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Prioritisation Method for Adaptation Measures to Climate Change in the Water Sector

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Prioritisation Method for Adaptation Measures to Climate Change in the Water Sector

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1. Introduction

Climate change brings new management challenges to the environment and to the economic sectors. The management of water in the face of climate change, as an intersection between the whole economy and the environment, is an example that demands for research input. Every step taken with regards to water policy and management should take into account how to adapt to the adverse effects that climate change model predictions expect to be occurring in the near and far future. Therefore, measures looking to enhance adaptation capacities to climate change are imperatively needed in order to guarantee future water supply, water sanitation, environmental restoration and conservation, and the management of extreme events.

Stakeholders involved in water management need advice to choose which adaptation measures are more suitable under the constraints of a changing climate and the ever growing budget limitations. Bringing economic analysis into adaptation, this report presents the development and implementation of a methodology that allows for the prioritisation of adaptation measures in water supply and water sanitation. This methodology supports selecting adaptation measures that would be more suitable to be financed by stakeholders, depending on their profitability and adaptation performance.

This prioritisation method is based on cost-benefit analysis (CBA), a very common process for calculating and comparing benefits and costs of a project, decision or government policy. However, one particularity of the prioritisation methodology proposed in this document has been the introduction of social and environmental externalities into the CBA, originating from the adaptation measure implementation, adding extra costs or benefits depending on their nature. For this, a set of criteria have been proposed, developed and calculated to provide a monetary value to some externalities that can be usually found in water management projects (e.g. water savings, pollution savings, etc.).

A second particularity of this prioritisation is the inclusion of climate change as a devaluation factor in the analysis, according to expected future negative effects. Special attention is given to discounting, the economic term for homogenisation of money in the future. In this report, discounting is calculated based on different emission scenarios (A1, A2, B1 and B2). The discounting shall vary depending on which scenario the adaptation project is submitted under in the CBA. The main reason for this it that impacts expected from one scenario will be different from the others. This will consequently affect the project's profitability and effectiveness.

The proposed prioritisation methodology seeks to evaluate adaptation measures separately, but also compare them as a group. Therefore, it includes a multicriteria comparison which considers not only the cost and benefits as criteria but also analyses the results through economic, environmental and social factors weighted separately. In doing so, it should be possible to select the one with the best performance to face future climate change challenges, independently of each measure's goals.

In this document, the methodology and the concepts involved are comprehensively explained. Prior to this, a theoretical focus is presented to link the concepts of climate change, water, adaptation and economics. Firstly, an understanding of how climate change can affect the water cycle is provided, along with an explanation and listing of different existing adaptation measures to climate change for water supply and sanitation management. Later, it is presented how climate change can be linked to economic analysis. Finally, the concepts and methodology of cost-benefit analysis are revised.

Following the theoretical part of the document, a case study is presented. The case study includes a hypothetical future scenario in which different adaptation measures for water supply and sanitation in the Spanish Mediterranean region have to be prioritised. Due to the actual lack of future adaptation measures for the region, five existing water supply and water sanitation projects have been selected where the implementation of adaptation strategies could be applied in the future. A review of reports on climate change is provided to synthesise which of the climate change impact predictions are expected for water resources on a Spanish, Mediterranean and regional level.

2. Water and Climate Change

Climate change will affect water cycles directly and consequently the quantity and quality of water resources available to meet the needs of societies and ecosystems. Climate change may result in (WWAP, 2012):

- → An increased intensity in precipitation, causing greater peak runoffs but less groundwater recharge.
- → Receding glaciers, melting permafrost and changes in precipitation from snow to rain are likely to affect seasonal flows.
- → Longer dry periods, likely to reduce groundwater recharge and lower minimum flows in rivers, with affects on water availability, agriculture, drinking water supply, manufacturing and energy production, thermal plant cooling and navigation.
- → Increased intensity in rainfall, melting glacial ice and large-scale deforestation is already increasing soil erosion and depriving the topsoil of nutrients.
- → Rising sea levels, having serious effects on coastal aquifers (salt intrusion), which supply substantial water to many cities and other users. This phenomenon can also have severe impacts on food production in major delta regions, which are the food bowl of many countries.
- → Affectation of coastal ecosystems, including loss in estuary productivity, changes in barrier islands, loss of wetland, and increased vulnerability to coastal erosion and flooding.
- → Alteration in composition and quality of water in rivers and lakes owing to changing precipitation and temperature, and in precipitation intensity and frequency influence on non-point source pollution, making the management of wastewater and water pollution more demanding and urgent.

Depending on the different IPCC scenarios, regions may become 'drier' or 'wetter', as there are a variety of possible ways in which climate change may impact the hydrological cycles in different areas and at different times. What is sure is that the uncertainties generated by climate change add a global dimension to the challenges of water resources management, as efforts to effectively manage water locally may be impeded by climate-induced hydrological impacts or increasing demands (WWAP, 2012).

Climate change negative impacts on water availability can produce a decrease in the Gross Domestic Product (GDP) of a country due to its direct affect on the agricultural, industrial, energy and leisure and tourism sectors. But even more importantly, it will challenge the guarantee of having enough safe drinking water to meet demands and a good sanitation system to prevent health and environmental deterioration, making this an imperative challenge to address (WHO, 2009). Following this line, this chapter takes a glance at how predicted climate change impacts could affect the two main elements within the human-altered water cycle: water supply and water sanitation.

2.1 Water supply, water sanitation and climate change

Climate models project a decrease in precipitation and as a consequence also in stream flow in several regions around the world. Surface water is a major source of water for almost all human activities, and its availability projections show a reduction in the future due to climate change in tropical regions. The groundwater scenario is likely to be similar or worse as reduced precipitation leads to reduced recharge. Moreover, increasing exploitation from socio-economic growth means groundwater will be subject to further stress. The regions currently under severe stress will face severe to catastrophic stress in the future under these conditions (WWAP, 2012).

Supply is strictly linked to demand; therefore, it is also connected to the difficulty of anticipating demographic and socioeconomic change and the limited understanding of how water responds to changing climate and policy conditions. Increasing demand is projected to occur in agricultural (for irrigation), domestic and industrial sectors, all which are linked to economic growth.

There can be several climate change impacts that are prone to affect the water infrastructure covering water supply, distribution, sewerage and sanitation. Not all the following impacts mentioned shall be addressed in this document, though several are highlighted to provide an overall idea:

→ Pipe systems for both drinking water supply and sewerage will be more prone to cracking as climate changes lead to greater soil movement as a consequence of changing wetting and drying cycles.
→ Assets on the coast or in flood plains (which covers most assets – networks, pumping stations, water and wastewater treatment works,) will be at increased risk from flooding, storm damage, coastal erosion and rises in sea levels.
→ Existing sewerage systems were not designed to take climate change into account. This means that more intense rainfall is likely to exceed the capacity of parts of the network and cause local flooding.
→ Dams will be more prone to siltation resulting from increased soil erosion, and the slippage risk to soil dams from intense rainfall events will also increase.
→ Lower river flows will reduce the dilution of wastewater effluent. Additional treatment may be needed to meet higher standards, which are likely to be achievable only by using energy-intensive processes, along with the accompanying implications to additional greenhouse gas emissions (Water UK, 2013).
→ Conventional water resources are going to be too scarce to rely on, especially in dry regions, having to turn to non-conventional resources such as desalination, rain water harvesting, etc.

If the widely anticipated flood and drought consequences of climate change come to pass, then both established water and sanitation services and future gains in access and service quality will be at real risk. Therefore, stakeholders involved in water resources planning and management will have to count on the climate change predictability to face future challenges (which, in fact, has already begun). Although some of the climate trends at regional level are uncertain, there is sufficient knowledge to inform urgent and prudent changes in policy and planning in most regions (WHO, 2009).

3. Adaptation Measures in the Water Sector

As illustrated in Chapter 2, climate change effects for the water sector are manifold. Many research results are already available that can facilitate decision making to determine the most convenient ways forward to face these possible challenges for the water sector.

To get an approximate idea of how important adaptation to climate change in the water sector is expected to be, some figures from the World Bank are able to provide an insight: The cost of adapting to the impacts of a 2°C rise in global average temperature could range from 53.375 million to 61 billion € per year between 2020 and 2050. Of these costs, between 10.545 million € (drier scenario) and 14.800 million € (wetter scenario) will be related to the 'water sector', predominantly through water supply and flood management. However, these estimates do not take into account the benefits water provides through other 'sectors' (food, energy, health, etc.) and thus under-represent the full value of the benefits that would be obtained from a greater focus on adaptation through water (WAAP, 2012).

3.1 Types of water adaptation measures

In the water sector several types of adaptation measures can be distinguished, depending on the resources used during their implementation. The following table compiles the main groups of measures that can be found:

Type of project	Description
Structural measures	Technical measures that imply a physical structure construction or installation as a final result. These require planning and applying new investments or working on maintenance, major rehabilitation and re-engineering of existing systems (e.g. reservoir volumes, desalinisation, drainage system installation, wastewater treatment plant construction, ecosystem restoration).
Communication and awareness instruments	Measures to increase awareness, knowledge and information (e.g. increase awareness through participatory work, information campaigns).
Training and technical assistance	Training of relevant stakeholders to improve their knowledge on climate change consequences (e.g. training of territory planning decision makers). Teach technical information to water users to make water consumption methods more efficient (e.g. teach ways to build or repair a water pump, water savings in building codes).
Coordination and planning	Better management and coordination for already existing regional projects and improving water resources management to deal with the impacts of climate change (e.g. more efficient allocation of water resources, Integrated Water Resources Management).
Legislation and regulation instruments	Develop regulations and laws to adapt society's and stakeholder's behaviour to climate change impacts (e.g. water price regulation, restriction of water uses and rationing in scarcity situations, improve insurance schemes against drought damage).
Resettlement	Measures involving movement of population or infrastructure so to lessen the environmental pressures of an area (e.g. relocation of production sites).

Table 4-1. List of types of water adaptation measures. *Source: adapted from ClimWatAdapt, 2011, UN Water, 2010.*

It has been also considered, for this document, to also distinguish measures according to their functionality, depending on which aspect of water management they relate to:

- → <u>Water supply/demand projects</u>: developed to guarantee a region's water supply and fulfil the water demand.
- → <u>Water quality and environmental projects</u>: developed to keep the appropriate quality of water for human and environmental standards.
- → <u>Extreme events prevention projects</u>: to prevent natural hazards' events like floods caused by the rise of the sea level or river flash floods.

For the Prioritisation Method and the case study that is later developed in this work (Chapter 8), only measures guaranteeing supply, sanitation and environmental recovery are contemplated. We will only consider structural adaptation measures. Extreme events prevention, even if it is an important subject to consider on when referring to adaptation to climate change in the water sector, is not the purpose of this document.

3.2 Identification of possible adaptation measures for the water sector

Here we present a list of adaptation measures and the corresponding description for two of the groups: water supply/demand projects and water quality/environmental projects.

It must be stressed that adaptation measures will depend on the specific needs of the region under study. Therefore, there may be measures that have been commonly used in the past in some areas, that were not implemented as proper adaptation measures to climate change, but which are useful experiences on which other regions suffering new climate change impacts can base their adaptation on. This happens especially between commonly “dryer” and commonly “wetter” regions. For example, while in dryer regions dam construction has been a frequent technique to guarantee water supply, dam construction can also serve as an adequate adaptation measure for wetter regions which begin to suffer the consequences of climate change induced water restrictions.

Water supply/demand projects

Both surface and groundwater resources constitute crucial ‘reservoirs’ of freshwater for several urban areas in the world. Climate change will increase the stress on these resources because of more irregular and, in general, lower rainfall, as well as creating diverse sources of pollution. Hence, these resources need to be protected and supported, and perhaps also augmented to cope with an increasing demand due to urbanisation (PREPARED, 2012). Water supply projects are developed to fulfil the demand that different water uses require and guarantee that enough water can be withdrawn sustainably from the sources on which the region relies. Adaptation projects related can be the following:

Water supply and efficiency measures
Enhancing or increasing water storage capacity
Water retention capability aims either to increase the natural water retention capacity of a landscape or to increase the water storage capacity using man-made structures. Diversifying water supplies prevents an overreliance on just one source and therefore reduce risks of water shortage. The establishment of long-term water supply planning generally includes a survey of all potential sources and relying on at least two water sources. This may include some redundancy in the supply system in order to enhance the system’s flexibility (PREPARED, 2012). Reservoirs can contribute to redistributing available water resources in volume, time and space. High volumes of water can be available for irrigation, industry and domestic purposes in water deficit regions. Water that is stored during high flows can be distributed in dry periods to supply water for additional irrigation, making a region less vulnerable to droughts and to provide extra availability of drinking water (ClimWatAdapt, 2011). Natural water retention can be improved through techniques like creating wetlands and increasing soil coverage. Additional water storage capacity can be achieved with structures such as off-stream polders. Winter water storage reservoirs reduce abstraction during the summer, increase flood storage capacity and benefit wildlife. • **Dam construction** • **Increase dam storage capacity** • **Diversion dams in little rivers for agriculture** • **Rain water harvesting with pools or ponds** • **Artificial wetlands** • **Winter water storage reservoirs** • **Off-stream polders**

Desalination

Desalination is the process of removing salt from water to make it useable for a range of purposes, including drinking. This provides a high quality and high volume of water for irrigation, industry and domestic supplies in water deficit regions. It is an energy intensive process, but advancing technologies could render desalination more energy efficient and reduce operating costs, becoming a very viable and weather/climate change independent alternative (ClimWatAdapt, 2011).

Inter-basin water transfer

Shift of potentially large water volumes from a water abundant basin to areas outside of the donor basin where water resources are low or very variable through year, limiting the region's development (ClimWatAdapt, 2011). Special care has to be taken when planning a project of this kind, making sure that river's ecological flow of the donor basin is kept and other supply services dependant of this basin are not affected.
Water transportation is a traditional and ancient technique, which is not primarily related to climate change adaptation; however it may facilitate the adaptation to new, irregular water regimes (PREPARED, 2012).

Groundwater supply

Groundwater stored in aquifers is usually extracted either through pumping or from natural pressure, for a variety of purposes. Avoiding over drafting and having previously marked out the limits of the aquifers, construction of wells and other extraction methods can be an alternative supply to surface water, especially when this one is polluted.
Raw, untreated water abstracted from groundwater of lower quality can be used for street cleaning, irrigation of gardens and parks or other non-potable uses. This measure can provide a secondary source and lower the pressure on freshwater aquifers, but also diminish the environmental impact of water treatment, thus being a useful option in the context of climate change adaptation (PREPARED, 2012).

- **Groundwater supply for drinking purposes (purification required)**
- **Groundwater supply for urban purposes (garden and city parks irrigation, street cleaning, etc. Less treatment required)**

Reclaimed water reuse

Reclaimed water (or recycled water) is former wastewater (sewage) that, additionally to the common treatment given in a wastewater treatment plant (primary treatment + aerobic/anaerobic treatment), goes through a tertiary treatment in which solids and certain impurities are removed, obtaining a high quality water used in sustainable landscaping irrigation or for recharging groundwater aquifers.
Reclaimed water has been proven to be a reliable alternative resource and wastewater reuse prevents degradation of receiving water bodies and the environment. Water reuse projects have been successful not only in arid and semi-arid regions but also in regions with temperate climates, to protect sensitive areas, recreational activities and water intensive economic sectors, and to cope with water crises caused by repeated droughts (Salgot, M., Lazarova, V., *et al.*, 2001).
Per se, this method of water reuse is the most sustainable as the urban water cycle of tap water is managed as a (nearly) 'closed loop'. This allows for a complete securing of the supply source despite all possible effects of climate change (PREPARED, 2012).
It also sometimes contains higher levels of nutrients such as nitrogen, phosphorus and oxygen which may somewhat help fertilise garden and agricultural plants when used for irrigation, thus helping to minimise artificial fertilisers.

- **Reclaimed water supply for agricultural and golf course irrigation**
- **Reclaimed water supply for urban purposes (garden and city park irrigation, street cleaning, etc.)**
- **Reclaimed water supply for environmental purposes (wetland recovery, aquifer recharge, etc.)**

Aquifer Recharge

Technique used in arid and semi-arid regions to enhance natural ground water supplies using man-made systems such as infiltration basins or injection wells. Excess water can then be used later for water supply or environmental protection. It is also a way of mitigating the threat of saltwater

intrusion by systematically maintaining higher water table levels for groundwater, thus reducing the hydrological gradient from seawater (ClimWatAdapt, 2011).
Aquifer Recharge is particularly relevant to address climate change in areas with low natural recharge or surface water quality problems. It enhances the flexibility of water utilities with regards to the increased risk of droughts due to climate change (PREPARED, 2012).

- **Infiltration basins**
- **Injection wells**
- **Saltwater intrusion barrier injection wells**

Recycling of greywater in public buildings and facilities

Greywater is wastewater generated from domestic activities such as laundry, dishwashing and bathing, which can be recycled on-site. Recycled greywater of this kind is never safe to drink, but following several phases of filtration and microbial digestion, it can be used to provide water for washing, flushing toilets or garden irrigation. If collected using a separate plumbing system from blackwater, domestic greywater can be recycled directly within the home, garden or company and used either immediately or processed and stored (Greensystems, 2012).
It can be applied in households, but also in public buildings, public facilities (such as sport centres, schools, and libraries), etc. It is estimated that at a household level, up to 45 L/pers·day of drinking and waste water could be saved. In sport centres, the amount could reach 60 L/pers·day. The measure would affect buildings belonging to public administration, public institutions and public facilities (Diputació de Barcelona, 2012).

Rain water deposits in public buildings and facilities

This refers to water stored from rain or direct run-off from rain. It can be applied at a single building level, where it is stored and used for gardening, swimming pools, etc; or it can be applied for multiple buildings or at a district level. A storage deposit is needed to capture this water, for which its dimensions will depend on the amount of water and the foreseen use, the space available, the region's climate, etc. The measure would affect buildings belonging to public administration, public institutions and public facilities (such as sport centres, schools, and libraries), and would take profit from the changeable rainfall due to climate change (Diputació de Barcelona, 2012).

Water distribution improvement

Controlling water leakage from extensive and aging municipal water distribution systems. This is one of the main causes of water loss, but can also be a risk to public health caused by contaminants entering the pipe system through leak openings. Age, but also a high system pressure, corrosion, winter temperatures, poor quality of joints or ground conditions, can be among the causes of leakage in the water distribution system.
If the quantity of water entering the distribution system is unknown, it is impossible to value the efficiency of water saving measures; thus, applying electronic water meters for every water distribution client can contribute to get a more accurate reading of the real amount of water being used and provide of statistical calculations of the system's water balance (Diputació de Barcelona, 2012).
Finally, dual water systems feature two separate distribution systems that supply potable water through one distribution network and non-potable water through another. The two systems work independently of each other within the same service area. Less water treated to drinking standards needs to be provided because activities such as toilet flushing, firefighting, street cleaning or irrigation are supplied with the non-potable distribution system. Therefore, it helps to lessen the amount of drinking water in the drinking water system, reducing the need to develop drinking water treatment facilities (Diputació de Barcelona, 2012).

- **Water leakage control**
- **Water meters installation**
- **Dual water systems**

Improving irrigation and gardening efficiency in public parks

A shift from gravity irrigation to modern pressurised systems (e.g. drip and sprinkler irrigation) and improved conveyance efficiency provide an opportunity for reduced water demand in irrigation of public green spaces (ClimWatAdapt, 2011).
Likewise, a garden design driven towards what is known as *xeriscaping* or *xerogardening* would also help save a significant amount of water, especially in dry regions; though it can be applied in every type of climatology. This refers to a kind of gardening design that optimises all its resources- though most predominately water- which focuses generally on native plants and trees that have adapted to the region's soil and climate, and have developed plague defences.

- **Improving irrigation efficiency in public parks**
- **Xerogardening in public parks**

Water shipment

If no local water sources are available, or if they do not cover the local demand for water, water can be transported from a remote location via ships. Even if it is not a common measure, it has already been used in heavy drought periods, which may become very common with climate change effects (PREPARED, 2012).

Table 4-2. "Water supply/demand" adaptation measures. *Source: own, based on ClimWadAdapt, 2011; PREPARED, 2012; Diputació de Barcelona, 2012, Greensystems, 2012.*

Water quality and environmental projects

Treating urban water pollution is one of the roles of urban water systems; indirectly securing the water supply and directly minimising the impact of the urban areas on the environment. However, due to climate change, more sudden and intense rainfall events as well as increased mean temperatures may have an impact on the quality of surface and groundwater. What is more, in the absence of proper sanitation, flooding can lead to pollution of water with contaminants from human waste and debris (World Bank, 2011).

Water quality and environmental projects are meant to guarantee sanitary standards for drinking (or potable) water directed for human consumption and avoid its deterioration because of climate change impacts. Furthermore, they are developed to meet the environmental freshwater quality requirements for the maintenance of the water bodies on which used water is discharged, or to focus on the environmental conservation or recovery of water biodiversity and aquatic ecosystems.

This is necessary because human activities significantly alter water levels of lakes, wetlands and river discharge, which may cause significant environmental damage due to floods, water shortages, changes of habitats and the accumulation of nutrients and contaminants. This management approach should be adapted on the basis of the best information available on climate variabilities and change and their impact on freshwater ecosystems, in order to deal adequately and improve the status of these ecosystems.

Water quality and environmental measures

Conventional wastewater treatment plants improvements

These plants are the combination of various infrastructures employed for removing contaminants from wastewater and household sewage. It includes physical, chemical and biological processes to remove physical, chemical and biological contaminants. The objective is to produce a treated and environmentally safe effluent. Quality of the sewage water and the population (population equivalent) being served will determine the design of the plant. Adaptation measures can imply the whole construction of a wastewater treatment plant in places which lack of facilities, or simply improve part of the treatment processes to make the quality of the effluent water higher.
Not to forget in this section the treatment of waste originating from the removal of contaminants, known as sludge. Once treated it is then suitable for disposal or reuse (usually as farm fertiliser due to its important content of N, K and P).

Natural treatment plants

These treatments refer to procedures in which contaminants from urban waste water can be removed by natural systems, without any kind of chemical additive being used in the process. Usually there are two different large groups of natural treatment techniques: methods of treatment by application on the ground water, and aquatic systems. In all cases, the decontamination effect is due to the combined action of vegetation, soil and microorganisms present in both, and to a lesser extent, the action of bigger plants and animals. Even if extended pieces of land are needed, benefits can be seen in less personnel requirements, less energy consumption and less sludge production, avoiding GHG emissions and increased climate change effects (EPA, 1999).
Aquatic systems are the most extended. Two main types can be found, depending on the size of the project: *lagooning* (also known as stabilisation ponds) and *constructed wetlands*. The operation system can be run stationary, annually or depending on climate and the objectives of the treatment (EPA, 1999).

Water purification plant improvements

These plants are the combination of various infrastructures employed to treat water, with the objective to make it suitable for human consumption. Different procedures and combinations of processes can be followed, including: pre-chlorination, aeration, coagulation and coagulant aids, sedimentation, filtration, desalination and disinfection.
There is no unique solution (selection of processes) for any type of water. Also, it is difficult to standardise the solution in terms of processes used, for water from different sources. Quality of the source and the population (population equivalent) being served will determine the design of the plant.
Adaptation measures can imply the whole construction of a water purification plant in places with lack of facilities, or simply improve part of the processes to get a highly efficient treatment for the water. A higher concentration of contaminants in water caused by climate change will demand more complex purification treatments to produce drinking water.

Sewerage improvement scheme

Improvements in the sewerage system must be carried out when the existence of factors, such as aging infrastructures, rise of population or storm frequency increase (and therefore volume of water captured by sewers), are identified. Actions taken can prevent wastewater filtration and underground contamination, sanitary problems, odour discomfort, and collapse of the distribution scheme due to excessive amount of water, etc.

River restoration

This measure especially applies to rivers in which anthropic pressure has modified the river system, changing its habitats, natural course, water flow, altering its river banks, etc. The measure focuses on the increase of flow capacity of the river system during flood events, and/or the reduction of the speed of water flow. This also helps to increase habitat quality and groundwater recharge (ClimWatAdapt, 2011).
Reforestation (reestablishment of forest cover) or afforestation (establishment of forest in an area where there was no forest), in particular near water courses, brings benefits for the regulation of water flow and the maintenance of water quality, reducing the intensity of floods and the severity of droughts.

Wetland and other water bodies restoration

Wetland restoration rehabilitates degraded wetland or re-establishes wetland that has been destroyed. Restoration takes place on land that has been, or still is, a wetland, with the aim to recover its previous health. Undegraded wetlands provide water quality improvement, flood attenuation, home for many migratory birds and other animal and plant species (maybe endangered), aesthetics, recreational opportunities, etc (ClimWatAdapt, 2011). Like wetlands, other water bodies such as lakes, lagoons or even man-made reservoirs, can see their environmental services enhanced and protected with restoration.
Establishing wooded riparian areas
Vegetated and unfertilised buffer zones alongside watercourses act as a shield against overland flow from agricultural fields and reduce run-off from reaching the watercourse, thus decreasing erosion and the movement of pollutants into watercourses. They also serve to prevent sea level rise and increased flooding induced by climate change, reduce potential for erosion in shore zones and lessen the impact on vegetation to worsen impacts of inundation (ClimWatAdapt, 2011).
Water Sensitive Forest Management
Forest management measures can increase water yield, regulate water flow, and reduce drought stress for a forest e.g. during current and future low-flow conditions. Measures in place in existing forests include reducing stand density (area occupied by trees), apply shorter length cutting cycles, planting hardwood species, regeneration from seedlings rather than sprouts, etc (ClimWatAdapt, 2011).
Sustainable Drainage Systems (SUDS)
Drainage systems can be improved by shifting to Sustainable Drainage Systems (SUDS), whose installation mimics natural drainage patterns to ease surface water run-off, encourage the recharging of groundwater, provide significant amenity and wildlife enhancements, and protect water quality (ClimWatAdapt, 2011). It is a solution with low environmental impact and drains away dirty and surface water run-off through collection, storage and cleaning, before allowing it to be released slowly back into the environment, such as into water courses. They require little or no energy input, and are resilient to use as well as being environmentally and aesthetically attractive.

Table 4-3. "Water quality" adaptation measures. *Source: own, based on ClimWadAdapt, 2011; PREPARED, 2012; EPA, 1999;* Salgot, M., Lazarova, V., *et al.*, 2001.

4. Climate Change Economics

In order to explain how adaptation measures to climate change can be evaluated under economic criteria, it is important to justify how climate change has been strongly studied from, and linked to, an economic view point.

Climate change affects people, species and plants in a variety of complex ways. It is now very evident that anthropogenic emissions of carbon dioxide and other greenhouse gases (GHGs) have accumulated in the atmosphere mainly over the past 100 years, accelerating these climatic patterns and making it a subject requiring imperative attention in the world-wide agenda (Stern, N., 2006). These emissions have represented, and still represent today, negative localised externalities. Global warming can manifest through different effects, affecting the ecosystem on either scale, such as follows:

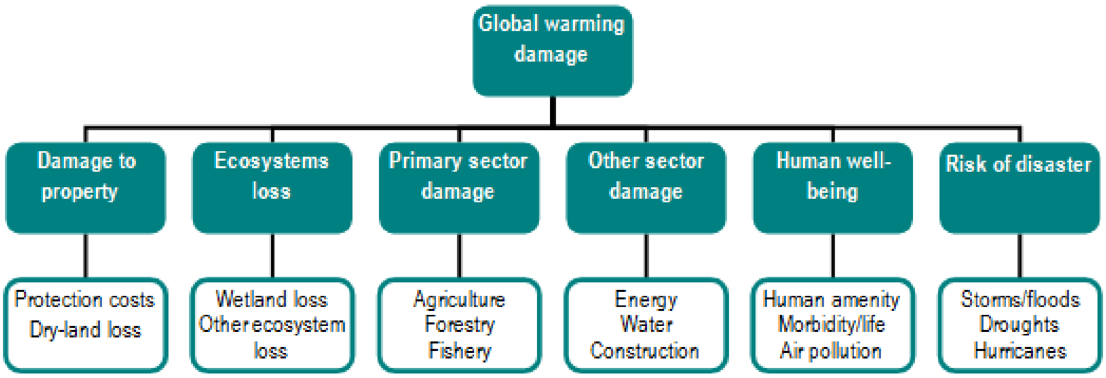

Table 4-1. Ecosystem scheme affected by global warming. *Source: Fankhauser, S. et al, 2008.*

Consequently, we most probably could have potentially catastrophic impacts in the future in different fields where economic activity is developed. Mitigating greenhouse gas emissions and enhancing our capacity to adapt to climate change are two of the objectives which environmental policies should be based on. Following this view, climate change economics work to lead the path to a low-carbon economy. Economic analysis should be understood as a fundamental tool to identify causes and consequences associated with climate change in order to implement development options for the future (Caballero, K., Galindo, L., 2010).

Instruments exist to carry out this economic analysis: Cost-Benefit Analysis (CBA) (on which the Prioritisation Method will be based on), Multi-criteria analysis and Cost-Effectiveness analysis are some examples.

4.1 Considerations for climate change economics

An economic analysis like the ones just mentioned, appraises the project's contribution to the economic welfare of the region or country. In fact, the possibility of achieving credible forecasts of benefits and costs often relies on the accuracy of the assessment of the macro-economic and social conditions of the region (European Commission, 2008). But also, in order to be developed correctly, must include a number of considerations on which climate change economics are based on:

- → Uncertainty
- → Emission scenarios
- → Discounting

4.1.1 Uncertainty

Forecasts of climate change are inevitably uncertain. Certainty is a near impossibility, no matter what kinds of improvements are made in understanding physical processes or the timescale of observations. Earth's climate is extremely sensitive and variable (Roe, G., 2007).

Societies, organisations and individuals have been adapting to changing conditions for centuries but human-driven climate change brings new challenges. Some of the challenges are brought about by issues related to the rate (and magnitude) of change of climate, the potential for non-linear changes and the long-time horizons. All these issues are plagued with substantial uncertainties, which make anticipatory adaptation difficult. The fact that we have partial knowledge of future climate is in itself a new challenge (van der Sluijs, J. et al., 2007).

In climate projections used for the development of long-term adaptation strategies, uncertainties from the various levels of the assessment accumulate. For example, there are uncertainties associated with future emissions of greenhouse gases and sulphate aerosols; uncertainties about the response of the climate system to these changes at global and local scales; uncertainties associated with the impact models and the spatial and temporal distributions of impacts, etc. Climate change impacts such as changes in temperature, precipitation, runoff or heating degree days are therefore characterised by major uncertainties regarding their magnitude, timing and spatial distribution, sometimes having opposite signs (e.g., some projections show more precipitation whereas others show less). These uncertainties pose major challenges for planners taking decisions on adaptation measures (van der Sluijs, J. et al., 2007).

4.1.2 Emission Scenarios

The Intergovernmental Panel on Climate Change (IPCC), in its Third Assessment Report, developed Emissions Scenarios, which are a reference point for policymakers and the scientific community. These new scenarios provide input for evaluating climatic and environmental consequences of future greenhouse gas emissions and for assessing alternative mitigation and adaptation strategies (IPCC, 2000). In the case of climate economics, they help to appraise the total costs of these mitigation and adaptation strategies. This way, it is possible to estimate quantitatively the nature of the problem (Caballero, K., Galindo, L., 2010).

The emissions scenarios have been built for a time horizon starting in 1990 and limited to the year 2100. At that time, the world will have changed in ways that are difficult to imagine – as difficult as it would have been at the end of the 19^{th} century to imagine the changes of the 100 years since (IPCC, 2000).

The IPCC's scenarios resulted from the combination of two main criteria: a vertical axis between economic development and environmental concern ("A" and "B"), and a horizontal axis from global to regional ("1" and "2"). So A1 is a growth oriented globalised scenario in a more integrated world, B1 the environmentally friendly integrated world, A2 the regionalised or fragmented growth driven in a more divided world, and B2 the environmentally friendly regionalised equivalent (which has been given additional nicknames such as "regional equity" and "local solutions").

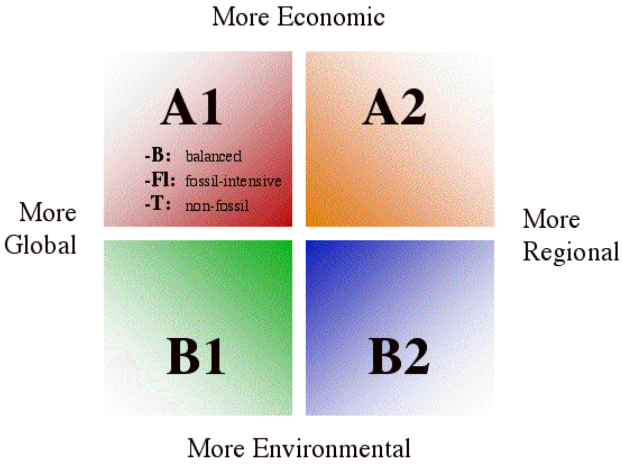

Table 4-2. IPCC Emission Scenarios distribution. *Source: IPCC, 2000.*

Going more into detail, the description of the scenarios assume for each storyline a different direction for the future to come depending on possible (and uncertain) "future" characteristics, such as demographic change, economic development, capacity building and technological change (referred to as *driving forces*). As a result, futures scenarios differ from each other. For the A1 storyline, three different scenario groups will diverge from it, considering alternative directions of technological change in the energy system: fossil fuel intensive (A1F1), non-fossil energy scenario (A1T), or a balance across all sources (A1B). For the other three storylines, the scenarios will remain the same (A2, B1, B2).

Within each scenario family, some scenarios are developed following harmonised assumptions about global population, economic growth and final energy use (the so-called Harmonized Scenarios, HS), and others have an alternative quantification of the storyline and do not share common assumptions about some of the driving forces (mentioned as OS). A total of 26 HS and 14 OS are distinguished. Therefore, a total of 40 different scenarios are given.

In this document only the main features for each storyline are reviewed, compiled as follows:

Storylines	Driving forces	Scenario groups
A1	- Rapid economic growth - Very high energy consumption - Population growth till 2050 and declining thereafter - Rapid introduction of new and more efficient technologies - Convergence among regions, capacity building and increase in cultural and social interactions - CO_2 concentration in 2100: 720 ppm	**A1F1** (Fossil intensive) **A1T** (Non-fossil energy sources) **A1B** (Balance across sources)
A2	- Economic development regionally oriented - Very high energy consumption - Continuously increasing global population - Fragmented and slower per capita economic growth and technological change than in other storylines - Heterogeneous world, preservation of local identities - Fertility patterns across regions converge very slowly - CO_2 concentration in 2100: 850 ppm	**A2**

B1	- Rapid changes in economic structures (service and information economy) - Population growth till 2050 and declining thereafter - Reductions in material intensity, introduction of clean and resource-efficient technologies - Global solutions to economic, social and environmental sustainability - CO_2 concentration in 2100: 550 ppm	**B1**
B2	- Continuously increasing global population (lower rate than A2) - Less economic development and more diverse technological change than A1 and B1 - Environmental protection and social equity, focused on local and regional levels - Local solutions to economic, social and environmental sustainability - CO_2 concentration in 2100: 620 ppm	**B2**

Table 4-3. Driving forces for each storyline and scenario group. *Source: adapted from IPCC, 2000.*

All these combined driving forces lead to different global carbon dioxide emissions outcomes (covering carbon dioxide, but as well other GHGs and other sulphur emissions), measured in gigatonnes of carbon (GtC/yr) for each scenario.

It has to be pointed out that regional climate change models tend to take scenarios A2 and B2 as a reference, precisely due to their more regionalised character. Not all climate modelling groups participating in the IPCC Assessment Reports run all 40 scenarios. Scenarios A2 and B2 are used the most and have received the most scientific peer review (CARA, 2013). As it will be seen later, this is the case for the Spanish regional model used in the case study.

4.1.3 Discounting

Discounting is the rate at which future values are discounted to the present, mainly used by economists to compare economic effects occurring at different stages of time. Discounting recognises that both individuals and societies prefer to get benefits sooner and to postpone any costs until later. Discounting gives lesser weight to benefits and costs that occur in future years. Thus, for each year that either costs or benefits are delayed, their value is homogenised by the annual discount rate (Goklany, IM., 2009).

The discount concept in climate change is important due to the extremely long time horizons, which policymakers have to work with, as the mitigation and adaptation costs tend to come much earlier than the benefits of avoided damages. The higher the discount rate, the less future benefits and the more current costs matter in the analysis (IPCC, 1995).

The term *social discount rate* also exists to value the costs of present measures against possible damages suffered by future generations if no action is taken. In this case, as it is the nonmarket impacts of climate changes that are being valued, a conversion to monetary units is more laborious.

4.2 Discount rate selection

One of the purposes of this document is to choose a range of discount rates adequate to link climate change future effects with water projects and apply them to the adaptation measures considered in the case study. It should reflect the particularities of A1, A2, B1 and B2 scenarios and, likewise, figures extracted from economic literature dealing with climate change or water management in which discounting aspects are contemplated.

Having analysed various literatures, we provide a brief collection of quotes on discounting by some authors:

→ Water distribution systems produce greenhouse gases during the manufacture, transport and installation of pipes and also particularly as a result of pumping when electricity is derived from the burning of fossil fuels. Typically in a life cycle analysis for the planning of new water distribution system infrastructure, that involves pumping, a present value analysis is carried out to convert annual operating costs for pumping into their present values. The way in which time preferences are incorporated into the calculations strongly affects the outcomes in terms of both costs and associated greenhouse gases. Many water utilities around the world use a discount rate equal to the interest rate or the current cost of capital of between 6 and 8%. (Simpson, A.R., 2008).

→ In moderate climate change scenarios, climate change often generates a mix of both positive and negative impacts in the short to medium term, moving to predominantly negative impacts in the longer term. A higher discount rate therefore leads to lower economic costs (as larger future negative effects are reduced through discounting). For example, EC Impact Assessment guidance recommends a 4 % discount rate (EEA, 2007).

→ The basic magnitude for a social discount rate for the evaluation of public investment in Spain is placed around 5% (Souto, G., 2001).

→ Time periods of 50 years and discount rates around 6% are common among most water recycling project proposals (De Souza, S. et al, 2011).

→ The discount factor used for our scenario will be 4%, similar to those used in other projects of great water transfers (San Martín, E., 2011).

→ One of the criteria for the analysis of water services (water caption, water extraction, reservoirs and water transport) is to adopt a 4% discount rate during the depreciation project (MMA, 2007).

→ The prescriptive approach to discounting leads to long-term discount rates of 2-3% in real terms, while the descriptive approach leads to rates of at least 4% after tax - sometimes much higher (Halsnæs *et al.*, 2007)

Besides considering these listed quotes, in this document it is intended to show special preference to those social discount rates that take into account the impact that climate change may have on future generations. Normally, analysis has the common assumption that if future generations will be richer, the discount rate is increased to reflect the expected differences in wealth. However, with climate change effects arising in the coming years (along with other factors) this may not be the rule. Thus, how much *should* we, as a society, care about the impact of our actions on future generations? Yet the answer to this question has a profound effect on model results. The higher the discount rate, the less important future climate damages are assumed to be for today's decision makers. At the extremes, a very high discount rate causes a model to ignore any climate damages that occur more than a few decades into the future, whereas at a very low discount rate, climate damages are almost equally important regardless of when they occur (Stanton, E., *et al.,* 2012).

Therefore, low discount rates are aimed to be selected during the analysis of adaptation measures. As there is some ambiguity between different cited authors, a range between 3 and 6% will be considered for a discount rate in the case study being analysed in this document. Depending on which climate change scenario the appraisal is carried out under, the range will be as follows:

Emission Scenario	Discount rate selected
A2 (regionalised or fragmented growth / very high energy consumption)	**3%**
A1 (growth oriented globalised scenario in a more integrated world / very high energy consumption)	**4%**
B2 (environmentally friendly regionalised world)	**5%**
B1 (environmentally friendly integrated world)	**6%**

Table 4-4. Discount rate selection for the different emission scenarios considered. *Source: own.*

The higher the impacts expected for a given scenario (A2 > A1 > B2 > B1), the lower the discount rate. In environmentally friendly scenarios, high discount rates can be chosen because future generations are expected to be in a better position than in energy intensive scenarios. Accordingly, adaptation measures should be less “necessary” due to the lower climate change impacts expected, as mentioned environmentally friendly scenarios would have already worked towards their mitigation, making adaptation less indispensable.

5. Cost-Benefit Analysis (CBA) as an Economic Method for Appraisal of Adaptation Measures to Climate Change.

The most commonly used economic methods to select the best alternative project among all the existing ones are:

- Cost-Benefit Analysis (CBA)
- Multi-Criteria Analysis (MCA)
- Cost-Effectiveness

In the present document the economic method chosen is CBA. Following, we describe it, defining its key concepts and methodologies and relating them to adaptation measures to climate change.

Cost-Benefit Analysis concepts

Cost-Benefit Analysis (CBA) is an analytical method associated with projects where their economic, social and environmental aspects have an important relevance. This method focuses on the quantitative evaluation of the impacts, and allows the estimation of the net benefits of adaptation options when several alternative management options are presented. CBA includes the direct costs and benefits and the indirect and external effects of the alternatives in order to assess the total welfare effects of an adaptation option (Pearce et al., 2006).

The essential features of CBA can be listed as follows (OECD, 1993):

→ A *benefit* is defined as any gain in human wellbeing, and a cost is defined as any loss in wellbeing.

- → If benefits exceed costs, the project is potentially worthwhile; potentially, because there may be many similar projects and policies and there is always a budget limit. Hence those projects and policies passing the initial cost benefit test must be ranked in order of preference. This will usually be done by ratios such as the Net Present Value.
- → Benefits and costs stretch over time. Future benefits and costs are therefore discounted at some discount rate. The resulting sums are present values.
- → In situations when the effect of production or consumption of goods and services imposes costs or benefits on others, which are not reflected in the prices charged for the goods and services being provided, it is referred as externalities[1].
- → An establish time horizon in which CBA can provide a proper forecast.

5.1 Methodology of CBA

In any CBA several stages must be completed. The essential steps are the following (Hanley N. et al., 1993):

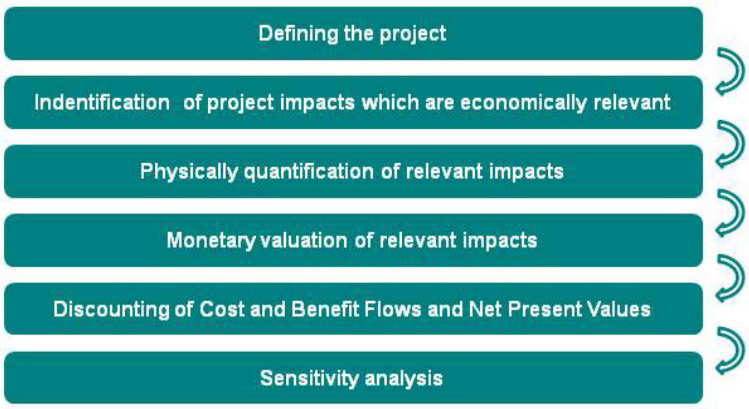

Table 5-1. Steps to follow in a Cost-Benefit Analysis (CBA) process. *Source: adapted from Hanley, N., 1993.*

Defining a project → This step contemplates the resources the project needs, and the population of winners and losers to be considered. A project must be defined because its appraisal cannot be completed without first determing what is to be appraised (Hanley N. et al., 1993).

Identification of project impacts that are economically relevant → Once the project is defined, the next step is to identify all the positive and negative impacts resulting from its implementation (Hanley N. et al., 1993).

Physical quantification of relevant impacts → This stage involves determining the physical amounts of costs and benefit flows for a project, and identifying when they will occur (Hanley N. et al., 1993).

[1] *Externalities:* costs ors benefit that are not transmitted through prices and are incurred by a party who was not involved as either a buyer or seller of the goods or services causing the cost or benefit. The cost of an externality is a negative externality, or external cost, while the benefit of an externality is a positive externality, or external benefit.

Monetary valuation of relevant impacts → In order to ensure that physical measures of impacts can be measurable, they must be valued in common units. The common unit in CBA is money. The remaining tasks for the CBA analyst is then to:

→ Predict prices for value flows extending into the future
→ Correct market prices where necessary
→ Calculate prices where none exist

Discounting of cost and benefit flows and Net Present Value → Once all relevant cost and benefit flows that can be expressed in monetary units have been identified, it is necessary to convert them all into present value terms (PV), which will be determined with the selected discount rate (Hanley N. et al, 1993).

Selecting the most efficient projects will be done through the Net Present Value (NPV) test. This simply suggests whether the sum of discounted gains exceed the sum of discounted losses. If so, it can be said that the project is efficient. If the NPV is higher than 0, the project is considered to be profitable, whereas being lower than 0 would indicate a non-profitable project. The result is determined using the following equation:

$$\boldsymbol{NPV} = \frac{\boldsymbol{B_t - C_t}}{\boldsymbol{(1+r)^t}}$$

	$\boldsymbol{NPV} > 0$	**Profitable project**
	$\boldsymbol{NPV} < 0$	**Non-profitable project**

Where

t = time horizon considered
B = benefit at time (i)
r = discount rate
C = cost at time (i)

After analysing the results of the CBA of different projects, all the stakeholders will decide which one to select taking into account the higher NPV. The prevailing project should have the highest value because it combines the best features to develop environmental, social, economic and cultural concepts (European Commission, 2008).

Sensitivity analysis → The NPV test described above give us advice about the efficiency of a given project, given the data input for the calculations. If data changes, the NPV test results will be modified too. In any CBA the analyst must make predictions concerning future physical flows and future relative values, some of these predictions are made with perfect foresight. This means recalculating NPV when the values of certain parameters are changed (Hanley N. et al, 1993).

5.2 Identification of costs and benefits of adaptation projects in the water sector

Many costs and many benefits have to be identified and regrouped in the economic analysis of a water project, particularly considering those which have a direct impact. These can be categorised on two groups:

- Private economic costs and benefits that can be found in any type of project in which infrastructure is needed (not limited to water projects).

- Non-market economic costs and benefits, specific of the project being analysed. These typically refer to social and environmental externalities; which are analysed further on in this document.

As follows, types of costs and benefits are identified within these two groups, providing some examples referring to water adaptation projects:

Private costs
- **Capital expenditure:** investment made to put a project with a useful life of more than one year into motion. They are capitalised and generally may be depreciated or amortised. *Examples: general engineering design (hydrology, geotechnical, etc.), environmental permits, construction costs (materials, machinery, etc.).* - **Operating expenditure:** company/administration/institutions' expenses related to the production of the project's goods and services. *Examples: labour costs, energy demand, construction timing, additional monitoring costs, quality surveillance.* - **Additional costs:** extra costs which emerge during the project's development. *Examples: reparations, leaks, overhead costs, replacement costs, unexpected poor water quality, sludge treatment and disposal, storm water peaks.*
Non-market costs (external costs)
- **Negative social externalities:** costs not transmitted through prices that impose a negative side-effect on a third party, in this case society. *Examples: Not-in-my-backyard effect, expropriation.* - **Negative environmental externalities:** costs not transmitted through prices that impose a negative side-effect on a third party, in this case environment. *Examples: landscape affection, river flow interception, carbon emissions, wetlands dry-up, seawater intrusion, overexploitation, reduction of river maintenance flow, odour discomfort, noise.*
Private benefits
- **Capital income***:* monetary benefits resulting from the activity developed. For water adaptation projects being developed with public funds generally no profit is being sought, due to the main goals being to increase water supply, increase water quality or reduce risk for extreme events.
Non-market benefits (external benefits)
- **Positive social externalities***:* positive side-effects on society. *Examples: water availability for different purposes, improved public health, employment, eradication of insalubrious conditions, enhance aesthetics of open spaces, better odour and taste of water, supply and distribution improvement.* - **Positive environmental externalities***:* positive side-effects on environment. *Examples: Pollution savings, reduce (over)exploitation of other water sources, low energy demand, increased water quality, sludge use in agriculture, prevention of water untreated discharges, mitigation of river/marine pollution, aquifer recovery, wetland/stream/lagoon/river and other fragile ecosystem's maintenance.* ** Depending on the case, Positive externalities can also be referred as "avoided costs": costs which would have been incurred if there not have been adaptation.*

Table 5-2. Types of costs and benefits to be identified for an adaptation measure in the water sector. *Source: own, based on Laffont, J., 2008.*

6. Building up the Prioritisation Method

The purpose of the Prioritisation Method is to provide stakeholders involved in water management an instrument to choose which measures are more suitable to be financed and implemented in a region under study. The prioritisation is carried out independently of the type of the adaptation measures considered.

The Prioritisation's Method's main particularity is in the application of the previously developed concept of the Cost-Benefit Analysis (CBA), which helps justifying an investment decision after having compared costs and benefits of different projects along their expected lifetime. The final Net Present Value (NPV) will determine if an adaptation measure is profitable or not, having applied a proper discount rate. Selecting an appropriate discount rate will depend on the different IPCC's emission scenarios. Climate change is an extra devaluation factor, and consequently the method's principle is to make use of these emission scenarios; depending under which one the adaptation project is being submitted in the CBA, discounting shall be modified, affecting consequently the project's NPV (and therefore its profitability).

Another particularity of this prioritisation is the will to introduce a number of external costs and benefits (negative and positive externalities) that derive from the measure's implementation and insert them in the CBA. For this, a set of criteria has been developed (Chapter 7) in order to calculate environmental and social externalities resulting from adaptation measures in the water sector.

These two concepts (discounting and criteria) are necessary to be included in the steps of the Prioritisation Method.

6.1 Prioritisation Method's process

To get an overall idea of the Prioritisation Method's process, the next steps have to be followed:

Step 1: The primary step is to become familiar with the region where adaptation measures plan to be implemented. Here, the main bio-physical and socio-economic parameters should be identified. The region under study can be small (adaptation measures considered for a village, city, etc.) or large (countries or other territorial sub-divisions, geographical areas with similar conditions, etc. For example, in the case study later described, the Spanish Mediterranean region is considered).

Step 2: Collection of information on climate change scenarios for the region under study. This information can be found in the region's climate change planning documents, scientific articles and other literature available. As well, having available figures from climate change's historical evolution for the region considered is an extra asset, especially when information from future scenarios is limited.

Step 3: From the climatic information compiled in step 2, conclusions on how climate change will affect water resources in the area of study are needed in order to know what the adaptation needs are. Impacts on water resources should consider, where possible, short and long-term future periods.

Step 4: With the adaptation needs in mind, identify what adaptation measures and opportunities can be suitable to implement in the region under study is necessary. This is to be done through literature review based on experiences in areas with similar conditions, interviews or workshops with stakeholders and interested actors (if possible), etc., in order to get a short-list of feasible measures that could be interesting for the region's adaptation.

Step 5: Identify the suitable criteria to be included in the economic analysis of the adaptation measures. These criteria should consider environmental and social parameters in order to calculate external costs and benefits resulting from the adaptation measure. In Chapter 7 a set of criteria for water supply and sanitation measures are proposed and, thus, can be selected from there. However, new ones can also be identified and developed by stakeholders.

Step 6: Calculate and introduce the externalities (based on step 5 criteria) in the Cost-Benefit Analysis methodology. Firstly, prioritise independently each of the measures chosen for the analysis, considering their profitability under different emission scenarios (hence, under different discount rates). Secondly, prioritise and compare the adaptation measures as a group under environmental, social and economic aspects. That is, depending under which aspect the group of adaptation measures are analysed, rank which ones offer a better performance.

The following aspects will be considered to demonstrate a ranking of adaptation measures:

- *Net Present Values:* prioritise considering the adaptation measure with the highest NPV.
- *Initial investment:* prioritise considering the adaptation measures needing a lowest initial investment.
- *Private costs:* prioritise considering the adaptation measures requiring lower annual private costs (annual expenditures).
- *Environmental external benefits:* prioritise considering the most environmentally effective adaptation measures. That is, those contributing with higher environmental externalities.
- *Environmental external costs:* prioritise considering the less environmentally harmful adaptation measures. That is, the ones with lower environmental negative externalities.
- *Social external costs:* prioritise considering the less socially costly adaptation measures. That is, the ones with lower social negative externalities.

Step 7: Analyse the results under every aspect being considered (environmental, social and economic) and conclude which adaptation(s) measure(s) is (are) best to be financed.

A schematic vision of the whole process can be seen in the next figure:

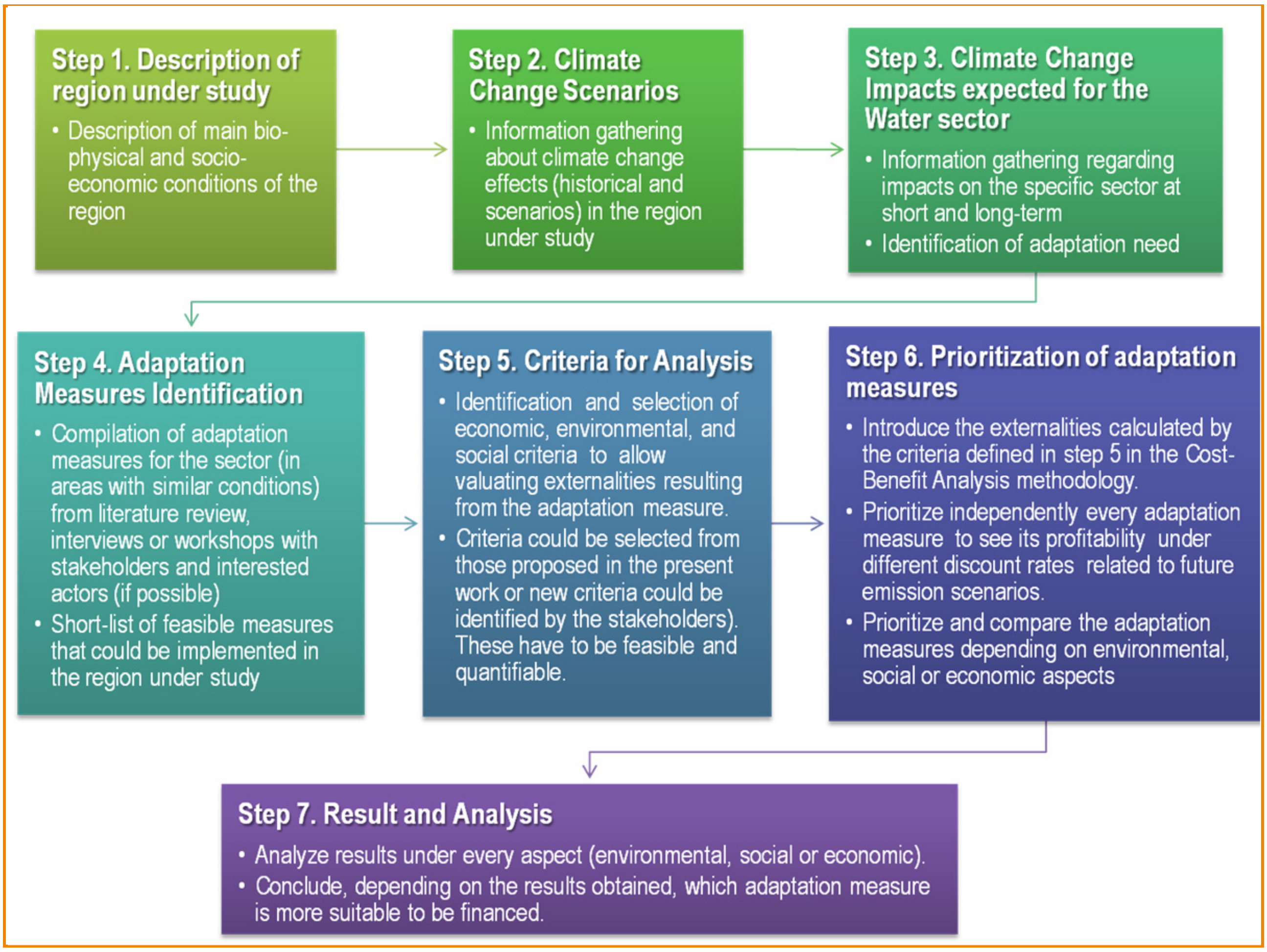

Table 6-1. Steps to follow in the Prioritisation Method. *Source: own.*

7. Criteria for Evaluating Social and Environmental Externalities Related to Adaptation Projects in the Water Sector

As previously explained, criteria to attribute a monetary value are needed for external costs and benefits that can result from the adaptation measure's implementation (step 5). These will later be included in the Cost-Benefit Analysis (CBA).

This chapter identifies and develop possible social and environmental criteria that can originate in adaptation measures in the water sector. Once this is done, it is essential to provide a calculation to monetise the criteria's value. An equation must be developed to translate the externalities into money values, based on literature and own reasoning. Afterwards, if this process is successful, the externality can be introduced in the CBA. In case of not being able to provide a monetary valuation for the criteria proposed, it has to be dismissed.

7.1 Criteria selection for water adaptation projects

We introduce a set of criteria to assess which are the most suitable water adaptation projects for a specific region. Each criterion reflects not only costs and benefits but also the environmental or social externalities resulting from an adaptation project.

The following table indicates the possible externalities (and its corresponding criterion) that were initially chosen:

Externality	Criterion established	
Water pollution saved due to a water quality project.	*"Pollution savings"*	✔
Use of sludge in agriculture resulting from wastewater treatment processes.	*"Sludge valuation"*	✔
Amount of water lost by leakage or evaporation in a reservoir or distribution scheme.	*"Water losses"*	✔
Water savings with water reuse policies (reclaimed water production used for urban, agricultural or environmental purposes).	*"Water reuse savings"*	✔
Greenhouse gas (GHG) emissions resulting from the project's energy consumption.	*"$CO_{2\text{-equivalent}}$ emissions"*	✔
GHG emissions saved from CO_2 neutral compensation projects.	*"CO_2 neutral compensation"*	✔
Project's affectation to the region's income per capita.	*"Income per capita affectation"*	✔
Potential population that could benefit from the project compared with the real population the project is intending to reach.	*"Urban agglomeration range"*	✘
Amount of money people would be willing to pay for good quality water in the river basin where they are living.	*"Willingness to pay for water quality"*	✘
Reduction of a river environmental flow due to water extraction, and therefore affectation of its ecological benefits.	*"Environmental flow valuation"*	✘

Table 7-1. Externalities and their corresponding criteria. *Source: own*

From this list, there are general criteria that can be applied to analyse the two groups of projects that have been previously described (*water supply/demand projects and water quality/environmental projects).* Criteria can be common to both types of projects or specific to either type. Retaking the list from Table 7-1, the overall scheme results as follows:

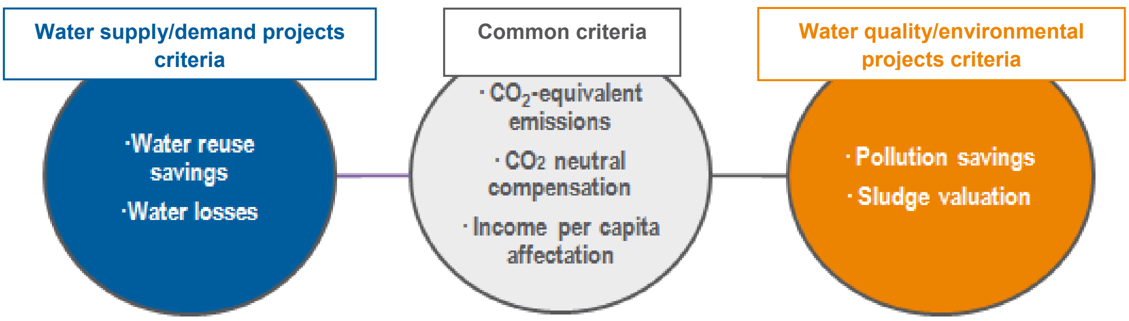

Table 7-2. Set of criteria developed to assess the different adaptation options in the water sector. *Source: own*

7.2 Criteria development

In this section, every fundamental criterion is explained, providing the reason for its selection, mentioning in what type of water adaptation projects it can be applied and revealing the related equation for its calculation. In chapter 8, they are applied for the case study presented.

Only those having been accepted due to their applicability are described in this chapter. Those dismissed for not having found a possible way to attribute monetary cost units to calculate them are not included.

7.2.1 Water gains

Application: *Water supply/demand projects.*

- *Potable water savings*

Projects or measures looking for water efficiency with improvements on the supply or treatment systems benefit from extra water that was not available before the amelioration was implemented. This volume of additional water is seen as a benefit (it is gained) due to the avoided cost of extra water supplementing the lost volume in the case of continuing with the original process.

- *Water reuse (reclaimed water)*

Water reuse has to be taken into account like a non-conventional resource that allows water availability for other purposes not related to drinking water. Many wastewater treatment plants have a tertiary process that produces *reclaimed water* with high enough quality standards to be used in agriculture, industry, aquifer recharge, golf courses and environmental purposes (wetland restoration, etc.). Therefore, these types of water re-use allow the replacement of an important volume of drinking water that, without this reclaimed water, would be addressed to the mentioned purposes.

Related equations:

For potable water savings, the benefit of the volume of water being saved can be calculated multiplying this water volume by the normal purification treatment price (€/m^3).

$$Water\ savings\ (€/year) = Volume\ of\ water\ saved\ \left(\frac{m^3}{year}\right)\ x\ Price\ of\ drinking\ water\ (\frac{€}{m^3})$$

For water reuse savings, the benefit can be evaluated by deducting the water recycling process price (€/m^3) from the normal purification treatment price (€/m^3), and comparing it with the total amount of reclaimed water used for a certain purpose:

$$Water\ reuse\ savings\ (€/year) =$$

$$\left[Price\ drinking\ water\ \left(\frac{€}{m^3}\right) - Price\ reclaimed\ water\ \left(\frac{€}{m^3}\right)\right] x\ Volume\ recaimed\ water\ (\frac{m^3}{year})$$

When referring to the price of drinking and reclaimed water production, it is referred to the prices of the region where the project is intended to be implemented.

7.2.2 Water losses

<u>Application</u>: *Water supply/demand projects.*

Every water supply infrastructure suffers from water losses to a certain extent. Leaks, such as in water reservoirs or distribution systems, are one of the main sources of water losses in the system. This water does not come back to the supply system and is therefore lost, incurring maintenance costs for the project to repair the leakage.

On a lower proportion, the amount of water evaporated from surface water bodies can also result in a significant consumption of water and, consequently, another type of loss that should be noted. In particular, the World Commission on Dams (WCD) estimated that evaporation from reservoirs is in the order of 188 km^3 per year, which equates to more than 8% of the totals human consumption of freshwater. In dry climates (such as the Mediterranean), evaporation from large reservoirs is currently estimated at close to 5% of total water withdrawals (WCD, 2000). Nevertheless, losses might enhance as temperatures warm due to climate change and so, water resources availability may decline (López Moreno, J., 2008).

Consequently, the criterion will contemplate losses by leakage and evaporation in the supply system.

Related equation:

Costs induced by water losses can be evaluated with consideration of the price for drinking water in the region where the adaptation projects is settled.

$$Water\ losses\ (€/year) = Volume\ of\ water\ lost\ \left(\frac{m^3}{year}\right) x\ Price\ of\ drinking\ water\ (\frac{€}{m^3})$$

7.2.3 Pollution savings

<u>Application</u>: *Water quality/environmental projects.*

This criterion addresses adaptation measures looking for an adequate treatment to remove harmful pollutants from water intended for discharge into a water body. Main aim is to avoid the water body's contamination. Water pollution, with or without climate change, is a relevant ecological and human health threat. Climate change, especially in dry regions, will reduce water availability, making this pollution cause more severe effects (less dilution in water, less treatment capacity, etc.)

The criterion's aim is to calculate pollution avoided in monetary terms, and to do so, valuation is carried out considering pollutants shadow prices, which exposes the environmental damage avoided or, accordingly, the environmental benefit. Using the concept *distance function,* a shadow price can be estimated for the environmental goods originating from human and productive activities (solid waste, emissions, wastewater, etc) for which the market does not offer any value even if they have important environmental impacts. From this estimation a value for the environmental benefit in terms of environmental damage avoided will be obtained, due to avoidance of the pollutants being spilled into the environment (Hernández, F. et al, 2009).

For the following non-desired outputs, these subsequence shadow prices have been established (Hernández, F. et al, 2009), both in €/kg and €/m^3 units.

Pollutant	Environmental value (€/Kg)	Environmental value (€/m^3)
Suspended matter (SM)	0,005	0,002
Chemical Oxygen Demand (COD)	0,215	0,066
Nitrogen (N)	20,575	0,481
Phosphorus (P)	45,785	0,245

Table 7-3. Environmental value estimated from shadow prices for the main pollutants in wastewater. *Source: Hernández, F., et al, 2009.*

Authors advice is to use the environmental value in €/Kg units. Therefore, in knowing the influent's pollutant concentration, a conversion to €/m^3 can be carried out. In case of a lack of information related to the influent's quality, the environmental value in €/m^3 should be used directly.

Related equation:

Pollution savings valuation is calculated with the total amount of treated water produced by the project being assessed along with the environmental value of either Nitrogen (N) or Phosphorous (P). If conventional treatment or tertiary water treatment (reclaimed water production) are the measure to follow, different equations must be used.
When the treated effluent derived from the project has the quality which is stipulated in the region's current legislation, pollution saving will depend on the proportion of N and P reduction in comparison with the influent entering the plant.

- If the effluent's N or P concentration is known:

$$Pollution\ saving_{treated\ water}\ (€/year) =$$
$$Environmental\ value\ N,P\ \left(\frac{€}{Kg}\right)\ x\ Influent\ N,P\ concentration\ \left(\frac{Kg}{m^3}\right)\ x$$
$$Volume\ of\ treated\ water\ \left(\frac{m^3}{year}\right)\ x\ \%\ N,P\ reduction$$

- If the effluent's N or P concentration is unknown:

$$Pollution\ saving_{\ treated\ water}\ (€/year) =$$
$$Environmental\ value\ N,P\ \left(\frac{€}{m^3}\right)\ x\ \ Volume\ of\ treated\ water\ \left(\frac{m^3}{year}\right) x\ \%\ N,P\ reduction$$

- On the other hand, if the effluent is reclaimed water, it will not be discharged into the river stream or sea because it will be used for other purposes (agriculture, environmental use, etc.). Thus, it is considered that N and P are totally reduced and, therefore, no reduction appears in the equation:

$$Pollution\ saving_{\ reclaimed}\ (€/year) =$$
$$Environmental\ value\ N,P\ \left(\frac{€}{m^3}\right)\ x\ \ Volume\ of\ treated\ water\ \left(\frac{m^3}{year}\right)$$

7.2.4 CO_2-equivalent emissions

<u>Application</u>: Water supply/demand projects, water quality/environmental projects.

"Carbon footprint" has been defined as the total set of greenhouse gas (GHG) emissions caused by an activity, organisation, event, product or person (UK Carbon Trust, 2008). An adaptation measure is an activity for which carbon footprint calculations must be taken into account, with many steps of the process being potential sources of GHG emissions (land clearance, energy consume, buildings, etc.). For this reason, this criterion will be based on the GHG emissions strictly produced by the energy consumed during the activity's operation.

Calculation for this criterion is to be carried out with the help of knowing the price of a ton of CO_2 in the actual Emissions Trading System. Knowing the project's energy demand and its equivalence in tones of CO_2-equivalent emitted into the atmosphere, a monetary valuation of the greenhouse emissions can be developed.

The price of a ton of CO_2 is constantly changing in the Carbon Market. Taking as a reference the European Union Emissions Trading Scheme (EU ETS), by far the world's biggest carbon market and the core of the international carbon market, the price throughout 2012 was 5,88 €/tCO_2 (Electronic System of CO_2 Emission Rights Negotiation, 2012).

Related equation:

To calculate the project's emissions, an energy emission conversion factor is needed to convert the equivalence of the energy demand into equivalent tons of CO_2 emitted. If the energy source is electricity, which is the common energy supply for water infrastructures, the conversion factor is 0,267 kg CO_2/kWh (Oficina Catalana del Canvi Climàtic, 2012). Other conversion factors are:

Conversion factors	CO_2 equivalent	(units)
Electricity (kWh)	**0,267**	*kg CO2/kWh*
Natural gas (m3)	**2,15**	*kg CO2/Nm3*
Butane gas (Kg)	**2,96**	*kg CO2/Kg*
Propane (Kg)	**2,94**	*kg CO2/Kg*
Diesel oil (L)	**2,79**	*kg CO2/L*
Fuel (Kg)	**2,3**	*kg CO2/Kg*
Coal - national (Kg)	**2,3**	*kg CO2/Kg*
Coal - imported (Kg)	**2,53**	*kg CO2/Kg*

Table 7-4. Conversion factors for the different types of energy supply. *Source: Oficina Catalana del Canvi Climàtic, 2012.*

For water projects, in which water is produced (purification plants) or treated (wastewater treatment plants), if the amount of energy consumed per m^3 is known (kWh/m^3) and the total amount of water used/produced is known, then it is possible to get the project's overall amount of equivalent CO_2 emissions.

Therefore, having this information on hand, the valuation of the total greenhouse emissions in millions of tons of CO_2 ($MtCO_2$) per year predicted to be produced by the assessed project can be calculated by:

$$\mathrm{CO_{2\text{-}equivalent}}\ (\text{€/year}) = Water\ produced\ or\ treated\ per\ year\ \left(\frac{m^3}{year}\right)\ x\ Energy\ consume\ per\ m^3\ \left(\frac{kWh}{m^3}\right)\ x\ Project\ CO_2\ emissions\ \left(\frac{MtCO_2}{year}\right)\ x\ Price\ Ton\ CO_2\ \left(\frac{€}{tCO_2}\right)$$

7.2.5 CO_2 neutral compensation

Application: Water supply/demand projects, water quality/environmental projects

Energy intensive projects that are aware of the impact of their GHG emissions have the option to reduce these emissions by implementing CO_2 compensation measures.

The idea of compensation measures for CO_2 emissions evolved from the Kyoto-Protocol. There are two project-oriented mechanisms: the Clean Development Mechanism (CDM) and Joint Implementation (JI). The principle of both mechanisms is similar: an investor carries out a project in a host country that reduces the emissions and therefore obtains emission credits. Requirement for the generation of emission credits is that the reductions of emissions are additional to measures that would have been carried out without the emission reduction project taking place. The background of these instruments is the idea that not all reduction commitments can be achieved within a short time period in his/her home country. The instruments are based on the conviction that the market will regulate supply and demand of certificates and thus will lead to an efficient CO_2 reduction. As well, there is voluntary compensation for consumers, households, middle-sized companies and other CO_2 emitters (Climate Alliance, 2008).

If the adaptation project being assessed has this kind of compensation measure, it is a benefit to take into consideration, as it counts as GHG emissions reduction.

Related equation:

The gain for emission compensation is to be calculated following the same pattern as the CO_2-equivalent emissions criterion, but considers the project's compensated CO_2 emissions instead of the emissions produced by it, and the price for a CO_2 ton equivalent.

$$CO_2\ compensation\ (€/year) =$$
$$Project\ CO_2\ compensated\ emissions\ \left(\frac{MtCO_2}{year}\right)\ x\ Price\ Ton\ CO_2\ \left(\frac{€}{tCO_2}\right)$$

7.2.6 Income per capita affectation

Application: Water supply/demand projects, water quality/environmental projects.

This criterion looks at evaluating the social effect of an adaptation project, such as the financial impact on the population benefiting from (or served by) the project. In other words, to what extent customer's pockets are affected by receiving, directly or indirectly, the adaptation measure service.

Two socio-economic ratios are frequently used for the evaluation of investment priorities, in this case for water sanitation infrastructures (MMA, 2007).

→ A ratio linking the overall volume of wastewater treated in the region where the adaptation project takes place, with the region's gross domestic product (m^3/€). This provides information on the growth of the region and its own capacity to treat its wastewater.

$$\frac{Volume\ of\ water\ treated\ (\frac{m^3}{year})}{GDP\ (€)}\ x\ 100$$

→ A ratio linking the average price of the region's sanitation system with the gross disposable income per capita. This ratio evaluates the user's capacity to pay up for a levying of taxes related to the wastewater treatment.

$$\frac{Sanitation\ average\ price\ (€)}{Gross\ Disposable\ Income\ per\ Capita\ (€)}\ x\ 100$$

For this document's purpose, a monetary valuation is needed instead of a percentage. Therefore, the way of assessing the social cost of the adaptation project is a combination of these two afore-mentioned ratios.

Related equation:

It will consider the following elements:

- *Average supply or sanitation price of the region (€/m³)*: it embraces the sanitation or supply system costs that have to be faced by the region where the adaptation project is implemented. Supply system costs include storage, caption, purification and distribution of water. On the other hand, sanitation system includes costs of the sewage system that allows wastewater transport and the later wastewater treatment.

- *Volume of produced or treated water (m³):* the total amount of water which the adaptation project is supplying or treating.

- *Gross domestic product of the region (€):* the market value of all officially recognised final goods and services produced within a country or region in a given period of time. GDP per capita is often considered an indicator of a country's standard of living.

- *Gross disposable income per capita (€/hab):* calculated by taking a measure of all sources of income in the aggregate (such as GDP or gross national income) and dividing it by the total population.

- *Population equivalent to which the project is serving (hab.):* Total population for which the adaptation project has been designed.

$$Income\ per\ capita\ affectation\ (€/year) =$$

$$= \frac{Region\ water\ supply\ or\ treatment\ price\ (€/m^3) x\ Volume\ of\ supplied\ or\ treated\ water\ \left(\frac{m^3}{year}\right)}{Region\ GDP\ (€)}$$

$$x\ Gross\ Disposable\ Income\ per\ Capita\ \left(\frac{€}{hab}\right)\ x\ Project\ P.E.(hab)$$

7.2.7 Sludge valuation

<u>Application</u>: *Water quality project*

Sludge is the waste generated in wastewater treatment processes. There are many ways to manage this waste: disposal, incineration, thermal drying process (so it can be used for construction purposes) or composting for agriculture.

Sludge can be destined to agriculture to enrich the soil due to its high level of nutrients contained. Nitrogen average's content in sludge is between 3% and 4%, depending on the sludge's origin, which makes it on one of the richest organic nutrients present. Furthermore, the agricultural use of sludge contributes to increase the amount of phosphorous which the soil can assimilate. The average content within the sludge is around 0,15% and 0,30% (Martínez, Y., et al. 2007). Benefits from the agricultural use of sludge generated in wastewater treatment plants should be contemplated, as it induces saving costs in the use of fertilisers, as explained below.

the dry matter production is understood as sludge production, because it is in this state in which the sludge is used in agriculture as manure. Therefore, figures relating to dry matter production have been selected to analyse this criterion.

Taking as a model the Spanish Mediterranean agriculture (the region on which the case study is based), average prices for fertilisers range from 2 - 4 €/kg. If a typical N-P-K fertiliser contains the average proportion of macronutrients in 40% N – 40% P – 20% K, the relating price for both N and P inside the fertiliser's price has to be considered. Therefore, if the fertiliser's price is 3 €/kg, the costs per unit of N or P are the following:

1 unit of N → 7,5 € / kg N
1 unit of P → 7,5 € / Kg P

Related equation:

Accordingly, it is worthwhile to calculate the quantity of sludge going to agriculture and the proportion of the two main nutrients from which the soil will benefit: N and P. Knowing the quantity of N and P that the sludge production could provide, a comparison can be made with the total cost saved in not having to resort to fertilisers. Moreover, it is necessary to consider the portion of N and P that can be found in the average sludge, the fertiliser's price for a N or P unit, and the proportion of sludge treated in the region or country, as it has been mentioned.

For nitrogen valuation in sludge, the equation is as follows:

$$Sludge\ valuation\ (€/year) =$$

$$Sludge\ production\ \left(\frac{kg\ N}{year}\right)\ x\ Region's\ sludge\ application\ (\%)\ x\ \ N\ present\ in\ sludge\ (\%)\ x$$

$$price\ kg\ N\ fertilizer\ \left(\frac{€}{kg\ N}\right)$$

*For phosphorous the same equation has to be applied, replacing N by P.

7.3 Criteria equations compilation

Table 7.4 below collects all the criteria detailed in previous sections with their related equations. These are the ones considered for the analysis developed within this document.

Criteria		Related equation
Water gains	Potable water savings	$\textbf{Water savings}\ (€/year) = Volume\ of\ water\ saved\ \left(\frac{m^3}{year}\right)\ x\ Price\ of\ drinking\ water\ \left(\frac{€}{m^3}\right)$
	Water reuse savings	$\textbf{Water reuse savings}\ \left(\frac{€}{year}\right) = \left[Price\ drinking\ water\ \left(\frac{€}{m^3}\right) - Price\ reclaimed\ water\ \left(\frac{€}{m^3}\right)\right]\ x\ Volume\ recaimed\ water\ (m^3)$
Water losses		$\textbf{Water losses}\ \left(\frac{€}{year}\right) = Volume\ of\ water\ lost\ (m^3)\ x\ Price\ of\ drinking\ water\ \left(\frac{€}{m^3}\right)$
Pollution savings	Influent concentration known	$\textbf{Pollution saving}_{\ treated\ water}\ (€/year) =$ $Environmental\ value\ N,P\ \left(\frac{€}{Kg}\right) x\ Influent\ N,P\ concentration\ \left(\frac{Kg}{m^3}\right)\ x\ Volume\ of\ treated\ water\ \left(\frac{m^3}{year}\right)\ x\ \%\ N,P\ reduction$
	Influent concentration unknown	$\textbf{Pollution saving}_{\ treated\ water}\ (€/year) = Environmental\ value\ N,P\ \left(\frac{€}{m^3}\right)\ x\ Volume\ of\ treated\ water\ \left(\frac{m^3}{year}\right) x\ \%\ N,P\ reduction$
CO_2 - equivalent emissions		$\boldsymbol{CO_{2-equivalent}}\ (€/year) =$ $Water\ produced\ or\ treated\ \left(\frac{m^3}{year}\right)\ x\ Energy\ consume\ per\ m^3 \left(\frac{kWh}{m^3}\right)\ x\ Project\ CO_2\ emissions\ \left(\frac{MtCO_2}{year}\right)\ x\ Price\ Ton\ CO_2\ \left(\frac{€}{tCO_2}\right)$
CO_2 neutral compensation		$\boldsymbol{CO_2\ compensation}\ (€/year) = Project\ CO_2\ compensated\ emissions\ \left(\frac{MtCO_2}{year}\right)\ x\ Price\ Ton\ CO_2\ \left(\frac{€}{tCO_2}\right)$
Income per capita affectation		$\textbf{Income per capita affectation}\ (€/year) = \frac{Region\ water\ supply\ or\ treatment\ price\ (€/m^3) x\ Volume\ of\ supplied\ or\ treated\ water\ \left(\frac{m^3}{year}\right)}{Region\ GDP\ (€)}$ $x\ Gross\ Disposable\ Income\ per\ Capita\ \left(\frac{€}{hab}\right)\ x\ Project\ P.E.(hab)$
Sludge valuation		***Sludge valuation (€/year)=*** *Sludge production (kg N) x Region´s sludge application (%) x N present in sludge (%) x price kg N fertilizer (€/(kg N))*

Table 7-5. Criteria equations compilation. *Source: own.*

CASE STUDY: Prioritisation of climate change adaptation measures for the water sector in the Spanish Mediterranean region.

8. Case study description

We develop a pilot virtual scenario to test and validate the methodology and to obtain results. For this purpose, a hypothetical future scenario is provided in which it would be necessary to prioritise between different adaptation measures for the Mediterranean coast of Spain. As it will be seen further on, the regional climatic model foretells a decline in water resources in the Spanish Mediterranean region under scenarios A2 and B2. This factor will imply effects such as long dry periods, water shortage, higher concentration of pollutants in water bodies, etc. This situation will have to be addressed with adaptation measures that have the purpose of guaranteeing and strengthening water supply, sanitation or environmental recovery.

The scenario is hypothetical due to the actual lack of planned adaptation measures in the water sector in the Mediterranean region. However, based on interviews with decision makers, real *water supply/demand projects* and *water quality and environmental projects* have been taken as examples of possible adaptation measures that could be implemented in this future scenario. The examples selected are projects located along the Mediterranean coast of Spain, specifically in the Valencian community (city of Valencia) and in Catalonia (cities of Empuriabrava, Sabadell and Badalona). All fall under similar climate and bio-physical Mediterranean conditions.

The five measures, depending on their location, are:

Valencian community

> **Adaptation Measure 1:** *Emergency wells in the purification plant "La Presa" (Valencia, Spain).*
>
> **Adaptation Measure 2:** *Carbon dioxide injection for purification process in the purification plants "La Presa" and "El Realón" (Valencia, Spain).*

Catalonia

> **Adaptation Measure 3:** *Reclaimed water re-use in Empuriabrava Water Treatment Plant (Spain).*
>
> **Adaptation Measure 4:** *Management plan for the use of waters external to the drinking water supply network of Sabadell (Spain).*
>
> **Adaptation Measure 5:** *Educational and awareness campaign to promote water savings in Badalona (Spain)*

For a correct development of the case study, the Prioritisation Method steps have been adhered to (see Figure 6-1). Therefore, the case study structure consists of:

→ A brief description of the location and main bio-physical and socio-economic conditions of the regions under study (Valencia and Catalonia) *(Chapter 9).*

→ Information gathering about climate change effects scenarios expected for Valencia and Catalonia, the impacts on the water resources and the need for adaptation *(Chapter 10).*

→ For every Adaptation measure selected:

- Description of goals, stakeholders involved, adaptation capacity relevant figures.
- Externalities calculation and Cost-Benefit Analysis *(Chapter 11).*

→ Prioritisation of the selected measures using the Prioritisation Method *(Chapter 12).*

→ Limitations detected in the use of the Prioritisation Method *(Chapter 13).*

9. Location and main conditions of the regions under study

The region studied has what is known as a Coastal Mediterranean climate. It is represented by irregular rainfall (between 400mm and 600mm a year), with a very pronounced summer minimum (three dry months from June to August), with highest rainfall in the autumn (September to November). In autumn the so-called "cold drop" phenomenon is common, in which torrential rains and flash floods can occur. The average temperature is around 15-18ºC, with a temperate winter (10-12ºC) and a hot summer (> 22ºC), making it a mild climate without extreme temperatures.

10. Climate change impacts on water resources in the regions under study

All locations described have very similar climatic conditions, referring to a typical Mediterranean climatic regime. There is a large scientific consensus when predicting that the Mediterranean area, where the region of study is located, is one of the areas of the world most likely to be affected by climate change. All the latest forecast models agree the climate in this region will become warmer and drier throughout the century than the current climate. Being a transition zone between two continents, the Mediterranean has some ecosystems and organisms that are very sensitive to changes in world patterns and climatic regimes (CREAF, 2010).

The same model-based results are being used for both regions, using the conclusions drawn by the Spanish Ministry of the Environment (MARM) and the Spanish Office of Climate Change (OECC) in the document *"Evaluación del impacto del cambio climatico en los recursos hídricos en regimen natural" (Evaluation of climate change impacts on the hydrological resources in natural regime)* (MARM, 2011). This document, in turn, is based on the climatic scenarios projected by AEMET (the Spanish Meteorology Agency) in the study *"Generación de scenarios regionalizados de Cambio climatic para España" (Creation of regionalized climate change scenarios for Spain)* (AEMET, 2009). The document examines the impacts on water resources for the whole of Spain, but also on a river basin scale: for Valencia the data related to the Jucar River Basin is selected, and for Catalonia the so-named Catalan Internal River Basins.

It is worth pointing out that other climatic models exist that may better regionalising climate change impacts only on a Valencia or Catalonia scale. However, it has been seen appropriate to take one single study covering all the case study area rather than risking adding additional uncertainties from different model results. The MARM's document offers projections for water indicators such as rainfall, evapotranspiration, and aquifer recharge or water run-off.

10.1 AEMET's Climatic models for Spain.

As said, to understand the effect of climate change in the Spanish Mediterranean region, the Spanish Meteorology Agency (AEMET) has been in charge of creating regional climate scenarios in order to offer scientific projections.

The AEMET chose twelve of these regional climate scenarios, obtained from the combination of six regional models[2] and two emission scenarios (SRES), the A2 and B2. For the AEMET, they are considered to be representative enough for the overall scenarios, as they scope a wide range of variations (MARM, 2011). A2 is based on a more pessimistic future scenario than B2; thus, a major impact to the climatic and hydrological cycle should be expected for A2 than for B2.

10.2 Impact of climate change on Spain's water resources

Referring to the MARM-OECC study (based on the AEMET), the hydrological cycle phases were simulated using a model for water resources under specific rainfall and temperature projections. This was made for water resources in a natural regime, that is, a hydrological cycle in which no human alteration has been made (water extractions from a river, aquifer or reservoir regulation, etc.), on the quantity nor on the temporary sequence (MARM, 2011).

The work was carried out for all Spain. The temporary scale was monthly, and the results refer to rainfall, evapotranspiration, aquifer recharge and water run-off (groundwater and surface run-off). Results show the variation on these four indicators during the four periods established by the AEMET (2011-2040, 2041-2070 and 2071-2100) if compared with the control period (1961-1990):

Indicators	Projections general predictions	A2 Scenario	B2 Scenario	*Time period*
Rainfall	General decrease of rainfall throughout the 21st century, affecting water availability. The eastern part of Spain (Mediterranean coast) would be less affected.	5-9% decrease	5-9% decrease	*2011-2040*
		17% decrease	8% decrease	*2041-2070*
		17% decrease	9% decrease	*2071-2100*
Evapotranspiration	Increase in temperature, resulting on a higher evaporation and plant transpiration. Thus, its effect on the hydrological cycle is minor, as it would affect mainly summer, when the level of water in the soil is low.	3% increase	5% increase	*2011-2040*
		6% increase	6% increase	*2041-2070*
		12% increase	7% increase	*2071-2100*
Aquifer recharge	A generalised reduction throughout Spain is predicted, being siliceous areas less vulnerable than limestone or detritic areas.	8% decrease	8% decrease	*2011-2040*
		15% decrease	12% decrease	*2041-2070*
		27% decrease	16% decrease	*2071-2100*
Water run-off (groundwater + surface)	Overall decrease of water run-off according to temperature and rainfall evolution.	8% decrease	8% decrease	*2011-2040*
		16% decrease	11% decrease	*2041-2070*
		28% decrease	14% decrease	*2071-2100*

Table 10-1. Spanish rainfall, evapotranspiration, aquifer recharge and water run-off variations under A2 and B2 scenarios for different time periods. *Source: Adapted from MARM, 2011.*

[2] These are global climatic circulation models: three referring to atmosphere-ocean modelling (named (ECHAM4, CGCM2 and HadCM3); and one exclusively atmosphere (HadAM3). Models have been developed by the "Max Planck Institute for Meteorology" in Hamburg (ECHAM), the "Hadley Centre" of UK's Meteorology Office (Had) and the "Canadian Centre for Climate Modelling and Analysis" (CGCM, Canadian Global Coupled Model). These have been combined with two statistical (FIC and SDSM) and dynamic techniques (PROMES-UCM and RCAO-SMHI) so to get the regionalisation of the models.

10.3 Climate change impacts on the water resources of the regions under study and identification of their need for adaptation.

As it has been explained, the study applies its results to the river basin scale: The Júcar river basin in the Valencian area, and the Internal Catalan river basins. For these two river basins, water indicators are analysed. Following table describes how water run-off would be affected under the A2 and B2 scenarios and for the six regional models used by AEMET.

		Escenario A2							Escenario B2						
Δ (%): > 0% (green); -20% a 0% (yellow); < -20% (orange)		Modelo regionalizado I	Modelo regionalizado II	Modelo regionalizado III	Modelo regionalizado IV	Modelo regionalizado V	Modelo regionalizado VI	Δ del promedio	Modelo regionalizado I	Modelo regionalizado II	Modelo regionalizado III	Modelo regionalizado IV	Modelo regionalizado V	Modelo regionalizado VI	Δ del promedio
Cuencas Internas de Cataluña	2011-2040	6	-4		-3			0	-9	-5		-8			-7
	2041-2070	-2	-5		-6			-4	-2	-6		-19			-9
	2071-2100	-11	-3	-13	-34	-30	-29	-21	-13	-5	-18	-14	-20	-18	-16
Júcar	2011-2040	1	-11		-4			-5	-21	-17		-1			-12
	2041-2070	-11	-28		-14			-18	-5	-20		-14			-13
	2071-2100	-21	-24	-18	-46	-45	-21	-32	-16	-27	-20	-18	-34	-14	-24

Table 10-2. Variation in water run-off (%) in the Internal Catalan River Basins and the Jucar River Basin for A2 and B2 scenarios in different time periods and regional models, in accordance with the control period (1961-1990). Red circle indicates the average. *Source: MARM, 2011.*

From the previous Table 10-2, it can be deduced that variations in the Júcar River basin and the Internal Catalan River Basins will influence water inflows for the locations studied. Taking all the locations as a unit, it can be summarised as follows:

→ *Rainfall* variation during 2011-2040 under scenario A2 will range from -5 to +5%

→ *Evapotranspiration* during 2011-2040 under scenario A2 will range from -5 to +10%. This increase is moderate due to the increase of temperatures during the summer period, when less water is available in the soil/plants to be lost by evapotranspiration (MARM, 2011). (No figures for B2)

→ For the Jucar River Basin, average *water run-off* during the period 2011-2100 under scenario A2 will range from -5% to -32%. For scenario B2, during the same period it will range from -12% to -24%. It can be observed that A2 water run-off variation is higher (it would diminish by 28%) than for B2 (12%).
For all the Catalan Internal River Basins (thus, for Badalona, Sabadell and Empuriabrava), average run-off during the period 2011-2100 under scenario A2 will range from 0% to 21%. For scenario B2, it will range from -7% to -16%. It can be seen that scenario B2 is more regular, as it will only vary 9% between 2011 and 2100; on the other hand, scenario A2 offers a more drastic variation, of 21%.
Lower run-off would be caused by a low rainfall, as falling water would predominately infiltrate rather than run-off (MARM, 2011).

It can be been observed that variations for the A2 scenario, independently of the region, get higher through time, while variations for B2 are remains more consistent. However, water regimes for all indicators are expected to be similar for both areas due to their Mediterranean patterns, with an evident water scarcity caused by, especially, the decrease in water run-off. This will affect water supply in a way that river flows will be reduced and less volume of water will be available for storing and capturing for distribution. Furthermore, a reduced flow will destabilise contaminant's dilution equilibrium, reducing water quality. Adaptation should, then, be working to face these main two challenges, so to guarantee there is enough water being supplied and maintain quality standards.

11. Description, analysis and prioritisation of the selected adaptation measures.

As mentioned in the case study description, in this chapter different selected water supply and water sanitation adaptation measures are assessed and prioritised. The adaptation measures are based on five real projects which have been planned and already implemented in the Spanish Mediterranean region. These are:

- **Adaptation Measure 1:** *Emergency wells in the purification plant*
- **Adaptation Measure 2:** *Carbon Dioxide injection for purification process in the purification plants*
- **Adaptation Measure 3:** *Reclaimed water re-use in Water Treatment*
- **Adaptation Measure 4:** *Management plan for the use of waters external to the drinking water supply network*
- **Adaptation Measure 5**: *Educational and awareness campaign to promote water savings*

11.1 Analysis procedure

Information is based on activity reports of the projects analysed here, where the aims, construction work's description, time periods and estimated budgets are justified. Supplementary information has been analysed and contrasted with documents and planning schemes, extracted from the available literature or through direct contact with experts that have offered their help to collaborate[3].

As it has been said, the purpose of the Prioritisation Method calculations is to introduce positive and negative externalities in the Cost-Benefit Analysis (CBA) calculation and checking the final Net Present Value's evolution under different emission scenarios (A1, A2, B1 and B2). Therefore, for each of the following measures chosen, externalities have been calculated with the help of the different criteria developed. Summarising, the criteria are[4]:

→ *Water gains:* benefit from extra water that was not available for supply before the adaptation measure was implemented, or water savings incurred with the measure.
→ *Pollution savings:* the environmental damage avoided considering pollutants shadow prices.
→ *CO_2 equivalent emissions:* GHG emissions strictly produced by the energy consumption needed for the operation of the adaptation measure, based on their equivalence in tones of CO_2 and its price in the European Union Emissions Trading Scheme.
→ *CO_2 neutral compensation:* GHG emissions reduction in case the adaptation project has a CO_2 compensation measure. It is based as well on the equivalence in tones of CO_2 and its price in the European Union Emissions Trading Scheme.
→ *Income per capita affectation:* budgetary impacts on the population who benefit from (or are served by) the adaptation measure.
→ *Sludge valuation:* benefits obtained from quantity of sludge going to agriculture and the proportion of the two main nutrients from which the soil will benefit: N and P.

[3] The case of Grupo Aguas de Valencia for adaptation measures 1 and 2, described later.
[4] See Chapter 8.2. for the criteria's development and equations.

→ *Water losses:* costs faced by water losses during the adaptation measure infrastructure, process and functioning.

All mentioned externalities resulting from the implementation of the measures are calculated. In the same way, the ones which do not derive from a project are not accounted. Social positive externalities, due to the absence of a criterion that can provide a monetary valuation of social benefits, are not taken into account.

Additionally, for the CBA other considerations have been made:

- A twenty-five year period since the project's completion is the time operation considered in the CBA, considering this a normal time operation period to meet the requirements for water supply and sanitation projects; or, at least, an operating period reaching the year 2030 for those measures which were implemented much earlier. Year 2030 is considered enough time to understand climate change impacts on a short-term scale.
- It is assumed that costs and benefits vary with time due to fluctuations. Calculations have taken into account the annual costs faced by the project from the beginning of the operation till now (2013). Nevertheless, due to the limited availability of figures for the subsequent years, estimation has been made taking costs and benefits figures the average value from the operating years.
- Year 0 is considered to be the year in which the initial investment is carried out.
- Costs and benefits terms considered in the Net Present Value (NPV) calculation are:
    - *Costs:*
        - First year (year 0): *Initial investment*
        - Following years: *Annual expenditure + negative externalities.*
    - *Benefits: Positive externalities.*
- Discount rates have been applied depending on the climate scenario considered. Even if A2 and B2 were the ones used to identify the adaptation needs of the regions under study through the AEMET regional model, A1 and B1 have been considered worthwhile to be analysed.
- In-depth budget estimations from the adaptation measures being analysed, as well as their corresponding NPV calculation processes, are integrated in ANNEX 1.

Once the NPV results are obtained, every adaptation measure is discussed, highlighting their profitability or unprofitability for the climatic scenarios considered. As well, a comparison takes place to know which adaptation measures could be financed, ranking them depending on the different criteria that have been used in the NPV analysis (private costs, external costs and benefits, etc.).

ADAPTATION MEASURE 1: Based on the emergency wells in the purification plant "La Presa".

- ❖ Location: Valencia, Spain.
- ❖ Year: 2008
- ❖ *Adaptation to climate change capacity: Provide an alternative source of water (groundwater) to the city of Valencia under heavy rains or drought periods expected from climate change scenarios.*
- ❖ Stakeholders involved: GRUPO AGUAS DE VALENCIA (EMIVASA)

Grupo Aguas de Valencia was founded in 1890 to supply the city of Valencia with drinking water. Nowadays, the group manages all aspects of collection, treatment and distribution of drinking water in the city of Valencia, and in most populations of the metropolitan area. It also serves as administer for all metropolitan high-level networks. To do this, two purification plants (La Presa and El Realón) are operated through its subsidiary company EMIVASA in charge of the supply of surface water coming directly from the Júcar and Turia Rivers. Aguas de Valencia Group contributes 80% of EMIVASA's capital, and the city council adds the remaining 20%.

- Concept:

Water entering the purification plant "La Presa", responsible for the water supply to the city of Valencia, comes from the Turia River (1 m^3/s) and the Júcar-Turia Canal (3 m^3/s), allowing flexibility of resources. "La Presa" is also authorised to obtain 0,6 m^3/s of underground water from five wells (called Number 11, 12, 13, 14 and "Radial", with depth ranging 50 and 89 metres).

Water is usually extracted from the canal due to its quality which it is higher and more consistent than the river's. This option is taken especially after heavy rains (a usual phenomenon in the Mediterranean regions), when Turia River's turbidity increases due to intense run-off, resulting in contamination peaks with high levels of organic matter and ammonia lasting at least 48hours.

Overall, the system has to guarantee the 1m^3/s minimum supply flow to the city of Valencia to fulfil the city's water demand. Nevertheless, when drought conditions occur (such as the ones suffered in 2007), the supply balance is altered: The Jucar River Basin authority stipulates that water flowing in the Jucar-Turia canal has to be preserved for other purposes and the system has to rely on the Turia River and the underground water sources (good quality waters). If severe droughts occur and superficial water becomes scarce, demand would have to be satisfied only by the flow obtained from the wells, which are insufficient to meet the minimum supply (EMIVASA, 2008).

Climate change scenarios predict severe droughts and heavy rains to become more common in Valencia's Mediterranean region. Therefore, the so called "Emergency wells" have been planned to complement underground water extraction, while at the same time it will modernise the old wells' equipment. This will allow an overall extraction of 0,95 m^3/s. Thus, its aim is to almost reach the minimum 1m^3/s supply and address the mentioned climate impacts.

Three Emergency wells (called Number 12-bis, 15 and 16, and deepening 100 to 150 metres) are completed and are actually working, fully equipped with the corresponding pumps, impermeable materials, electrification, interconnection with the actual well system, etc. The Emergency wells are shall be complemented with three extra explorations ranging between 40 and 96 metres deep, with the aim to study and provide confirmation that hydrodynamic conditions of the extraction area are favourable (EMIVASA, 2008).

Figure 11-1. Actual wells and Emergency wells location in the purification plant "La Presa". *Source: EMIVASA, 2008*

Volume of extracted water since the Emergency wells came into service in 2009 is:

Year	Volume of water
2009	1.516.108 m^3
2010	4.668.557 m^3
2011	10.082.567 m^3
2012	12.229.682 m^3
Average (2010-2012)	8.993.602 m^3

Table 11-1. Volume extracted from the Emergency wells (average figures have been calculated taking years with higher volumes extracted). *Source: Grupo Aguas de Valencia, 2013.*

Adaptation Measure 1 Analysis

❖ Budget estimation:

- Initial investment (Year 0): **1.830.946,42 €** (Grupo Aguas de Valencia, 2013)[5]
- Annual expenditure: **539.616,12 €**

Due to lack of figures concerning the annual expenditure, expenditure has been estimated taking as a reference the unitary cost of groundwater extraction for urban supply in the Jucar River Basin, which is 0,06 €/m^3 (MMA, 2007). This value includes the main variables that determine the financial costs of groundwater use: costs of drilling and construction of wells, pumping systems, pumping rate and energy costs (MMA, 2007).

5 See ANNEX 1 for detailed investment.

Knowing the groundwater unitary cost and the average annual groundwater extracted from the Emergency wells (8.993.602 m^3), an annual expenditure can be suggested, resulting in 539.616,12 €.

- ❖ <u>Externalities to be considered for this measure:</u>

  → *CO_2-equivalent emissions:* produced by the energy consumption of the Emergency wells operation.

  → *Income per capita impacts:* the budgetary impact on the population being served by the project, 895.603 inhabitants (Grupo Aguas de Valencia, 2013).

  → *Water gains:* this concept will take account of the water production benefits from using another alternative water source such as groundwater.

- ❖ <u>Externalities calculation</u>

Calculation is based on the period of exploitation since the Emergency wells came into service, from 2009 to 2012. Externalities corresponding to the years after 2012 have been considered taking as a reference the average from the 2010-2012 period, as in year 2009 the measure was still in the initial stages of implementation and, therefore, not functioning at full performance potential.

→ ***Positive externalities:***

Year	2009	2010	2011	2012	Average (2010-2012)
Water gains (water production benefits)	343.456,07 €	1.057.605,57 €	2.284.084,56 €	2.770.487,70 €	2.037.392,61 €

Figures considered:

- Water gains
  - **Water supply price of the region (Valencia):** 0.226538 €/m^3 (EMSHI, 2012)
  - **Volume of water produced annually:** 1,516,108 m^3 (2009)**,** 4,668,557 m^3 (2010), 10,082,567 m^3 (2011), 12,229,682 m^3 (2012), 3,099,780 m^3 (2013).

Table 11-1. Adaptation measure 1 positive externalities. *Source: own, based on EMSHI, 2012; Grupo Aguas de Valencia, 2013.*

→ ***Negative externalities:***

Year	2009	2010	2011	2012	Average (2010-2012)
$CO_{2\text{-equivalent}}$ emissions	7.378,71 €	22.721,29 €	49.070,60 €	59.520,35 €	43.770,75 €
Income per capita impcat	579.273,23 €	579.273,23 €	579.273,23 €	579.273,23 €	579.273,23 €
TOTAL	**586.651,94 €**	**601.994,52 €**	**628.343,84 €**	**638.793,58 €**	**623.043,98 €**

Figures considered:

- $CO_{2\text{-equivalent}}$ emissions
  - **Energy consumption per m^3:** 0,195 kW/m^3 (Grupo Aguas de Valencia, 2013). **Energy source:** Electricity
  - **Volume of water produced annually:** 1.516,108 m^3 (2009)**,** 4.668.557 m^3 (2010), 10.082.567 m^3 (2011), 12.229.682 m^3 (2012) ,

3.099.780 m^3 (2013)

- Income per capita impact
  - **Water supply price of the region (Valencia):** 0,226538 €/m^3 (EMSHI, 2012)
  - **Volume of water produced annually:** 1.516.108 m^3 (2009), 4.668.557 m^3 (2010), 10.082.567 m^3 (2011), 12.229.682 m^3 (2012), 3.099.780 m^3 (2013)
  - **Region's Gross Domestic Product (Valencia):** 100.047 M € (Datosmacro, 2012).
  - **Gross Disposable Income per Capita (Valencia):** 19.964 €/hab (Datosmacro, 2012).
  - **Population to which the project is serving**: 895.603 hab (Grupo Aguas de Valencia, 2013).

Table 11-2. Adaptation measure 1 negative externalities. *Source: own, based on EMSHI, 2012; Grupo Aguas de Valencia, 2013; Datosmacro, 2012.*

→ *Net Present Values (NPV) obtained*

Considering the discount rates selected for every emission scenario in Chapter 4.2, the following NPV have been obtained[6]:

Emission Scenarios (discount rate)			
A2 (3%)	A1 (4%)	B2 (5%)	B1 (6%)
NPV A2	NPV A1	NPV B2	NPV B1
11.746.191,48 €	10.181.781,83 €	8.847.953,51 €	7.704.958,81 €

Table 11-3. Emission scenarios NPV for adaptation measure 1. *Source: own.*

[6] See ANNEX 1 for NPV calculation.

❖ Results discussion

Net Present Values for all climate scenarios are positive and very high, indicating that the measure implemented is going to be very profitable on the short-term future, independently of the emission scenario. In the two first years losses are higher than profits, however, the opposite results transpire for the rest of the time period analysed. Therefore, turning to groundwater as an alternative water resource in the case of droughts or heavy rains produced by climate change is an adequate measure for guaranteeing water supply.

However, it is worth to point out that NPV's vary considerably from one scenario to another, showing that groundwater supply is an adaptation that would be much more needed (thus, would more profitable) in high impact climate change scenarios (A2) than in low ones (B1). NPV for scenario A2 is 34.4% higher than NPV for scenario B1.

Considering the average values, the *Income per capita impact* represents the 49.8% of the total costs, *$CO_{2\text{-equivalent}}$ emissions* of 3.76% and the strictly economic expenditure of 46.44%. On the other hand, taking a glance to the resulting benefits (*water gains*), they are 75.2% higher than the total costs. From the water supply point of view, calculations show that it could be a very successful measure for climate change adaptation in the Mediterranean region.

ADAPTATION MEASURE 2: Based on the Carbon Dioxide Injection for purification process in the purification plants "La Presa" and "El Realón".

❖ Location: Valencia, Spain.

❖ Year: 2008

❖ *Adaptation to climate change capacity: Improve water purification process to guarantee quality drinking water for the city of Valencia, even if pollutants dilution in extracted water is low due to water scarcity caused by climate change.*

❖ Stakeholders involved: GRUPO AGUAS DE VALENCIA (EMIVASA)

(see Adaptation measure 1)

❖ Concept:

GRUPO AGUAS DE VALENCIA

Due to the increase of water demand in Valencia and the variety of types of water (Turia River, Júcar River and groundwater) subject to purification treatment in the purification plants of "La Presa" and "El Realón", Valencia city council and EMIVASA searched for a new reagent system to ameliorate water taste and quality (specially pH). The chosen option has been Carbon Dioxide Injection.

High pH's typical from hard waters such as Valencia's drinking water can be neutralised with CO_2. Carbon dioxide is a gas, which once dissolved into water produces as weak acid: carbonic acid. This substance reacts immediately with alkalis such as caustic soda, sodium carbonate and dissolved lime, turning them into neutral carbonates and bicarbonate salts.

CO_2 is introduced into the high pH water by means of a diffuser, which is typically installed in an existing pressurised pipe or at the bottom of a basin. Small CO_2 bubbles are then released by the diffusers into the high pH water, neutralising it.

Among the benefits of CO_2 pH control are the low maintenance system it requires: it is safe-to-use (carbon dioxide in the absence of water is inert and non-corrosive), it is more strict to regulation limits (CO_2 is better than strong acids for controlling pH because it forms a mild but highly reactive acid which minimises risks of over acidification), and it is flexible and environmentally safe (there is no secondary pollution introduced into the treated water by salts such as chlorides from HCl, or sulphates from H_2SO_4). The introduction of CO_2 will contribute to the chemical equilibrium of water by forming neutral carbonates and bicarbonates.

For this, the measure in “La Presa” and “El Realón” purification plants implements the installation of CO_2 dosing, CO_2 injection, CO_2 storage tanks, atmospheric CO_2 vaporisers and all other necessary equipment. The measure started functioning in “La Presa” in 2009, while in “La Presa” it did not start until 2011 (Grupo Aguas de Valencia, 2013).

The most important particularity of this project from an environmental externality point of view is that CO_2 used in this process is a by-product recovered from other technologies (fermentation process from ethanol operations, distilleries or wineries, and industrial sources). Therefore, it can be understood as a CO_2 compensation project, as CO_2 from other external processes are reused in the purification treatment, rather than being emitted to the atmosphere.

This measure intends to be an improvement step in the process of purifying the water extracted from river flows and guarantee quality conditions for the population consumption. River flows in future climate change scenarios will be scarcer and, consequently, will get more concentrated with contaminants. This higher concentration of impurities, nutrients and other compounds from raw water extracted for urban supply will need better purification processes than the existing ones in place, and this measure is one additional step towards addressing this need.

Year	“La Presa” (kg CO_2)	“El Realón” (kg CO_2)	TOTAL (kg CO_2)
2009	359.358	-	359.358
2010	269.012	-	269.012
2011	161.800	209.100	370.900
2012	285.697	322.370	808.067

Table 11-4. CO_2 consumption for the pH reduction process. *Source: Grupo Aguas de Valencia, 2013.*

Figure 11-2. CO_2 storage tanks in "La Presa". *Source: EMV-Levante, 2010.*

Adaptation Measure 2 Analysis

❖ Budget estimation:

- Initial investment (Year 0): **934.114 €** (EMV-Levante, 2010)
- Annual expenditure: **20.000 €** (Grupo Aguas de Valencia, 2013)

❖ Externalities to be considered for this measure:

→ *CO_2 neutral compensation:* reuse of the CO_2 from other external processes.

The *Income per capita affectation* is not being considered due to the annual expenditure the measures have to face is too little (20.000 €) to be compared with the total population to which it is serving.

❖ Externalities calculation

Calculation is based on the period of exploitation since the Emergency wells came into service, from 2009 to 2013. Further figures are estimations considering the average of the operation period.

→ ***Positive externalities:***

Year	2009	2010	2011	2012	Average
CO_2 neutral compensation	2114,33 €	1581,79 €	2180,89 €	4751,43 €	2657,11 €

TOTAL	**2114,33 €**	**1581,79 €**	**2180,89 €**	**4751,43 €**	**2657,11 €**

Figures considered:

- CO_2 neutral compensation
  - **Annual reuse of CO_2:** 359.358 kg CO_2 (2009), 269.012 kg CO_2 (2010), 370.900 kg CO_2 (2011), 808.067 kg CO_2 (2012).

Table 11-5. Adaptation measure 2 positive externalities. *Source: own, based on Grupo Aguas de Valencia, 2013.*

→ ***Net Present Values (NPV) obtained***

For every emission scenario, the following NPV have been obtained[7] :

Emission Scenarios (discount rate)			
A2 (3%)	**A1 (4%)**	**B2 (5%)**	**B1 (6%)**
NPV A2	**NPV A1**	**NPV B2**	**NPV B1**
-1.236.223,90 €	**-1.205.195,24 €**	**-1.178.724,39 €**	**-1.156.024,37 €**

Table 11-6. Emission scenarios NPV for Adaptation measure 2. *Source: own.*

❖ Discussion of results

Even if the ideal circumstance is to ensure reuse of CO2 emissions from other projects where the CO2 would otherwise be released directly into the atmosphere an NPV < 0 for all climate scenarios shows that this measure on a short (and long term) is not profitable.

However, this may be not the case if the fixed price per Ton of CO_2 in the Emissions Trading System increases in the future, as benefits would be higher. The value of CO_2 emission rights is very volatile and factors such as climate, political and economic situations and the volume of assignments at European level, directly influence their evolution. Benefits resulting from the CO_2 reuse would be much higher if the price for a Ton would remain above 20 € [8], and could exceed annual expenditure, which is not very high.

It has to be noted as well, that this measure is a part of a whole purification process taking place in “La Presa” and “El Realon” purification plants. Thus, costs that are the outcome of this measure are compensated with the overall infrastructure process (e.g. a better purification treatment achieved with CO_2 injection may increase confidence in tap water by Valencia’s population who, therefore, may choose this water at the expense of bottled one).

[7] See ANNEX 1 for NPV calculation.
[8] The historical maximum relies in 30,5 €/Ton CO_2 (SendCO2, 2013).

ADAPTATION MEASURE 3: Based on the reclaimed water reuse in Empuriabrava Wastewater Treatment Plant.

- Location: Alt Empordà, North-East of Catalonia (Spain).
- Year: 1998
- *Adaptation to climate change capacity: Collection and use of reclaimed water to guarantee water supply for preserved wetlands facing water scarcity in summer periods and possible climate change scenarios.*
- Stakeholders involved: CONSORCI DE LA COSTA BRAVA (CCB)

This consortium was created between Girona's council and 27 coastal municipalities of the region in 1971. The initial target was to be in charge of the water resources management with the goal of preservation of the water quality, especially for the coast considering the region's increasing tourism industry. At the present day, its main functions are related to high level supply and sanitation. They are being in charge of purification plants, one desalination plant and 19 wastewater treatment plants.

- Concept:

The main defining feature of the Empuriabrava Wastewater Treatment Plant (WWTP) is the presence of a lagooning system and a constructed wetland that allows the reuse of water, the so-called "Wastewater Reclamation and Reuse Systems" (WWRRS). The constructed wetland system is constituted by three cells in parallel (0.8 ha of surface area each one, 0.5 m depth and 12,000 m^3 total volume) and a large shallow wetland (4.5 ha). The system was set in operation in 1998 and mainly treats the secondary effluents from Empuriabrava WWTP, where it previously follows an activated sludge process (Seguí, L., et. al. 2007). The tertiary treatment (WWRRS) allows the reclaimed water effluent to be used for environmental purposes for the Aiguamolls de l'Empordà Natural Park, an important wetland protected area in the Alt Empordà (North-East of Catalonia, Spain). Main reasons for producing reclaimed water with a natural water treatment were (CCB, 2013):

- Guaranteeing the availability of good quality water, especially during the summer. Wetlands tend to dry up due to water consumption in agriculture, extracted in the upper stream of the Muga River (which supplys the wetlands).
- Being a preventive measure to face water scarcity induced by climate change.
- Guaranteeing a major ecological flow for the Muga River, as well as a good microbiological quality of the beach located on the river mouth.
- Inducing groundwater recharge and avoiding sea water intrusion.
- Avoiding the dumping of 25,000 kg N and 6,250 kg P per year to the final stream of the river and to the sea, therefore reinforcing local biodiversity.
- Providing N and P for irrigated croplands (saving in the use of fertilisers).
- Avoiding eutrophisation that could occur in case of not having a sufficient nutrient elimination.

- Reinforcing biodiversity, as nutrients are recycled through the wetland's food chains.
- Recreating endangered ecosystems (lagoons and wetlands) to provide shelter for migratory and autochthonous birds.
- Promoting research and environmental education.

The remaining part of the flow entering the Empuriabrava WWTP goes through a conventional primary and secondary treatment and is discharged to the Muga River. As well, sludge resulting from the water treatment is destined for agricultural use.

Figure 11-3. Scheme and aerial view of the Empuriabrava WWTP, the lagooning system and the constructed wetlands (WWRRS). *Source: Seguí, L., et al., 2007.*

Design figures:	
- Turn into operation: 1995 - Occupied area: 49.500 Ha - Treatment lines: 2 - Installed power: 135 kW	- Design flow: 16.750 m^3/day. - Population equivalent: 67.000 p.e. - Sludge production destination: Agriculture (external compost). - Type of process: Lagooning system and aeration.

Year	Treated flow (m^3/year)			Energy consumption (kW/m^3)	Sludge production (Tn dry matter)	Influent concentration (mg /L) and reduction in the effluent (%)	
	To the river (secondary effluent)	To the Natural Park (tertiary treatment – reclaimed)	TOTAL			N (mg N/L)	P (mg P/L)
2004	503.081	438.630	941.711	0,73	351,7	67,1 (73%)	10,7 (48%)
2005	151.497	903.478	1.054.975	0,65	284,4	61,4 (77%)	9,5 (55%)
2006	397.291	660.837	1.058.128	0,57	322,4	56,5 (71%)	8,1 (47%)
2007	84.403	948.382	1.032.785	0,63	220,8	57,6 (85%)	7,8 (43%)
2008	44.785	1.017.784	1.062.569	0,68	286,0	56,4 (86%)	9,68 (46%)
2009	4.008	1.031.677	1.035.685	0,66	252,3	62,67 (88%)	9,09 (69%)
2010	157.846	1.187.474	1.345.320	0,51	260,8	53,0 (84%)	8,0 (84%)
2011	162.237	1.380.521	1.542.758	0,44	348,1	51,0 (85%)	10,5 (76%)
2012	204.497	1.199.244	1.403.741	0,45	277,1	55,0 (90%)	7,2 (90%)

Table 11-7. Empuriabrava water treatment plant design figures and treated flows during period 1998-2011.
Source: adapted from CCB, 2013.

Adaptation Measure 3 Analysis

❖ Budget estimation:

- Initial investment (Year 0): **1,378,599 €** (CCB, 2001) [9]
- Annual expenditure**: 231,376 €** (CCB, 2001) [10]

The performance of the WWRRS at Empuriabrava depends on the good condition and good management of both the WWTP and the constructed wetlands. It is important to point out that in the first stage only the WWTP had been constructed and was thus under management. This fact allows for the separation of the different costs from wastewater treatment and reclamation (Seguí, L. et al., 2007).

9 See ANNEX 1 for detailed investment.
10 See ANNEX 1 for detailed annual expenditure.

❖ Externalities to be considered for this measure:

→ *Water gains:* volume of reclaimed water produced by the WWRRS that can be used for environmental restoration purposes and that replaces an substancial volume of drinking water.
→ *Pollution savings:* pollution avoided that, without the treatment received in the Empuriabrava WWTTP and WWRRS, would be spilled into the Muga River and the Aiguamolls de l'Empordà Natural Park.
→ *Sludge valuation:* benefits from the agricultural use of sludge generated in the Empuriabrava WWTTP.
→ $CO_{2\text{-equivalent}}$ *emissions:* produced by the Empuriabrava WWTTP's electricity consumption.
→ *Income per capita affectation:* the budgetary impact on the population equivalent being served by the project (67,000 p.e.).

As it can be deduced from above figures, it is an innovative and pioneering water treatment plant in Spain, in terms of reclaimed water production and reuse combined with environmental restoration. This makes it an example from which many externalities can be calculated.

❖ Externalities calculation

Calculation is based on the period of exploitation from 2004 to 2012. Further figures are estimations based on the average during the operation period. Year 0 is considered to be 2003.

→ ***Positive externalities***

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Water gains (water reuse savings)	38.292,40 €	78.873,63 €	57.691,07 €	82.793,75 €	88.852,54 €	90.065,40 €	103.666,48€	120.519,48 €	104.694,00 €	85.049,86 €
Pollution savings (secondary effluent + reclaimed water)	1.365.656,51 €	1.717.952,85 €	1.407.504,74 €	1.546.616,32	1.685.972,19	1.765.348,71	1.923.010,76€	2.316.269,36 €	2.021.371,76 €	1.749.967,02 €
Sludge valuation	1.279,57 €	1.034,72 €	1.172,97 €	803,33 €	1.040,54 €	917,93 €	948,86 €	1.266,47 €	1.008,16 €	1.052,51 €
TOTAL	**1.405.228,49 €**	**1.797.861,20€**	**1.466.368,78 €**	**1.630.213,40 €**	**1.775.865,28 €**	**1.856.332,05 €**	**2.027.626,10 €**	**2.438.055,32 €**	**2.127.073,92 €**	**1.836.069,39 €**

Figures considered:

- Water gains
  - **Water supply price of the region (Catalonia - 2013):** 0,4469 €/m^3 (ACA, 2013).
  - **Price of reclaimed water:** 0,3596 €/ m^3 (Seguí, L., et al., 2007)
  - **Volume of reclaimed water produced annually**: 438.630 m^3 (2004), 903.478 m^3 (2005), 660.837 m^3 (2006), 948.382 m^3 (2007) 1.017.784 m^3 (2008), 1.031.677 m^3 (2009), 1.187.474 m^3 (2010), 1.380.521 m^3 (2011), 1.199.244 m^3 (2012)
- Pollution savings
  - **Influent N concentration (mg N/L) and its reduction in the effluent:** 67,1 (73%) (2004); 61,4 (77%) (2005); 56,5 (71%) (2006); 57,6 (85%) (2007); 56,4 (86%) (2008); 62,67 (88%) (2009); 53,0 (84%) (2010); 51,0 (85%) (2011); 55,0 (90%) (2012).
  - **Influent P concentration (mg P/L) and its reduction in the effluent:** 10,7 (48%) (2004); 9,5 (55%) (2005); 8,1 (47%) (2006); 7,8 (43%) (2007); 9,68 (46%) (2008); 9,09 (69%) (2009); 8,0 (84%) (2010); 10,5 (76%) (2011); 7,2 (90%) (2012).
  - **Volume of reclaimed water produced annually**: 438.630 m^3 (2004), 903.478 m^3 (2005), 660.837 m^3 (2006), 948.382 m^3 (2007) 1.017.784 m^3 (2008), 1.031.677 m^3 (2009), 1.187.474 m^3 (2010), 1.380.521 m^3 (2011), 1.199.244 m^3 (2012)
  - **Volume of treated water (secondary effluent):** 503.081 m^3 (2004), 151.497 m^3 (2005), 397.291 m^3 (2006), 84.403 m^3 (2007), 44.785 m^3 (2008), 4.008 m^3 (2009), 157.846 m^3 (2010), 162.237 m^3 (2011), 204.497 m^3 (2012)
- Sludge valuation:

- **Region's sludge application (Catalonia – 2009):** 84% (ACA, 2009)
- **Nitrogen present in sludge:** 3,5%
- **Phosphorous present in sludge:** 0,22%
- **Price 1 Kg of N in fertiliser:** 7,5 €/ kg N **Price 1 Kg of P in fertiliser:** 7,5 €/ kg P.
- **Sludge production:** 351,7 Tn (2004), 284,4 Tn (2005), 322,4 Tn (2006), 220,8 Tn (2007), 286,0 Tn (2008), 252,3 Tn (2009), 260,8 Tn (2010), 348,1 Tn (2011), 277,1 Tn (2012).

Table 11-8. Adaptation measure 3 positive externalities. *Source: own, based on ACA, 2013; Seguí, L., et al., 2007; CCB, 2013; ACA, 2009.*

→ ***Negative externalities***

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
$CO_{2\text{-equivalent}}$ emissions	1.079,27 €	1.076,57 €	946,89 €	1.046,57 €	1.134,37 €	1.073,15 €	1.077,17 €	1.065,71 €	991,72 €	1.054,60 €
Income per capita affectation	121.948,71 €	136.616,05 €	136.616,05 €	133.742,51 €	137.599,45 €	134.118,06 €	174.214,85 €	199.782,47 €	181.780,19 €	150.713,15 €
TOTAL	**123.027,98 €**	**137.692,63 €**	**137.562,95 €**	**134.789,08 €**	**138.733,82 €**	**135.191,21 €**	**175.292,02 €**	**200.848,18 €**	**182.771,91 €**	**151.767,75 €**

Figures considered:

- $CO_{2\text{-equivalent}}$ emissions
  - **Energy consumption per m^3:** 0,73 kW/m^3 (2004), 0,65 kW/m^3 (2005), 0,57 kW/m^3 (2006), 0,63 kW/m^3 (2007), 0,68 kW/m^3 (2008), 0,66 kW/m^3 (2009), 0,51 kW/m^3 (2010), 0,44 kW/m^3 (2011), 0,45 kW/m^3 (2012). **Energy source:** Electricity
  - **Volume of water treated annually (secondary effluent + reclaimed):** 941.711 m^3 (2004), 1.054.975 m^3 (2005), 1.058.128 m^3 (2006), 1.032.785 m^3 (2007), 1.062.569 m^3 (2008), 1.035.685 m^3 (2009), 1.345.320 m^3 (2010), 1.542.758 m^3 (2011), 1.403.741 m^3 (2012).
- Income per capita affectation
  - **Wastewater price of the region (Alt Empordà):** 0,38 €/m^3 (Seguí, L., et al., 2007).
    Volume of water treated annually (secondary effluent + reclaimed): 941.711 m^3 (2004), 1.054.975 m^3 (2005), 1.058.128 m^3 (2006), 1.032.785 m^3 (2007), 1.062.569 m^3 (2008), 1.035.685 m^3 (2009), 1.345.320 m^3 (2010), 1.542.758 m^3 (2011), 1.403.741 m^3 (2012).

- **Region's Gross Domestic Product (Alt Empordà):** 3.401,3 M € (Idescat, 2013).
- **Gross Disposable Income per Capita (Alt Empordà):** 17.300 €/hab (Idescat, 2013).
- **Population Equivalent that the project is serving:** 67.000 p.e.

Table 11-9. Adaptation measure 3 negative externalities. *Source: own, based on Seguí, L., et al., 2007; CCB, 2013; Idescat, 2013.*

→ ***Net Present Values (NPV) obtained***

For every emission scenario, the following NPVs have been obtained[11] :

Emission Scenarios (discount rate)			
A2 (3%)	**A1 (4%)**	**B2 (5%)**	**B1 (6%)**
NPV A2	**NPV A1**	**NPV B2**	**NPV B1**
25.105.459,61 €	**22.165.349,53 €**	**19.681.091,83 €**	**17.569.682,69 €**

Table 11-10. Emission scenarios NPV for Adaptation measure 3. *Source: own.*

[11] See ANNEX 1 for NPV calculation.

- Discussion of results

All Net Present Values indicate that the Empuriabrava reclamation water reuse measure is highly profitable in all climate change scenarios, especially from an environmental point of view. Benefits are evident as it is a very complete measure: an extensive volume of water is saved for environmental restoration while pollutants are removed, it requires very low energy consumption to achieve its targets and sludge produced is destined to agriculture. All these positive aspects make it a worthwhile measure to be adopted as a model for other environmental adaptation measures.

Independently of the climate change scenarios, Net Present Values are very high, indicating clearly that the benefits are much more significant than the costs incurred. These high values obtained suggest that this measure is redundantly necessary in any climate change scenario, even if climatic impacts would be minimal.

Considering the average values, *income per capita affectation* represents 39.33% of the total costs, while $CO_{2\text{-equivalent}}$ emissions only 0.28%, and economic costs 60,38%. But the most positive aspect of the analysis is that environmental benefits are 4.78 times higher than total costs (without discounting depreciation).

NPV for scenario A2 is 30% higher than for scenario B1, reflecting the high importance of implementing this measure in high impact climate change scenarios such as A2.

ADAPTATION MEASURE 4: Based on the management plan for the use of waters external to the drinking water supply network of Sabadell.

- Location: Sabadell, Barcelona metropolitan area (Spain).
- Stakeholders involved: *Sabadell City Council* and *Companyia d'Aigües de Sabadell (Sabadell Water Company)*
- Year: 2004
- *Adaptation to climate change capacity: Use of reclaimed water and groundwater for non-drinking urban and industrial purposes in the city of Sabadell, so to avoid using water from the drinking supply network and thus guaranteeing resources in drought periods induced by climate change.*

- Stakeholders involved:

SABADELL CITY COUNCIL

COMPANYIA D'AIGÚES DE SABADELL (Group CASSA)

This is the company in charge of drinking water supply to the city of Sabadell from the Llobregat River. It also manages the sanitation and water reuse infrastructure. It was founded in 1949. The company is owned by the Group CASSA, a business group for which Sabadell's city council is one of its stockholders.

- Concept:

This is a pioneering project in the city of Sabadell, where a management plan has been projected and executed (and is functioning today) in order to make use of water resources external from the usual drinking water supply system. The main target of the plan is to replace drinking water that previously was destined for urban purposes (street cleaning and urban park's irrigation) and for potential industrial utilisation with lower quality water from other sources. A total volume of 1.107 Hm^3/year of drinking water is saved with this measure (from a total of 19 Hm^3 of Sabadell's annual consumption, representing a 7% of the total demand, the equivalent to 25 days of supply per year) (Companyia d'Aigües de Sabadell, 2005).

Infrastructure planning was based on the indirect use of the reclaimed water effluents from the city's wastewater treatment plants, "Riu Ripoll" and "Riu Sec", both having a tertiary treatment. These two plants recover all of Sabadell's both domestic and industrial wastewaters. In the past, there was an intensive extraction of groundwater from the Ripoll River's[12] aquifer due to the high industrial activity in the Sabadell area, and river water flow was very scarce in the section where it crossed the city. To solve this, the reclaimed water effluent (30,000 m^3/day) from the wastewater treatment plant "Riu Ripoll", located down the city, is pumped upstream through a 6,295 meters pipe and is discharged in the upper part of the river, allowing water to flow through the city section. Meanwhile, it also recharges the river aquifer (Vinyoles, J., et al., 2005).

[12] Ripoll River: See Chapter 10.3 for more information

This aquifer recharge enables recovering an old mine ("Mina del riu Ripoll") as one of the plant's strategic point for water capture. This mine connects with a well that was abandoned in 1985 and put into function again in 2004. In this well, groundwater from the aquifer is retained and a disinfection system has been installed to meet the quality standards (chlorination and ultraviolet). Afterwards, water is distributed along the North Zone pipe network, which is used for park irrigation and street cleaning purposes. Therefore, it is a closed water circuit, as part of water extracted from the aquifer is water from the wastewater treatment plant that was previously discharged into the Ripoll River, upstream. This closed-circuit guarantees a normal flow interaction between the river and the aquifer, and the volume of groundwater extracted does not have a negative effect.

On the other hand, there is the South Zone pipe network. It distributes the volume of reclaimed water produced by the wastewater treatment plant "Riu Sec" mainly for industrial purposes, and a small proportion is for irrigation and street cleaning. Reclaimed water is captured directly from the plant's effluent exit.

North and South distribution networks have 18,000 meters of pipes and five regulation deposits altogether, and are complemented with another well ("Mina de Ribatallada") which extracts a small volume of water destined to fill the tanks of the trucks that are in charge of street cleaning.

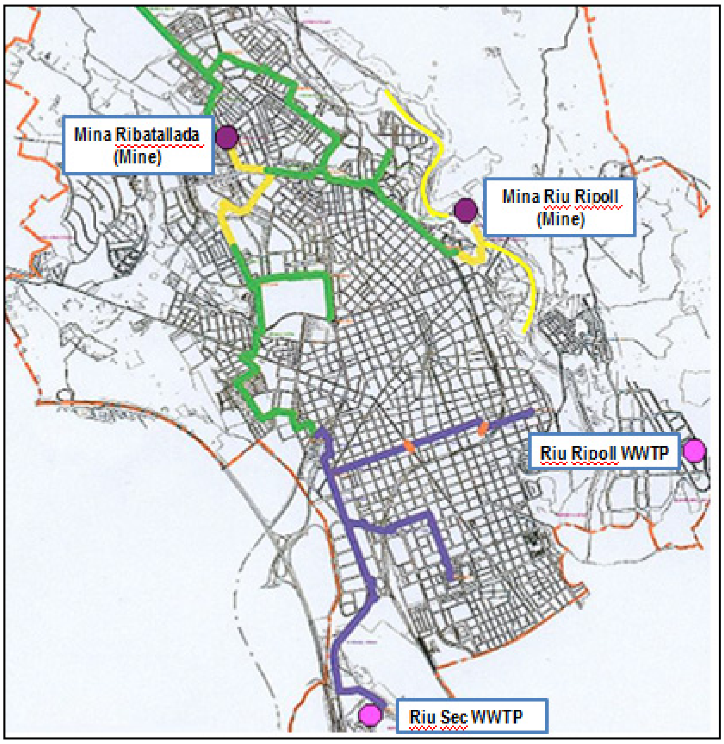

Figure 11-4. Reclaimed water distribution networks (yellow: 2004 existing pipes; green: North Zone network; blue: South Zone network). *Source: Vinyoles, J., et al., 2005.*

The total volume of water distributed depends on the potential demand to be managed, which was calculated assuming a 85% network efficiency:

Sector	North Zone network (m^3/year)	South Zone network (m^3/year)	Total Demand (m^3/year)
Park irrigation	271.000	58.000	329.000
Street cleaning	125.000	125.000	250.000
Industrial use	-	362.000	362.000
TOTAL	**466.000**	**641.000**	**1.107.000**

Table 11-11. Water distributed through North and South Zone networks. *Source: Companyia d'Aigües de Sabadell, 2005.*

<u>Adaptation Measure 4 Analysis</u>

❖ Budget estimation:

- Initial investment, 2004 (Year 0): **739,500 €** [13]
- Annual expenditure: **204,600 €** (Companyia d'Aigües de Sabadell, 2005)[14].

This measure contemplated the possibility of receiving support from public economic help (e.g. from the European Cohesion Funds or the Catalan Water Agency) (Ajuntament de Sabadell, 2004). Even if investments for year 0 are 4,390,000 €, the management plan foresaw a subsidy of 85% of the total investment to make the infrastructure attractive to the industrial stakeholders who may be interested in introducing reclaimed water into their own industrial processes.

This financial help was justified through making reference to the savings on other water infrastructures extension (dams, high level supply network) on a long term. Additionally, it also pointed out the increase in the guarantee of supply from which Sabadell would benefit, especially in case of possible future drought periods.

Thus, the total investment is comprised as follows:

- Public funds: **4,190,500 €** (85%)
- Private investment: **739,500 €** (15%)

Only private investment is considered for the analysis.

❖ Externalities to be considered for this measure:

→ *Water savings:* this concept will take account of the water savings made from using another alternative water sources such as reclaimed and groundwater instead of drinking water.
→ $CO_{2\text{-equivalent}}$ *emissions:* produced by the North and South network electricity consumption.
→ *Income per capita affectation:* the budgetary impact on the population being served by the project.

❖ Externalities calculation:

13 See ANNEX 1 for detailed investment.
14 See ANNEX 1 for detailed annual expenditure.

Calculation is based only on the figures of 2005 (annual expenditure, reclaimed water production and electricity consumption figures), due to the lack of information concerning the following years. Therefore, annual expenditure and the externalities values considered for the NPV calculation will remain the same for the period of study, covering 2004-2030.

→ ***Positive externalities***

Year	2005	2006	2007	2008-2029	2030
Water savings	277.967,7 €	277.967,7 €	277.967,7 €	[…]	277.967,7 €
TOTAL	**277.967,7 €**	**277.967,7 €**	**277.967,7 €**	**[...]**	**277.967,7 €**

Figures considered:

- Water gains
  - **Water supply price of the region (Catalonia - 2013):** 0,4469 €/m^3 (ACA, 2013).
  - **Price of reclaimed water:** 0,1889 €/m^3 (Companyia d'Aigües de Sabadell, 2005).
  - **Volume of reclaimed water produced annually**: 1.107.000 m^3/year (Companyia d'Aigües de Sabadell, 2005).

Table 11-12. Adaptation measure 4 positive externalities. *Source: own, based on ACA, 2013; Companyia d'Aigües de Sabadell, 2005.*

→ ***Negative externalities***

Year	2005	2006	2007	2008-2029	2030
$CO_{2\text{-equivalent}}$ emissions	41.710,7 €	41.710,7 €	41.710,7 €	[…]	41.710,7 €
Income per capita affectation	55.559,77 €	55.559,77 €	55.559,77 €	[…]	55.559,77 €
TOTAL	**97.270,47 €**	**97.270,47 €**	**97.270,47 €**	**[...]**	**97.270,47 €**

Figures considered:

- $CO_{2\text{-equivalent}}$ emissions
  - **Energy consumption per m^3:** 0,03 kW/m^3 [deduced from the energy costs, 23.700 € (Companyia d'Aigües de Sabadell, 2005), and the industrial unit price for a kW in 2005, 0,69 €/kW (MINETUR, 2012)]
  - **Energy source:** Electricity
  - **Volume of reclaimed water produced annually**: 1.107.000 m^3/year.
- Income per capita affectation
  - **Price of reclaimed water:** 0.1889 €/m^3 (Companyia d'Aigües de Sabadell, 2005).
  - **Volume of reclaimed water produced annually:** 1.107.000 m^3/year.
  - **Region's Gross Domestic Product (Sabadell):** 4.988,2 M € (Idescat, 2013).
  - **Gross Disposable Income per Capita (Sabadell):** 24.300 €/hab (Idescat, 2013).
  - **Population of which the project is serving:** 86.650 clients (Companyia d'Aigües de Sabadell, 2005).

Table 11-13. Adaptation measure 4 negative externalities. *Source: own, based on MINETUR, 2012, Idescat, 2013, Companyia d'Aigües de Sabadell, 2005.*

→ ***Net Present Values (NPV) obtained***

For every emission scenario, the following NPV have been obtained[15] :

Emission Scenarios (discount rate)			
A2 (3%)	**A1 (4%)**	**B2 (5%)**	**B1 (6%)**
NPV A2	**NPV A1**	**NPV B1**	**NPV B1**
-1.155.722,46 €	**-1.112.910,98 €**	**-1.076.380,32 €**	**-1.045.057,62 €**

Table 11-14. Emission scenarios NPV for Adaptation measure 1. *Source: own.*

❖ Discussion of results

Net Present Values indicate that this measure would not be profitable under any climate scenario. Annual expenditure needed for the implementation of this measure is (and would) be too high for the positive externalities to overcome it. With the exception of an alternative condition that would lower the annual expenditure (such as co-financing, as with the initial investment), this measure, unfortunately, would not be attractive to invest in.

Nevertheless, from the externalities point of view, positive outcomes resulting from this adaptation measure are 2.85 times higher than other measures (taking average figures and without discounting depreciation). Water savings that can be achieved with this management approach are a very important fact to consider, as the region would clearly face water scarcity resulting from climate change induced droughts.

Additionally, this measure represents a guarantee for the Ripoll River's flow to be maintained; otherwise, its typical Mediterranean low water regime could be severely affected under whichever climate change scenario. Therefore, it is very necessary to remark that more environmental positive externalities would derive from this measure, but monetarily it is not viable.

15 See ANNEX 1 for NPV calculation.

ADAPTATION MEASURE 5: Based on the Educational and awareness campaign to promote water savings in Badalona.

- Location: Badalona, Barcelona Metropolitan Area (Spain).
- Year: 2001, 2003.
- *Adaptation to climate change capacity: Educate and increase citizen awareness to promote water efficiency in the domestic sector and, therefore, save significant volumes of water.*

- Stakeholders involved:

BADALONA CITY COUNCIL

AIGÜES DE BARCELONA (AGBAR)

This private company is in charge of the water supply for the city of Badalona, as well for Barcelona and for 22 municipalities of its metropolitan area: in total 1,400,000 clients. The company is part of a large group called AGBAR, one of the major international water companies, which is present in nine countries and serves 25.6 million people (AGBAR, 2013).

- Concept:

Two campaigns, one in 2001 and another in 2003, were carried out in the city of Badalona to promote water savings in the domestic sector. The domestic sector is responsible for 78% of Badalona's total water consumption, 12% goes to the commercial and industrial sector and 5% to municipal use (Diputació de Barcelona, 2007). Therefore, awareness of efficient water usage is important.

Both campaigns were based on the free distribution of 1,000 *kits* (2,000 for the two years) containing water regulation instruments for households: one regulation valve for the shower and one diffuser for the tap. Citizens could monitor themselves water savings with easy to install instruments (La Xarxa, 2003).

Any resident of Badalona who requested it could participate in the campaign. After receiving the *kit,* participants would commit to install the regulation instruments, provide the latest water bill and collaborate with the campaign's monitoring. One year later, a telephone questionnaire was conducted with a random selection of participants.

Considering the two campaigns together, it was calculated that savings in average amounted to 15.5% per client. That represented a total amount of 110,700 litres saved per day (Diputació de Barcelona, 2007), which per annum represents an equivalent of 40,405.5 m^3/year.

Figure 11-5. Tap diffuser distributed for the Badalona water saving awareness campaign. *Source: Diputació de Barcelona, 2007.*

<u>Adaptation Measure 5 Analysis</u>

❖ <u>Budget estimation</u>:

- Initial investment, 2004 (Year 0): **none**
- Annual expenditure: **6.000 €** (Diputació de Barcelona, 2007).

❖ <u>Externalities to be considered for this measure</u>:

→ *Water savings:* resulting from the implementation of water efficient instruments in a portion of Badalona households.

The *Income per capita affectation* is not being for this measure.

❖ <u>Externalities calculation</u>:

Calculation is based on the implementation of the measure every two years. Therefore, after a campaign there is a gap year.

→ ***Positive externalities***

It is considered that every two years, an extra volume of 20,202.5 m^3/year is saved.

Year	2001	2003	2005	2007-2028	2030
Water savings	11.858,86 €	23.717,72 €	33.576,60 €	[…]	166.024,04 €
TOTAL	**11.858,86 €**	**23.717,72€**	**33.576,60 €**	**[...]**	**166.024,04 €**

Figures considered:

- Water gains
  - **Water supply price (Badalona- 2013):** 0,587 €/m^3 (AGBAR, 2013).
  - **Volume of reclaimed water saved:** + 20.202,5 m^3 every two years (Diputació de Barcelona, 2007).

Table 11-15. Adaptation measure 5 positive externalities. *Source: own, based on AGBAR, 2013; Diputació de Barcelona, 2007.*

→ ***Net Present Values (NPV) obtained***

For every emission scenario, the following NPV have been obtained[16] :

Emission Scenarios (discount rate)			
A2 (3%)	**A1 (4%)**	**B2 (5%)**	**B1 (6%)**
NPV A2	**NPV A1**	**NPV B2**	**NPV B1**
587.908,18 €	**510.043,06 €**	**444.839,47 €**	**389.998,06 €**

Table 11-16. Emission scenarios NPV for Adaptation measure 1. *Source: own.*

❖ Discussion of results

Net Present Values show that if this water saving campaign could be implemented up until 2030, it would be highly profitable, especially taking into account the low costs involved in developing it. Furthermore, this measure that would double water savings (a positive environmental externality) every two years. Only considering the first year of implementation, benefits were 1.98 times higher (almost double) than current average annual expenditure. At the end of the study period, in 2030, this would amount to almost 28 times higher. That is a highly valuable volume of drinking water that could be saved (and, therefore, not extracted). This is a strong argument to finance this profitable adaptation measure.

[16] See ANNEX 1 for NPV calculation.

12. Prioritisation of the selected Adaptation measures

Prioritisation of which adaptation measure among the five analysed would be the most attractive to invest in will be based on the steps explained in Chapter 6.1. Many factors might play a key role on the final decision. Below, all Net Present Values (NPV) from all measures are compiled, and an analysis of costs and benefits calculated for all the adaptation measures is carried out, taking as a reference the average values:

	Emission Scenarios NPV (discount rate)			
	NPV A2	NPV A1	NPV B2	NPV B1
Adaptation Measure 1	11.746.191,48 €	10.181.781,83 €	8.847.953,51 €	7.704.958,81 €
Adaptation Measure 2	-1.236.223,90 €	-1.205.195,24 €	-1.178.724,39 €	-1.156.024,37 €
Adaptation Measure 3	25.105.459,61 €	22.165.349,53 €	19.681.091,83 €	17.569.682,69 €
Adaptation Measure 4	-1.155.722,46 €	-1.112.910,98 €	-1.076.384,32 €	-1.045.057,62 €
Adaptation Measure 5	587.908,18 €	510.043,06 €	444.839,47 €	389.998,06 €

Table 12-1. Net Present Values compilation corresponding to the five adaptation measures analysed. *Source: own.*

MEASURE 1: Emergency wells Initial investment: 1.830.946,42 €

	Costs	Benefits	Net Benefits
Private	539.616,12 €	0,00 €	- 539.616,12 €
Environmental	43.770,75 €	2.037.392,61 €	1.993.621,86 €
Social	579.273,23 €	0,00 €	- 579.273,23 €
TOTAL	**1.162.660,10 €**	**2.037.392,61 €**	**874.732,51 €**

MEASURE 2: CO_2 injection Initial investment: 934.114 €

	Costs	Benefits	Net Benefits
Private	20.000 €	0,00 €	- 20.000,00 €
Environmental	0,00 €	2.657,11 €	2.657,11 €
Social	0,00 €	0,00 €	0,00 €
TOTAL	**20.000 €**	**2.657,11 €**	**- 17.342,89 €**

MEASURE 3: Reclaimed water Initial investment: 1.378.599 €

	Costs	Benefits	Net Benefits
Private	231.376 €	0,00 €	- 231.376,00 €
Environmental	1.054,60 €	1.836.069,39	1835.014,79 €
Social	150.713,15 €	0,00 €	- 150.713,15 €
TOTAL	**383.144 €**	**1.836.069,39 €**	**1.452.925,64 €**

MEASURE 4: Water re-use plan Initial investment: 739.500€

	Costs	Benefits	Net Benefits
Private	739.500 €	0,00 €	- 204.600,00 €
Environmental	41.710,70 €	277.967,70 €	236.257,00 €
Social	55.559,77 €	0,00 €	- 55.559,77 €
TOTAL	**836.770 €**	**277.967,70 €**	**- 558.802,77 €**

MEASURE 5: Water saving campaign Initial investment: none

	Costs	Benefits	Net Benefits
Private	6.000 €	0,00	- 6.000,00 €
Environmental	0,00 €	11.858,86 €	11.858,86 €
Social	0,00 €	0,00 €	0,00 €
TOTAL	**6.000 €**	**11.858,86 €**	**5.858,86 €**

Table 12-2. Compilation of economic costs and environmental and social externalities resulting from the implementation of the adaptation measures analysed. *Source: own.*

Taking a look at Tables 12-1 and 12-2, prioritisation can be made according to the aspect to which decision makers attach most importance to at the time of choosing the most appropriate adaptation measure to finance. If the available budget is very restricted, then the prevailing decisive aspect would be the economic costs (initial investment and annual expenditure). However, if budget leeway is wide enough, the choice of adaptation measures could also be made considering the *highest NPV value*, the *lowest initial investment*, the *lowest private costs*[17], *the most environmentally effective*[18], the *less environmentally harmful*[19] or *the less socially costly*[20] (see Chapter 6.1)

Taking into account these different decision making aspects, the adaptation measures can be ranked in terms of preference:

	NPV	Initial investment	Private costs	Environmental external benefits	Environmental external costs	Social external costs
Rank # 1	AD.M. 1	AD.M. 5	AD.M. 5	AD.M. 1	AD.M. 2 or 5	AD.M. 2 or 5
Rank # 2	AD.M. 3	AD.M. 4	AD.M. 2	AD.M. 3	AD.M. 2 or 5	AD.M. 2 or 5
Rank # 3	AD.M. 5	AD.M. 2	AD.M. 3	AD.M. 4	AD.M. 3	AD.M. 4
Rank # 4	AD.M. 4	AD.M. 3	AD.M. 1	AD.M. 5	AD.M. 4	AD.M. 3
Rank # 5	AD.M. 2	AD.M. 1	AD.M. 4	AD.M. 2	AD.M. 1	AD.M. 1

Table 12-3. Ranking of the analysed adaptation measures under different decision aspects (AD.M. = Adaptation Measure). *Source: own.*

As it can be seen, prioritisation varies depending on the aspect assessed:

→ *NPV:* from an adaptation to climate change point of view, this aspect should be the most complete to rely on. Adaptation measures 1 and 3 are the ones with highest NPV and, therefore, the ones that give the most satisfactory performance during the period being considered (till 2030).

→ *Initial investment:* clearly a decision factor at the time of financing an adaptation measure. The lowest initial investments would be for adaptation measures 1 and 4. It is worth to point out that measure 4, which has been assessed an unprofitable in the CBA analysis, is the second "cheapest" measure of the group.

→ *Private costs:* very important to consider in case of budgetary restrictions after initial financing. From this point of view the cheaper adaptation

[17] Annual expenditure
[18] Total of environmental external benefits (annual average)
[19] Total of environmental external costs (annual average)
[20] Total of social external costs (annual average)

measures are 5 and 2, which correspond to those measures requiring less complexity during initial implementation.

→ *Environmental external benefits:* along with NPV, the adaptation process of a measure should take into account environmental benefits as a priority, especially on climate change scenarios highly likely to affect the environment. Those with a higher NPV, that is adaptation measures 1 and 3, are the ones that also have the highest environmental benefits.

→ *Environmental external costs:* these refer exclusively to $CO_{2\text{-equivalent}}$ emissions, showing that adaptation measures 2 and 5 are the most efficient due to the absence of CO_2 emissions during their respective processes (measure 2 is based on CO_2 compensation, and in measure 5 no energy is consumed). At the other end, measure 1 is the most energy intensive of all measures, which in terms of climate change, should be a factor to mitigate.

→ *Social external costs:* those adaptation measures for which heavy infrastructure is needed, such as measures 1 and 3, are the ones for which income per capita of the population served by the measure would be more greatly affected.

Consequently, if prioritisation is based strictly on NPV under the emission scenarios considered, the adaptation measure that should be chosen would be the one with the highest NPV values. Nevertheless, if there are budget restrictions, prioritisation would focus on how high the economic costs are and their potential affordability. In case of non-existent budget limitations, environmental positive externalities should be considered first: measures with the higher or more complete and diverse environmental benefits should be selected.

13. Conclusions

The projects selected as examples have shown that financing water projects under climate change scenarios relies on different variables that have to be considered separately. This makes financing possibilities not only dependent on the amount of money available and the measure's profitability but also on the performance of the adaptation capacity. This capacity in turn depends on the emission scenario under which the adaptation measure is considered and the external costs and benefits resulting from its implementation along the time period analysed.

It is highly important to measure external costs and benefits. Within this project monetary valuation was proposed for some externalities, which once calculated and integrated in the Cost-Benefit Analysis have seemed to be valid. Nonetheless, the prioritisation tool has been conceived assuming that the list of externalities is extendable and that more externalities resulting from water supply projects and water quality/environmental projects could be added.

Regional climate change scenarios are imperatively needed in order to predict possible location specific future challenges for the water sector. Climate change regional models prove to be essential instruments.

Prioritising each measure's performance independently and comparatively should be a distinguished step in climate change adaptation policies.

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ANNEX 1: Figures and calculations for the adaptation measures analysis.

ADAPTATION MEASURE 1:

→ **Estimated budget**

Costs estimated by Grupo Aguas de Valencia in the emergency wells project's report, corresponding to year 0:

Concept	Cost
Study Explorations (three)	27.167,73
Exploration in well Num. 12-bis	45.153,97
Exploration in well Num. 15	38.578,50
Exploration in well Num. 16	35.545,11
Installation of explorations in wells 11-14	7.845,41
Equipment for well Num. 15	72.326,04
Equipment for wells Num. 11 - 12 bis - 13 - 14	107.353,80
Electrification well Num. 15	84.583,88
Electrification well Num. 11 - 12 bis - 13 - 14	307.548,54
Conduction well Num. 15	40.413,65
Conduction well Num. 12	3.802,10
Improvements in well "Radial"	80.291,01
Remote control and instrumentation	86.643,21
Security, risk prevention and quality control	33.523,56
Others	10.000,00
Total concepts	**980.776,51**
5% unforeseen expenses	49.038,83
Material implementation budget	**1.029.815,34**
20,73% price updating	213.480,72
Upgraded material implementation budget	**1.243.296,06**
13% general costs	161.628,49
6% industrial benefit	74.597,76
Execution budget estimated in contract	**1.479.522,31**
Project drafting fee	49.439,89
Construction site management fee	49.439,89
Subtotal	**1.578.402,09**
16% VAT	252.544,33
TOTAL	**1.830.946,42**

Table A-1. Emergency wells budget estimation. *Source: Grupo Aguas de Valencia, 2013.*

→ **NPV calculation**

						Emission Scenarios (discount rate)			
Operating period	Year	Costs	Benefits	Net Benefits	Discount Factor	Present Value A1 (3%)	Present Value A2 (4%)	Present Value B1 (5%)	Present Value B2 (6%)
2009	0	1.830.946,42 €	0,00 €	-1.830.946,42 €	1,00 €	-1.830.946,42 €	-1.830.946,42 €	-1.830.946,42 €	-1.830.946,42 €
2010	1	1.126.268,06 €	343.456,07 €	-782.811,99 €	0,97 €	-760.011,64 €	-752.703,83 €	-745.535,22 €	-738.501,87 €
2011	2	1.141.610,64 €	1.057.605,57 €	-84.005,07 €	0,94 €	-79.182,84 €	-77.667,41 €	-76.195,08 €	-74.764,22 €
2012	3	1.167.959,96 €	2.284.084,56 €	1.116.124,60 €	0,92 €	1.021.412,12 €	992.230,71 €	964.150,40 €	937.119,74 €
2013	4	1.178.409,70 €	2.770.487,70 €	1.592.078,00 €	0,89 €	1.414.540,68 €	1.360.914,95 €	1.309.806,51 €	1.261.074,90 €
2014	5	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,86 €	754.551,95 €	718.966,36 €	685.375,81 €	653.651,02 €
2015	6	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,84 €	732.574,71 €	691.313,81 €	652.738,87 €	616.651,90 €
2016	7	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,81 €	711.237,58 €	664.724,82 €	621.656,06 €	581.747,08 €
2017	8	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,79 €	690.521,92 €	639.158,48 €	592.053,39 €	548.818,00 €
2018	9	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,77 €	670.409,63 €	614.575,46 €	563.860,38 €	517.752,83 €
2019	10	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,74 €	650.883,14 €	590.937,94 €	537.009,88 €	488.446,06 €
2020	11	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,72 €	631.925,38 €	568.209,56 €	511.437,98 €	460.798,17 €
2021	12	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,70 €	613.519,78 €	546.355,34 €	487.083,79 €	434.715,26 €
2022	13	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,68 €	595.650,27 €	525.341,68 €	463.889,33 €	410.108,73 €
2023	14	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,66 €	578.301,24 €	505.136,23 €	441.799,36 €	386.895,03 €
2024	15	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,64 €	561.457,51 €	485.707,91 €	420.761,29 €	364.995,31 €
2025	16	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,62 €	545.104,38 €	467.026,84 €	400.725,04 €	344.335,20 €
2026	17	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,61 €	529.227,55 €	449.064,27 €	381.642,90 €	324.844,53 €
2027	18	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,59 €	513.813,16 €	431.792,57 €	363.469,43 €	306.457,10 €
2028	19	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,57 €	498.847,73 €	415.185,16 €	346.161,36 €	289.110,48 €
2029	20	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,55 €	484.318,18 €	399.216,50 €	329.677,48 €	272.745,73 €
2030	21	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,54 €	470.211,83 €	383.862,02 €	313.978,56 €	257.307,29 €
2031	22	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,52 €	456.516,34 €	369.098,09 €	299.027,20 €	242.742,73 €
2032	23	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,51 €	443.219,74 €	354.902,01 €	284.787,81 €	229.002,58 €

2033	24	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,49 €	430.310,43 €	341.251,94 €	271.226,48 €	216.040,17 €
2034	25	1.162.660,10 €	2.037.392,61 €	874.732,51 €	0,48 €	417.777,12 €	328.126,86 €	258.310,93 €	203.811,48 €
						NPV A1	**NPV A2**	**NPV B1**	**NPV B2**
						11.746.191,5 €	**10.181.781,83 €**	**8.847.953,51 €**	**7.704.958,81 €**

Table A- 2. Emergency wells NPV calculation. *Source: own.*

ADAPTATION MEASURE 2:

→ **NPV calculation**

						Emission Scenarios (discount rate)			
Operating period	**Year**	**Costs**	**Benefits**	**Net Benefits**	**Discount Factor**	**Present Value A1 (3%)**	**Present Value A2 (4%)**	**Present Value B1 (5%)**	**Present Value B2 (6%)**
2008	0	934.114,00 €	0,00 €	-934.114,00 €	1,00 €	-934.114,00 €	-934.114,00 €	-934.114,00 €	-934.114,00 €
2009	1	20.000,00 €	2.114,33 €	-17.885,67 €	0,97 €	-17.364,73 €	-17.197,76 €	-17.033,97 €	-16.873,27 €
2010	2	20.000,00 €	1.581,79 €	-18.418,21 €	0,94 €	-17.360,93 €	-17.028,67 €	-16.705,86 €	-16.392,14 €
2011	3	20.000,00 €	2.180,89 €	-17.819,11 €	0,92 €	-16.307,01 €	-15.841,12 €	-15.392,82 €	-14.961,27 €
2012	4	20.000,00 €	4.751,43 €	-15.248,57 €	0,89 €	-13.548,16 €	-13.034,54 €	-12.545,04 €	-12.078,30 €
2013	5	20.000,00 €	2.657,11 €	-17.342,89 €	0,86 €	-14.960,13 €	-14.254,59 €	-13.588,61 €	-12.959,62 €
2014	6	20.000,00 €	2.657,11 €	-17.342,89 €	0,84 €	-14.524,40 €	-13.706,34 €	-12.941,53 €	-12.226,05 €
2015	7	20.000,00 €	2.657,11 €	-17.342,89 €	0,81 €	-14.101,36 €	-13.179,17 €	-12.325,27 €	-11.534,01 €
2016	8	20.000,00 €	2.657,11 €	-17.342,89 €	0,79 €	-13.690,64 €	-12.672,28 €	-11.738,35 €	-10.881,14 €

2017	9	20.000,00 €	2.657,11 €	-17.342,89 €	0,77 €	-13.291,88 €	-12.184,88 €	-11.179,38 €	-10.265,23 €
2018	10	20.000,00 €	2.657,11 €	-17.342,89 €	0,74 €	-12.904,74 €	-11.716,24 €	-10.647,03 €	-9.684,18 €
2019	11	20.000,00 €	2.657,11 €	-17.342,89 €	0,72 €	-12.528,87 €	-11.265,61 €	-10.140,03 €	-9.136,02 €
2020	12	20.000,00 €	2.657,11 €	-17.342,89 €	0,70 €	-12.163,95 €	-10.832,32 €	-9.657,17 €	-8.618,89 €
2021	13	20.000,00 €	2.657,11 €	-17.342,89 €	0,68 €	-11.809,66 €	-10.415,69 €	-9.197,30 €	-8.131,02 €
2022	14	20.000,00 €	2.657,11 €	-17.342,89 €	0,66 €	-11.465,69 €	-10.015,09 €	-8.759,34 €	-7.670,78 €
2023	15	20.000,00 €	2.657,11 €	-17.342,89 €	0,64 €	-11.131,74 €	-9.629,89 €	-8.342,23 €	-7.236,58 €
2024	16	20.000,00 €	2.657,11 €	-17.342,89 €	0,62 €	-10.807,52 €	-9.259,51 €	-7.944,98 €	-6.826,96 €
2025	17	20.000,00 €	2.657,11 €	-17.342,89 €	0,61 €	-10.492,73 €	-8.903,38 €	-7.566,65 €	-6.440,53 €
2026	18	20.000,00 €	2.657,11 €	-17.342,89 €	0,59 €	-10.187,12 €	-8.560,94 €	-7.206,33 €	-6.075,97 €
2027	19	20.000,00 €	2.657,11 €	-17.342,89 €	0,57 €	-9.890,41 €	-8.231,67 €	-6.863,17 €	-5.732,05 €
2028	20	20.000,00 €	2.657,11 €	-17.342,89 €	0,55 €	-9.602,34 €	-7.915,07 €	-6.536,35 €	-5.407,60 €
2029	21	20.000,00 €	2.657,11 €	-17.342,89 €	0,54 €	-9.322,66 €	-7.610,64 €	-6.225,10 €	-5.101,50 €
2030	22	20.000,00 €	2.657,11 €	-17.342,89 €	0,52 €	-9.051,12 €	-7.317,93 €	-5.928,66 €	-4.812,74 €
2031	23	20.000,00 €	2.657,11 €	-17.342,89 €	0,51 €	-8.787,50 €	-7.036,47 €	-5.646,35 €	-4.540,32 €
2032	24	20.000,00 €	2.657,11 €	-17.342,89 €	0,49 €	-8.531,55 €	-6.765,83 €	-5.377,47 €	-4.283,32 €
2033	25	20.000,00 €	2.657,11 €	-17.342,89 €	0,48 €	-8.283,06 €	-6.505,61 €	-5.121,40 €	-4.040,87 €
						NPV A1	**NPV A2**	**NPV B1**	**NPV B2**
						-1.236.223,9 €	**-1.205.195,24 €**	**-1.178.724,4 €**	**-1.156.024,4 €**

Table A- 3. CO_2 injection NPV calculation. *Source: own.*

ADAPTATION MEASURE 3:

→ **Estimated budget**

The performance of the WWRRS at Empuriabrava depends on the good condition and good management of both the WWTP and the constructed wetlands. It is important to point out that in the first stage only the WWTP was built and being managed. This fact allows the separation of the different costs from wastewater treatment and reclamation itself (Seguí, L. et al., 2007). Accordingly, budgets estimated by the Consorci Costa Brava for the Empuriabrava WWTP and WWRRS are:

Investment Year 0		
	Concept	**Cost**
WWRRS	Civil works	632,957
	Equipment	449,543
	Building projects	296,099
	TOTAL	**1,378,599**

Table A- 4. Initial for the Empuriabrava WWRRS. Source: adapted from CCB, 2001; Seguí, L. Et al. 2007)

Annual expenditure		
	Concept	**Cost**
WWRRS annual expenditure	Operation costs	16,332
	Variable costs	3,005
	Fixed costs	9,616
	TOTAL (WWRRS)	28,953 €
WWTP annual expenditure	Operator's labour	77,976
	General costs	15,982
	Ordinary maintenance	11,700
	Waste evacuation	16,332
	Reactive agents	6,351
	Energy	63,502
	Additional costs	10,580
	TOTAL (WWTP)	202,423 €
	TOTAL (WWTP + WWRRS)	**231,376 €**

Table A- 5. Annual expenditures for the Empuriabrava WWTP and WWRRS. *Source: adapted from CCB, 2001; Seguí, L. Et al. 2007)*

→ **NPV calculation**

						Emission Scenarios (discount rate)			
Operating period	Year	Costs	Benefits	Net Benefits	Discount Factor	Present Value A1 (3%)	Present Value A2 (4%)	Present Value B1 (5%)	Present Value B2 (6%)
2003	0	1.378.599,00 €	0,00 €	-1.378.599,00 €	1,00 €	-1.378.599,00 €	-1.378.599,00 €	-1.378.599,00 €	-1.378.599,00 €
2004	1	354.403,98 €	1.405.228,49 €	1.050.824,51 €	0,97 €	1.020.217,97 €	1.010.408,18 €	1.000.785,25 €	991.343,88 €
2005	2	369.068,63 €	1.797.861,20 €	1.428.792,57 €	0,94 €	1.346.774,03 €	1.320.999,05 €	1.295.956,98 €	1.271.620,30 €
2006	3	368.938,95 €	1.466.368,78 €	1.097.429,83 €	0,92 €	1.004.303,76 €	975.611,12 €	948.001,15 €	921.423,25 €
2007	4	366.165,08 €	1.630.213,40 €	1.264.048,32 €	0,89 €	1.123.090,56 €	1.080.513,80 €	1.039.935,68 €	1.001.244,66 €
2008	5	370.109,82 €	1.775.865,28 €	1.405.755,46 €	0,86 €	1.212.617,01 €	1.155.428,52 €	1.101.446,19 €	1.050.462,26 €
2009	6	366.567,21 €	1.856.332,05 €	1.489.764,84 €	0,84 €	1.247.654,60 €	1.177.382,79 €	1.111.685,46 €	1.050.225,43 €
2010	7	406.668,02 €	2.027.626,10 €	1.620.958,08 €	0,81 €	1.317.987,26 €	1.231.794,92 €	1.151.984,64 €	1.078.029,70 €
2011	8	432.224,18 €	2.438.055,32 €	2.005.831,14 €	0,79 €	1.583.421,62 €	1.465.641,17 €	1.357.625,47 €	1.258.483,27 €
2012	9	414.147,91 €	2.127.073,92 €	1.712.926,01 €	0,77 €	1.312.815,16 €	1.203.479,09 €	1.104.167,38 €	1.013.878,27 €
2013	10	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,74 €	1.081.113,13 €	981.544,50 €	891.970,31 €	811.306,09 €
2014	11	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,72 €	1.049.624,40 €	943.792,79 €	849.495,53 €	765.383,10 €
2015	12	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,70 €	1.019.052,81 €	907.493,07 €	809.043,36 €	722.059,53 €
2016	13	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,68 €	989.371,66 €	872.589,49 €	770.517,49 €	681.188,24 €
2017	14	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,66 €	960.555,01 €	839.028,35 €	733.826,18 €	642.630,41 €
2018	15	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,64 €	932.577,68 €	806.758,03 €	698.882,08 €	606.255,11 €
2019	16	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,62 €	905.415,22 €	775.728,88 €	665.601,98 €	571.938,78 €
2020	17	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,61 €	879.043,91 €	745.893,15 €	633.906,64 €	539.564,89 €
2021	18	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,59 €	853.440,69 €	717.204,95 €	603.720,61 €	509.023,48 €
2022	19	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,57 €	828.583,19 €	689.620,15 €	574.972,01 €	480.210,83 €
2023	20	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,55 €	804.449,70 €	663.096,30 €	547.592,39 €	453.029,08 €
2024	21	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,54 €	781.019,13 €	637.592,59 €	521.516,56 €	427.385,93 €
2025	22	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,52 €	758.271,00 €	613.069,80 €	496.682,44 €	403.194,27 €

2026	23	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,51 €	736.185,43 €	589.490,19 €	473.030,90 €	380.371,95 €
2027	24	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,49 €	714.743,14 €	566.817,49 €	450.505,62 €	358.841,47 €
2028	25	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,48 €	693.925,38 €	545.016,82 €	429.052,97 €	338.529,68 €
2029	26	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,46 €	673.713,96 €	524.054,63 €	408.621,87 €	319.367,63 €
2030	27	383.143,75 €	1.836.069,39 €	1.452.925,64 €	0,45 €	654.091,22 €	503.898,69 €	389.163,69 €	301.290,21 €
						NPV A1	**NPV A2**	**NPV B1**	**NPV B2**
						25.105.459,6 €	**22.165.349,5 €**	**19.681.091,8 €**	**17.569.682,7 €**

Table A- 6. Reclaimed water re-use in Empuriabrava NPV calculation. *Source: own.*

ADAPTATION MEASURE 4:

→ **Estimated budget**

Investment Year 0		
	Concept	**Cost**
North Zone network	Pipe system and deposits	2.164.500
	Equipment and pumps	245.000
	Network automatic control	74.500
	TOTAL	2.484.000
South Zone network	Pipe system and deposits	1.988.900
	Equipment and pumps	395.600
	Network automatic control	61.500
	TOTAL	2.446.000
	TOTAL (North + South)	**4.930.000 €**

Table A- 7. Year 0 investment for the management plan for the use of waters external to the drinking water supply network of Sabadell. *Source: Adapted from Companyia d'Aigües de Sabadell, 2005.*

Annual expenditure		
	Concept	**Cost**
North Zone network	Operator's labour	19.600
	Transport	2.350
	Administration expenses	7.100
	Electricity	23.700
	Maintenance and conservation	3.800
	Water analysis	4.300
	Water treatments (Chlorination + UV)	2.100
	TOTAL	74.900 €
South Zone network	Operator's labour	19.600
	Transport	2.350
	Administration expenses	4.900
	Electricity	30.400
	Maintenance and conservation	2.450
	Water analysis	1.600
	Water treatments (Chlorination + UV)	47.700
	TOTAL	129.700 €
	TOTAL (North + South)	**204.600 €**

Table A- 8. Annual expenditure for the management plan for the use of waters external to the drinking water supply network of Sabadell. *Source: Adapted from Companyia d'Aigües de Sabadell, 2005.*

→ **NPV calculation**

						Emission Scenarios (discount rate)			
Operating period	Year	Costs	Benefits	Net Benefits	Discount Factor	Present Value A1 (3%)	Present Value A2 (4%)	Present Value B1 (5%)	Present Value B2 (6%)
2004	0	739.500,00 €	0,00 €	-739.500,00 €	1,00 €	-739.500,00 €	-739.500,00 €	-739.500,00 €	-739.500,00 €
2005	1	301.870,47 €	277.967,70 €	-23.902,77 €	0,97 €	-23.206,57 €	-22.983,43 €	- 22.764,54 €	- 22.549,78 €
2006	2	301.870,47 €	277.967,70 €	-23.902,77 €	0,94 €	- 22.530,65 €	-22.099,45 €	- 21.680,52 €	- 21.273,38 €
2007	3	301.870,47 €	277.967,70 €	-23.902,77 €	0,92 €	-21.874,42 €	-21.249,48 €	- 20.648,11 €	- 20.069,23 €
2008	4	301.870,47 €	277.967,70 €	-23.902,77 €	0,89 €	- 21.237,30 €	- 20.432,19 €	-19.664,87 €	-18.933,23 €
2009	5	301.870,47 €	277.967,70 €	-23.902,77 €	0,86 €	- 20.618,74 €	-19.646,33 €	-18.728,45 €	-17.861,54 €
2010	6	301.870,47 €	277.967,70 €	-23.902,77 €	0,84 €	-20.018,19 €	-18.890,71 €	-17.836,61 €	-16.850,51 €
2011	7	301.870,47 €	277.967,70 €	-23.902,77 €	0,81 €	-19.435,14 €	-18.164,14 €	-16.987,25 €	-15.896,71 €
2012	8	301.870,47 €	277.967,70 €	-23.902,77 €	0,79 €	-18.869,07 €	-17.465,52 €	-16.178,34 €	-14.996,89 €
2013	9	301.870,47 €	277.967,70 €	-23.902,77 €	0,77 €	-18.319,48 €	-16.793,77 €	-15.407,94 €	-14.148,01 €
2014	10	301.870,47 €	277.967,70 €	-23.902,77 €	0,74 €	-17.785,91 €	-16.147,85 €	-14.674,23 €	-13.347,18 €
2015	11	301.870,47 €	277.967,70 €	-23.902,77 €	0,72 €	- 17.267,87 €	-15.526,78 €	-13.975,45 €	-12.591,68 €
2016	12	301.870,47 €	277.967,70 €	-23.902,77 €	0,70 €	-16.764,92 €	-14.929,60 €	-13.309,96 €	-11.878,94 €
2017	13	301.870,47 €	277.967,70 €	-23.902,77 €	0,68 €	-16.276,62 €	-14.355,38 €	-12.676,15 €	-11.206,55 €
2018	14	301.870,47 €	277.967,70 €	-23.902,77 €	0,66 €	-15.802,55 €	-13.803,25 €	-12.072,52 €	-10.572,22 €
2019	15	301.870,47 €	277.967,70 €	-23.902,77 €	0,64 €	-15.342,28 €	-13.272,36 €	-11.497,64 €	-9.973,79 €
2020	16	301.870,47 €	277.967,70 €	-23.902,77 €	0,62 €	-14.895,42 €	- 12.761,88 €	-10.950,13 €	-9.409,24 €
2021	17	301.870,47 €	277.967,70 €	-23.902,77 €	0,61 €	-14.461,57 €	-12.271,04 €	-10.428,70 €	-8.876,64 €
2022	18	301.870,47 €	277.967,70 €	-23.902,77 €	0,59 €	-14.040,36 €	-11.799,08 €	- 9.932,09 €	-8.374,19 €
2023	19	301.870,47 €	277.967,70 €	-23.902,77 €	0,57 €	-13.631,42 €	-11.345,27 €	- 9.459,14 €	-7.900,18 €
2024	20	301.870,47 €	277.967,70 €	-23.902,77 €	0,55 €	-13.234,38 €	-10.908,91 €	- 9.008,70 €	-7.453,00 €
2025	21	301.870,47 €	277.967,70 €	-23.902,77 €	0,54 €	-12.848,92 €	-10.489,34 €	- 8.579,72 €	-7.031,13 €
2026	22	301.870,47 €	277.967,70 €	-23.902,77 €	0,52 €	-12.474,68 €	-10.085,90 €	- 8.171,16 €	-6.633,14 €
2027	23	301.870,47 €	277.967,70 €	-23.902,77 €	0,51 €	-12.111,34 €	- 9.697,98 €	- 7.782,06 €	-6.257,68 €

2028	24	301.870,47 €	277.967,70 €	-23.902,77 €	0,49 €	-11.758,58 €	- 9.324,98 €	- 7.411,48 €	-5.903,47 €
2029	25	301.870,47 €	277.967,70 €	-23.902,77 €	0,48 €	-11.416,10 €	- 8.966,33 €	- 7.058,55 €	-5.569,31 €
2030	26	301.870,47 €	277.967,70 €	-23.902,77 €	0,46 €	-11.083,59 €	- 8.621,47 €	- 6.722,43 €	- 5.254,07 €
						NPV A1	**NPV A2**	**NPV B1**	**NPV B2**
						-1.155.722,46 €	**-1.112.910,98 €**	**-1.076.384,32 €**	**-1.045.057,62 €**

Table A- 9. NPV calculation for Management plan for the use of waters external to the drinking water supply network of Sabadell. *Source: own.*

ADAPTATION MEASURE 5:

→ **NPV calculation**

Calculation is based on the implementation of the measure every two years. Therefore, after a campaign there is a gap year.

						Emission Scenarios (discount rate)			
Operating period	**Year**	**Costs**	**Benefits**	**Net Benefits**	**Discount Factor**	**Present Value A1 (3%)**	**Present Value A2 (4%)**	**Present Value B1 (5%)**	**Present Value B2 (6%)**
2001	0	6.000,00 €	11.858,86 €	5.858,86 €	1,00 €	5.858,86 €	5.858,86 €	5.858,86 €	5.858,86 €
2002	1	0	0	0	0,97 €	0	0	0	0
2003	2	6.000,00 €	23.717,72 €	17.717,72 €	0,94 €	16.700,65 €	16.381,03 €	16.070,49 €	15.768,71 €
2004	3	0	0	0	0,92 €	0	0	0	0
2005	4	6.000,00 €	35.576,58 €	29.576,58 €	0,89 €	26.278,41 €	25.282,18 €	24.332,73 €	23.427,42 €

2006	5	0	0	0	0,86 €	0	0	0	0
2007	6	6.000,00 €	47.435,44 €	41.435,44 €	0,84 €	34.701,53 €	32.747,03 €	30.919,76 €	29.210,35 €
2008	7	0	0	0	0,81 €	0	0	0	0
2009	8	6.000,00 €	59.294,30 €	53.294,30 €	0,79 €	42.071,01 €	38.941,62 €	36.071,68 €	33.437,50 €
2010	9	0	0	0	0,77 €	0	0	0	0
2011	10	6.000,00 €	71.153,16 €	65.153,16 €	0,74 €	48.480,07 €	44.015,14 €	39.998,39 €	36.381,18 €
2012	11	0	0	0	0,72 €	0	0	0	0
2013	12	6.000,00 €	83.012,02 €	77.012,02 €	0,70 €	54.014,68 €	48.101,48 €	42.883,17 €	38.272,61 €
2014	13	0	0	0	0,68 €	0	0	0	0
2015	14	6.000,00 €	83.012,02 €	77.012,02 €	0,66 €	50.914,02 €	44.472,52 €	38.896,30 €	34.062,49 €
2016	15	0	0	0	0,64 €	0	0	0	0
2017	16	6.000,00 €	94.870,88 €	88.870,88 €	0,62 €	55.381,39 €	47.448,89 €	40.712,77 €	34.983,69 €
2018	17	0	0	0	0,61 €	0	0	0	0
2019	18	6.000,00 €	106.729,74 €	100.729,74 €	0,59 €	59.168,11 €	49.723,03 €	41.855,29 €	35.290,04 €
2020	19	0	0	0	0,57 €	0	0	0	0
2021	20	6.000,00 €	118.588,60 €	112.588,60 €	0,55 €	62.337,58 €	51.383,97 €	42.433,46 €	35.105,66 €
2022	21	0	0	0	0,54 €	0	0	0	0
2023	22	6.000,00 €	130.447,46 €	124.447,46 €	0,52 €	64.948,20 €	52.511,28 €	42.542,35 €	34.534,80 €
2024	23	0	0	0	0,51 €	0	0	0	0
2025	24	6.000,00 €	142.306,32 €	136.306,32 €	0,49 €	67.053,68 €	53.176,02 €	42.264,22 €	33.664,74 €
2026	25	0	0	0	0,48 €	0	0	0	0
2027	26	6.000,00 €	154.165,18 €	148.165,18 €	0,46 €	68.703,41 €	53.441,59 €	41.670,08 €	32.568,19 €
2028	27	0	0	0	0,45 €	0	0	0	0
2029	28	6.000,00 €	166.024,04 €	160.024,04 €	0,44 €	69.942,79 €	53.364,41 €	40.821,11 €	31.305,53 €
2030	29	0	0	0	0,42 €	0	0	0	0
						NPV A1	**NPV A2**	**NPV B1**	**NPV B2**
						587.908,18 €	**510.043,06 €**	**444.839,47 €**	**389.998,06 €**

Table A- 10. NPV calculation for management plan for the use of waters external to the drinking water supply network of Sabadell. *Source: own.*

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