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Tools for the economic evaluation of wastewater reclamation and reuse

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ABSTRACT

The economic evaluation is basic for any reclaimed water reuse project. Nevertheless, the calculation tools for this evaluation have scarcely been developed due to the lack of application of the existing models and the need to consider more circumstances that the actually used for the evaluations. The authors develop a comprehensive tool, comprising several steps, as follows: analysis of the basics of any project; socioeconomic characterization; building, operation and maintenance of the facility; and evaluation of the positive and negative externalities.

Keywords: Economic evaluation; Wastewater reclamation; Reclaimed water use; Reuse

1. Introduction

The increase in the use, and subsequently in demand, of water resources in a given area is due to various causes, such as the increase in living standards and the irrigation of larger areas of agricultural land, as well as the quick urbanization patterns worldwide. An additional pressure is put on the demand of water for ecological sustainability of implied ecosystems. On the other hand, more and more human activities are related to water, especially the ones related to leisure and tourism, which demand a landscape grown up with continuous contributions of water: urban grass areas, green spaces, golf courses, etc. The industrial uses contribute also to the growing demand for water [1].

Water is a limited resource in arid and semi-arid regions, but if water demands in some water-rich areas are analyzed, temporary and structural scarcity problems can also be detected. Medellín-Azuara et al. [2] indicate that, in northern Europe, crops are grown using "natural" rainwater, but due to the demand for a quality product they require irrigation during part of the growing season, at which time agriculture competes for water with other users to obtain the necessary supply. Looking at these facts from an economic point of view, these authors indicate that the value that water generates when using it in agriculture should be considered when making political, economic or financial decisions on water resources use. The value of water and the ability of farmers to pay for irrigation water, in whole or in part of its value, can be taken as a reference to assign a price to it, apart from other less relevant considerations which also exert influence on the prices.

It is to consider if the price should be intervened by the relevant authorities for any water supply and for any user. Conversely, the European Union (EU) considers that any costs incurred should be included in the price of the water. In any case, it is true that water cannot be treated as a consumer good, as is essential for life on earth, and is also relevant when considering the health of the entire population and cattle, as well as safe and sustainable environmental conditions. Hygiene and human health, as conceived in modern societies, depend heavily on a reliable supply of water from a qualitative and quantitative point of view.

This concept of sustainable, reliable and safe supply is assumed by the legislation of a part of the EU countries, in which water is regarded as a demanial good, which cannot be privatized. However, in other countries water can be

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legally privatized. This is the case, for example, of Anglo-Saxon countries, which have a different water regime than the ones with Roman rules' origins.

In practice, the user could have the legal right to obtain certain amount of water: this is the concept of concession. However, concessions have a number of weaknesses, which are not the subject of this work. In this sense, it is worth to remember, for example, that if all the water concessions in certain rivers were used, there would be a very significant flow deficit (negative flow).

The solution to the timely, temporary or structural scarcity of water resources has been varying throughout history [3], and one of the solutions to demand problems is to use the so-called non-conventional resources (Table 1), among which the most relevant are reclaimed water, salty or brackish water, grey and runoff waters [4].

Instead of working with the supply to increase the resources available, demand can be managed; for example, in agriculture, with savings methods or by improving the efficiency of use, as specified in Table 2.

Among the mentioned non-conventional resources, the most important ones in terms of quantity are reclaimed water and water with high salts content, including seawater. Runoff, especially from towns, and grey water, are increasingly being studied over the past decades in developed areas. In this paper, we will focus on reclaimed water from urban/domestic uses and its necessary treatment and, secondly, on the most widespread use, agriculture.

The use of water in several successive processes is an historical practice, prior to Greeks and Romans and already described in the Minoan civilization. From 1960 to the present day, a period of increased reclamation, recycling and reuse of wastewater can be described [5]. This activity has endured over the centuries in many places, especially for irrigation, since the greatest demand for resources in the arid and semi-arid areas of the world corresponds to agriculture, as repeated several times.

In the last two centuries, such practices have been scientifically described, either for agriculture (priority), so as not to dispose untreated wastewater into rivers (Germany and France, for example) with the parallel agricultural use, or in industry [6]. In fact, considering water uses in modern society (Table 3), virtually all of them can be satisfied with treated wastewater.

Today's technologies allow water of any quality to be treated up to the final quality desired, provided that the necessary economic resources are available. This claim is technologically true, but it can be extremely unreasonable from an economic point of view in some cases. The exception is drinking water, where any investment can be made, however expensive it may be if the resource is necessary for supply.

Because wastewater reuse has been the most widespread use of non-conventional water resources, the volume of related literature about this practice is very important, and its citations must necessarily be limited in any paper. However, some authors edited books that summarize reuse practices. We can highlight Asano et al. [8] and Jiménez and Asano [9], as well as a number of papers [10].

2. Sociological analysis

The social aspects of reuse have been raising concerns in recent years, due to the societal worries and reluctance on the reuse of reclaimed water in a number of regions. While it is true that such concerns have been diminishing in the last decades, a number of reasons for refusal still persist, which to a greater or lesser extent cause resistance to the use of these waters. According to Asano [11], the reasons of end-users for refusing the reuse used to be as follows:

Table 1
Water resources

Type of resource	Resource	Comments
Conventional	Surface water	Rivers, lakes. Includes water transfers. Usually requires big infrastructures.
	Groundwater	Aquifers, karst waters. They require prior identification and quantification of the amount of resources available.
	Sometimes rainwater is considered as a conventional resource	
Non-conventional	Grey water	Originates from the kitchen, bathroom, sinks, etc. excluding excreta.
	Reclaimed (waste)water	Treated wastewater including usually a reclamation process.
	Runoff	Water flowing over the soil surface or impervious surfaces, usually after precipitation: collected with devoted systems.
	Saline-, brackish water, including seawater	Usually require desalination, including reverse osmosis. Sometimes used directly with success for irrigation of certain crops (Table 2).
	Water transported by non-conventional means	Using boats, trains, tanker trucks, etc., in cases of drought or extreme need (disasters, etc.).
	In-situ reuse	Without using external sewerage systems, for example, spacecraft.

Source: Authors' elaboration.

Table 2
Methods for improving efficiency in the use of water resources in agriculture

Method	Description	Remarks
Classic	Change of irrigation method	From extensive (furrow, flooding) to intensive (drip, exudation); Require significant investments.
	Increase effectiveness of irrigation techniques/technologies	They usually require significant investments. Can cause localized salinity problems.
	Change of water source (especially in terms of salinity)	Better qualities require less irrigation water (e.g., to avoid leaching for salt elimination).
	Crop model changes	Changes in species or cultivars, rotation, etc. that consume less water whit an equivalent production
Innovative	Substitution of water (change of sources)	Adapt the water source to the necessary quality (salinity, chemistry, biology, etc.), with significant investment in innovative technologies.
	Changes in water quality	Use water of different qualities (especially in terms of salinity) depending on the vegetative stage of the crop.
	Deficit irrigation	Subjecting the crop to water stress situations; Can improve the quality of the crop (e.g., sugar content in fruits).
Other	Minimal irrigation	Maintain the crop with the minimum amount of water possible for its survival if water is temporarily unavailable.

Source: Authors' elaboration.

Table 3
Possible uses of non-conventional water resources (including reclaimed water)

Category	Use	Feedback
Agricultural and landscape, gardening and leisure areas irrigation (traditionally it has been the most studied use for reclaimed water)	Crops	Traditionally the most widespread use; can account for more than 85% of the resources used in a given area.
	Commercial nurseries	Very intensive and homogeneous crops. Great added value.
	Parks	In cities or leisure areas. Require excellent quality if public access is allowed.
	School yards	Require excellent quality. Very sensitive use from a health point of view.
	Highway/road medians	Ideal place to use reclaimed water (with drip irrigation or similar).
	Golf courses	Use of water resources much discussed from a public image point of view. In many places it is compulsory the use of non-conventional resources for these facilities.
	Cemeteries	With scarcely-visited gardens. Ideal for using reclaimed water. Restrictions on the hours of operation.
	Green areas without access, green belts	Landscape or buffer use. Ideal for using reclaimed water.
	Residential areas and private gardens	Overuse is common. It requires very good quality water. Systems with high health risk.
	Windbreaks	Fast-growing vegetation is required. Accepts reclaimed or low-quality water.
Industry	Conditioning water	Cooling, heating in premises.
	Cooling materials	In energy generation, steel mills, etc. Reclaimed water with adequate quality can be used.
	Boiler feed	Water with few salts, requires many additives, highly polluting effluent.
	Process water	Requires good quality water, with treatments that can be (very) costly depending on the industry.

(Continued)

Table 3 Continued

Category	Use	Feedback
	Water in the product	Some very sensitive uses: fantasy drinks, drugs, etc. Drinking quality. Reuse not accepted at present in this case.
	Packed waters, spas	Includes medicinal waters, need excellent sanitary quality. Reuse not accepted in this case.
Industry	Hot springs	Uses in health and heating. Disinfection problems. Reuse not accepted in this case.
	Public works	Dust control, aerosols can be formed.
	Transport of materials	Drag, usually in mining, without quality requirements.
	Dust control	Quarries, public works, roads, etc.
Urban uses	Domestic supply "potable"	Uses for drinking purposes, hygiene, baths, etc. Excellent sanitary quality required. Use for drinking water is mainly not accepted, although this is currently under discussion, and in a few places is practiced.
	Ornamental (outdoors) water	Ornamental fountains, ponds, running water (streams, canals). Can be recirculated with adequate treatment. No direct contact with public.
	Firefighting	It may require a specific distribution network. Discussion on the adequate quality.
	Public and private works	Building activities, dust control, etc. Aerosol and salinity control is necessary.
	Various cleanings	Washing, toilets, vehicles, boats.
	Street cleaning	Cleaning at night. Requires adequate quality, aerosol control. Health risk.
	Sewer management	Obstruction control, maintenance. Relatively low quality.
	Parks and public gardens (ornamental)	Very good quality water: regular users with risk.
	Private parks and gardens	Overuse is common. It requires very good quality water. Very high health risk.
	Circulating waters	Rivers, urban water flow.
	Zoological gardens	Good quality water for contact with animals (drinking, bathing, habitats). Dragging materials with reclaimed water.
Generation of "biomass"/ organisms	Aquaculture	Fish, shellfish, etc. Excellent quality required, forbidden the use of reclaimed water for this purpose in many countries.
	Conventional cattle farming	Includes slaughterhouses. Drinking water quality required.
	Biomass/wood/fodder	Includes generating support material for composting processes.
	Algae crops	Require nutrients and light. Adequate reclaimed water improves productivity.
	Biofuel/biofuel production	Water for irrigation of vegetation. Adequate reclaimed water improves productivity.
Environmental uses/leisure/recreation other than irrigation	Flow maintenance of water bodies	Lakes, ponds, rivers, wetlands, groundwater recharge (includes urban water systems).
	Snow "manufacturing"	Acceptation/Ecological problems when using good quality resources from high mountain ecosystems; can be replaced by reclaimed water.
	Water storage ponds	Firefighting, birds, etc. Good quality.
	Ecosystem's recovery	Flora and fauna. Adequate quality, interaction with surface and groundwater.
	Recharge against seawater intrusion (MAR)	In the coastline: aquifer/sea interface. Excellent quality water is often used after extraction, even if it comes from reclamation activities.
	Subsidence control (MAR)	In overexploitation of aquifers, reclaimed water can be used to recover levels or maintain them.
Managed aquifer recharge (MAR)	Recharge of aquifers (depleted or not) for further uses	Several possibilities. Aquifer used for potable water supply, maintain levels near the coastline, subsidence control and other.

Notes: Some uses appear twice, because they can be included in more than one concept.
Source: Modified from Salgot, 2008.

(1) concern about the harmful effects of reclaimed water on industrial processes, gardening or crops;
(2) may possess their own water supply, which may have for them a lower cost than connecting to the municipal network or the price offered for the use of reclaimed water;
(3) a disagreement in the price of regenerated water;
(4) reluctance to pay for additional costs in driving or transporting reclaimed water to the reuse point;
(5) the point-of-use may be located outside the limits proposed in the project, requiring negotiation with other jurisdictions;
(6) local or state health departments may disapprove of the use of reclaimed water because of the existence of public health risks.

Awareness raising and dissemination of information on the various benefits of water reuse, among all key stakeholders. This would have two main objectives, to build trust, credibility and confidence in water reuse solutions (addressing health risks-related concerns of the general public and workers potentially exposed to reclaimed water); and raise awareness on the benefits of reuse for the various stakeholders involved in the development of reuse schemes. The implementation of such instruments could build on previously developed guidance in the EU and non-EU countries and on successful examples, and could involve working with NGOs, farmers and industry to help build trust among the different groups of stakeholders that need to be targeted. Recent research has shown that key success factors to gain public acceptance are to make people aware of the water cycle, of the need to recycle water and of the associated benefits [12].

Whatever the attitude of users for the implementation of reuse projects with success, the community is required to be involved, informed about the origins of this water resource and know the security of the process, including also relevant associated costs for information and training. Globally, public administrations have almost always acted without a clear policy of relationships with the reclaimed water end-users. Usually, the end-user does not have direct access to the proceedings of the project nor has participated in the discussion of its performances. This approach to projects has many drawbacks, as most stakeholders are increasingly aware that environmental decisions have a significant influence on their quality of life, and do not easily accept direct proposals from water authorities on sensitive fields, not consulted with them. Responding to this concern, one of the EU's cross-cutting policies is communication. In other countries with environmental concerns fostered by the economic development, participation and communication policies have been initiated, as is the case in Australia, the United States or Japan [13,14].

On the other hand, the need to comply with restrictive or excessively demanding rules and regulations, even if those legal pieces are from low technical quality, requires significant costs, both in infrastructure and in maintenance and control, including analytics. It should also be considered that conventional drinking water is increasingly tending not to be separated from other kind of water resources, called unconventional (stormwater, regenerated, desalinated, transported by unconventional means, etc.). This means that all resources must be considered in an integrated way, allocating their use according to the actual quality of the water [15].

In this context, communication techniques about reuse are being progressively developed and described by several authors in recent years. The objective is to train the end-user who must afterwards be able to contemplate critically the information provided to him and any possible attempt of manipulation. As an example of these environmental concerns, controversy has begun in recent years over the public's tendency to consume bottled water instead of "tap" water. Howd and Fan [16] states that in some ways it is an example of public use (by the consumer) of the precautionary principle. Consumers have heard or read information about drinking water contamination, and some of them have even analyzed their company's report or water management.

However, the most important aspect of bottled water use is the exercise of consumer choice: the public chooses what they perceive as a higher quality product, even without evidence to prove it. In this same context you can find the home devices that are connected to the taps to "theoretically" generate better quality water. This consumer concern can be defined as an erroneous association on which of the two products (bottled water and tap water) presents the least risk; mistakenly associating organoleptic quality with sanitary quality. In this context Doria et al. [17] indicate that the less quantifiable or intangible aspects of the subject, such as taste, comfort and even the fashion of consumption of a given bottled water, should not be underestimated.

By applying the previous concepts to reuse, public acceptance has been revealed to be essential to the success of reclaimed water reuse projects.

As a consequence, there is growing concern from EU, USA and other developed countries on the communication about users' concerns on water quality and the impact of the media on creating fake health alarms. Public concern is also affected by the fact that, in recent years, recurring episodes of drought have sharpened the perception that there is a water scarcity problem and users want to be well informed about the whole water cycle [18].

As a result, communication and participation policies that aim to allow stakeholders (including end-users) to have an opinion on the environmental and water issues affecting them have been developed.

An additional need for social purposes, is the formation of the stakeholders, not all but usually the most interested. There are several ways to implement the information, addressing it to different populations groups; that is, secondary school students.

One of the systems to overcome some of the difficulties is how to know the public acceptance. Perceived health risks may result from a lack of knowledge and misconceptions on what reclaimed water means and how it may be used. The surveys can help to solve the training problem [19].

3. Environmental analysis

Wastewater recycling is a hazardous practice, and consequently its management must be associated with a risk analysis. The aim is to achieve the maximum quality of water resources while minimizing health, environmental, agricultural and food-related risks. In parallel, water authorities should develop strategies for managing the use of reclaimed water, including those to deal with waste generated in the reclamation processes. The primary objective of this management should be the production of high-quality water with reduced, legal, levels of pathogens and chemical contaminants.

Depending on the quality of wastewater, restrictions on end-uses are required in order to control the routes of human, crops and livestock exposure to pathogens and chemical contaminants. As a result, generators, suppliers and users of reclaimed water and other types of water resources, should work together to identify and establish the potential exposure routes associated with reuse schemes. The development topics on the subject are: environmental impacts, human and animal health, safety of crops and food, and legal responsibility, apart from training and information policies.

The dangers posed are variable, depending for example (agriculture) on the physical situation (in relation to residences or watercourses, for example); land characteristics (soil types, slopes, salinity, aquifer depth, etc.); facility size (volume of reclaimed water); and application and end-use techniques (e.g., golf courses irrigation, food crops irrigation).

When wastewater is reused in a planned manner, water authorities take proactive actions, granting permits (authorization or concession) and becoming ultimate managers of the entire process. With these premises, water authorities want to be reasonably sure that the system does not create any hazard to the people or the environment. This safety against hazards and risks must be determined using appropriate tools. Two of those tools are considered to control what happens to the environment and citizens when reclaimed water, and in general all non-conventional water resources, reaches the environment:

(a) environmental impact calculations or assessments;
(b) hazard/risk assessments in relation to the environment and humans.

In all reuse studies it is necessary to define: the legally established quality of reclaimed water, its system of application, the contact between water and the receiving environment including humans, the effects of the contact, what happens with the water once it reaches the environment, and what happens to the different matrices that come into contact with reclaimed water.

In general, a wastewater treatment or reclamation system has a complex relationship with the place where it is located and its effluent used, as described in Table 4 and Fig. 1.

Treatment, reclamation and reuse systems are "physically" in the field, creating servitudes (e.g., infrastructures passing through the area) and maintenance needs must be considered. The aesthetic impacts of the installations must not be forgotten, as well as the organoleptic incidents (basically odors) that happen more or less periodically, and that are both internal and external. Although those impacts are difficult to fight against, a good communication policy can help make them more acceptable.

4. Economic analysis

In a first global approach, it may seem that the use of non-conventional water resources is beneficial, without drawbacks, thus following the institutional propaganda that

Table 4
Environmental, economic and social impacts of a wastewater treatment and reuse facility (not exhaustive)

Time	Primary effects	Side/secondary effects	Tertiary effects
Direct negative impacts			
Short term	Soil erosion during construction.	Degradation of aquifers, habitats or streams; Recharge of water bodies.	Reduced fish catches; Landscape and leisure uses' improvement.
Long term	Periodic emission of harmful/odorous gases and aerosols; Ecosystem recovery.	Increased price of agricultural lands; Reduced price of adjacent properties.	Changing the socioeconomic composition of the neighborhood.
Direct positive impacts			
Short term	Local/regional increase of ecosystems quality (especially waters);	Increase good water availability.	Re-arrangement of the resources' distribution.
Long term	Availability of useful by-products.	Increase reclaimed water availability.	Economic effects (agriculture, tourism, leisure, etc.).
Indirect impacts			
Short term	Employment in construction tasks.	Temporary homes (accommodation).	Necessary infrastructure changes.
Long term	Housing developments in the service area.	Increased traffic on local roads.	Traffic congestion, noise, smog, etc.

Source: Authors' elaboration.

presents it as a solution to drought episodes or generating other benefits. A second approach shows that the practice also has weaknesses, such as negative environmental and health impacts.

The use of non-conventional resources is conditioned by the economy of the practice, especially compared to common, conventional resources. For this reason, and because each geographical situation has specific conditions/determinants, in-depth economic studies are needed that define the cost-benefit constraints and the viability of each project.

In general (Table 5), each conventional and non-conventional water resource has specific characteristics associated with the economy. In this context, the question arises as to what the price of water should be for some of the activities described in Table 3.

Detailed studies of the economy of the projects allow to compare them, at least initially, with other initiatives and to justify the investments and expenditures necessary for the development of new water sources, mainly reclaimed water. By combining the economy with communication, the user must understand that any decision has an economic impact and that he must be willing to cover all or part of the costs of decisions through the relevant taxes or fees; and in this sense must also understand that there are options most onerous than other.

Most economic analyses of water use have been carried out for agricultural practices. In this sense, economic feasibility analyses should consider the costs involved in the alternative water supplies [20], but also crop type, profit margins, local esteem for the environment, irrigation methods and supply guarantees, among other aspects. However, water quality must be analyzed before the calculations are considered and whether the quality needs to be modified to meet legal requirements. The cost of this quality change should also be taken into account in economic calculations.

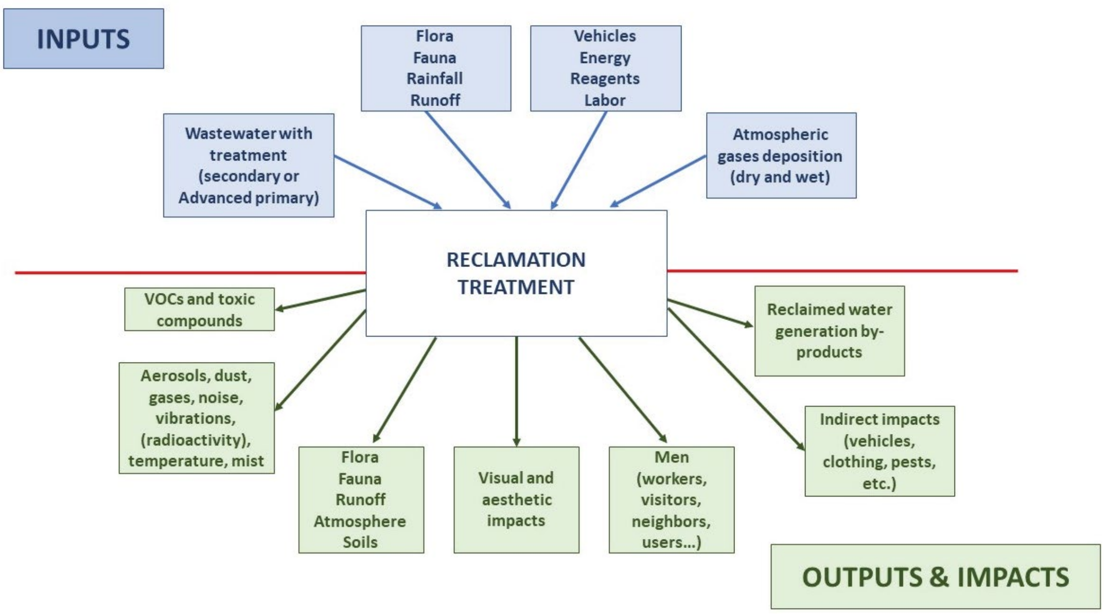

Fig. 1. Inputs, outputs, or impacts (outputs) of an active working wastewater reclamation plant. *Source*: Authors' elaboration.

Table 5
Relationship between water resources and economy: main aspects

Resource	Use	Economics (costs)
Surface water	Drinking, agriculture, other irrigation practices, industry, urban uses, landscaping, transportation, etc. with or	May require regulation (reservoirs) and transportation to the point of use.
Groundwater	without treatment.	Pumping and distribution needed.
Reclaimed water	Virtually all uses except for drinking purposes.	Regeneration, distribution and control.
Seawater	Cooling. With desalination: all uses.	Desalination (very expensive in terms
Brackish/Saline water	Cooling or irrigation of non-sensitive crops without desalination. With desalination all uses allowed.	of energy).
Rainwater/Runoff	With treatment, all uses. Without treatment agriculture-related uses.	Recovery costs (collection), treatment, storage and distribution.
All	All	Formation, information and marketing.

Source: Authors' elaboration.

Comparisons with the remaining water resources, whether conventional or non-conventional, can be made from here on.

While there is limited economic work in the literature on wastewater reclamation and reuse, the necessity to include such analysis has been gradually increasing and in recent years the need for economic studies for the design and implementation of efficient water resource management policies, as set out in the Water Framework Directive itself (Directive 2000/60/EU) is becoming increasingly evident.

To initiate a comparative analysis of the costs associated with each alternative supply, which must be compared with reuse calculations, several wastewater aspects should be considered:

(a) additional treatment and other expenses to convert secondary effluent into reclaimed water (reclamation process): must include operation, maintenance, and cost of reagents;
(b) pumping and distribution of the resource: operation and maintenance;
(c) costs related to analysis, bureaucracy, formation and information.

Analytical costs should be considered to differ, mainly due to the different regulations and recommendations applicable to the different water resources. The operation concept includes energy costs. In general, the cost structure varies depending on the size of the facilities: the determination of the cost-effectiveness threshold will also indicate the minimum size of a plant so that the competitive use of the water it generates can be ensured.

To determine the potential for reuse [21], the water flow rates should be analyzed, including the determination and calculation of:

(a) potentially available "reclaimed water" resources; that is, those that can be obtained from existing plants or facilities, but after building the necessary reclamation systems through investments, or, if there is capacity, increase the volume of reclaimed wastewater produced (more than previously);
(b) the resources of reclaimed water that could be obtained from newly built facilities.

The following points should be considered:

(1) detailed analysis of wastewater treatment and reclamation processes, in order to obtain cost functions;
(2) determination of the efficiency of reclamation infrastructures;
(3) determination of the existence of possible differences at cost level depending on the end-use of the effluent (specific use).

Knowledge of the costs associated with the reclamation treatment and water reuse is seen as a basic requirement for assessing the actual potential for reuse at a given site and facility. These calculations do not include the cost of conventional wastewater treatment, except where additional installations are required in order to proceed with reclamation [22]. The obvious reason is that conventional or secondary treatment must be performed by law, and should be paid by citizens with their taxes, regardless of whether the purified water is reused or disposed of into the environment at a later date.

Additional information on potential water demands will be required to analyze the reuse possibilities, for example: (a) in the case of agricultural irrigation, crop type and surface, seasonal water demand, irrigation frequency, quality (especially salinity) and availability (security of supply) of irrigation water from conventional sources; (b) for urban uses, the type of use (watering parks and gardens, street cleaning, sewer management, etc.), quality for each case, seasonal or continuous demand for water, and security of supply; and (c) for ecological flow (minimum flow) seasonal demand and its relationship to climate, quality, ecotoxicity, etc.

The classic method of water resources management has traditionally been to meet demands by increasing supply. This type of management is currently considered obsolete and is being replaced by the so-called integrated management, which, among other things, attempts to adjust qualities to demand; that is, to use the existing water resource that is most adapted to the specific use, thus saving on treatment costs. The main economic objective is the optimization of resources (currently and potentially available) in terms of costs and in the specific area of study, with the primary purpose of efficiently meeting the different types of demand.

From a demand perspective it is important to analyze in each case: current uses, quality needs, water saving possibilities, forecasts of new needs, seasonal nature of demand, and potential uses. The underlying idea is to analyze the water supply from various origins (sources) that is used for various purposes and ensure that demand is met at the lowest possible cost.

To be able to make more complete calculations it is necessary to know the price that is paid to use surface and/or underground water. In this sense, it is important to consider the availability of resources, their quality, whether or not they are from aquifers, their cost of collection, etc. In addition, there are several considerations that should or should not be considered depending on the depth of the economic study: differences in economic analysis procedures, associated bureaucracy, communication, formation and information costs, and positive or negative impacts on the environment.

Reclaimed water is what is called a "replacement resource"; that is, it is exchanged for another, allowing the latter to be available for other uses. If these have a higher value (e.g., for drinking water instead of agricultural irrigation) benefits of the practice can be expected.

When analysis is done at the basin level, direct or indirect benefits can be defined. Among the direct benefits we will first highlight the hydraulic infrastructures: new collection and storage infrastructures are reduced and the available water resources are increased. Among the indirect benefits we will highlight:

(a) *Recycling of pollutants*: nitrogen and phosphorus are useful for agriculture, so that their negative environmental impacts are reduced;
(b) *Use of the resource*: guarantee of supply in times of structural or seasonal scarcity and water quality adaptable to various uses;

(c) *Environmental benefits*: avoid water bodies contamination and recovery of rivers and wetlands;
(d) *Education*: contributes to the knowledge of water culture;
(e) *Social benefits*: new jobs, greater integration into European Union policies, maintenance of environmental quality (important for tourism).

Regarding costs (negative impacts) among other, will be highlighted:

(a) Cost of reclamation infrastructures and additional costs of operation, maintenance and analysis;
(b) Chemical and biological health risks associated with the reuse of reclaimed water;
(c) Loss of value of areas near the reclamation plant;
(d) Costs associated with socioeconomics.

There are six main types of barriers which explain the lack of development in any Member States of the EU. One of them is fully related to economy: inadequate water pricing and business models. Insufficient price differentials between reclaimed water and freshwater, exacerbated by a lack of full cost recovery within most EU water markets (poor enforcement of the cost recovery principle set by Art. 9 of the WFD, in particular) limit the economic attractiveness of water reuse projects. Water is incorrectly priced, failing to account for the range of external costs associated with the abstraction, purification and discharge cycle. This issue can be considered as a regulatory failure as it results from improper implementation of the WFD provisions [23].

5. Economic valuation techniques

When it is necessary to study the social and economic impact of a given policy or project, in the context of implementing policies and selecting measures; a series of methodologies are applied as support systems, being the cost-benefit analysis (CBA) one of the techniques traditionally used. As the OECD [24] states, CBA is trying to answer a main question: is it necessary (or not) to initiate a specific investment among different alternatives, and if the investment funds are limited, which one or ones should be selected.

The CBA has the purpose to describe and quantify the pros and cons of an expenditure project. The objective function of a CBA consists on the net social benefits, while the objective function of any firm is the private net benefits. Then, the immediate difference between the valuation of expenses policies based on the CBA or on private incomes is that the CBA is trying to consider all the losses and earnings from the standpoint of the society.

The maximization of the net social benefit requested with the CBA requires the identification of the entire costs and entire benefits relate to a specified project of public expenditure. For this reason, all the internal and external benefits of the project should be included, as well as the opportunity cost, which means the cost of the discarded alternative.

According to the European Union [25], performing a CBA to evaluate the economic viability of a project consists on seven steps:

(1) Description of the context
(2) Definition of the objectives
(3) Identification of the project
(4) Technical viability and environmental sustainability
(5) Financial analysis
(6) Economic analysis
(7) Risk (or sensibility) analysis

Adapting it to a wastewater reuse system, the previous steps could be reduced to which follows:

(1) *Context description*: It is important at this point to clarify the scope of application of the project, that is, the institutional framework: national, regional or local. This will clearly affect the appropriate rules and regulations, and can also affect the tariffs and the organization and characteristics of the water services.

    It is also important to know the socioeconomic information, like the number of inhabitants of the area, population affected, economic activities of the area: agriculture, fisheries, touristic and leisure activities, etc.; also, the per capita income, the added value which involve the economic activities, and its contribution to the GDP, among other.

(2) *Definition of the objectives and identification of the project*: at this point, it is necessary to specify the type of reuse project: irrigation, reduction of the aquifer stress, etc. The technical description of the project (machinery, manpower, etc.) will allow a clear identification of the internal costs, as well as the start point to identify several possible external effects. The definition of the area of study is basic to establish the influence of the project and in this way determine the impacts generated inside this area.

(3) *Identification of the costs and benefits*: the maximization of the net social benefit as required by the CBA, makes it necessary to identify all costs and benefits related to the project, that is, all the impacts generated by the project, which implies both the internal or private, and external impacts.

    Because an inadequate management of wastewater can generate important costs, both in social and environmental terms, can be considered that their adequate management and treatment imply considerable benefits, in term of avoided costs.

    Additionally, other types of costs can be mentioned as "costs derived of no-action" or opportunity costs; which are benefits derived from the adequate treatment of wastewater which would be foregone in case of no treatment; not implementing the reuse program. Then, those will be the benefits derived from the reuse project.

    Alternatively, it is also necessary to consider the costs and benefits derived from the action, that is, the reuse project itself. Two types of impacts (benefits and costs) can be described: direct and indirect, depending on if they affect the stakeholders directly implied on the project or they have effects on third parties. Then, those will be the benefits derived from the reuse project. Examples of direct or indirect impacts appear in Table 6.

Table 6
Costs and benefits in the wastewater reclamation projects

Direct costs	Distribution of reclaimed water
	Additional treatments (reclamation).
	Storage systems.
	Quality monitoring and evaluation (safety).
	Additional management (administration).
	Formation and information (including marketing).
	Project preparation.
Indirect costs	Effects on the carbon footprint of the water cycle.
	Public health effects.
	Public perception of reduced quality.
	Effects on downstream flows.
	Water quality impacts (perception).
	Effects on soil, plants and wildlife.
	Effects on agriculture.
Direct benefits	Additional water supply.
	Environmental sustainability.
	Reliable resource (related to health, agriculture and other).
	Avoided cost of other projects.
	Diversion of effluent discharge (consider impacts).
	Regulatory certainty.
	Win-win approach for owners/users.
Indirect benefits	Environmental changes (including landscape changes).
	New resource value (improvement of the quality of the existing water).
	Value of nutrients (for irrigation), aesthetic value.
	Safety (more resources in a continuous way).
	Value of properties.
	Resilience (drought episodes, guarantee of supply, etc.).
	Greenhouse gas reduction/energy conservation.
	Integrated resources management.

Source: Modified from AQUAREC [26] and De Souza et al. [27].

(4) *Valuation of the benefits and costs*: Once the benefits and costs arising from the project have been identified, they need to be assessed. If all the values could be observed in terms of market prices, the measurement will be easy. Nevertheless, this is not always true, because many times the costs and benefits are intangible, and sometimes the market prices will need an adjustment, because the markets are not perfect and distortions could appear.

Considering that the final objective of the CBA is to obtain the highest degree of efficacy in the expenditure behaviour, the prices at which the costs and benefits are evaluated must reflect the social valuations of the goods and resources at stake.

The main problem of this type of evaluation is that because of the characteristics of several types of goods reflect the public expenditure, it is not possible to establish market prices for them. Following this criterion, the market prices can be a poor indicator of the social costs or benefits, and cannot be accepted without modifications when evaluating costs and benefits. Then, adjustments will be required.

The different possibilities of evaluation of each group of costs and benefits will be analyzed from now on.

First of all, the direct (internal) impacts will be studied considering as positive impacts the incomes derived from the sale of reclaimed water or any by-product, and as negative impacts the investment, operation, distribution and maintenance costs.

There are also included all the costs related to civil works, supply and installation of electromechanical equipment, design and project costs, salaries, energy, reagents, etc.

The evaluation of this cost modality is a fundamental phase in the planning of a wastewater reuse system and is also necessary for making a comparison with other conventional and non-conventional resources. Although there are various methods for the valuation of these costs, in recent years multiple linear regression methods have been used.

With regard to indirect (external) impacts, it should be noted that in this case reference is made to external effects or externalities, which can be positive (benefits) or negative (costs). As an example of indirect benefits and costs of a reuse project we could highlight the modification of existing surface water and groundwater hydrology, and changes in water quality.

These impacts can affect: human health, the environment, and economic activities [28].

The valuation of health impacts includes aspects such as: medical expenses for the treatment of diseases, indirect costs derived from the disease, pain and suffering associated with the disease. It is necessary to consider that a high number of illnesses are related with water quality or organisms living in it, etc.

Of the three, the first has direct and clear references for its valuation, while the other two require indirect formulae. Indirect costs derived from illnesses refer to issues such as the value of lost work time, decreased productivity, etc. The most widely used method for valuing these indirect costs is the human capital method [29,30], which calculates the expected lifetime earnings that the individual would have had if the illness or premature death had been avoided, thus using lost earnings as a proxy for lost productivity. In the health and sanitation field this is known as DALYs (Disability Adjusted Life Years).

When dealing with non-market values, the most commonly used methods for estimating the economic value of avoided health costs derived from risk reduction associated with improvements in drinking water quality, have been based on the Willingness to Pay (WTP) approach [31].

In the valuation of environmental impacts, it should be noted that, in the case of water, some environmental goods and services are traded in the market and therefore have assigned prices, for example, commercial fishing. There are, therefore, revealed preference methods, in which consumer preferences are inferred from purchases made of goods with a market price. These methods reflect the payments that consumers actually make for better quality water, for better recreational facilities, etc.

However, there are other values associated with improved water quality, such as aesthetic values and species diversity, that have no connection to markets. In these cases, other valuation methods have to be used, through hypothetical markets. These are the so-called direct preference methods, in which individuals are asked directly about their preferences on the basis of questionnaires.

Among the revealed preference methods, two are worth mentioning: the "travel cost" method and the "hedonic price method".

The "travel cost" method is commonly used to estimate the value of recreational sites. The basic premise of this method is that the time and travel cost that people spend to visit a place represent the "price" of access to this place. Thus, the "willingness to pay" for the visit can be estimated based on the number of trips people make to this place with different travel costs. This is a useful method when trying to understand the benefits of improving the environmental quality of particular places, for example, the benefits of reducing eutrophication in a lake and thus increasing the aesthetic quality of its waters.

The "hedonic price" method breaks down the price of a private, market good into several characteristics. Each of these characteristics has an implicit price, and their sum determines, in an estimable proportion, the price of the market good being observed. If we take the purchase of a house as an example, this method consists of analyzing the data using regression analyses that relate the price of the house to its intrinsic characteristics and the environmental characteristics of interest, which in this case could be the quality and quantity of the water in the area. In this way, the effects of the different characteristics on the price of the property can be obtained. The regression results indicate how much house prices will change as a function of small changes in each characteristic, holding all other characteristics constant.

In the case of water this method would recognize that water quality affects home prices near a lake or river. Differences in housing prices would reflect individuals' valuation of clean water.

So-called direct preference methods, known as "contingent valuation" methods, allow the estimation of the value directly from respondents' answers. For example, the survey may ask the willingness to pay to reduce eutrophication in such a way as to increase transparency in the water or to increase fish species and diversity by a certain amount.

All of the above techniques require the collection of a significant amount of data and are sometimes expensive methods. When the cost of data collection is very high or the time available is limited, another valuation technique can be applied: the so-called "benefit transfer" [32], which consists of using the results of other similar studies already completed, although there may be difficulties in applying them to specific cases where there is no significant degree of coincidence.

Finally, we refer to the impacts on economic activities. It will be necessary, in this case, to have perfectly identified those economic activities negatively affected by wastewater and, therefore, positively affected in the case of carrying out the wastewater reuse project.

There are many and varied economic activities that can be affected by the improvement of water quality, such as industrial production, crops, fishing, agriculture or tourism.

All these impacts usually have a market value and can be valued monetarily, without too much difficulty, by analyzing the changes in the production of each economic activity when changes in water quality occur; keeping other production factors constant.,

All these impacts usually have a market value and can be valued monetarily without too much difficulty by analyzing the changes in the production of each economic activity when changes in water quality occur, keeping other production factors constant.

Table 7 shows some examples of externalities and possible valuation methods in a water reuse project.

(5) *Comparison of costs and benefits*: Once all the costs and benefits derived from the project have been identified and assessed, it is necessary to compare them in order to decide whether or not to carry out the project.

So far, no account has been taken of the fact that benefits and costs may not flow instantaneously, but over time. Certain expenditures yield immediate benefits

Table 7
Externalities related to water reuse systems and methods for their valuation

Section	Externalities	
	Identification	Valuation method
Infrastructure	Avoids water purification costs.	MP
	Building of pipes for water distribution.	MP
	Infrastructure costs from regenerating and reusing water will depend on the purpose the water is used for.	MP
Pollutants	Avoids drawn out treatment processes to eliminate certain useful compound such as fertilizers.	MP
	Nitrogen reuse in agriculture.	MP
	Phosphorus reuse in agriculture.	MP
	Reuse of already digested mud for agriculture.	MP
	Reuse of thermal energy.	MP
Public health	Monitoring and controlling biological pollutants present in regenerated water.	MP
	Cost of monitoring and controlling chemical pollutants present in regenerated water.	MP
	Risks associated to the spread of illness and disease.	MP and CV
Environment	Avoids energy consumption and, in turn, gas emissions.	MP and CV
	If the regeneration plant is far from the area of consumption and long pipes are required, habitat fragmentation and a loss of biodiversity can arise.	CV and TC
	Decrease in nitrate pollution of aquifers.	MP and CV
	Decrease in the eutrophication of wastewater discharge areas.	MP and CV
	Noise and smells from the regeneration plant.	HP and CV
	Increase in water quality.	MP and CV
	Increase in the ecological flow rate of rivers, contributing to the maintenance of biodiversity and preventing floods.	CV, TC and MP
	Avoids over-exploitation of aquifers, decreasing land cave-ins and prevents salt from entering coastal area.	MP
	Decrease in water pollution and increase in the aesthetic quality of the water, allowing it to be used for recreational purposes.	MP, TC and CV
	Change in the use of land (transforming dry land to irrigated land) and its environmental impact.	MP and CV
	Increase in the quality of beach water if located in a coastal area.	MP and TC
	Decrease in the value of nearby land.	MP
Education	Enhances social awareness of a new water culture.	CV
	Personnel expenses in order to convince local inhabitants of the quality of the water used.	MP

Source: AQUAREC [26].
MP: Market price; CV: Contingent valuation; TC: Travel cost; HP: hedonic prices.

and costs, while others yield a stream of benefits and costs over many years. They are heterogeneous magnitudes and, therefore, cannot be added or subtracted without homogenizing them, that is, without updating the costs and benefits of future years. Only by comparing the present values of costs and benefits for each year can the most efficient alternative be chosen. It will therefore be necessary to perform discounting operations.

To be able to add up the benefits and costs that arise over the life of the project, it is necessary as mentioned above, to homogenize their monetary values. For this purpose, the monetary value of the benefits and costs obtained in subsequent years is translated into their comparable value in year zero, that is, all the values of future periods are updated to the present time. This updates the entire flow of benefits and costs associated with the project over time, so that it is possible to compare them. To do this, it will be essential to apply an appropriate discount rate.

(6) *Decision criteria*: Once the cost and benefit streams have been updated, that is, homogenized, a decision criterion must be used to choose the most efficient alternative.

There are three possible decision criteria: the net present value (NPV), the internal rate of return (IRR) and the benefit-cost ratio (B/C). The NPV is probably the most commonly used decision criterion and consists of maximizing the difference between total benefits and costs. For a project to be considered potentially valuable, the present value of the net benefits must be greater than zero (NPV > 0).

The internal rate of return is the rate that equals the present value of the project's benefits and costs, making the NPV zero. If it is greater than the discount rate, the project is valid (IRR > Discount rate).

Like NPV, the benefit-cost ratio sums total benefits and costs using the discount rate. However, instead of subtracting costs from benefits, they are presented as a ratio of benefits to costs. A ratio greater than one indicates that benefits exceed costs and the project is economically acceptable (B/C > 1).

(7) *Sensitivity analysis*: Finally, in a cost-benefit analysis, it is recommended to carry out a sensitivity analysis. Sensitivity analysis allows to test, for different scenarios, the strength and robustness of the assumptions and data, and also allows to recognize the uncertainty of the expected results. The objective is to determine to what extent the outcome of the project appraisal is sensitive to changes in some of the parameters used in the analysis, such as the discount rate, financing conditions, energy costs, reclaimed water price, etc. Once the changes in the Net Social Benefit for each of the proposed scenarios have been analyzed, the robustness or true feasibility of the project can be assessed.

6. Conclusions

- Wastewater reclamation and reuse is basic for the economic development of arid and semiarid countries.
- Technology, health considerations, formation and information should be established and applied to real reuse systems.
- The economics of reuse must consider a large number of factors and circumstances, which can be classified as follows:
  - Costs: Associated with the Technology and Analytical data interpretation;
  - Socioeconomic aspects: Information to the public and Training of personnel and users;
  - Services and health considerations: Determination of ecosystem services and Implementation of sanitation safety planning procedures;
  - Application of the WASH (Water Sanitation and Hygiene) approach;
  - Definition of economic tools;
  - When in-depth economic analyses are carried out, it is necessary to calculate the economy of reuse processes considering: the relationship with the other existing resources available; the reclamation treatment deemed necessary; the distribution approaches; the calculable costs; and the intangibles.
- According to the EU and OECD, the CBA technique is the best one for the economic appraisal of alternative spending projects.

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