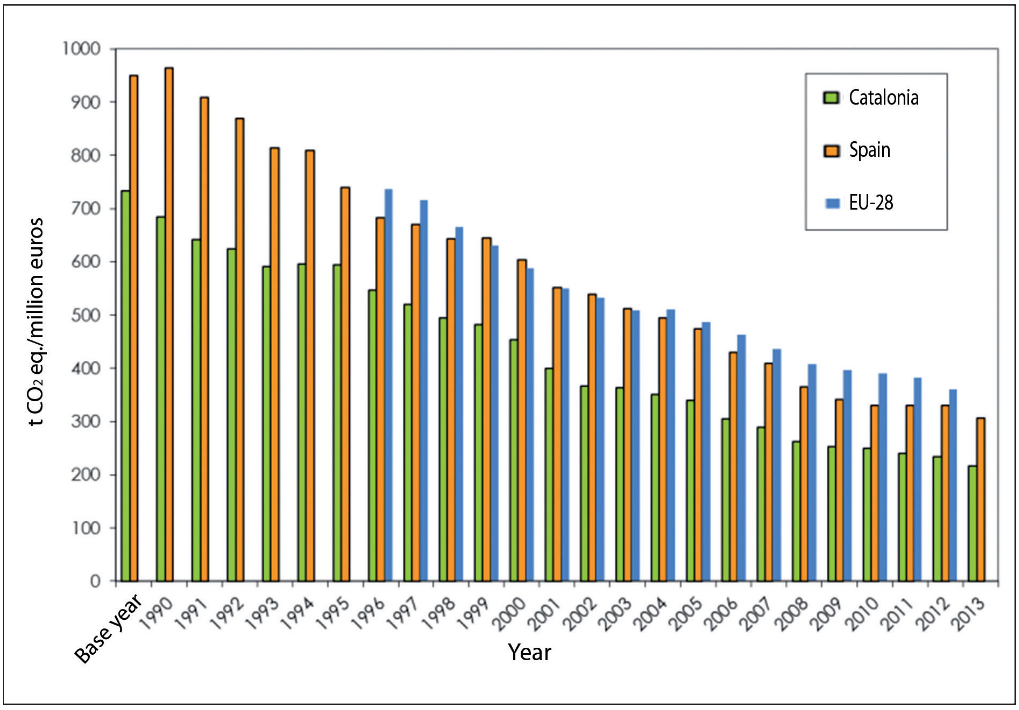



Figure 5. The relationship between GHG emissions and GDP for Catalonia, Spain and Europe between 1990 and 2012.

Source: INE, Idescat and Eurostat.

in order to produce a given type of energy—which depends on the percentage of the different types of fossil fuels—it is possible to calculate the GHG discharged into the atmosphere for each production unit.

This means that the fewer the emissions produced when wealth is generated, the more eco-efficient a country is. So growth no longer depends on using more fossil fuels, but instead on producing the energy required in a more efficient way, and with renewable sources. In short, producing more with fewer emissions.

In Catalonia, GHG emissions per unit of GDP produced fell by 68.4% between 1990 and 2013. This figure was similar for Spain as a whole: 68.2 %. This was not because GHG emissions did not increase, but because GDP grew at a much faster rate. Figure 5 shows the trend for Catalonia, Spain and Europe.

### *A first international treaty to fight against climate change*

The Kyoto Protocol was the first international treaty to reduce GHG emissions. It was drafted in the Japanese city which it was named after, in late 1997. The signatory countries pledged to reduce their total greenhouse gas emissions by 5.2% between 2008 and 2012 (compared to their 1990 levels).

The Protocol, which came into force in February 2005, was drawn up and signed under the auspices of the United Nations Framework Convention on Climate Change. In fact, in a globalised economy, the United Nations is the only instrument for global governance, and it has established the Conference of the Parties, the main instrument in the fight against climate change.

The European Union, which at that point consisted of fifteen Member States, pledged to reduce GHG emissions by 8% compared to its emissions in the base year (1990). This overall target was planned with various requirements for each State—some of which could even increase their GHG emissions.

In overall terms, the European Union complied with the Protocol. Total emissions between 2008 and 2012 were on average 11.8% lower than in 1990. Spain's commitment was not to increase its emissions by more than 15 %—a limit that was exceeded by 8.7 percentage points, as its emissions increased by 23.7%. The figures were even worse in 2004, when Spain emitted 53% more, but the economic crisis led to a reduction.

In these initial unfavourable circumstances, Spain agreed with the European Union to add 2% to the target of 15% as an increase in sink capacity, and a further 20% for the purchase of credits. This finally meant that Spain was committed not to increase its emissions by more than 37% compared to the base year.

Spain finally achieved the objective by increasing the carbon fixation of its sinks, and purchasing emission reduction credits from other countries, although finally it had to buy fewer credits than initially anticipated. Nevertheless, the Spanish Government spent more than 800 million euros on purchasing emission rights in order to meet the commitment between 2008 and 2012.

Spain did not distribute its commitments under the terms of the Kyoto Protocol and the European Union on a territorial basis, or in terms of population, GDP or any other criteria. As a result, between 2008 and 2012 the target agreed by Spain (the 37% noted above) was also adopted as a benchmark for Catalonia.

In the first period of the Kyoto Protocol, the average in Catalonia for the years between 2008 and 2012 compared to the base year was an increase of 16.3% of total GHG emissions—only 1.3% above 15%, but below 17% if the 2% increase in sink capacity is taken into account.

In other words, Catalonia meets the reference target established by the Kyoto Protocol, and the target in the Framework Plan for Climate Change Mitigation in Catalonia 2008-2012, by using its sink capacity without having to purchase credits from other countries.

The failure to reach agreement on a protocol to replace Kyoto in 2012 led that year to the signing of a second commitment period for the Kyoto Protocol in Doha (Qatar), making it applicable until 2020, when the Paris Agreement is to enter into force.

Catalonia has made its own commitment: to reduce GHG emissions by 40% by 2030 compared to the 2005 levels. The calculation was performed using the criteria used by the European Union for States: the reductions are distributed on the basis of GDP per capita.

This means that Catalonia is making a greater effort than the average for Spain, despite the fact that Catalonia, due to not being a state, has no legal obligation to reduce emissions, although it does have the moral commitment and the desire to do so. However, in order to achieve this, it needs to become a low-carbon emissions economy—an objective which must be a political priority.

It will be necessary to transform the mobility model and prioritise public transport over private transport, among other measures. At the same time, we must electrify some of the overhead transport system, prioritise the commuter train network and implement energy efficiency measures, particularly in buildings.

Two complementary paths need to be taken in the field of energy: reducing emissions in production and reducing consumption. In short, this means moving actively and decisively towards positions of leadership.

### *When gases are traded*

Among the instruments that can potentially be applied, the Kyoto Protocol provides for *flexible mechanisms*. In other words, to meet the targets for reducing GHG emissions, a country can ‘buy’ credits from other countries that have a surplus in order to undertake projects to reduce emissions. However, this is subject to limits and controls, and is therefore not a mechanism that can be used indiscriminately.

Meanwhile, the European Union established a series of measures aimed at achieving the targets of the Kyoto Protocol, including implementation of a trading scheme for emission rights.

In this case, the recipients are industrial facilities (electricity generation, oil refining, combustion, steel, ceramic products, cement, glass, lime, paper and cardboard, aviation, and other industrial sectors such as petrochemicals, chemicals, aluminium and non-ferrous metals, etc.), which have to assume the economic costs if they exceed the emissions limits assigned to them.

In this way, companies that fail to reduce their emissions under the terms assigned to them may purchase gas emissions rights from facilities which have reduced their emissions to below their target level. As a result, facilities that are part of the regulated market in the European Union would not have emissions above the overall limit which has been established for the entire European Union.

The annual emissions limit for European facilities is falling, and the associated cost for facilities that emit more than the limit is increasing.

### *Nonpoint emissions in the territory*

Emissions from the activities and facilities that are not subject to the European Union's emissions trading system are called *nonpoint emissions* and include industrial sectors not subject to European Union directives, fossil fuel consumption in the residential, institutional and services sectors, fugitive emissions, the use of solvents, transport, waste and farming (agriculture and livestock).

Nonpoint emissions in Catalonia have tended to decline in recent years, mainly in the transport sector and unregulated industrial sectors. Unfortunately, this has taken place primarily because of incidental reasons associated with the economic crisis and structural reforms. Maintaining and accentuating this downward trend therefore requires the firm policies mentioned above.

## 1.3. Forests, pastures and crops: natural carbon sinks

A proportion of the $CO_2$ that is sent into the atmosphere is reabsorbed. The concentration of the gas would otherwise increase exponentially, and would undoubtedly be irreversible. Natural systems are responsible for part of this absorption. They have a limited capacity which can also change the effects of climate change or how we use different ecosystems, such as turning forests into farmland, or conversely, the loss of agricultural land. Ultimately, the recirculation of carbon—the carbon cycle—is not a fixed process. It changes depending on environmental, physiological and human conditions.

Most natural systems have stored carbon, and the amount that is stored at any given time is called a *carbon reservoir* or *carbon stock*. If the amount in this system naturally increases over time, then it is described as a *sink*, which helps reduce the concentration of $CO_2$ the atmosphere. This process is called *carbon sequestration*. However, if the amount of carbon in the system declines, this is a $CO_2$ *emission source*.

When plants grow, they capture $CO_2$ from the atmosphere. This means that in Catalonia, forests are the land system with the largest carbon stock per hectare, at 149.5 tons per hectare. They are followed by pastures, with 121.4 tonnes per hectare. These are followed by scrubland (112.1 tonnes per hectare) and woody crops (104.0 tonnes per hectare), and finally, arable crops, with 100.8 tonnes per hectare. Most of this carbon is stored in the soil as humus.

In absolute terms, taking into account the total area of each ecosystem, forests are in first place, with a total of 173 Tg (million tonnes) of stored carbon. Forests are followed at some distance by crops, with 98 Tg (partly attributable to the area occupied by each ecosystem: 42% and 29% respectively) and Catalonia's sea, with 92 Tg. Scrubland, pastureland, meadows and inland waters have much smaller stocks. In crop areas, meadows and pastures, the main reservoir is not plants, but instead the soil—hence the importance of management.

However, land systems are not the only ones that capture carbon: the sea stores both the $CO_2$ that dissolves in water and the $CO_2$ captured by various marine organisms (such as marine plants). Catalonia's sea (with an area of 74,000 km$^2$) has increased its carbon stock since 1750, and now holds 92 Tg.

### *Forests: major but insufficient sources of sequestration*

Catalan forests currently offset about 9.7% of our emissions. In other words, it would take 10.3 times Catalonia's forested area to offset one hundred per cent of the emissions. In this hypothetical and completely impossible situation, all the emissions we produced would be absorbed, and the concentration of $CO_2$ would not therefore increase.

The forested area in Catalonia has increased greatly in recent years (130,000 hectares): while it accounted for 38% of the territory in 1993, in 2009 it was 42 %. Why has it increased to such an extent? What has been reduced as a result? The increase has been mainly at the expense of scrubland, and to a lesser extent, albeit a significant one, has involved an abandonment of crops.

Changes in land use have a major impact on both emissions and the ability to absorb carbon. Considering the period between 1993 and 2009 once again, there was a marked increase in the urbanised area (78,000 hectares) and the area occupied by transport infrastructure, as a result of high levels of economic activity prior to the crisis.

However, this period also saw two processes that ran counter to the one above. The first was the decline in agriculture, leading to a net reduction of 166,500 hectares of crops, with a net increase of 88,600 hectares of forest cover (pastures and forests), despite the reduction in scrubland. The second is the natural dynamics of ecosystems: in the absence of major disturbances and human activities, pastureland has become scrubland, and scrubland has become forests.

Although there is no data available as yet from the *Fourth Spanish National Forest Inventory*, which would update the information for the period between 2001 and 2015, it is very likely that Catalan forests maintained their sink capacity during this period. The reasons for this are as follows:

1) They are still young enough to continue growing—and capturing carbon—with little competition for resources and consequently with low mortality rates.
2) The level of forestry harvests has remained stable but low.
3) There have been no major losses associated with forest fires (about 28,000 hectares of forest was burned between 2001 and 2014, or less than 2,000 hectares per year) or any other disturbances.

In short, there have been losses, but they have been largely offset by the increase in the carbon stock in unaffected forests and by the increase in the forested area.

However, there are some figures that do not make for such a positive reading. Forests are not exploited as extensively as they used to be, when they gave us many products with a high economic value, and the decline in economic interest has in many cases led to neglect in their management.

In less carefully managed forests, the density of trees increases and the amount of resources for each one is reduced. This means that the trees have to compete (especially for water, which will become increasingly scarce as a result of climate change), and this could limit their growth and increase their mortality rates.

The simulations for the future that have been conducted suggest that Catalonia's forests will maintain their sink capacity until 2050, although this will begin to decline from the 2020s onwards, and they could become net emitters of $CO_2$. This is because the forests will grow less vigorously and capture less carbon, and with less water, tree mortality rates will increase and carbon will be released.

In other words, one of the main carbon sinks will be less able to eliminate part of our emissions from the atmosphere. As a result, since most of our forests are already suffering from the effects of climate change, flexible forest management adapted to each species and geographical region is essential.

Although farming is less and less profitable, we must prevent it from being gradually abandoned because crops are also an effective carbon sink. Furthermore, since forests are very scarce when rainfall is below 400 mm, communities of shrubs and woody crops play a key role in mitigating climate change.

In addition to being carbon sinks, crops have other basic roles: they generate economic benefits, they enable the population to settle in a more balanced way across the whole country, they protect the natural and cultural heritage, and they preserve the landscape. They are also valuable as ecosystems: they regulate the water, nutrients and carbon cycles, maintain biodiversity, help to control forest fires, protect the soil and prevent it from suffering from erosion.

Measures are therefore needed to prevent the rural exodus, and, more specifically, the exodus from farming. These measures, combined with others to protect pastures and meadows, would maintain the sink capacity of all these natural systems.

A mature Scots pine forest, with large trees acting as carbon reservoirs.

Source: Lluís Comas.

## 1.4. In Catalonia, the climate is already changing

The effects of climate change are already making themselves felt in Catalonia. It is not easy to say whether the changes experienced by the climate can be attributed to this phenomenon, but despite the uncertainty, all the available data suggests that the climate is changing, in the way envisaged in the climate models.

Between 1950 and 2014, the air temperature increased by an average of 0.23°C per decade (see Figure 6). This variation is not uniform throughout the year: the increase in average temperature is more marked in summer, at 0.33°C/decade. The average annual maximum temperature also shows an increase: +0.28°C/decade. The average minimum temperature has also risen, but less than the maximum temperature: +0.17°C/decade.

### *Both droughts and floods*

Climate change does not only affect temperature. For precipitation, an analysis of sixty-eight monthly series from the period between 1950 and 2014 shows a slightly negative annual trend (-1.2%/decade) for Catalonia as a whole, although this decline is not statistically significant.

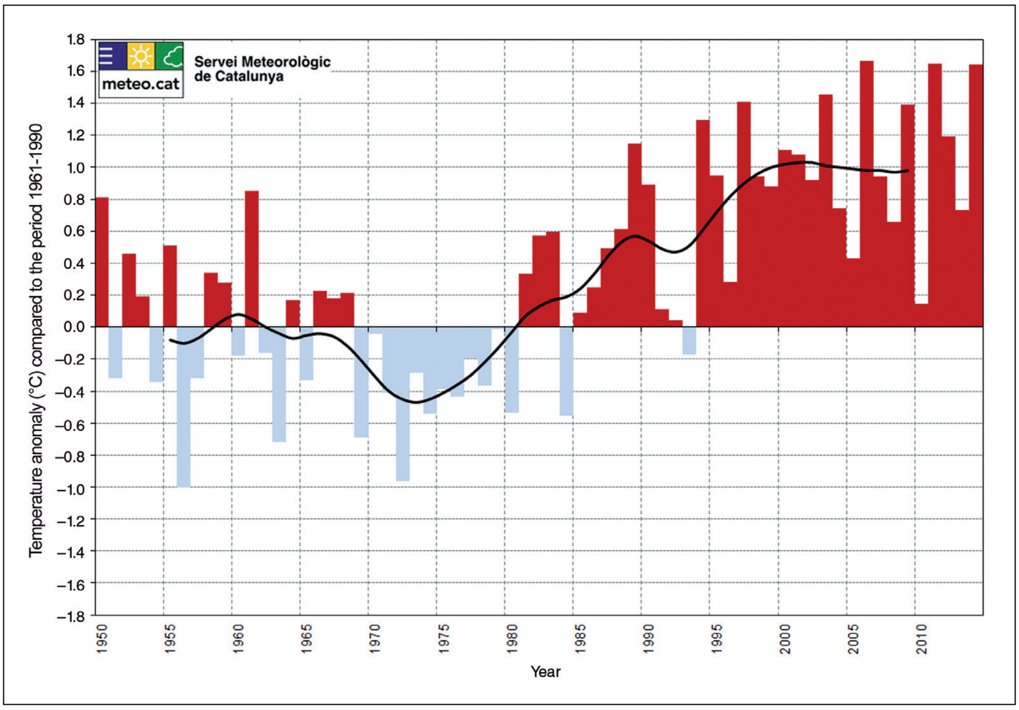



Figure 6. Average annual temperatures in Catalonia (1950-2014) expressed as an anomaly from the benchmark period of 1961-1990. The curve is a Gaussian filter with thirteen members.

Source: *Annual Bulletin of Climate Indicators*, 2014.

However, this covers the whole country. If we look at the geographical variations (see Figure 7), the Pyrenees and Pre-Pyrenees are the areas in Catalonia where precipitation has fallen the most, with declines of between -2.4%/decade and -3.9%/decade. These data are significant, and show that rainfall has declined in these areas since 1950.

A significant trend in rainfall extremes has only been observed in increased precipitation per day of rain, in its convection in some regions (with short and localised showers and thundery rains of high intensity, which are events typical of warm periods) and in the duration of dry spells. These changes are especially noticeable in the summer, and may worsen in the future.

The number of episodes leading to local flooding has increased since the mid-nineteenth century, probably due to increased exposure and vulnerability. This increase is more pronounced in the summer—a season when there is a strong increase in exposure in summer holiday and tourist areas, and a possible increase in torrential rains. However, there is not yet enough evidence to support this theory.

The scenarios for the future are not conclusive, but if there were an increase in torrential rainfall, combined with increased vulnerability, exposure and changes in land use, the risk of flooding would increase significantly.

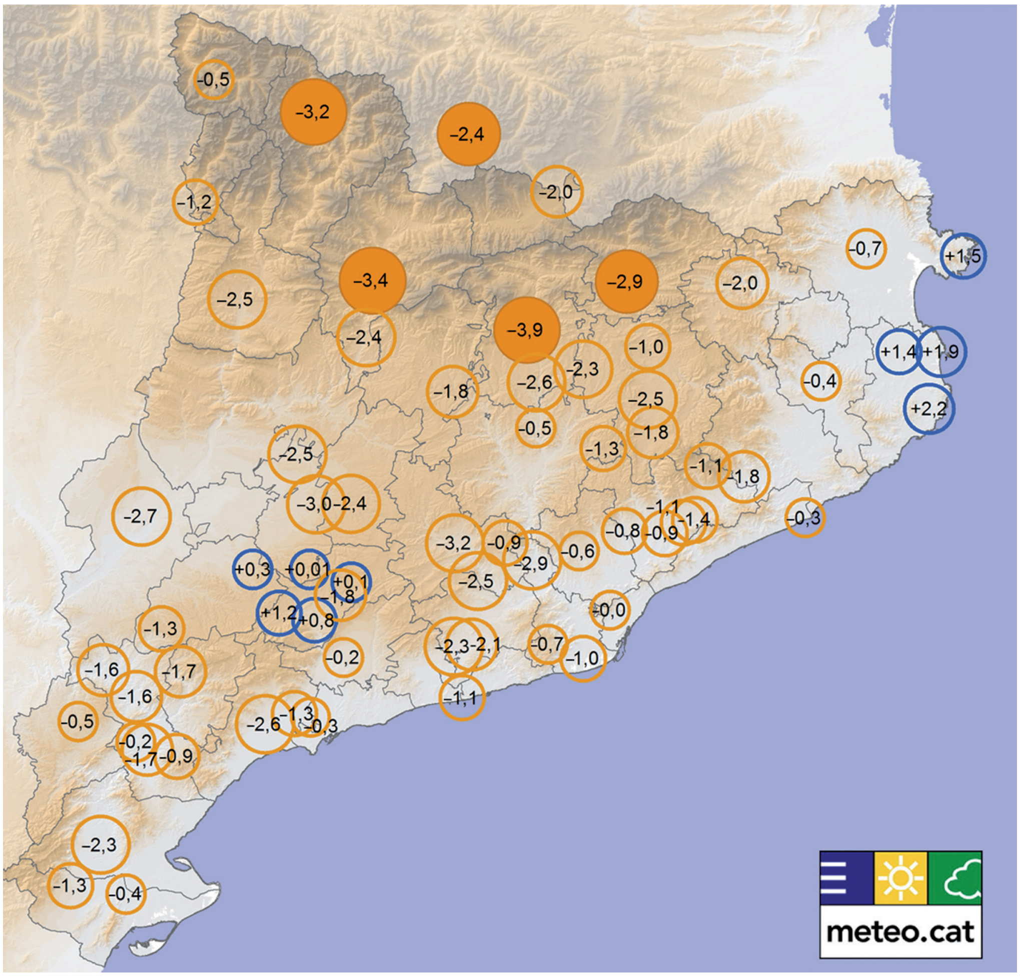



Figure 7. Changes in average annual rainfall in Catalonia (1950-2014) expressed in %/decade. The radius of the circle is proportional to the percentage change in precipitation per decade, and the colour shows whether it is positive or negative (blue = rising, orange = falling). The orange circle shows that the trend is statistically significant according to the Mann-Kendall test ($p < 0.05$).

Source: *Annual Bulletin of Climate Indicators*, 2014.

Landslides, rockslides and debris flows at a local level are more frequent than is commonly thought and are an annual occurrence in some basins. Nevertheless, there is as yet no evidence that this increase in frequency is the result of a change in the intensity or duration of rainfall. It could instead be related to changes in our perception and more events of a lesser magnitude being observed.

At the other extreme, meteorological, hydrological and agricultural droughts have increased, and will continue to increase in frequency and severity during the twenty-first century. This will have a major impact on water resources, water quality, the preservation of ecosystems and the danger of fire in forests.


The Fabra Observatory, founded by the Royal Academy of Sciences and Arts of Barcelona and opened in 1904, was built with a legacy from Camil Fabra i Fontanills, the first Marquis of Alella. It is located on Mount Tibidabo and has always worked in three areas: astronomy, meteorology and seismology. It has kept records of its meteorological observations since late 1904 (continuously since 1913). Since it was established, it has received recognition from the international scientific community in its three specialist fields, and has devices that are almost unique in the world, such as the Jardi rate of rainfall gauge.

Source: Maria del Carme Llasat.

Weather conditions (higher temperatures and more droughts) and the increase in forest crops will increase the risk of fire in the forests. Contrary to what might be expected, the number of forest fires (> 0.5 hectares) and the area burned fell every year between 1970 and 2010. This reduced risk is due to improved prevention and risk management in Catalonia.

The more extreme temperature, humidity and precipitation conditions foreseen by the climate scenarios suggest that the number of forest fires will increase, but that the area burned will be smaller. The increase in exceptional weather conditions may lead to more frequent fires covering large areas, and to fires in areas where they are at present uncommon or fires in seasons other than summer.

There are other data that show how the climate is changing. Evapotranspiration—the sum of evaporation and plant transpiration—has increased significantly since 1950. That means that not only is it less likely to rain, but also that plants lose more water to evaporation.

The Ebro Observatory is a Ramon Llull University research institute. It was founded in 1904 by the Society of Jesus to study the relationship between the Sun and the Earth, and worked in the fields of seismology, meteorology and astronomy, showing that religion, philosophy and science were compatible. The continuity and reliability of its observations for over a century mean that its archives are of incalculable scientific value: the seismic and ionospheric records date back further than any others in Spain, and the meteorological records, which began in 1905, preserve records from the Roquetes Jesuit School dating back to 1880.

Source: Pere Quintana.

According to the records kept at the Fabra and Ebro observatories since the beginning of the twentieth century, a reduction in days of snowfall has only been recorded at the latter. The observatories have recorded fewer foggy days, which is something that has also been observed in Lleida since 1940. There has also been a marked increase in insolation (the number of hours of real sunshine) since 1960.

Catalonia has experienced considerable extremes of temperature since 1950. Warm days and nights have increased, and the number of cold days and nights has fallen significantly. The trend in the climate is obvious: heat is becoming more prevalent, and cold less so.

All climate scenarios suggest an increase in extremely high temperatures, more frequent heatwaves and tropical nights (especially in the coastal and pre-coastal areas), an increase in the number of hot days and nights, and longer periods of dry weather.

### *The sea level is rising and glaciers are receding*

This is something that not only affects species like ours, which live on land. The water in the sea is also heating up. Fortunately, we have a very long series of water temperature measurements at various depths from L'Estartit, in the region of El Baix Empordà, dating back to 1974.

However, what they tell us about the climate does not provide grounds for optimism: the temperature of the water in the sea has increased at a rate of 0.30°C/decade between the surface and depths of up to 50 metres (the increase has been slightly less marked from that level to depths of 80 metres) (see Figure 8). This warming has taken place in all seasons of the year, but has been most pronounced in the summer and autumn.

This is not merely another sign of the climate becoming warmer, but may also have important consequences for marine life and for the sea's ability to act as a carbon sink. In the previous section, we explained how Catalonia's waters have increased their carbon stock. Part of this is $CO_2$, which has combined with the water to produce carbonic acid.

However, the rise in the temperature rapidly reduces the sea's ability to dissolve carbon dioxide, and as a result, hotter water will be less able to capture carbon from the atmosphere. This is a problem that applies to all the world's seas and oceans.

The rise in the temperature is accompanied by another sign of climate change: the rise in the sea level. The data from L'Estartit show that the sea level has risen by 3.9 cm/decade since 1990 (see Figure 9). This is a statistically significant increase, as are the increases recorded for different seasons except for winter: +4.5 cm/decade in the spring, and +3.3 cm/decade in the summer and autumn.

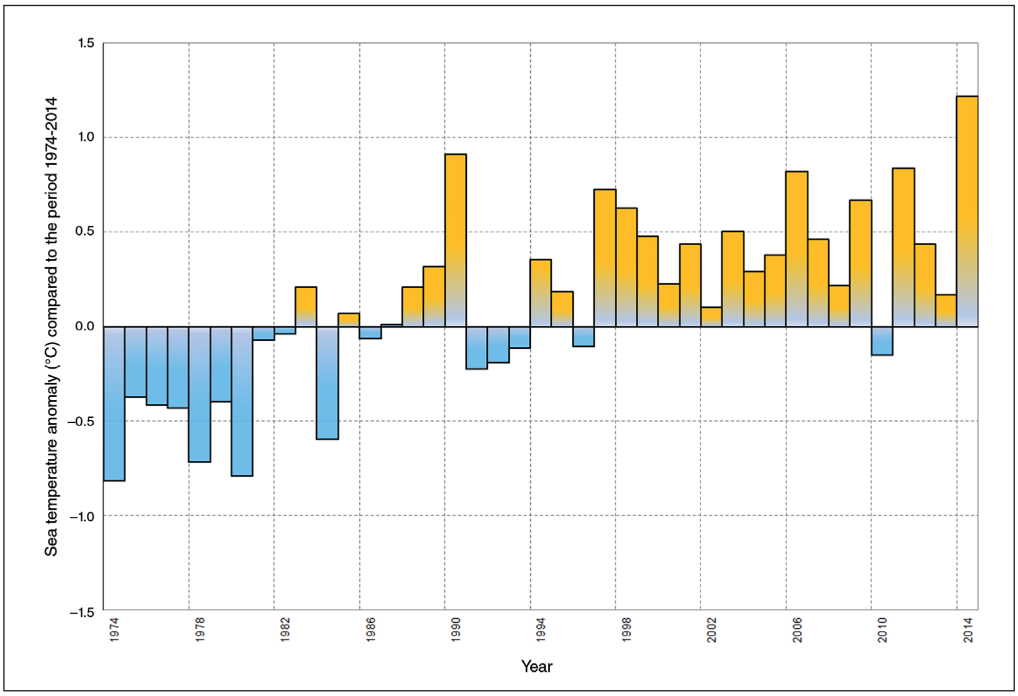



Figure 8. Variations in the average annual temperature of sea water at the surface in L'Estartit (1974-2014).
Source: *Annual Bulletin of Climate Indicators*, 2014, based on data provided by Josep Pascual.

These data are similar to those obtained in other areas on the Mediterranean coast. They are also consistent with those in the IPCC's *Fifth Assessment Report*, published in 2014. According to the report, the global average rate of rising sea levels was 2.0 mm/year between 1971 and 2010, and that rate must have increased to 3.2 mm/year between 1993 and 2010. The latter figure is highly consistent with the trend towards rising sea levels measured in L'Estartit.

For water in its solid form, the news is even worse, because there has been an upward trend in the number of cycles of large avalanches in the Catalan Pyrenees since 1970. More recently, periods of wet snow have also increased, mainly because of rainfall in the middle of winter.

The masses of ice and snow in the upper reaches of the western Catalan Pyrenees have been analysed in detail based on images and photographs taken since 1980.

The conclusion is as striking as it is chilling: we can state categorically that no glacier is visible anywhere in Catalonia, and we can only guess at the existence of a rocky glacier in the Besiberri Massif in L'Alta Ribagorça. This is a firn (i.e. an area where ice accumulates at a level below the glacier itself), which is probably fragmented, and may only be thicker than 10 metres in a few places.

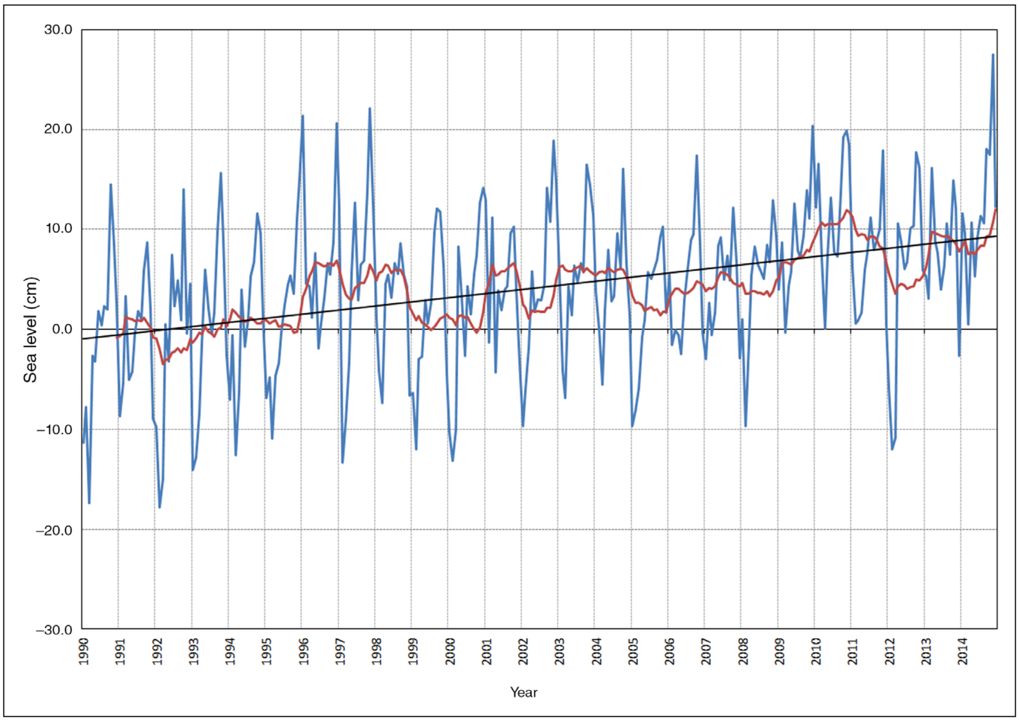
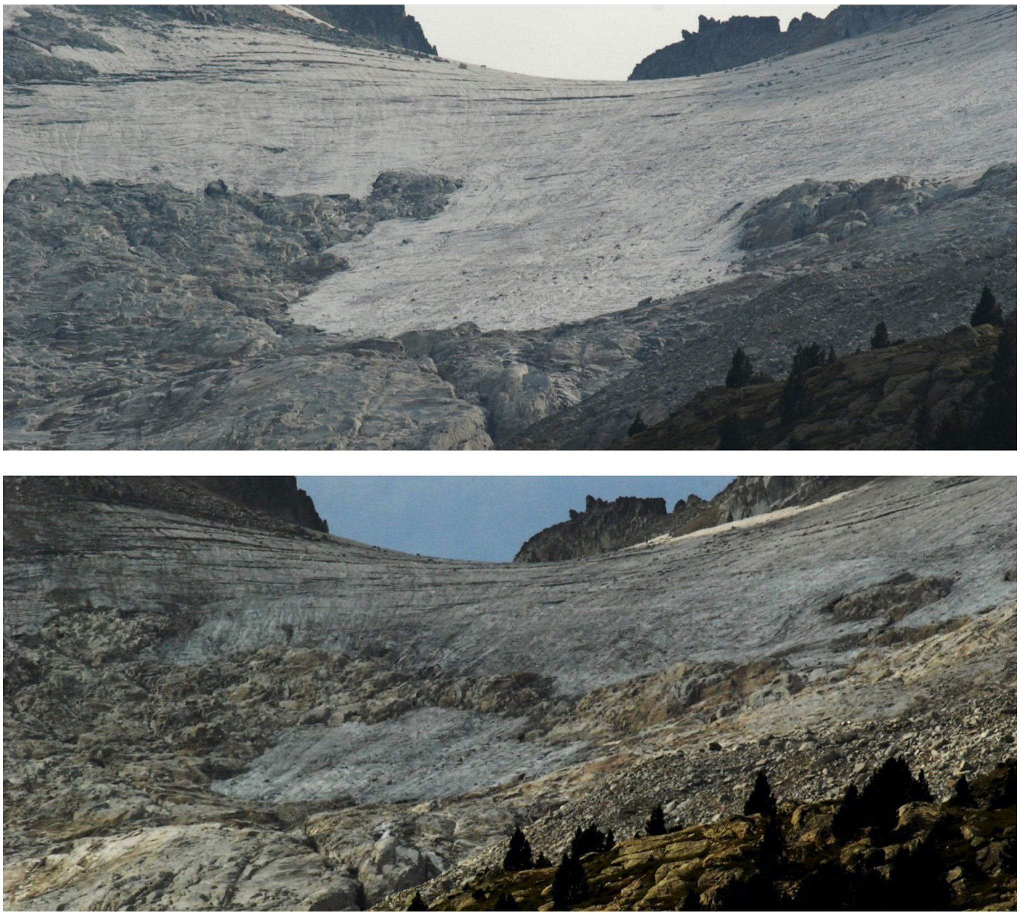



Figure 9. Monthly sea levels in L'Estartit (1990-2014). The red line shows the moving twelve-month average for the period, and the straight line shows the linear trend.

Source: *Annual Bulletin of Climate Indicators*, 2014, based on data provided by Josep Pascual.



The Aneto Glacier. Comparison 2009-2012. Fragmentation of the bottom of the eastern lobe that creates the firn below the Aneto mountain.

Source: Jordi Camins.

The closest genuine glaciers are located in two Pyrenean massifs bordering Catalonia: on Mont Valier in Ariège in France, bordering the Val d'Aran, and the Aneto-Maladeta, in Aragon, adjacent to the L'Alta Ribagorça.

However, the news from there is no better: on the Aneto-Maladeta Massif, the thirteen glaciers catalogued in 2008 had fallen to eleven by the end of 2014, and they had all declined in thickness and area. This has led to their fragmentation, and in some areas they are now catalogued as firns or residual glaciers.

If as expected this trend continues, the glaciers closest to Catalonia will continue to deteriorate and eventually disappear; even the largest glaciers in the best positions will cease to be active within about twenty-five years, and they will have disappeared completely ten years later, after a brief residual period.

The above shows us that in order to have a thorough knowledge of the climate of the past and to prepare for the future, it is necessary to have extensive and high-quality climate records. This requires a meteorological observation network that is in good condition, well maintained and, above all, has the appropriate geographical density. The latter factor is essential because of Catalonia's wide climatic diversity.

## 1.5. The climate of the future: what do the climate projections say?

In the previous section, we discussed data on climate change in the past with some forecasts about the trends for the future, which are called *climate projections*. These are simulations using numerical models, which are based on what we know about the climate of the past and the complex mechanisms that drive the climate system. Simulations project the future climate in a specific area, taking into account changes in emissions and concentrations of GHG and aerosols, which means they must make various assumptions because we do not how many GHG and aerosols there will be in the atmosphere.

The temperature, changes in land use and the behaviour of sinks may also vary, among other factors. There may also be changes in economic conditions or in technological tools. However, projections are crucial for obtaining some idea of how the climate may evolve, and for considering measures to cope with those changes.

On a global scale, the most comprehensive projections which are considered benchmarks are those that the IPCC summarises in its reports. Nevertheless, the results apply directly to large regions, on a scale of thousands of kilometres. Furthermore, in areas like Catalonia, where the topography is complex and the climate is influenced by a land-sea interaction, global models do not give us a very good representation, which is why we need to regionalise (i.e. reduce the scale) the results of these global models.

The results of global climate models have been used to obtain the future scenarios for Catalonia, but particular consideration has been given to the results of various regionalisation projects recently carried out on an international, national and Catalan scale. The projections that emerged from ten-year predictions using various global models have also been taken into account for the immediate future.

The projections provided by most models confirm the trend that has been described above. Taking the average for the period between 1971 and 2000 as the benchmark, there will be an increase in the average annual temperature of +0.5°C to +1°C for the period between 2012 and 2021 for Catalonia as a whole, and by the middle of the century (2031-2050) the increase will be between 0.9°C and 2°C. The increases will occur in all seasons of the year and all over Catalonia, but could be more marked during the summer and in the Pyrenees. The results are shown in Tables 1 and 2.

TABLE 1. Variation in temperature and precipitation in Catalonia by season (1971-2000)

| | | Winter | Spring | Summer | Autumn | Annual |
|---|---|---|---|---|---|---|
| Temperature (°C) | 2012-2021 | 0.7 | 0.7 | 0.9 | 0.8 | 0.8 |
| | 2031-2050 | 1.3 | 1.2 | 1.8 | 1.7 | 1.4 |
| Precipitation (%) | 2012-2021 | 2.2 | –4.6 | –3.0 | –5.2 | –2.4 |
| | 2031-2050 | –3.8 | –10.7 | –10.2 | –9.4 | –6.8 |

Note: the values are averages from climate projections produced based on various global and regional models and projects.

Source: *Third Report on Climate Change in Catalonia*, 2016.

TABLE 2. Variation in temperature and precipitation in Catalonia by region (1971-2000)

| | | Coastal/ Pre-coastal | Inland | Pyrenees | Catalonia |
|---|---|---|---|---|---|
| Temperature (°C) | 2012-2021 | 0.7 | 0.7 | 0.8 | 0.8 |
| | 2031-2050 | 1.4 | 1.4 | 1.6 | 1.4 |
| Precipitation (%) | 2012-2021 | –2.4 | 0.7 | –0.2 | –2.4 |
| | 2031-2050 | –8.3 | –6.5 | –5.3 | –6.8 |

Note: the values are averages from climate projections produced based on various global and regional models and projects.

Source: *Third Report on Climate Change in Catalonia*, 2016.

These increases may seem small if we think in terms of the current differences between regions or seasons, or even within a single day. Nevertheless, as an example, during the last ice age the Earth's average temperature was only between 5°C and 8°C lower than it is now. So there should be little doubt that if these projections come true, the changes that take place will be significant.

Although different projections give different results, and the trend is said to be uncertain as a result, most models suggest a decline in precipitation levels. If we consider the regionalised projections—designed with a spatial resolution of 10 to 30 km instead of 150-300 km in the global projections—there is a decline in precipitation for Catalonia as a whole and across the whole year, as well as a decline in the annual average of -6.8% (2031-2050).

All these simulations are based on 'moderate' emissions scenarios—i.e. with a rate of increase of GHG emissions tending towards stability. If the generation of gases increases at a faster rate—which depends on various factors, but primarily on the policies implemented on a global scale—the changes may be more noticeable, the temperature could rise and precipitation could fall. However, this effect would not be clearly apparent until the second half of the twenty-first century.

As well as the averages, we must consider whether there may be more extreme events. Daily maximum and minimum temperatures may rise by up to 3.5°C and 1.5°C respectively by 2050.

We can also expect the number of warm months to increase significantly over the next forty years. However, the number of very cold months would be similar to the amount observed in the reference period (1971-2000).

The number of tropical nights (when the temperature is greater than or equal to 20°C) would increase significantly in coastal and pre-coastal areas. In high mountain regions, the projections suggest a significant decline in the number of days with frost (when the minimum temperature is 0°C or below).

Episodes of torrential rain may also increase, and this is not incompatible with an overall decline in precipitation. This means that the probability of episodes of precipitation exceeding 200 mm in twenty-four hours is expected to increase. However, the severity and duration of droughts could increase significantly, due to the combined effect of increased temperature and a decline in precipitation.

There will therefore be more torrential rains and longer droughts. The climate will be more variable, with a tendency towards an increase in these extreme events.

# PART 2

# Natural systems: impact, vulnerability and adaptation

In the previous section, we discussed the trends for the main climatic variables recorded during recent decades and the projections that have been produced for the period until 2050. In overall terms, there are a number of events or situations which will almost undoubtedly increase in frequency and often in intensity.

It is very safe to say that climate change will lead to an increase in very high temperatures and extreme heatwaves, there will be more tropical nights and warm periods will last longer.

However, there is no significant general trend towards an increase in the number of days of heavy rain, or in maximum precipitation in a twenty-four hour period, or any related indices. The duration of dry spells is also very likely to increase. This will be most obvious in the summer—the season when the rise in temperature and the fall in precipitation will be most marked.

These changes will have a marked impact on agriculture and the state of ecosystems, because the soils will be drier in the spring and the dry summer will last longer. The availability of water resources will also be affected, as they will diminish and become more variable. This will make them more difficult to manage in order to cope with periods of drought. The large amount of water that is stored in snow will also continue to decline.

If there are more prolonged hot and dry periods, crops will need more water and water stress in plants will increase; this is the logical consequence of an increased demand and decline in the availability of water.

## 2.1. Fires, floods and other climate hazards

The decline in the availability of water will increase the danger of fires caused by high temperatures and more severe droughts. These events could spread to areas where they are not currently very common, such as mountainous areas, or occur in seasons where they are currently infrequent, such as winter and spring.

Two crucial factors to counter this are forestry management, to prevent fires from spreading, and planning, to facilitate access to the affected areas.

We must also consider our responsibility for events which may take place more frequently due to climate change, and which therefore require firmer measures.

This means that although it has always been important to raise awareness about actions and situations that could lead to fire, it will be even more important if conditions mean that these fires start more frequently and spread more quickly.

The number of events leading to local flooding has increased since the mid-nineteenth century, probably as a result of increased exposure and vulnerability. There has also recently been a rise in the number of events in the summer, which could

Effects of the forest fire that affected the Sant Llorenç de Munt Natural Park in August 2003.
Source: Meteorological Hazards Analysis Team, University of Barcelona.

A street in Badalona during flooding on 29 July 2010.
Source: O. Rodríguez.

be related to an increase in torrential rains, although there is not enough evidence to be certain.

The scenarios outlined by the models for the future are inconclusive, but an increase in heavy rains could lead to a significant increase in the risk of flooding. However, factors that are not related to climate change may contribute to this, such as increased vulnerability and exposure and changes in land use.

Although urban planning and the installation of infrastructure should always consider the risk of floods and flood waves, the probability of an increase in torrential rains and landslides makes this even more necessary, as this risk leads to major economic losses and is responsible for the most occasions on which civil protection plans are activated.

Landslides, rockfalls and debris flows at local level are more common than previously thought. Nevertheless, there is currently no evidence that the increase in the frequency of these events is due to any change in the intensity or duration of rainfall. This increase is probably due more to the development of communication technologies, which raise awareness of them, rather than climatic reasons.


A bridge on the N-II highway destroyed after the flooding of 10 June 2000.
Source: Maria del Carmen Llasat.

However, measuring instruments have been installed in experimental basins. This has provided more precise information, and confirmed that the rainfall thresholds that trigger landslides are lower than they were previously.

However, the number of accidents due to avalanches is now higher. While there is a tendency towards an increase in the number of cycles of major avalanches in the Catalan Pyrenees, and wet snow avalanches have increased at the same time, many more people also participate in mountain activities. Despite the increase in the number of accidents, there are fewer deaths. This is probably because of the greater perception of risk among people taking part in leisure activities and those working in the mountains.

This means that, apart from the impact of the climate on some specific phenomena, increased awareness and prevention measures can lead to a reduction of the negative effects. It is therefore necessary to adopt a holistic perspective, and include risk management and adaptation to climate change in both territorial and sector planning. It is essential to establish inter-ministerial committees to reduce risks, to ensure the coordination of all the stakeholders involved.

However, at the same time we must improve awareness and responsibility among the public, and especially among very vulnerable groups of the population. Good planning and good management, accompanied by an increased awareness and more responsible behaviour, are essential for meeting the challenges created by climate change in terms of natural risks associated with climate.

## 2.2. Water—an increasingly scarce resource

One of the most noticeable effects of climate change in Catalonia will be a reduction in available water. In the future, water resources will be scarce all over Catalonia, although the varied nature of the territory means that there will be various levels of vulnerability.

Water will become scarcer everywhere, but this scarcity will vary widely depending on the area. Using a water balance based on data from climate projections and the land uses in each hydrographic basin, it has been calculated that the availability of water will fall by 11% by 2021 and by 17.8% by 2051. In this latter time frame, the decline will be much smaller—albeit significant—in the regions in the Pyrenees than in Catalonia as a whole, and is estimated at 9.4%. In the inland districts, the decline will be 18.2%, and in coastal areas, it may reach 22%.

The effects will be similar in both inland Catalonia and on the coast, and will be particularly marked in the southern half of the country. In this area, calculations suggest that the available water resources will fall by between 70% and 75% of current values by 2051. This shows that the availability of water for both human use and for the preservation of rivers and wetlands will be one of the most important issues in the coming decades.

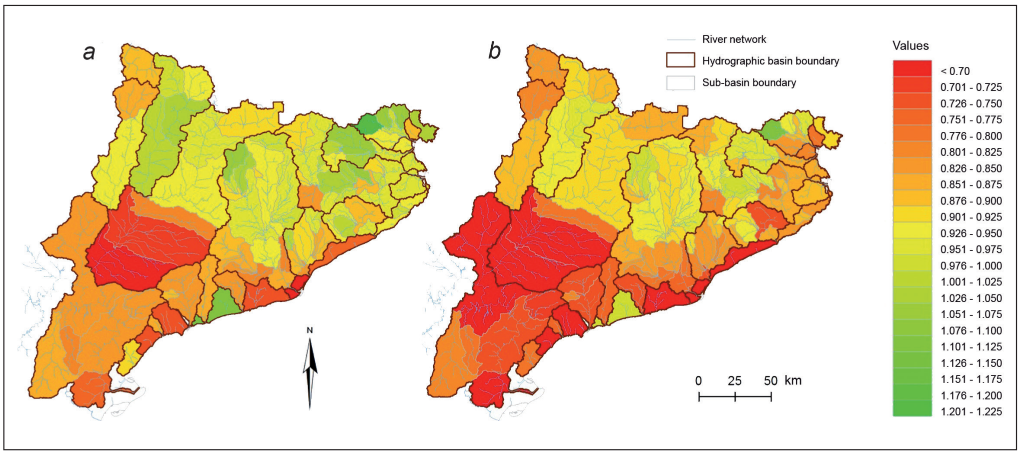



Figure 10. Regional distribution of available water resources in Catalonia for the time frames *a*) 2021 and *b*) 2050, using the *R/P* ratio for each time frame and the present value based on data recorded at 168 observatories in Catalonia. The current distribution of land use is a determinant factor in the evapotranspiration of the water balance, and has also been taken into consideration in the calculation of the total available resource.

Source: *Third Report on Climate Change in Catalonia*, 2016.

The Sau reservoir in 2008, during the drought that left the church exposed.
Source: Meteorological Hazards Analysis Team, University of Barcelona.

The Susqueda reservoir during the severe drought of 2008, taken on 5 March that year.
Source: Catalan Water Agency, Government of Catalonia.

The estimates for the sub-basins in the Pyrenees are particularly important, as they will determine the water resources available to regulate reservoirs—the primary tools for management for various human uses, and for guaranteeing the ecological and hydrological roles of Catalonia's most heavily anthropically affected rivers: the Ter, the Llobregat, the Segre and the Noguera Pallaressa and the Noguera Ribargorçana.

Chapter 7 of the TICCC presents unpublished maps of the future availability of water in Catalonia, based on a calculation of the water balance under various climatic conditions. This availability is expressed by the ratio *R/P* (the relationship between the resources available from river runoff and refilling of aquifers, and precipitation) for the 2021 and 2050 climatic time frames (see Figure 10), and today's *R/P* value, based on average precipitation and temperature over the last decade. The temperature values, as well as the distribution of land uses, are necessary to calculate the loss of evapotranspiration in the balance, which is heavily dependent on the type of vegetation, and specifically on forested areas.

### *Climate change—changes in management models*

According to various studies carried out in Catalonia, this projection is explained by the change in climate variables and, in a direct way, by changes in land use, and especially by the exodus from farming and the resulting increases in forest areas.

This means that there are two key factors which play an important role in the availability of water resources, apart from the consequences of climate change: changes in land use, and the management of the water resources. The changes that took place in land use and in the management of basins, rivers and aquifers during the twentieth century changed the regional water balance.

As a result, apart from the rise in temperatures and fall in rainfall, a comprehensive management of the demand is necessary in order to adapt it to the availability of the resource—either by savings, by using alternative local sources or, above all, by reusing reclaimed water wherever this is possible. The next challenges are to improve efficiency in the distribution of resources, and to consider the links between networks to ensure a balanced and committed supply.

The estimated population growth in Catalonia will not entail any significant increase in the demand for water in inland basins, where there are the most pressing urban needs, and specifically in the metropolitan areas of Barcelona, Girona–Costa Brava and Camp de Tarragona. Even some big cities, such as Barcelona and the surrounding area, have reduced their daily consumption by up to 15% in recent decades. This is largely due to the implementation of savings measures and a more efficient use of water. However, these measures are still insufficient to cope with the decline in water availability caused by climate change. The objective for management must therefore be to gradually reduce consumption and achieve efficient water management.

Agricultural development projects will have to take place within a general context of scarcity of resources. For example, the new irrigation projects and the large dams planned to supply them in the current Hydrological Plan for the Ebro Basin will increase agricultural needs at the expense of the river's flow levels. The river is already lacking resources due to climate change, and this will affect the water supply in the lower parts of the basin. Environmental uses and more specifically, the stability of the Ebro Delta in all areas that depend on the hydrological and sedimentary cycle will be particularly sensitive and vulnerable.

### *A problem of both quantity and quality*

Another aspect to consider in the context of increasing water scarcity is the quality of water resources. On the one hand, it is important for preserving river ecosystems and the services they provide by assimilating nutrients and undesirable chemical elements in solution. On the other, it affects how other types of pollution are diluted, such as pollution in groundwater, due to a lack of recharging in the subsoil. Rising sea levels, another consequence of climate change, will be very important in coastal areas. As sea levels rise and groundwater resources are used in coastal areas, the saline wedge will move towards the mainland, and the level of salinity in the aquifers will rise.

The River Ebro brings life to the delta before it reaches the Mediterranean Sea.

Source: Mariano Cebolla. Delta de l'Ebre Natural Park Archives.

The situations in the Llobregat and Ebro deltas differ in this respect. In the Llobregat Delta, the wedge is caused by groundwater being extracted in the delta, and the measures taken to control it have involved building hydraulic barriers (which can also be effective against rising sea levels).

However, in the Ebro Delta, the balance between fresh water and salt water is extremely delicate both along the river channel and in the aquifers. This is because of the geography of the delta itself, but above all because of how the water balance is controlled by agriculture. The Ebro is itself the paradigm of a coastal water system that is subject to the effects of climate change from both the land (reduction and changes in flow levels, reduced sediment deposits) and from the sea (seawater intrusion, coastal erosion).

## 2.3. The Catalan coast—much more vulnerable

One of the consequences of climate change is rising sea levels, which will affect coastal systems, such as beaches and ports. However, this cannot be generalised because these systems are very diverse in terms of the natural and anthropogenic pressures they are subject to. The responses to oceanographic and meteorological factors are currently very varied, and will remain so in the climates of the future.

### *Marine erosion and rising sea levels*

The most indicative value for swell levels, the average wave height, is anticipated to fall slightly in most of Catalonia, which is consistent with a drop in wind speed. However, there will be an increase in areas near the Gulf of Genoa, i.e. on the northern Catalan coast. Furthermore, the patterns are very different in winter and in summer, when the height of waves will increase in the south.

The impact on beaches has been assessed in terms of marine erosion and flooding. The former expresses the difference between incoming and outgoing sediment, i.e. between sediments that have been deposited by various mechanisms, and those which have been extracted by waves.

In its strictest sense, erosion occurs when this balance is negative, i.e. more sediment has been removed than has been deposited. Most Catalan beaches suffer from erosion. The average figure for the coast as a whole is between 0.60 m/year and 0.90 m/year. The projections for erosion caused by changes in the levels of waves, which carry sediment longitudinally along the coast, show that 26% of the Catalan coast will continue to experience the same levels of erosion or accretion (when the opposite occurs) in 2050.

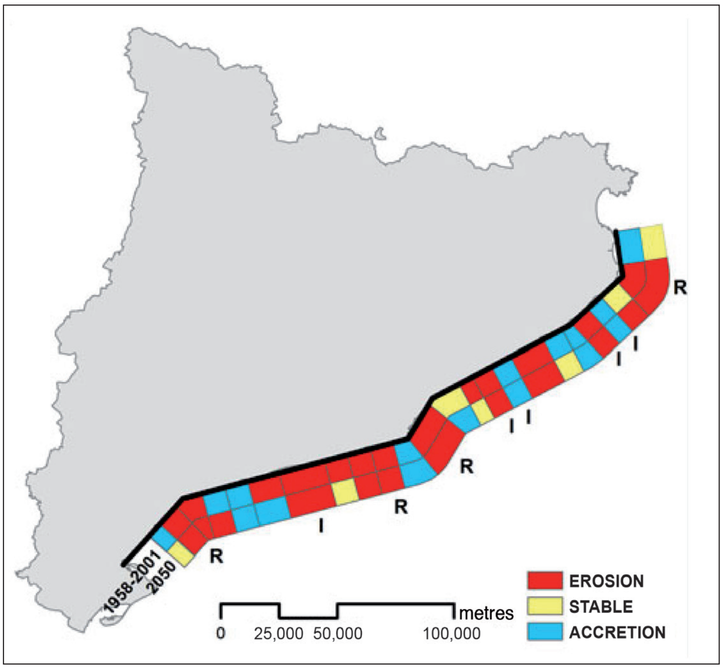



Figure 11. Behaviour of the coast in the current medium term (1958-2001) and in a climate change scenario, in 2050. I (intensification): indicates coastal areas where the effects of climate change intensify erosion. R (reduction): shows stretches of coast where the effect of climate change leads to a reduction in erosion.

Source: Casas-Prat, M.; Sierra, J. P. "Trend analysis of wave direction and associated impacts on the Catalan coast". *Climatic Change*, 115, 2012, pp. 667-691.

This means that over 70% of the beaches will undergo a change in their current conditions; of these, about 50% will deteriorate (more erosion), while the rest will improve (accretion). The diagnosis warns of the vulnerability of the northern Catalan coast. Figure 11 shows the potential erosion and accretion.

The desert-like appearance of the Fangar headland, one of the emblems of the Delta de l'Ebre Natural Park. Source: Mariano Cebolla. Delta de l'Ebre Natural Park Archives.

**Ebro Delta**

Current conditions

Flooding due to a 1.0-m relative rise in the average sea level

Flooding due to a 2.0-m relative rise in the average sea level

Flooding due to a 3.0-m relative rise in the average sea level

Figure 12. Effect of the relative rise in sea levels on the Ebro Delta. The delta as it is today is shown at the top left. This is followed by the flooding caused by relative increases of 1.0, 2.0 and 3.0 m. This is calculated bearing in mind that changes in land-sea levels do not apply in the delta, and as such a ‘bathtub’ or simple flooding model can be applied, which suggests that there is no reaction by the beach profile. The relative level is a rise in sea levels of up to 2.0 m and a subsidence of up to 1.0 m. This means a sensitivity analysis can be performed, and those levels can be associated to a specific time frame.

Source: The topography comes from a digital terrain model obtained from images by the Cartographic and Geological Institute of Catalonia.

This transportation of sediment will be the key factor in how the characteristics of the beach evolve in the medium term. However, in the long term, it is necessary to consider the combination of coastal subsidence and the rise in the average sea level. It is also necessary to consider the episodic changes caused by storms. More than 50% of the coast of Catalonia is expected to become vulnerable or very vulnerable to erosion caused by the action of storms.

As a result, considering the contribution made by the longitudinal transport, by 2060 Catalonia will have 140 km of coast which is very vulnerable to the effects of storms, in contrast to the current figure of 61 km. El Montsià, El Baix Ebre, El Tarragonès and El Baix Penedès are the districts where the increase in vulnerable kilometres will be most significant (especially in El Montsià, where the figure would increase from 3 km to 65 km). Figures 12 and 13 show the effect of the relative rise in sea levels on the Ebro Delta and the Barceloneta beach, respectively.

Finally, if we consider the combined effect of longitudinal sediment transportation and the relative rise in the average sea level, the models suggest that Catalonia will have 164 km of coastline—out of a total of 218 km studied—at a high or very high risk of erosion. The region of L'Alt Empordà, where one hundred per cent of the coast would become vulnerable, provides particular cause for concern.

### *Ports—the most vulnerable infrastructures*

Another coastal feature affected by climate change (and particularly by rising sea levels) are ports. In this case, the main potential direct impacts are breakwaters being breached, and harbours and port areas being flooded.

According to the models, the breach flow rates, i.e. the water that would pass over the breakwater, would increase significantly in many Catalan ports. This would lead to an increase in the number of vulnerable ports, and particularly those vulnerable to medium- or high-intensity storms, which would affect the ports' operations and could lead to serious problems with management of port facilities.


Figure 13. Changes in the edge of the Barceloneta beach, caused by rising sea levels, with a sandy beach (the theoretical case) and rigid infrastructures (the real case).

Source: *Third Report on Climate Change in Catalonia*, 2016.

If the sea level rises even higher than in the model (almost 4 cm/decade), the situation will worsen significantly. Most of the potential problems associated with breaches are located on the northern Catalan coast.

The northernmost ports will also experience increased agitation, i.e. the variations caused by short duration waves within the port due to changes in swell levels. The same will happen to those located further south. Meanwhile, the annual average agitation could persist or decline in the ports located on the central Catalan coast. The time of year when agitation will increase will be the summer, just when the amount of people on the coast is at its highest.

## 2.4. Ecosystems: changes in structure, operations and the services they perform for us

Ecosystems are important from various points of view. They perform a number of productive services, such as food, pasture for cattle, medicines, timber, etc., as well as environmental services, such as maintaining biodiversity, regulating the composition of the atmosphere and climate, conservation of soil and water and carbon storage, among others.

They also have a social dimension: recreational educational and leisure uses, traditional cultural values, tourism, hiking, etc. Many of these services also clearly have an economic dimension. The effect of climate change on ecosystems is therefore a crucial issue, which has an impact in many areas.

First, rising temperatures, new patterns of precipitation and other climate changes are already affecting terrestrial ecosystems in Catalonia. Many people have already experienced or guessed that some changes are taking place. Is spring coming earlier? Is winter taking longer to arrive? Are there plant species that are blooming earlier in the year, or migratory animals which have changed their patterns of arrival and departure? Several studies confirm and quantify these impressions.

For example, it is well-known that the onset of spring is earlier and winter arrives later, meaning that the growing season has been lengthened by an average of about three or four days over the last fifty years. And in nature, where there are so many interactions and so many species are dependent on each other, this can lead to even more visible changes (e.g. migratory birds may lack some food to feed their young, because plants have changed their flowering or fruit production patterns).

Some species are more vulnerable to these changes than others, and this reduces their competitive ability. Ultimately, the composition of communities changes (in scrubland, for example, the wealth of species has declined), and so does the distribution of species (some Mediterranean species will move to higher altitudes to compensate for the rise in temperatures).

### *Genetic changes that transform ecosystems*

The evidence is apparent from the lowest level, on a molecular scale, to the areas shown in satellite images, which highlight major changes in the country as a whole. In between, there are changes in the metabolism of organisms, changes in the demography of plant and animal populations, changes in the composition of communities, and differences in how ecosystems are structured and operate.

We can find an example on the smallest scale: field studies in the Montseny mountains and climate manipulation experiments carried out in the El Garraf region (which have created warming and water shortages) show that many species are able to acclimatise and adapt quickly in response to climate change, because they take advantage of their populations' genetic variability.

Consequently, two conclusions can be drawn: 1) the severe impacts on Catalonia's organisms and ecosystems may be very significant; and 2) the less genetic variability that species have, the more limited their ability to respond and adapt.

Genetic material—DNA—can undergo variations in the sequence of nucleotides—the four letters, A, C, T and G, which combine to produce the extraordinary diversity of life. However, in recent years, changes have been reported in gene expression that are not attributable to changes in this sequence. This is known as *epigenetics*, and basically consists of changes in some parts of DNA, such as *methylation processes*, which determine whether a particular gene is expressed or not.

This means that not only is the genetic sequence of nucleotides relevant in genetics, and therefore the genes that an individual has, but also the existence of a kind of trigger that can start or stop their activity.

Changes in the methylation profiles of holm oak trees (*Quercus ilex*) subjected to an experimentally induced drought have been studied, and epigenetic differences clearly attributable to the drought were observed. Techniques based on studying various metabolites to measure activity in heather (*Erica multiflora*) and holm oaks have also been used, and a reduction of activity in metabolic pathways linked to the accumulation of energy and growth has been reported, as well as an increase in secondary metabolic pathways linked to anti-stress mechanisms in response to the increase in the level of the drought.

The consequences may be very varied and unexpected. Metabolic changes lead to changes in the chemical composition of different plant organs, and these changes in turn affect the taste of plants, which may be more or less appealing to herbivores' palates. This means that metabolic changes can affect the entire food chain.

All metabolic responses have a strong effect on the growth and development of organisms in the medium and long term. As a result, a small reduction in soil moisture has been observed to lead to a very significant reduction in the increase of biomass in the holm oak of the Prades mountains. This sharp decline in tree growth was caused by a decline in net photosynthetic rates and an increase in defoliation.

### *Nature's calendar changes*

Mediterranean species have a marked capacity for acclimatising to hot, dry conditions, but may be sensitive to persistent drought and high temperature stress. One of the strategies that these species can use is to make the most of periods in which conditions are favourable.

This can be achieved by means of phenological changes, i.e. cycles linked to the climate. In fact, climate change has been found to alter not only when leaves fall and the flowering season, but also to affect the falling of leaves from deciduous species in winter.

In general, warming slows down the leaf's ageing and falling process. However, drought accelerates it, although the intensity of this change varies depending on the species. The impact of climate change will ultimately depend on the relative importance of each of these factors in specific regions or years.

Because of the dependency or mutual relationship between plants and animals, animals will experience phenological changes. We now have convincing data showing that bees appear earlier in the year, and the plants they pollinate flower sooner.

There are numerous examples of species that are spreading to latitudes closer to the poles or to higher altitudes of mountains.

### *Large trees, tiny microorganisms*

Not all tree species are affected by drought in the same way. The holm oak, a dominant species in the Catalan Mediterranean forests, has suffered a significant decline in productivity and an increase in mortality and defoliation rates in recent years. By contrast, the effects of the drought on other species of tall shrubs which have adapted better to arid environments have been minimal.

We would therefore expect that if the Mediterranean climate becomes drier in the future, the holm oak would be replaced by this type of shrub, and consequently, there will be a decline in the $CO_2$ sink capacity of Catalonia's forests.

The effect of climate change on microbial communities in the soil must also be taken into account. Despite their small size, these organisms regulate cycles of carbon and nutrients on a global scale.

Changes in precipitation levels can, firstly, alter the composition of the microbial community as a result of the extinction on a local scale of some operational taxonomic units—in microorganisms rather than species. They can also change the relative abundance of bacteria and fungi, which are involved in the decomposition of other organisms in various ways, and may therefore affect the availability of organic material for other organisms such as macroinvertebrates.

Microorganisms are more resilient and can adapt to changes. However, the impact of climate change on these communities remains to be seen, because they can cause changes on a larger scale.

The alterations caused by climate change in land ecosystems are therefore already apparent, and are expected to become more visible in the future. However, they may be more marked and more significant if climate change combines with other disturbances associated with it, such as flooding, drought, heatwaves and forest fires. Other factors will also come into play, such as changes in land use, pollution and the overexploitation of resources.

These disturbances compromise—and will continue to compromise—the environmental, social and productive tasks that terrestrial ecosystems perform for us. Environmental management and forestry policies must therefore take into account the characteristics of our ecosystems, and the climate, environmental and social conditions projected for the years and decades to come.

### *Drought—a key factor in the integrity of freshwater ecosystems*

In Catalonia, the fauna and flora in continental freshwater ecosystems (rivers, ponds, lakes, ponds, lakes and reservoirs) is highly diverse. These organisms have adapted to the extreme hydrological changes typical of the Mediterranean climate. However, their resilience may reach its limits if these changes increase or become more marked.

In the medium term, some ecological niches may empty and may be exposed to invasion by non-native species, which could lead to more homogeneous communities and a decline in the number of endemic species, which are currently much more abundant than in many other climatic regions.

The main change that these aquatic systems are experiencing is related to the hydrological cycle, which is more influenced by human activity than by climate change: in Catalonia's inland basins, 36.4% of the flows—30% including the Segre—is intercepted for urban or agricultural uses.

Climate change may also have a major effect on the species that live in these ecosystems: it may lead to an increased frequency of extreme and short-lived events that affect the presence of some species, such as droughts and floods, as well as changes in normal hydrological conditions.

The unusual rise in temperatures may be the reason behind the decline in ice cover on the lakes in the Pyrenees, the earlier arrival and longer stratification period of the water in the lakes, and the rise in the temperature of river water, with has biogeochemical implications and effects on biodiversity.

Various phenomena closely related to climate, such as drought, may affect the state of aquatic ecosystems. The increased severity and frequency of droughts (especially in summer, as has been seen in the entire Iberian Peninsula over the past five decades) can break up a river's continuum, turning it into a fragmented series of disconnected and ephemeral bodies of water.

This increase in the time water spends in the water system, known as a *slowdown* in the water flow, is especially evident in Catalonia, because many of the country's rivers are regulated by a highly dense network of locks. During periods of drought, these locks, along with small isolated ponds in dry riverbeds, hold most of the water and account for most biological activity in river networks.

If the average temperature of the Earth's atmosphere increases by 2°C compared to pre-industrial levels (which is something the Paris Agreement is aiming to avoid), all the resulting changes could lead to a 13% increase in the residence time of water in Catalan rivers.

This increase could lead to an accumulation of organic matter, a lack of oxygen, increased salinity, the acidification of rivers and lakes in waters with few minerals, and even an increase in methanation and the production of methane, which is a powerful greenhouse gas. The appearance of large and stable populations of macrophytes in regulated rivers such as the Ebro and the Segre provides clear evidence of these biogeochemical alterations and the changes in the flow levels.

### *The unpredictable rise of river levels*

The opposite situation—an increase in the frequency of flooding of rivers, is more subtle. There is no significant trend for the frequency of catastrophic events in Catalonia, although extraordinary floods—overflows occasionally involving the destruction of property—have tended to become more common since 1850, especially in the late summer and early autumn. These events not only are related to the water flowing in the river, but also to urban development models and land use.

From the point of view of aquatic ecosystems, an increase in the frequency of these events may lead to a sporadic increase in the concentrations of many substances dissolved in the water, such as dissolved organic carbon and nitrates. The river's ecosystem has difficulty retaining or processing these substances, and they will end up in lakes and reservoirs, alluvial and delta areas, and coastal areas.

An increase in these extreme events, which mobilise the substratum, erode the riverbed and transport sediments, may lead to changes in river habitats and the consequent decline in heterogeneity. Another effect may be that floods bring drainage networks and treatment plants in urbanised areas to a standstill.

### *The impact on the distribution of aquatic species*

The rise in the water temperature affects the life cycle and distribution of species, triggers changes in interactions and food webs, and leads to invasive species establishing themselves in the environment. Some life processes, such as metamorphosis, are also taking place earlier in native species. By contrast, development time is shortened with rising temperatures, which results in smaller adults with less potential for reproductive success.

Baborte Lake and the Sellente Pass in the L'Alt Pirineu Natural Park.
Source: Government of Catalonia.

The distribution of cold water species such as the brown trout (*Salmo trutta*) and some species of insects could be reduced due to the effects of temperature in the pre-coastal foothills and the Pre-Pyrenees. However, the impact of global warming can also be felt in high mountain ecosystems. Studies conducted in the lake Estanh Redon (Val d'Aran) show a clear trend towards the water warming throughout the twentieth century. This has accelerated in recent years due to rising temperatures in the summer, and especially in the autumn. Warming has an obvious impact on some of the species that inhabit this area.

Meanwhile, changes in the duration of the ice cover have an impact on the composition of communities in high mountain lakes.

### *Far-reaching changes below the sea's surface*

The Mediterranean Sea is a semi-enclosed sea, with both a wide variety of biological richness and very strong pressure from human activity on the coast. These two aspects that make it particularly vulnerable to climate change. Recent decades have seen changes in various parameters, although not all of these changes have been caused by this phenomenon alone.

According to a recent study, only around 42% of the warming observed in recent decades has been caused by human action; the rest is the result of the influence of the Atlantic Multidecadal Oscillation (AMO), a pattern of variability in the ocean which causes cyclical variations in temperature.

This observation is important for future projections because, on the one hand, the AMO could mitigate the effects of global warming, but on the other it could also enhance the rise in temperatures during certain periods.

In any event, the change in weather conditions has clearly had an impact on both ecosystems and specific species, and needs to be considered in the future.

First, as already noted above, the valuable time series from L'Estartit provides data on the temperature of seawater at various depths (since 1974) and changes in the sea level (since 1990).

In short, the information shows increases in the average annual temperature of between 0.3°C to 0.19°C per decade in the first 50 metres and at a depth of 80 metres, respectively. The sea level has risen was 3.9 cm per decade on average.

These data cannot be extrapolated to all of Catalonia's sea area, which covers approximately 74,000 km$^2$. The Mediterranean already has some natural variability in these two parameters. Apart from being valuable in themselves for monitoring changes at a specific point on the coast of L'Empordà, the data from L'Estartit give a general profile for the Catalan coast.

Salinity levels in the Mediterranean have also risen since the mid-twentieth century. The increase has been much higher at depths of over one thousand metres. However, the increase has been smaller in water nearer the surface. The results of the various models for the future differ and consequently it is not currently possible to say whether salinity levels will rise or fall.

As is the case in most seas and oceans, a process of acidification of the water is taking place in the Mediterranean. This is due to the increase in $CO_2$ in the atmosphere, which means that more $CO_2$ is dissolved in the seas and oceans, leading to a decline in the water's pH level (i.e. it becomes more acidic). Predictions suggest that this process will become more significant in the coming years.

According to the consensus in the scientific community, this acidification will reduce calcium carbonate levels, which will indirectly restrict the growth of species that have a skeleton or shell made of this compound, such as coralline algae, molluscs (mussels, clams, snails), crustaceans (lobsters, crabs) and many corals.

The Mediterranean is a sea that tends towards oligotrophy, i.e. a low concentration of nutrients. Forecasts suggest that climate change will extend the period when nutrient depletion is at its height, between late spring and early autumn.

However, the presence of nutrients may be more closely related to human actions than to global warming. Our intensive use of rivers has reduced the volume of water that reaches the sea, and the amount of nutrients that end up in it as a result.

Meanwhile, more ecological products, such as phosphate-free detergents, and regulations that restrict the use of certain products such as synthetic fertilisers and manure, have led to reductions in the amount of phosphorus and nitrogen that reaches the sea.

As a result, there has been no upward or downward trend in the concentration of nitrates, ammonium or silicate in seawaters observed in the last twenty-five years, although phosphate levels have declined.

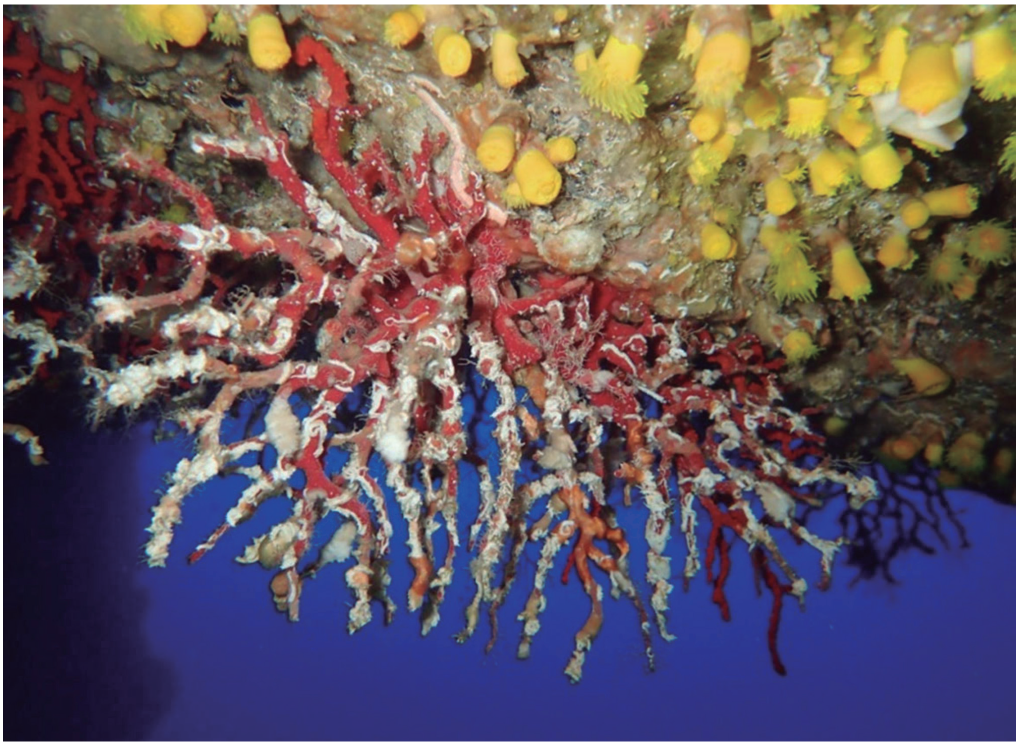
### *Coralline and seagrass—two communities at risk*

All these gradual changes, accompanied by occasional episodes of overheating in the summer or an increase in autumn storms, have effects on marine ecosystems. One of the communities that is most severely affected is the coralline on coastal seabeds. This community is found only in the Mediterranean, which consists mainly of certain types of encrusting calcareous algae. Up to 1,666 different species have been identified, although this figure is considered a conservative estimate. This clearly shows its value as a biodiversity reserve.

The coralline community is subject to the impact of trawling, ships anchoring, being stepped on, pollution and the proliferation of exotic species. However, the greatest impact is caused by climate change: surface and subsurface warming continues until the autumn. This interferes with natural processes such as the vertical mixing of the water, and eventually leads to mass mortalities, mainly of suspension-feeding invertebrate species, which is very difficult for these communities to recover from.

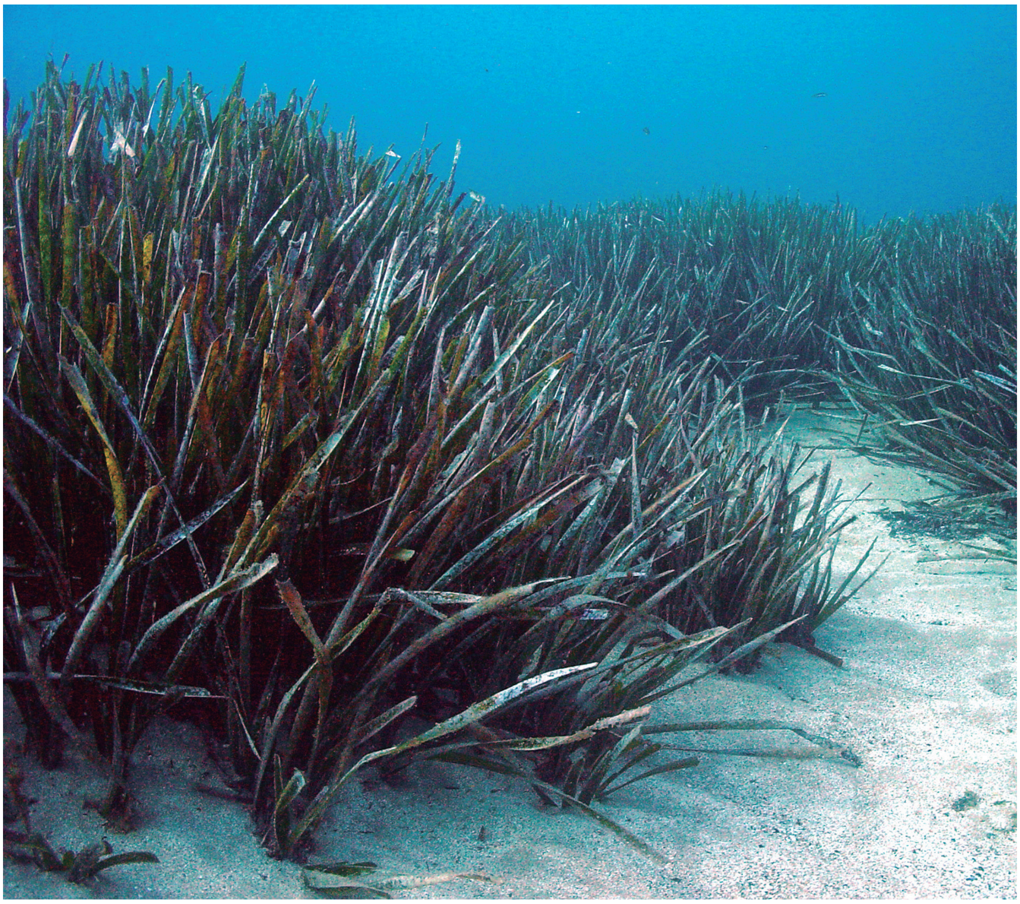
Meanwhile, *Posidonia oceanica*, or Mediterranean tapeweed, a seagrass endemic to the Mediterranean, is also sensitive to changes in temperature and sea level. The meadows that it creates retain organic material, which enable some organisms which normally live in hard-bottom environments to settle there. They also provide a refuge and breeding grounds for fish and other animals, stabilise sediment and protect the coast, as well as being a major carbon sink, as noted in the first part of this summary.

However, seagrass meadows are among the most heavily endangered marine communities due to human activities, and in particular, by changes in deposits of sediment from inland areas, which can hang from or undercut algae fields. They are very sensitive to the rising water temperatures and acidification caused by



Colony of red coral (*Corallium rubrum*) affected by necrosis associated with rising temperatures. After the fabric has deteriorated, it exposes the limestone skeletons which are colonised by opportunistic species.

Source: Government of Catalonia.



Natural seagrass meadows consisting of *Posidonia oceanica*, a species endemic to the Mediterranean.
Source: Government of Catalonia.

climate change, and will be affected by rising sea levels, as this may reduce the amount of light that reaches them.

This all gives rise to a highly pessimistic prognosis: in around 2049 (or ten years either way) the seagrass meadows on the Catalan coast may be functionally extinct (the stage at which the density of leaf bundles falls below 10% of current levels).

### *Algae, mussels, sardines and anchovies*

Changes of species are particularly important in the case of algae, invertebrates and fish. The diversity of algae is so great that it is difficult to predict whether they will benefit or suffer from climate change.

Among the invertebrates, sea fans and other sessile species are very vulnerable. The rise in water temperatures may increase the amount of episodes of heat. This would have harmful effects on the farming of mussels in the Ebro Delta (an event of this type in 2015 ended all mussel farming in the Alfacs Bay and part of the mussel farming on the Fangar headland).

Warmer waters will also encourage exotic species to proliferate, such as the Lessepsian migrants that come into the Mediterranean from the Red Sea through the Suez Canal. Finally, some may also have been accidentally introduced with ballast water or aquaculture.

For fish, it is not easy to distinguish between the effects of climate change and those which are caused by direct human action, such as overfishing. In the pelagic ecosystem, the models project an increase in the gross primary production of phytoplankton. This is not reflected in an increased net productivity of plankton, because their respiration is also increasing.

What is apparent is a northward movement of the species commonly found on the north Catalan coast, including both sessile species—those that are attached to a substrate—and vagile species, which can move. The rising temperatures of Catalonia's waters make these species seek cooler waters. However, as has been seen, thermophilic species from the south may gradually settle along Catalonia's coast.

There are some correlations between climate and fish that are not due to the planet's gradual warming, but instead due to recurring events like the Western

Seine fishing boat towing the boat with lights returning to port with blue fish (sardines and anchovies) after a night of fishing.

Source: Government of Catalonia.

Mediterranean Oscillation (WeMO). Periods with positive WeMO values are associated with low sea temperatures, high river discharges and high levels of vertical mixing in the water column, as well as larger catches of small pelagic fish, such as sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus).*

The commercial value of catches of these small pelagic species may decline as a result of the larger proportion of thermophilic fish, such as the round sardinella (*Sardinella aurita*), in overall catches of the three species.

The effects on mussel farming and catches of sardines and anchovies have major socio-economic consequences. However, other phenomena also have the same effects. Mild winters, low rainfall levels and hot summers lead to an increase in the proliferation and permanence of swarms of jellyfish on beaches. Some toxic microscopic algae also find it easier to grow in warmer and more stratified waters. Once again, climate change is not the only cause: toxic algae are encouraged to proliferate by coastal infrastructures that have quadrupled in the last half century (there are now over forty harbours on 400 km of Catalan coastline).

### *Protecting the Mediterranean and making it stronger*

The Mediterranean, which accounts for only 0.82% of the area and 0.32% of the volume of all the world's seas and oceans, has a much greater biodiversity and is home to a much higher percentage of marine organisms than would be expected for its size.

As noted above, climate change threatens some of these species or the communities to which they belong. Moreover, the sea regulates the climate, and coastal ecosystems protect the coastline. It is a vital cultural reference point for many people, as well as a source of economic and leisure activities. It is therefore essential to protect the sea.

Climate change affects it, and the general measures aimed at reducing the concentrations of $CO_2$ are also crucial for maintaining marine ecosystems. However, the section above has shown that many of the problems that affect it are not due to climate change, but are instead the result of direct human activities.

For precisely this reason, measures such as promoting the sustainable exploitation of marine resources and ensuring the preservation of the rich marine biodiversity of Catalan seas are needed to protect the Mediterranean.

We must also take action to repair ecosystems that have already experienced changes, which will not only restrict the negative impact of human activities in the Mediterranean, but will make it stronger—or at least less weak—for coping with the rise in temperature and all its consequences.

## 2.5. Soil—a living element that regulates the climate and suffers from its impact

Soil has a dual role to play in terms of climate change. On the one hand, it is passive because its properties and characteristics change at varying speeds depending on its resilience and the uses made of it. On the other, it acts as a sink and emitter of GHG, as explained in the first part of this summary.

Estimates suggest that climate change will affect both the soil and the dynamics of the organic matter it contains, although these effects are still unpredictable. What is certain is that changes in land use can have as much or more of an impact as climate change. Meanwhile, dry farming crops have lower emissions when conservation crops are used, but the levels in irrigated soils are harder to predict.

The changes in the climate and their impacts on vegetation will lead to increased aridity, and consequently more erosion which could be mitigated by appropriate conservation measures.

Some processes are much more serious in particular regions. For example, the erosion caused by rain is particularly serious in the Pyrenees and the Ebro valley. Meanwhile, the increase in evapotranspiration will reduce the availability of water, and soil salinity will increase. This means that larger water supplies will be needed for irrigation in irrigated areas, also taking into account the amount of water that will be needed to "wash" the soil, to prevent salts from accumulating.

The rise in temperatures could allow agriculture to move to areas at higher altitudes. However, in Catalonia these areas are also at higher risk of erosion because they are located in areas with more pronounced slopes. A combination of measures for crops based on technical criteria should therefore be adopted, involving conservation and terraces.

The average reserves of organic carbon in Catalonia's Mediterranean and semiarid agricultural land amount to 100 Mg per hectare (up to a depth of one metre). Forecasts suggest that our soils will experience a slow decline in levels of organic matter for mineralisation in the coming decades. To offset this, crop residues should be returned to the soil, and high-quality organic fertiliser applied at doses appropriate to agricultural land, and the management of organic waste needs to be improved.

One way to mitigate the effects of climate change on the soil is by applying biochar, the solid fraction that is left over when different types of waste biomass are converted by pyrolysis. This can be applied to the soil for carbon sequestration, and to improve its fertility, or can be used as a culture substrate. To encourage this, current energy plans must be adapted to include the processing of residual biomass, which would produce biochar, energy and other chemicals.

Applying the appropriate doses and methods of livestock waste and an efficient use of water are two basic practices for both reducing emissions from the soil and maintaining its levels of salinity, while not harming its quality.

A more accurate way of estimating sequestration capacity and the carbon stored in the country's soil is also needed. This would improve the models for estimating the country's reservoirs of organic carbon.

For now, however, the lack of information, the current legal framework and recent legislative proposals do not allow sufficient progress to be made in soil protection, or the enhancement of its role in the fight against climate change, which, as mentioned above, is in many cases less important than changes in land use and other human activities.

Protecting the soil therefore also involves proper regional planning and promoting the practices appropriate to each area and situation.

# PART 3

# Human systems: impact, vulnerability, adaptation and mitigation

## 3.1. Climate change and food security

Catalonia is Europe's leading food and agriculture industry cluster: the country produces more than 7 million tonnes of agricultural products, and more than 3.7 million hectolitres of wine and olive oil (2013). In overall terms, the Catalan food and agriculture system, including the primary, secondary and tertiary sectors, accounts for 20.8% of Catalan industrial GDP, and 3.8% of the country's GDP, which highlights the sector's social economic importance.

Despite this strength, it also has some characteristics that make it vulnerable to climate change. Agriculture and livestock farming occupy one-third of the country's area, and are sectors that may have major effects on climate change.

Catalonia's current level of food self-sufficiency is 40%, which means that an increase in the population and the effects of climate change (basically on water availability) can further reduce this percentage, and lead to an increasing dependence on foreign goods in a future scenario that identifies food as a critical area worldwide.

### *From crops to herds*

The effects of climate change on food and agriculture systems are complex and varied. However, uncertainty about food production will increase.

Catalonia is very varied in environmental terms which means that the effects of climate change will be different depending on the type of cultivated areas—irrigated or dry (30% and 70%, respectively)—and the varieties and the production systems involved. Moreover, rising temperatures may extend the growth cycles of some crops and reduce those of others, cause problems with flowering and ripening, and affect the organoleptic quality of products.

The main challenges for Catalan agriculture in terms of climate change are to improve its efficiency in water use and in the management of fertilisers, especially nitrogen, a more efficient and/or new use of plant material, and precision agriculture, among other areas. There are also positive aspects to cope with the changes: carbon sequestration by crops and soil, the increase in organic farming, which is in growing demand, the promotion of conservation agriculture and better management of crop residues help to reduce and mitigate GHG emissions.

The decline in water resources, from both rainfall and irrigation (rivers, reservoirs, groundwater, recycled water, etc.) is particularly important in the case of agriculture, which accounts for between 70% and 80% of the water resources managed in Catalonia. This means that it is the main user, as well as being a key regulator of the water system.

The probable decline in rainfall in Catalonia will take water availability per person per year to levels of around 1,850 $m^3$—a value close to water stress, according to the Food and Agriculture Organization (FAO) of the United Nations. In this scenario, a more efficient use of water in both dryland and irrigated crops will be necessary to meet the irrigation needs of agriculture. Among other measures, this can be achieved with distribution and management systems established by irrigation communities, and strategies for conservation agriculture in the soil.

The other key aspect is the management of nitrogen fertilisers, which are essential for increasing the soil's productivity, but contribute to climate change with GHG emissions (especially $N_2O$). At present, they are not used to excess in Catalonia, although there are no exact figures.

The environmental consequences of using nitrogenous fertilisers on a regional scale are significant, and in some cases negative. To improve this situation and prevent worse circumstances from arising, participatory systems are needed to transfer knowledge about careful management of nutritional elements in agriculture, and more efficient and sustainable management models need to be promoted.

Rising temperatures will have various effects on productivity in livestock farming depending on the species. Heatwaves will negatively affect milk production in ruminants (and its chemical composition will also vary). Pigs and poultry have a narrower range of thermal comfort, meaning that higher temperatures could have a major effect on them if the facilities in which they are kept are not adapted. Indeed, they need to be adapted to the animal welfare conditions stipulated by the European Union.

It seems apparent that in order to compensate for these problems arising from the increased heat, it will be necessary to cool the animals and/or the facilities where they are kept. This will mean an increase in water requirements for the livestock farming sector, although the use of water by this sector accounts for between 3% and 5% of all the water used by agriculture.

As well as the effect of temperature on each species, there is also an effect on food: climate change will affect pastures, the availability of fodder and the raw materials used for the feed industry. However, the availability of food is an issue of global change, which must be assessed with a view to mitigating climate change and ensuring sustainability for Catalonia's food availability.

### *Some activities also enhance climate change*

As well as the impact that climate change can have in these sectors, it is necessary to consider the opposite effect, i.e. how these sectors make temperatures rise. In global terms, the livestock farming sector is responsible for 14.5% of GHG emissions.

In Catalonia, total emissions by the agricultural and livestock sector in 2014 amounted to about 4.1 million tons of $CO_2$ equivalent, and nearly half of this figure, 47.5%, was due to manure management. These emissions must therefore be reduced to help reduce the impact on climate change.

The efficiency of both meat and milk production must be improved to achieve this. Several measures are possible, such as improvements in the selection of animal genetics, by breeding animals with greater tolerance to temperature, more resilience for survival and more resistance to disease.

We must also try to use nutrients more effectively, because improving livestock feed can reduce the carbon footprint. Breakthroughs in new disciplines such as nutrigenomics and nutrigenetics will help to adapt these foods to the genetic characteristics of each species, and even to each individual.

Other measures that can be taken include: the addition of additives to reduce methane emissions, technological breakthroughs to improve farms and animal welfare, the promotion of organic meat production, improvements in the management of livestock waste, and reductions in the environmental impact of manure. In any case, it is not simply a question of trying to reduce pollution, but also obtaining a resource (a nutrient, energy or others) that means we do not have to extract it from other sources.

### *The future of fish and fishing*

The current situation and future scenarios of coastal fishing are worrying, as highlighted by an analysis of the impact of climate change on marine and coastal ecosystems. Some projections put the decline in catches at 20% by the middle of the century.

The European Union is considering a change in its approach to fisheries management to deal with this scenario. Instead of managing stocks, ecosystems will be managed, so that fish stocks are no longer treated simply as a product that is caught, with quotas distributed based on the demand for each species. A holistic perspective will instead be adopted.

The issue will therefore no longer be one of monitoring the amount of certain types of fish that can be caught, but instead applying knowledge and uncertainties about biotic and abiotic components and the interactions in an ecosystem.

However, this is not a new approach, as the FAO proposed its adoption in the 1990s. It is aimed at the following objectives: maintaining the economic viability of fishing, halting the loss of biodiversity and restoring the productivity of the marine environment. In some parts of the world, the growing decline in fish stocks has led to the creation of fishing exclusion zones and the protection of habitats like seagrass meadows.

As a corollary, it is necessary to raise the level of scientific knowledge and increase public awareness of it, because this objective, proven, holistic and cross-disciplinary knowledge must be the cornerstone for the development of technologies that ensure the maintenance of marine ecosystems and fishing.

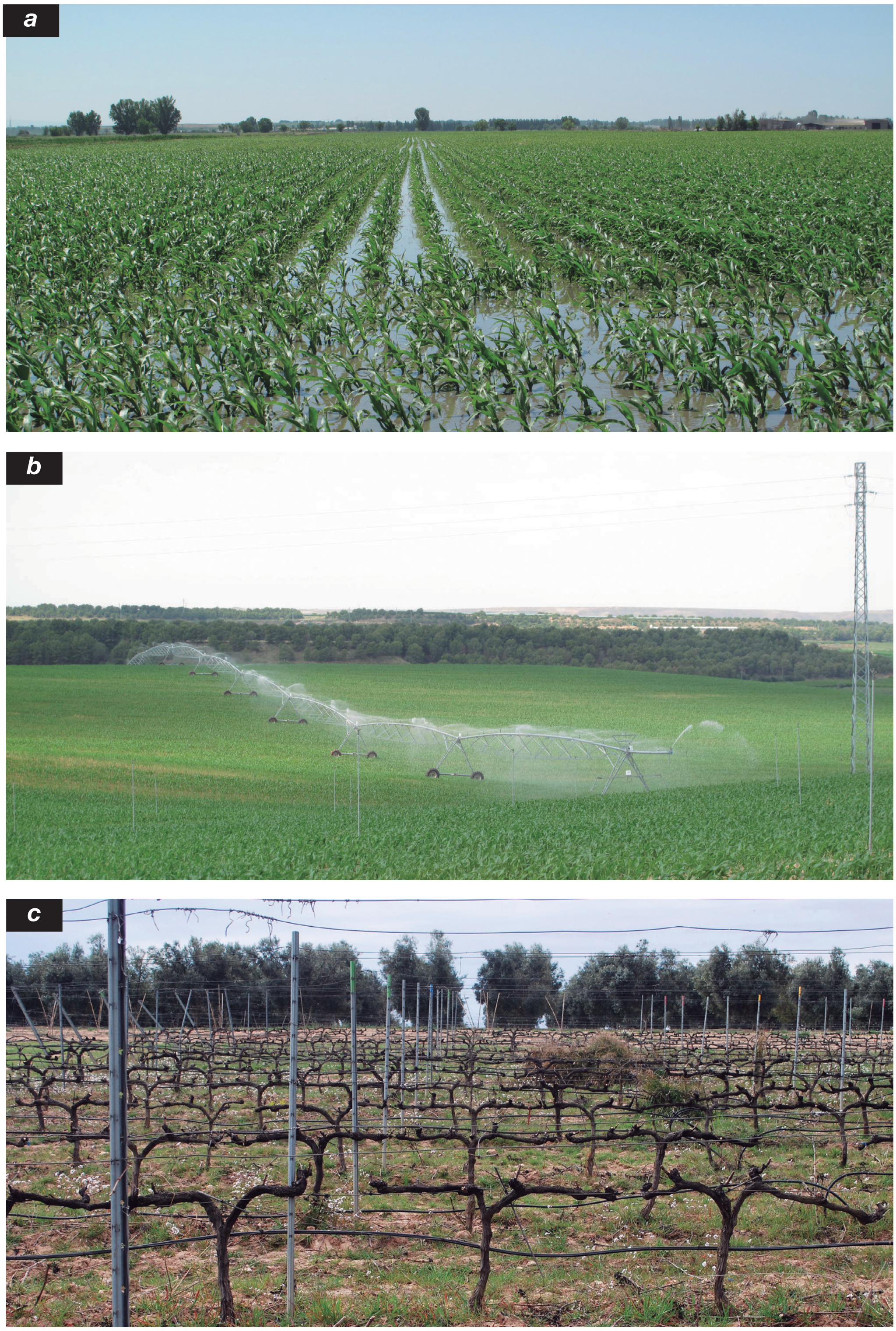
### *The challenge of water and food production*

The lack of natural resources used in agriculture (basically water and mineral nutrients), or low efficiency in their use, may become a problem in the future, with a growing population in a developed society. This situation, involving increasing demand for agricultural products and a greater intensification of production in order to obtain more productivity per unit of area and input unit, together with a clear and decisive environmental conservation policy, poses a major challenge for agriculture in the twenty-first century.

The new climate situation in Catalonia may lead to a substantial decline in the water usable by agriculture (mainly as a result of erratic rainfall) and an increase of 7.9% in the demand for water for crops.

From an agricultural perspective, improving the productive efficiency of water should be a primary objective, as well as commitment to efficiency that does not entail high energy requirements or sophistication in its management. Agronomy and common sense have a key role to play in this task.

To meet these needs, we must create an R&D and innovation system that enables water resources in agriculture to be managed efficiently, which increases efficiency




Agriculture consumes about 75 % of the water managed in Catalonia, and it is primarily used to produce food. Examples of (*a*) surface irrigation, (*b*) sprinkler irrigation and (*c*) drip irrigation.

Source: Jaume Lloveras, Jaume Camps and the Institute of Agrifood Research and Technology, respectively.

as much as possible (in terms of kilograms of food produced per cubic metre of water used) within limits for farms' effectiveness and sustainability.

It is also necessary to address the issue of planning and management of the use of water in Catalonia on an overall, non-sector-based scale (agricultural and urban uses, etc.), taking into account the effects of climate change on the water in the Mediterranean in particular.

## 3.2. Energy and industry: two key sectors for reducing GHG emissions

In Catalonia, the production of primary energy—the energy extracted from nature—is negligible compared to total consumption. The country is therefore heavily dependent on foreign energy. In this context, and within the predominant energy model, oil prices affect the economy and the competitiveness of Catalan companies.

### *An energy model needing transformation*

We must develop new energy policies to cope with climate change, aimed both at reducing the use of fossil fuels and using energy more efficiently. Improving efficiency and saving energy would contribute to mitigating the carbon footprint and to reducing our energy dependence on other countries, with the economic costs and the uncertainty that entails. This means making a firm commitment to renewable energy sources.

At the time the TICCC was written, the most recent data on energy consumption in Catalonia were for 2009, and those are the figures listed in the report. However, in this executive summary, they have been replaced by the 2014 data, which are now available. Final consumption (the result of the transformation of primary energy, minus the losses caused by this transformation and transportation) has fallen every year, but this is more due to the effect of the crisis than to structural changes. Nevertheless, the percentages have varied little from one year to another.

Petroleum by-products account for almost half of final energy consumption: 48.4 %. They are followed by electrical electricity, with 27.2%, natural gas, with 20.8%, renewable energy, with 2.8%, and coal and non-renewable waste, with the remaining 0.8%. By sector, transport consumes the most, with 42.3 %. Industry consumes 27.3 %; domestic uses account for 15.1%; services for 12.2%; and the primary sector, 3.1%.

In Catalonia, energy is responsible for over 75% of GHG. This means that we have to rethink the energy mix. Renewable energies must play a greater role, and there must be a clear commitment to the efficient use of energy and to rethinking mobility in order to reduce dependence on fossil fuels.

Wind energy is based on harnessing the kinetic energy of the wind, to convert it into mechanical or electrical energy.

Source: Catalan Energy Institute. Government of Catalonia.

Nuclear energy still accounts for a large proportion of production of the electricity consumed in Catalonia. Without drastic measures that are difficult to implement, when the forty-year life cycle is over, which will be shortly after 2020, it will not be able to be replaced by renewable energies.

It is therefore necessary to begin a wide-ranging debate as soon as possible to decide what to do when these nuclear plants have been in operation for forty years. Consideration must be given to both the advantages and the disadvantages.

The advantages usually include emphasis on the fact that this energy does not emit GHG. However, this argument needs to be qualified: nuclear plants produce emissions while they are being built, and emissions are generated when a fuel is unavailable in Catalonia and needs to be imported.

In terms of their life cycle, after a nuclear power plant becomes operational it takes a few years to offset the GHG emitted during its construction. The disadvantages include the treatment of waste, and the possible hazards and costs, which are difficult to evaluate, of closing them.

It will be necessary to make a firm commitment to the relevant decisions, whatever they may be. According to the TICCC, it is unwise to extend their lifespans every few years as has happened elsewhere in Spain. In this case, it is impossible to adopt the complimentary safety measures that will be necessary if they are given a longer working life to make any significant investments profitable.

However, it is necessary to take careful stock of the costs. This must include the costs arising from dismantling the plant and treatment of spent fuel, so that the decisions do not end up having a major impact on the cost of the energy produced, or on processes for which the State may end up having to take responsibility.

Figures for total emissions (those subject to the Directive and nonpoint-source GHG) are now available for GHG in Catalonia (except for a negligible percentage). In 2012, the final year of the second period defined by the Kyoto Protocol, energy processing, which includes emissions caused by combustion in the energy, industrial, transport and services sectors and fugitive emissions from fuel, accounted for 75.7% of total emissions.

Industrial processes (without energy and combustion emissions) accounted for 8.3 %; agriculture for 9.5 %; waste treatment and elimination for 6%; and the use of solvents and other products for 0.5%. Within energy and combustion emissions, transport accounted for 36.8%; manufacturing and construction industries for 25.2%; the energy sector industries for 20.2%; the residential and services sectors for 17.7%; and fugitive emissions from fuels for 0.1 %.

A period with no free transfers of emission rights for all sectors began in 2013. Data are available for the emissions subject to the Directive (approximately 34% of the total) and although the figures are lower than those for 2012, they are clearly higher than those assigned, with the consequent cost of purchasing emission rights.

### *The new European approach to energy*

The European Union has established specific directives for the residential and services sectors, calling for energy efficiency measures to be put in place. The trend in recent years has been towards a reduction in emissions in energy sectors in the strictest sense, such as electricity generation.

The European Union has always been ambitious in its plans to fight against climate change—at least on paper. The European Union's legislative climate and energy package established the 20/20/20 targets: in other words, a 20% reduction in emissions in Europe from 1990 levels, a 20% share for renewable energy in the European energy mix, and 20% savings in primary energy consumption. The Energy Efficiency Directive was approved in order to achieve these targets.

The European Union has established more ambitious objectives for 2030: a minimum 40% reduction in GHG emissions compared to 1990 levels, a 27% share of renewable energies in the energy mix, and 27% as the target for energy efficiency.


Photovoltaic conversion is based on the photoelectric effect, i.e. the direct conversion of light energy from the sun into electrical energy.

Source: Catalan Energy Institute. Government of Catalonia.

Another ambitious proposal came from the European Commission, and was approved by the Council in late 2013. Its ultimate goal is to achieve a reduction of 80% to 95% in GHG emissions from 1990 levels by 2050. As several studies point out, a scenario like this one requires a transition far beyond the bounds of our current system for producing and using energy.

It proposes moving towards an energy union, with an ambitious climate policy that offers consumers energy that is secure, sustainable, competitive and accessible. In the energy system of the future, citizens will be the primary stakeholders and responsible for the energy transition. It is they who must be able to decide how to manage their demand, with greater flexibility and range of options than that provided by the current offer from suppliers.

This new model is not an ideological commitment, but rather an urgent requirement, considering that the European Union imports 53% of its energy at a cost which at times has exceeded one billion euros a day, depending on the price of hydrocarbon fuels.

Several European documents establish the scope of the energy transition: security, solidarity and confidence in the energy field, an integrated European market, a slowdown in demand due to energy efficiency, a carbon-free economy and a firm commitment to research, innovation and competitiveness.

In Catalonia, which is limited in terms of its powers and which undertakes initiatives that must form part of measures in Spain, the main instrument is the Catalan Energy and Climate Change Plan 2012-2020. Its main objective is to reach the scenario that the European Union has targeted for 2020. Catalonia is a long way from meeting this target for renewable energies and as a result, the efforts must be very significant.

### *The transition of industry*

In Catalonia, industry generates 25% of overall GHG emissions. Processing materials to be transformed into products, the chemical and fertiliser industry, the paper industry and food processing are the main contributors.

Seventy-six per cent of emissions from Catalan manufacturing are associated with energy use, according to data from 2012. If we compare this with the emissions in 2005, it is apparent that a reduction of almost 40% has been achieved, although the effects of the economic crisis must be taken into account. The remaining 24% are emissions related to processes without combustion—mainly decarbonation.

In fact, 90% of direct GHG emissions by Catalan industry are the result of using fossil fuels for boilers and cogeneration and the cement industry. In the cement sector, the process inevitably releases $CO_2$ with the calcination of limestone.

In terms of mitigation policies for the industrial sector, in addition to the Law on Climate Change (passed by the Catalan Parliament on 27 July 2017), the Government of Catalonia has launched the Voluntary Agreements Programme and has taken various measures to promote the green economy. Various companies and even institutions have taken measures to reduce emissions within these voluntary agreements. In some cases they have been very simple and involved minimal investment or no costs, while making financial and energy savings.

In short, despite the differences between sectors, Catalan industry has made significant progress towards adapting to climate change, although there is still a great deal of potential for improvement and innovation.

Apart from energy efficiency, one of the challenges for Catalan industry is the efficiency of the materials it uses, which is related to reducing yield losses in production and to reuse. Reducing the use of coal and oil and increasing gas use and the networks installed in production centres would reduce emissions.

Finally, and very importantly, product design has a major impact. A life-cycle assessment, including all the environmental costs involved in the process, between obtaining raw materials and manufacturing to the use and end of a product's life may be crucial for mitigating climate change.


Figure 14. Changes adopted by twenty-first century industries to achieve greater efficiency, more recycling and lower GHG levels.

Source: Composition by Jaume Josa.

All these challenges are particularly important in the sectors that make the largest contributions to the gross added value of the Catalan economy: the food and beverage manufacturing industries, chemical and pharmaceutical companies and motor vehicle manufacturers. Figure 14 shows some of these changes that will contribute to increased efficiency and recycling, and to reducing GHG emissions.

## 3.3. Mobility: a question of habits and planning

The new climate situation means that we have to rethink the models for transporting people and goods in order to provide cleaner energy for the propulsion of vehicles and to reduce mobility (the distance travelled by vehicles).

However, the impact of transport on climate change is also related to planning. A dispersed model means more journeys. If public transport does not provide a reliable and attractive alternative, at a similar or significantly lower cost in terms of time and money, it is difficult to stop using private vehicles.

In overall terms, transportation by land, sea or air of people and goods is a sector that is very sensitive to economic cycles. As a result, apart from its serious socio-economic consequences, the crisis has brought good news from an environmental perspective. The number of journeys on linear infrastructure and movements of vehicles in ports, airports and stations has fallen and consequently, so have emissions. Cyclical effects have been felt to a lesser extent in the aviation sector.

The environmental impact of this sector is concentrated in cities and metropolitan areas, where 70% of the European population lives. In Catalonia, there are clear differences between the thirty-six municipalities that make up the Barcelona metropolitan area—2% of the country's territory, but with 43% of its population—and the rest of the country.

Most journeys, and therefore the bulk of emissions and local pollutants, are concentrated in the Barcelona area, and accordingly most of the municipalities have special protection plans for the atmospheric environment.

Directive 2008/50/EC of the European Parliament and of the Council of 21 May on ambient air quality and cleaner air for Europe focuses particularly on the transport sector, and has been essential for establishing plans to improve air quality, although many municipalities are struggling to achieve the objectives set: for example, Barcelona's Urban Mobility Plan aims to reduce traffic by 21% by 2018, but the evidence suggests that not only will there be no reduction but in fact, in a period of economic recovery, traffic will increase by 5%.

These plans are aimed at reducing local pollutants, but have an overall effect on GHG. The measures are aimed at promoting active mobility (walking and cycling), public transport, electric vehicles and vehicles with environmental labelling, and certificates for vehicles with emissions below a certain level.

They also seek to improve the vehicle population, because if vehicles are too old—due to the crisis, which has made it difficult to purchase new ones—their consumption levels are higher and they pollute more, even if they are used to a lesser extent.

The goods transport lorries that travel long-haul routes have reduced their emissions over the past two decades. There is still a great deal of work to be done in transferring freight from road to rail, because the proportion of goods transported by rail is still very low compared to other European countries.

Improvements in rail infrastructure and links with other transport systems, such as ports, as well as logistics exchange centres are essential to achieve this.

Movements of both goods and passengers have declined in the ports of Barcelona and Tarragona. The challenge for vessels which need large propulsion engines because of their size is to reduce the impact of their local emissions by replacing diesel motors with others that pollute less.

The economic crisis has led to a reduction in the number of aircraft movements in Catalonia since 2008. However, the number of passengers has increased, and freight transport levels have remained stable. The aviation sector has made a significant commitment to innovation in order to reduce its environmental impact, and companies like Boeing and Airbus are clearly committed to energy efficiency in their aircraft.

Mitigating the impact of the transport sector on global warming, which is very significant, implies implementing unpopular policies. Limiting the use of private vehicles or access to specific urban areas—which is also being promoted in order to reduce the pollutants responsible for poor air quality—usually leads to many complaints from the public, who see it as limiting their accessibility, from the taxi industry, the goods distribution sector and the transport industry for tourists and other services.

It also requires a commitment to research into technologies and new-generation vehicles, which as is the case in Germany, should involve planning that is not—for example—limited to creating more charging points for electric vehicles, but which also involves industry, services, universities and research, education and training centres. This is the only way it will be possible to achieve some degree of competitiveness in this sector.

Making the transition to means of transport with greater capacity which generates fewer emissions means taking coercive measures involving a more limited use of private vehicles. This political commitment comes at a political and economic price, and there is a great deal of resistance to it from the automotive industry. However, it is essential from the environmental point of view in general, and with regard to climate change in particular.

## 3.4. Tourism: the search for new models

The scientific community has become interested in the effects of climate change on tourism in recent years. The institutions and the industry itself have contributed to research on the relationship between tourism, adaptation and mitigation, in the form of both regular publications and specific monographs.

In Catalonia, tourism is a crucial economic driving force: there were 6,200 establishments with 760,000 tourist beds in 2014, and there were more than 71.9 million overnight stays. The strategic importance of this area, as well as its vulnerability to climate change, means that some practices in the industry must be reconsidered and improved, and it is necessary to make a clear distinction between sun and sand tourism and winter tourism.

### *Sun and sand tourism—a competitive range based on fragile resources*

Receding beaches and a lack of water resources are the scenarios that must be faced by sun and sand tourism. Geographical and urban development conditions have an impact on the extent to which beaches recede. Studies carried out in Catalonia show that the most heavily affected areas are located south of marinas, which prevent sediment from being transferred. However, in areas to the east of sports harbours, which sediment can reach, some beaches are expanding.

The ongoing reduction in beach areas and increased levels of tourism may endanger the satisfaction of tourists in the medium term. This means that many coastal municipalities must rethink their urban development and tourism models, and engage in an integrated management of the entire Catalan coast through a supramunicipal institution. In any case, what our coastline has to offer is very competitive in terms of climate comfort and has the potential to extend beyond the demand in summer, due to rising temperatures. Conversely, the rise in minimum temperatures is an increasing hazard to thermal comfort during summer nights.

Water resources are the other side of the coin. Despite being uncertain, the decline in rainfall in Catalonia that climate models forecast means a reduction in the main sources of the water supply on the coast. If the temperature rises, so will

Pressure from residents and tourists and the loss of sand on open beaches endanger the comfort and competitiveness of Catalan beaches (S'Abanell Beach, Blanes).
Source: Playa+ Project.

the demand for water, both directly and indirectly. This may lead to tensions and conflicts between tourism and other users.

### *Winter tourism—the need for a rethink*

Winter tourism is more vulnerable to climate change than sun and sand tourism. The natural and technical viability of the ski resorts in the Pyrenees is subject to many doubts. The existing resorts will be affected to varying degrees, and some will even be doomed to close if the current weather conditions continue.

In general, a rise in snow levels is plausible. A redistribution and territorial concentration in fewer resorts is foreseeable, and Baqueira-Beret is the resort that will benefit most.

Faced with a lack of snow, many resorts have started manufacturing it with snow cannons, with high economic, energy and environmental costs. But if we need to reduce energy expenditure and there is also less water, the cost of producing artificial snow may be exorbitant. The installation of snow cannons is only technically feasible if the temperature rises less than 2°C; if it rises any higher, this technique is not feasible.

Cycling trip through the woods of Sant Joan de l'Erm (L'Alt Urgell).
Source: Government of Catalonia.

An alternative would be to make tourism less seasonal and diversify in order to make the ski resorts into mountain resorts. This would involve promoting non-winter activities—as some resorts already do—and limiting the range of activities related to snow.

However, winter tourism is not the only area facing challenges. All areas of tourism must take more measures to increase savings and improve energy efficiency. They should also promote a type of sustainable tourism with more environmental certificates.

## 3.5. Waste—from a problem to a resource

Identifying waste as a valuable resource can help reduce the consumption of resources and consequently, reduce the various environmental impacts, including the global warming caused by GHG emissions.

There has been a decline in waste generation in Catalonia since 2007, especially in industrial waste and debris. The figure for municipal solid waste fell from 1.47 kg waste/person/day to 1.30 kg waste/person/day between 2011 and 2013 (Table 3). However, the economic crisis has also probably had some effect.

Waste from livestock manure—especially pig slurry—has been affected by the closure of cogeneration and slurry treatment plants, as a result of a policy that prioritised energy production over waste management. In 2015, the Ministry of Agriculture, Livestock, Fisheries and Food of the Government of Catalonia changed the management model for manure from farms.

TABLE 3. Waste in Catalonia in 2000, 2007 and 2013

| | 2000 | 2007 | 2013 |
|---|---|---|---|
| Industrial (Mt)* | 5.6 | 5.4 | 3.6 |
| Municipal (Mt) | 3.5 | 4.3 | 3.6 |
| Rubble (Mt) | 5.5 | 10.7 | 2.3 |
| Population (number of inhabitants) | 6,090,040 | 7,210,508 | 7,553,650 |

* Does not include by-products.

Source: *Third Report on Climate Change in Catalonia*, 2016.

The management and treatment of municipal waste directly and indirectly generate GHG emissions. The direct emissions are due to biological degradation and the combustion of waste, and are generated in the waste management operations themselves. Meanwhile, the indirect emissions take place outside the scope of management operations (e.g. emissions from generating electricity consumed).

The Waste Agency of Catalonia (ARC) has used CO2ZW, the Carbon Footprint Tool for Waste Management in Europe, to measure GHG emissions since 2011.

This methodological approach considers the future emissions from controlled landfills associated with the waste generated in the present. This means that it is not completely consistent with the approach used in national emissions inventories prepared using the methodologies of the IPCC. Furthermore, the latter include only the emissions in the process, and do not include energy recovery plants within the section on waste. Instead, they include them in the chapter on energy, except for incineration with no energy recovery; they do not take into account emissions prevented by the recovery of material and energy; and finally, they do not include the transport of waste in the chapter on waste, and instead include it in the general chapter on transport.

Applying the ARC methodology, the emissions generated by municipal waste in Catalonia in 2013 were 1,440,861 t $CO_2$ eq. By contrast, the emissions prevented from energy and material recovery amounted to -730,369 t $CO_2$ eq. Based on these figures, the carbon footprint per capita would be 94 kg $CO_2$ eq./inhab. for 2013.

Landfills, which emit large quantities of methane despite the capturing of biogas, make the largest contribution to emissions. Interurban waste transport makes a small contribution, amounting to 1%. Urban transport during the collection and transport of secondary waste has not been taken into consideration. Selective

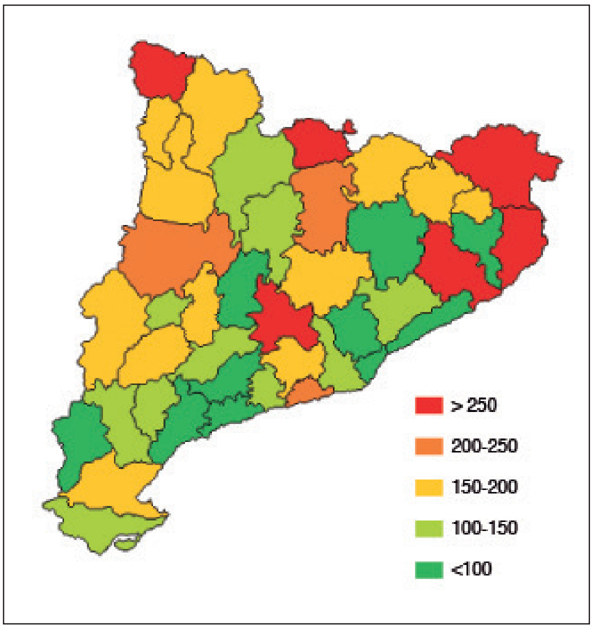



Figure 15. Carbon footprint (emissions generated and avoided) by municipal waste management in the regions of Catalonia in 2013.

Source: *Third Report on Climate Change in Catalonia*, 2016.

collection also helps reduce the sector's carbon footprint.

The use of biogas is a key factor in reducing emissions—whether they are used as a highly efficient source of energy to replace natural gas or if it is recovered in anaerobic digestion plants and landfills. Improved management of the organic fraction of municipal waste in the collection system, the type of transport and the size of facilities can also contribute to reducing emissions.

At a local level, 80% of Catalan municipalities had a carbon footprint of between 38 kg $CO_2$ eq./inhab. and 296 kg $CO_2$ eq./inhab in 2013. On a regional level, the areas that are most heavily dependent on landfills have higher carbon footprints, while the regions with higher rates of selective collection have the lowest carbon footprints per inhabitant. Figure 15 shows the data for each region.

Reducing the consumption of resources is one of the main objectives, in both environmental and economic terms. An efficient way to reduce them is to think of waste as a valuable resource; in other words, to encourage recycling and reuse instead of seeing waste as a nuisance to be removed or hidden. Recycling involves recovering materials and preventing them from being managed by a final treatment, such as landfill or incineration, which are net emitters of greenhouse gases. Figure 16 shows the total proportions of municipal and industrial waste paper, plastic and aluminium selectively collected in Catalonia in 2013.

Ecodesign is a key aspect to facilitate recycling. It makes the use of materials in production and planning much more efficient, so that once their life cycle is over, the materials can be separated and reused or recycled in a simple way. It is also important to use methodologies such as life-cycle assessment, which evaluates both the emissions generated in recycling—which also produces them—and those prevented by using materials that are not virgin.

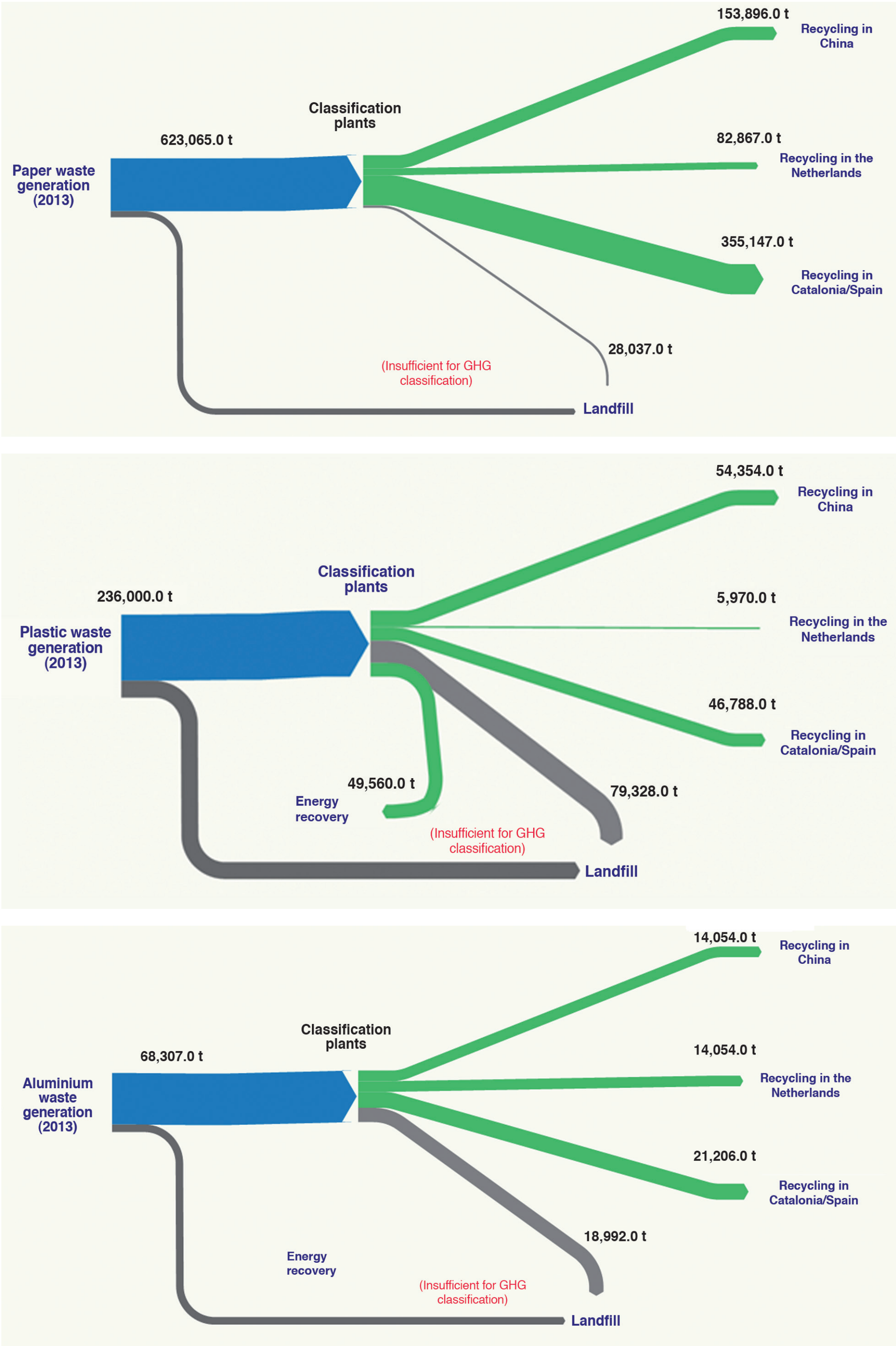



Figure 16. Flow of municipal and industrial waste paper, plastic and aluminium selectively collected in Catalonia in 2013.

Source: *Third Report on Climate Change in Catalonia*, 2016.

Finally, it is necessary to consider the water cycle. This resource is extracted, transported, distributed, used, poured away and treated, and this process generates emissions. A calculation of GHG emissions resulting from the water cycle of urban networks in Catalonia shows that emissions amount to 395 g $CO_2$ eq./$m^3$ of water consumed. Given the volume of water consumed in Catalonia in 2013 (almost 560 million cubic metres), these are emissions of 220,639 t $CO_2$ eq./year or 29 kg $CO_2$ eq./inhab./year.

One way to reduce these emissions and electricity consumption would be to improve the integrated management of wastewater in treatment plants and water distribution systems for human consumption.

## 3.6. Climate change is a health issue

Waves of heat and cold, atmospheric pollution, forest fires, allergies, diseases transmitted by vectors such as mosquitoes, are among other events that may be associated with climate change and affect human health. The effects vary considerably depending on the populations and territories studied, but there is no global consensus which considers climate change as the greatest threat to health.

Individual and social factors and the type of work people do determine their degree of vulnerability, but the effects are universal. In Catalonia, the most vulnerable population groups are the elderly (those aged sixty-five years old and over, especially if they are chronically ill), babies, pregnant women, the mentally ill, groups with a lower socio-economic level and some professions wit high levels of risk.

Population groups with a low socio-economic status, which have the worst health indicators, are more vulnerable to climate change because they tend to have older and poorly heated homes (which aggravates the energy poverty that they frequently suffer from) and live in areas with fewer green and blue areas (water).

As for the effects of heat on health, deaths and hospitalisations associated with high temperatures are mainly due to cardiovascular diseases, respiratory diseases, mental diseases, kidney diseases and diabetes, and are more prevalent among older people. Various studies show that during heat waves in Catalonia, mortality increases by 20% among people aged sixty to seventy years old, and by 40% among those aged eighty to ninety years old. Recent studies of pregnant women have found a relationship between the risk of premature births and heat.

Today, 40% of all deaths attributed to heat in Catalonia occur during periods of extreme heat that have not been recorded as heatwaves. Estimates suggest that, by 2050, deaths related to heat episodes may increase as much as eightfold, to more than 2,500 deaths every year. However, these estimates do not take into account a possible adaptation to higher temperatures, which may moderate this increase.

In large cities, the effects are aggravated due to the phenomenon known as the *urban heat island*: this is when an area has higher temperatures than the rural areas that surround it. Metropolitan areas also have the highest rates of atmospheric pollution caused by vehicles. Heatwaves usually coincide with air stagnation events. These prevent pollutants from dispersing and concentrate them near ground level, increasing their harmful effects on health.

Exposure to airborne particulate matter, which is common in urban areas with high levels of traffic, has a major impact in terms of respiratory and cardiovascular diseases: in the Barcelona metropolitan area, there are an estimated 3,500 premature deaths caused by air pollution each year.

Ozone is a gas that protects us from the sun's ultraviolet rays when it is in the stratosphere. However, tropospheric ozone, which is located at the level where life develops, is a very dangerous secondary pollutant caused by the combination of sunlight with pollutants generated by traffic, such as nitrogen oxides and volatile organic compounds.

Secondary pollutants are primary pollutants that react with water vapour and light radiation and create new substances. The levels of these pollutants usually increase during anticyclonic situations in the summer. If the concentrations are high, this can lead to a deterioration in respiratory problems, difficulties in cognitive development and a decrease in performance, accompanied by general malaise.

In addition, the winds from the Sahara, which carry large amounts of dust towards southern Europe, also affect air quality. The toxicity of the dust from the Sahara is compounded when it is mixed with other sources of pollution, such as pesticides and industrial emissions. Meanwhile, rising temperatures have direct effects on plants. This will change their distribution and phenological cycle, potentially leading to an increase in asthma attacks and allergies.

The scientific evidence shows that rates of development, survival and reproduction of cold-blooded organisms such as mosquitoes increase as the temperature rises. Changes in temperature and precipitation patterns therefore also create the conditions for the proliferation of vectors such as mosquitoes and ticks, which transmit some diseases.

This may lead to an increase in cases of malaria in Catalonia—a disease which was endemic in the country and other times in its history—and diseases that have never before been reported there, such as chikungunya.

Among other measures to mitigate climate change, experts recommend the proliferation of green spaces in the most heavily populated areas. They also suggest promoting public transport and walking and cycling. In addition to reducing $CO_2$

emissions and environmental pollution, these two measures also reduce obesity and being overweight in the population, improve mental health and reduce both traffic accidents and expenditure on healthcare.

## 3.7. Rethinking the territory

Increasing green areas in more populated areas, as mentioned above as a health measure, is just one among many items in urban and regional planning. Recent years have seen the development of numerous tools and instruments to produce energy and adaptation plans for the improvement of air quality, etc. Urban and regional development tools and a *strategic environmental assessment* also make a contribution, providing a reappraisal of open spaces, protected areas and the urban space.

This new analysis of the capabilities and limitations of a territory includes the concept of *biocapacity*, considered in terms of nature's capacity for regeneration. Areas with a high biocapacity, which preserve the system's diversity and complexity, therefore make the environmental challenges even more demanding.

This approach varies depends on the type of territory being considered. Open spaces, i.e. territories that have been considered *undevelopable land*, have traditionally been considered from the perspective of production.

However, thinking of agricultural and forest areas, protected areas and landscapes simply as organic assets or liabilities is an obsolete perspective that a minority view. The increase in the urban population has also impacted on the dynamics of open spaces, which have suffered from an impoverishment of habitats and ecosystems. The current trend internationally is to consider open spaces as green infrastructures.

Protected areas preserve an important part of our biodiversity and have very low levels of anthropogenic disturbance, which favours the life cycles of species and the preservation of ecosystems. In any case, many areas are sensitive to changes in environmental conditions and it is therefore essential to monitor the impact of climatic disturbances. Nevertheless, we must also assess their important role in coping with these climate changes.

Protected areas occupy a third of the territory of Catalonia and are subject to different levels of protection. Natural areas are crucial for mitigating and adapting to climate change. This means that a review is necessary of Law 12/1985 of 13 June, concerning natural spaces, from a more strategic, more environmentally friendly and less naturalistic perspective—based on service rather than protection *per se*—with criteria of efficiency.

The urban space has been planned and managed without giving sufficient consideration to the water and waste cycles, landscapes and the poor biodiversity, for example. The development of urban ecology has changed our perspective of cities. There are two main ideas: first, the characteristics of the rings that surround cities determine the flows inside and outside each one, and second, urban areas are also mosaics.

From an ecological perspective, urban planning and design should consider anthropogenic structures (infrastructures); residential, commercial and industrial areas; and in particular, green spaces, urban and peri-urban parks, urban agricultural areas and green corridors in terms of a system.

An understanding of cities based on all the dimensions mentioned above makes them less vulnerable to ecological crises as well as more equitable. At the same time, they perform new functions, such as the one mentioned in the section above, related to increasing green areas to improve health.

This ecological view of urban spaces must be implemented as adaptation measures in order to reduce GHG emissions. Designing and constructing buildings with low levels of energy demands is one of these measures, and it must also be taken into account when undertaking refurbishments.

Given the long life of most buildings, an inadequate design can lead to many wasted years of reduced emissions. Measures must be taken to achieve a rational use of water; to reduce waste, prioritising the reuse and recycling of materials; and to minimise the use of private vehicles, among other aspects involved in more sustainable planning.

## 3.8. The challenge of the mountains

Catalonia is a mountainous country. According to the criteria used by the TICCC, between 30% and 50% of Catalonia's area is mountainous. Like other mountainous areas in the world, the Catalan mountains are experiencing major demographic, cultural, economic and ecological changes.

Global warming affects mountain regions in two major ways: first, the increase in extreme events such as floods and landslides, and second, the gradual effects of biophysical processes, such as warmer summer temperatures.

Indeed, climate change is already apparent in the Catalan mountains, and particularly the Pyrenees, where all the permanent snow has practically disappeared due to rising temperatures during the summer, and the shorter winters. This affects both rural communities and tourism.

In mountainous areas, the impact of climate change can be added to a number of transformations associated with the globalisation of the economy: population movements are taking place, involving both emigration and immigration, and the European Union's policies to help agriculture have an impact on whether these practices are maintained or abandoned. If they are abandoned, one of the major consequences is that forests grow and become homogeneous. At the same time, some demands on rural areas are emerging and increasing, such as recreational and landscape uses, and conservation and cultural uses. Rural economies are therefore undergoing a process of becoming service economies, which is creating a difficult process of adaptation in mountain regions.

The identity and dynamics typical of mountain areas (the Pyrenees, Ports de Beseit, Montseny, etc.) are very different from the surrounding areas but are also closely linked to them. They can be considered as a socio-economic unit—a region where nature and society make up a very complex but closely related system, and where adaptation policies involve social, economic and conservation challenges. This all makes them crucial in policies for adapting to and mitigating climate change.

The starting point for adaptation is to clearly define the possible future scenarios for mountain areas, and the mental frameworks and associated actions that make up these regions. The research done highlights four mental frameworks or approaches to the rural environment in the Pyrenees: the conservationist approach,

Bruna dels Pirineus cows grazing—an example of extensive livestock farming in the mountains.
Source: Government of Catalonia.

the entrepreneurial approach, the farming approach and the endogenous development approach.

First, the conservationist approach focuses on protected areas as key factors in boosting economic and social development. The entrepreneurial approach considers tourism and construction to be the strongest assets of mountain areas. The farming approach is committed to agriculture and especially to livestock farming as activities that generate goods and services that are very valuable to society. Finally, the endogenous development approach is critical of the model that focuses primarily on tourism and construction. It advocates economic diversification and active participation by local people in decision-making.

Based on the mental frameworks described above, and an analysis of various development strategies observed in other mountain regions, there are various instruments and types of management to adapt to the new situation.

The Cadí mountains, the River Segre and the village of Alàs from La Seu d'Urgell (L'Alt Urgell).

Source: Marisa Tartera. L'Alt Urgell Regional Council Archive.

First, there is co-management, which is the construction of new types of networked horizontal social organisation. This applies to land stewardship and adaptive management, for example. Second, there is intensification, focusing on entrepreneurship and exploiting the productive potential of each area. Third, there is social innovation, which is also linked to the entrepreneurial approach, but which explores new activities such as new crops and new professions. Finally, there is the diversification approach, which advocates as broad an economic base as is possible.

In any event, the adaptation of Catalonia's mountain regions to climate change, and especially the Pyrenees, entails defining the economic development model, taking into account the gains and losses that each initiative entails for the different sectors.

# PART 4

# Governance and management of climate change

## 4.1. International commitments and our own policies

The fall of the Berlin Wall in 1989 changed the world. Among other effects, the globalisation of the economy and the increasingly prominent role of emerging economies, especially China and India, led to an increase of 51% of global energy emissions in the period between 1990 and 2012.

In a globalised economy facing various ecological crises, the United Nations is the only instrument for governance on a global scale. Although the organisation's decision-making could be improved, it has launched the Conference of the Parties—the main instrument in the fight against climate change.

The 2009 United Nations Climate Change Conference, known as the Copenhagen Summit, was very disappointing because it failed to meet the high expectations that it had aroused. However, it was the first time that the United States and China genuinely engaged with the fight against climate change.

Remarkable progress was made at each of the subsequent conferences, although in some cases it appeared modest. The confidence and transparency in negotiations that had been lost in Copenhagen were restored in Durban.

The second phase of the Kyoto Protocol was approved in Doha in the absence of Japan, Russia and Canada. The Warsaw Climate Change Conference saw progress made in the voluntary contributions of each state. However, disagreements between developed and undeveloped countries according to the official criteria emerged once again at the Conference in Lima. Finally, the COP21 in Paris in late 2015 restored the consensus, and an agreement was signed by all countries.

There have also been other significant developments, such as the acceptance of sub-state entities (*subnations*) as a concept in the official documents of the United Nations. The steps taken in the international arena by the Catalan Office for Climate Change, with the support of African governments, were essential for the recognition by the preparatory documents of the Paris Conference of the key role of subnations and local authorities in the fight against climate change.

Indeed, it is now fully accepted that international agreements between states need to be complemented by subnations, local authorities and the participation and involvement of scientists, entrepreneurs, representatives of non-governmental organisations, and citizens as a whole.

The policy of the European Union, which considers the fight against climate change to be a priority, contains various directives and regulations. The climate and energy programme aims for a 40% reduction in internal emissions compared to 1990 levels by 2030. And it also sets an ambitious target of a reduction of 80% to 85% by 2050, also compared to the 1990 emissions levels. To achieve these objectives, the European Union is promoting renewable energies, the creation of a European emissions market, the efficient use of energy and a reduction of emissions in waste management, transport and buildings.

Some states, such as Spain, have launched national plans, at varying speeds, to comply with the various European Union directives. The Government of Catalonia has the Catalan Office for Climate Change and a special inter-ministerial committee on this subject.

As part of Catalonia's strategy against climate change, the Catalan Energy and Climate Change Plan 2012-2020 and the Catalan Strategy for Adapting to Climate Change with a time frame of 2013-2020 have been established in recent years.

In Catalonia, local authorities, through the Covenant of Mayors for Climate and Energy promoted by the European Commission, and various tools and support networks for governance, have become heavily involved in the fight against climate change, despite the economic and technical limitations and the restrictions on their powers. Nevertheless, adapting to climate change means that a change towards governance on a local level is necessary.

## 4.2. Emissions trading

Since 2005, putting a price on $CO_2$ emissions has been an important step towards reducing emissions, especially by industry. In short, the aim is for states, industries and companies that have not met their targets for reducing emissions to purchase rights from others who have exceeded them. This means that the overall objective is achieved, although it becomes more restrictive every year. Meanwhile, those who meet their targets can receive an added benefit, while failing to do so entails extra expenditure.

Although the entire emissions market, in its broadest sense, can be considered a mechanism for global action, the most important and highly developed trading system to date is the European Emissions Trading System (EU ETS), which includes all the European Union Member States as well as Iceland, Norway and Lichtenstein, and covers emissions by over twelve thousand industrial facilities and around twenty-eight airline operators.

The sectors covered by the $CO_2$ Emissions Trading Directive account for about 45% of GHG emissions in Europe, and these represent about 11% of energy emissions of GHG internationally. It is therefore the basic policy instrument of the European Union for achieving its climate and energy targets for 2020.

In Catalonia, 153 facilities were subject to the trading system in 2014. In total, they emitted 13.2 Mt $CO_2$ eq., or in other words, 3.85 Mt $CO_2$ eq. as well as the free allocations they received, which accounted for about 35% of emissions in Catalonia. The sector with the largest deficit was once again electricity generation.

The challenge is to make the emissions market truly global, and to find mechanisms to make the supply flexible in situations where there are unforeseen changes in demand. The creation of an efficient central bank of rights and the development of the agreements signed in Paris will shape the $CO_2$ markets of the future.

## 4.3. Research on climate change in Catalonia

Eighty-eight groups recognised by the Government of Catalonia were working on climate change in 2015. Their research is very varied and is mainly carried out at seven universities, the CERCA (Research Centres of Catalonia) centres, and the centres of the Spanish National Research Council.

Measurement and reduction of $CO_2$ levels and the greenhouse effect are the two subjects that generate the most scientific production (2009-2014), followed at some distance by droughts, air quality and rising sea levels. The three most cited articles are a research study by the Centre for Climate Change at Rovira i Virgili University and two studies published by the Centre for Ecological Research and Forestry Applications (CREAF). In the period between 2011 and 2014, Catalan researchers published 3,643 articles on climate change indexed in Web of Science, of which 13 were in the journal *Nature* and four were in the journal *Science*.

In the same period, Catalan groups were awarded 310 European projects—111 from the private sector and three projects for the European Research Council (ERC). They have been awarded 171 projects as part of the Spanish National Plan since 2010.

The projects which have received European support, particularly from the ERC, include the Imbalance-P project, led by the CREAF. As a leader in the field of renewable energies, the Catalonia Institute for Energy Research (IREC) is also a major participant in the European Union's InnoEnergy KIC, an institution that brings together assets, talent and resources. European collaborative projects include the Field-AC project led by the Maritime Engineering Laboratory of Universitat Politècnica de Catalunya-BarcelonaTech (UPC), which uses satellites to monitor coastal areas.

Financing is one of the major challenges for groups undertaking research on climate change in Catalonia. The Government of Catalonia has a research policy that complements calls for research projects on climate change with Spanish or European Union funds. In the European arena, one of the unknown factors is whether the Juncker Plan will provide funding for research and innovation in climate change.

The funding for European projects doubles the level of Spanish competitive projects. This shows the major role played by Catalan universities and CERCA centres in attracting funds.

The Government of Catalonia has had a strategic commitment to attracting talent for a decade. The calls by the Catalan Institution for Research and Advanced Studies (ICREA) are its flagship project and have led to brilliant scientists coming to live and work in Catalonia. There are seventeen ICREA researchers working on subjects relating to climate change.

Meanwhile, the Serra Húnter Programme began in 2013, enabling lecturers with a high level of research to be recruited by Catalan universities.

## 4.4. The public perception of climate change

Citizens are concerned about climate change, but are demanding new ways to receive scientific information and knowledge. The sometimes alarmist and sensationalist narrative that focuses on risks and impacts has led to some degree of fatigue. The alternative is to develop new mechanisms and action networks that create a useful type of knowledge for seeking viable solutions to the challenge posed by climate change.

This is a fundamental objective, because it is very difficult to fight against climate change without public awareness, so that people accept the measures taken, or take them themselves on a personal level.

One possible strategy to overcome the old ways of communicating and socialising information is called *learning communities*. Agents and organisations operating at the interfaces between science, politics and the public must play a leading role and be recognised in order to construct a new narrative and new forms of action. Creating learning communities can become a catalyst for social and environmental transformation.

Various studies have shown that interpretations of climate change are becoming increasingly complex. For some, climate change is a major global threat; for others, it is an economic opportunity to rethink the labour market and to increase our quality of life.

Within the European Union, Spanish public opinion is most strongly convinced that climate change is an opportunity to boost the economy and employment. However, the Spanish are among the most critical of their government's environmental policies, and are also concerned about the effects of climate change on health.

Spain is one of the European Union countries where citizens feel least well informed about environmental issues and where they have the least trust in the media, and especially the television. The sources that they consider most reliable are environmental groups and scientists, while the information they find least reliable is provided by the government, trade unions and businesses.

In Catalonia, the Government has been monitoring public opinion on climate change since 2010. For Catalans, pollution in general and air pollution are the issues that cause the most concern. Climate change appears in third place, followed by waste.

The processes involved in conveying scientific knowledge on climate change to society as a whole are complex. A recent study on communication of the IPCC's *Fifth Assessment Report* in Spain and Catalonia reinforces the idea that is necessary to rethink the old model of one-way communication, which is focused on risks, impacts and vulnerability.

However, the twenty agents chosen for the study and an analysis of the content, which were based on newspaper articles, confirm that the traditional narrative is still predominant. They also unanimously agree about the trend towards a new and more complex open and multidirectional model for creating meaning, which is most readily apparent in the new digital media.

The new tools mean it is possible to choose the sectors which need to receive a particular message. Massive campaigns are no longer required. Instead, specific information and proposals can be sent to the groups where the messages will have the most impact or are most necessary. In other words, it is a question of establishing a model aimed at targeting audiences and users of knowledge that meets the criteria of demand rather than supply.

## 4.5. Complex solutions for a phenomenon that is also complex

From a political standpoint, the Paris Agreement has been considered a success. The large contingent of world leaders attending and French diplomacy, under the guidance of Laurent Fabius, contributed to this impression. The COP21 is a qualitative change and a change in the international community's model for dealing with climate change. The Agreement entered into force in November 2016, after it had been ratified by 55 parties, whose emissions accounted for 55% of total emissions.

The challenge is also to validate and consolidate the change from the Kyoto model (*top-down*, i.e. establishing goals that states must meet) to the Paris model (*bottom-up*, depending on the initiative and commitment of states deciding to put the agreements into practice).

The Paris Agreement has a great deal of impact on the legal framework of the European Union and on all levels of government. Europe is in the process of reforming its emissions trading system to adapt it to the general commitments for reduction agreed at COP21. Both the Spanish and the Catalan Government must enhance their actions, update their strategies and establish and promote new plans and timetables for implementation.

In addition to the many initiatives promoted by the Government of Catalonia in recent years, there is also Law on climate change in Catalonia, passed by the Catalan Parliament on 27 July 2017 and published in the *Official Journal of the Government of Catalonia* (DOGC) on 1 August 2017.

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