SOCIO-ECONOMIC INTERESTS FOR TREATED WASTEWATER REUSE IN AGRICULTURE IRRIGATION AND INDIRECT POTABLE WATER REUSE: CLERMONT-FERRAND AND CANNES CASE STUDIES' COST-BENEFIT ANALYSIS

INTERETS SOCIO-ECONOMIQUE DE LA REUTILISATION DES EAUX USEES TRAITEES POUR L'IRRIGATION AGRICOLE ET LA PRODUCTION INDIRECTE D'EAU POTABLE: ANALYSES COUTS-BENEFICES DES CAS DE CLERMONT-FERRAND ET DE CANNES

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ABSTRACT

Unlike many structuring projects, treated wastewater reuse projects are rarely subjected to economic analysis. And when they are, social and environmental benefits and costs are often not accounted for or are not properly quantified. Here we show that the widely used cost-benefit analysis method showing a project’s interest from the whole collectivity point of view can be adapted to treated wastewater reuse projects. The remaining evaluation difficulties are more due to the system's complexity rather than its methodological limits. Indeed, the operator must be able to understand, formalize and imagine constraints and risks associated to different domains like urbanism, agriculture, climate, hydrology and trade. Remaining uncertainties on key parameter values can however be properly considered through scenarios and/or stochastic approaches. We illustrate the implementation of this methodological approach with 2 case studies: Clermont-Ferrand where treated wastewater is reused by a collective irrigation network; and Cannes where surface and groundwater recharge could enable indirect reuse for multiple purposes including indirect potable water production. These 2 French case studies highlight how economic analysis, dealing with uncertainties, can support decision making.

RÉSUMÉ

Les projets de réutilisation des eaux usées traitées font rarement l'objet d'analyses économiques. Lorsque c’est le cas les coûts et bénéfices sociaux et environnementaux ne sont pas correctement pris en compte ou quantifiés. Nous montrons ici que la méthodologie d’analyse coût-bénéfices (ACB) permettant d’évaluer la rentabilité d’un projet à l’échelle d’un territoire peut être adaptée à l’évaluation de projets de réutilisation des eaux usées traitées. La méthodologie employée est bien maitrisée et les difficultés de mise en œuvre sont davantage liées à la complexité du système. L'opérateur doit en effet être en mesure de comprendre, de formaliser et d'imaginer les contraintes et les risques associés à différents domaines tels que l'urbanisme, l'agriculture et l'hydrologie. Les incertitudes résiduelles sur les valeurs de paramètres clés peuvent être prises en compte par l’étude de différents scénarios et/ou par des approches stochastiques. Nous illustrons cette approche à travers les études de cas français de Clermont-Ferrand où des eaux usées traitées sont réutilisées par un réseau collectif d'irrigation, et de Cannes où la recharge de milieux permet la réutilisation indirecte pour différents usages dont la production indirecte d’eau potable. Ces études de cas illustrent comment l’analyse économique peut aider à la prise de décision.

Keywords: Cost-Benefit Analysis, Treated wastewater reuse, Irrigation, Indirect potable reuse, Risks and uncertainties

Introduction

Treated or untreated wastewater reuse is a particularly appealing solution in water-stressed areas, and can be used to tackle water scarcity but also to recover surface water quality (Asano, 1998; Lazarova et al., 2001). Nevertheless projects need to be sustainable. Economic considerations become of high importance when assessing the potential of treated wastewater (TWW) reuse projects (Asano, 1998). But projects' process design rarely includes a balanced economic analysis compared to other types of structuring projects and the economic feasibility of TWW reuse projects thus remains insufficiently studied (Molinos-Senante et al., 2011). This is partly because internal and external economic impacts are difficult to identify and quantify properly. While internal impacts may be easily translated into monetary units, externalities are not considered by the market, thus requiring economic valuation methods for their quantification (Molinos-Senante et al., 2011). Consequently, the true or overall benefits and costs of many projects are not properly evaluated (Segui, 2004). Studies carried out in Mediterranean countries (Molinos-Senante et al., 2011; Condom et al., 2012) showed that when external benefits are properly quantified and integrated into the economic analysis the number of economically viable TWW reuse projects increases. Cost-Benefits Analyses (CBA) for wastewater reuse projects are therefore of growing interest but the methodology has scarcely been applied in France as well as in the Mediterranean area on TWW reuse projects.

Two French projects have been selected to apply the CBA methodology and to assess TWW reuse profitability. Both contexts are representative of the French and Mediterranean area's water resources scarcity and quality issues that could be partly addressed by TWW reuse:

(1) The agricultural reuse project of Clermont-Ferrand is by far the largest TWW reuse project implemented in France with 1 400 Ha equipped for irrigation since 1996, half of which is irrigated every year. The detailed economic analysis is therefore an *ex post* assessment.

(2) In the Cannes area a TWW reuse scenario has been designed to recharge surface and groundwater at the head of the Siagne Low Valley (SLV) in order to indirectly supply numerous downstream uses including potable water production, but also golf course and agricultural irrigation. This project is not implemented yet. The economic analysis detailed is therefore an *ex ante* assessment.

The CBA methodology is first described, as used to deepen the assessment and highlight the conditions that will make the analysis results useful in supporting the decision-making process. Then the Clermont-Ferrand and Cannes TWW reuse case studies are detailed. The objectives are (1) to assess the CBA methodology's applicability without specific difficulties to TWW reuse projects and to highlight its limitations; (2) to assess the economic profitability of TWW reuse projects for territories in IWRM and circular economy perspectives, and to analyze the stakeholders' costs and benefits share.

1. Materials and methods

1.1 Cost-benefit analysis, a method to assess TWW reuse project's profitability

The CBA is a technique used for analyzing projects to determine whether or not they are in the public's and private sector's interest. CBA assigns monetary value to each input and output resulting from the project (Verlicci et al., 2012). This very well-known methodology is rarely carried out for treated wastewater (TWW) reuse projects, or only partially. CBAs are implemented (i) to assess projects’ economic profitability for a community on a specific territory, and (ii) to identify which stakeholders win/lose to draft correction actions to implement to reach a win/win balance. The terms “community” or “territory” designate here all the stakeholders and funding agencies directly or indirectly involved in the project.

The methodology includes the following successive steps: (1) identification of the different TWW reuse scenarios, single option is possible, (2) characterization of the analysis sphere (geography and actors involved), (3) business as usual (BAU) scenario (no reuse) characterization (including future changes), (4) time line setting (from 20 to 50 years), (5) costs and benefits identification and assessment for the reuse and business as usual (BAU) scenarios, (6) Net Present Value (NPV) calculations (considering discount rate) to compare scenarios, (7) sensitivity analysis of NPV to the main parameters.

Once they have been estimated, all future costs and benefits need to be assessed in present value before being summed (Step 5). The discounting principle is used to integrate the preference for the present into the analysis: a discounted cost or benefit (Xd) is then calculated using a discount rate.

FORMULA 1: ABOUT HERE

The Net Present Value (NPV) calculated in Step 6 is then equal to the sum of differences of discounted costs and benefits between the 2 compared scenarios (e.g. reuse and business-as-usual scenarios).

FORMULA 2: ABOUT HERE

Many of the costs and benefits are easy to identify and to monetize (added value, investments, expenses, etc.) but some are particularly difficult to monetize like the environmental externalities, the employment evolution in downstream chains or even the individual satisfaction. Specific, complex and time-consuming economic methods are developed to assess in detail these costs and benefits. This requires a good knowledge of economic concepts and time to carry out these analyses. Carrying out only a single economic analysis, i.e. from the collectivity's point of view, highlights potential advantages (NPV>0) or disadvantages (NPV<0). For non-profitable projects, no further analysis is required. For profitable projects, economic analysis must be completed with financial analysis to be sure that every actor recieves interest by collaborating in the project. When it is not the case, the project could not be implemented even though it advantages the collectivity. The financial analysis' aim is then to identify the corrections (subsidies, pricing, taxes…) to implement for reaching win-win solutions (Loubier, 2015). Economic (CBA) and financial analyses are based on the same concepts but some parameters are different.

In economic analyses, the recommended discount rate in France is 2.5% for public projects and the time line is generally set between 40 and 50 years. From private actors' point of view, i.e. for financial analysis, the discount rate is higher (6% to 8%, sometimes more) and the time lines shorter (20 years) (Loubier, 2015).

In a CBA, if an investment is set in Year x, then associated maintenance and operation costs and benefits start in Year x+1. Therefore initial investments are set in Year 0.

In the CBA, whether the analyse is ex-post or ex-ante, some differences may exist between the original plan and the observed situation. Sensitivity analyses are therefore carried out to assess the NPV dispersion and to test the robustness of the deterministic calculated results (in Step 7). A Monte-Carlo method can therefore be used: it consists in carrying out a succession of thousands of random draws for the values of some key but uncertain parameters and then in analyzing the related NPV dispersion.

1.2 Sites and contexts

1.2.1 The Siagne Low Valley (SLV) in the Cannes area

The Cannes area is a water stressed territory with many constraints related to intensive urbanization and a planned increase in permanent and seasonal population in the upcoming years (Acteon, 2014).

The 15 km² Siagne Low Valley (SLV) is the downstream area of the 520 km² Siagne river basin. The SLV widens from 1 km to nearly 4 km as it flows South until reaching the Mediterranean. It is surrounded by smooth hills in the East and in the West and is subdivided into 2 main areas: (1) the upstream valley is an agricultural area with high added-value crops produced, in particular aromatic and medicinal crops, vegetables and fruit trees grown over 100 Ha. Crops are irrigated using mainly surface or drip irrigation systems; (2) the downstream valley is densely urbanized and constituted of commercial and industrial areas. Residential areas of Cannes, Mandelieu-la-Napoule, Pégomas et La Roquette-sur-Siagne cities are spread along the foothills as the SLV is subject to major floods.

The Aquaviva WWTP treatment process includes a biological reactor and membrane ultrafiltration. The plant treats Mandelieu-la-Napoule, Cannes, and 6 other cities' domestic effluents. More than 16 Mm^3 of TWW are discharged every year into the Mediterranean with very low impact on bathing areas and sea biodiversity (Ecofilae, 2015).

The Siagne river module flow upstream of the SLV is 9.09 m^3/s (Base Hydro, 2015). The river is subjected to major water uptakes in the SLV area including from upstream to downstream: (1) the Beal, an old irrigation canal that reaches the sea with 5 to 10% of the Siagne river flow uptaken in the upstream SLV; (2) direct agricultural uptakes for irrigation; (3) the Mandelieu-la-Napoule city's 2 water uptakes for potable water production and the Golf course irrigation.

The SLV groundwater is used for: (1) potable water production by the SICASIL that distributes water to Cannes' urban area (except Mandelieu-la-Napoule) with 3 wells located in the upstream area of SLV; and (2) for irrigation and private domestic uses with an unknown number of wells and pumped volume. Groundwater is not suffering major depletion up to now but salinity is getting high in the Southern SLV: the golf course and southern farmers cannot use it anymore. Salted front is slowly rising (BRL et al., 2008); the phenomenon is aggravated as groundwater uptakes increase.

We considered that water sources for agricultural irrigation in the SLV are 70% from groundwater, 20% from the Beal canal and 10% from the Siagne river (Ecofilae, 2015). Indeed, farmers no longer rely on the Beal water resource as their uptakes are uncontrolled and as the Beal is the output of many urban rainwater canals, therefore leading to highly variable flows and low quality water with high levels of pathogens (Ecofilae, 2015)

A flow monitoring station is located in the Siagne river a few meters downstream of Mandelieu-la-Napoule's water uptakes. A minimum summer low-water flow is set to 475 L/s[5]. This limit flow has not been respected during summer months from 2010 to 2014. Furthermore maximum legal volumes that can be abstracted in the 3 groundwater wells in the upstream SLV compel the SICASIL to limit water uptakes. We therefore consider that there is no additional local water resource available in the SLV, nor in the Siagne river and Beal canal or in the SLV groundwater, to face increasing demand for potable water related to the planned population increase. We also

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[5] Prefectoral regulatory decision of the 1st of August 2014

consider that water uptakes for irrigation (golf course and agriculture) will not change in the following years: we consider that water demand increase due to climatic change will be offset by planned transitions to water management systems with higher efficiency (switching to drip irrigation systems, better irrigation scheduling, etc.) and by the decrease of cultivated irrigated lands.

1.2.2 The Limagne Noire plain in the Clermont-Ferrand area

The Limagne Noire is a very fertile agricultural plain located North-East of the city of Clermont-Ferrand. The area is rural. Main crops are maize (grain and seeds), sugarbeet and wheat. Seed maize has the highest gross margin and farmers are compelled by local seed companies to irrigate their production for security reasons. Sugarbeet production is sent to a sugar factory which owns 12 Ha of lagoons.

Water resources are scarce in the area: the Bedat and Artière rivers' flows cannot satisfy the whole irrigation water demand; they are both affluents of the Allier river that flows 20 km east.

The Clermont-Ferrand WWTP includes activated sludge, specific denitrification and dephosphatation processes and treats around 40 Mm^3 of domestic wastewater per year. TWW is then discharged into the Artière river. The WWTP belongs to the Clermont-Ferrand urban community and is adjacent to the sugar factory.

Treated wastewater (TWW) is therefore being reused to irrigate farmers’ production since 1996. 1 400 Ha of agricultural land is equipped for irrigation with half being irrigated each year in rotation. The Limagne Noire Water Users Association was created at the beginning of the project and the distribution system (network and pumps) installed. The project is detailed in Part 1.3.2.

1.2.3 French TWW reuse regulations

In France, agriculture and green areas' (including stadium and golf courses) irrigation with treated waste water (TWW) is authorized and regulated by the 2nd of August 2010 national regulatory decision. Discharge of TWW into surface water is allowed[6] but submitted to impact assessment on downstream uses (French Environmental Code). Other wastewater uses such as urban cleaning or groundwater recharge can be assessed in pilot projects in order to get feedback and to create or revise regulations. These initiatives are supported by state authorities.

1.3 TWW reuse and BAU scenarios

1.3.1 In the Siagne Low Valley

Several short, medium and long term TWW reuse scenarios that integrate different end-uses have been designed and analyzed through juridical, regulatory, administrative, social and technical aspects (Ecofilae, 2015). Finally, and considering the above mentioned aspects, economic and financial analysis, using CBA methodology, have been carried out on 1 TWW reuse scenario selected by local stakeholders. This scenario is divided in to 2 technical options.

The Cannes city Mayor, specified that economic profitability would be a major decision criterion (Berard, 2015). The objectives of the CBA are therefore: (i) to assess TWW reuse profitability and sustainability for the “community” and for each stakeholder; (2) to compare options to select

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[6] National regulatory decision of the 21th of July 2015

the most profitable one for the "community". So far no final decision has been taken by stakeholders but CBA outputs shall support local decision-makers in their choice.

As the CBA was carried out before project implementation, the CBA is called « ex ante » with high uncertainties on TWW reuse scenario parameters. 1 TWW reuse scenario with 2 technical options is compared to the BAU scenario. The time line is set to 40 years, from 2017 (Year 0) to 2057. The main stakeholders involved are the SICASIL and the Mandelieu-la-Napoule city as they both produce potable water.

The **TWW reuse scenario** consists in recharging 10 000 m^3/day of TWW into surface and groundwater resources in the upstream SLV. Indirectly, TWW reuse will then enable to meet part of the expected increased demand in potable water in the upcoming years for both producers SICASIL and Mandelieu-la-Napoule. Recharge of the Beal canal will also enable farmers to return to this historically dedicated water resource and abandon well drilling, therefore releasing the pressure on groundwater resources and limiting salty intrusion close to the sea.

2 temporal steps are planned for the project's implementation as we consider that groundwater recharge will only be authorized in 5 years' time in France. TWW resource will then be allocated to the Siagne river and Beal canal in Time 1 (system operational in Year 1 = 2018) and then partly to SLV groundwater in Time 2 (system operational in Year 6 = 2022). The recharge will only be operational from mid-May to mid-September (4 months) during touristic and irrigation periods.

TABLE 1: ABOUT HERE & FIGURE 1: ABOUT HERE

In the **BAU scenario** the alternative for additional potable water would be to transfer and to buy water from neighboring territories. Many solutions could be considered but none have been technically assessed at this stage. We also consider that the golf course will keep using Siagne water and that farmers will keep on with the present resource distribution for water uptake (see Part 1.2.1).

1.3.2 In the Limagne Noire plain

The Limagne Noire plain is by far the biggest area irrigated with TWW in France. The project launched in 1996 was initiated in the early 90s by local farmers that feared for the disappearance of their activity in an area without aquifer or any other major surface water resource. Indeed irrigation was considered indispensable: (1) to increase and secure yields in the area where climatic conditions are highly variable from one year to another; and (2) to enable farmers to comply with production specifications from a local seed company that requires irrigation on seed maize.

As the CBA was carried out after the project's implementation, the CBA is called « ex post » with high uncertainties on the counterfactual BAU scenario parameters. Here, the implemented TWW reuse scenario and the counterfactual BAU scenario are compared. The time line is set to 50 years, from 1996 (Year 0) to 2046 (Year 50). The main stakeholders involved are the sugar factory and the farmers (as a whole). We also considered the funding agencies (EU, state, region, water agency, others) in this ex-post analysis.

In the **TWW reuse scenario** TWW is supplied for free by the Clermont-Ferrand urban district, owner of the WWTP, to the farmers. According to the project convention, Clermont-Ferrand urban district is committed to supply TWW at a quality level that complies with regulation standards for surface TWW discharge. The farmers' association is in charge of additional treatment and responsible for irrigation water quality (compliance with irrigation TWW reuse regulation – Part 1.2.3).

A complementary treatment is therefore required before use. The method involves 12 Ha of lagoons, property of the sugar factory. In winter, the sugar factory uses the lagoons to store its effluents before spreading them onto the perimeter using the distribution system (Step 1). Farmers are then sure to start the spring with the water storage capacity at its maximum in the soil. Then in early spring, when lagoons are empty, they are used as tertiary treatment and storage space for TWW before irrigation (Step 2).

FIGURE 2: ABOUT HERE

59% of initial investments (distribution system, irrigation material, lagoons rehabilitation and sanitary studies) were subsidized in 1996. The Water User Association's budget is balanced. The 50 farmers' fees cover annual expenses. The Water User Association is then neutral in the analysis since all expenses are transferred to farmers. The sugar factory bears part of the maintenance and operation (energy) costs proportionally to the transiting volumes.

FIGURE 3: ABOUT HERE

The hypothetical **BAU scenario** is the situation as it would have been without reuse from 1996 to 2046. In 1996 only a few farmers used the Bedat river whose irrigation potential was only for 200 Ha located nearby the river. We considered that farmers would have kept using it to irrigate 200 Ha without affecting its quality as we could not figure out the impacts. Irrigated seed maize surfaces would have significantly decreased since the Bedat water wouldn't have been enough to satisfy the present irrigated seed maize area. We also considered that the rain-fed crops in the remaining perimeter (1 200 Ha) would have stayed similar to a non-irrigated perimeter located nearby the farmer's association irrigated perimeter.

Before 1996 (before TWW reuse implementation) the effluent produced in winter by the factory used to be stored in the 12 Ha lagoon system before being conveyed and treated by the Clermont-Ferrand WWTP in summer when domestic entrance flow is lower (the Clermont-Ferrand population decreases in summer). In the BAU scenario we consider that the sugar factory would have kept on sending its effluent for treatment to the WWTP at a high cost (1.9 €/m^3).

FIGURE 4: ABOUT HERE

1.4 Costs and benefits assessments

An annual planned increase in energy cost of 3.6 %/year was considered (Eurostats, 2017) when calculating each energy cost (electricity or fuel) in the operation costs of the different systems and scenarios considered below. The price for industrial energy was set to 0.09 €/kWh in April 2017.

1.4.1 In the Siagne Low Valley

Hydraulic infrastructures to transport TWW from Aquaviva WWTP to recharge points and specific recharge infrastructures are the major expenses in the TWW reuse scenario. Potable water benefits in the TWW reuse scenario have been assessed by considering the avoided cost of buying potable water in the BAU scenario. Those costs and benefits for **both TWW reuse and BAU scenarios** are detailed below.

Hydraulic infrastructures for transportation

Hydraulic infrastructures for transportation are required in the TWW reuse scenario to carry water from Aquaviva WWTP to the upstream SLV. They have been pre-dimensioned at this stage of the project. Pumping systems could be set on a plot adjacent to the WWTP while pipes crossing the valley will face hydraulic and land constraints that have been considered. In Time 2 an additional pipe will be necessary to connect the Siagne and Beal recharge points to the groundwater recharge point which is located upstream of the SICASIL wells. A 4 600 m^3 storage basin is also necessary in the upstream SLV close to the Siagne and Beal reinjection points.

Respective investment, maintenance and operation costs have been assessed. Maintenance costs are estimated at 3% of the investment cost per year for the pumping system, and at 0.5% for the storage and pipes (Plantey et Blanc, 1998). When calculating operation costs, quarter-time technician support (5 750 €/year) and pumping energy costs have been considered with a pumping energy consumption set to 408 065 kWh for 4 months.

TABLE 2: ABOUT HERE

Recharge of natural resources and additional treatments

We consider that surface water recharge with TWW requires no additional treatment system as the quality of Aquaviva TWW is sufficient to be discharged into surface water (see Part: French TWW reuse regulations) nor does it need any major hydraulic infrastructures at the recharge points.

However 2 technical options concerning groundwater recharge can be considered at this stage: (Option 1) infiltration through dedicated basins; or (Option 2) direct reinjection through pumping wells. Both practices are not authorized in France where water quality standards and pilot projects do not exist yet. TWW infiltration is a common practice in Mediterranean countries. NGEST project in Gaza and the Korba project in Tunisia (Condom et al., 2017) have been used as models to pre-design Option 1. No additional treatment has been considered necessary in Option 1 considering Aquaviva's TWW quality and the soil's capacity to remove pathogenic agents. However land constraints could be a major issue in the upstream SLV area as land prices around 13 €/m² and slopes are relatively steep.

TABLE 3: ABOUT HERE

TWW reinjection is implemented in Oregon USA and in Spain (ex: Llobregat del Prat). The Orange county project in Oregon USA (Chalmers et al., 2013) has been used as a model to pre-design Option 2. Groundwater contamination risks are higher than in Option 1 and an additional treatment before reinjection composed of reverse osmosis and UVA treatment units has been considered, prior to reinjection through 2 wells.

Operation and maintenance costs for groundwater recharge have been calculated. Energy cost is considered equal to zero in Option 1 but half-time technician support is needed. The Additional treatment operation and maintenance cost in Option 2 is estimated at 0.028 €/m^3, while reinjection (through 2 wells) operation costs have been calculated considering a pumping energy consumption set to 162 384 kWh for 4 months and a fifth-time technician support.

TWW production costs for project stakeholders can be calculated. Costs and benefits over 40 years are considered. The subsidy rate coming from external bodies is set to 50% of total investments. TWW production costs are then equal to 18.2 and 59 c€ per m^3 of TWW reused respectively for Option 1 and Option 2.

FORMULA 3: ABOUT HERE

Potable water production benefits

The main expected benefit of the TWW reuse scenario is an increase of available water to face the planned summer increase in demand for potable water in the cities of Mandelieu-la-Napoule and Cannes. The Planned potable water demand's increase annual rates are set to: (1) 1% per year from 2017 to 2027; (2) 0.5% per year from 2027 to 2037; (3) 0% per year from 2037 to 2057 (Acteon, 2014).

With the TWW reuse scenario we consider that the additional volumes available in the SICASIL wells are of 50% in recharged TWW in Option 1 and 60% in Option 2. It is higher in Option 2 than in Option 1 as reinjection could be directed easily to appropriate location. 244 000 m^3/year and 195 000 m^3/year are therefore left in the aquifer respectively in Option 1 and Option 2. We also consider that 100% of the TWW volume recharged into the Siagne river will be available downstream for Mandelieu-la-Napoule's water uptake for potable water and golf irrigation.

In the BAU scenario, the external production cost for potable water would in any case be higher than the present production cost from local sources. Therefore we considered that costs in the BAU scenario are at least equal to present local production costs for potable water: 1.24 €/m^3 and 0.36 €/m^3 respectively for SICASIL and Mandelieu-la-Napoule.

TABLE 4: ABOUT HERE

168% of the planned increase of potable water demand in Mandelieu-la-Napoule will be satisfied by TWW after 2037, while it will only be 31% (Option 1) and 38% (Option 2) in Cannes. Then a transfer of the 68% excess water of Mandelieu-la-Napoule could be anticipated. Connections seem technically feasible in some points of the network at limited cost.

The benefits of recharging the Beal canal are: (1) to improve its quality in terms of pathogens with a calculated decrease of *Escherichia Coli* content ranging between 2,4% and 5,6% during irrigation period; (2) to increase available water flow for farmers with a calculated increase of water flow ranging between 3% and 6% during irrigation period. Shifting farmers towards the Beal canal for irrigation instead of drilling groundwater, combined with recharging groundwater upstream will enable to release quantitative pressure on groundwater and downstream uses. Salinity effects will be likely to be limited then. Benefits are not well known and can hardly be quantified nor monetarized. They have not been included in the present CBA.

1.4.2 In the Limagne Noire plain

For the existing **TWW reuse scenario** all effective initial subsidies, investments, operation and maintenance costs data since 1996 were supplied by the Limagne Noire farmers' association (data from Year 0 = 1996 to Year 17 = 2013). These data were used to forecast future costs up to Year 50 = 2046.

The irrigation is performed by 2 pivot systems and nearly 40 hose reel gun machines. Their maintenance costs have been assessed at 3 000 €/year/pivot and at 400 €/year/pivot with a service life of 20 years.

TABLE 5: ABOUT HERE

In the **BAU scenario,** some farmers use individual systems to uptake water in the Bedat river. Local farmers that were already settled in 1996 considered that only 3 reel machines and 2 pumps could have been set up with a service life of 20 years. Fuel is used and an initial cost of energy of 12 500 € in Year 1 was considered.

The sugar factory effluents' treatment costs in the BAU scenario are set to 1.9 €/m^3. This value was set by the Clermont-Ferrand urban community for other agro-industrial industries that discharged wastewater into the WWTP in 2013.

TABLE 6: ABOUT HERE

Agricultural gross margin data values for irrigated and rainfed crops in the area were supplied by the Agricultural Chamber of the Puy-de-Dôme (63). Total gross margins were calculated for **both scenarios** considering the crops distribution.

TABLE 7: ABOUT HERE

2. CBA results

2.1 NPV calculations

2.1.1 In the Siagne Low Valley

The total discounted cost for the TWW reuse project is around 7 700 k€ for Option 1 while the total discounted benefit is around 7 900 k€. Calculated economic NPV is then positive and equal to around 200 k€. Project profitability can nevertheless hardly be considered as certain since the NPV result does not seem significant if we take into account the 40 years' analysis timeline. A sensitivity analysis of the NPV regarding the main parameters is relevant to deepen the analysis and better interpret the results.

TABLE 8: ABOUT HERE

The total discounted cost of the TWW reuse project is around 13 300 k€ for Option 2 while the total discounted benefit is around 9 100 k€. Calculated economic NPV is then negative and around – 4 200 k€. The project does not seem profitable. Compared to Option 1, direct reinjection of TWW into groundwater in Option 2 requires expensive treatment and hydraulic infrastructures that penalize the project heavily.

TABLE 9: ABOUT HERE

In both options the results could not account for the environmental benefits of the projects (Beal and groundwater salinity). It could be worth to deepen the environmental analysis within Option 1 as the NPV could be significantly positively impacted. However we expect that the NPV would stay negative in Option 2.

FIGURE 5: ABOUT HERE

2.1.2 In the Limagne Noire plain

Calculated economic NPV is positive and around 10 100 k€. The project is sustainable for the community and it was worth being subsidized. The 2 stakeholders involved (farmers and the sugar factory) also get a financial positive NPV. Our results could not account for the possibility that agricultural land would be used for other activities in the BAU scenario. However we expect this would not have negatively impacted the NPV.

Furthermore the project's NPV would still be positive without public subsidies and the benefit shared among the two agents is largely in favor of the sugar factory.

FIGURE 6: ABOUT HERE

2.2 Sensitivity analysis using the Monte-Carlo method

Some differences exist between the original plans and the future real situations. Sensitivity analyses have therefore been carried out to assess the NPV dispersion and to test the robustness of the deterministic results above. The Monte-Carlo method has been used in the sensitivity analysis: 1 000 successive NPV calculations were conducted following random draws for the values of key parameters between specific lower and upper limits.

2.2.1 In the Siagne Low Valley

The uncertain parameters concern mainly investment and operation costs. Later in the project assessment, in the case of a positive NPV, further technical analyses will allow to reduce this uncertainty. The other uncertain parameters concern the increase rate of energy prices and hydrogeological parameters (percentage of the infiltrated water available for pumping).

TABLE 10: ABOUT HERE

The NPV for Option 2 (groundwater reinjection) is negative in 99.5% of the simulations and, thus, the project is not profitable as suspected after the deterministic analysis in Part 2.1.1. With Option 1 (groundwater surface recharge) the project is profitable in 45.6% of the simulations and the project's NPV is below the deterministic value calculated in 58.4% of the simulations. It would be very hazardous at this stage to implement Option 1 without further studies on the expected costs and benefits of the project.

FIGURE 7: ABOUT HERE

Probability shows that TWW production costs would be between 15 and 19 c€ in Option 1 and between 44 and 60 c€ in Option 2. Uncertainty is higher for Option 2 than for Option 1 because of higher uncertainties on reinjection infrastructure costs.

FIGURE 8: ABOUT HERE

2.2.2 In the Limagne Noire plain

Since here the analysis is an ex post one, uncertainties mainly concern parameters of the BAU scenario (crop area and gross margin), some operation costs (energy price and treatment costs) and the equipment's service life. Unlike the Cannes project, investment costs are known with certainty in the Limagne Noire TWW reuse project.

TABLE 11: ABOUT HERE

No combination of parameters leads to negative NPV for the sugar factory and for the community, while only 3% of the simulated combinations would lead to a negative NPV for farmers. NPVs are below the deterministic NPVs calculated in Part 2.1.2 in almost 85% of the cases for farmers, 43% for the sugar factory and 76% for the community. Project profitability is confirmed and benefit sharing among the two agents is in any case largely in favor of the sugar factory. The total NPV is lower than the sugar factory NPV because of public subsidies that are deducted from the total NPV.

FIGURE 9: ABOUT HERE

3. Discussion

Some benefits and costs are difficult to quantify. The value of the results presented above is then limited by the way major benefits have been taken into account in the analysis.

1) In the Siagne Low Valley present production costs from local sources have been used as indicators to assess benefits from increasing available potable water in the TWW reuse project. It would have been more judicious and realistic to consider production costs of potable water from external water resources (buying water from neighboring territories) but data was not available. Benefits from TWW reuse would have been higher since avoided production costs would have been higher. Moreover and beyond avoided costs, potable water production from TWW can constitute a multiple-benefit for local stakeholders and politics through: (1) securing water resource in crisis periods; (2) making the territory independent and (3) communicating on circular economy and environmental protection. Those benefits have not been considered in the analysis.

2) In the Limagne Noire the advantages for the community and for farmers to maintain agriculture on a territory where it would likely have decreased for the benefit of other activities (residential, industrial or commercial?) have not been integrated: it is likely that the agricultural land area and farmers’ number would have decreased. These socio-economic impacts could not be integrated in the analysis at this level nor the farmers' advantage associated to the reduction of the variability of their revenue.

3) In both case studies, environmental impacts could be quantified but not integrated into the analysis. The restauration of the Siagne and Beal flow will have positive effects on the local inland environment as with the groundwater. In the case of Clermont-Ferrand a specific analysis has to be conducted to identify the effect of the substracted volume to the Artière river on the ecological balance. Monetizing these impacts is possible. Several economic methods can enable it. But these methods are time consuming, therefore expensive for small local communities and with rather low potential benefits. A solution could be to use benefits' transfer methods (Genty, 2005). These methods consist in transferring past values assessed in similar sites and for similar goods to the studied sites. However, several limits exist in transferring value and necessary conditions to operate a transfer are rarely met (Loomis et al., 2006). Because of these constraints and limits, environmental impacts are generally qualitatively described and come in complement of the economic and financial analysis to support the decision.

In both case studies, major hypotheses have been made concerning future general projected evolutions: (1) on French TWW reuse regulation with new uses that will likely be authorized in the upcoming years, and (2) on price energy trends. Territorial socio-environmental impacts are also very difficult to integrate in the analyses: difficulties are generally more related to system complexity understanding than to methodological limits. CBA methodology nevertheless gives for some cases results with clear guidance and project profitability can then quickly be identified.

More feedback from TWW reuse projects (detailed costs and CBA) would be necessary to improve database and methodology.

Feedback from presentations of the analysis results to local stakeholders highlight the fact that the concept of discounting is very difficult to integrate thus leading to a misunderstanding of the methodology and wrong uses of the results. The methodology and discounting concept have to be clearly explained prior to presenting results.

4. Conclusion

CBA methodology enables us to make a value judgement on the economic profitability of TWW reuse projects and to seek for opportunities to increase development of TWW reuse projects. Economic profitability has been demonstrated with the Limagne Noire case but economic incentives could be implemented to allocate equally the collective net benefit. Economic profitability could nevertheless not be demonstrated for the Siagne Low Valley project where the surface TWW infiltration option requires further studies and analyses prior to being selected.

Some benefits and costs are difficult to quantify such as the socio-economic benefits of increasing potable water in the Siagne Low valley or the advantages for the community and for farmers to maintain agriculture on the territory and to reduce risks in the Limagne Noire. The sensitivity analysis is necessary. It demonstrates here the robustness of the deterministic results calculated during the CBA.

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FORMULAS

Formula 1: Discounted cost or benefit calculation formula

$$\mathrm{Xd} = Xt/(1 + \mathrm{d})^t$$

$$Xt = a\ cost\ or\ a\ benefit\ in\ year\ t;\ Xd = the\ discounted\ value\ of\ Xt;\ d = \ discount\ rate$$

Formula 2: NPV calculation formula

$$\mathrm{NPV} = (\sum \mathrm{Bdproj} - \sum \mathrm{Cdproj}) - (\sum \mathrm{Bdbau} - \sum \mathrm{Cdbau})$$

$\mathrm{Bd} = $ discounted benefits; $\mathrm{Cd} = $ discounted costs; “bau” characterizes the business as usual scenario; “proj” characterizes the scenario with project

Formula 3: Production cost calculation formula

$$\mathrm{Pc} = (\sum_{y=0}^{T} Ic\,(1 - Sr) + \sum_{y=1}^{T} (Mcy + \ Ocy))\ /\sum_{y=1}^{T} (Vy)$$

$$Pc = Production\ cost\ ; y = year\ ; T = analysis\ Time\ ; Ic = Investment\ costs; Sr = Subsidy\ rate; Mc = Maintenance\ costs\ in\ year\ y\ ; Ec = Operation\ costs\ in\ year\ y\ ; Vy = TWW\ volume\ reused\ in\ year\ y$$

TABLES

Table 1: TWW allocation - Siagne Low Valley

Time for analysis	Siagne river	Beal canal	SLV Groundwater	Total
Time 1 [0-5 years]	8 000 m^3/day	2 000 m^3/day	/	10 000 m^3/day
Time 2 [6-40 years]	4 000 m^3/day	2 000 m^3/day	4 000 m^3/day	10 000 m^3/day

Table 2: Hydraulic infrastructures and costs – Siagne Low Valley

	Technical characteristics	Investment costs	Annual maintenance costs	Annual operation costs
Pumping systems	5 bars	375 000 € (Yr 0)	11 250 €/yr	0 € (Yr 0) 42 798 € (Yr 1) 151 632 € (Yr 40)
Pipes	Time 1: 7 350 lm Time 2: 1 500 lm	Time 1: 3 491 250 € (Yr 0) Time 2: 393 750 € (Yr 5)	Time 2: 17 456 €/yr Time 2: 19 425 €/yr	
Storage	4 600 m^3	150 000 € (Yr 0)	750 €/yr	
TOTAL		Time 1: 4 016 250 € (Yr 0) Time 2: 393 750 € (Yr 5)	Time 1: 29 456 €/yr Time 2: 31 425 €/yr	

Table 3: Infiltration and reinjection infrastructures and costs – – Siagne Low Valley

	Technical characteristics	Investment costs	Annual maintenance costs	Annual operation costs
Option 1 Infiltration	8 basins x 1500m²	Land acquisition: 234 000 € Basins: 240 000 €	1 200 €/yr	11 500 €/yr
Option 2 Direct reinjection	Add. Tr.: RO + UVA 2 wells: 50m depth – 10 bars	Add. Tr.: 3 000 000 € Wells: 115 000 €	Add. Tr.: 136 640 €/yr	
			Wells: 3 450 €/yr	Wells : 0 € (Yr 0) 19 783 € (Yr 1) 62 813 € (Yr 40)

Table 4: Benefits of TWW reuse on potable water production – Siagne Low Valley (Year 10 = 2027 and Year 20 = 2037)

		2017	2027	After 2037
Planned potable water consumption (4 summer months)	Mandelieu-la-Napoule	1 940 000 m^3/yr	2 142 967 m^3/yr	2 230 201 m^3/yr
	Cannes	5 107 600 m^3/yr	5 641 971 m^3/yr	5 871 641 m^3/yr
Percentage of planned increase of potable water demand satisfied with TWW reuse recharge scenario	Mandelieu-la-Napoule	/	481%	168%
	Cannes (Option 1)	/	45%	31%
	Cannes (Option 2)	/	54%	38%
Benchmark scenario cost = avoided production cost of potable water from external sources	Mandelieu-la-Napoule	/	74 082 €/yr	105 865 €/yr
	Cannes (Option 1)	/	296 880 €/yr	296 880 €/yr
	Cannes (Option 2)	/	356 256 €/yr	356 256 €/yr

Table 5: Main costs and benefits in TWW reuse scenario – Limagne Noire

FARMERS	TOTAL INVESTMENTS	3 020 329 €
	Lagoons' rehabilitation and hydraulic infrastructure	2 784 369 €
	Irrigation material	235 960 €
	TOTAL OPERATION AND MAINTENANCE COSTS	138 549 €/yr
	TWW purchase	0 €/yr
	Electricity costs	46 340 €/yr (Year 1)
	Irrigation equipment maintenance	22 000 €/yr
	Other operation and maintenance costs	70 219 €/yr
	AGRICULTURAL GROSS MARGIN	2 609 863 €/yr
SUGAR FACTORY	TOTAL INVESTMENTS	548 359 €
	TOTAL OPERATION AND MAINTENANCE COSTS	36 329 €/yr
	Electricity costs	10 468 €/yr (Year 1)
	Land application plan	10 000 €/yr
	Other operation and maintenance costs	15 861 €/yr
GRANTING	TOTAL SUBSIDIES	5 135 429 €

ORGANIZATIONS	European Union	1 253 393 €
	Local Water agency	1 175 056 €
	Frenchstate	1 453 588 €
	Department Council (63)	1 148 943 €
	Other partners	104 449 €

Table 6: Main costs and benefits in BAU scenario – Limagne Noire

FARMERS	TOTAL INVESTMENTS	54 000 €
	TOTAL OPERATION AND MAINTENANCE COSTS	18 781 €/yr
	Electricity costs	12 500 €/yr (Year 1)
	Irrigation equipment maintenance	3 400 €/yr
	Uptaking fee	2 881 €/yr
	AGRICULTURAL GROSS MARGIN	2 158 813 €/yr
SUGAR FACTORY	Treatment costs	397 371 €/yr
ORGANIZATIONS	Local Water agency (uptaking fee)	2 881 €/yr

Table 7: Crops' distribution for the 2 scenarios (surface in Ha) – Limagne Noire

		Surface (Ha)	**Surface (Ha)**	**Gross margin (€/Ha)**
		TWW reuse scenario	**Reference scenario**	
Seed maize	Irrigated	434	50	2 800
Consumption maize	Irrigated	119	50	1 409
	Rainfed	322	300	1 035
Sugar Beet	Irrigated	147	100	1 940
	Rainfed	126	200	1 644
Wheat	Rainfed	252	700	1 593

Table 8: Economic Costs-Benefits Analysis results (40 years) - Option 1-Infiltration basins

	Discounted values 40 years
TOTAL COSTS	7 710 402 €
Total investments	4 783 215 €
Hydraulic infrastructures (network, storage, pumping)	4 364 268 €
Infiltration infrastructures	418 947 €
Total Maintenance and operation costs	2 927 188 €
Hydraulic infrastructures (network, storage, pumping)	2 696 216 €
Infiltration infrastructures	230 972 €
TOTAL BENEFITS	7 910 623 €
Potable water – SICASIL	5 962 691 €
Potable water – Mandelieu-la-Napoule	1 947 932 €
Environment	Not monetarized
NPV	200 221 €

Table 9: Economic Costs-Benefits Analysis results (40 years) - Option 2-Aquifer recharge by pumping

	Discounted values 40 years
TOTAL COSTS	13 287 445 €
Total investments	7 117 474 €
Hydraulic infrastructures (network, storage, pumping)	4 364 268 €
Infiltration infrastructures	2 753 206 €
Total Maintenance and operation costs	6 169 972 €
Hydraulic infrastructures (network, storage, pumping)	2 696 216 €
Infiltration infrastructures	3 473 756 €
TOTAL BENEFITS	9 103 161 €
Potable water – SICASIL	7 155 229€
Potable water – Mandelieu-la-Napoule	1 947 932 €
Environment	Not monetarized
NPV	- 4 184 284 €

Table 10: Parameters integrated in the sensitivity analysis - Siagne Low Valley

	Determinant value	Lower limit	Upper limit
Option 1 and Option 2			
Investment costs - Hydraulic infrastructures – Time 1 (2017)	4 016 250 €	3 500 000 € (-13%)	4 500 000 € (+12%)
Investment costs - Hydraulic infrastructures – Time 2 (2022)	393 750 €	350 000 € (-11%)	440 000 € (+12%)
Maintenance rate – pumping station	3%	1.5% (-50%)	5% (+67%)
Industrial kW price in 2017	0.0900 €	0.0800 € (-11%)	0.0900 € (0%)
Increase in annual rate of electricity price (average for 40 years)	3.6%	2.5% (-31%)	4% (+11%)
Option 1			
Investment costs – Infiltration basin layout cost (1 unit)	30 000 €	20 000 € (-33%)	50 000 € (+67%)
Investment costs – Land purchase price	13 €/m^2	13 €/m^2 (0%)	15 €/m^2 (15%)
Additional volume available at SICASIL wells / Groundwater recharged volume	50%	30% (-40%)	70% (+40%)
Option 2			
Investment costs – Additional treatment units (RO+UVA)	3 000 000 €	2 000 000 € (-33%)	3 000 000 € (0%)
Operation costs – Additional treatment units (RO+UVA)	0.28 €/m^3	0.20 €/m^3 (-29%)	0.70 €/m^3 (+159%)
Investment costs – Drilling infrastructures (1 unit)	50 000 €	50 000 € (-0%)	100 000 € (+100%)
Additional volume available at SICASIL wells / Groundwater recharged volume	60%	40% (-33%)	80% (+33%)

Table 11: Parameters integrated in the sensitivity analysis – Limagne Noire

	Determinant value	Lower limit	Upper limit
Gross margin per crop	/	(-30%)	(+30%)
Seed maize area variation – TWW reuse scenario	434 Ha	303.8 Ha (-30%)	477.4 Ha (+10%)
Energy price increase rates	3.6%	3.24% (-10%)	3.78% (+5%)
Sugar factory effluents' treatment costs	1.9 €/m^3	1.52 €/m^3 (-20%)	2.47 €/m^3 (30%)
Irrigation equipment's service life	20 years	18 years (-10%)	24 years (+20%)