DELIVERABLE 6.3

Predicting water consumption

PROJECT NUMBER: 619186
START DATE OF PROJECT: 01/03/2014
DURATION: 42 months

DAIAD is a research project funded by European Commission's 7th Framework Programme.

Dissemination Level	Public
Due Date of Deliverable	Month 38, 30/04/2017
Actual Submission Date	31/08/2017
Work Package	WP6, Water Demand Management
Task	Task 6.4 Predicting water consumption
Type	Report
Approval Status	Submitted for approval
Version	1.0
Number of Pages	30
Filename	D6.3_DAIAD_Predicting-water-consumption_v1.0.pdf

History

version	date	reason	revised by
0.1	28/08/2017	Initial version	Christian Sartorius
1.0	31/08/2017	Revised version	Christian Sartorius
1.1	22/11/2017	Correction of a minor error	Christian Sartorius

Author list

organization	name	contact information
Fraunhofer ISI	Christian Sartorius	christian.sartorius@isi.fraunhofer.de

Acknowledgments

Abbreviations and Acronyms

AEMET	Agencia Estatal de Meteorología
AMAEM	Aguas Municipalizadas de Alicante E.M. (Water utility of Alicante)
EPB	Evapotranspiration-precipitation balance
GCM	General circulation model
INE	Instituto Nacional de Estadística
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative concentration pathway

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1. Introduction

It is the vision of DAIAD to promote sustainable water consumption in two different ways. On the one hand, water consumers are enabled by DAIAD@home and DAIAD@know to self-monitor their water consumption through low-cost sensing technologies and, e.g., by comparing this information with consumption figures of reference groups, turn it into actionable knowledge and, eventually, into lower water use. This approach relies on the endogenous motivation of all water users and has been tested in the Trials (in WP7) and assessed in Deliverable 7.3. On the other hand, the water consumption data collected from different users and processed by DAIAD@utility can be combined with data concerning water supply and other relevant issues to enable the water utility to react on certain challenges, for instance an immanent water shortage (which is not uncommon in the city of Alicante during summertime).

In order to enable DAIAD@utility to support decision making in a water utility in such a way, it needs to be able first to explain the water consumption of the supplied people (e.g., the inhabitants of a city like Alicante) based on certain characteristics of those people and their environment. In a second step, DAIAD@utility has to enable predictions as to how the water consumption of those people may change in the future as a function of their characteristics. Eventually, in a third step, DAIAD@utility has to allow the water utility to compare alternative predictions and analyze how it can influence by means of its pricing policy and related measures the conditions of water use in such a way that the water demand revealed by its clients meets its own water supply potential. While the identification of the factors influencing water consumption (Step 1) and the use of pricing policies for intervention (Step 3) are outlined in the Deliverables 6.2 and 6.4, this deliverable (D 6.3) covers the second step – how the prediction of consumed water volumes is done.

It has to be noted that no model is, and will be, able to predict *the* exact water volume consumed by the population of a city at a given point in time. Therefore, we are using a scenario approach, where certain assumptions concerning the size and temporal change of factors relevant for the determination of the used water volume are made. These factors can refer to the water users themselves, to the general conditions influencing their water use, or to the interventions executed by the utility, for instance in the context of its pricing policy. As the one and only exact path of change of most of these factors or conditions is not known in advance, we will use a set of different assumptions for each of these factors or conditions, which cover the likely range of them developing in the future.

In Deliverables D1.1 and D6.1, a variety of socio-demographic and psychological factors has been identified, which possibly influence the water demand of people living in a city (or elsewhere). These factors were determined specifically for the case of Alicante and integrated into a water use model developed in Deliverable D6.2. As it turned out, the *number of supplied households* and the *number of people* living in those households were the most decisive, and the only significant, *socio-demographic* factors influencing water consumption as a whole. At the same time, these factors are influenced not only by birth and death rates, but also by domestic and external migration and cultural factors; therefore, they are indeed subject to substantial change. A different source of change are the *weather* and *seasonal* factors. Here it is not so much the holidays and weekdays, which lead to some, but fairly predictable changes in water use. Rather, *climate change* is foreseen to lead to changes in the *temperature* and *precipitation*, which in turn influence water consumption and water availability. While both, demographic and climate change are given from the perspective of the water utility, others may be used by the utility to *adapt* the water demand to changing conditions, in particular to a changing supply (e.g., due to decreasing precipitation). The most important of those factors are the *water price* and *tariffs,* as well as the use of DAIAD@home and DAIAD@know with their psychological effects.

Against this background, after a short description of the scenario method in Section 2, Section 3 will consider the demographic change foreseeable in Alicante, present studies that were developed in the past, and derive scenarios for the relevant factors, as well as the change in water consumption resulting from their changes. Similarly, Section 4 will investigate climate change and describe the change of those factors relevant for water consumption. Then, it will identify the scenarios covering the likely total range of their changes, and calculate their effect on water consumption. In Section 5, we assume the position of the water utility and develop strategies to respond to the demographic and climatic challenges investigated in Sections 2 and 3 by means of price or DAIAD-based intrinsic motivational instruments. Also in this case, the model developed in Task 6.2 is used to show whether and to which extent the chosen instruments are sufficient to respond to the arising challenges. Finally, Section 6 concludes the results.

2. Scenario approach to future water consumption

In order to investigate the effect of relevant factors on the water demand of the entire population of the city, we need to form expectations about the future change of the explanatory variables. As these changes depend on a variety of other factors that are not known in advance, it is **impossible to make specific predictions** for the water consumption of people in Alicante at any point in time. Instead, we can specify certain consistent sets of assumptions about how the explanatory variables may look like under **certain conditions**. Using these specifications of the variables as input to the water consumption model developed in Deliverable D6.2 will yield the consumed water volume under those conditions. This approach is called **scenario approach**, and each set of assumptions corresponds to one scenario. As in principle, the variety of conditions is very large, we would have to conduct a large number of calculations to cover all these conditions. Fortunately, however, we are not interested in all those conditions. Instead, we conduct a kind of sensitivity analysis in order to learn how much water is consumed if the conditions are changed by a certain degree. In the context of this work, the analysis of lower or upper boundaries is of special interest, as the results tell us which minimum or maximum limits of collective water use may or may not be transgressed.

If several factors are involved in the determination of the used water volume, each of them can assume a minimum and a maximum value and it may not always be evident which maximum or minimum value of one factor has to be combined with the minimum or maximum of another to achieve a total maximum (or minimum) of the consumed water volume. In this case, different combinations of minimum and maximum values have to be assessed and compared. This will extend the number of scenarios that have to be analyzed, but this number still remains manageable.

According to the described characteristics of the scenario approach, the assessments carried out in the following Sections 3 and 4 will proceed along two steps. First, we will identify and select scenarios giving rise to assumed minimum or maximum effects in terms of water consumption. Then, in the second step, the total water consumption is calculated based on these scenarios.

3. Effect of demographic change on water consumption

3.1. Scenario selection

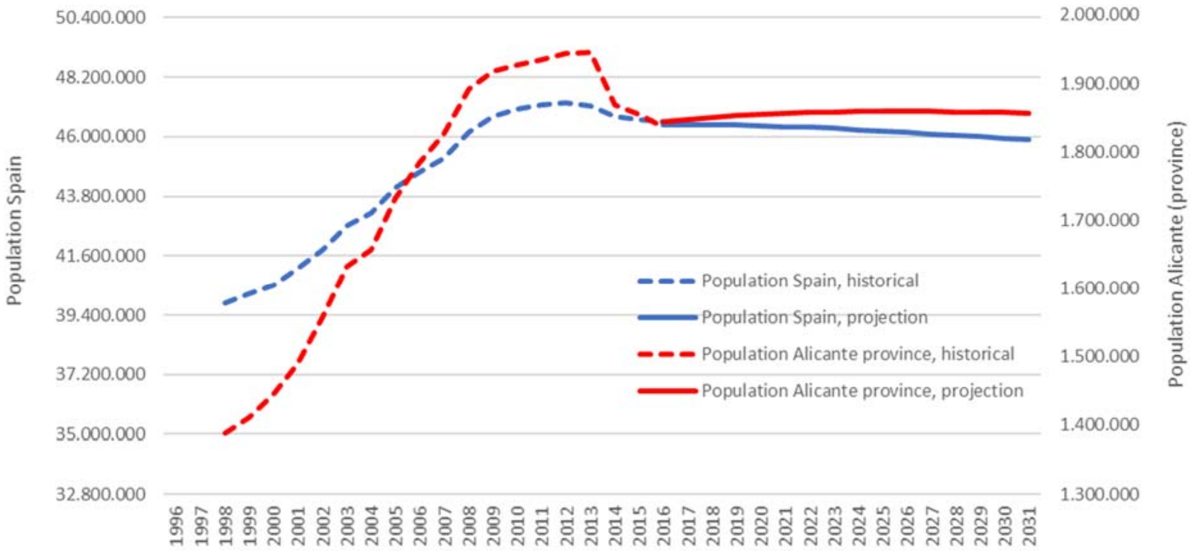
A variety of socio-demographic factors has been identified in the literature, which possibly influence the water demand of people living in a city (or elsewhere) (see Deliverable D6.1). These factors were assessed specifically for the city of Alicante and integrated into a water use model developed in Deliverable D6.2. As it turned out, the number of supplied households and the number of people living in those households were the most decisive, and the only significant, socio-demographic factors influencing water consumption as a whole. The income of the water users, by contrast, was found to exert some influence on water consumption, but this effect failed to be statistically significant.

3.1.1. Projections of population

For the investigation of future water consumption in Alicante, the development of the population is of particular interest for the water utility, because it is unable to influence this factor, but needs to be able to react to any changes of it. At the same time, these factors are influenced not only by birth and death rates, which do not change substantially in the short term, but additionally by *domestic* and *external migration* and *cultural* factors, which are subject to substantial change within a matter of years.

The development of the population is of interest for the national, regional and local governments of all developed countries, because it enables their administrations to form expectations as to which governmental services and infrastructures may be needed at some time in the future and to plan their provision. This is why such projections are available also in Spain and for the city of Alicante.

In Spain, nationwide and provincial population figures and projections are provided by the Instituto Nacional de Estadística (INE). Historical data for the country and the provincial population range from the present (2016) back to 1971. Projections look ahead from 2016 to 2031 (provinces) and 2066 (nationally). For the comparison of both time series with other more limited time series to be discussed below, we focus on the period from 1998 to 2031 (see Figure 1). For the entire country, the population *increased* until 2011, and *decreased* thereafter due to the financial crisis starting in 2009. Causes for the nation-wide decrease were a lower birth rate (as people worry about their and their children's future) and a higher emigration rate (as Spain appeared to be more strongly affected by the crisis than most other countries in the EU) (INE 2017a). While the crisis appears to have become less influential in the most recent years, the demographers nevertheless expect the population to continue to decrease slightly as a consequence of a continued excess of death rates over birth rates (INE 2017b).



Source: INE (2017a-d); Note: The scales of both vertical axes are designed to maintain their relative proportions.

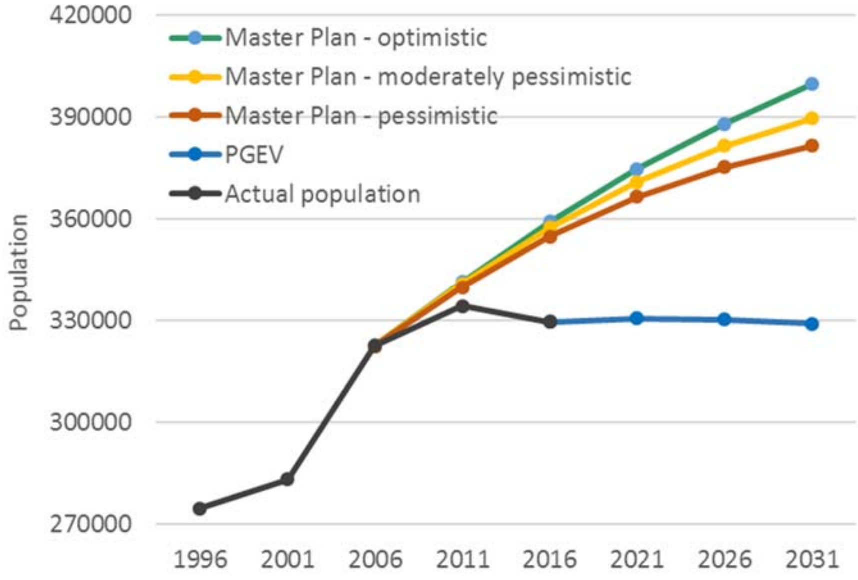
Figure 1: Population change (1998 to 2016) and its projection for Spain and the province of Alicante

Compared to the whole country, the province of Alicante appears to have experienced the nation-wide development, but more intensely. The province benefitted from the particularly favorable economic development of the Mediterranean region in the past decades and, not the least, from the (domestic and foreign) tourists and pensioners coming to Alicante due to its favorable climate. When the resulting boom in the construction sector, which was itself a major reason for the economic crisis, collapsed, the decrease in population turned out to be all the stronger (INE 2017c). The slightly higher projection until 2031 (compared to Spain as a whole) is caused essentially by a higher rate of immigration of people from abroad (INE 2017d).

For the population of the city of Alicante, historical data were available back to 1998 (INE 2017e). For the projections into the future, we could tap on two sources. The first set of projections was produced in 2006 for the Master Plan of Alicante (Laboratorio de Proyectos 2008). It used three scenarios to describe alternative development paths:

- Trend scenario, also called "cautiously optimistic", which considered the trends existing at that time (2001 to 2006) to persist unchanged with a moderate growth of immigration;
- "Moderately pessimistic" scenario, which holds basically the same assumptions concerning the birth vs. death rate balance as the trend scenario, but assumed a lower net immigration rate;
- "Pessimistic" scenario, where once again birth and death rates followed the trend observed in the recent past, but the net immigration rate decreased more rapidly to reach zero by the end of the projection period.

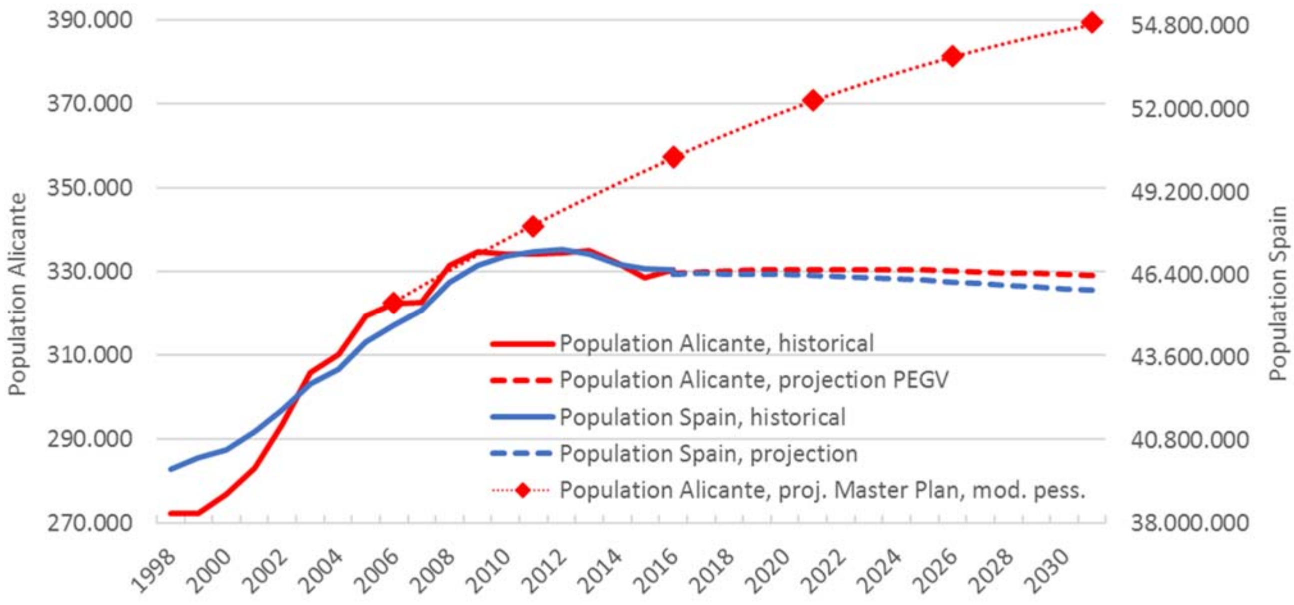
As is evident from Figure 2, all three scenarios started with the actual population of 322,400 in 2006 and reached between 381,000 (pessimistic scenario) and 400,000 inhabitants (optimistic scenario) in 2031. All these figures were thwarted by the economic crisis starting in 2008/2009, which led to the sudden interruption of any increase – in economic as well as demographic terms. Since even the most pessimistic scenario turned out to exceed the actual development by far, the Master Plan was published in the end, but not approved by the city government. The second set of projections for the city of Alicante was published quite recently by the Generalitat Valenciana (the autonomous provincial government of the Valencian Community) (PGEV 2017). It comprises only a single scenario without specified assumptions and shows a very slight increase (to just 330,000 inhabitants) until 2021, with almost no change in the next 5-years period, and a very slight decrease thereafter.



Sources: Laboratorio de Proyectos (2008), PGEV (2017), INE (2017e)

Figure 2: Population projection scenarios for the city of Alicante

The comparison of the scenarios in Figure 2 shows to which extent the outcome of the scenarios depends on their respective assumptions. Remarkably, the total range of population increases covered by all three scenarios included in Alicante's Master Plan is much too small to include, and lies far above, the increases experienced in the recent past and foreseen in the PEGV scenario. For the purpose of the actual study, we know that the PEGV scenario refers essentially to the economic and demographic experiences made in the recent past – during and after the crisis. Consequently, the scenario can be assumed to reflect a more pessimistic development path foreseen for an industrialized country. As can be depicted from Figure 3, the same is probably true for the actually published projections of the National Statistical Institute for Spain. Still, notable differences also exist between the population changes reported and projected quite recently for Alicante and Spain. Before the crisis, the population increase in Alicante appears to have been stronger and, after the crisis, the population decline in Alicante is foreseen to be later and slower than for the whole country. The reason for this difference lies mainly in Alicante's taking advantage of higher net immigration from other parts of Spain.



Source: Laboratorio de Proyectos (2008), INE (2017c), PEGV (2017)

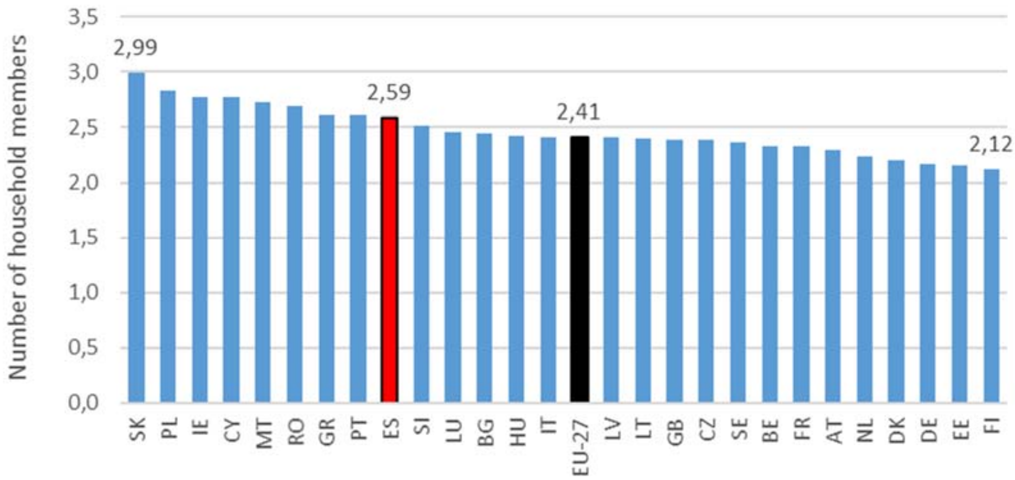
Figure 3: Comparison of actual and projected population changes in Alicante and Spain

The Master Plan scenarios, by contrast, were made in reference to a period of high prosperity. While in an industrialized country like Spain, economic prosperity does not influence death rates so much, it does lead to higher birth rates, because people are more likely and better able to live their own life, start a family and procreate. Moreover, prosperity is synonymous with more, better paid jobs, which attract people from other places and detains the actual inhabitants from leaving. This leads to higher immigration and lower emigration – an effect more pronounced on the scale of a city than of a country, since regions and even more cities can take advantage additionally from intra-country migration. From a dynamic perspective, prosperity is also often subject to self-enforcement, as growth creates more jobs and people occupying these jobs produce more growth. Although such periods do not usually persists over a long time, they may give rise to the upper limit of population increase.

With respect to our search for scenarios representing quite different paths for the development of population figures in Alicante, we adopt the previous arguments to assume that the PEGV and the intermediate (moderately pessimistic) Master Plan scenario are the two scenarios representing low and high population dynamics in this study.

3.1.2. Changes of household size

Beside the number of people living in a city, the number of households is another decisive parameter for the determination of water consumption in that city. As we found out in in our analyses reported in Section 2.1 of Deliverable D6.2, the water consumption within a household is composed of (increasing) shares for all people living in that household plus an extra-share for the household as such, which is independent of the number of household members. Owing to this extra-share, the same number of people consumes more water, if it is allocated to a larger number of households. In order to account for this effect, we need to know the number of households and its rate of change for the city of Alicante. In Spain, to start with, the average number of members in all households was 2.59 in 2011, slightly more than the EU average of 2.41 (see Figure 4).



Source: Eurostat (2017)

Figure 4: Average household sizes in the EU and its member states in 2011

Only 25 years ago, in 1991, Spanish households were much larger giving home to 3.36 people on average, and in 2001, this number was 2.91. In the autonomous province of the Communidad Valenciana, to which Alicante belongs, the figures were slightly lower, declining from 3.27 in 1991 over 2.86 in 2001 to 2.5 in 2011 (Laboratorio de Proyectos 2008). For the city of Alicante, the Master Plan makes the following assumptions with respect to household sizes. For the year 2006 and the period until 2011, the average household gives home to 2.5 people. For the time thereafter, the pessimistic Master Plan scenario assumes an unchanged average household size of 2.5 members until 2031, while the optimistic Master Plan scenario presumes a linear decrease from an average of 2.5 household members in 2011 to 2.1 members in 2031 (see Table 1).

Table 1: Number of household members assumed in different scenarios of the Master Plan of Alicante

Scenario	2006	2011	2016	2021	2026	2031
Master Plan, pessimistic scenario	2.5	2.5	2.5	2.5	2.5	2.5
Master Plan, optimistic scenario	2.5	2.5	2.4	2.3	2.2	2.1

Source: Laboratorio de Proyectos (2008)

The argument relating the change of the average household size to the state of the economy goes as follows. As discussed above, in the context of the migration balance being influenced by the economy, economic prosperity renders people more likely and better able to live their own life and start a family. As a consequence, such people will usually establish their own household, which leads to an increase in the number of households and a decrease in the average number of household members. Although, later, the birth of children within a household may again increase the number of household members, but this will usually not counterbalance the primary effect on the societal scale.

With respect to our search for reasonable scenarios, the pessimistic Master Plan scenario appears to represent indeed the most conservative development for the average number of household members, since it is hardly imaginable that this figure could increase again after the development it has taken in the past (see above). On the other hand, it is also hard to imagine that the decrease of the number of household members could proceed faster than presumed in the optimistic Master Plan scenario. Therefore, we adopt those two scenarios for representing the most divergent development paths for household size.

3.2. Projections of water demand

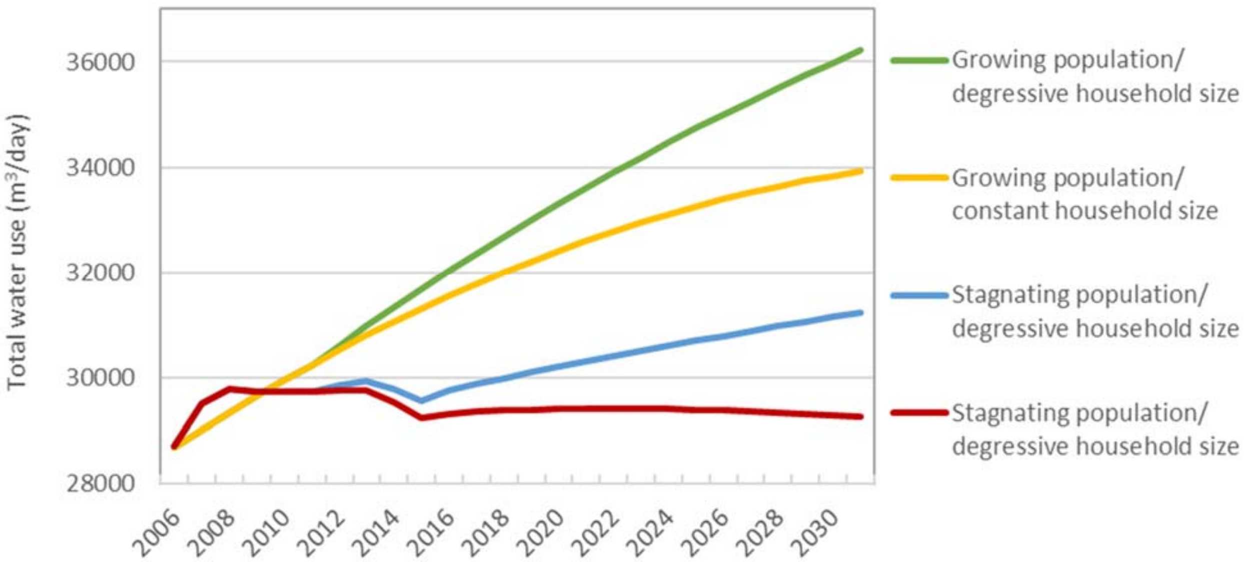
In order to form projections for the future water demand of households in Alicante, we can now make use of four scenarios: two scenarios representing respectively substantially growing (Master Plan, moderately pessimistic) and stagnating population (PEGV) and two scenarios representing respectively constant (Master Plan, pessimistic) and degressive household size (Master Plan, pessimistic). As population size and household size are both independent determinants of water demand, they have to be combined to enable the projection of water consumption. The number of all possible combinations is again four:

- Growing population/constant household size
- Stagnating population/constant household size
- Growing population/degressive household size
- Stagnating population/degressive household size

While we can expect the Growing population/degressive household size and the Stagnating population/ constant household size scenarios to be the most extreme scenarios in terms of the total consumed water volume, we nevertheless investigate all four alternatives to estimate more precisely the respective contributions of both factors.

The calculation of the total water consumption in all four scenarios is based on our findings in Section 4.1.1.1 in Deliverable D6.2, where each household member consumed an average of 57 liters per day plus 79 liters per day (independent of the members) for the household as such. Together with the scenario data, this gave rise to the results shown in Figure 5. It turns out that our expectations are confirmed: while the Stagnating population/constant household size scenario shows hardly any change with a total domestic water demand of slightly below 29,000 cubic meters per day, the Growing population/degressive household size scenario is characterized by an *increase* of that figure to more than 36,000 cubic meters per day by 2031 – a plus of 23.8 percent. Disentangling the effects of population and household size we find that the former (+15.9%) is more than twice as strong as the latter (+6.8%). Especially in the summer, when Alicante's natural water sources are limited and water is in short supply, such substantial increases can make a difference and ask for a strategy of the water utility AMAEM with respect to water demand management. We will return to this point in Section 5.

Due to the limitation in data availability, a precise calculation of the foreseeable water demand was only possible until 2031. From the shape of the Master Plan projection in Figure 3, we can only roughly estimate that the curve may reach a maximum at a population of about 420,000 people sometime between 2040 and 2050. If this guess turned out to be true, it would give rise to an increase in population-based water demand



Source: Fraunhofer ISI, own calculation

Figure 5: Development of total domestic water consumption in Alicante under different scenarios

by 28 percent. In contrast to the population increase, it is more difficult to estimate the decrease of average household size after 2031. Between 2011 and 2031, this figure was assumed to undergo a linear decrease from 2.5 to 2.1 in the optimistic scenario. As the minimum household size is 1 and a certain fraction of three-and-more-persons households (i.e., families) is needed to support the population increase, this linear trend cannot continue in the future. By contrast, we would assume this figure not to fall below 1.8. If this assumption held, the increase in water demand resulting from decreasing household size alone would be around 12 percent. Taken together, an increase in water demand by 42 percent is the maximum to be expected at any time after 2031.

4. Effect of climatic change on water consumption

Beside demographic change, climate change is another major challenge for human water supply, because changes in temperature and precipitation influence water supply and demand. People as well as nature as a whole rely for their water supply on the availability of various water flows and reservoirs, both of which depend on precipitation and, through evaporation and freezing, on temperature. While water supply is not the primary focus of the DAIAD project, water demand is at its core. In this context, the question arises, how water consumption is determined by climate change, whether the demand for water will tend to increase and by how much.

4.1. Scenario selection

Temperature and precipitation are the most evident characteristics of weather and climate and both of them also matter for the determination of water consumption. Reasons for this are, for instance, that people feel a stronger need to take a shower when sweating in the summer heat and they want to water their garden when they are exposed to prolonged time periods with no precipitation. In Section 4.3.1 of Deliverable D6.2, we could show that the *average temperature* of a day is a slightly better predictor for people's water use than the maximum temperature. With respect to precipitation, we learned that the time since the last rainfall is more decisive for the quantification of water demand than the quantity of precipitation. In order to find out, whether climate change is likely to lead to an increase in water demand, we took a look at the climate projections provided on the website of the Agencia Estatal de Meteorologia (AEMET).

4.1.1. Temperature

Spain is covered by a wide variety of different climate zones from temperate and wet in the northwest to hot and arid in the southeast. Although climate change with its increasing average temperature affects all of them in some way, the specific annual pattern of changes in temperature and precipitation differ substantially.

The data provided on the AEMET website (AEMET 2017) are not always in just the specification we need. Therefore, they need some processing. First, all parameters and their changes until 2100 are estimated based on three different approaches. These approaches refer to the method by which the data of the global climate model, the *General Circulation Model* (GCM), are scaled down to the local level of a city, for instance. One of these methods is based on dynamic modeling, i.e., it repeats the calculations of the GCM for a specified region on a smaller scale and with input from the original GCM. The other methods are statistical approaches, which try to use statistical correlations between the outcome of the GCM and the local weather events. One of the two statistical approaches used by AEMET applies regression analyses to identify these correlations, while the other approach is based on pattern analysis and tries to find similar pattern (FIC 2017). An example for the outcome of the three methods for one parameter (maximum annual temperature) is given in Figure 6.

Each of these methods has its pros and cons, but since we are not able to decide how the pros and cons can be summarized in an unambiguous vote in favor of one of these approaches, we use the arithmetic mean of the outcomes of all three methods.

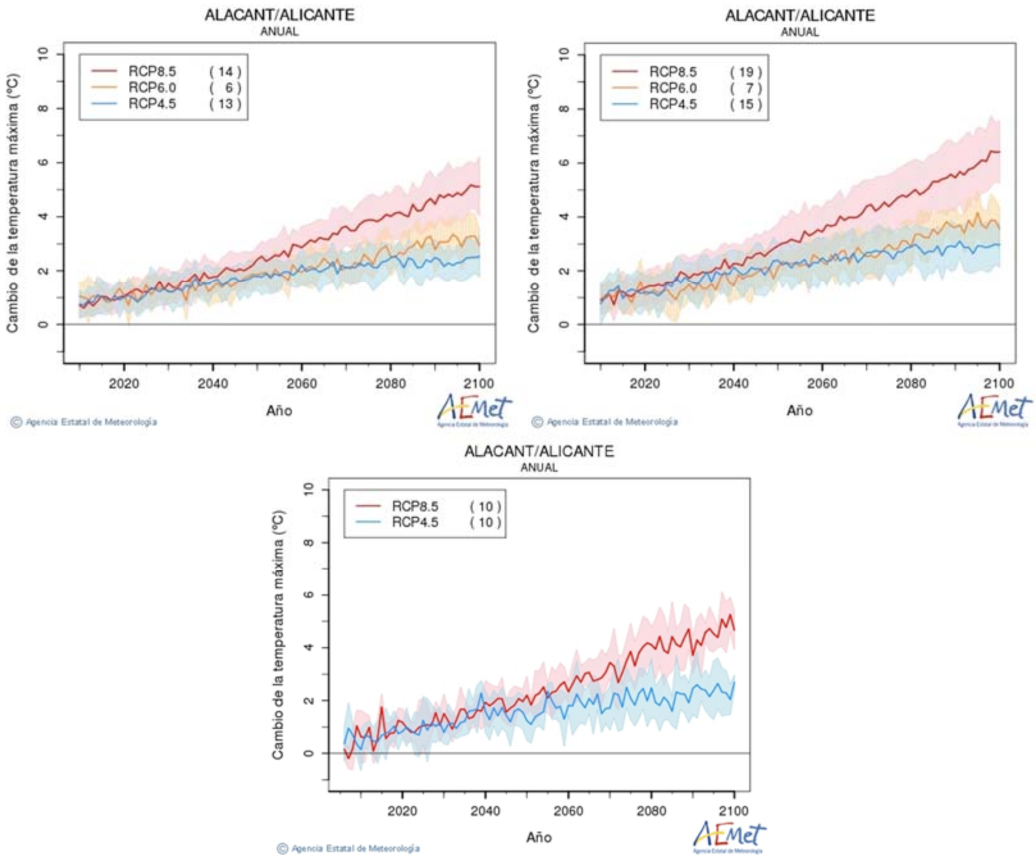


Figure 6: Projections for the maximum annual temperature in Alicante as estimated by analogue estimation (upper left), statistical regression (upper right) and dynamic modelling (center below)

Second, the AEMET website only provides minimum and maximum, but not medium temperatures. As a substitute, we determine the medium temperature by calculating the arithmetic mean of maximum and minimum temperature.

Eventually, we had to decide, exactly which data we wanted to collect and assess. The time series provided by AEMET reach from 2010 to 2100 and show the temperature increase relative to the reference period of 1961 to 1990. This gave us the opportunity to collect data concerning the temperature increase until 2100, which is the maximum increase recorded, and until 2050, which is a time span more suitable for practical considerations. Additionally, we captured the temperature increase recorded for 2017, because we are interested in the increase taking place from now on.

The data provided by AEMET usually contain time series for different – sometimes two, in most cases three – scenarios (as is evident in Figure 6 and Figure 7). These scenarios are *Representative Concentration Pathways* (RCP) specified by the *Intergovernmental Panel on Climate Change* (IPCC) in its *Fifth Assessment Report* (AR5) (IPCC 2014). They describe 21^{st} century pathways of emissions and atmospheric concentrations of greenhouse gases, air pollutant emissions and land use. Originally, the IPCC has designed four scenarios: the very stringent mitigation scenario RCP2.6 (which corresponds to a temperature increase of only 1.5 degrees by 2100), the quite stringent (2 degrees temperature increase) and slightly less stringent scenarios RCP4.5 and RCP6.0, and the business-as-usual scenario RCP8.5. For the purpose of this investigation, we refer to the scenarios RCP4.5 and RCP8.5, as data were available for them throughout.

The results of the corresponding collection and assessment of data concerning the climate change-induced annual temperature increase are summarized in Table 2. They show a strong temperature increase by more than 4 degrees C in 2100 for the RCP8.5 scenario (i.e., if no mitigation is done) and moderate increases by less than 2 degrees C in 2100 for the mitigation scenario RCP4.5 and in 2050 for both scenarios.

Table 2: Climate change-induced annual temperature increases in Alicante for two time horizons and two scenarios

Down-scaling method	Parameter	2017	2050		2100	
		RCP4.5/RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Analogue estimation	T_{max} (°C)	0.9	1.75	2.2	2.5	5.1
	T_{min} (°C)	0.8	1.7	2.2	2.3	4.8
Statistical regression	T_{max} (°C)	1.1	2.2	2.9	2.9	6.3
	T_{min} (°C)	0.9	1.8	2.4	2.5	5.4
Dynamic modelling	T_{max} (°C)	0.7	1.6	1.9	2.3	4.7
	T_{min} (°C)	0.8	1.6	2.2	2.2	4.7
Average of all methods	T_{max} (°C)	0.9	1.9	2.3	2.6	5.4
	T_{min} (°C)	0.8	1.7	2.3	2.3	5.0
	T_{med} (°C)	0.9	1.8	2.3	2.5	5.2
	ΔT_{med} (°C)		**0.9**	**1.5**	**1.6**	**4.3**

Source: AEMET (2017) and own elaboration

For the purpose of the DAIAD project, it is important to distinguish between different seasons. If, for instance, the climate change-induced temperature increase was larger in the summer than in other seasons, this effect could cumulate with other effects materializing in the same season and lead to a special challenge for the water utility. However, the AEMET website provides maximum and minimum temperatures only for entire years. The seasonal differentiation is only made for maximum temperature. Therefore, we determined the seasonal deviation from the annual average for the maximum temperature (as depicted in Figure 7) and used it to correct the medium temperature estimated on an annual basis. The results are summarized in Table 3. It is evident that the increases of the average daily temperatures in spring and winter are respectively slightly and markedly lower than the annual average. Conversely, the temperature increases in autumn and summer are respectively slightly and substantially higher than the annual average. In the summer season with a high likelihood of short water supply, temperature is likely to increase by between 1.2 and 2.2 degrees until 2050 and 2.2 and 5.7 degrees until 2100, depending on the scenario.

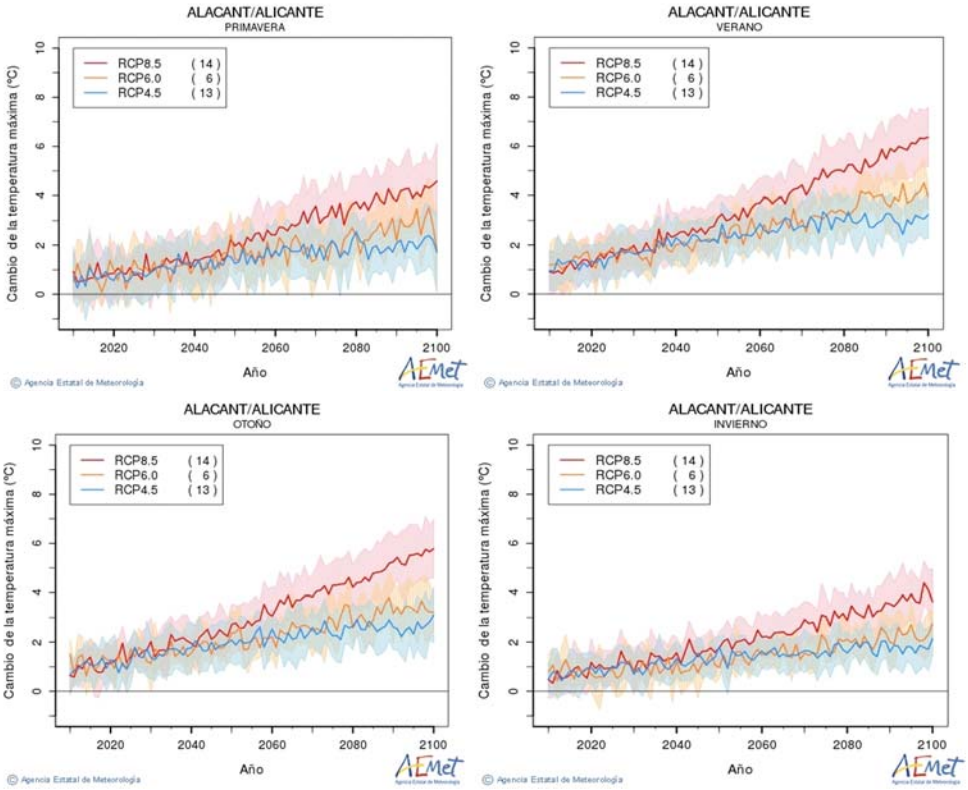


Figure 7: Projections for the maximum daily temperature in Alicante as estimated by analogue estimation in spring (upper left), summer (upper right), autumn (lower left) and winter (lower right)

Table 3: Determination of the climate change-induced seasonal temperature increases in Alicante for two time horizons and two scenarios (average of all methods)

Season	Parameter	2017	2050		2100	
		RCP4.5/RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Annual	Tmax (°C)	0.9	1.9	2.3	2.6	5.4
Spring	Tmax (°C)	0.8	1,6	2,2	2,3	5
Summer	Tmax (°C)	1.3	2,6	3,4	3,6	7,2
Autumn	Tmax (°C)	1.1	2,1	2,9	3,2	6,3
Winter	Tmax (°C)	0.7	1,5	2	2,1	4,6
Annual	ΔTmed (°C)		0.9	1.5	1.6	4.3
Spring	ΔTmed (°C)		0.7	1.5	1.4	4.0
Summer	ΔTmed (°C)		1.2	2.2	2.2	5.7
Autumn	ΔTmed (°C)		0.9	1.9	2.0	5.0
Winter	ΔTmed (°C)		0.7	1.4	1.3	3.7

Source: AEMET (2017) and own elaboration

4.1.2. Duration of dry periods

AEMET provides data also for the climate change-induced increase of the duration of dry periods, which are again specified for the RCP scenarios and by the downscaling methods described in the preceding section. Graphical representations of the model outcomes are shown in Figure 8. The results of the evaluation of the data for the time horizons 2050 and 2100 and the scenarios RCP4.5 and RCP8.5 are summarized in Table 4.

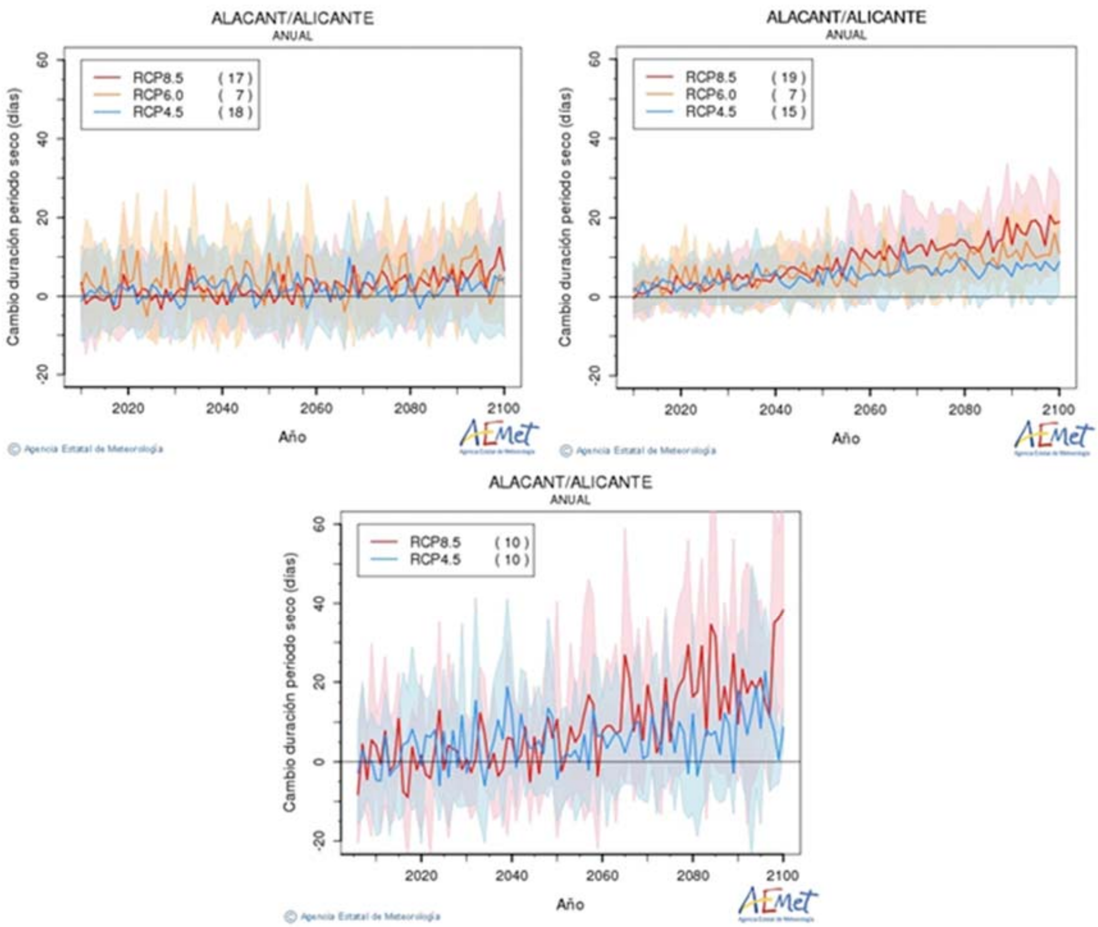


Figure 8: Projections of the duration of dry periods in Alicante as estimated by analogue estimation (upper left), statistical regression (upper right) and dynamic modelling (center below)

Table 4: Climate change-induced increase of the duration of dry periods in Alicante for two time horizons and two scenarios

Down-scaling method	2017	2050		2100	
	RCP4.5/RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Analogue estimation	1	2	2	4	7
Statistical regression	3	6	8	8	18
Dynamic modelling	1	5	6	11	24
Average of all methods	2	4	5	8	16
Average increase since 2017		**2**	**3**	**6**	**14**

Source: AEMET (2017) and own elaboration

With respect to the scenarios to be investigated in the following part of this section, we stick to the two IPCC scenarios used above. As a business-as-usual scenario, PCP8.5 is likely to represent the worst case in terms of climate change including the strongest imaginable increase in temperature and the duration of dry periods. RCP 4.5, on the other hand, might not the most stringent mitigation scenario (see RCP2.6); as a still quite stringent scenario it can nevertheless be expected to represent the weakest climate change imaginable. In this sense, RCP4.5 and RCP8.5 yield reasonable lower and upper limits for the investigated parameters.

4.2. Projections of water demand

For the climate change-based projection of the water demand in Alicante we refer to two parameters: average daily temperature and duration of dry periods. The effect of a change of the average temperature may be subject to change, but is continuous and lasts as long as the temperature change persists. The duration of dry periods, by contrast, refers to certain events, notably the rain event terminating the dry period. Its effect is not continuous, but is connected to the emergence of a dry period, which is now prolonged due to climate change. Due to this difference in the nature of the two effects, we have to evaluate both effects separately and combine them in the end.

For the calculation of the effect of temperature rise on water demand, we refer to the ΔT_{med} values in Table 3 and to the evaluation in Section 4.3.3 in Deliverable D6.2, where the parameter ADT was calculated to be 1.36 (±0.14) liter of (additional) daily water use per degree increase in daily average temperature. The resulting effects on water demand for the selected climate change scenarios and the time horizons 2050 and 2100 are given in Table 5.

Table 5: Effect of the climate change-induced temperature increases on average daily water demand (in liters per household) in Alicante

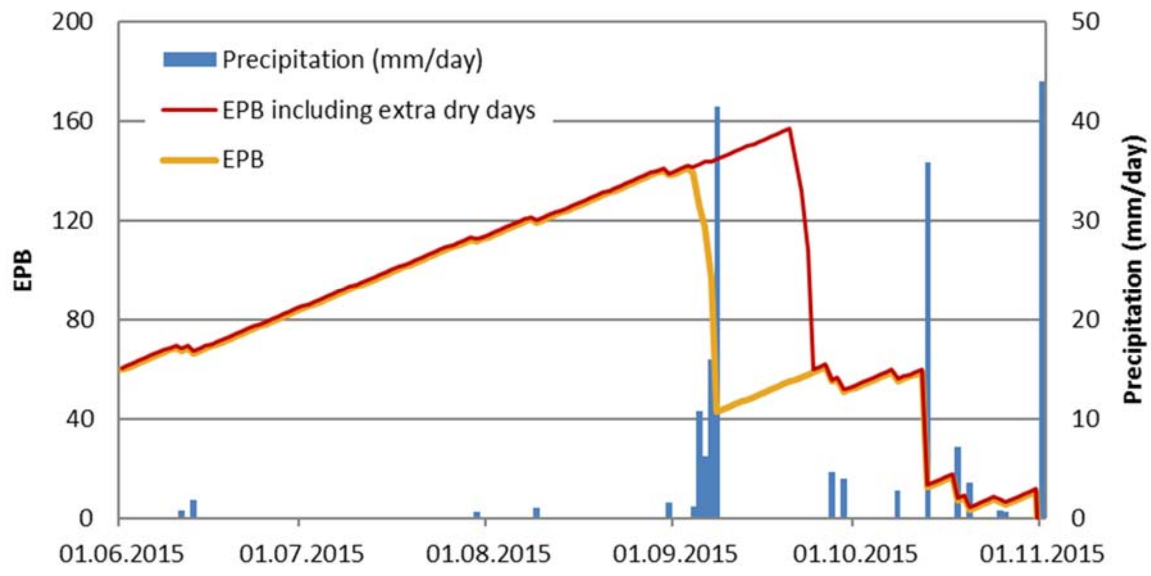
Season	2050		2100	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Annual	1.2	2.0	2.2	5.8
Spring	1.0	2.0	1.9	5.4
Summer	1.6	3.0	3.0	7.8
Autumn	1.2	2.6	2.7	6.8
Winter	1.0	1.9	1.8	5.0

Source: Own elaboration

Evidently, the effects are quite low, ranging between only 1 and 3 liters per day and household for the time horizon 2050 and both scenarios. This corresponds to an increase by less than one percent compared to the actual water consumption. Only for the time horizon 2100 and the RCP8.5 scenario, the additional water demand exceeds two percent, i.e., an additional 5 to 8 liters per day and household. In the same context, the influence of the seasons is noticeable, but does not lead to significant changes in the total water demand.

The evaluation of the effect of the duration of dry periods on water demand turned out to be more difficult, not the least because AEMET did not provide its definition of a dry period. The most crucial question to be answered in this context is: how much rain does it need to terminate a dry period? If this figure was very small, even the faintest rain would interrupt a dry period. As a consequence, dry periods would be shorter than if this figure was larger. Another question: How long does a period with no rain have to be, to be called a dry period? If this figure was very small, it would yield a larger number of dry periods all year round and all of them would by prolonged (in average) by the increments indicated in Table 4. Since we do not know, which thresholds were applied in the analysis of AEMET, we refer in our analysis to rain events with more than 2 millimeters of precipitation and dry periods lasting at least 30 days. The latter assumption is made, because it is hardly imaginable that any shorter dry period could be extended by the periods indicated in Table 4. Moreover, the extension of (already long) dry periods has a larger effect on water demand, because it increases the already high EPB balance, which in turn influences the water demand.

In order to estimate the effect of the extension of dry periods on water demand, it makes sense to have a look at the precipitation events taking place in the temporal context of an actual dry period lasting from June to August 2015 (see Figure 9). Irrespective of two small rain events at the end of July and the beginning of August, the dry period under investigation was terminated by a series of rain events taking place from 6 to 9 September 2015. Owing to this rain, the evapotranspiration-precipitation balance (EPB)[1] decreased by roughly 100 units from 140 to 40. If we assume, climate change did extend this dry period and postpone the terminating rain events by 16 days (as might be the case in scenario RCP8.5 in 2100) and everything else remained unchanged, the EPB curve would continue to increase for another 16 days and then decline until it



Source: Own elaboration

Figure 9: Effect of the extension of a dry period on the evapotranspiration-precipitation balance (EPB)

[1] Unlike just counting the number of consecutive days with no rain (DNR), the evapotranspiration-precipitation balance (EPB) does not fall back to 0 after even the lightest rain. Instead, its decrease is proportional to the strength of the rain. Only substantial rainfall makes it fall to 0. What appears reasonable from a water users view point, could be established in the regression analysis: EPB was a better predictor of water consumption than DNR (see Section 4.3.1 in Deliverable D6.2).

reaches the original curve. The difference between the two curves corresponds roughly to an incremental increase of EPB by 100 units for a period of 16 days. In order to translate the increased EPB units into additional water consumption, we multiply it with the respective parameter value of 0.041 yielded by multivariate regression. As a result, water consumption would be increased by slightly more than 4 liters per household and day, or 1.4 % of the total water use, for this 16 days' period.

Evidently, the EPB increment – and thus, the outcome of our model – depends on many factors, especially the size of the terminating rain event. In the actual case, it is rather large; in most cases, it would be smaller, and so would be the additionally consumed water volume. It could be argued that an increase in the duration of dry periods might lead to a decrease in their frequency. However, as the total precipitation is expected to decline by as much as 20 percent by 2100 in the scenario RCP8.5, such a decrease in the frequency is less likely to occur. In any case, it should be noticed that the periods of increased water demand due to prolonged dry periods occur several times per year. Statistically, such periods are most likely in the summer and to a lower extent in the winter, but this is subject to change from year to year.

Adding up the expected effects of climate change on the consumption of water in Alicante, we see that the water demand is increased by as much as 2.5 percent only in the business-as-usual scenario, in summer, and with the time horizon of 2100. In the other seasons the increase is only 2 percent and in the other scenario or with the 2050 perspective, the increase does not even exceed 1 percent. To this continuous increase we have to add repeated periodical increases by up to 2 percent (maximum) mainly in the summer. As a consequence, the water utility might face increases in water demand of up to 4.5 percent mainly in summer and for limited periods of time, if all unfavorable conditions come together. Otherwise, this increase is limited to a maximum of 3 percent. In both cases, the increases are much smaller than the expected impacts of the demographic change, which give rise to increases in water demand of roughly 6 percent (already by 2031!) based on the quite likely increase in the number of households and another 18 percent based on the less likely population increase (see Section 3.2).

5. Strategies for responding to the challenges

After recognizing in the preceding sections that the water demand could happen to increase due to the change of the demographic and climate conditions, the question arises in the first place, whether these are challenges to be responded to. As we have also learned in Deliverable D6.4, the water sources used to supply water in Alicante are rather limited all year round, but especially in the summer. The foreseen climate change will even aggravate this challenge, since the precipitation needed for the replenishment of the water sources is likely to decrease. As a consequence, the water utility AMAEM faces the situation that water supply in the future would not be able to meet the future water demand, if everything was left as it is. Therefore, there is no other choice than to respond to the challenges.

As we intend to design a strategy to respond to the challenges posed by the expected demographic and climate changes, two aspects are of special relevance: the size of the effect and its temporal appearance. As we could learn from Sections 3.2 and 4.2, the impacts on water demand – and the required responses – are stronger in the case of demographic, especially population, change than in the case of climate change. Moreover, the demographic change is a continuous challenge that may change slowly over the years, but is present constantly all year round. The climatic challenge, by contrast, shows impacts that vary quite a lot in terms of seasons and the occurrence of dry periods. In order to respond to these challenges, we have got a variety of possibilities, which are described in Deliverable D6.4.

5.1. Responses addressing extrinsic motivation

The tariff system refers to the extrinsic motivation of the water users. Changes to it are moderately effective, since the price elasticity of the water demand is rather low. For Alicante, we could show in Deliverable D6.2 (Section 4.2.1), that the price elasticity is -0.37. This means: the price has to be increased by 3.7 percent to yield a one-percent decrease in water demand. For the Growing population/degressive household size scenario with its water demand increase by 25.2 percent (until 2031), this would imply a **uniform price increase** (over all blocks) by 118 percent – more than a doubling. If only the population growth *or* the decline of the household size applied, where water demand increases by 15.9 or 6.8 percent, respectively, had to be compensated, uniform price increases by 62 or 20 percent, respectively, would be required. Of course, price increases do not need to be uniform. Instead, they can vary from block to block. In Section 5.2.2 of Deliverable D6.4, for instance, price increases were designed to address first the water users with the highest demand, in the largest-price block, where the responsiveness (= absolute value of elasticity) is highest, and only later, when the scarcity increased further, the successively lower-price blocks. However, this successively broadening focus was chosen for responding to a successively prominent scarcity situation. In the case of an increasing population or a decreasing household size, the character of change is different: it is long-term and foreseeable. Therefore, a uniform price increase appears to be the more adequate response in this case.

The successively broadening focus of the price increase may, however, be the right approach for responding to the other challenge: climate change. Like the case of seasonal water scarcity described in Section 5.2 of

Deliverable 6.4, the climate change scenarios investigated in Section 4 of this study address periods of water scarcity, but with additional focus on the increase of their duration. While this increase gives rise to a temporary increase in water consumption (which is in excess of the additional water use caused by actual dry periods), this increase is rather small, not exceeding 4.5 percent even under the most unfavorable conditions. In terms of a uniform price adaptation, this would correspond to a necessary price increase by 13 percent. With respect to the tariff type, this type of challenge can be managed perfectly by means of a **peak tariff**, which is the preferable approach for managing temporary variation in water supply already under the actual conditions (compare Section 5.2 in D6.4). Even the proposed water scarcity levels and the respective threshold values don't have to be changed; the higher levels would just be activated more frequently and for longer periods of time.

5.2. Responses addressing intrinsic motivation

Alternatively to price increases, the immanent increases in water demand can also be prevented by appealing to the intrinsic motivation of water users. In this respect, the following potentials for reducing water consumption could be identified in Deliverable D7.3, Section 4.2. In a first phase, providing the water users with real-time feedback (via amphiro during the shower event) and enabling them to learn about their water use behavior and ways to influence it, leads to a reduction of the average water consumption by 16 percent. This effect is not sustainable and fades away to about half of its impact within a period of about two months. In a second phase, combining the real-time (and diagnostic) feedback with social comparison, the reduction effect increases again to reach 13 percent and it maintains a slightly lower reduction level of 12 percent for a longer period of time. While a reduction by 12 percent is sufficient to respond to the challenges caused by climate change or demographic change in its more pessimistic appearances, the optimistic population scenario alone would give rise to an increase in water demand by 18.4 (with constant household size) or even 25.2 percent (with decreasing household size) until 2031, which cannot be offset completely by appealing to the intrinsic motivation of the water users. In order to achieve nevertheless the full compensation of the increases (by 18.4 or 25.2 percent), trying to apply a combination of intrinsic and extrinsic motivation is doomed to failure, as extrinsic motivation tends to crowd out intrinsic motivation. This means, if we force a person to limit her water use by setting a higher price, she will not do it anymore voluntarily, even when she did it before. The water utility would therefore have to return to extrinsic motivation completely.

Summarizing the preceding analysis, we can conclude that applying a peak tariff is the preferable option for managing the temporary increases in water demand (coinciding with water shortages on the supply side) now and all the more in times of climate change. The peak tariff is preferably combined with the DAIAD system, which induces itself a reduction in water consumption by appealing to the intrinsic motivation of water users. While this effect does not come to bear fully due to the crowding-out effect, it may have some effect, which reduces to some extent the need to increase the water price more generally, for instance in the context of population increase. The main advantage of DAIAD, however, lies in its capacity to enable, or at least facilitate, the communication between the water utility and its clients. Doing so, DAIAD increases the effectiveness of applying the peak tariff. In order to respond to a population increase, a uniform increase of the water price or a more or less proportional increase of all block prices appears to be best suited, because the challenging population changes are slow long-term changes and adaptations are not needed frequently. If the DAIAD system is already in place, its remaining effect (going beyond crowding-out) can be used and reduces somewhat the need to increase the water price. The main effect for steering the water demand, however, is exerted by the general price level underlying the peak tariff.

6. Conclusions

Two major challenges were taken as motives for predicting the related changes in water demand in the city of Alicante: population change and climate change. With respect to climate change, two factors were known from preceding analyses (in Deliverable D6.2) to be of special relevance: the number of people living in the city and relying on water supply by the water utility AMAEM and the size of the households. The latter factor is relevant because a certain share of every household's water demand is independent of the number of people living in it; so, even if the total population remained constant, an increase in the number of households (with less members) would lead to an increase in water demand. In order to predict the development of water consumption induced by these demographic factors, we identified a set of scenarios based on the change paths of both factors in two projection studies: an optimistic path with a substantial increase in population and a decrease in household size as assumed in the Master Plan of Alicante in 2006 (before the economic crisis) and the much more pessimistic path anticipated by the Projections of the Generalitat Valenciana in 2016 (with the experience of the crisis) with almost no change in the population size and a constant household size. Both studies enabled us to study the demography-based change of water demand until 2031.

With respect to climate change, also two factors were known from our preceding studies to be relevant for water demand: the medium daily temperature and the extension of periods with no rain. The respective data were provided by the Agencia Estatal de Meteorología (AEMET) for a series of scenarios defined by the Intergovernmental Panel on Climate Change (IPCC). For the purpose of this study, we selected the two scenarios RCP4.5 and RCP8.5 roughly corresponding respectively to a 2-degrees and a business-as-usual scenario. For both scenarios, we analyzed the changes foreseen by the years 2050 and 2100.

Although the changes in water demand caused by demographic change were analyzed only for the relatively short period until 2031, they show quite significant increases at least for the optimistic scenario. If the population increased and the average household size decreased as foreseen in the selected Master Plan scenario, the water consumption would increase by 25.2 percent. If only the population increased *or* the household size decreased, the increases would amount to 18.4 and 5.8 percent, respectively. In the pessimistic scenario, where the average household size remained constant and population changed only very slightly, also the water demand remained basically unchanged. For the time after 2031, it can be expected that even in the optimistic scenario, the population increase will reach a maximum some time after 2040 and the household size will not fall below a minimum figure not far below 2. Therefore, the maximum increase in water demand would not exceed 42 percent even in the longer term.

Compared with the demography-based changes in water consumption, the effects of climate change are rather small. Even in the more unfavorable business-as-usual (RCP8.5) scenario and in the long time perspective of 2100, the increase in water consumption caused by the climate-induced temperature increase does not exceed 2.5 percent and the increase caused by the foreseen prolongation of dry periods will be less than 2 percent. It should be noticed, however, that the challenge of a warming climate is posed less by the demand side than by the supply of water. Higher temperatures, less rain and longer periods without any rain will impair the water supply much more than the water demand.

As the water supply in Alicante is known to be critical especially in summer insofar as the natural water sources are not sufficient and have to be supplemented by energy-intense and costly seawater desalination. If this supplementation is to be avoided, the water utility has to take measures to reduce the consumption of water. One way to do so is appealing to extrinsic motivation and changing the price of water. We could show that a uniform increase of the water price by 118 percent would be necessary to completely offset the increase in demand induced by the strongest demographic impulses. The strongest climate-induced increases, by contrast, could be offset by a price increase of only 13 percent. Alternatively, the water utility can appeal to the intrinsic motivation of the water users, giving rise to a decreased water use without the need to increase prices. However, the effect of intrinsic motivation, e.g. by using the DAIAD system is limited to a reduction in water demand of up to 12 percent. Therefore, stronger effects cannot be achieved unless they are supplemented by price increases. And in this case, one part of the intrinsic effect is lost due to crowding-out by the extrinsic effect. It appears nevertheless useful to combine the two approaches in the following way. The change of water tariffs (extrinsic motivation) is used primarily as a response to the long-term changes, such as population increase and decrease of household size. The climate effects, by contrast, are subject to short-term changes. In order to manage them, the application of a combination of a peak tariff and the DAIAD system appears to be useful. In this case, the DAIAD system takes on two roles: first, it serves as a communication device between the utility and its clients and facilitates the application of the peak tariff. Second, it acts as intrinsic motivation and reduces water demand by up to 12 percent without any price increase. While the first function is essential for the effectiveness of the peak price approach, the second function can be used to reduce the price increases that were necessary, if neither DAIAD nor any other intrinsic motivation approach was in place.

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