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Economic Effects of Climate Change on Scarcity Costs and Residential Water Prices in Cyprus

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Abstract

This paper presents an assessment of the cost of water scarcity in Cyprus, today and in the next 20 years, taking into account the effect of projected climate change in the region. It focuses on the residential sector, accounting also for tourism and industry. Using a simple demand function, total scarcity costs in Cyprus are computed for the period 2010–2030, and three scenarios of future water demand are presented. The central estimate shows that the present value of total costs due to water shortages will amount to 72 million Euros (at 2009 prices), and, if future water demand increases a little faster, these costs may reach 200 million Euros. Using forecasts of regional climate models, costs are found to be about 20% higher in a climate change scenario. Compared to the loss of consumer surplus due to water shortages, desalination is found to be a costly solution, even if environmental damage costs from the operation of desalination plants are not accounted for. Finally, dynamic constrained optimization is employed and shows that efficient residential water prices should include a scarcity price of about 40 Eurocents per cubic meter at 2009 prices; this would constitute a 30–100% increase in current prices faced by residential consumers. Reductions in rainfall due to climate change would raise this price by another 2–3 Eurocents. Such a pricing policy would provide a clear long-term signal to consumers and firms and could substantially contribute to a sustainable use of water resources in the island.

Keywords: Consumer surplus, desalination, pricing, water shortage.

1. Introduction

Like other countries in the Middle East, Cyprus has a semi-arid climate associated with limited water resources. The principal cause of water scarcity is the combination of limited availability and excess demand of water among competing uses; this is clearly illustrated by the fact that

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Cyprus has the highest Water Exploitation Index[37] (45%) in the EU (EEA 2009) – which becomes much higher in years of excessive drought. The two main water-consuming sectors in the country are agriculture and households.

Water management has been problematic since the 1960s due to the limited development of water infrastructure for domestic and irrigation supply. The national government's top priorities were to ensure food security and constant supply of good quality water so that the adverse effects of water scarcity do not impede socioeconomic development, given that agriculture was the backbone of the economy, contributing by about 20% to the country's GDP. As Cyprus gradually became service-dominated, the contribution of agriculture has decreased dramatically, and currently accounts for about 2% of GDP and 7% of the total workforce (Cystat 2009a). Nevertheless agriculture still remains the dominant water user in the country, accounting for 69% of total water use, while the domestic sector accounts for 25% – of which one fifth goes to tourism (Savvides et al. 2001). In order to store as much freshwater as possible, Cypriot governments have constructed numerous dams on key catchments in the course of the years. As a result, the water storage capacity of the island increased from 6 million cubic metres (c.m.) in 1960 to 327 million c.m. in 2009, making Cyprus one of the most developed countries in terms of dam infrastructure (Klohn 2002; WDD 2009).

The Eastern Mediterranean region is expected to be affected adversely by climate change. According to detailed regional climate models, which have been derived from global circulation models downscaled for regional application, maximum and minimum temperatures are projected to increase by about 2°C in the mid-21st century and by even more by the end of the century, with the strongest increases to be observed during summer months. Annual precipitation levels are forecast to decline by 7–25% in the same period[38]. Such projections illustrate that climate change effects will have serious consequences for the (already scarce) water resources of the country.

This paper provides a policy-relevant summary of a study presented in more detail elsewhere (Zachariadis 2010). It starts by assessing the social costs caused by water shortages in non-agricultural sectors in Cyprus for

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[37] The index compares available water resources in a country to the amount of water used. An index above 20% indicates water scarcity.

[38] See forecasts on the World Bank Climate Change Portal (http://sdwebx.worldbank.org/climateportal) and Hadjinicolaou et al. (2010)

the period 2010–2030, and comparing them with the economic cost from the deployment of additional desalination plants during the same period. It then presents the results of the first attempt to assess the economic costs of climate change in Cyprus in the medium term (up to the year 2030) in non-agricultural water use. Although major climate changes are expected to happen later in the 21st century, the year 2030 is important because it constitutes the forecast horizon of several national and international studies and also enables more plausible scenarios of future economic development since forecasts into the longer term are fraught with much higher uncertainty. Finally, we assess the efficient scarcity price of non-agricultural water which, if included in end-user water prices, may lead to sustainable utilisation of the water resources of the island. As the island constitutes one single river basin and most regions are interconnected through water pipelines, this is effectively a nationwide assessment of scarcity prices; this makes the assessment presented here quite unique because in most cases reported in the literature scarcity costs and prices are calculated for a specific water basin or region (e.g. Duke and Ehemann 2004; Grafton and Compas 2007). Despite the fact that in principle total scarcity costs, optimal allocation of water resources and efficient water prices must be determined on the basis of a broader approach that includes the agricultural sector as well, this assessment is a first step towards this direction.

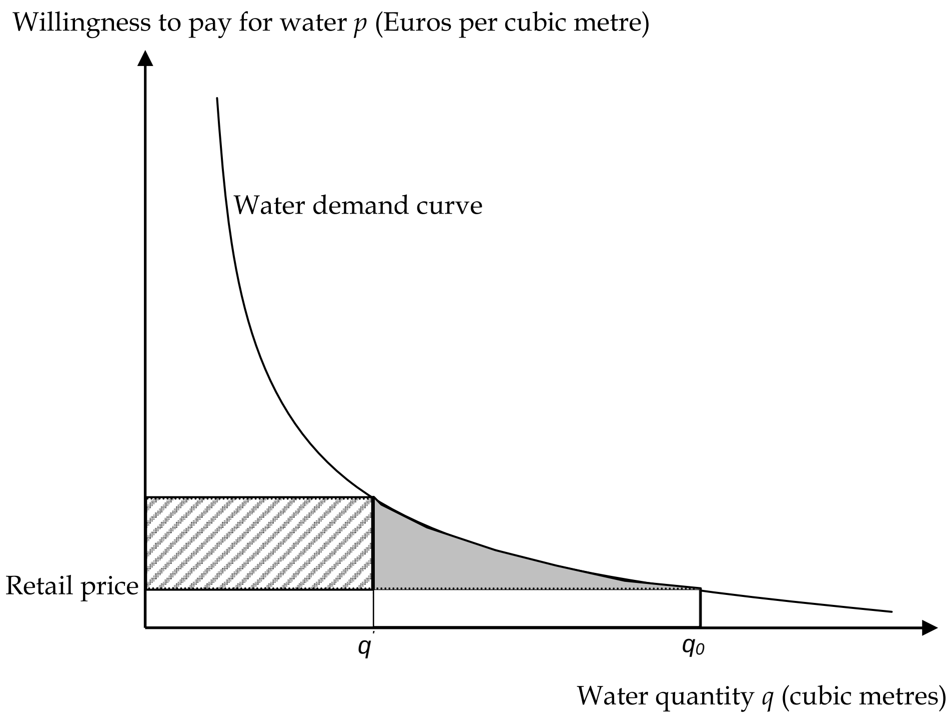
2. Scarcity costs without climate change

As mentioned above, water scarcity is inherent in Cyprus and is expected to deteriorate under climate change conditions. It is therefore necessary, as a first step, to assess scarcity costs without climate change. In our case, these costs for the residential sector will be equal to the loss of consumer surplus due to reduced availability of water. Figure 1 illustrates graphically this cost, which is equal to the area between the demand curve and the price line. Hereby we assume that there is no producer surplus so that supply cost is equal to consumer price; for a discussion on this issue see Zachariadis (2010). The lower the price elasticity of water demand (in absolute terms), the steeper the demand curve, which leads to higher economic losses.

Similarly to other studies (e.g. Jenkins et al. 2003), we formulate a water demand function and use 2006 as the base year of the calculations because it is the most recent year for which all necessary data are available and which exhibited moderate rainfall patterns. Actual water consumption is the sum of water sales by the three Municipal Water Boards of Cyprus, supplying households and enterprises in the three major cities of Nicosia, Limassol and Larnaca, and water sales of municipalities and village communities that supply water to end users in the rest of the country. Retail water prices are a weighted average of prices imposed by the Water Boards. In the absence of reliable empirical information from Cyprus, our reference calculations are conducted with a price elasticity of –0.3, which is approximately the average value from other European studies; a sensitivity analysis with different elasticity values is discussed by Zachariadis (2010).

FIGURE 1

Illustration of economic losses associated with water shortage.



Note: q_0 is the quantity that would be consumed in the case of no shortages, and q' is the quantity actually consumed. The shaded area corresponds to the loss of consumer surplus due to reduced water availability. The rectangle with the diagonal pattern to the left of the shaded area corresponds to the scarcity rent to be paid by consumers due to water shortages; however, since water is supplied by governmental authorities, this scarcity rent remains at state ownership and hence is not considered to be a social cost.

As regards future demand up to the year 2030, it is expected that the demand function will shift outwards as a result of increasing population and income. Based on official statistics of water sales from the Municipal Water Boards, per capita water use has increased by more than 2% annually over the last 15 years – excluding those years with water restrictions on households – and with about 1.5% annually during the period 2000–2008 (Cystat 2009b). We therefore constructed three scenarios on the future evolution of residential water demand, assuming annual growth rates of per capita water use of zero, 1% and 2% respectively, and combined them with official demographic statistics to arrive at forecasts of residential water use. An earlier study by WDD and the UN Food and Agriculture Organisation (Savvides et al. 2001) assumed a 2% annual growth rate of domestic water demand per capita. On the other hand, using the income elasticity of water demand estimated by Hadjispyrou et al. (2002) from Cypriot household data, coupled with official GDP growth forecasts, yields similar water use forecasts with the zero per capita growth scenario. It was therefore deemed appropriate to retain all three per capita water demand scenarios mentioned above.

Although demand is expected to rise in the future, available water quantities will remain more or less constant (if one ignores both the periodic variability of rainfall patterns and the effects of climate change, and assuming that no further desalination plants will operate). It is therefore possible to compute the decrease in economic benefits because of reduced water availability for each future year, by integrating the annual demand function from the given 'normal' level of water consumption in the base year to the consumption level of each future year, which corresponds to the maximum demanded water quantity for that year.

For each one of the three water demand scenarios used, the results are shown in Table 1. The present value of costs is projected to range between 15 and 200 million Euros (at constant prices of year 2009); according to the probably more realistic scenario 2, costs will approach 72 million Euros'2009.

TABLE 1

Annual costs of residential water shortages in Cyprus

	Scenario 1: Constant per capita water use		*Scenario 2: Per capita water use grows 1% p.a.*		*Scenario 3: Per capita water use grows 2% p.a.*	
Year	Water demand (Mm³)	Cost (M€'2009)	Water demand (Mm³)	Cost (M€'2009)	Water demand (Mm³)	Cost (M€'2009)
2010	54.8	0.21	54.8	0.21	54.8	0.21
2015	57.0	0.75	60.0	1.95	63.0	3.84
2020	58.5	1.27	64.6	5.15	71.3	12.81
2025	59.5	1.73	69.1	9.86	80.1	29.12
2030	60.1	2.01	73.3	15.84	89.3	54.80
Total economic loss, 2010–2030		25.57		130.69		381.97
Present value of economic loss, 2010–2030		15.20		71.96		204.21

Notes: [1] The above water quantities refer to water actually consumed by households, i.e. do not include water distribution losses.
[2] Present value of costs has been computed with a social discount rate of 4%.

One has to keep in mind that these costs reflect the long-term costs of water shortages because the price elasticity used is considered to be a long-term elasticity, in line with results from other European countries. It is well known that demand for many goods and services is much less elastic in the short term. For example, a household facing a doubling price of water cannot immediately make significant changes to its everyday preferences – it may only try to partly conserve water in order to mitigate the high increase in water expenditures. Over a period of some years, however, if high water prices persist, the household can adjust its daily routine by installing appliances consuming less water and adopting less water-intensive habits. This is also valid for aggregate water consumption: facing a severe water shortage in 2008, governmental authorities reduced residential water supply and imported water quantities from abroad at comparatively very high prices, while at the same time re-scheduling their medium-term investment decisions in order to provide more desalinated water in a few years' time. The short-term solution of water imports was very costly, reflecting the very low short-term elasticity of both water demand and supply. These remarks do not imply that the costs calculated here are necessarily lower than real-world costs, but they try to explain why short-term costs observed in Cyprus in recent years may have been considerably higher. This is another reason to emphasise the need for a long-term water policy which can tackle water scarcity in Cyprus in an economically efficient manner.

3. Additional scarcity costs due to climate change

Households in Cyprus are supplied with water from both dams and desalination plants. Obviously, the amount of water stored in dams (and subsequently available for residential, agricultural and other uses) depends on precipitation levels. Future precipitation levels can be forecast through climate simulations. Since global climate models cannot simulate the climate of small regions with sufficient accuracy, regional models are used, which represent further refinements of global models at a regional scale.

To assess water scarcity costs under climate change conditions, we used results of regional climate simulations[39]. According to these, precipitation levels are expected to decline by approximately 10% in the period 2021–2040 compared to the most recent twenty-year period 1987–2006. In line with suggestions from climate modellers, we considered this 10% reduction to apply for the year 2030 (the middle of the period 2021–2040) and assumed that precipitation will decrease linearly between 2010 and 2030; although the latter assumption is not realistic because rainfall levels may fluctuate considerably from year to year, it was considered appropriate because of the uncertainties of climate models and the short period examined in this analysis. It is important to underline that the relationship between precipitation and water availability is not straightforward; depending on changes in the intensity and the duration of rainfall that may be caused by climate change, a 10% reduction in rainfall levels may lead to a higher or lower reduction in the amount of available surface water. In the absence of more detailed hydrological simulations that would be necessary for this purpose, we considered this 10% precipitation decrease to cause an equal reduction in water stocks; such an assumption seems to be a reasonable starting point.

As mentioned earlier in Section 2, in years with serious water shortage authorities prefer to continue supplying the residential and tourist sector as smoothly as possible, and reduce the quantities of water supplied to

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[39] See regional model forecasts available at the World Bank Climate Change Portal (http://sdwebx.worldbank.org/climateportal).

farmers. In this study, however, we assume that reduced freshwater availability will hurt famers and households alike, thereby allocating climate change costs to each sector according to the actual stress that each sector puts to the island's water resources.

Evidently the projected reduction in precipitation levels is moderate, and becomes even less important for non-agricultural water use in Cyprus since about 60% of the quantities supplied to these sectors comes from desalination plants that provide water irrespective of climate conditions. Therefore, additional water scarcity costs associated with climate change up to 2030 turn out to be quite modest; they are presented in Table 2. The present value of additional costs for the entire period 2010–2030 ranges between 6 and 31 million Euros at 2009 prices, 15%–40% more than the costs due to the already existing water scarcity in the country; the central estimate (scenario 2) shows a 22% cost increase – or 15.7 million Euros.

TABLE 2

Annual costs of residential water shortages in Cyprus under climate change assumptions

		Additional scarcity cost due to climate change (MEuros'2009)		
Year	*Difference in water availability due to climate change*	*Scenario 1: Constant per capita water use*	*Scenario 2: Per capita water use grows 1% p.a.*	*Scenario 3: Per capita water use grows 2% p.a.*
2010	0.0%	0.00	0.00	0.00
2015	−0.9%	0.17	0.28	0.41
2020	−1.9%	0.46	1.00	1.74
2025	−2.8%	0.85	2.27	4.58
2030	−3.7%	1.28	4.17	9.72
Total additional economic loss, 2010–2030		11.11	29.42	60.19
Present value of economic loss, 2010–2030		6.12	15.69	31.49

4. Comparison of scarcity costs with desalination costs

In response to increasing water demand and stagnating or decreasing supply of freshwater, and like other governments in water scarce regions of the world such as Middle East and Australia, Cypriot authorities have promoted the operation of desalination plants. Until 2008 two plants had been in operation, with a nominal water production capacity of 92 000 c.m.

per day; the capacity of both plants has recently been expanded by about 30%. Moreover, two temporary desalination units started operating in 2009, and significant new investments are under way. Table 3 shows the desalination units currently planned. As these investments are based on the BOOT (Build, Own, Operate and Transfer) system, private investors operating each plant incur investment and operating costs and sell water to the authorities (the Cyprus Water Development Department) at an agreed price so as to cover their costs; Table 3 also displays these prices.

TABLE 3

Desalination plants in operation or scheduled to operate in Cyprus (except the area of Paphos)

Location	*Start year*	*Capacity (m^3/day)*	*Price of water sold to WDD (Euros/ m^3)*
Dekelia	1997	40,000	0.6424
Larnaca	2001	52,000	0.6817
Moni (mobile)	2009	20,000	1.3870
Garyllis aquifer	2009	9,000	0.2992
Dekelia (expansion)	2009	20,000	0.7800
Larnaca (expansion)	2009	10,000	1.3200
Limassol	2012	40,000	0.8725
Vasilikos	2012	60,000	0.8130
Limassol (expansion)	2015	20,000	0.8725

Source: Cyprus Water Development Department (website www.moa.gov.cy/wdd and official announcements, February 2010).

Note: The mobile plant of Moni is scheduled to stop operating at the end of year 2011, and desalination at Garyllis aquifer is planned to cease operation at the end of 2014.

The schedule shown in Table 3 has been designed in order to ensure that virtually all urban residential water needs in Cyprus can be met by desalination-generated water, so that a) water supply to households and firms becomes independent of weather conditions and b) all freshwater reserves are supplied to the agricultural sector in order to restore groundwater reserves, which are currently being depleted due to over-exploitation by farmers.

On the basis of these data, it is possible to calculate the costs to the governmental authorities associated with the operation of all these desalination plants. It has to be reminded that desalination is an energy-intensive process requiring large amounts of electricity – about 4.5 kilowatt-hours of electricity per cubic metre of water produced. This explains to a large extent the quite high prices of desalinated water purchased by authorities.

Table 4 demonstrates the resulting costs from the operation of all new desalination plants (i.e. except the plants of Larnaca and Dekelia that already existed before 2008). These are the costs of purchasing desalinated water plus operation and maintenance costs of governmental authorities that supply this water to consumers, minus the current country-average water price; this means that we calculate here only the desalination costs incurred in addition to current cost levels, because it is appropriate to compare only these additional costs with the loss of consumer surplus due to water shortages. According to Table 4, these additional costs are pretty high, exceeding 400 million Euros'2009, and thus seem to be considerably higher than the social costs of water shortages shown in Tables 1 and 2. A sensitivity analysis of the results of the previous section reveals that only under assumptions of high growth of water demand and at a rather low price elasticity (below 0.2 in absolute terms) can desalination costs become comparable to the social costs reported above.

TABLE 4

Future annual desalination costs for the government of Cyprus (million Euros) due to desalination plants starting operation after 2008

Year	*Desalinated water quantity (Mm^3)*	*Net desalinated water quantity (Mm^3)*[1]	*Costs at current prices*	*Costs at 2009 prices*[2]
2010	19.4	15.3	18.3	18.1
2015	49.3	38.8	39.8	36.4
2020	49.3	38.8	39.8	33.8
2025	49.3	38.8	39.8	31.4
2030	49.3	38.8	39.8	29.1
Total costs, 2010–2030			779.9	658.1
Present value of costs, 2010–2030			506.6	435.7

Notes: [1] Quantity available from desalination plants minus water distribution losses

[2] Assuming that half of the costs have to be adjusted for inflation and using a GDP deflator of 3% p.a.

Three aspects of this calculation have to be kept in mind:

– First, the calculated desalination costs do not include costs from eventual local environmental degradation due to a) the potentially negative impact of desalination plants on marine ecosystems and b) local air pollution caused by emissions of sulphur dioxide, nitrogen oxides or particulate matter from power plants that have to operate more intensively in order to fulfil the electricity needs of desalination plants. As explained by Zachariadis (2010), air pollution costs alone may lie around 5 Eurocents per c.m..

- Second, we have not accounted for the fact that electricity prices will increase due to the obligation of the Electricity Authority of Cyprus (EAC), the major power company in the island, to purchase carbon dioxide permits because of its participation in the EU Emissions Trading System. This extra cost will be passed through from desalination plant operators to the government. For the period 2010–2012, the costs of permits to be purchased by EAC will amount to an increased cost of production for desalinated water of 3.5–6.5 Eurocents per c.m. From year 2013 onwards, purchase costs for desalination water shown in Table 3 may rise by about 5 to 10 Eurocents per c.m. so that desalination costs may be 5–8% higher than those shown in Table 4. Zachariadis (2010) provides more details on the assumptions behind these calculations.
- Third, we have partly adjusted these costs for inflation, assuming an annual GDP deflator of 3%. The initially agreed price at which the WDD purchases desalinated water will increase over the years because the contracts signed between the government and desalination plant owners allow for changes in prices due to changes in a desalination plant's labour and energy costs. This will affect both energy costs and operation and maintenance (O&M) costs, which represent about 45% and 20% of total desalination costs respectively[40].

The result shown in Table 4 illustrates that if no new desalination plants are built the costs from the resulting water shortages in non-agricultural sectors seem to be considerably lower. This finding implies that, instead of desalination, a less costly approach to water scarcity in Cyprus would be the increase in end-user water prices in order to account for the costs of this scarcity and encourage water conservation. This possibility is analysed in the following section.

When interpreting these results it is important to keep in mind that our calculations assume that, regardless of the water quantities delivered to non-agricultural consumers, the availability of water to agriculture will not be affected. As already mentioned, in periods of intense water scarcity it is standard practice of governmental authorities to restrict the amount of freshwater supplied to farmers, which leads to overexploitation of groundwater reservoirs. Our calculations do not deal with this problem

[40] Based on information gathered from personal communication of the author with WDD officials.

because the analysis shown here attempts to assess the costs of water scarcity to non-agricultural sectors *all else being equal*, i.e. assuming that agriculture will not be better-off or worse-off after the implementation of one or the other measure.

5. Efficient residential water pricing to account for scarcity

As a European Union member, Cyprus has to comply with the requirements set out by the EU Water Framework Directive (WFD) (EC 2000), which is considered the most important landmark in the history of the EU's water policy. The WFD builds on previous legislation and aims to achieve a "good ecological status" of water resources within the EU by 2015. Among other provisions, the Directive introduces new water management approaches with particular emphasis on the role of economic tools. More specifically it requires full cost recovery to be the guiding principle for water pricing: end-user water prices should incorporate not only the cost of water service provision, but also environmental and resource costs[41]. The latter costs correspond approximately to the scarcity costs discussed in the previous paragraphs.

Based on the information collected to calculate scarcity costs in Sections 4 to 6, it is possible to use annual residential water demand functions and the restrictions in water availability discussed above in order to estimate the marginal user cost for residential water in Cyprus through a dynamic optimisation approach. This user cost corresponds to the shadow price of scarcity, which shows how much end-user water prices of households, industry and tourism should increase in order to account for water scarcity in the country and ensure sustainable use of water resources over the longer term, until an alternative 'non-exhaustible' technology (i.e. desalination) becomes less costly. This shadow price reflects the opportunity cost of scarcity, i.e. the economic benefits foregone due to the water quantities not consumed each year in order to ensure water availability in the future. The optimisation is carried out assuming that no new desalination plants will operate from 2009 onwards unless their marginal water production cost becomes cheaper than the sum of marginal conventional water production cost plus scarcity cost. In other words this assessment attempts to answer the question 'how much should residential water prices increase, and at what rate should available water quantities be

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[41] For a detailed analysis of the policy implications of the WFD in Cyprus see Zoumides and Zachariadis (2009).

used, in order to maximise net social benefits and manage water sustainably'. This optimisation method determines also at what time in the future new desalination plants should start operating.

To assess the scarcity price, we used the annual demand functions described in Section 2. As for supply costs, since the analysis is carried out at the consumer level, the costs of water supply to end-users is of interest – and not the costs of water distribution from the main governmental authority (WDD) to individual water boards that further sell water to end users. We further assumed, in the scenarios without climate change, that stocks of freshwater in dams that are available for residential water use each year of the period 2010–2030 remain constant at the average level of years 2005–2006. Those were two years with sufficient to moderate water storage in dams, and with more or less acceptable supply of water to agriculture. For the climate change scenarios we used the 10% reduction factor (mentioned in section 3) for freshwater availability in 2030, and linear interpolations between the 2010 figure and the 2030 figure for intermediate years. We considered water distribution losses to remain constant as a fraction of total water supply. Obviously, water supplied from desalination plants that existed before 2009 was also taken into account. Further assumptions are reported by Zachariadis (2010).

Calculation of efficient water prices was carried out by maximising the present value of total net benefits to consumers due to water consumption for the entire period 2010–2030, subject to the constraint of water availability and in the presence of two technologies: a 'conventional' water supply technology and an alternative 'non-exhaustible' technology, i.e. new desalination plants, with higher cost (see e.g. Tietenberg 2006).

Table 5 presents the resulting shadow prices (denoted with λ) and optimal water quantities to be provided by existing dams and plants and by new desalination plants for each one of the three scenarios used earlier in this paper, with and without climate change assumptions. According to our central estimate, prices for residential water users – including industry and tourism that are supplied with water from the same sources – should currently rise by about 40 Eurocents per cubic metre to account for scarcity; for each consecutive year this amount should increase by 4% (the social discount rate)[42] and should be further adjusted for inflation since the

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[42] The discount rate reflects the notion that today's consumption is somewhat more valuable than future consumption because, among other reasons, the future is fraught with uncertainty and because the society will be richer in the future, so that an additional Euro today will contribute more to welfare than an additional Euro in the future. The 'social' discount rate expresses the preference of society as a whole – private discount rates are

shadow price is expressed in constant Eurocents of year 2009. At an annual inflation of 3% this might lead to a water price increase of over 80 Eurocents per c.m. in year 2020 and over 1.60 Euros per c.m. in 2030 at nominal prices. Compared to current tariff levels in Cypriot cities, the additional 40 Eurocents per c.m. would amount to an increase in end-user price of 30–50% for the cities of Nicosia and Larnaca and up to more than 100% for the city of Limassol. Evidently the value of λ varies according to how binding the constraint becomes in the future, which in turn depends on the water demand scenario. If per capita water demand rises at a faster rate in the future as assumed in scenario 3, i.e. at 2% per year, the scarcity price reaches 43 Eurocents per cubic metre. Conversely, if per capita water demand remains stable as in scenario 1, the scarcity price falls to 27 Eurocents per c.m.. Using the climate model predictions up to 2030 provided to us, it seems that climate change is expected to have a moderate effect, of the order of less than 2 Eurocents'2009 per c.m. for scenario 2.

Table 5 demonstrates also what is the 'appropriate' timing for the introduction of new desalination plants under the different demand scenarios. If per capita water demand remains constant in the future (Scenarios 1 and 4), new desalination remains costly throughout the period up to 2030: the total marginal cost (supply cost plus scarcity cost) of existing water supply options remains below the assumed desalination cots of 150 Eurocents'2009 per c.m. even in 2030 despite the fact that the real scarcity price increases by the discount rate every year. The temporal evolution of marginal costs is illustrated in Figure 2 for the case of our central scenario 2, according to which new desalination options become economically preferable in year 2025, whereas under stronger water demand assumptions (scenario 3) new desalination should enter the market in 2023. Under increased water shortages due to climate change, the entry year for the new plants moves one or two years earlier (2024 and 2022 for scenarios 5 and 6 respectively). In any case, our model indicates that under a long-term water resource planning schedule in Cyprus, extensive use of desalination would have to wait until after 2020 – in contrast to the current policies that promote such plants already in 2010 and which, as shown in section 4, constitute clearly a costly solution.

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usually higher. We use a social discount rate of 4%, in line with guidance from governments of developed countries (see e.g. HM Treasury, 2003) and assuming that, as in the last three decades, the annual real economic growth rate in Cyprus will be somewhat higher than that of other developed economies. It is usual to apply declining discount rates when an analysis extends into the longer term (e.g. above thirty years), but this is not the case in our study.

TABLE 5

Marginal scarcity price (λ) and optimal water quantities to be supplied by existing sources or by new desalination plants in Cyprus

Optimal annual water quantities, without climate change (Mm³)

	Scenario 1			*Scenario 2*			*Scenario 3*		
Year	From existing dams/plants	From new desalination plants	Total	From existing dams/plants	From new desalination plants	Total	From existing dams/plants	From new desalination plants	Total
2010	50.8	0.0	50.8	49.2	0.0	49.2	48.9	0.0	48.9
2015	52.1	0.0	52.1	52.9	0.0	52.9	55.1	0.0	55.1
2020	52.6	0.0	52.6	55.8	0.0	55.8	61.0	0.0	61.0
2025	52.5	0.0	52.5	25.8	32.4	58.2	0.0	67.5	67.5
2030	51.8	0.0	51.8	0.0	61.8	61.8	0.0	75.2	75.2
λ (€ cents'2009):	*27.0*			*39.9*			*43.1*		

Optimal annual water quantities, with climate change (Mm³)

	Scenario 4			*Scenario 5*			*Scenario 6*		
Year	From existing dams/plants	From new desalination plants	Total	From existing dams/plants	From new desalination plants	Total	From existing dams/plants	From new desalination plants	Total
2010	50.1	0.0	50.1	49.1	0.0	49.1	48.7	0.0	48.7
2015	51.3	0.0	51.3	52.7	0.0	52.7	54.9	0.0	54.9
2020	51.6	0.0	51.6	55.5	0.0	55.5	60.7	0.0	60.7
2025	51.4	0.0	51.4	0.0	58.2	58.2	0.0	67.5	67.5
2030	50.6	0.0	50.6	0.0	61.8	61.8	0.0	75.2	75.2
λ (€ cents'2009):	*32.7*			*41.4*			*44.8*		

FIGURE 2

Evolution of marginal water supply costs in the period 2010–2030 according to results of scenario 2; from 2025 onwards existing water supply options are substituted by new desalination plants

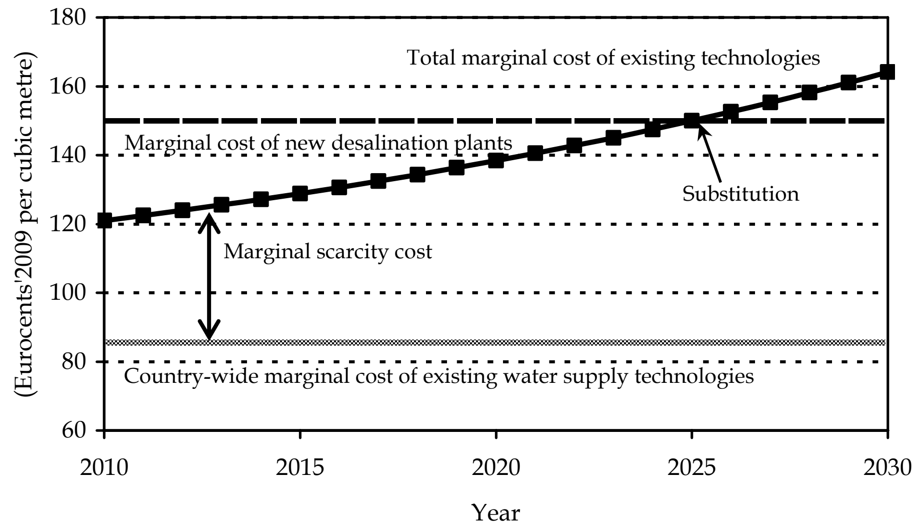
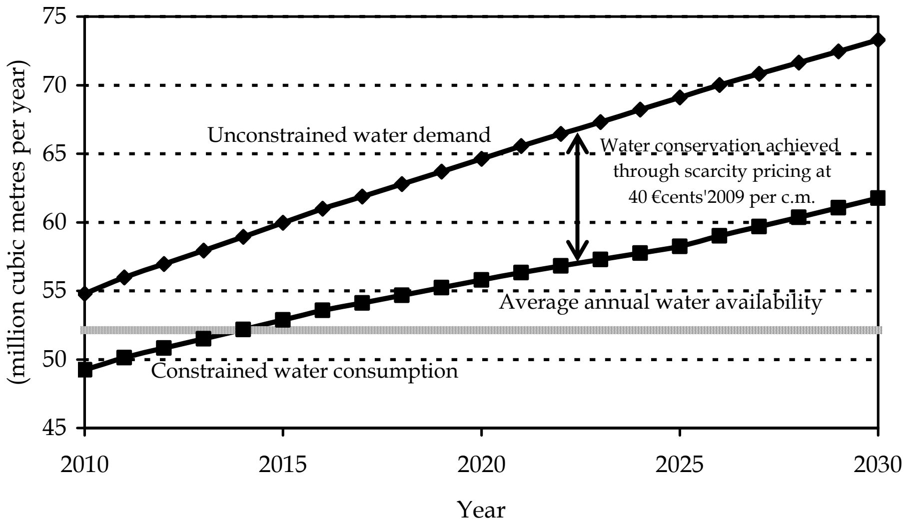


Figure 3 illustrates the evolution of optimal annual water consumption quantities in the period 2010–2030 according to scenario 2, using our central elasticity assumption of –0.3. The upper curve shows the evolution of water demand in the absence of any constraint; this is the evolution shown on Table 1 for scenario 2. The lower curve represents the solution of the constrained optimisation problem; the quantities are the totals shown on Table 5 for scenario 2. The difference between these two curves represents the water savings that can be attained if the scarcity price of 40 Eurocents'2009 per c.m. is implemented throughout the whole period; in fact water conservation is attained until 2025 because from that year onwards new desalination plans replace the existing water supply methods, scarcity is not a concern any more and hence water consumption starts rising at a higher rate. Obviously this approach is somewhat simplified since a price increase today will not be fully effective in the short run but within a period of a few years; nevertheless this graph demonstrates both the large adjustment that is necessary in order to bring future consumption in line with water reserves and the potentially great contribution of an appropriate pricing mechanism towards sustainable water management.

FIGURE 3

Evolution of optimal water consumption quantities throughout the period 2010–2030 according to scenario 2 at a price elasticity of –0.3

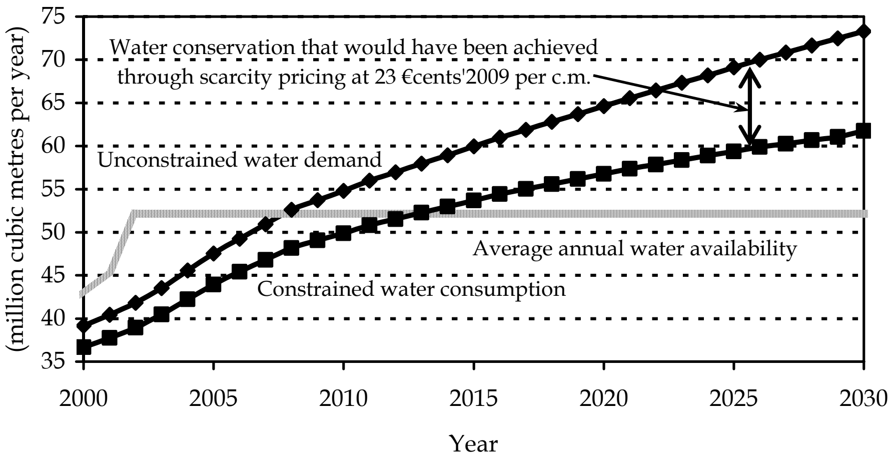


Note: Annual water availability takes into account the existing desalination plants of Dekelia and Larnaca, without their capacity expansions that became operational in 2009.

If such a pricing policy had been implemented a decade ago, it might have been sufficient to address the water scarcity problem of Cyprus without the need for extensive use of desalination; apart from the two desalination plants that have been operating for some years now, the construction of new plants might not have been necessary until 2030. To quantify this, we made a retrospective assessment for the entire period 2000–2030, illustrated in Figure 4: A policymaker trying to assess the efficient scarcity price back in the year 2000 – at water consumption levels of that period, assuming an increase in water consumption until 2030 similar to that of scenario 2 and with one desalination plant operating and the second one under construction – would estimate this price at about 23 Eurocents per cubic metre at 2009 prices. Our model shows that new desalination plants would become economically preferable only in the year 2030. This means that if this price had been implemented in the year 2000 for the entire 30-year period until 2030, available water quantities might have been able to meet demand without further desalination plants.

FIGURE 4

Evolution of optimal water consumption quantities for the period 2000–2030 if efficient pricing had been implemented in the year 2000



Note: Annual water availability takes into account the desalination plants of Dekelia (which started operating in 1997) and Larnaca (which became fully operational in 2002).

As things currently stand (by the end of year 2010 when several desalination plants have started operating or are being constructed), an implementation of the pricing policy described above might allow mitigating the additional needs for desalination in the future, thereby reducing the costs of adapting to water scarcity.

It is understandable that, apart from economic efficiency, equity is also a priority for governmental authorities. A substantial increase in the end-user price of water might put a burden on low-income households whose water demand, as mentioned in Section 3, seems to be the most inelastic. According to the Family Expenditure Survey carried out by the Statistical Service of Cyprus for the year 2003, domestic water expenditures represent less than 0.5% of total household expenditures on average, and this fraction becomes somewhat higher – but still less than 1% – for the poorest 20% of households[43]. Therefore, a doubling in the price of water would increase the cost of living for these households by 80–120 Euros per year at

[43] I am grateful to Alexandros Polycarpou from the Economics Research Centre of the University of Cyprus for providing these data.

2009 prices; if governmental authorities wish to provide a compensation for these extra costs, a direct payment to households in the form of a lump sum would be preferable. In any case, it is not advisable to subsidise water use on equity grounds, e.g. by reducing water prices for low-income households or waiving the extra scarcity price for low water consumption levels. Although access to clean water is essential for human life, current water use levels in Cyprus are far higher than the minimum amount needed: Savvides et al. (2001) estimated water demand at over 200 litres per person per day in Cyprus, and official data show a daily per capita consumption of 120–150 litres, whereas basic water needs for human subsistence (drinking, cooking and basic sanitation) are estimated at 20–50 litres per person per day (Gleick 1999; Hanemann 2006). Therefore, in an economically developed country like Cyprus it is essential to calculate water prices on the basis of marginal willingness of consumers to pay for water services – which leads to the implementation of the scarcity pricing system proposed above.

6. Conclusions and outlook

This paper has presented an assessment of the costs of water scarcity in Cyprus, today and in the next twenty years, accounting also for the effect of projected climate change in the region. We focused on the residential sector (including tourism and industry since these sectors are largely supplied with water from the same sources – freshwater from dams and desalination plants). Using a simple demand function in the absence of more detailed national data, assuming a price elasticity comparable to that of other European countries and taking 2006 as a reference year because it was a period without serious water scarcity, we first computed the total scarcity costs in Cyprus for the entire period 2010–2030 for three scenarios of future water demand. Our central estimate shows that the present value of total scarcity costs in this period will amount to 72 million Euros (at 2009 prices), and if future water demand increases somewhat faster these costs may reach 200 million Euros’2009. Regional climate models forecast annual rainfall levels to decrease by 10% at about 2030, with more serious decreases happening later in the 21st century; using this forecast, scarcity costs up to 2030 were found to be by 15 million Euros (or 22%) higher than the costs due to the already existing water scarcity in the country.

In response to increasing water demand and stagnating or decreasing supply of freshwater, Cypriot authorities have promoted the operation of additional desalination plants. We compared additional desalination costs with the social costs of water scarcity calculated earlier. Results show that desalination is most probably a costly solution under all scenarios, even if environmental costs from the operation of desalination plants are not fully accounted for.

Finally, to illustrate the alternative to desalination, we computed the efficient levels that water prices in all non-agricultural sectors should reach in order to account for water scarcity in Cyprus. As the country constitutes one single river basin and most of its regions are interconnected through water pipelines, this is effectively a nationwide assessment of scarcity prices, quite a rare case in the literature. Our central estimate of an appropriate scarcity price is 40 Eurocents per cubic metre at 2009 prices; this would constitute a 30–100% increase in current prices faced by residential consumers and an even higher increase in future decades. If per capita water demand increases faster than assumed in our central scenario, the scarcity price becomes higher. Modest reductions in rainfall levels due to climate change would raise this price by another 2–3 Eurocents'2009. Although politically difficult to implement, such costs should be incorporated in end-user prices in order to provide a clear long-term price signal to consumers and firms, with the aim to attain a sustainable use of water resources in the island – instead of depending entirely on more costly and energy-intensive desalination.

Such a pricing policy, if implemented gradually over a few years and then adjusted annually to account for both inflation and a discount rate, might provide adequate incentives for water conservation in households over the medium and longer term. If a similar policy had been implemented a decade ago, with a considerably lower scarcity price, it might have been sufficient to address the water scarcity problem of Cyprus without the need for extensive use of desalination; apart from the two desalination plants that have been operating for some years now, the construction of new plants might not have been necessary until after the year 2020. In any case, it is unlikely that consumer awareness campaigns and other incentives will have any discernible effect on water conservation in the absence of a strong price signal; if consumers get the message that they have access to sufficient water quantities without a substantial increase in water prices, they will have very little motivation for water savings.

A substantial increase in the end-user price of water might put a burden on low-income households, whose water demand seems to be the most inelastic. If governmental authorities wish to provide a compensation for these extra costs, a direct payment to households in the form of a lump sum would be preferable. In any case, it is not advisable to subsidise water use on equity grounds, e.g. by reducing water prices for low-income households or waiving the extra scarcity price for low water consumption levels, because such subsidies would weaken the overall target of water conservation.

The major policy challenge for Cyprus, as for all other Mediterranean countries, is to determine the appropriate long-run water price levels for all end users so that marginal benefits are equalised across all sectors. It is therefore particularly important to carry out efficient pricing studies including the agricultural sector, which consumes most of the water in the country with questionable economic benefits, accounting also for climate change over the longer term, which may dramatically affect available water resources and the associated social costs.

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