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in

López-Francos A. (comp.), López-Francos A. (collab.).
Economics of drought and drought preparedness in a climate change context

Zaragoza : CIHEAM / FAO / ICARDA / GDAR / CEIGRAM / MARM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 95

2010
pages 183-189

Cost-effectiveness analysis of a water scarcity management plan: Considering long term socio-economic and climatic changes

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Abstract. This paper presents an economic analysis of a water scarcity management plan developed with local land and water planning agencies in a 5000 km² Mediterranean costal area in Languedoc Roussillon, France. A baseline scenario is first developed for 2020-2040. Using statistical data and a consultation of experts, we formulate consistent assumptions related to future population growth, agricultural land use and production, irrigation performance and type of urban development. Agricultural and urban water demand are predicted and compared with future water resource availability, estimated taking into account climate and hydrological change assumptions. The gap between demand and available resources is estimated at 10 to 50 millions m^3 per year, depending on assumptions made. A programme of actions is then developed to reduce this gap, considering demand management actions (e.g. modernisation of irrigation systems, rain water harvesting, water saving technologies, water pricing) and the mobilisation of new water resources (desalination, inter-basin transfer, deep groundwater use). A cost effectiveness analysis is performed to optimise the programme of actions.

Keywords. Climate change – Cost-effectiveness analysis – River basin planning.

Analyse coût-efficacité d'un plan de gestion de la rareté de l'eau. Comment prendre en compte les évolutions socio-économiques et le changement climatique à long terme ?

Résumé. *Cet article présente une évaluation économique d'un plan de gestion de la rareté de l'eau dans deux bassins versants littoraux en région Languedoc Roussillon, France. Un scénario tendanciel est d'abord développé pour 2020-2040. Ce scénario repose sur une série d'hypothèses relatives à l'évolution future de la démographie, de l'aménagement du territoire, de la performance des systèmes irrigués et du type de développement urbain. Les demandes en eau urbaine et agricole sont estimées et comparées aux ressources susceptibles d'être disponibles dans le futur, en intégrant la perspective de changement climatique. Le déficit en eau estimé est compris entre 10 et 50 millions de* m^3 *selon les hypothèses climatiques considérées. Un programme d'actions permettant de résorber ce déficit est ensuite élaboré, en intégrant des actions visant à mobiliser de nouvelles ressources, à moderniser les périmètres irrigués ou à gérer la demande en eau potable. Une analyse coût-efficacité est ensuite mise en œuvre pour comparer ces mesures et en optimiser la combinaison.*

Mots-clés. *Changement climatique – Analyse coût-efficacité – Planification de la gestion de l'eau.*

I – Introduction

In the Mediterranean basin, actors in charge of irrigation and urban water supply systems are frequently facing drought situations, often during the summer season. Resulting social and economic conflicts are particularly acute as drought occurs when water demand reaches its maximum level in agriculture, tourism and the urban sector. In France, available resources and infrastructures are generally still sufficient to prevent serious repeated crises from happening. The situation could however deteriorate in the coming two decades for three main reasons: (i) urban water demand is expected to increase due to internal migration and population growth in coastal areas; (ii) environmental water allocation will increase (minimum in stream flow constraints) reinforcing competition with and between economic uses; and (iii) climate change will reduce resources available and increase water needs in agriculture. As a result, cases of structural deficit between water resources and demands may become more frequent in the medium term (2020-2040) and the consequences of occasional drought situation exacerbated.

At the regional level, the perspective of intensification of risk drought is an increasing source of concern for policy makers. The first policy response has been to consider (or reconsider) projects aiming at mobilising new resources at large scale, including for instance inter-basin transfer, desalination and deep groundwater exploitation. However, increasing attention is also paid to water demand management options, such as the use of incentive pricing, improvement of irrigation efficiency, adoption of water saving technologies in industry, different types of wastewater recycling, etc. This progressive change from supply to demand management policies increases the complexity of water planning and decision making. Where problems were traditionally solved in the past through construction of dams and pipelines, water planners now have to combine and coordinate many different types of actions focussing on infrastructure, agriculture, industry, urban planning, etc. To support decision making, they increasingly call for the development of tools which can help them comparing a large number of options and strategies, in particular in economic terms. Cost-effectiveness (CE) analysis is one of these tools and the European Water Framework Directive has promoted its use. However, a review of river basin district management plans which were published at the end of 2009 reveals that CE analysis is not often used in practice.

This paper aims at illustrating through a real case study conducted in Southern France, how cost effectiveness analysis can support the design of a long term water scarcity management plan. In the following section, we present 2020 baseline scenario depicting anticipated changes in agricultural and urban water demand. The total demand is then compared to water resource available at the same time horizon, considering possible impacts of climate change (Section 3). In Section 4, we describe the different strategies which have been considered to reduce the gap between supply and demand and compare these strategies in terms of cost and effectiveness. The last section shows how to combine actions assuming different levels of climate change impact.

II – Water demand scenarios

The analysis presented in this paper is based on several years of data collection and field work carried out in a coastal area of Languedoc Roussillon region. The case study covers an area of about 5000 km². It encompasses 310 municipalities depending from the three major water resources of this area: the Orb and Hérault rivers; the alluvial aquifers of these two rivers; and the Astien sand confined aquifer (see Fig. 1). During dry years, these three main resources are very near to over-exploitation and any increase in abstraction would result in failing to meet the objectives of the European Water Framework Directive. Water resources are likely to become a major constraint as population is growing at a very high rate (1.6%/year between 2000 and 2006).

The first step of our analysis consisted in constructing scenarios of future water demand, for agriculture and the urban sector. Concerning agriculture, a simple model was developed to estimate irrigation water use, taking into account types of crops, irrigated areas, irrigation technologies and climate (Maton, forthcoming). The model operates at the district level (i.e. groups of 10 to 15 municipalities) which is the scale at which agricultural statistical data are available. Urban water needs where estimated at the municipal level, considering population data but also type of housing (detached *vs* apartment flats) and using simple water consumption ratio per type of households and types of housing. Demand elasticity to price is not included in this simple model. The models were calibrated by comparing simulated water demand in 2006 with observed values. After calibration, the error in demand estimation is estimated at 5%.

These two simple models were then used to simulate future evolution of water demand for different scenarios.

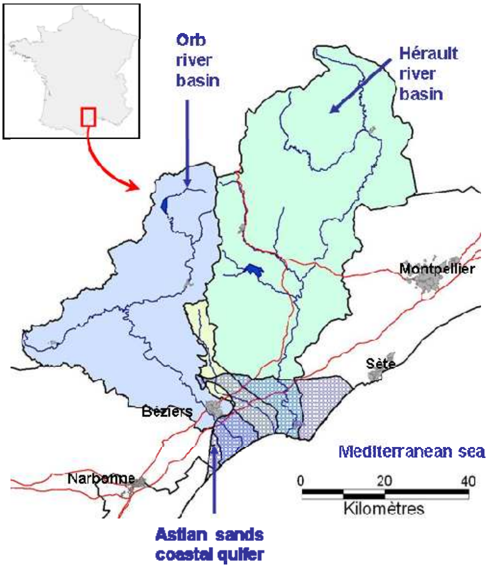

Fig. 1. Location of the case study area, Southern France.

Approximately 30 agricultural experts were consulted to identify irrigation development driving forces. The main factors considered are: (i) future cereal prices; (ii) future Common Agricultural Policy reform; (iii) development of bio-fuel industry; (iv) opening of the European fruits and vegetable market to Northern African countries; (iv) development of drop irrigation of vineyards; (v) urbanisation of arable land; and (vi) and increased crop water needs due to climate change. Three contrasted scenarios (decline, development or stabilisation of irrigation) were then developed, combining assumptions for the 6 driving forces in a consistent manner. Considering the expected increase of evapo-transpiration linked to global warming, irrigation water demand is expected to increase for two scenarios and only slightly decrease for another (see Table 1).

Table 1. Anticipated evolution of irrigation water demand for three economic change scenarios, with and without considering impact of climate change (CC) on crop water requirements

Scenario	Net withdrawal from 3 main resources in Mm3 (June to September)	
	Without CC	With CC
Reference (2006)	34.4	–
Decline 2020	26	31.5
Stabilisation 2020	37.4	**44.2**
Development 2020	45.9	54.5

Future urban water demand was calculated using results from demographic growth models. Experts were also consulted to formulate assumptions related to the type of housing to be constructed in the coming 15 years and the spatial distribution of the new population (considering scenarios of road development, etc.). The urban water model was then used to simulate the impact of these changes. Overall, urban water demand is expected to increase from 27.6 to 36.9 millions m^3 in summer, most of this increase being attributed to households living in detached houses.

Considering the scenario "stabilisation 2020 with climate change" for agriculture (see Table 1) and urban water increase (+9.3 Mm3), total water demand is expected to increase of 19 millions m^3 during the peak period.

III – Climate change and water deficit scenarios

While water demand is expected to increase, resources available for economic uses are likely to decrease drastically due to two main factors. The first factor is the strengthening of environmental regulations. To achieve good ecological status as required by the Water Framework Directive, minimum in-stream flow will need to be raised in the Orb and Hérault rivers. The corresponding volume of water over three summer months is roughly estimated at 2 millions m^3. This increased allocation of water to the environment will reduce water availability for economic uses by the same volume.

In addition, climate change is also expected to reduce water availability. We used two approaches to estimate changes in available resources, relying the advice of experts in hydrology. The first approach is based on hydrological modelling work conducted by one of the authors and its team in nearby small coastal Mediterranean basins (see VULCAIN project at http://agire.brgm.fr). They estimated that river discharges would be reduced of approximately 30% in spring and summer, due to the cumulated effect of reduced precipitations and increased evapo-transpiration (2020-2040 period). Similar results were found by Boé *et al.* (2009) who predict a 15% decrease in annual discharge for the Hérault river (in the longer term). We assume a 30% discharge reduction, which is roughly equivalent to a 19 Mm^3 decrease of available resources during the peak period (June to August included).

In the second approach, we used simulation results of the French ARPEGE climate model which predicts changes in rainfall for several CO_2 emission scenarios and for different periods (MEDCIE, 2008). A simple model is then developed to assess consequences of changes in precipitations in terms of river discharge. Using conservative assumptions, we estimate that water resource availability will decrease by respectively 10, 15 and 21 Mm^3 in summer for three SRES scenarios A1B, B1 and A2 (IPPC, 2000). These results which are compatible with those of the first approach, suggest that the impact of climate change on water resource availability will be of the same order of magnitude than changes in water demand (approximately 20 Mm^3 in summer for both).

A total water deficit can be calculated by comparing future water demand (from agriculture and the urban sector) and water resources available for use (assuming environmental allocation will be enforced). Depending on the assumptions made, we estimate that future deficit will range between 11 and 53 millions m^3 (Table 2). This range of results highlights the level of uncertainty faced by policy makers.

Table 2. Estimated deficit in the case study area with different assumptions

		Low	Medium	High
Change in available resources	Increased environmental allocation	0	2	2
	Impact of climate change	10	15	20
Demand increase	Agriculture	-8.4	9.8	20
	Urban sector	9.3	9.3	9.3
Deficit		10.9	36.1	51.3

IV – Design of a water scarcity management plan

The next step of the work consisted in identifying all possible strategies that could be implemented to reduce the gap between future water demands and available water resources. Concerning new resource mobilisation, several large scale projects have been indentified, including construction of desalination plants of various capacities, the construction of an inter-basin transfer pipeline (several variants considered), the use of deep aquifers and changes in the regulation of existing reservoirs. The annual cost of each of these projects was calculated considering investment, operation and maintenance costs and indirect costs (with a 4% discount rate). Effectiveness of each type of action is measured by the volume of water saved – or mobilized – during volume mobilized. CE ratio was then calculated to compare these options. The calculated ratio range between 0.44 to 2.07 € per cubic meter saved in summer.

Water demand management projects were also considered both in agriculture and in the urban sector. Concerning agriculture, we analysed the cost and the volumes of water which could be saved by rehabilitating and modernizing existing irrigation systems. The analysis was based on case studies conducted for each of the 55 main irrigation systems located in the case study area. Concerning the urban sector, we evaluated the costs and the volumes which could be saved by implementing a variety of water saving actions. Cost and volumes saved were calculated for each of the 300 municipalities, using data collected at this level.

Actions were ranked according to their cost-effectiveness ratio. A number of actions characterised by very high CE ratio were eliminated, such as installation of rain water harvesting systems in detached houses (between 9 and 17 €/m^3 depending on size of the system). Two programmes of actions (P1 and P2) were then designed (see Table 3 and Fig. 2). The first programme is designed to cope with a situation where the gap between future water demand and available resource would be 11 millions m^3 in summer (lower estimate). Its total annual cost is 4.7 millions € and its average cost-effectiveness is 0.5 €/m^3. The second programme is designed to cope with higher water deficit estimates (36 millions m^3). Its total annual cost is 26 millions € and its average cost effectiveness ratio is 0.72 €/m^3.

Table 3. Cost effectiveness of various projects aiming at modernising irrigation systems

Code	Action description	P1	P2	Vol†	Cost††	CER†††
DW 1	Distribution of water saving devices to households	X	X	1.45	0.56	0.39
RS 1	Change reservoir management rules (+3 Mm^3)	X		3.00	1.31	0.44
DW 2	Searching and repairing leaks in drinking water networks	X	X	1.34	0.72	0.55
RS 2	Change reservoir management rules, option 2 (+15 Mm^3)		X	15.5	8.7	0.56
AG 1	Rehabilitation of existing gravity irrigation systems	X		3.55	2.06	0.58
RS 3	Reclamation of contaminated groundwater resources	X	X	0.13	0.9	0.69
AG 2	Rehabilitation of pressurized irrigation systems	X	X	5.3	3.92	0.74
AG 3	Replacement of flood irrigation with low pressure piped systems		X	5.54	4.16	0.75
AG 4	Development of drip irrigation in pressurised irrigation systems	X	X	2.62	2.14	0.82
DW 3	Seasonal drinking water pricing	X	X	1.39	1.38	0.99
RS 4	Inter-basin transfer (pipeline option 1)	X		3.33	3.8	1.14
DW 4	Installation of water saving devices in hotels		X	0.02	0.01	1.24
RS 5	Desalination plant capacity 30,000 m^3/day		X	2.7	4.19	1.55
RS 6	Inter-basin transfer (pipeline option 2)		X	7.8	13.99	1.80

† Total volume saved during the peak period (June to August included) in millions m^3.
†† Total equivalent annual cost (millions €/year).
†††Cost effectiveness ratio in € per m^3 mobilized or saved during the peak period.

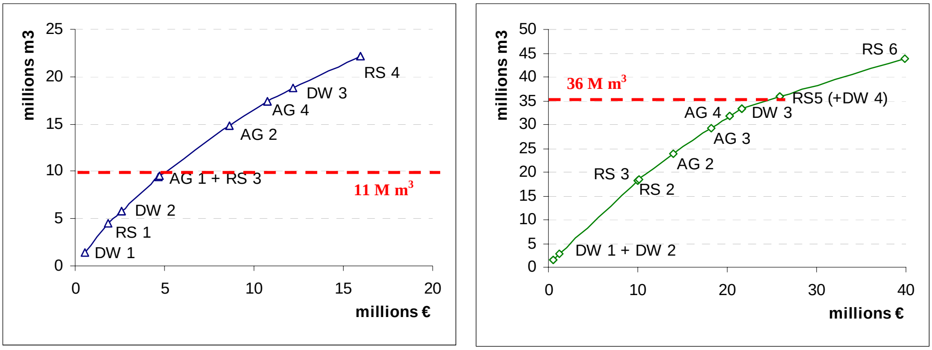

Fig. 2. Cost-effective combinations of actions with different objective levels in terms of water deficit reduction.

V – Discussion and conclusion

The main lessons learnt from this case study are the following. We first highlighted the uncertainty faced by water planners concerning future water deficit. Actions to promote and the related cost are very different if we assume a 10 or a 50 Mm^3 deficit for 2020. This calls for developing new approaches to support this type of decision making in context of uncertainty, using for instance a Bayesian approach. The second lesson learnt is that the equilibrium between water demand and supply can only be restored by a combing water demand management and resource mobilisation. At the regional level, this puts an end to a strict opposition between the proponents of theses two strategies which were sometimes considered as mutually exclusive.

From a methodological point of view, the approach described in this paper has three major caveats. The first one is that cost-effectiveness ratios calculated (Table 3) are average values computed for 300 municipalities (drinking water related actions) and 55 irrigation systems (agriculture related actions). These average values hide significant variation of CE ratio which can be found between municipalities or between irrigation systems. Average cost-effectiveness values can indeed help regional stakeholders to define priorities, for instance to select types of actions they will financially support through subsidies. But they are not sufficient to optimise the implementation of the programme of actions. To ensure the highest level of cost-effectiveness, the analysis should be repeated at the local level, which implies to compare, rank and optimize the combination of some 1420 different local actions specified at the level of municipalities or irrigation systems.

The second caveat is related to the geographical scale at which the analysis is conducted. The global approach adopted does not account for differences in water deficit between sub-basins. The different steps of the analysis (water demand and resource availability forecasting, CE analysis) should therefore be repeated at sub-basin level. The third caveat is that the analysis does not take into account certain indirect costs. Water saving actions implemented in the urban sector for the cost of developing water distribution systems (smaller pipes are needed to supply future population). These three issues will be addressed in the second phase of the project.

Acknowledgments

The authors would like to acknowledge the technical and financial support provided by the Rhône Mediterranean and Corsica Water Agency, the Languedoc Roussillon Regional Council and the Département de l'Hérault.

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