THIRD REPORT ON CLIMATE CHANGE IN CATALONIA

Chapter abstracts

Generalitat de Catalunya

Institut d'Estudis Catalans

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Summary

1 The global carbon balance and scenarios for stabilising climate change

Author

Josep Canadell Gili

Abstract

The most significant emissions of greenhouse gases (GHG) have led to an atmospheric increase of 40 % in carbon dioxide (CO_2), 150 % in methane (CH_4) and 20 % in nitrous oxide (N_2O) since the start of the Industrial Revolution. Emissions of these gases have continued to rise since the *Second Report on Climate Change in Catalonia*, although CO_2 emissions have slowed down somewhat since the levels observed during the 2000s.

Another new and important factor since the last report is the proof that there is an almost proportional relationship between cumulative human CO_2 emissions and the increase in global temperatures. This is a significant discovery which enables us to understand the scale of the mitigation necessary to achieve the objective of climate stabilisation without having to determine the combined effects of the more than thirty components that make up anthropogenic radiative forcing. Based on this interpretative framework, the share of remaining emissions to keep global warming below 2 °C, with a probability of > 66 %, is 590 to 1240 Gt CO_2. If the current emissions of almost 40 Gt CO_2 per year continue, this balance will be exhausted within fifteen to thirty years.

Every socioeconomic and technical evaluation has shown that it is impossible to decarbonise the global economy with these tiny carbon balances. This would require climate stabilisation trajectories at low warming levels to exceed the permitted carbon quota with the requirement of actively removing CO_2 from the atmosphere later on. This entails additional risks, as many of the technologies for removing CO_2 from the atmosphere are either unavailable or have not been sufficiently tested.

Even so, there are positive signs: the slowdown in the annual rise in emissions from fossil fuels in recent years, the huge acceleration in introducing renewable energies and, above all, the creation of a much better political framework through the Paris Agreement, with the final goal of achieving zero net emissions during the second half of this century. This convergence of events opens up a unique, though very small, window of opportunity to decide whether we want to embark on an unprecedented transformation of our energy and socioeconomic systems in order to keep global warming under 2 °C.

2 Carbon balances: greenhouse gases emissions in Catalonia

Author

José M. Baldasano Recio

Abstract

Since the industrial revolution emissions of GHG have hugely increased. Between 1750 and 2011, CO_2 emissions from fossil fuels and production of cement are estimated at 1.370 Gt CO_2, and for deforestation, estimated at 660 Gt CO_2. The average emission per capita is around 4.56 t CO_2 $year^{-1}$. The energy sector accounts for 67 % of it. A strong

link between economic growth and CO_2 emissions has been posited since the beginning of industrialization. In the EU, GHG has been cut by 24.4 % between 1990 and 2014, and only transport emissions grew gradually. GHG emissions in the EU-15 for the Kyoto period were 3.760 Mt CO_2 equiv. Trade system emissions (EU ETS) covers 45 % of total emissions. The EU will need to outdo target set for 2020 (20 %) to cut GHG emissions by 24 %. In Spain, emissions during the Kyoto period were 358.4 Mt CO_2 equiv., due to the economic recession and the change in fuel distribution used for power generation and coal use. CO_2 is the highest contributor, with values between 80-85 %. Distribution per sectors clearly points at the energy group (77 %).

Catalonia's emissions represented 13.3 % of total Spanish emissions for year 2013; Catalonia's population represents 16 % in Spain, and its GDP represents 19 %. From 1990 to 2013 emissions evolved from 39.2 to 42.8 Mt CO_2 equiv., representing an increase by 9.2 %, due to the economic crisis and contraction of socio-energetic activity. Anyway, these are circumstantial reasons, not structural. In 2013 Catalonia had 5.7 t CO_2 equiv. emissions per capita. CO_2 is the biggest contributor, with 77 % in year 2013. The «processing of energy» sector is generating a greater amount of emissions (70 % in 2013); combustion activity increased emissions in the «transport» sector, growing by 9.7 % in the period 1990-2013 (+27.3 % in 2013). In 2012, 30.8 % of it was attributed to emissions from installations subject to the Emission Trade System (EU ETS), and the remaining 69.2 % was due to diffuse sectors. The crossing of data for GHG emissions with GDP data shows that the ratio has decreased in the period 1990-2013; for Catalonia it is estimated at 685 t CO_2 equiv./M€ for 1990 and at 217 for 2013, that is to say, a decrease by 70 %. Ratio for the EU-28 in 2012 stands at 360.

For the EU-15, the Kyoto Protocol implied an 8 % decrease in GHG emissions for period 2008-2012, with average decrease at 11.8 %, below the yearly basis. For Spain the commitment was not to exceed an increase by 15 %, but it has been surpassed by 8.7. In the case of Catalonia, total emissions represent 1.3 % above the 15 % limit; average diffuse emissions for 2008-2012 were 30.6 Mt of CO_2 equiv., which means observance of the Kyoto Protocol commitment.

Evolution of GHG emissions in Catalonia is mainly due to the dynamics of the business cycle and not to any policy aiming at emission reduction. Although there have been reduction attempts, these should grow in number, at least trying to cover for actions as established by the EU Commission for 2030.

3 Carbon balances: carbon sinks in Catalonia

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Abstract

In this chapter we will determine which are the biggest carbon (C) sinks and stocks among the various terrestrial and marine ecosystems. The forest is the terrestrial system storing the biggest amount of C per ha, 149.5 Mg C ha^{-1} (in a ratio of vegetation/soil [v:s] of 60:100). Meadows come in second position with 121.4 Mg C ha^{-1} (v:s of 11:100), followed by woody crops and shrublands, with 104.0 Mg C ha^{-1} (v:s 12:100) and 112.1 Mg C ha^{-1} (v:s of 15:100), respectively. Herbaceous crops showed the lowest value, 100.8 Mg C ha^{-1} (v:s of 1:100). The Catalan sea has been increasing the C

stock from year 1750 onwards up to 2001, with a cumulative amount of 12 Mg C ha^{-1}. Outstanding are meadows of flowering plants, accumulating 330 Mg C ha^{-1} (in a ratio plant/sediment of 4:100). Freshwaters show a value of 47.9 Mg C ha^{-1}, but it's basically inorganic C dissolved from the C dioxide-carbonates system, estimated to be 30 times higher than organic C.

In absolute terms, that is, estimating power per total surface taken by resource, the biggest C stock are forests, with 173 Tg, followed by crops, with 98 Tg and the Catalan sea, with 92 Tg. The lowest values are those of shrublands, with 60 Tg, meadows and pastures, with 21 Tg, and freshwaters, with only 0.33 Tg. In the case of crops, meadows and pastures, the major contributor is the soil. In the case of the Catalan sea, C is mostly concentrated in water.

With regard to C sequestration, sediments of freshwaters are the system that sequestrates the highest amount of C per unit of surface, 7 Mg C ha^{-1} $year^{-1}$, seven times higher value of forests, 1 Mg C ha^{-1} $year^{-1}$, which, in turn, almost doubles value of woody crops, estimated at 0.4 Mg C ha^{-1} $year^{-1}$.

Expressed in absolute terms, forests are the main C sink, with 1.3 Tg C $year^{-1}$. On the other hand, freshwater sediments show the lowest value, with 0.12 Tg C $year^{-1}$, a very similar value to that of woody crops, with 0.14 C Tg $year^{-1}$. For the remaining compartments and systems, it is assumed that either their sink capacity is slightly positive but close to zero, as in shrublands and meadows, or is totally neutral, as with herbaceous crops. Unfortunately, for soils and marine ecosystems there is not yet enough information available to reliably estimate their sink capacity.

4 Late evolution in temperature, rainfall and other climate factors in Catalonia

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Collaborators

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Abstract

These pages analyze the evolution of the mean temperature in Catalonia, jointly with the mean maximum and minimum temperatures and the rainfall mean. 24 temperature series and 68 rainfall series were used covering years 1950-2014, and with yearly and seasonal data. Additionally, information of evolution of other relevant climatic variables was added (i.e. evaporation, sunshine rate, snow precipitation rate, weather extremes, sea surface temperature, ice masses on the Pyrenees…). Data from the Ebre and Fabra observatories and data series from Barcelona across centuries were brought into the data, thus magnifying time span of analysis. The clearest result is an increase in mean yearly air temperature of +0.23 °C/decade, for Catalonia as a whole and for years 1950-2014, with an increase rate of mean annual maximum temperature of +0.28 °C/decade, higher than the raise in minimum temperature, of +0.17 °C/decade. Across seasons, the average temperature increase is highest in the summer: +0.33 °C/decade. In contrast, yearly rainfall rate does not show a statistically significant variation for the whole country. Moreover, along with the increase in temperature, there has been a statistically significant raise in number of hot and warm days, hot summer nights and sea surface temperature at the Costa Brava, while a statistically significant decrease has been reported for number of cold

days and cold nights as well as for days of snow. The most crucial advice is to monitor observed climate change and variability through maintaining a network of meteorological observation with enough observing stations across the land that may provide homogeneous and high quality climatic series, and to improve dissemination and communication actions to avail information on climate evolution to the general population and to the most relevant economic sectors.

5 Climate forecasts and future scenarios

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Abstract

This paper tackles climate projections in Catalonia for the future, that is, offers an estimate of some future variations in temperature and rainfall up to the first half of the current 21st century. To this aim, and for the targeted Catalonian region, outputs from global climate models participating in the most recent IPCC *Assessment Report* have been analysed. More importantly, results from several international, national and Catalan initiatives producing regional climate projections have also been considered. Likewise, and for the nearest future, decadal predictions obtained through different global climate forecast systems have been used.

The analysed climate projections reveal a robust temperature rising trend over Catalonia for the coming decades. This warming trend is shown over all time horizons, seasons, and geographical/climatic areas in Catalonia. Using the median from all downscaled datasets considered representative, the surface temperature increase could be +0.8 °C in the current decade, and even reach +1.4 °C by mid century, as compared to the reference period 1971-2000. The rising trends may be even more powerful for the Pyrenean region, particularly in the summer. As for rainfall, the climate projections show a decreasing trend, but with an uncertain slope. Indeed, variation of rainfall rate in the current decade is barely significant. By mid century, on the contrary, decrease in rainfall is clear, with a median in distribution of estimated values around –10 % in spring, summer and autumn. As regards rainfall, it is of paramount interest to downscale climate simulations in areas such as Catalonia, since its complex orography and land-sea contrast are largely misrepresented in global models. In this work, moderate emission scenarios of radiative forcing have been employed (i.e. A1B, RCP4.5), and as a consequence, other estimated values associated with future climate change might be slightly higher than those discussed here, particularly in the case of analysing more extreme emissions/concentrations (i.e. RCP6, RCP8.5). However, the added effect of a more intense radiative forcing scenario might not be noticeable until the second half of the 21st century.

6 Risks sourcing from climate

Authors

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Abstract

This paper focuses on the advances in knowledge, as of publication of the *Second report of climate change in Catalonia,* on evolution of main natural hazards of a meteorological origin. Studies agree

about the increase in extreme temperatures, heat waves and tropical nights, warm days and nights and duration of warm spells. This increase is and will continue to be higher in the summer and in mountain areas. As for rainfall, only a trend has been identified: raise of precipitation per rainy day and through convective precipitation. A trend is also drawn in the duration of dry spells, trend aggravated in the future particularly in the summer. The slight increase in flash floods in the summer may be related to an increase of exposure and vulnerability, but an increase in short and heavy rainfalls should also be considered. Looking ahead, the scenarios are not conclusive, but the likely increase in torrential rainfall will also increase flood risks. There are signs that drought may be increasing in frequency and severity. Higher temperatures stimulate evapotranspiration. The snow mantle shrinks and melting occurs ever earlier. This, together with the reforestation of the headwaters of most basins, is causing a decrease in river flow. These trends will continue in the future. Thus, meteorological, hydrological and agricultural drought will be more frequent and severe over the 21st century, affecting water resources, water quality, ecosystems and wildfires. In the last forty years (1970 to 2010) fire activity in Catalonia displayed a decreasing trend. Modelling results indicate that, if improvements in fire management had not been taken into account, the warming trend by itself would have increased the number of wildfires. Future scenarios indicate that higher temperatures will promote an increase in the number of fires if no further improvements in fire management are seen to.

As for geological risks associated to meteorological factors, both the work of experts and the facilities of search engines have materialised an inventory of landslides and rock falls, thus overcoming the difficulty of working with events scattered throughout the country. The improvement of quality and resolution of observations has allowed the spotting of a high number of local events, sometimes happening yearly and significantly lowering the triggering rainfall thresholds. No obvious changes were identified in the pattern of large landslides, more sensitive to seasonal rainfall. A significant positive trend in major avalanche activity has been observed from the early 70s. As for avalanche types, there has been an increase in wet snow avalanches and their magnitude, although data are insufficient to draw a trend. In this respect, cycles of wet avalanches due to rain in 2013-2014 and 2014-2015 are remarkable. As for the Catalan Pyrenees area, a statistically significant negative correlation has been described for the lasts 40 years between occurrence of major avalanche cycles and the North Atlantic Oscillation (NAO). Last but not least, as far as snow accidents are concerned since last SICCC 2010 report was published, both the yearly accident average and average number of casualties have raised, but average number of deaths has decreased, probably because of an increase in the use of self-protection measures and social awareness.

7 Water resources

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Abstract

The effects of climate change on the availability of water resources in Catalonia is one crucial element for the country's development in the coming decades. The need of water to cover for human needs and to maintain ecosystems makes water resources one of major factors for territorial sustainability. Different studies and projects carried out in Catalonia in recent years consider that changes

in hydrological processes are the result of both climatic and anthropogenic variations; among others, changes in land use. All of them, and according to different methods and perspectives (hydrological, ecological, socioeconomic), agree in forecasting a scenario of water scarcity that requires adaptive measures.

This paper presents supplemental information mapping climate projections on water resources, the so-called *blue water*, available for all hydrological sub-basins of Catalonia. These estimates, based on forecast variations in temperature and precipitation for 2021 and 2051 and on the current distribution of land uses per sub-basin, indicate a significant decrease in water resources availability, highly contrasted across geographical areas: a rough 10 % average decrease nearest to the Pyrenean basins and a maximum average of 22 % decrease in coastal basins for 2051. This decrease will be already apparent in the short run.

In the necessary process of adaptation, the role of the Pyrenees headwaters as key areas for water supply is outstanding. What's more, an integrated managerial approach of the territory will become essential to cope with scarcity of water resources, one incorporating a new approach to infrastructures, connectivity, use of alternative water resources and geographical allocation of those according to separate water needs.

8 Coastal systems and littoral dynamics

Authors

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Abstract

This paper makes a forecast of climatic impacts over vulnerable coastal zones along the Catalan littoral. It starts reviewing the geological and meteorological diversity of the coastal stretch. The forecast is a wide fan of possible impacts under present climate conditions and particularly under future climate changes, though the analysis offers some uncertainty on outputs and thus on decisions to be made. The chapter is based on the RCP projections for mean sea level and wave storms. From here, impacts associated to beach erosion and flooding and to harbour stability and overtopping is described and assessed. This leads to spotting of the coastal stretch subject to such climatic impacts and of the resulting risk levels for beaches and harbours. The paper ends with a list of sequential interventions, termed «adaptation pathways», that should allow to establish explicit risk levels under present and particularly future climate over coastal socio-economic activities.

9 Terrestrial ecosystems

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Abstract

Climate change produces, and most likely will continue to produce, an increase in temperature and drought in our country (IPCC, 2013). If the combination of climate change, associated disturbances (e.g. floods, droughts, forest fires) and changes in other components of global change (especially changes in land use, pollution and overexploitation of resources) continue as up to now, it is likely that they will exceed the resilience of many ecosystems (IPCC, 2014), alter their structure and function (Peñuelas *et al*., 2013) and compromise the services that they currently provide (Millennium Ecosystem Assessment, 2005). The impact of climate change, which is the subject of this report, is further influenced by interactions with these other pressures and by the management measures to be adopted.

In Catalonia, as in the whole world, numberless lines of observational and experimental evidence have been described binding climate change to biological and physicochemical processes of ecosystems. Rising temperatures, new patterns of precipitation and other climatic changes are already affecting our ecosystems and also our societies. For example, it is well known that the onset of spring occurs ever earlier in general terms and that the onset of winter has been delayed, so that seasons have been extending by 3-4 days on average per decade in the last fifty years.

It has been proved, both in observational studies of the last few decades and in experimental studies on global warming and drought, that some species are more vulnerable to these changes than others, which can alter their competitive ability. Ultimately, this changes the composition of communities and shifts the distribution of species, as for example in the observed migration of Mediterranean species to higher peaks in Catalonia, or the decline in species variety in our scrublands. In the most extreme cases, populations of some species are endangered by the synergy between the stress caused by climate change, which makes their habitats unsuitable to live in, and by changes in land use such as the fragmentation of the territory, which hinders migration toward habitats with appropriate conditions for their survival.

In parallel to these structural changes, functional changes of ecosystems have been described as a result of global warming, such as the decrease in the absorption of CO_2 in periods of drought or an increased loss of nutrients by leaching after rain. Many other changes have been observed in response to climate change, for example more frequent droughts in forests, an increased risk of fire or an increase in the emission of biogenic volatile organic compounds.

These changes affect and will continue to affect many ecosystem services, including provisioning services (supply of renewable natural resources such as pastures, food, medicines, or consumer products such as timber, hunting or mushrooms),

environmental services (maintenance of biodiversity, regulation of atmospheric composition and climate, conservation of soils and water, or carbon storage) and social services (recreational, educational and leisure uses, traditional cultural values, or tourism and hiking). One of the current priority services in terms of environmental policy is linked to carbon balance, as climate change and other global change factors alter carbon stock in forests, although the magnitude and the direction of change are not yet clear.

In the coming years, and to mitigate both the effects of climate change and the increase in atmospheric CO_2 that produces it, policies of reforestation of disturbed zones and management of "afforestation" (forest colonization) of abandoned agricultural spaces should take into account the more arid climatic conditions predicted for the next years and decades. In particular, there will be decreasing water availability as a consequence of decreased rainfall and/or an increase in potential evapotranspiration, caused for example by an increased demand for more fertilized ecosystems due to human actions and to a growing global population. Management of forest areas, and of natural areas in general, should incorporate a hierarchy of landscapes, including a large scale plan that considers the combination of different type areas, as well as multiple uses and the effects of perturbations, such as forest fires.

10 Inland aquatic systems

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Abstract

Inland aquatic systems include rivers, lakes, ponds and reservoirs. These are subject to both climatic influences and human activities affecting their hydrological, sedimentary, biological and biogeochemical dynamics. Climate change affects the amount and frequency of rainfall and evapotranspiration in the basin, with in turn a direct effect on the magnitude and frequency of hydrological patterns. It has been estimated that climate change may trigger an increased frequency of extreme and transient (droughts and floods) events in regions with Mediterranean climate, and that baseline hydrological conditions will become rare. Systems will therefore increasingly develop episodic regimes, while progressive and seasonal changes will become more diffuse. The abnormal rise in temperature may be behind the decrease in the ice cover in the Pyrenean lakes, which will force a prolonged stratification of lake water masses and will favor an increase in river water temperatures, with biogeochemical and biodiversity implications.

The increasing frequency of these extreme events has many consequences for freshwater ecosystems. On the one hand, they will favor the rapid pace of flood water and materials, creating specific pulses of increased productivity in the receiving ecosystems (lakes and reservoirs, alluvial, deltaic and coastal areas). Secondly, river fragmentation

will increase as a result of ongoing drought, or will experience a drastic reduction in the time span of masses flowing. During extensive periods of low flow resulting from climate change, the time of water residing in the system will be considerably extended. This will importantly bear on biogeochemical processes and favor anaerobic processes (producing greenhouse gases such as nitrous oxide or methane). It is also expected that the respiration of organic matter on the production of new biomass will be favored, which we understand as a progressive easing of heterotrophic functioning.

Biodiversity of inland aquatic systems may be affected by climate change. Mediterranean aquatic ecosystems possess a high diversity of fauna and flora, and although its biota is adapted to extreme hydrological changes, climatic change may overtake its resilience capacity. This may worsen the living conditions of organisms, leaving many habitats exposed to invasion by non-native species niches. Both communities' homogenization and effects on endemic species, today more abundant in the Mediterranean than in other climatic regions, may be expected as general consequences for biodiversity.

Direct human action may have a synergistic effect adding to the potential consequences of climate change. The nutrient retention capacity of rivers (the process of self-purification) decreases when nutrient concentration increases, since the system becomes supersaturated with nutrients. The continuous inputs from wastewater treatment plants contribute to nutrients excess, maximized at low flow conditions. Both derivation and regulation (through canals, dams, reservoirs) or confinement of water masses interfere in the hydrological and sedimentary dynamics of the respective ecosystems and complicate the interpretation of the effect of climate change, and may even screen the effects of climate change on these ecosystems. This is the so-called global change, which includes both the effects of climate change and those associated to human action, each with their separate timings and particular site of action.

11 Marine and coastal ecosystems

Authors

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Abstract

The Mediterranean is a semi-enclosed sea with increasing pressure from human activities along the shoreline. These two aspects make it particularly vulnerable to climate change. Multi-decadal observations show that the Catalan sea is warming up at a rate of 0.3ºC per decade, accompanied by an increase in the sea level of nearly 4 cm per decade. Modelling studies suggest that almost half of this warming trend is due to anthropogenically-driven global warming. These progressive changes, together with occasional overheating events and an increase in fall windstorms have severe effects on marine ecosystems. Littoral coralligenous communities, mainly composed of sessile and slow-growth organisms, undergo massive mortality from which they take long to recover. The extension of *Posidonia* meadows is sensitive to both temperature and variations in sea level. In the pelagic ecosystem, the potential increase in phytoplankton carbon fixation does not yield observable increase in net plankton productivity because respiration increases as well. Among bottom and water column organisms, a northwards shift is observed of species characteristic of the Catalan littoral, while southern thermophile species are becoming more abundant. Mild winters, decreased rainfall and warmer summers favour the occurrence of jellyfish swarms near the seashore. Also, blooms of some toxic microalgae can be triggered by warmer and calmer waters. A number of these observed and predicted changes represent threats on marine ecosystem services to society:

cultural references, direct economic resources (fishing, tourism), protection against erosion, uptake and storage of atmospheric CO_2, potential pharmaceutical or industrial use of genetic and metabolic richness, etc. Unfortunately, climatic agents act synergistically and push in the same direction as many other anthropic agents. We therefore recommend that efforts towards global warming mitigation are accompanied with efforts towards improving and regulating activities with strong environmental impacts, such as some fishing practices, pollution, recreation or construction. It is mandatory to develop strategies that favour investment into scientific research, monitoring practices and into protection of unique habitats.

12 Soils

Authors

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Abstract

Effects of CC on soil and its contribution to emissions, among other topics, were analysed. Previsions for CC impliy higher incident energy on soil aimed, partly to maintain life (and GHG emissions), and partly to preserve stocks of organic C. Land use changes, also related to CC, are larger than CC contribution to GHG emissions and therefore must be taken into account in mitigation policies. In rainfed crops, emissions are lower when adopting conservation tillage; in irrigated soils they are more difficult to predict.

The combination of climatic factors and vegetation and its evolution under CC conditions still indicate a trend of increasing aridity, and consequently, of erosion, which may be attenuated by soil conservation practices. Higher potential evapotranspiration due to CC will reduce water availability in soils. In irrigated areas, a greater supply of water and leaching fractions to prevent salt accumulation will be required. On the other hand, the temperature rise will displace agricultural activities to higher altitudes, which in Catalonia equals higher erosion risk. Therefore, a combination of conservation tillage and terracing practices, as calculated using technical criteria, should be implemented.

Organic C stocks of the Mediterranean and semiarid agricultural soils of Catalonia are about of 100 Mg ha^{-1} (up to 1 m). In order to estimate the carbon sequestration capacity of soils throughout the country, available data should be processed and integrated into global models. CC previsions indicate that our soils will experience a slow loss of organic matter by mineralization in the coming decades. To compensate for that, the use of good quality organic fertilizers in proper dosage in agricultural soils, or organic amendments in the rehabilitation of degraded lands, may contribute to maintain the organic C stocks. Some loss of soil biodiversity by CC at medium or long term is also foreseen, but in all events lower than loss due to other human activities.

Improvements in waste management facilitate its usability into the soil, which is key for maintaining environmental quality. To reduce emissions of N_2O and NO and loss of soil quality, only organic wastes and good quality manures in their adequate doses should be applied. Biochar is a mitigation option against the effects of climate change that must definitely be considered. To that end, though, a change in the current energy plans should be introduced so as to include pyrolysis of biomass waste, as well as a realistic and conservative estimate of the biochar holding capacity of Catalan soils.

The existing regulatory framework is not adequate either for soil protection or to fight against climate change. Information of soils is scarce and the most appropriate measures for their protection are missing, and so are too for adapting / fighting

CC. Maintaining soil quality is the best advice for agro-ecosystems, so that they can contribute to mitigating the effects of climate change. Therefore, actions on soil use and management are the most effective mitigation resources.

13 Agri-food systems: agriculture, livestock and fisheries

Authors

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Abstract

The Catalan agricultural sector is very much aware of climate change and global change, and instigated policies and actions to mitigate and adapt to these changes some time ago. The basis for this is the move towards an agronomy based on scientific knowledge to adapt production methods and systems to these new environmental conditions and ensure that the qualitative and quantitative factors of production can be maintained, at all times bearing in mind the socioeconomic, environmental and cultural context in which they are planned.

In recent times we have seen increased awareness among producers and consumers of agri-food products in terms of the existence and effects of climate change. This explains the intensification of high-tech and precision agriculture which, helped by consumer-awareness campaigns, have had great success (by promoting 'zero kilometre' or local produce).

The agricultural sector has two major challenges: the use of water and the management of nitrogen. Irrigation-based farming offers larger profits than dry farming in both productive and economic terms. In this respect, improvements in the efficient use of water (i.e. an increase in the quantity of product obtained per drop of water used) is key to sustainability when it comes to climate change. Dry farming, which accounts for the greatest percentage of agricultural land in Catalonia, presents a higher risk and to maintain productive output care needs to be taken in selecting the most drought-resistant species and varieties and making greater use of management strategies, such as crop rotation, letting land lie fallow, and other farming systems (such as conservation, organic farming, integrated production and precision agriculture).

In farming, the management of nitrogen-rich fertilizers is a key factor in crop production. However, they need to be used more efficiently to reduce emissions from nitrogen composts and the effect of the eutrophication of surface and subterranean water. In this respect, there is a need to refine the ratio of fertilizer-irrigation-soil and the handling of nutrients in the fields.

When it comes to livestock, the intensity and quantity of emissions vary according to the species and production system. It is therefore essential to improve livestock management practices and animal waste management to increase production efficiency and reduce emissions. Precision livestock breeding and the use of new technologies, such as nutrigenomics, can contribute to maintaining production and, at the same time, mitigating climate change.

Given their global importance, coastal marine ecosystems are a major concern in relation to climate change. Because of its economic and social importance, coastal fishing is deeply rooted in Catalonia. The management of this activity must be based on criteria of sustainability, and the effects of climate change (such as global warming and the acidification of the seas) must be taken into account.

14 Energy

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Abstract

Carrying on from where the second report on climate change in Catalonia (SICCC) left off, the chapter starts by bringing up to date the figures for energy production and consumption in Catalonia during the last few years and for the corresponding greenhouse gas emissions (GHG). It does not go into the SICCC in detail, to avoid repeating concepts and because the severe economic crisis has such an effect on all figures that it is hard to tell which improvements are due to corrective measures and which are a result of the crisis. Nevertheless, the paper compares the forecasts with the facts, as well as measures undertaken with those recommended by the European Union (EU), always bearing in mind the enormous influence energy consumption has on GHG emissions, which accounts for over 75 %.

Following on from these comparisons, it analyses the measures that need be implemented in the coming years to bring Catalonia in line with EU's policies on energy and emissions reductions, the most advanced presently in the global context. To back these proposals up, they are also compared with the position of key centres in the United States (USA), which map fully the proposals in this chapter. One that stands out is the need for a real improvement in energy efficiency, which calls for technological measures and demands management strategies. This will only bear out if consumers are both sufficiently well-informed and well-prepared.

Secondly, the development of renewable energies must be enforced, which, as well as specific improvements in the production systems themselves, require important advances in distribution networks and in the ability to store this type of energy, as a continuous top quality supply must be guaranteed and renewable energies are typically discontinuously produced.

Another aim is to reduce proportion of hydrocarbons in automobile fuel, but as this report already contains a chapter on transport, this is just mentioned in passing. All measures should be gradual and objectives should be clear in order to avoid gaps arising from hasty decisions, which may produce unforeseen rejections, and delays caused by overcaution. In this respect, the debate on the future of Catalan nuclear power stations should not be postponed any longer.

To implement all these measures, three requirements at least must be met: the Government must have sufficient legislative and normative powers; public and private resources must be harnessed to give rise to an energy industry; and research must be furthered in areas considered fundamental for reaching the set goals, which should map those areas object of attention in countries at the forefront of research.

15 Industry

Authors
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Abstract

The paper is structured in four main sections: Section 15.2 precisely defines the scope of the manufacturing industry, its building blocks, and the assessed GHG emissions. Section 15.3 analyses the GHG industry emissions inventory in Catalonia, their distribution among industrial sec-

tors and emission type, their source within the industrial processes, and their relative weight in the total of Catalonia. Section 15.4 examines the current situation regarding control of GHG emissions, emphasizing the three top industrial sectors bringing higher added value to Catalan economy: food, chemicals and automotive. Several main action plans are outlined in order to reduce GHG emissions in these three sectors and several KPI are suggested as well; this is an open door to innovation by redesigning the product and, consequently, leading to reduction in GHG emissions during its use phase. Section 15.5 leverages the previous one, emphasizing the synergies among GHG emissions reduction, increased resource productivity in the industry sector and improvement on the main environmental and socioeconomic challenges in Catalonia. Outstanding is the idea that an inclusive and balanced industrial development willing to attain environmental, social and economic objectives might require more effort in improving resource productivity (including infrastructures) than merely in improving labour productivity. Finally, some advice is outlined to develop and to coordinate main policies, building up at the same time on the Industrial Strategy in Catalonia for 2014-2020.

16 Tourism

Authors

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Abstract

Recent international research on the relationship between tourism and climate change demonstrates the growing interest in the area. Particularly in Catalonia, where tourism is a strategic sector on the rise, it's mandatory to determine how future climate scenarios will affect the two main tourist sectors: sun and sand tourism, and snow tourism. This paper tackles the effects of climate forecasts regarding how climate change might affect tourism, including the effects of rising sea levels and coastal erosion on the amount of beach space available for recreational purposes, and the effects of the predicted decrease in rainfall on the availability of water resources in coastal areas. As for snow tourism, we studied the natural and technical viability of Catalan skiing resorts by evaluating the effects of climate change on three scenarios. Finally, we analyzed the response to these issues by examining first the adaptation strategies applied, and then the relief strategies and measures deployed.

Sun and sand tourism is highly sensitive to and fully dependent on weather and climate. Fortunately, different models have concluded that the Catalan coast will continue to enjoy favorable weather conditions to maintain its competitiveness in the sun and sand tourism market. However, deseasonalization and diversification of tourism activities and products is one of the key strategies to adapt to climate change.

The general trend for Catalan beaches to erode and the strong pressure of recreational demand has led to a decrease in user satisfaction and is threatening the sustainability of the resource. The building of defense dams and the regeneration or restoration of sand and dune systems are examples of the hard and soft measures being implemented to stabilize beaches.

Ensuring the availability of both water quantity and quality is essential for the development of touristic practices. Combined government-backed actions such as desalination, reuse and recovery of aquifers, interconnecting networks and improving efficiency must be accompanied by water efficiency measures by tourists and by the tourism industry itself.

The mountain areas of Catalonia are particularly vulnerable to the effects of climate change, since almost all resorts are sited at latitudes that jeopardize their future viability. As far as snow tourism is concerned, adapting measures seek an increase in the capacity to manufacture artificial snow via snow cannons. Although this will increase the number of ski slopes and skiing areas, it will not join ski resorts or skiable surface areas. With a view to deseasonalize activities, snow destinations suggest to adapt from ski resorts into mountain resorts, and thus offer a wider range of activities that do not depend on snow.

Finally, it is worth noticing that the tourism sector is responding to the effects of climate change variously. In Catalonia, some hotels, campsites, marinas and other tourism providers are, among other actions, applying energy saving and efficiency measures as well as reducing greenhouse gas emissions thanks to the introduction of environmental certification procedures.

17 Waste and resources

Authors

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Gara Villalba

Abstract

Waste management, along with preventive strategies to reduce consumption, opens up opportunities for resource optimisation through reuse and recycling to reduce and prevent greenhouse gas emissions (GHG). Selective collection figures in Catalonia have stalled, and in recent years have reached 38 %-40 %, though in 2007 they accounted for just 34 %. The main means of treating the remaining fraction (preferable to the term *rest fraction*) in Catalonia in 2013 was mechanical biological treatment (MBT) (52 %), followed by controlled landfill (37 %) and energy recovery by incineration (11 %). The quality of biostabilisation from MBT is variable, the most critical parameter being the lack of biological stability. Biostabilisation is managed by controlled landfills, which generate methane emissions as a result of anaerobic digestion. This increases the potential for global warming associated with the management of this waste flow. With regard to the technologies for treating the organic fraction of waste, the consumption of energy increases with a rise in the complexity of the treatment facility. Conversely, emissions into the atmosphere decrease when the complexity of the plant increases. Thus processes based on voltaic piles have lower energy consumption but, as they do not have a system for capturing and treating gases, they have a higher impact in terms of atmospheric emissions.

In order to calculate its greenhouse gas emissions, since 2011 the Waste Agency of Catalonia has used the Carbon Footprint Tool for Waste Management (CO2ZW®), developed by the research group Sostenipra. The main source of emissions from waste treatment processes are controlled landfills, which emit large amounts of methane (despite the harvesting of biogas). On the other hand, selective collection contributes to a large extent to reducing the sector's carbon footprint ('avoided impacts'). The variables that most strongly determine these emissions are: 1) the generation of waste per inhabitant, and 2) the remaining fraction sent directly to landfill sites, which contribute to increasing emissions; and 3) selective waste collection, which helps to minimise emissions. In the case of the carbon footprint of municipal waste management per inhabitant, between 2011 and 2013 a reduction of 21 % was observed, reaching 94 kg of CO_2 equivalent per capita, as a result of the decline in waste generation (of 11 %) and the reduction in emissions per tonne of waste generated. In relation

to GHG credits, the balance between those generated and those avoided, aluminium is the fraction that generates the most credits, –12,580 kg CO_2 equivalent per tonne, compared to the 354 kg CO_2 equivalent per tonne of plastic or the 46 kg CO_2 equivalent per tonne of paper. These credits are obtained by taking into account the fact that 38 % of paper, 25 % of plastics and 57 % of aluminium are taken outside Catalonia and Spain, and that the credits avoided in each country depend on the technology as well as the energy mix.

The overall GHG emission factor from the water cycle could be as high as 2,148.4 g CO_2 equivalent per cubic metre of water consumed or more. The uncertainty of this data makes it essential to continue working on global studies of the urban water cycle in Catalonia.

The situation of waste of livestock origin, especially slurry, is unsustainable and has made it necessary to close down the six treatment plants in Catalonia, so we are now back to the same point as ten years ago.

18 Health

Authors

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Èrica Martínez
Krijn Paaijmans
Jordi Sunyer

Abstract

The goal of this chapter is to describe the main effects of climate change on health in Catalonia. The chapter is based on a review of recent scientific evidence focused in Catalonia and it also forecasts the expected effects on health of the estimated climate conditions for the next few decades.

One of the most widely studied health effects are heat waves, causing increases in the number of deaths and hospitalizations by more than 20 %, mostly among the elderly and in persons with previous chronic conditions. The results presented in this chapter show that the expected number of heat-related deaths in Catalonia may grow eightfold by 2050, resulting in over 2.500 deaths per year during the summer months.

Air pollution is a problem aggravated under certain weather conditions, especially during periods of high temperatures, which cause numerous respiratory and cardiovascular problems among the population. In Catalonia the estimate is 3.500 premature deaths per year associated to air pollution effects.

Climate change may also have an impact on the prevalence of vector-borne diseases. Changes in temperature and rainfall favour the development of mosquitoes, the main transmitter of this type of disease. In the case of Catalonia, the potential risk of diseases such as dengue, malaria or chikungunya is estimated to grow.

But climate change may affect health by other means. This chapter describes the risks posed by cold waves and exposure to smoke from forest fires, which have been associated to increases in the number of hospitalizations and deaths, especially due to cardiopulmonary problems. It also briefly mentions other factors that may mediate the relationship between climate change and health, which however pose lesser risks for Catalonia (such as waterborne diseases) and presents several uncertainties about how they may affect Catalonia in the future (as in the case of ultraviolet radiation).

As for the adapting measures to global warming, the chapter discusses the plan of prevention of health effects from heat waves and two mitigation measures with various health benefits: green spaces, especially in urban areas, and the promotion of active transportation.

By way of conclusion, health is an area of the outmost relevance as regards climate change effects. The chapter highlights, among others, the need to foster healthy lifestyles through policies promoting the use of active transportation, to deploy plans to prevent heat waves' effects, to improve energy efficiency of buildings, and to implement policies to reduce social and economic inequalities.

19 Transport, mobility and logistics

Authors

Francesc Robusté
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Abstract

Emissions and energy consumption resulting from the transport, logistics and mobility sector decreased in period 2010-2015 by 20 % as compared to data from 2005, but this descent, incidentally close to the target, is circumstantial. Despite new technologies being developed to promote transport decarbonisation, still governmental action, general growing awareness about climate change and sustainability, emissions and energy consumption in the sector are clearly insufficient and will prove to continue being so unless coercive measures are implemented (restrictions, pricing, regulation, etc.), at the expense of some political disfavor.

20 Territory and urban spaces

Authors

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Clara Montaner Augé

Abstract

This chapter basically approaches the connections between territory and urban areas and their relevance in the current context of climate change.

It considers the current situation in relation to climate change and claims the need to develop regional and urban policies and actions in the coming years.

The last decade Catalonia has seen intensive and unprecedented regional and urban planning activity through innovative strategic environmental assessment, which for the first time ever has taken on environmental and sustainability aspects for the drafting and planning stages. The chapter, thus, includes two separate sections (territory and urban areas), which essentially draw the approximate territory's and urban immediate futures. The sections cover implementing actions of the planning instruments carried out so far, particularly in relation to the considerations and determinations they set out for adaptation and mitigation of climate change.

As regards urban planning, even though aspects relating to flows of energy and matter had lately already been taken into account (especially in the construction and housing areas), further environmental and sustainability aspects are recently being incorporated too, which range from urban strategies, urban modeling and designing (buildings included) and their corresponding materializations.

21 Man-natural systems interaction in areas most vulnerable to climate change: the mountain chains

Authors

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Bernat Claramunt

Abstract

For most, the word *mountain* evokes images related to hiking, skiing, grazing cows, diary industries, fresh air and/or snowy slopes. But mountains are beyond both that pastoral picture with farms in the background or the idyllic wild site for family hiking. Mountains provide ecosystem services and other services of diverse nature that are crucial to all the population, even to those living in the lowlands. Actually, a major component to the general quality of life is largely dependent on the goods and services that mountains provide. Mountain inhabitants have been sustainably decreasing in numbers, moving down to the lowlands; glaciers are melting away; the population in the highlands is aging; winters get ever shorter… There's no doubt that climate change is a major factor in many of the challenges that mountains are facing. This chapter provides an overall view of the current situation of mountains taking the Catalan Pyrenees as base. It does not only take into account the effects of climate change on natural systems; it also considers man-made performance as a factor of change itself. The analysis of the various elements and working agents in the system and their interactions provides insights on the possible future scenarios for the Catalan mountain chains, also integrating the wishes and interests of the Pyrenean inhabitants. We conclude that there are no magic solutions, and that land management when tackling climate change requires establishing priorities and trade-offs. Readers will see (and decide) by themselves which the ideal scenario might be and which of the potentialities of mountains may be jeopardized in the trading-off.

22 Policies and instruments for mitigating and adapting to climate change

Authors

Josep Garriga Sala
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Abstract

The aim of this chapter is to describe the main policies and instruments available locally, in Catalonia, in Spain and internationally to facilitate the management and governance of climate change.

In the international sphere, negotiations between the different states by means of the Conference of the Parties to the United Nations Convention (COP) have been the main instrument in the fight against climate change. This chapter describes the negotiations that have taken place to date, the main agreements reached, from Copenhagen (2009) to Paris (2015), and the recognition, thanks to the efforts made by the Catalan Office for Climate Change, of the role of sub-state governments in official documents.

There are various international instruments, such as the climate-energy legislative package whereby the European Union has made a commitment

to reduce emissions by 40 % by 2030 compared to 1990 levels, which envisages measures for financing, promoting renewable energies and increasing efficiency, creating a Europe-wide emissions trading market, and so on. With regard to adaptations to climate change, noteworthy is the European Strategy on Adaptation to Climate Change.

In Spain, the National Allocation Plan, the Spanish Strategy for Climate Change and Clean Energy, and the National Climate Change Adaptation Plan were passed in 2007.

At the end of 2006, the Catalan Government established two very important instruments: the Catalan Office for Climate Change and the Interdepartmental Commission on Climate Change. In 2008 the Framework Plan for Climate Change Mitigation in Catalonia was established, which was subsequently updated as the Energy and Climate Change Plan 2013-2020, and the Catalan Strategy on Adaptation to Climate Change was passed in 2012. There are also other instruments in place such as the Voluntary Agreements Programme.

There is currently no doubt whatsoever about the importance of local governments in the fight against climate change due to the capacity for leadership and advancement that they have demonstrated. However, in a framework of multi-level governance on a national and international scale, the actions of local authorities still depend on the sensibilities of national and state governments. In this respect, there are various initiatives underway to empower the actions of local governments, such as the Covenant of Mayors for Climate and Energy and the Covenant of Mayors Initiative on Climate Change Adaptation (Mayors Adapt).

Finally, the last section deals with the emissions market as a tool for reducing emissions from industrial sectors, and follows up the developments of the last few years (the evolution of prices, clean development mechanisms and joint action plans) and the main novelties in this respect.

23 Public opinion, communication processes and citizen involvement in climate change in Catalonia

Author

Joan David Tàbara

Abstract

This chapter examines some of the main research results on evolution of public opinion on climate change. It also analyses communication processes and the political usage of the climate knowledge body. The paper puts forth some specific advice for improvement in this area of research and action in Catalonia. On the one hand, climate change remains a major concern among citizens, despite this concern having decreased somewhat after 2007. This can be seen partly as an effect of the economic crisis but also as the result of the topic attracting less and less attention by the media. However, new interpretative frameworks are now available, in particular those taking climate change either as a *global threat* or as an *opportunity:* for new jobs emerging, for an improvement in the quality of life and for boosting economic development. The opportunity construction is particularly prevalent among Spanish public opinion, which fact may ease the implementation of policies aimed at boosting low carbon economy.

Seeing how crucial dissemination of scientific climate knowledge turns out to be, the paper also analyses the dissemination of results contained in the *Fifth Assessment Report* (AR5) of the Inter-

governmental Panel on Climate Change (IPCC) in Spain and Catalonia. For this purpose, a questionnaire was designed and sent to twenty relevant actors and an analysis was performed of the coverage of the launch of this report by the press. This established a list with the most prevalent messages circulated, the difficulties reported by agents and the main interpretative frameworks that may help in the spreading of the climate change challenge. Interpretative frameworks such as those focusing on health and welfare issues and opportunities for transformation, like those targeting people's active involvement, were reported to be far more convenient than those focusing on «more bad news». In particular, this supports the need to focus not only on potential risks and effects of climate change, but also on solutions and examples of what people can really do in their everyday lives to meet this challenge.

Proposals contained in this work arise from the consultation with relevant stakeholders as well as from the analysis of secondary material, and have to do with the following criteria: 1) improve the monitoring of public opinion in Catalonia; 2) take advantage of the prevalent interpretive framework of climate change as an *opportunity* to develop low carbon economy; 3) substantially improve capacities and communicative processes to disseminate climate change in Catalonia; 4) create and support boundary organizations that may establish the divide between that belonging to science, to politics and to citizens, and help improve their working interfaces and relations; 5) tell audiences and relevant agents apart and «listen first» to relevant stakeholders so as to connect them through interactive networks, and 6) integrate the apparent socio-environmental complexity so as to avoid reductionisms.

24 Research on climate change

Author

Lluís Rovira i Pato

Abstract

Catalonia has developed a considerable and heterogeneous research team in climate change based on the separate research groups spun from public organisations. Private corporations participate actively too, especially in the European Union R&D projects. Scientific production is thus large. This analysis shows the peaks of quality in the system and puts forth some relevant advice. At the same time, data on different funding sources are highlighted, both structural and based on competitive projects, in order to foresee the future scenarios that may secure the whole scientific potential.

Legal epilogue: from Kyoto to Paris (COP21). Scenarios and future challenges of international climate change policies

Authors

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Abstract

The twenty-first session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) and the eleventh Meeting of the Parties to the Kyoto Protocol (COP-MOP11) adopted, on 12 December 2015, the Paris Agreement and the Decision that approves and supports it. Compared to its preceding agreement, the Kyoto Protocol, the Paris Agreement is a more flexible instrument with more sections that covers a much larger spectrum of emissions and proposes a more lightweight institutional architecture. This chapter analyses the key elements and the legal implications of the Paris Agreement, primarily from the perspective of Catalonia. With regard to the different initiatives and public actions currently taking place on the subject of climate change, the analysis focuses particularly on the bill currently going through the Catalan Parliament and highlights the potential for tackling the challenges that will be thrown up by this new international legal framework.

Obra Social "la Caixa"