Chapter 15

Considerations on climate variability and change in Spain

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ABSTRACT: This chapter summarizes the existing knowledge about climate change in Spain and its potential impacts on water resources and demands. Increasing evidence of climate changing conditions has prompted Spanish water agencies and governments to take into account possible water scenarios, which mostly indicate a reduction of runoff and the increased likelihood of extreme events, into basin management plans. Yet, uncertainties are still high and predictions have considerable interval ranges. This chapter argues that water institutions and adaptive management are important to anticipate no regret measures to tackle the worsening of hydrological regimes. Also greater efforts need to be placed in searching for mitigation measures.

Keywords: climate change, runoff decrease, adaptation, extreme events, evapotranspiration

1 INTRODUCTION

The latest published report of the Intergovernmental Panel on Climate Change concluded that between 1970 and 2004 global CO_2 emissions had increased 80% (IPCC, 2007). As a result mean global temperature has augmented significantly, more so in the Northern Hemisphere where annual temperature has risen between 0.2 and 2°C. Predictions to 2030 forecast a possible increase in global temperature ranging from 1.8 to 4°C, depending on the emission scenario used. Southern Europe is expected to be particularly vulnerable to climate change (CC), at least in all environmental and social aspects that depend on water resources (e.g. reduction of water availability, hydropower potential or agricultural productivity and increasing risk of wildfires) (Giorgi & Lionello, 2008). This chapter updates the CC projections for Spain and the possible impacts on water resources, by looking at both projected changes in runoff and expected variations in water demand in three different domains: agriculture, forests and urban areas.

2 PROJECTED CHANGES IN PRECIPITATION AND TEMPERATURE

The Mediterranean region is likely to suffer more severe climate change impacts than other EU countries (Bates *et al*., 2008). Droughts could become more intense and frequent, and rivers' run-off may decrease (Fischer *et al*., 2007; Lorenzo-Lacruz *et al*., 2012). Despite these projections, Spain lacked a detailed spatial assessment of potential changes in temperature and precipitations induced by an increase in CO_2. This assessment is needed to forecast as far as feasible potential on-site hydrological changes and identify possible adaptation measures. Most national assessments performed so far (de Castro *et al*., 2005; Iglesias *et al*., 2005) relied on calculations obtained from broad-scale assessments from Atmosphere-Ocean coupled General Circulation Models (AOGCMs), which have low spatial resolution and a high degree of uncertainty. In response to this information gap, the Spanish Climate Change Office (*Oficina Española de Cambio Climático*, OECC), coordinator of the National Adaptation Plan to Climate Change (*Plan Nacional de Adaptación al Cambio Climático*, PNACC) issued in 2006, commissioned the elaboration of a regional assessment on the likely impacts of Climate Change on water resources in Spain. The first output has been the publication of the so-called *Assessment of the effects of CC on natural water resources* (CEDEX, 2011), which represents the most up to date report on future climate scenarios at the regional scale for Spain (1 km^2 resolution). According to this report, the mean annual temperature in Spain is expected to increase progressively along the 21st century, +0.065°C/year under A2 scenario and +0.048°C/year under scenario B2. This means that by 2040 mean annual temperature in Spain could increase between +1.4 to +1.9°C.

According to the CEDEX report, the mean annual precipitation is likely to decrease by up to –0.88 mm/year under A2 scenario, and –0.18 mm/year under a B2. This implies that annual precipitation could decrease between 5 and 6% by 2040. Yet, there is still a high degree of uncertainty linked to future rainfall trends in Spain, since most regional models show prediction errors above 15% when estimating annual variations. The uncertainty in forecasts is even higher across seasons, with mean errors ranging between –33% to +30%.

Despite the uncertainties surrounding future precipitation trends, it is pertinent to learn what may happen under different scenarios across different Spanish basins. According to the CEDEX report (2011), precipitation will decrease especially in the Canary Islands and the Southern Peninsular basins between 7–14%, depending on the scenario by 2040 (see Figure 1). The Eastern and Northern basins are not expected to experience large changes in rainfall patterns. Meanwhile a rise in temperature is expected in all basins, with inland catchments experiencing a larger increase (between +1.4 and +1.6°C). Coastal Atlantic and Mediterranean basins will be less affected by the increase in temperature.

If the above projections materialise, the Southern Mediterranean region of Spain will move towards its *aridification* while the Northern part of the country will experience a *Mediterranization* process. From a hydrological perspective, the projected increase in temperature together with the likely decrease in annual rainfall, might lead to an overall reduction in water availability in most basins. Figure 2 shows the projected regional decrease in runoff and recharge between 2010 and 2040 for the

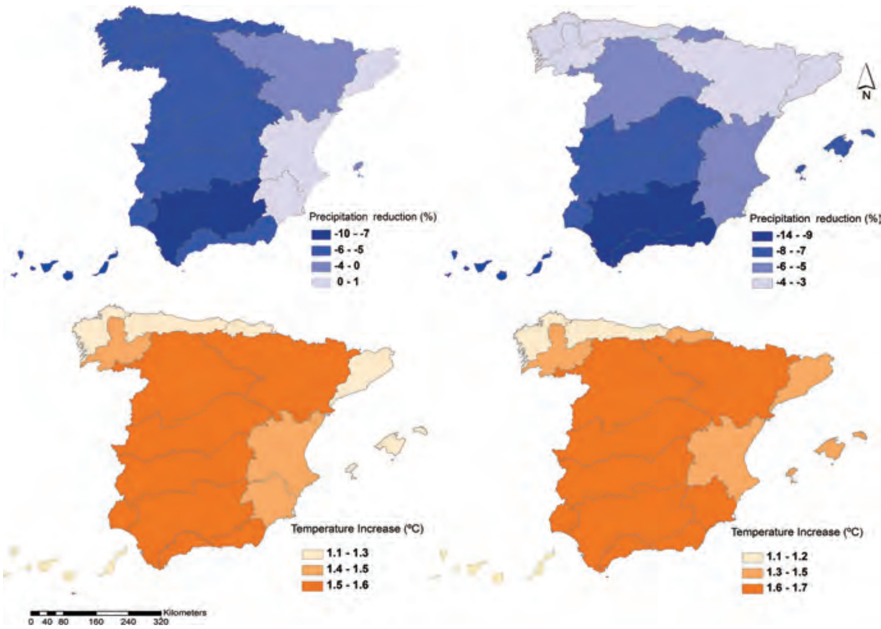

Figure 1 Forecasted changes in mean annual precipitation (%) and mean annual temperature (°C) between 2010 and 2040. Projections represent the mean value obtained from the regionalization of three AOGCMs (HadCM3, ECHAM4 & CGCM2). (Source: Own elaboration based on CEDEX (2011)).

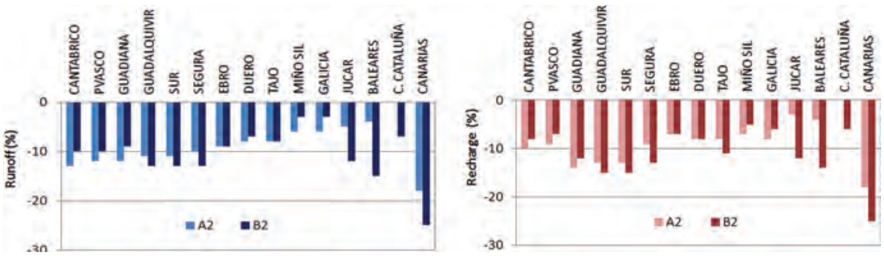

Figure 2 Mean annual reductions in runoff and recharge (%) in the different Spanish River basins between 2010–2040 under A2 and B2 scenarios. Projections represent the mean annual value obtained from the regionalization of three AOGCMs (HadCM3, ECHAM4 & CGCM2). (Source: Own elaboration based on CEDEX (2011)).

different basins. The Canary Islands would suffer the largest reduction in runoff and recharge (up to 25%). Within the Iberian Peninsula, the Southern basins of Guadalquivir, Sur, Guadiana and Segura would experience a significant reduction in surface and groundwater resources (up to 13% of runoff and 15% of groundwater recharge). Mediterranean basins like the Ebro, Catalonia Inland basins and Jucar would suffer a smaller reduction in water availability (below 10%), as the temperature increase along the coast is not expected to rise as much as inland. However, some detailed studies conducted in the Ebro Basin predict greater reductions. For instance, Quiroga *et al*. (2011) project a runoff reduction up to 29% under B2 scenario and even greater under scenario A2 (–46%). According to CEDEX (2011) Northern basins will also experience a similar runoff reduction, but the impact of water shortages might be smaller, since most of them are water abundant basins.

The water resource scenarios shown in Figure 2 have nevertheless a high level of uncertainty. Foremost, because future climate trends remain unclear and this is compounded by the inherent variability of the Mediterranean climate itself and the complex Spanish geography, which adds important challenges and unknowns when trying to make plausible climate change predictions.

3 INCREASED CLIMATE VARIABILITY AND MORE EXTREME EVENTS

The IPCC report on climate change and water (Bates *et al*., 2008) forecasts that for mid-latitudes regions like Spain, the frequency of extreme rainfall events would increase and drought periods would be longer and more frequent. Yet, no clear increase in the frequency of floods has been observed during the 20th century, although the rate in short-term droughts has increased slightly since the 1950s (CEDEX, 2011).. These trends seem to also be supported by regional studies like Valencia *et al*. (2010), who found that in the Ebro basin the precipitation regime is now more homogenous than thirty years ago, although the rate of droughts has augmented. Vicente-Serrano & Cuadrat-Prats (2007) also demonstrated that from 1951 to 2000 there has been an increase in the severity of droughts in the Middle Ebro Valley, although with wide spatial variability.

Lorenzo-Lacruz *et al*. (2012) analyzed the evolution of the streamflow in the main rivers of the Iberian Peninsula during the last half of the 20th century. His study evidences a downward trend in annual, winter and spring streamflows, especially pronounced in the Central and Southern basins. The reduction in winter and spring streamflow is attributed to several causes, including changes in the seasonal rainfall pattern. Other important non-climatic factors such as reforestation, an increase in water demand and current water management strategies all play an important role in the observed streamflow evolution.

4 AGRICULTURAL WATER DEMAND

The uncertainty of climate change's projections makes difficult to develop and implement adaptation strategies. Small changes in agricultural water use could have significant economic and hydrological impacts. Water policy faces the dilemma of ensuring the sustainability of water resources in the future, while maintaining the strategic targets of agriculture, society and environment. Improving access reliability and meeting all users' expected availability are potential opposing goals for water management, which require compromises and adaptive capacity.

Crops' water demand is especially sensitive to changes in precipitation and runoff patterns, increase in temperature and to high levels of CO_2 concentration (Frederick & Major, 1997). If temperature rises, photosynthesis activity could increase and stomatal conductance could be lower. Therefore, crops' water use efficiency could be higher. Changes in crop's water needs will depend on the thermal requirements of each crop, and the period of the year in which the crop grows. It may be necessary to replace high water-demanding crops like rice, maize in some areas, and to stop the irrigation of inadequate soils (Iglesias *et al*., 2005).

Crops' evapotranspiration rate could increase due to higher temperatures, and this could lead to greater water needs (Moratiel *et al*., 2010). However, even if traditional varieties and sowing dates are maintained, the crop cycle could be shortened because of higher temperatures, and this would have the opposite effect on crops' total water needs. Controversy exists about whether improved yields under drought conditions must come at the expense of yields in the seasons when the rainfall is favourable. However, research is making improvements on those areas, and most likely varieties will emphasize one or another trait to offer farmers best or more suitable options to their specific climate circumstances.

Climate change is likely to have a wide range of impacts on agriculture, but there is a great deal of uncertainty in the implications that this might have for water management and water policy. In Spain, irrigation is the main water consumer, accounting for about 65% of total water demand (See Chapter 6). Changes in water demand will affect irrigated crops' profitability if more water is needed for irrigation. Also,

Box 1 Climate change and the case of maize in Spain

Maize's evapotranspiration and irrigation requirements are expected to decrease in all sites studied in the Iberian Peninsula under A2 climate change scenario (Rey *et al*., 2011) (Figure 3). The decrease in maize's evapotranspiration could be caused by decreases in the number of growing days and in Leaf Area Index due to higher temperatures, and a lower transpiration due to stomata closure caused by a higher concentration of CO_2. Maize's yield could be lower, because it is a very sensitive crop to high temperatures.

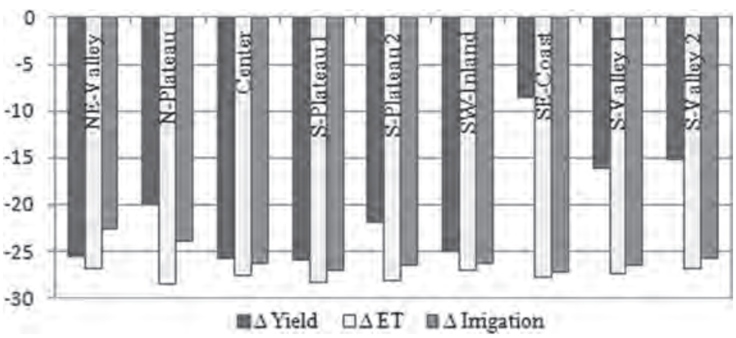

Figure 3 Variations (in %) of yield, evapotranspiration (ET) and irrigation needs of maize between control period (1961–1990) and future climate (2071–2100), due to CC in each site under study (A2 emissions scenario). Projections for current maize's varieties. (Source: Rey *et al.* (2011)).

As shown in Figure 3, ET decreases would be above 25% in most cases and almost 28% in the Plateaus. Reduction in maize's irrigation needs is lower. Yield decrease is less homogeneous, but significant in all sites. Therefore climate change could have very negative impacts on maize's yield in Spain, with decreases potentially exceeding 25% in the Central Plateau. However, maize's water needs due to new climatic conditions could also be lower than under current conditions. Ultimately, for each production area, water and maize prices will determine whether climate change makes the crops' profit larger or smaller. It largely depends on the price of maize, irrigation and energy prices. Probably, new maize's varieties better adapted to the new climate conditions will be developed in the next decades. If this was the case, the potential impacts reported here would not be so pronounced.

if precipitation decreases water will be scarcer, prices are expected to rise, increasing farmers' costs. Understanding how climate change could affect Spanish agriculture is the first step to mitigating the potential negative impacts of new climatic conditions. Moratiel *et al.* (2011) found that the expected climate change in the Duero Basin will cause an increase in reference evapotranspiration between 5% and 11% in the next 50 years compared to the current situation.

5 FOREST'S WATER DEMAND UNDER CLIMATE CHANGE

Forests, shrubs and natural pastures occupy approximately 54% of the Spanish territory (MARM, 2011), and consume on average 42% of the annual rainfall (see Chapter 11). Thus, if climate change predictions are plausible, these will have important effects on forest's ecology and its water balance.

From a water management perspective, gaining insight on the potential impacts of climate change on forests is crucial since changes in temperature and precipitation might alter forests' evapotranspiration, and consequently available water resources downstream (Otero *et al.*, 2011). Likewise, changes in forests' productivity due to water shortages might have important economic consequences for the Spanish forest sector, which annually generates over 1,000 M€ (AE, 2010).

Gracia *et al.* (2005) summarized the impacts of climate change on Spanish forest dynamics in three main aspects. First, if temperature and CO_2 increase, this will accelerate the leaf phenology in broadleaf forests and the renewal leaf capacity in evergreen species. As a result, leaf litter could increase and the overall carbon budget would become negative, implying that Spanish forests would become net sources of CO_2. Second, warmer conditions could increase the risk of pests in forests. Lastly, if the climate becomes drier, soil moisture could decrease and competition for water among trees could be higher, making trees potentially more vulnerable to droughts and extreme climatic events. Accordingly, CC is likely to reduce forest cover, and so will the forest's evapotranspiration. Also, there is a high chance that the remaining forest stands could shift from carbon sinks to net sources of CO_2.

Despite this general trend, the impacts of climate change on forests' water and carbon budgets would vary from region to region. The *fertilizer effect* caused by an increase in temperature and CO_2 concentrations could enhance primary productivity in the Atlantic region. In this area precipitation exceeds potential evapotranspiration, thus net primary productivity is likely to remain positive, implying a positive balance in carbon sequestration and a higher evapotranspiration. However, in the Mediterranean region where water is the most important limiting factor for forest growth, the likely impacts might differ. In these regions, and especially during spring and summertime when potential evapotranspiration is much greater than precipitations, primary productivity is likely to decrease due to a lack of water. Consequently, forest cover and evapotranspiration would decrease just in the Southern Mediterranean.

Several management measures have been studied to increase forest resilience and adaptation to CC. These measures include modifying the periods of forest intervention and the intensity of forest clearance. Different studies conducted in Mediterranean forests of Northern Spain show that lowering the intensity of forest intervention, i.e. maintaining a greater forest basal area will increase the capacity of forest as carbon sinks, both in the aerial part and in the soils. However, this increase in forest cover is likely to rise the water demand and reduce runoff. On the contrary, an increase in the intensity of forest clearance will reduce the carbon sequestration capacity of forest but it will increase soil water availability. According to Gracia *et al.* (2005) modifying the period of forest intervention seems to have a smaller effect on the carbon and water budget of forests. The EU project *Silvicultural Response Strategies to Climatic Change in the Management of European Forests* (SilviStrat) (Kellomäki & Leinonen, 2005) assessed the influence of different forest management regimes to cope with climate change in Europe. The report concludes that in forests subjected to extreme conditions – either due to low temperatures (boreal forests) or due to lack of sufficient water availability (Mediterranean forests) – none of the management measures mentioned above would remarkably increase the adapting capacity of forests to CC.

An important adaptation measure to cope with CC includes the improvement of land use planning by preventing forest ageing; and promoting the use of native species within afforestation programs which are best adapted to droughts. This is particularly important in the Mediterranean arc, since large afforestation programs might have negative consequences from the water availability perspective, due to the associated increase in water demand by forests (see Chapter 11). Further measures include the control of shrub encroachment linked to the abandonment agricultural fields.

6 URBAN DEMAND AND ADAPTATION MEASURES

Cities cover only 2% of the land surface, yet are responsible for almost 3/4 of CO_2 emissions concentrating more than half the world´s population. In Spain, Madrid and Barcelona represent examples of these global metropolitan areas (see Box 2). The importance of cities in the context of climate variability and change is because often these metropolitan areas generate a large part of the country's Gross Domestic Product (GDP), e.g. the capital city of Madrid contributes 12% to the national GDP. Cities and urban areas are key areas for mitigation and adaptation for at least three reasons: first, in terms of mitigation, because of the large ecological footprint of cities, compared to its land area, with processes like water treatment which are energy intensive; second, because the urban water system is highly vulnerable to climate change impacts without foresight and planning (Loftus *et al.*, 2011); and third, due to the potential interaction of climate change with the urban heat island effect, the urban climate is hotter than surrounding areas, with implications into peak energy and water demands.

One of the difficulties in relation to water and CC is the upfront costs of adaptation, since these are immediate, whereas the potential benefits are uncertain, with pay back into the future and where there is an onus on no regret strategies, based on the precautionary principle. Infrastructure like water storage and distribution, water treatment plants, etc. normally requires large upfront investment, and key questions centre on the ideal timing of investment. Once investments are made, these infrastructure systems become locked in, which can perpetuate inefficiencies. There are therefore large associated issues related to investment risk, in e.g. water supply and drainage, flood management, or issues like how to retrofit existing infrastructure and how to plan for new or replacement infrastructure as this age or become obsolete. Normally, water and wastewater systems correspond to an important percentage of total infrastructure costs in an urban system. A key question therefore when considering both impacts of climate change and potential adaptation and mitigation measures are related to equity, i.e. the distributive effects of potential impacts of climate change and solutions like efficiency policies to invest on improved drainage and water infrastructure, or issues related to social cohesion, city competitiveness and the distributional effects of costs and benefits and who bears the costs of adaptation (OECD, 2008).

In terms of adaptive responses there are a number of options, from the technological, behavioural, economic instruments like markets or price signals, managerial and policy design (e.g. regulatory changes, incentives), or adequate insurance schemes (Fankhauser *et al.*, 2010; Garrido *et al.*, 2012). Some of these measures are softer, based on developing capacity or looking at institutional mechanisms like water rights and allocation, or water markets while others focus more on *hard infrastructure* like improved drainage.

In relation to integrated water (and land use) resources management, the implications and potential for regional planning are often overlooked, i.e. the consequences of a low carbon city and low carbon growth for spatial planning and establishing the potential implications of e.g. urbanization and urban development models in relation to CC. The potential for using spatial planning as an adaptation measure to CC, particularly for cities framed within their surrounding catchment, are largely unexplored in order to identify existing spatial climate variations, microclimates and the potential vulnerability to extreme events. Finally, on a more general note, a Climate Change National Adaptation Plan is being developed in Spain. This establishes a general reference framework to evaluate CC impacts, vulnerability and adaptation. According to Estrela (pers. comm.) climate change impacts are being taken into account in water balances of the upcoming River Basin Management Plans in Spain. This represents an opportunity to take into account climate change effects in water decision-making policies. This Plan includes an assessment of the management and capacity of the Spanish hydrological systems under different water resource scenarios, a second assessment of potential climate change effects on irrigation and a third one of climate change impacts on the ecological status of water.

Box 2 Climate change and water resources in the city of Madrid

The case of Madrid in some ways reflects general trends applicable to Spain as a climate variability and change hotspot. The Spanish capital experienced the highest temperature increases amongst 16 European capitals between 1970 and 2005. Moreover, the *Ayuntamiento de Madrid* (2008) on the basis of information from the Tagus Water Authority and scenarios from the National Adaptation Plan to Climate Change, projects that temperatures will increase significantly between 4°C and 7°C in the summer and between 2°C and 4°C in the winter in the last quarter of the 21st century, compared with temperature records between 1960 to 1990. Meanwhile precipitations are expected to decrease, especially during the summer and spring seasons. In addition, evapotranspiration is expected to decline between 40% and 60% during the summer, between 20% and 40% during the autumn, and less than 20% during the spring. In winter an increase in evapotranspiration of less than 20% is also predicted. Water availability is also expected to be negatively affected by CC. Predictions anticipate a reduction in reservoir water inflow and available water resources of 7%, whilst demand for irrigation from 2027 to 2050 is expected to increase by 10%, thus adding pressure on diminished water resources, with increased variability. Water resources have already decreased by 30% in the last 30 years in the so called short climatic cycle (from the 1970s), and this is already being incorporated into the current river basin planning cycle. As regards extreme weather events, uncertainty is large, but, overall, more frequent heat waves are expected, as well as more floods in areas close to the river Manzanares, which crosses the city of Madrid and is very close to residential housing. Finally, severe droughts are a further possible consequence of CC. Since Madrid is located in a continental Mediterranean area, with semi-arid conditions, reductions in water availability may lead to having to ban certain non-essential activities in the city of Madrid (watering parks and gardens, washing cars, etc.). Sometimes there will be trade-offs between mitigation and adaptation in other cases, some policy choices will be able to tackle both. In the case of Madrid, an example of autonomous adaptation for example is how the water supply company of Madrid is incorporating in current planning the probability that drought events might become more frequent and possibly longer, thus in equity terms the new customers and existing customers would be bearing this additional cost for potential events into the future. Reducing energy consumption and greenhouse gas emissions (GHG) derived from water pumping and final uses (heating and pressurising) could hence be fostered by regular awareness raising campaigns that may complement the use of water saving devices for showers or for example the installation of drip irrigation systems. In addition, the water supply company of Madrid has been pro-active in developing Manuals for Droughts (Cubillo & Ibáñez Carranza, 2003) to guarantee access to water resources, as well as a guide for decision-making under scarcity conditions. There are also plans for water trading with farmers in the Madrid catchment.

(Source: Lázaro-Touza & López-Gunn, 2011).

7 CONCLUSIONS

Scientific observations are showing ongoing climate change processes taking place in Spain. Future predictions indicate that CC may aggravate water scarcity in Spain, by increasing evapotranspiration, reducing precipitation and increasing the likelihood of extreme events. However these projections are still subject to considerable uncertainty. Difficult trade-offs will have to be faced in the future: if the reliability of water supplies is to be maintained, then demands might have to be curtailed. This will require proactive, flexible and adaptive management practices. Adoption of technological innovations will certainly help, more capital investment will be needed in urban and agricultural supply networks. A combination of more decentralization and liberalization, combined with targeted public intervention could be a win-win strategy. A consensus exists about the potential of water markets to add some degree of allocation flexibility, however these need to be better regulated (Chapter 16). As Chapter 6 shows, importing virtual water in the form of agricultural commodities is probably the cheapest adaptive mechanism Spain has to cope with drought cycles. However, an excess of imports reliance also generates large environmental externalities elsewhere (e.g. deforestation), which paradoxically might accelerate climate change. Overall, a combination of these measures will certainly contribute to adapt under eventual possible climate change scenarios. However, if we consider climate change as an effect rather than a cause, any major strategy to mitigate should place land use planning, including the agricultural and urban sectors, at the centre.

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