HAL
archives-ouvertes.fr

Tradable water saving certificates to improve urban water use efficiency: an ex-ante evaluation in a French case study

Jean-Daniel Rinaudo, Javier Calatrava, Marine Vernier de Byans

▶ **To cite this version:**

Jean-Daniel Rinaudo, Javier Calatrava, Marine Vernier de Byans. Tradable water saving certificates to improve urban water use efficiency: an ex-ante evaluation in a French case study. Australian Journal of Agricultural and Resource Economics, Wiley, 2016, 60 (3), pp.422 - 441. 10.1111/1467-8489.12132 . hal-01695861

HAL Id: hal-01695861
https://hal-brgm.archives-ouvertes.fr/hal-01695861

Submitted on 3 Apr 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

This is the author's version of a paper published in the **Australian Journal of Agricultural and Resource Economics**, 59, pp. 1–20. Available on line at: http://onlinelibrary.wiley.com/doi/10.1111/1467-8489.12132/abstract

---

Tradable Water Saving Certificates to Improve Urban Water Use Efficiency: an ex-ante evaluation in a French case study

Jean-Daniel RINAUDO

Javier CALATRAVA

Marine VERNIER DE BYANS

Abstract

This paper proposes a system of tradable Water Saving Certificates to improve the efficiency of water allocation between Drinking Water Utilities at river basin level. A market institutional set-up, inspired from recent policy developments in the energy sector, is proposed. An original analytical price-endogenous model is developed to simulate trade intensity, equilibrium price and efficiency gains in this urban water market. The economic model is implemented in a French case study using mathematical programming. It is used for conducting an ex-ante evaluation of trade possibilities and efficiency gains, considering different spatial restrictions aimed at controlling environmental externalities. Our modelling exercise provides evidence of the benefits of the proposed Water Saving Certificate scheme.

Keywords: water management & policy; water market ; tradable water saving certificates; mathematical programming; efficiency.

JEL classification: C61 ; D47 ; Q25.

1-INTRODUCTION

By contrast with many other European Countries, the French water sector is characterized by a very high number of Drinking Water Utilities (more than 14,000 in 2009) organized at the level of groups of municipalities and presenting very different level of water use efficiency (Barraque 2007). Differences are particularly striking concerning losses occurring in distribution networks (AGRESTE 2010). While Drinking Water Utilities (DWUs) confronted with limited water resources and increasing water demand have heavily invested in reducing leakage (reaching 80% efficiency level in 36% of the municipalities), losses occurring in pipes still represent 20% to 50% (and sometimes above) in many other municipalities which face very little economic incentive to invest in water conservation. Moreover, very few utilities have initiated water conservation programs targeting their customers, with a few noticeable exceptions in Aquitaine and Brittany regions.

In southern France, where water demand is increasing due to national immigration, the most efficient DWUs are looking at alternative water resources – including inter-basin transfers, desalination and deep groundwater pumping – to increase water supply. Mobilizing these new resources will however cost much more than reducing losses in less efficient DWUs and transferring conserved water to meet new demands (Rinaudo et al. 2010; Rinaudo and Barraque 2015). This theoretically opens-up a space for establishing win-win cooperative agreements between DWUs, in which the most efficient DWUs would pay less efficient ones for reducing leakages and water usage, obtaining in return a quota corresponding to the water savings achieved. Such cooperative agreements could also involve other actors (as buyers) such as golf courses or industries for instance. The possibility of establishing such agreements would create the required incentives for inefficient and non-constrained DWUs to invest in the rehabilitation of their distribution networks and initiate water conservation programs targeting their customers. It would attract investments in water efficiency measures characterized by long paybacks for their direct beneficiaries, and which would otherwise be slow to enter in the market. This would enhance the overall economic efficiency of water allocation at the river basin level.

A global review of existing programs indicate that a variety of institutional frameworks can be designed for allowing such agreements which represent a specific form of water market. However, a major constraint to be considered in the French case is that water quotas cannot be exchanged between users, water being officially allocated on the basis of administrative authorizations which cannot be transferred. Thus traditional forms of water markets relying on the exchange of water rights like in USA or Australia (Grafton, Landry et al. 2010; Hanak 2010), or concessions like in Spain (Garrido et al. 2013) do not represent workable options. The mechanism proposed in this paper assumes that, similarly to what is being done in the energy sector (Oikonomou, Rietbergen et al. 2007; Vine and Hamrin 2008), Water Saving Certificates (WSC) or Water Efficiency Credits could be created and allocated to users investing in water conservation actions and that a market could be created to trade these certificates. This "cap and trade" policy instrument would first require that water saving targets be set for water utilities that must fulfil this requirement by implementing various water conservation measures – in particular reduction of losses in distribution networks. Utilities which over-fulfil their obligations would receive Water Saving Certificates (with an attached volume of water) that could be sold to other users or utilities that are not meeting their own target. The WSC market would be regulated by a public authority. This policy instrument could theoretically ensure flexibility and contribute to the implementation of cost-effective water saving measures. The fact that such a system is already operating in the energy sector suggest that there should be no major legal impediment to its implementation in France and other EU countries (Oikonomou, Rietbergen et al. 2007).

The objectives of this paper are threefold. First, the paper suggests a possible institutional set-up for creating a market for Water Saving Certificates at the river basin level as an potentially effective option to promote urban water saving. It subsequently presents a model to simulate the potential reallocation of water between domestic water utilities that could result from the implementation of such a system and its benefits. The proposed model is original and novel, as it adapts the price endogenous special equilibrium models used in the water markets modeling literature to simulate a different type of market (water saving certificates instead of water) between a different type of participant (water managers with cost-minimization objectives instead of water users with utility-maximization objectives). Last, the model is demonstrated in two basins in southern France, where it is used to estimate volumes exchanged and prices and to analyse the cost-efficiency of the proposed WSC system. In addition, different models are formulated considering hydrological constraints that could restrict trading to account for potential environmental impacts.

2- INSTITUTIONAL SET-UP FOR TRADING WATER SAVING CERTIFICATES

2.1. Water saving certificates

The first principle of the policy instruments considered in this paper is that a public authority imposes restrictions on water abstraction, based on (i) an analysis of long term water resources availability at the river basin level and considering (ii) historical water uses and (iii) technical efficiency of all users. In the drinking water sector focused upon in this paper, each utility would receive a limited quota of water (or a series of seasonal quotas) to comply with by a certain timeframe (e.g. 2030). A water saving target is assigned to each utility considering its specific technical and economic characteristics (urban or rural, type of dwellings, type and number of industries, etc.). Financial penalties are charged for noncompliance with water saving objectives, the penalty exceeding the estimated market value of the missing certificates. In the longer term, quotas are likely to be revised if water scarcity increases, in particular due to climate change.

Utilities can use three different approaches to generate water saving. They can fund water conservation programs directed at their customers (domestic or industrial) and aiming at increasing the adoption rate of affordable water efficient technologies for instance through information campaigns, audit or rebate programs. They can also develop water conservation programs targeting public water uses (public gardens, public buildings, etc.). Alternatively they can invest in distribution network leakage detection and control to reduce losses beyond the official objectives.

The second principle is that utilities that have achieved greater water saving than their target obtain a WSC corresponding to the surplus water savings, which can be sold to those which are short of their target or that need additional water resources to meet the demand of a growing population. A WSC is a document certifying that a certain reduction of water consumption has been attained. The reduction of water consumption is expressed as the total volume of water saved during the lifetime of the water conservation action or project. A WCC is therefore valid for a certain period of time (1 to 10 years depending on the nature of the water conservation action). The volume of water saved can be estimated ex-ante (based on standardized engineering estimates) or ex-post (based on comparison of water consumption before and after, taking into account changes in other factors such as weather, population growth, economic activity). At the end of the period, the WCC can be renewed, extended or withdrawn, depending on the level of investment made by the beneficiary to maintain the same level of water use efficiency.

An independent certification authority should be established for issuing the certificates and verifying water savings. Technical provisions should ensure real and measurable savings. The certification authority would only consider as certifiable water savings those that are additional to what would have occurred without a program (beyond business as usual savings). For instance, water saving due to rebate programs on water efficient appliances should be estimated considering a baseline rate of adoption of such appliances. Determining this baseline in practice is likely to be a challenging task.

An electronic tracking system is also needed to register WSCs (unique serial number, specification of lifetime and volume), track transactions (prevent double counting / selling) and prove compliance of users with water saving objectives. All participants in the WSC market need to register and open an account. Transfers of WSCs are followed from the generator's account (where WSCs are first issued) to other accounts that have purchased the certificate, until the certificate is retired (end of lifetime). This electronic tracking system is an accounting system, totally different from a trading platform that could be developed in parallel. The tracking system could also be used as an integrative platform to verify the savings, assuming that all account owners are imposed using electronic water meters for monitoring water abstraction.

2.2. Economic functioning of the market

The basic idea underlying the establishment of tradable Water Saving Certificates is that DWUs can decide whether to implement water saving measures or to purchase WSCs depending on their marginal costs, in order to meet their water saving target. The buyer is paying for compensating another DWU in the same basin that over-fulfils its water-saving obligation. Differences in marginal costs of water conservation measures make trade possible. The intensity of exchange will depend on the difference in marginal cost and the level of transaction costs. The change in water allocation resulting from trade consists in some DWU not reducing their abstraction as much as legally required (buyers of WSC) and another DWU reducing more than they have to (sellers of WSC). In both cases, water abstraction is reduced below the reference situation so the existing water infrastructure is not representing a constraint.

Trading can either occur on the basis of bilateral agreement or be organized by a central regulation agency linking buyers and sellers. In the former case, the terms of the transaction are negotiated by the parties, the regulator's role being limited to tracking WSC movements, recording and publicizing price information. In the latter case, the market regulator operates as a clearinghouse for the trade of WSCs. All buyers and sellers submit their offers to the regulator by a certain date, specifying the number of WSCs they want to sell / buy and the minimum / maximum price at which they are willing to sell / buy. The market operator then assess a pool price that maximizes the volume of WSC trade, using an approach similar to the Australian Watermove system (Brooks and Harris 2008). Figure 1 below summarizes the role played by the different actors of this hypothetical market.

INSERT FIGURE 1 ABOUT HERE

Figure 1: *Role of the different actors in the market for Water Saving Certificates.*

2.3. Geographic restrictions

Like in any other form of a water market, the issue of third part effects may arise. For instance, the purchase of WSCs by a DWU located upstream a river to another one located downstream will result in a reduction of water flowing in the river stretch between the two contracting utilities – with possible impacts on ecosystems and water related leisure activities (fishing, canoeing, swimming) if any. Specific externality control mechanisms should then be designed, like for instance restricting trade to within sub-catchments in the same river basin. To what extent these restriction impact on trade needs to be simulated.

3- ECONOMIC MODELING OF THE MARKET FOR WSCS

An analytical model was developed and demonstrated using mathematical programming in two basins located in Southern France to simulate hypothetical exchanges of WSCs between Drinking Water Utilities. This model is presented below.

3.1. Modelling water markets

Most studies that simulate hypothetical exchanges of water among different users use mathematical programming models that simulate agents' market behaviour. These simulate hypothetical water market schemes in a strict sense, where an agent buys or sells water under different institutional and behavioural assumptions, generally perfect competition (Flinn and Guise, 1970; Vaux and Howitt, 1984; Weinberg et al. 1993; Horbulyk and Lo, 1998; Garrido, 2000; Calatrava and Garrido, 2005a and 2005b; Pujol et al., 2006).

To simulate exchanges in a water market, some authors use price endogenous models, such as those developed by Enke (1951), Samuelson (1952) and Takayama and Judge (1964) to solve the problem of equilibrium in spatially separate markets (McCarl and Spreen, 1997). Examples are Flinn and Guise (1970), Vaux and Howitt (1984), Booker and Young (1994), Becker (1995), and Calatrava and Garrido (2005a, 2005b).

The objective function in these price endogenous models is to maximise the sum of all trading partners' economic surplus (obtained from previously estimated water demand functions). The analytical solution to this model is equivalent to that of a central planner that optimises social welfare and identifies efficient non-market water reallocation among users (Calatrava and Garrido, 2005a). Theoretically, a central planner with perfect information would allocate water efficiently according to the Kaldor-Hicks criteria. Thus, the resulting optimal allocation would be equivalent to that of a competitive water market, though no compensation would take place among users. Water price can be derived as the dual value of water availability constraints and used to compute the market outcome from the optimal reallocation established by the spatial equilibrium price endogenous model.

3.2. Model's assumptions

In this paper we simulate the exchange of water saving certificates using an original and novel endogenous price model. We have adapted the price endogenous special equilibrium models used in the water markets modelling literature in order to simulate a different type of market: a market for water saving certificates instead of a market for water or water rights. Moreover, as in Rey *et al.* (2015), we consider a different type of decision maker, namely water managers with cost-minimization objectives instead of water users with utility-maximization objectives. Instead of maximising the sum of welfare for all the market participants (which are water final users), our objective function minimises the sum of all trading partners' cost of water saving subject to achieving individual saving targets either by implementing saving measures and/or buying water. The result is equivalent to a competitive market for WSCs. Water market prices for WSCs are derived as the dual value of market equilibrium constraints.

Our modelling approach is based on the assumption of perfect competition and a price-taking behaviour that is only present in large markets. We base such assumption on the features of the proposed WSC scheme in terms of market transparency, homogeneity of the traded good and especially the large number of potential market participants. A frequent problem found in water trading is market thinness, a problem that arises when the number of potential trading partners is small due to the limited extent of the market, for example because of spatial or hydrological restrictions to trade (Tisdell, 2011) or because water rights are not homogeneous (Saleth et al., 1991). Thin markets are more likely to be manipulated by participants, resulting in price dispersion and inefficient markets (Saleth et al., 1991; Tisdell, 2011). To prevent this problem, adequate bargaining rules must be set. However, according to Saleth et al. (1991), the choice of the bargaining rule only has relevance when the number of market participants is less than twelve in the case of equal sharing water rights systems and less than eight in the case of appropriative or priority water rights. These authors show that, as the market size increases, market outcome converges with a competitive market outcome. In sum, based on the characteristics of the proposed WSC scheme it is unlikely that problems of market thinness arise and the assumption of perfect competition can be considered as realistic.

Another relevant assumption in our model relates to the temporal horizon. We assume stable long run average conditions. A market for WSCs resembles more a market for water rights or entitlements than a spot water market (market for water allocations). Trading of WSCs is framed within urban water utilities' long-term investment decisions aimed to complying with water saving objectives, which are in our specific case study set by the government. Utilities would plan their investments and actions aimed at reducing both water seepage and consumption taking into account the possibility of buying or selling WSCs to achieve specific consumption targets. Consequently, we have modelled average conditions in the long run.

3.3 Water Saving Certificates Market Model

We simulate the exchange of water saving certificates using an endogenous price model that minimises the sum of all trading partners' cost of water saving subject to achieving individual saving objectives either by implementing saving measures and/or buying water.

$$Min \sum_i \sum_j ws_{ij} \cdot mc_{ij} \quad [1]$$

subject to the following constraints:

$$ws_{ij} \leq WSP_{ij} \qquad \forall i,j \qquad [2]$$

$$\sum_j ws_{ij} - \sum_k s_{ik} + \sum_k b_{ik} \geq T_i \qquad \forall i \qquad [3]$$

$$\sum_i \sum_k (b_{ik} - s_{ik}) \leq 0 \qquad [4]$$

$$b_{ik} = 0 \qquad \forall (i,k) \ / \ x_{ik} = 0 \qquad [5]$$

$$s_{ik} = 0 \qquad \forall (i,k) \ / \ z_{ik} = 0 \qquad [6]$$

$$s_{ik}, b_{ik} = 0 \qquad \forall (i,k) \ / \ i = k \qquad [7]$$

$$ws_{ij}, s_{ik}, b_{ik} \geq 0 \qquad \forall i,j,k \qquad [8]$$

Where:

- i and k are municipal drinking water utilities (DWUs);
- j denotes the water-saving measure;
- ws_{ij} is the amount of water saved by the drinking water utility i using water-saving measure j (measured in m^3/year);
- mc_{ij} is the marginal cost of water-saving measure j in the drinking water utility i (measured in euros/m^3/year);
- T_i is the water-saving target, i.e. the total amount of water that must be saved annually by each DWU i (measured in m^3/year);
- s_{ik} is the amount of water saving certificates sold by DWU i to DWU k (measured in m^3/year);
- b_{ik} is the amount of water saving certificates bought by DWU i from DWU k (measured in m^3/year);
- WSP_{ij} is the water-saving potential of each measure j in the drinking water utility i (measured in m^3/year), i.e. the maximum amount of water that can be saved annually by applying each measure in each DWU;
- x_{ik} is a parameter that is equal to 0 if DWU i cannot buy water from DWU k or equal to 1 otherwise;
- z_{ik} is a parameter that is equal to 0 if DWU i cannot sell water to DWU k or equal to 1 otherwise.

The model's decision variables are the amount of water saved by the drinking water utility i using water-saving measure j (ws_{ij}) and the amount of water saving certificates bought or sold by each DWU i from or to DWU k (b_{ik} , s_{ik}).

The objective function [1] minimizes the total cost of implementing water-saving measures in the basin. The first set of constraints [2] restricts the amount of water that can be saved by each DWU using each water-saving measure (ws_{ij}) to its maximum potential (WSP_{ij}). Constraints [3] forces all DWUs to meet their water-saving objectives (T_i), either by saving water (ws_{ij}) or by buying certificates (b_{ik}), and prevents a DWU with surplus certificates from selling (s_{ik}) more certificates than it holds. Constraint [4] forces the market equilibrium (supply of water certificates to be greater than or equal to the demand of water certificates). The set of constraints [5] restricts the spatial extent of water purchases by not allowing a DWU to buy water from DWUs in a sub-basin where buying water from is forbidden. The set of constraints [6] restricts the spatial extent of water selling by not allowing a DWU to sell water to DWUs in a sub-basin where selling water to is forbidden. Parameters x_{ik} and z_{ik} in the sets of constraints [5] and [6] are binary variables that define the spatial restrictions to the trade of WSCs in each basin. The set of constraints [7] stops any DWU from trading water with itself. Last, expression [8] are a set of non-negativity constraints for the decision variables water saving (ws_{ij}), water buying (b_{ik}) and water selling (s_{ik}).

The water-saving target (T_i) is positive when the DWU is over the water consumption quota that has been allocated to it and must either apply water-saving measures to reduce its water consumption or buy water saving certificates in the market (equation 3). On the contrary, it takes a negative value when the DWU's water consumption is below its quota and do not need to save water. In the absence of a market for water saving certificates, a DWU in this second situation would do nothing. If a market for water-saving certificates exists, a DWU that is below its water consumption quota could just sell its extra certificates or even implement further saving measures to obtain additional water-saving certificates and sell them in the certificates' market.

The model is based on the cost minimization of achieving water saving targets. The objective of the municipalities (DWU) is to minimise the cost (equation 1) of reaching their water saving targets (equation 3), restricted by the water saving potential of each measure (equation 2). Water-saving targets can be met either by saving water or by buying certificates, and surplus certificates can be sold to other DWUs with higher costs of water saving measures. Note that in our model water is not valued as a production good (i.e. in terms of marginal utility) because water itself it is not traded. The traded good (the certificate) is the right to not save water and its market value (the price of the certificate) comes from the marginal cost of saving water in the market equilibrium (given by the dual value of equation 4). Thus, in the optimum, the model equals the marginal value of saving water (either by implementing saving measures or buying certificates) for all municipalities. The model computes the optimal amount of water to be saved using each measure by each DWU in order to minimize the total costs of achieving the total water saving target. The comparison of the water saved by each DWU with each DWU's individual water saving target yields the amount of certificates to be bought or sold by each DWU to comply with such individual target (equation 3).

We solve this WSC market model by linear programming using GAMS (Brooke et al, 1992). It yields the optimal amount of water to be saved by each DWU, the optimal allocation of water saving certificates (i.e. the optimal amount of certificates to be bought or sold by each DWU) and the market-clearing price for water-saving certificates in each market (P_m) that is calculated from the dual value of the third constraint [4].

The above model provides results in terms of: water-saving measures implemented by each DWU; the amount of water saved each year in each DWU and each sub-basin and basin; the cost of implementing water-saving measures for each DWU and in each sub-basin and basin; the market-clearing price of water saving certificates; the amount of certificates sold or bought by each DWU and in each sub-basin and basin; the cost or revenue of buying or selling certificates for each DWU and in each sub-basin and basin; the total cost or revenue from saving water and buying or selling water certificates for each DWU and the total cost of achieving the water-saving target (by saving water and purchasing water certificates) in each sub-basin and basin.

3.4. Simulating the impact of spatial restrictions

Parameters x_{ik} and z_{ik} in the sets of constraints [5] and [6] are binary variables that define the spatial restrictions to the trade of WSCs in each basin. By changing their value we can simulate different scenarios of spatial extent of the market and include spatial restrictions to the pattern of trade.

Three scenarios of spatial restrictions were simulated. In scenario 1 (basin level market), WSCs can be traded between DWUs within the same basin with no further spatial restrictions. Parameters x_{ik} and z_{ik} thus take the following values:

$$x_{ik}, z_{ik} = 0 \qquad \forall i = k$$

$$x_{ik}, z_{ik} = 1 \qquad \forall i \neq k \qquad [9]$$

x_{ik} and z_{ik} only take zero values for the same DWU. The result is equivalent to a competitive market for WSCs in each basin (Scenario S1).

In the second scenario, WSCs can be traded between DWUs only within the same sub-basin. Parameters x_{ik} and z_{ik} thus take the following values:

$$x_{ik}, z_{ik} = 0 \qquad \forall i = k$$

$$x_{ik}, z_{ik} = 0 \qquad \forall i \neq k \ / \ i \ is \ in \ a \ different \ sub-basin \ than \ k$$

$$x_{ik}, z_{ik} = 1 \qquad \forall i \neq k \ / \ i \ is \ in \ the \ same \ sub-basin \ as \ k \qquad [10]$$

x_{ik} and z_{ik} take zero values for the same DWU and when *i* and *k* are in different sub-basins. The result is equivalent to a competitive market for WSCs within each sub-basin (Scenario S2).

In the case of the third scenario, there is a single market for WSCs in each of the basins but trading of WSCs is restricted to the upstream-to-downstream direction to account for environmental impacts. DWUs can buy WSCs from DWUs in both their own and other sub-basins but WSCs can only be sold from upstream areas to downstream areas. Parameters x_{ik} and z_{ik} thus take the following values:

$$x_{ik}, z_{ik} = 0 \qquad \forall i = k$$

$$x_{ik} = 0, z_{ik} = 1 \qquad \forall i \neq k \ / \ i \ is \ in \ a \ sub-basin \ upstream \ from \ k$$

$$x_{ik} = 1, z_{ik} = 0 \qquad \forall i \neq k \ / \ i \ is \ in \ a \ sub-basin \ downstream \ from \ k \qquad [11]$$

The result of running the model with these values is equivalent to a competitive market for WSCs in each basin with upstream-to-downstream restrictions to trade (Scenario S3).

4- CASE STUDY AND MODEL IMPLEMENTATION

4.1. Presentation of the case study

The model described above was implemented in a coastal area of Languedoc Roussillon region in Southern France. The case study area corresponds to the Orb and the Hérault river basins, each one being further divided into four sub-basins (O1 to O4 for the Orb and H1 to H4 for the Hérault basin). It covers an area of about 5000 km² that encompasses 310 DWUs hosting over 640,000 inhabitants. The basin is characterized by a Mediterranean climate, with dry summers and wet winters. During dry summers, water resources are very near to over-exploitation. Due to rapid demographic growth, urban water demand is increasing quickly (1.6% per year).

Water use (in m^3 per inhabitant) and water distribution efficiency are highly heterogeneous in the area, with sharp differences between coastal developed areas and inland rural areas. For instance, leakage in distribution systems varies from 15% in some coastal cities to over 50% in hilly areas where water is relatively abundant.

4.2. Water saving targets

The local water management authorities are currently engaging in the development of a long-term water resource management plan in which they will define municipal level water allocation. The plan will specify water abstraction quotas that should not be exceeded by 2030. Since water only represents a constraint during 4 months (from May 15th to September 15th), quotas will be defined for that period only, water use remaining unlimited the rest of the year when the resource is abundant. The research presented in this paper may not exactly predict the decisions that will be taken and the methods that will be used to calculate the quota, but it is in line with the spirit of the policy.

We estimated water saving targets at the 2030 time horizon as follows. We first estimated future water demand (2030 baseline scenario) at the municipal level using a econometric model which was developed in the same area as part of a previous study (Rinaudo et al, 2012; Rinaudo, 2015)). Demands are estimated for the 4 months of the peak demand period (May 15th to September 15th) when water becomes a limiting factor. We then calculated a theoretical water entitlement for each DWU considering (i) an average gross water allotment per inhabitant (250 l/day/capita during the peak demand period) and (ii) distribution network efficiency targets (i.e. acceptable leakage) which are differentiated based on various technical criteria (as specified in the decree 2012-97 of January 27th, 2012). The gap between estimated future demand and theoretical entitlement represents the water saving target. The total water saving target is estimated at 6.2 million cubic meters. While 75% of the DWUs have a positive water saving target (meaning they have to reduce water use), 25% are using less (in 2030) than the quota they have been allocated (meaning they automatically obtain water saving certificates which they can sell).

4.3. Water saving potential

The next step involved estimating a water saving marginal cost function for each of the 300 DWUs. A discrete number of water saving actions was considered (described in Table 1) and their marginal cost (in €/m3/year noted mc_{ij} above) and their potential in volume ($WSP_{i,j}$) were estimated based on results from a series of pilot projects analysing options for water saving in urban areas in the two basins considered in the case study (Rinaudo et al., 2013; Girard et al, 2015). The water saving measures considered are accompanied by information and communication campaigns that are taken into account in the definition of the water saving potential, with those costs included in the marginal costs of the measure. Accordingly, we do not expect any rebound effect linked to the installation of water efficient technologies to be significant and therefore we do not consider it in our analysis[1]. Water savings are calculated for the 4 months of the peak demand period. Cost estimates include total investment and annual recurring cost, including the costs of information and communication to water users, levelized using a 4% discount rate. The average marginal cost mc_j for each water conservation measure *j* and the corresponding cumulated water saving potential ($\sum_i WSP_{ij}$) are shown in figure 2, which ranks measures by increasing average marginal cost (dark dots) and shows how the marginal cost of each measure is

[1] A rebound effect may appear when users know that water saving devices have been installed and adapt their water use practices in such a way that overall water use is increased. Such offsetting behaviour would reduce the effectiveness of some technical water saving solutions (Olmstead and Stavins, 2009). In our case, only measures M2, M8 and M9 could potentially suffer from a rebound effect. The literature on domestic water demand provides ambiguous evidences on this issue (Geller et al., 1983; Campbell et al., 2004; Davis, 2008; Bennear et al., 2011; García-Valiñas et al., 2013; Fielding et al., 2013). However, Geller et al. (1983) and Campbell et al. (2004) show that adding adequate information and communication measures to the technical solutions would eliminate the offsetting behaviour.

variable across DWUs (*1st and 3rd quartiles are provided for each measure*). The blue bars show the maximum water saving that can be achieved by implementing each measure in all DWU.

INSERT TABLE 1 ABOUT HERE

***Table 1**: Description of water conservation measures considered in the study.*

INSERT FIGURE 2 ABOUT HERE

Figure 2: *Water saving potential during peak demand period (bars) and Marginal Cost (average, 1st and 3rd quartiles) of the ten water conservation measures considered in the study.*

The marginal cost of each water saving measure in each municipality (mc_{ij}) is considered constant, as the available data does not allow identifying how such marginal cost changes with the intensity of application of that specific measure. The dots in figure 2, which indicate the average marginal cost of each water saving measure, illustrate how the water conservation measures considered present marginal costs that increase with the amount of water saved, as water managers will first implement those with a lower marginal cost and then move to implement additional measures with higher marginal costs. The effect of increasing marginal costs of water saving in each DWU comes from sequentially moving to a more expensive water saving measure once the immediately cheaper one has been fully implemented.

Despite not being considered in our analysis, the proposed WSC model can be extended to include increasing marginal costs of each measure in each DWU and /or the rebound effect. First, in the case that the marginal cost for each water saving measure would increase with water saved, equation [1] in the WSC trading model would change to $Min\ \sum_i \sum_j ws_{ij} \cdot mc_{ij}(ws_{ij})$, where the marginal cost of water saving measure *j* in DWU *i* (mc_{ij}) would be an increasing function of the amount of water saved by that DWU using that specific water-saving measure *j* (ws_{ij}). The constraints would be the same and the model should be solved using non-linear programming. Second, the offsetting behaviour can be accounted for by multiplying the water-saving potential of each measure in each DWU (parameter WSP_{ij} in equation [2]) by another parameter α_{ij} ($0 \leq \alpha_{ij} \leq 1$) representing the effectiveness of each measure *j* in the drinking water utility *I* to achieve its maximum water saving potential.

5- RESULTS

5.1 Gains from trading

In the reference situation, where trade is not allowed, each DWU has to meet its water saving target through implementing water conservation actions in its own territory. The simulation results show that 72 of the 312 DWUs cannot achieve their individual targets by implementing all possible conservation actions. In other words, the total Water Saving Potential is lower than the saving target in these DWUs. At the basin level, the aggregate gap between actual saving and the target is equal to 0.95 and 0.8 million m^3 for the Orb and Hérault respectively, equivalent to 28% and 23% of the total saving target for the entire area.

When trade is allowed, without spatial restriction, these 72 DWUs can reach their target by purchasing certificates from other DWUs. Other DWUs also engage into trade as purchasing WSCs reduces their cost. Overall, 138 DWUs (44%) purchase WSCs from 174 other DWUs (66%). Trade allows decreasing the total cost from € 1.526 million in the reference situation to €1.131 million in the unrestricted trade scenario (-26%) (table 2). The average cost per unit of water saved decreases from 0.29 €/m^3 in the reference situation (in which the saving target is not reached) to 0.18 €/m3 in the unrestricted market scenario. Gains may be very significant in some sub-basins like H1 and O4 where the average water saving cost is divided by a factor 3 and 2 respectively. Total cost increases in one sub-basin (O3) where the saving target was not reached in the reference situation.

The simulated equilibrium price is respectively 0.54 and 1.03 €/m3 in the Hérault and Orb basins. The total amount of WSCs traded corresponds to a volume of 2.46 million m3, i.e. 39% of the total water saving target (respectively 41% and 37% in the Hérault and Orb basins). Water purchases exceed sales in 5 sub-basins while the three other sub-basins are net sellers.

INSERT TABLE 2 ABOUT HERE

Table 2*: Comparison of the outcomes of the reference (no trade) and unrestricted trade scenarios for the eight sub-basins.*

5.2 Impact of trade spatial restrictions

Unrestricted trade may generate negative environmental impacts when downstream basins sell WSCs to upstream basins. In that case, the upstream user abstracts more water from the river, reducing the flow downstream until the point where the seller takes water. The reduction of river flow in the stretch between the buyer and the seller may impact third parties. Restricting trade within a sub-basin is one possible strategy to control for negative externalities. Another possibility consists in restricting the sale of WSCs to buyers located downstream of the seller. These two restriction scenarios were simulated using the model described in the previous sections (scenarios 2 and 3 respectively).

The results obtained for scenario 2 are depicted in Table 3 below. Restricting trade to users located within the same sub-basin leads to a small increase of the volume of transactions (+6%) and to a 17% increase in total cost (€188 000 per year). This moderate aggregate impact hides a diversity of situations within sub-basins. Restrictions induce a very significant increase in costs for basins H1 and to a lesser extent H4 and O3. This is mainly due to a sharp increase in equilibrium price on restricted markets for WSCs (+109%, +31% and +33%) as compared to the unrestricted scenario. Restrictions benefit sub-basins H2, H3, O1, O2 and O4.

INSERT TABLE 3 ABOUT HERE

Table 3*: Comparison of the unrestricted trade with the sub-basin restricted trade scenarios (for the eight sub-basins).*

The results obtained for scenario 3 are shown in Table 4. Restricting trade of WSCs to the upstream-to-downstream direction to account for environmental flows has no impact at all in terms of water saving in both basins, and a quite reduced impact in terms of the volume of WSCs transactions and costs with respect to the unrestricted trade scenario (+1% and + 3% -€39 024 per year- respectively). The major difference is that environmental restrictions to WSCs trade change the spatial pattern of trade: trading takes place among different sub-basins. This clearly suggests that the best way to control negative externalities consist of restricting trade with a simple rule allowing sales to downstream users only (scenario 3). Sub-basins restrictions (scenario 2) are likely to be less efficient both from an economic and an environment point of view.

However, such reduced aggregate impact hides a diversity of situations across sub-basins. While some sub-basins have to make additional water saving efforts to comply with their saving targets because their buying possibilities are more restricted, others see their costs increased by the greater equilibrium prices (+209% and 105% with respect to scenario 1 in the Herault and Orb respectively). On the other hand, these restrictions benefit other sub-basins that reduce their costs by saving less water and relying more on the purchase of WSCs.

INSERT TABLE ABOUT HERE

***Table 4**: Comparison of the unrestricted trade with the upstream-downstream restricted trade scenario (for the eight sub-basins).*

6- DISCUSSION AND CONCLUSION

The model presented above shows that the development of a market for WSCs is likely to generate significant benefits, estimated at 25% of total water saving costs. There are however several problems that may restrict the potential for trading and reduce the estimated benefits.

First, the model presented above does not account for transaction costs. These costs are likely to be significant, considering all the conditions required for the establishment of this type of market (see section 2). Instituting a rigorous system of water saving measurement, evaluation and verification introduces additional cost on the system participants. These costs are however unavoidable as the credibility of the system depends on this verification system. Additional economic simulations should thus be performed considering fixed and variable transaction costs. It is very likely that a number of actors will not engage into transaction for buying or selling small amounts of water as simulated in the current model.

A second problem stems from the necessity for DWUs to balance their operational budgets. A DWU that invests in water conservation actions to obtain additional WSCs in view of selling them also reduces the amount of water sold, thus its revenues. This may generate a cost recovery problem, since fixed costs (infrastructure) represents about 80% of total production costs in the drinking water sector. A consequence of this is that this Utility will have to raise the price (either fixed or variable rate) charged to consumers. Price will further need to be raised to cover the cost of water conservation measures. However, it must also be taken into account that, if the proposed WSC scheme allows achieving water saving objectives at a lower cost, domestic water users as a whole would be benefited because the financial burden of water saving to be borne through increased water tariffs will be reduced.

There are several other potential obstacles to the participation of DWUs to the WSC market. Small municipal utilities may in particular lack knowledge, technical skill and access to capital to implement the measures. The uncertainty related to WSCs market price may also prevent potential selling Utilities from investing in water conservation measures. And last but not least, social acceptability problems may drastically reduce the market – in particular the fear of speculation problems if brokers are allowed to participate. These issues should be addressed using qualitative and participatory approaches (Figureau et al, 2015).

As shown, the proposed model can be extended to account for increasing marginal costs of each water saving measure and /or for potential rebound effects. Such extensions of the model could improve the model's accuracy but its results would change quantitatively rather than qualitative and the paper's conclusions would still hold. The objective of the paper is to propose the Water Saving Certificates scheme as an option to promote urban water saving at lower costs and to illustrate its potential and benefits using a modelling-based simulation of the WSC's market functioning. Despite our model's limitations, it shows the benefits of the proposed WSC scheme.

REFERENCES

AGRESTE (2010). Services d'eau et d'assainissement: une inflexion des tendances? *Agreste Primeur* 250.

Barraque, B. (2007). Small communes, centralisation, and delegation to private companies: the French experience. *Journal of Comparative Social Welfare* 23, 121-130.

Becker, N. (1995). Value of moving from central planning to a market system: lessons from the Israeli water sector. *Agricultural Economics* 12 (1), 11-21.

Bennear, L. S., Lee, J. M. and Taylor, L. O. (2011). Participation incentives, rebound effects and the cost-effectiveness of rebates for water-efficient appliances, Technical Report Paper EE11-10, Duke Environmental Economics Working Paper Series.

Booker, J.F. and Young, R.A. (1994). Modeling Intrastate and Interstate Markets for Colorado River Water Resources. *Journal of Environmental Economics and Management* 26 (1), 66-87.

Brooke, A., Kendrick, D. and Meeraus, A. (1992). *Gams: A user's guide*. Boyd and Fraser, Danvers, Massachusetts, 289 pp.

Brooks, R. and Harris, E. (2008). Efficiency gains from water markets: Empirical analysis of Watermove in Australia. *Agricultural Water Management* 95, 391-399.

Calatrava, J. and Garrido, A. (2005a). Modelling water markets under uncertain water supply. *European Review of Agricultural Economics* 32(2), 119-142.

Calatrava, J. and Garrido, A. (2005b). Spot water markets and risk in water supply. *Agricultural Economics* 33(2), 131-143.

Campbell, H. E., Johnson, R. M. and Larson, E. H. (2004). Prices, devices, people, or rules: The relative effectiveness of policy instruments in water conservation. *Review of Policy Research* 21(5), 637-662.

Davis, L. W. (2008). Durable goods and residential demand for energy and water: evidence from a field trial. *RAND Journal of Economics* 39(2), 530-546.

Enke, S., 1951. Equilibrium between spatially separate markets: solution by electric analogue. *Econometrica* 19, 40-47.

Farinelli, U., Johansson, T.B., McCormick, K., Mundaca, L., Oikonomou, V., Örtenvik, M., Patel, M. and Santi, F. (2005). "White and Green": Comparison of market-based instruments to promote energy efficiency. *Journal of Cleaner Production* 13, 1015-1026.

Fielding, K. S., Spinks, A., Russell, S., McCrea, R., Stewart, R. and Gardner, J. (2013). An experimental test of voluntary strategies to promote urban water demand management. *Journal of Environmental Management 114*, 343–351.

Figureau, A. G., Montginoul, M., & Rinaudo, J. D. (2015). Policy instruments for decentralized management of agricultural groundwater abstraction: A participatory evaluation. *Ecological Economics*, 119, 147-157.

Flinn, J.C. and Guise, J.W.B. (1970). An application of spatial equilibrium analysis to water resource allocation*. Water Resources Research* 6 (2), 398-409.

Garcia-Valiñas M.A., Athukorala W., Wilson C., Torgler B. and Gifford R. (2013). Nondiscretionary residential water use: The impact of habits and water-efficient technologies. *Australian Journal of Agricultural and Resource Economics* 58, 185–204

Garrido, A. (2000). A mathematical programming model applied to the study of water markets within the Spanish agricultural sector. *Annals of Operations Research* 94, 105-123.

Garrido, A., Rey, D. and Calatrava, J. (2013). Water trading in Spain, in Lucia de Stefano, L. and Llamas, M.R. (eds), Water, Agriculture and the Environment in Spain: Can We Square the Circle? CRC Press/Balkema, Taylor and Francis, Leiden, The Netherlands, pp. 205– 216.

Geller, S.E., Erickson, J.B. and Buttram, B.A. (1983). Attempts to promote residential water conservation with educational, behavioral and engineering strategies. *Population and Environment 6*(2), 96–112.

Girard, C., Rinaudo, J. D., Pulido-Velazquez, M., & Caballero, Y. (2015). An interdisciplinary modelling framework for selecting adaptation measures at the river basin scale in a global change scenario. *Environmental Modelling & Software*, 69, 42-54.

Grafton, R.Q., Landry, C., Libecap, G.D., McGlennon, S. and O'Brien, R. (2010). *An integrated assessment of water markets: Australia, Chile, China, South Africa and the USA*. National Bureau of Economic Research, Working Paper Series 16203, Cambridge, MA.

Hanak, E. (2011). California's Water Market: Lessons from the Field, in Hansjürgens, B., Antes, R. and Strunz, M. (eds), *Permit trading in different applications*. Routledge, Abingdon, United Kingdom.

Horbulyk, T.M. and Lo, L.J. (1998). Welfare Gains from Potential Water Markets in Alberta, Canada, in Easter, K.W., Rosegrant, M. and Dinar, A. (eds.), *Markets for Water: Potential and performance*. Kluwer Academic Publishers, New York, pp. 241-257.

McCarl, B.A. and Spreen, T.H. (1997). *Applied Mathematical Programming using Algebraic Systems*, © Bruce A. McCarl and Thomas H. Spreen, 567 pp. Available at: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/mccspr/thebook.pdf

Oikonomou, V., Rietbergen, M. and Patel, M. (2007). An ex-ante evaluation of a White Certificates scheme in The Netherlands: A case study for the household sector. *Energy Policy* 35:1147-1163.

Olmstead, S. M. and Stavins, R. N. (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resources Research 45*(4), W04301

Pujol, J., Raggi, M., Viaggi, D. and Scaravilli, P. (2006). The potential impact of markets for irrigation water in Italy and Spain: a comparison of two study areas. *Australian Journal of Agricultural and Resource Economics 50*(3), 361–380.

Rey, D., Calatrava, J. and Garrido, A. (2015). Optimization of water procurement decisions in an irrigation district: the role of option contracts. *Australian Journal of Agricultural and Resource Economics*, doi: 10.1111/1467-8489.12110.

Rinaudo, J.D., Maton, L. and Caballero, Y. (2010). Cost-effectiveness analysis of a water scarcity management plan: considering long term and climatic change, in López-Francos A. (ed), *Economics of Drought and drought preparedness in a climate change context*, CIHEAM, Zaragoza, Spain, pp. 183-190.

Rinaudo, J.D., Neverre, N. and Montginoul, M. (2012). Simulating the Impact of Pricing Policies on Urban Water Demand: A Southern France Case Study. *Water Resources Management* 26(7), 2057-2068.

Rinaudo J.D., Girard, C. and Vernier de Byans, M. (2013). Analyse coût efficacité du programme de mesures de gestion quantitative: Application de deux méthodes au bassin versant de l'Orb. Final report. BRGM/RP- 62713 -FR, p.52

Rinaudo, J.-D. and B. Barraque (2015). Interbasin transfers as a supply option: the end of an era ? . In: Understanding and managing urban water in transition. Q. Grafton, K. Daniell, C. Nauges, J.-D. Rinaudo and N. Wai Wah Chan (eds). Dordrecht, Springer: 175-200.

Rinaudo J-D. (2015). Long term water demand forecasting. In: Understanding and managing urban water in transition. Q. Grafton, K. Daniell, C. Nauges, J.-D. Rinaudo and N. Wai Wah Chan (eds). Dordrecht, Springer: 175-200.Saleth, R. M., Braden, J. B. and Eheart, J. W. (1991). Bargaining Rules for a Thin Spot Water Market. *Land Economics*, *67*(3), 326–339.

Samuelson, P.A. (1952). Spatial price equilibrium and linear programming. *American Economic Review* 42 (2), 283-303.

Takayama, T. and Judge, G.C. (1964). Spatial equilibrium and quadratic programming. *Journal of Farm Economics* 46 (1), 67-93.

Tisdell, J.G. (2011). Water markets in Australia: an experimental analysis of alternative market mechanisms. *Australian Journal of Agricultural and Resource Economics*, *55*(4), 500–517.

Vaux, H.J. and Howitt, R.E. (1984). Managing Water Scarcity: An Evaluation of Interregional Transfers. *Water Resources Research* 20 (7), 785-792.

Vine, E. and Hamrin, J. (2008). Energy savings certificates: A market-based tool for reducing greenhouse gas emissions. *Energy Policy* 36:467-476.

Weinberg, M., Kling, C.L. and Wilen, J.E. (1993). Water markets and water quality. *American Journal of Agricultural Economics* 75 (2), 278-291.

TABLES

	Description of water conservation measure
M1	Improve detection and repair of leaks of distribution network.
M2	All households receive a voucher for free water conservation devices (faucet aerators + shower flow reducer)
M3	Water intensive landscapes replaced with xeric vegetation (public gardens)
M4	Seasonal water pricing (increased rate in summer) + automated reading meter
M5	Water saving appliances / kits in all public building (hospital, etc.)
M6	Distribution of water saving devices in hotels (faucet aerators, toilet flushes)
M7	Free plumber assisted audits of campsites and holiday parks. Installation of low flow flushes / showers, leakage detection in campsite distribution network, etc.
M8	Free plumber assisted water use audit for single houses owners; fixes leakages and installs various water saving devices depending on the situation
M9	Same as U8 for multifamily houses + automated reading meter.
M10	Replacement of irrigated lawns with artificial turf for sport grounds

Table 1*: Description of water conservation measures considered in the study.*

	Reference situation (no trade)			Trade without spatial restriction					
Basin	Vol saved[(a)]	Total cost [(b)]	Average cost[(c)]	Vol saved[(a)]	Total cost[(b)]	Total cost var.[(d)]	Average cost[(c)]	Vol bought[(a)]	Vol sold[(a)]
H1	173	99	0.57	129	20	20%	0.16	84	25
H2	461	92	0.20	586	92	100%	0.16	43	271
H3	381	72	0.19	453	48	68%	0.11	36	99
H4	1 762	566	0.32	1 976	304	54%	0.15	1 135	903
O1	429	52	0.12	508	46	89%	0.09	35	96
O2	501	108	0.22	547	95	88%	0.17	67	107
O3	1 038	276	0.27	1 367	305	111%	0.22	674	482
O4	512	261	0.51	691	221	85%	0.32	385	476
Herault	2 777	829	0.30	3 144	465	56%	0.15	1 298	1 298
Orb	2 479	696	0.28	3 113	666	96%	0.21	1 162	1 162
TOTAL	5 256	1 526	0.29	6 257	1 131	74%	0.18	2 459	2 459

[a)]: in thousand m^3 per year. *[(b)] in thousand € per year.* *[(c)] : in € per m^3 per year.*

[(d)] cost with trade / cost without trade in %

Table 2*: Comparison of the outcomes of the reference (no trade) and unrestricted trade scenarios for the eight sub-basins.*

Basin	Vol. saved		Vol. exchanged		Total cost		Price	
	x1000 m^3/y	% of UTSc	x1000 m^3	% UTSc	x1000 €	% UTSc	€/m^3	% UTSc
H1	188	146%	39	71%	70	349%	1.13	209%
H2	357	61%	171	109%	24	26%	0.16	30%
H3	390	86%	76	113%	27	56%	0.21	39%
H4	2 208	112%	1 080	106%	448	147%	0.71	131%
O1	446	88%	78	119%	17	36%	0.12	12%
O2	507	93%	84	97%	63	67%	0.66	64%
O3	1 559	114%	647	112%	525	172%	1.37	133%
O4	601	87%	437	101%	145	66%	0.72	70%
Herault	3 144	100%	1 366	105%	569	122%	-	-
Orb	3 113	100%	1 246	107%	751	113%	-	-
Total	6 257	100%	2 612	106%	1 319	117%	-	-

UTSc = Unrestricted Trade Scenario.

Table 3: *Comparison of the unrestricted trade with the sub-basin restricted trade scenarios (for the eight sub-basins).*

Basin	Vol. saved		Vol. Bought		Vol. Sold		Total cost		Price	
	x1000 m^3/y	% of UTSc	x1000 m^3	% UTSc	x1000 m^3	% UTSc	x1000 €	% UTSc	€/m^3	% UTSc
H1	188	146%	39	46%	39	157%	70	348%	-	-
H2	576	98%	49	115%	268	99%	87	95%	-	-
H3	452	100%	37	103%	99	100%	48	98%	-	-
H4	1 927	98%	1139	100%	858	95%	279	92%	-	-
O1	515	101%	35	100%	103	107%	54	116%	-	-
O2	550	101%	67	100%	111	103%	98	104%	-	-
O3	1447	106%	670	99%	558	115%	389	127%	-	-
O4	601	87%	437	113%	437	92%	145	67%	-	-
Herault	3 144	100%	1 263	97%	1 263	97%	483	104%	1.13	209%
Orb	3 113	100%	1 208	104%	1 208	104%	687	103%	1.08	105%
Total	6 257	100%	2 472	101%	2 472	101%	1 170	103%	-	-

UTSc = Unrestricted Trade Scenario.

Table 4: *Comparison of the unrestricted trade with the upstream-downstream restricted trade scenario (for the eight sub-basins).*