UNEP

ECONOMIC VALUATION OF WASTEWATER

THE COST OF ACTION AND THE COST OF NO ACTION

GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities

UNITED NATIONS UNIVERSITY

IWMI International Water Management Institute

This report was commissioned by:
The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), through the Global Wastewater Initiative (GW²I).

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The Global Wastewater Initiative

The Global Wastewater Initiative (GW²I) is a voluntary multi-stakeholders platform aiming to initiate comprehensive, effective and sustained programmes addressing wastewater management.

The Secretariat for the GW² I is provided by the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA).

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Acknowledgements

Citation: Economic Valuation of Wastewater - The cost of action and the cost of no action

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The UNEP **coordination team** provided essential support, in particular *Vincent Sweeney (Coordinator, GPA, UNEP-DEPI), Birguy Lamizana-Diallo (Programme Officer, GPA), Maite Aldaya (Senior Researcher, UNEP-DTIE), Sonia Valdivia (Secretariat, UNEP/SETAC Life Cycle Initiative), Djaheezah Subratty (Programme Officer, UNEP-DTIE), Mick Wilson (DEWA) Pushpam Kumar (Head, ESE, UNEP-DEPI), Geraldine Deblon (Communication, GPA), Milcah Ndegwa (Communication, FMEB) and Marjorie Nyabuti (Associate Project Officer, GPA).*

We would like also to thank those who provided their valuable time to carry out the external peer review of the report: *Dr Gueladio Cisse (Swiss Tropical and Public Health Institute), Drs. Munir Hanjra and Pay Drechsel (IWMI), Prof. P.S. Minhas (National Institute of Abiotic Stress Management, India), Prof. Ziad Al-Ghazawi (Water Resources and Environmental Engineering Group, Jordan) and Dr Othniel Mintang Yila (Stockholm Environment Institute, Kenya).*

ISBN: ISBN: 978-92-807-3474-4
Job Number: DEP/1938/NA

Division of Environmental Policy Implementation

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Foreword

Over the years, wastewater has been a source of pollution due to urbanization, growing cities, industrialization and improved material consumption, among other factors. Today, an estimated 80 per cent of global wastewater is being discharged untreated into the world's waterways. This affects the biological diversity of aquatic ecosystems and disrupts the fundamental web of our life support systems, on which a wide range of sectors from urban development to food production and industry depend.

With only 8 per cent of the required capacity to treat wastewater effectively, low-income countries are the hardest hit by contaminated water supplies and resulting impacts: loss of ecosystem services and economic opportunities; climate change aggravation through wastewater-related emissions of methane (CH_4) and nitrous oxide (NO_2); spreading of "Dead Zones" impacting fisheries, livelihoods and the food chain; and health impacts due to waterborne diseases.

Yet, if properly managed, wastewater could be a source of water, energy, fertilizer and other valuable materials and services. Each year, for instance, approximately 330 km^3 of municipal wastewater are generated globally. A recent study showed that resources embedded in this wastewater would be enough to irrigate and fertilize millions of hectares of crops and produce biogas that could supply energy for millions of households.

Adequate wastewater collection, treatment, and safe use or disposal can lead to significant environmental and health benefits. From a business perspective, valuation of the costs of no action in wastewater management is necessary to justify suitable investment in this domain. Economic analysis provides the information needed for public policy decisions that support improvements in wastewater management.

Countries have finalized the next development agenda and endorsed a new set of Sustainable Development Goals (SDGs), which include a goal to ensure sustainable water and sanitation for all. With this in mind, Economic Valuation of Wastewater therefore identifies economic benefits for municipalities associated with wastewater treatment. This book further highlights that including external benefits (environmental and health) in economic feasibility analysis generates positive results for all the evaluated water reuse projects. As illustrated by the successful stories from around the world in this report, investing in wastewater management is economically feasible, and produces benefits of higher value than non-action.

Through the Global Wastewater Initiative and other relevant activities, UNEP is committed to working with all stakeholders to reduce the impacts of untreated wastewater on the environment and to promote it as a valuable resource worthy of investment. This will require cross-sector global collaboration with governments and other agencies to develop effective legislation, innovative financial mechanisms and waste management infrastructure, especially in developing countries. All involved parties may need to digest the findings of this book and consider the benefits of investing in wastewater management from an economic, environmental and social point of view.

ACHIM STEINER
United Nations Under-Secretary-General and
Executive Director, United Nations Environment Programme

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ACRONYMS

AM	Asset Management
BOD	Biological Oxygen Demand
CAPEX	Capital Expenditures
CBA	Cost-Benefit Analysis
CNA-CA	Cost of No Action versus Cost of Action
COD	Chemical Oxygen Demand
CV	Contingent Valuation
CVM	Contingent Valuation Method
CW	Constructed Wetlands
DSS	Decision Support System
EFA	Education For All
GHG	Greenhouse Gases
IWMI	International Water Management Institute
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing
MDG	Millennium Development Goals
Mm^3	Million cubic meters
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration
PPCP	Pharmaceutical and Personal Care Products
PE	Population Equivalents
OPEX	Operational expenditures
SP	Shadow Price
SS	Suspended solids
P	Phosphorus
PS	Pond System
UNU-INWEH	United Nations University Institute for Water, Environment and Health
WHO	World Health Organization
WTP	Willingness To Pay
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This book presents the results of an analytical study on the economic valuation for wastewater, comparing the cost of no action versus the cost of effective wastewater management.

One of the Millennium Development Goals (MDGs) adopted by the United Nations was to reduce by half the proportion of people without access to safe drinking water and improved sanitation by 2015. Further, at the Rio+20 Summit in June 2012, governments recognized the need to adopt measures to significantly reduce water pollution, increase water quality and significantly improve wastewater treatment which is now reflected in the Sustainable Development Goals. To achieve these objectives, substantial investment in sanitation including septage and sewage management is required, in particular in developing countries.

Although economic valuation of wastewater management is complex, it remains an important tool to guide policymakers and investors to take informed decisions. A financial analysis of wastewater management looks at its private costs and benefits and can underpin decision making from a business or treatment plant operator standpoint. Economic analysis looks at the broader costs and benefits for society, providing information for public policy decisions to support improvements in wastewater management. Adequate wastewater collection, treatment, and safe use or disposal can lead to significant environmental and health benefits. However, because some of these benefits do not have a market price, they have not traditionally been considered in the financial analysis of wastewater treatment projects, therefore underestimating total benefits.

The valuation of the benefits of action or, in other words, valuation of the **costs of no action** is necessary to justify suitable investments in wastewater management. The costs of no action can be categorized into three groups: adverse human health effects associated with reduced quality of drinking and bathing/recreational water; negative environmental effects due to the degradation of water bodies and ecosystems where untreated or inadequately treated wastewater is discharged; and potential effects on those economic activities that use polluted water for crop production, fisheries, aquaculture, or tourism.

Several methodologies allow the valuation of cost and benefits of wastewater management and the comparison between the estimated cost of no action (benefits lost) with the cost of action to provide essential information for decision-making processes. This book reviews these methods and shows the application of some of these methodologies in empirical examples. Results from these cases show that implementing wastewater programmes in developing countries is often feasible from an economic point of view if environmental and health benefits are integrated into the overall economic assessment.

Next to a set of empirical studies, a hypothetical example is used to illustrate a possible procedure for assessing the economic feasibility (**cost of action versus cost of inaction**) of implementing two extensive technologies — pond systems and constructed wetlands — for treating wastewater over 25 years in small settlements in developing areas. Both technologies are characterized by relatively low investment, operational and maintenance costs if compared with conventional treatment processes like activated sludge systems. While the comparison of costs and benefits can vary depending on the valuation approaches used, the calculated example confirmed that implementing either of these technologies will be economically feasible with health and environmental benefits of higher value than costs .

The selection of best practices/strategies for wastewater management requires consideration of multiple objectives and criteria (e.g. financial, environmental, technical and social) and their complex interactions. Moreover, a reliable analysis of wastewater management demands identifying both strong and weak points of the different operational strategies; uncertainty/risk should be part of evaluation to analyze how it affects decision making. This complexity requires the development of rigorous and systematic multi-criteria decision analysis. With such a tool, policymakers can evaluate and compare the alternatives in a **cost of no action versus cost of action** (CNA-CA) approach appropriately.

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INTRODUCTION

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INTRODUCTION

The world is facing a water quality crisis caused by increasing pollution loads from growing cities, unsustainable industrialization and food production practices, improving living standards and poor water and wastewater management strategies. Wastewater is both an asset and a problem in an urbanizing world (*Drechsel et al.*, 2015a; UN-Water, 2015). Unmanaged wastewater is an important source of pollution and a hazard for human health and ecosystems services. The costs related to the pollution of water bodies can be significant: the Millennium Ecosystem Assessment report suggests the cost of degradation of ecosystem services in coastal waters is mostly associated with impacts on human health (MEA, 2005), while the overall economic value of the goods and services delivered by healthy coasts and oceans are worth trillions of dollars.

Recognition that wastewater is an economic resource capable of supplying water, nutrients, energy and other valuable materials and services has become a major driving force to improve water quality and stimulate effective wastewater management. Each year, 330 km3 of municipal wastewater are generated globally. Theoretically, the resources embedded in this wastewater would irrigate and fertilize millions of hectares of crops and produce biogas to supply energy for millions of households (*Mateo-Sagasta et al.*, 2015).

However, despite the potential benefits of treatment and reuse, managing wastewater is typically perceived only as a cost. Common difficulties include the diversity of wastewater types and sources at city level and lack of infrastructure to gather wastewater flows from diverse areas to a single common point of proper treatment. As a result, only a small proportion of wastewater is treated, and the portion that is safely reused is significantly smaller (*Mateo-Sagasta et al.*, 2015). Multilateral development banks, bilateral donors and other development agencies find it challenging to get policymakers and managers in national and local governments to develop policies to address wastewater management effectively.

Sick Water (*Corcoran et al.*, 2010), a report by UNEP and UN-Habitat, highlights that a key challenge emerging in the twenty-first century for targeting strategic investments is transforming wastewater from a major health and environmental hazard into a clean, safe and economically attractive resource. However, the lack of effective economic and risk management frameworks has deterred investors from engaging in wastewater management and sanitation projects.

Investments in wastewater management are required both in developed and developing countries. The selection of the most appropriate wastewater management approach requires an economic appraisal of alternate options (FAO, 2010; *Pearce et al.*, 2012; *Hanjra et al.*, 2015). The cost-benefit analysis (CBA) and, more recently, the life-cycle assessment (LCA) are the most widely applied tools to evaluate the feasibility of water and wastewater management programmes (*Rodriguez-Garcia et al.*, 2011).

Wastewater treatment and reuse involves significant environmental, social and health benefits (*Hanjra et al.*, 2012). However, the value of these benefits is often not calculated because there is no baseline or control (*Drechsel et al.*, 2015b), or the market does not determine these values. Valuation of these benefits is nevertheless necessary to justify suitable investments and financing mechanisms to sustain wastewater management.

Purpose of the book

With this background, the study reviewed different methods to analyze the costs and benefits of wastewater management, and to illustrate these methods with examples and data. The proposed methodologies should provide water practitioners with tools to better understand the economics of wastewater management. We also hope the examples will show why it is worth investing in wastewater management from the economic and social points of view.

Structure of this book

The book is structured in three main sections. The first deals with the cost of no action in wastewater management and shows methodologies to value the impacts of untreated wastewater discharge into the environment; it also illustrates these impacts with empirical cases from the literature. The second addresses the cost of action i.e. it provides

methodologies to assess the costs of investment, operation and maintenance of wastewater collection, treatment and reuse, and shows empirical cases from the literature that apply these methods. The third compares the cost of taking action versus the benefits lost by taking no action. Subsequently, it reviews documents and publications that assess the cost of no action and the cost of action. Further, it compares the cost of two extensive technologies of wastewater treatment versus the benefits lost by taking no action in a detailed empirical application. The approach used in this study has been highlighted in Figure 1.

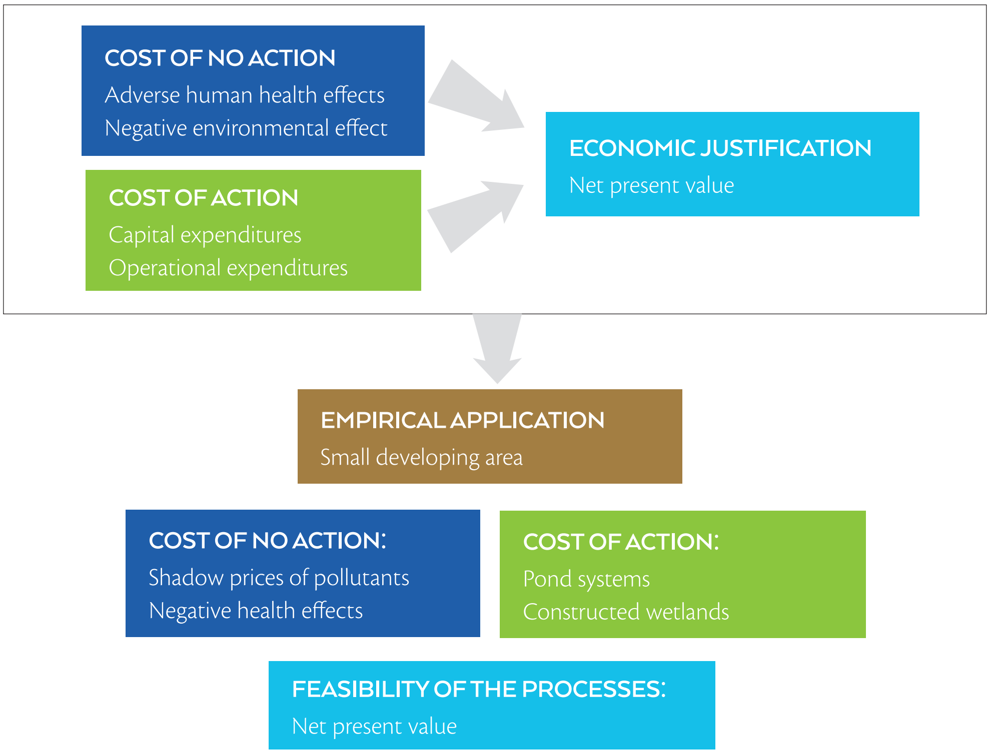

Figure 1

Schematic of the approach followed to assess the cost of action and the cost of no action for wastewater management

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2
COST OF NO ACTION

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COST OF NO ACTION

2.1 Introduction

Managing wastewater is obviously linked to the management of the entire water cycle. Inadequate wastewater management pollutes water bodies that are also important sources for drinking water, fisheries and other services. Therefore, the discharge of wastewater, without or with inadequate treatment, involves significant costs, including environmental and social ones.

2.1.1 Impacts of no action

Ever-increasing amounts of wastewater discharged into canals, rivers, lakes and seas affect human health, environment quality and productive activities (Table 1).

Wastewater may pollute drinking and bathing waters, exposing users to pathogens and chemical contaminants. In so doing, it increases the burden of disease on exposed populations, particularly the most vulnerable: the poor, undernourished and children. Additionally, if polluted waters are used for irrigation, pathogens and chemicals can enter the food chain and have negative impacts on consumers of the polluted product, the farmers that used these waters and the surrounding populations.

Table 1

Examples of potential negative impacts of wastewater on human health, the environment and productive activities

IMPACTS ON	EXAMPLES OF IMPACTS
Health	• Increased burden of disease due to reduced drinking water quality • Increased burden of disease due to reduced bathing water quality • Increased burden of disease due to unsafe food (*contaminated fish, vegetables and other farm produce*) • Increased risk of diseases when working or playing in wastewater-irrigated area • Increased financial burden on health care
Environment	• Decreased biodiversity • Degraded ecosystems (*e.g. eutrophication and dead zones*) • Bad odours • Diminished recreational opportunities • Increased GHG emissions
Productive activities	• Reduced industrial productivity • Reduced agricultural productivity • Reduced market value of harvested crops, if unsafe wastewater irrigation • Reduced number of tourists, or reduced willingness to pay for recreational services • Reduced fish and shellfish catches, or reduced market value of fish and shellfish

Health risks depend on the different forms of exposure faced by diverse social groups. They also vary according to gender, class and ethnicity. Buechler et al. (2006) report fevers, diarrhoea and sores on the hands and legs of farmers and labourers exposed to domestic wastewater. Exposure to industrial wastewater can be much more severe. *Carr et al*. (2004) reported a 36 per cent increase in enlarged livers and 100 per cent increases in both cancer and congenital malformation rates in China, compared to controlled areas where industrial wastewater was not used for irrigation.

Wastewater can disrupt aquatic ecosystems with deleterious impacts on aquatic biodiversity, landscapes and recreational opportunities. Additionally, improper wastewater management produces CO_2 and CH_4 without the opportunity for carbon sequestration and energy recovery and, thus, contributes to global warming: CO_2 and CH_4 emissions associated with wastewater discharges could reach the equivalent of 0.19 million tons of CO_2 per day in 2025, with even more dramatic impact in the short-term (Rosso and Stenstrom, 2007).

Finally, the use of polluted waters may also affect economic activities. For example, land and water salinization induced by industrial wastewater discharges may have severe impacts on agricultural productivity if these waters are used for irrigation (Chapman and French, 1991). Some chemicals in wastewater can have negative impacts on agricultural productivity due to phytotoxicity; a pollutant (trace metals, pesticides, personal care products and/or salts) could have a toxic effect on plant growth.

Consumers of wastewater-irrigated farm produce are also at risk of illness when they handle and ingest contaminated crops, particularly vegetables eaten raw or inadequately prepared (*Cissé et al*., 2002). Toxic effects of wastewater on aquatic fauna, including fish and shellfish, can dramatically reduce their stocks and catches, and can poison people via heavy metal and contamination with bacteria such as ***E. coli***. A key challenge for any economic assessment where untreated wastewater is already discharged or reuse, is to have comparable empirical data on the impact of wastewater versus freshwater, which can be a larger challenge than the economic evaluation itself. Another situation is where wastewater treatment or reuse are still in the planning stage. Here ex-ante risk modeling can help to quantify and value the likely change in the expected diseases burden compared to no-action, using quantitative microbial risk assessment (QMRA) (*Drechsel et al*., 2010; *Drechsel and Seidu*, 2011).

2.1.2 Economic analysis

Wastewater management and treatment involves significant benefits (avoided costs). Therefore, the cost of no action may be interpreted as benefits not achieved due to the discharge of the wastewater with no or inadequate treatment. In other words, if untreated or inadequately treated wastewater is discharged directly into the environment, costs are generated or potential benefits are lost. The potential benefits associated with improving wastewater management can be grouped into two general categories: market and non-market benefits. Most environmental and health benefits have significant value, but — unlike most benefits from productivity — cannot be valued in monetary units as market prices do not exist.

Market benefits are easily identifiable and quantifiable, while non-market benefits are difficult to measure and require specific economic valuation methods. Where these benefits cannot be valued in monetary units because the techniques are in infancy, they should be reported per se into the analysis; no effort should be made to conflate non-monetary units onto monetary values (*Hanjra et al*., 2015).

2.2 Valuation methodologies

2.2.1 Valuing impacts on human health

The value of the adverse health effects includes: (i) direct medical expenditures for illness treatment; (ii) indirect costs resulting from illness, which includes the value of time lost from work, decreased human productivity, potential for demotion, money spent in care giving and premature death (*Calhoun and Bennett*, 2003); and (iii) pain and suffering associated with illness.

Some negative health effects refer to market value and can be directly estimated (i.e. the health costs generated by drinking contaminated water). Others, however, are a non-market value that can only be quantified through non-market based approaches.

The medical costs of treating several illnesses associated with drinking unsafe water have been widely studied (*Hutton et al*., 2007; *Gordon et al*., 2011; *Kim et al*., 2012). But the methodologies used to analyze medical costs are diverse and depend on the type

of illness. Therefore, identifying the most significant wastewater-related diseases is the first step to quantify cost type. Achieving this requires cooperation between regional economic and health professionals.

In general, many factors affect health costs, including geographic region, sex and age. The value of productivity lost from illness or premature mortality results in substantial losses to society. Consequently, an economic assessment of interventions to improve water quality should integrate avoided costs. For example, Wilking and Jönsson (2005) estimated the indirect cost of absenteeism in the German workplace due to cancer (excluding premature mortality costs) at 0.7 per cent of gross domestic product (GDP).

Of the several ways to estimate indirect costs associated with illness, the human capital approach is most widely applied. This method, which relies on earnings as a measure of productivity, calculates expected lifetime earnings that would have been earned had disease or premature death been avoided (*Bradley et al*., 2008). Consequently, lost earnings are used as a proxy for loss in productivity. Wage and production structure data can be obtained at national or regional bureaus of statistics.

In relation to non-market values, the methods used to estimate the economic value of risk reductions are based on willingness to pay (WTP), described in the next section. Many studies have examined WTP for reducing different types of risk, including air pollution (*Roman et al*., 2012), road safety (Hakes and Viscusi, 2007) and accidents in the workplace (*Tsai et al*., 2011). Contributions to drinking water quality have been more limited, and served to estimate the economic value of avoided costs to health derived from risk reductions associated with improving drinking water quality (*Adamowick et al*., 2011).

2.2.2 Valuing impacts on the environment

Traditional valuation techniques are based on the demand approach. Stated preference methods are the most common for valuing the environmental impacts (*Bateman et al*., 2006) using survey techniques to elicit for example individuals' WTP for the hypothetical provision of an environmental good (e.g. an improvement in water quality as consequence of wastewater treatment). The values obtained are taken to represent the economic benefits or costs avoided of the proposed change in environmental quality. They can then be aggregated in a cost-benefit framework to obtain the social and environmental benefits of public policies aimed to improve wastewater management.

Unlike most commodities, pollution of lakes, rivers and streams is generally not traded in a market. Therefore, there is no market price for pollution or lack of it. Among different approaches to the valuation of non-market goods, three are most commonly used:

i) The travel cost method. Although people do not pay direct fees to visit an aquatic site, they do spend time and meet other costs, such as cost of gasoline, to travel to the site. The opportunity cost of time plus other costs are their price for access to clean water. Hence, "travel cost" can be used to elicit the value of clean water.

ii) The hedonic method. This method recognizes that water quality affects housing prices. A house on a very clean lake or river is usually more expensive than one on a polluted lake or river. Thus, the differences in the housing price reflect peoples' valuation of clean water.

iii) The contingent valuation (CV) method is not based on what people do, but what people say they will do under certain scenarios in a hypothetical market. This approach directly elicits the maximum WTP for better water quality in a survey.

The travel cost and the hedonic methods are revealed preference methods; economic values are indirectly "revealed" from behaviour. The CV method is a stated preference method because people directly state their preference (in a survey, for example).

Despite the popularity of these three methods for water quality valuation, other (and probably cheaper) methods have been recently tested. One, for example, considers wastewater treatment as a productive process in which a desirable output (treated water) is obtained together with a series of undesirable outputs (suspended solids, heavy metals, nutrients, etc.) using inputs (labour, energy, etc.). This production perspective makes it possible to estimate the shadow prices of pollutants (*Färe et al*., 1993, 2001). A shadow price for these undesirable outputs would be the equivalent of the environmental damage avoided if these pollutants are removed or recovered. Therefore, they can be interpreted as an estimate of the environmental benefits gained from the treatment

or recovery process. This method has very low costs compared to surveying processes. Some empirical applications of shadow price methodology have been made in the field of atmospheric pollutants, industrial wastes and the removal of pollutants from wastewater (*Hernández-Sancho et al.*, 2010; *Molinos-Senante et al.*, 2011a).

The suitability of each method will depend upon several factors. The CV is a very flexible technique that can be applied to a great variety of non-market goods and to ***ex ante*** and ***ex post*** assessments.

It is, however, very expensive to carry out. Funding can be a limiting factor, especially if representative samples of the entire population are needed (*Randall*, 1997). The results from a CV study depend on the assumptions on the elicitation format chosen and the empirical model to estimate the mean WTP (*Bengochea-Morancho et al.*, 2005); this can be troublesome when using benefit transfer to support decision making. Shadow pricing, despite its more limited scope, may be useful to quantify environmental impacts derived from production processes. It does present an advantage since obtaining the necessary information is more direct and cheaper (*Färe et al.*, 2001).

2.2.3 Valuing impacts on economic activities

Water quality degradation can potentially affect all economic activities that use water such as industrial production, crop production, fisheries or aquaculture. Tourism can also be impacted by water quality degradation for two reasons. First, tourists demand clean water for drinking and other domestic purposes. Second, water pollution can degrade the landscape, limit recreation opportunities and produce bad odours and other environmental effects.

All these impacts (most especially reduced production and loss of tourists) have market value and can be monetized. The controlled conditions of a research pilot can measure production changes of a given economic activity (e.g. agricultural production) when water quality changes, while all other production factors remain constant. This can allow construction of production functions or dose-response functions where, for example, the yield is a function of a specific water quality parameter (e.g. salinity). In real conditions (as opposite to controlled conditions), one can compare two similar productive systems in different locations where the only difference is the water quality. For example, consider two irrigated plots along the same river; both are close to the riverside, have the same types of soil and climate, and use the same farming pattern. If one plot is irrigated with water polluted with toxic substances (e.g. from industrial discharges) and the other uses clean water, then the productivity (and product quality) of these two plots will be different. Similarly, changes in production (in terms of quality

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and quantity) observed can be analyzed before and after polluted water is used for irrigation.

Wastewater has useful plant food nutrients that can enhance crop yield. Consequently, comparing wastewater irrigated farms with those using freshwater, from surface and groundwater sources, could also provide insights on the marginal contribution of wastewater towards agricultural productivity and economic benefits/farm income if crops and soils are the same (*Drechsel et al.*, 2015b). Production as a function of water quality has been well studied for salinity effects on some crops, among others (*Ayers* and *Wescod*, 1994; *Kiani* and *Abassi*, 2009). The same applies to the loss of plant nutrients through wastewater treatment which can either be valued through reduced productivity or via the replacement cost approach based on the price farmers pay for organic or industrial fertilizer (*Drechsel et al.*, 2004). But the valuation of the environmental effects (e.g. eutrophication, ecosystems degradation or bad odours that could indirectly affect tourism) is more complex. It may require the use of other methods, such as those described in section 2.2.2.

2.3. Empirical applications

2.3.1. Health implications for children in wastewater-irrigated peri-urban area of Aleppo, Syria

The use of wastewater in untreated, partly treated and/or diluted forms for irrigated agriculture may pose environmental and health risks. Few studies have focused on health implications of wastewater use in developing countries and options for risk mitigation (*Drechsel et al*. 2010). To provide information about health implications of wastewater irrigation on children (8-12 years old), *Grangier et al*. (2012) compared in a more recent example farming communities in wastewater and freshwater areas under similar agro-climatic conditions and farming practices in 12 villages in the peri-urban area around Aleppo, Syria.

Specifically, the study took place in six villages within wastewater-irrigated areas and six villages where freshwater (groundwater, in the case study) is used for irrigation. Interviews with the farming communities included 40 children from each irrigation scheme (wastewater and freshwater).

A community facilitator from the International Center for Agricultural Research in the Dry Areas (ICARDA) helped with communication in each interview.

Two waterborne (typhoid fever and gastroenteritis) and three non-waterborne (flu, chickenpox and strep throat) diseases were selected as common diseases in the study area. An additional disease (eczema) was included in the study since it may or may not be waterborne. Additionally, information about health cost data was collected in the interviews.

The main results of the study appear below.

- **Non-waterborne diseases:** Flu and strep throat are common diseases among children within and around the study area regardless of the source of irrigation water. Both diseases had significantly higher prevalence rates in children living in freshwater-irrigated area than those in wastewater-irrigated area. On the other hand, very few children reported to have had chickenpox in either wastewater- or freshwater-irrigated areas.
- **Waterborne diseases:** The prevalence rate of gastroenteritis was much higher in children living in wastewater-irrigated areas (75 per cent) than those living in freshwater-irrigated areas (13 per cent). Differences in the prevalence of typhoid fever were also found in 3 per cent of freshwater-irrigated areas against 10 per cent in wastewater-irrigated areas. Children living in a wastewater-irrigated area had a four times greater prevalence rate for the two waterborne diseases than those within their age group living in the freshwater-irrigated environment.
- **Eczema:** Prevalence rate for children living in the wastewater-irrigated environment was 43 per cent, while in freshwater-irrigated area it was 3 per cent.

Grangier et al. (2012) also investigated the distribution of waterborne diseases along the wastewater channel. In doing so, results on disease prevalence in one village were split into three sections: upstream, midstream and downstream. The study hypothesized that pollution would be higher downstream than upstream if there are different discharge points along the wastewater channel. In this case, the statistical analyses show no significant differences between the stream locations

for prevalence rates of both waterborne diseases (gastroenteritis and typhoid).

Regarding health costs, *Grangier et al.* (2012) demonstrated important differences between wastewater and freshwater-irrigated areas. On the average, the annual health cost per child in the wastewater-irrigated environment was US$67.1 (€49.4); this was 73 per cent higher than the annual health cost per child in the freshwater-irrigated area (US$38.7, or €28.5, on average). Despite such health-cost differences, farmers from wastewater-irrigated areas still use wastewater because of their priority for overall economic gains (fewer or no expenses on fertilizer purchase and field application, lower energy cost in water pumping and additional benefits through greater income due to crop intensification and diversification).

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2.3.2 Impact of industrial wastewater pollution on rice production in Viet Nam

In Viet Nam, Khai and Yabe (2013) surveyed rice farmers in two areas in the Mekong River Delta (Phuoc Thoi and Thoi An). They had almost similar natural environment conditions and social characteristics (e.g. social and farming culture, ethnicity, type of soil), and only differed with respect to pollution. Phuoc Thoi, with 148 ha and 214 interviewed farmers, received wastewater from nearby industrial parks; Thoi An, with 150 interviewed farmers, was assumed to be non-polluted, being distant from sources of industrial pollutants.

Estimates of total economic loss due to water pollution considered three factors: (i) a reduction in rice quantity (assuming that water pollution decreased rice yield); (ii) a reduction in rice quality, which is measured as price difference (assuming that water pollution reduced rice quality in a particular region and led to lower prices); and (iii) an increase in input costs (assuming that farms may introduce new technologies to reduce water pollution that can offset these other losses).

Rice productivity loss from water pollution was estimated as the difference in rice yield between the two regions coupled with production costs and profit. The results showed the yield of rice in the polluted area was about 0.67 tons per ha per year less than in the non-polluted area. The production cost increase due to additional compensatory inputs was US$46.6 per ha per year, giving a total profit loss of US$150.4 per ha per year as compared to the non-polluted area. For the 148 polluted ha, the total cost increase due to water pollution could be estimated at US$6,750 and approximately US$22,260 per year for the total economic loss – slightly over US$100 per household.

2.3.3 Environmental benefits from wastewater treatment in Spain

Many empirical approaches can be used to value environmental benefits (cost of no action). One is to use shadow prices, i.e. the avoided costs resulting from removing pollutants during wastewater treatment. *Hernández-Sancho et al.* (2010), in a pioneering work using a sample of 43 wastewater treatment plants in Spain, estimated the shadow prices of five indicators: nitrogen (N); phosphorus (P), suspended solids (SS), biological oxygen demand (BOD) and chemical oxygen demand (COD) as shown in Table 2. The economic value of these pollutants differs depending on the type of the receiving water body and the different reference water prices assumed. The shadow prices are negative since they are associated with undesirable outputs that represent negative value in contrast to desirable outputs.[1] The main environmental benefits for all four analyzed destinations are the elimination of phosphorus followed by nitrogen; an excess of both nutrients causes serious eutrophication problems and significantly reduces biodiversity by stimulating the growth of algae.

1 Undesirable outputs not treated generate environmental cost; undesirable outputs treated represent an avoided cost.

Table 2

Reference price of water treated (€/m3) and shadow prices for undesirable outputs (€/kg)

		ESTIMATED SHADOW PRICES FOR UNDESIRABLE OUTPUTS (€/kg)				
Effluent destination	Reference price of water (€/m^3)	Nitrogen(N)	Phosphorus (P)	Suspended solids (SS)	Biological oxygen demand (BOD)	Chemical oxygen demand (COD)
River	0.7	-16.3	-30.9	-0.005	-0.03	-0.10
Sea	0.1	-4.6	-7.5	-0.001	-0.005	-0.01
Wetlands	0.9	-65.2[1]	-103.4	-0.01	-0.12	-0.12
Reuse	1.5	-26.2	-79.3	-0.01	-0.06	-0.14

Source: Hernández-Sancho et al. (2010).

Based on this work, *Molinos-Senante et al.* (2013a) estimated the economic value of removing five pharmaceutical and personal care products (PPCPs) from wastewater that require intensive treatments based on membranes. Developed countries with increasingly strict legislation governing water quality are increasingly interested in knowing the environmental benefits associated with removal of PPCPs from wastewater. The average values of shadow prices for the five PPCPs evaluated are shown in Table 3.

Table 3

Estimated shadow prices for undesirable outputs (€/kg)

SCENARIOS	DICLOFENAC	TONALIDE	GALAXOLIDE	SULFAMETHOXAZOLE	ETHINYL ESTRADIOL
Non-sensitive water bodies	- 42.2	-11.0	- 8.7	- 35.0	- 73.7
Sensitive water bodies	- 53.5	-14.0	- 11.1	- 44.5	- 93.8

Source: Molinos-Senante et al. (2013a).

Another study by *Molinos-Senante et al.* (2011b) in the Serpis River Basin (SRB) (Spain) compared the value of environmental benefits obtained using shadow price with the results of *Del Saz-Salazar et al*. (2009), who valuated the same programme using the contingent valuation (CV) method. The Serpis River Basin is a clear example of a Mediterranean watershed in which wastewater discharged from the wastewater treatment plants (WWTPs) represents a high proportion of the total stream flow, accounting for up to 50 per cent during winter and 90 per cent during summer. In addition, WWTPs are responsible for up to 90 per cent of the river's annual load of solids, organic matter and nutrients.

To improve the quality of the river water, the River Basin Authority proposed to improve the quality of effluent from the two largest WWTPs: Alcoy and Font de la Pedra. The treatment flow rate of the Alcoy plant was 20,800 m^3/day, serving a population equivalent[2] (PE) of 127,271[3] inhabitants. The Font de la Pedra WWTP has a nominal flow rate of 15,000 m^3/day with a PE of 60,701. The environmental benefits derived from improving the quality of the Serpis River were quantified through CV methodology. Moreover, the value of pollutants removed in the wastewater treatment has been quantified using the shadow prices approach (*Molinos-Senante et al*., 2011b). These results are aggregated and compared in Table 4.

2 Population equivalent is conventionally defined as the average amount of pollution load produced and introduced into wastewater by a permanently residing inhabitant in one day.
3 This is real information from the WWTP as opposed to an estimation.

Although with different intensity, both methodologies indicate that improving the ecological status of water bodies in the SRB can be economically feasible.

Table 4
Net present value and benefit-cost ratio for CV and SP methodologies

	CONTINGENT VALUATION (CV)	SHADOW PRICES (SP)
Discount rate (3%)		
Net present value (EUR)	1 710 008	2 355 994
Benefit-cost ratio	1.03	6.31

Source: Molinos-Senante et al. (2011b).

2.3.4 Conclusion regarding cost of no action

Based on the above three empirical cases, there are different types of costs from not acting against the problem of untreated wastewater. Furthermore, the presence of these health, environmental and productive costs can be quantified using reliable methods that allow comparison with the costs required to prevent such pollution. The result of this comparison can demonstrate the profitability of acting against pollution from untreated wastewater. Despite the obvious difficulties of calculation, mainly associated with the availability of statistical information, these costs should be identified and quantified to avoid them being ignored and, therefore, not addressing corrective measures.

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3
COST OF ACTION

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COST OF ACTION

3.1 Introduction

Implementing effective water recycling, safe reuse or disposal involves costs referred to as cost of action; their assessment includes costs of investing, as well as operating and maintenance of the required facilities.

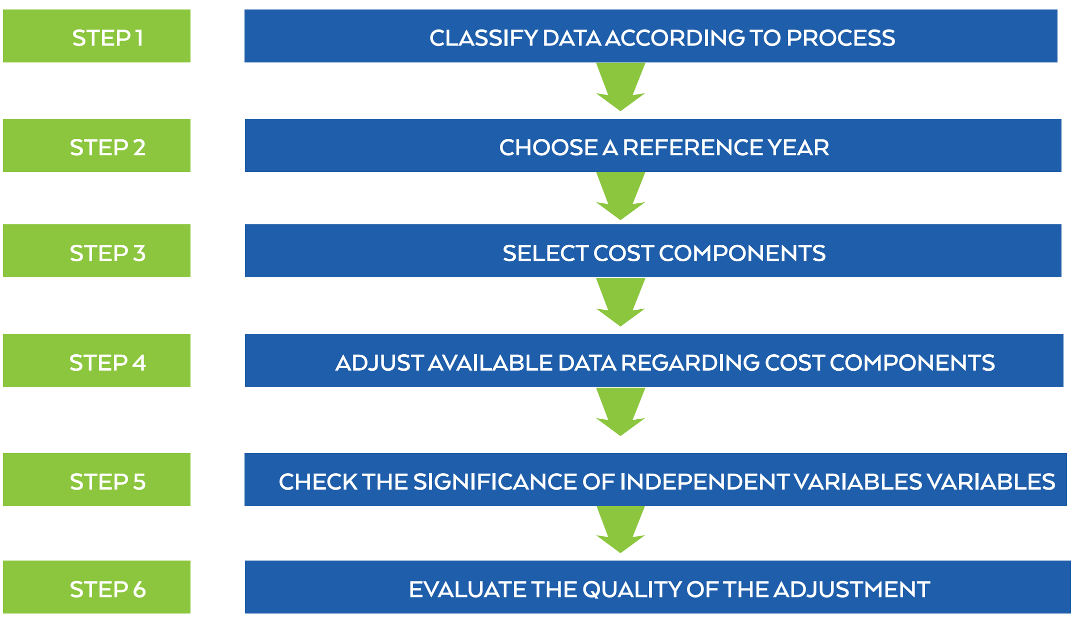
The three types of actions needed for wastewater management are wastewater collection, wastewater treatment, recovery of resources from wastewater (such as water, nutrient, organic matter, biogas and energy) and safe reuse, as described below.

In the context of wastewater management, cost functions are a suitable tool to help analyze costs. As reported by *Molinos-Senante et al.* (2012a), there are three main methodologies for developing cost functions related to "wastewater economics":

- The first views the wastewater treatment facility as a system of components or subsystems (*Panagiotakopoulos*, 2004), each of which is simulated in detail. For various facility schemes, the design parameters are allowed to assume values within a wide but realistic range. This simulates many alternative facility forms, each with its own cost estimate.
- The "factor method" recognizes and directly estimates major cost drivers related to specific parameters for the wastewater treatment facility (*Le Bozec*, 2004). Through conversion coefficients for the cost drivers, estimates from one region or country can be transferred to another.
- Statistical and mathematical methods are often used when cost figures (actual or estimates) are available. These figures might relate set-up cost and/or operating cost to the main variables of the wastewater treatment facilities. Other factors, such as the type of treatment process, also affect costs.

Previous studies (*Sipala et al.*, 2005; *Papadopoulos et al.*, 2007; *Hernández-Sancho et al.*, 2011) show that the statistical method is the most common approach for developing cost functions in the context of wastewater management. Steps ranging from the collection of the raw data to the generation of the cost functions are summarized in Figure 2.

Figure 2
Steps for cost modelling from the collection of the raw data to the generation of the cost functions (Based on *Molinos-Senante et al.*, 2013b).



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1) *Classify data according to process*. For the cost functions of wastewater activities, sorting means first to distinguish each activity (sewer networks or wastewater treatment). Later, in each activity, based on its process, a classification is made (e.g. wastewater treatment based on extended aeration, membranes, etc.).

2) *Choose a reference year*. Due to the difficulty in obtaining economic data relating to the investment and the operation of wastewater activities, sometimes the reference year of all available information is not the same. In this case, the reference year is generally the year of analysis.

3) *Select cost components*. Usually, treatment capacity is the most important factor to determine cost. However, other factors such as contaminants removed or age may affect operation of facilities.

4) *Adjust available data regarding cost*. Several statistical methods can be used to study the relationship between the independent variable (cost) and a series of variables (dependent ones) such as the capacity or the age of the facility. The most common is regression analysis (*Gonzalez-Serrano et al*., 2006; MARM, 2009), which can express the relationship between variables in a simple equation that connects a variable response, Y to one or more explanatory variables (X_1, X_2, ...X_k).

5) *Check the significance of independent variables*. Once the regression model has been developed, the next step is to check that all independent variables are significant. At its simplest, this involves checking that all the regression coefficients, β, have the expected sign. A further step is to carry out a statistical hypothesis test.

6) *Evaluate through quality of the adjustment*. Quality can be assessed through the coefficient of determination. This coefficient measures the proportion of total variability of the dependent variable relative to its average, which is explained by the regression model. Its value is between 0 and 1. If the determination coefficient value is 1, the adjustment between actual and estimated data is perfect. If it takes the value of 0, there is no relationship between these variables.

3.1.1 Wastewater collection

Methods and effectiveness of wastewater collection differ between developed and less-developed countries and between urban and rural areas. Sewerage networks in developed urban and rural areas collect and transport domestic and industrial wastewater to a treatment plant and play a key role in protecting public health. Their main components are drains, collectors, conduits and pumps. Uncollected rainwater that does not infiltrate pervious surfaces (i.e. soils), runs on impervious surfaces (i.e. concrete) and also ends up in the sewer system. Historically, sewer systems have collected both domestic sewage and stormwater, transporting them to a wastewater treatment plant. Referred to as a combined sewage system, this system has been questioned because rainwater is not as polluted as wastewater. This means that rainwater needs less treatment before its discharge to a water body or its

infiltration to the groundwater. Thus, treating rainwater in wastewater treatment plants leads to unnecessary economic costs and lesser environmental benefits. To avoid such impacts, systems can be built to collect domestic sewage and stormwater separately. Here, the costs to build two separate sewer systems would be crucial in the overall economic assessment.

3.1.2 Wastewater treatment

The treatment process (physical, chemical and biological) removes pollutants and organic matter from wastewater. The aim of this treatment is to produce an effluent (and sludge) with the appropriate quality to be released to the environment or re-used. The requirements for the treatment and effluent quality are established in the legislation of each country. Clearly, a greater quality effluent will be associated with higher treatment costs. WWTPs can include different levels of treatment: preliminary, primary, advanced primary, secondary and tertiary.

In **preliminary treatment**, gross solids such as grit are removed since these materials may cause operational problems. In **primary treatment**, physical operations — such as sedimentation — remove floating and settleable suspended materials and a portion of organic matter. Chemicals can be added to enhance the removal of suspended and dissolved solids. **Secondary treatment** uses biological processes and clarifiers to remove biodegradable organic matter and suspended solids, and also eliminate nutrients such as nitrogen and phosphorus. Finally, **tertiary treatment** uses techniques such as membrane filtration or disinfection for effluent before water is reused or released.

Appropriate, effective and low-cost wastewater treatment technologies increase the coverage of wastewater treatment in developing countries (*Hanjra et al.*, 2015). A number of methods can evaluate the benefits from wastewater treatment as part of a broader cost-benefit analysis (CBA) of wastewater treatment options. Undertaking CBA of actions with environmental impacts is complex because many environmental resources, including most water resources, have public good dimensions that do not trade in markets that determine full prices (*Hernández-Sancho et al.*, 2010).

3.1.3 Resource recovery and water reuse from wastewater and sludge

In the literature some works offer guidelines and evaluation criteria for economic feasibility studies on projects of water reuse (WateReuse Research Foundation, 2006; AQUAREC, 2006; *De Souza, et al*, 2011). Reclamation and use of reclaimed water must consider how treatment and reuse affects both economic costs and benefits of the whole process.

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Economic drivers for resource recovery and water reuse are energy savings and generation (biogas), the recovery of plant nutrients plus cost savings in wastewater disposal and water supply (*Drechsel et al*., 2015a) (Table 5) all offering additional value propositions on top of the protection of the environment and public health.

Table 5

Costs and benefits associated with wastewater reuse

DIRECT COSTS	INDIRECT COSTS	DIRECT BENEFITS	INDIRECT BENEFITS
Distribution of reclaimed water	Effects on the carbon footprint of water cycle	Additional water supply	Environmental changes (including landscape changes)
Additional treatments (reclamation)	Public health effects	Availability is not affected by the climatology	Recreation (quality improvement of existing water)
Storage systems and pressure maintenance	Public perception of reduced quality (lack of confidence in the quality of the effluent)	Local control	Value of nutrients (for irrigation)
Quality monitoring and evaluation (safety)	Effects on downstream flows	Avoided cost of other projects	Value of properties
Additional management (administration)	Water quality impacts (perception)	Adaptation of the effluent quality to the use and improvement of water governance	Resilience (drought episodes, guarantee of supply)
Training and information to increase awareness and social acceptance of wastewater reuse	Effects on soil, plants and wildlife	Regulatory certainty	Greenhouse gas reduction/energy conservation
Project preparation	Effects on agriculture	Win-win approach for owners/users	Integrated resources management

Source: Adapted from Salgot et al. (2013).

Resource recovery and reuse are key considerations to wastewater management, if it is considered a resource.

One role as a resource, for example, would be as input for biogas production that produces a stabilized sludge for use in agricultural production. This approach has four-fold outcomes: reducing contamination load on water bodies, producing renewable energy, reducing CO_2 emission and recycling nutrients as fertilizers in food production. *Rudolph* (2013) estimated the main values recovered in the Saigon Brewery Plant in Can Tho, Vietnam, to be 35 per cent thermal energy, 50 per cent recovered materials and 10 per cent substitution of water supply of the area.

Next to energy, especially the value of nutrients in fecal matter and urine is high. Studies in Burkina Faso and Niger, showed that the nutrient value in urine and faeces from a family of 10 corresponded to the quantity of nitrogen and phosphorus in 50 kg of urea and 50 kg of nitrogen-phosphorus-potassium (NPK)4 (*Dagerskog et al*., 2014). The economic value of these fertilizers is estimated at US$80 compared to local prices of chemical fertilizers. While in this case the recycling was promoted at household level, the recovery of nutrients from sewage is a larger challenge. However, WERF (2011) showed that especially **P** recovery can achieve full cost recovery through savings in maintenance costs (avoiding unplanned **P** crystallization in pipes and valves), while the recovered **P** crystals can become a valuable resource for the fertilizer industry.

4 NPK=N+P_2O_5+K_2O

3.2. Valuation cost methodologies

3.2.1. Valuing internal costs

Wastewater collection, treatment and reuse projects cannot be one-shot investments. Instead, they require continuous expenditures in operation, maintenance and rehabilitation, each with associated costs. The first phase for calculating internal cost is to gather and analyze data, particularly on capital and operation expenditures. Capital expenditures (CAPEX) are those related to investment in assets that will last for many years. Operational expenditure (OPEX) includes the expenses needed to operate and maintain the system assets. CAPEX and OPEX costs are regarded as internal to the processes and are born typically by the public or private organization in charge of the construction, operation and maintenance of the wastewater management infrastructure.

Box 1. Two approaches to quantify costs of wastewater management

Engineering methodology: The process of wastewater treatment is divided in many different parts followed by a detailed cost analysis of each part. The sum of the results obtained gives the process final cost. The detailed study of cost breakdown will allow: (i) identification of cost factors with major weight in the different processes and a detailed sensitivity analysis, all to highlight hotspots in costs; (ii) guidance for facilities to better monitor their costs in different processes and; (iii) identification of an order of magnitude for each part in the cost breakdown for use as criteria to check quality of fit in cost estimates derived from parametric methodologies.

Parametric methodology: Equations are developed to identify relationships between costs and explanatory variables. A parametric methodology may consider explanatory factors of cost that are not considered directly in the engineering method, such as the age of the plant or climate. In this context, parametric methods, represented mainly by cost functions, are useful since they enable simulations to generate results for new facilities. Cost functions enable us to improve understanding of the relationship between the costs of wastewater management activities and their most representative variables. Hence, this tool is a scientific approach for planning new facilities or wastewater services (*Hernández-Sancho et al.*, 2011).

3.2.2 Valuing external costs

Wastewater collection, treatment and reuse projects — like any other project — can also have external costs (also called externalities, or environmental and social costs). These are costs that go beyond construction, operation and maintenance of wastewater management infrastructure. The bearers of such costs can be either particular individuals or society at large. External costs are often both non-monetary and problematic to quantify, making them difficult to compare with monetary values. They include variables like land and water pollution, emissions of greenhouse gases (e.g. CO_2, CH_4), and environmental nuisance such as noise and bad odours.

Life cycle assessment (LCA) is a common tool to assess the environmental and ecological impacts of products or processes throughout their life cycle. For instance, Sydney Water in Australia produced a comprehensive LCA of their integrated water and wastewater infrastructure to forecast environmental and ecological impacts under different development scenarios. Life-cycle costing (LCC) provides a useful tool building on the LCA to value these impacts over the lifespan of a given project. It also enables decision makers to compare different, equally viable approaches to a project including costs from upstream and downstream processes. Recent progress in the monetization also of social impacts such as morbidity and mortality effects is however not without criticisms and requires further research (*Guest et al.*, 2009).

The methodologies described in Section 3.2 provide the means to estimate cost functions for sewer networks and WWTPs. Results of selected empirical studies are presented in Sections 3.3.1 and 3.3.2.

3.3. Empirical applications

3.3.1 Cost on sewerage systems and on-site sanitation

The main drivers for the costs of the sewer systems are i) the volume of wastewater transported; ii) the characteristics of the wastewater network and components (e.g. age, materials and size) and type

(combined sewer system or separate sewer system, depending if rainwater is collected with wastewater or separately); and iii) the type of soil and the rehabilitation strategy (e.g. reactive versus proactive maintenance, etc.). In fact, the cost of excavation will be affected if the soil is rocky or not.

Only a very few studies have developed cost functions for wastewater networks, and the major part of the existing literature focuses on network optimization models and strategies. A lack of accurate information on sewer networks and their condition might be the main reason for the relatively few publications providing cost functions (*Abraham et al*., 1998; *Fenner*, 2000; *Breysse et al*., 2007; *Ugarelli et al*., 2010).

Some studies have estimated the cost of sewer systems. For example, *Dogot et al*. (2010) provided statistical information on the costs of different components of the sewerage system; it also models the investment costs for collective sewage systems constructed during 2000-2007 in the Walloon Region of Belgium. Of particular relevance is the statistical information on investment, operation and maintenance costs. Table 6 presents the average investment cost (€/m) for sewerage and collector networks, revealing the investment cost per linear metre of separate systems is approximately two times larger than that of combined systems.

Table 6

Average investment costs (€/m) for sewerage and collector networks in the Walloon Region of Belgium

NETWORK TYPES	AVERAGE INVESTMENT COST (€/M)	SAMPLE SIZE
Collector networks	1 177	112
Collector networks (7 outliers excluded)	772	105
Combined and separate sewer networks	486	265
Combined sewer networks	395	213 (*approximately*)
Separate sewer networks	865	52 (*approximately*)

Source: Adapted from Dogot et al., (2010).

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Studies using the parametric approach that develop cost functions for the sewer system are given by *Yeh et al*. (2008), *Bester et al*. (2010) and the *Hunter Water Corporation* (2012).

Based on a sample of Taiwanese networks, *Yeh et al*. (2008) developed construction cost functions of sewer systems. Their study differed from previous ones as the model estimated construction costs based on excavation depths (variable h); it estimated construction cost functions separately for different items such as pipes, manholes and work shafts. This approach leads to a large number of estimated cost functions, the most significant examples of which are provided in Tables 7 and 8.

Table 7

Estimated construction costs for pipes, work shafts and manholes for open cut techniques in Taiwan

PIPES		
DIAMETER (mm)	**DEPTH (m)**	**COST FUNCTION (TWD/m)***
200	H ≤ 3	C_{cpi}=108.11h_{cp} + 6,038.5
400	H ≤ 3	C_{cpi}=133.76h_{cp} + 10.522
600	H ≤ 3	C_{cpi}=163.24h_{cp} + 11,425
600	3 < H ≤ 8	C_{cpi}=163.23h_{cp} + 12,611
1.000	3 < H ≤ 8	C_{cpi}=216.22h_{cp} + 18,472
MANHOLES		
DIAMETER (MM)	**DEPTH (m)**	**COST FUNCTION (TWD/m)***
600	3 < H ≤ 8	C_{cmi}=17,017h_{cm} + 38,231
1.000	3 < H ≤ 8	C_{cmi}=19,347h_{cm} + 53,064
1.200	3 < H ≤ 8	C_{cmi}=19,484h_{cm} + 62,575

*The variables C_{cp} and C_{cm} reflect pipe and manhole costs in TWD[5]/m, h_{cp} and h_{cm} are excavation depths of pipes and manholes.

Source: Adapted from Yeh et al. (2008).

From these tables we can see the direct relationship between the cost per metre and depth of excavation for pipes and manholes. In the case of pipes (at the same depth), the cost per metre is more expensive depending on the diameter of the pipe. For manholes, the influence of diameter in the cost per metre is only visible from a 600 mm diameter.

Table 8

Estimated construction costs for pipes, work shafts and manholes for jacking techniques in Taiwan

Pipe diameter (mm)	**Pipe cost function (TWD/m)***	**Manhole cost function (TWD/m)**
900	C_{JLS}=168,169h_{ls} + 210,186	C_{JM}=17,769h_m + 16,786
1.200		
1.350	C_{JLS}=160,318h_{ls} + 258,600	C_{JM}=18,425h_m + 32,313
1.650		

*The variables C_{JLS} and C_{JM} represent pipe and manhole costs, h_{ls} and are h_m excavation depths of pipes and manholes.

Source: Adapted from Yeh et al. (2008).

Bester et al. (2010) determined cost functions for a sample of South African sewer systems and provided a simplified cost function for estimating construction costs during the planning stage. The authors considered pipe diameter and the type of surface to be the most relevant determinants of capital costs of pipelines (Table 9).

5 TWD: Taiwan Dollar; 100 TWD = 3.2 USD.

Table 9

Examples of construction cost functions of pipelines in separate sewer systems in South Africa

TYPE OF LAND COVER	RISING MAIN CONSTRUCTION COSTS[2*]
Public open spaces	$Cost = L * (0.0032D^2 + 4.0755D - 52)$
Reserve areas	$Cost = L * (0.0031D^2 + 3.1947D - 211)$
Road areas	$Cost = L * (0.0026D^2 + 2.8788D - 198)$
TYPE OF LAND COVER	**GRAVITY PIPELINE CONSTRUCTION COSTS**
Public open spaces	$Cost = L * (0.0024D^2 + 2.8788D0 - 300)$
Reserve areas	$Cost = L * (0.0024D^2 + 2.4544D - 190)$
Road areas	$Cost = L * (0.0021D^2 + 1.9783D - 154)$

Source: Adapted from Bester et al. (2010).

For example, constructing a network in roads was more costly than on the side of the road. Construction costs of pipelines in a separate sewer system were estimated independently for different types of surfaces to be reinstated (public open spaces, reserve areas and road areas) and for different types of sewer systems (rising main and gravity pipelines).

A function for the construction costs of pumping stations within a separate sewer network was determined as: $Cost = 91.169* PC^{0.5444}$ where *cost* is expressed in Rand (South Africa monetary unit, 1 Rand= 0.09 $ approximately) and *PC* is the total volume of water that can be pumped per unit time (l/s). According to this study, the main drivers of the construction costs of pumping stations were related to civil works such as covering structures or buildings around pumps, costs of pipelines connecting with the pumps and costs of electrical and mechanical components.

A guideline for estimating **operating and maintenance costs** of water and wastewater systems is proposed by the Hunter Water Corporation (2012). Even though this report is aimed at estimating the company's own costs, it provides some insights into the general cost structure of sewer systems (Table 10). The study's main limitation is the lack of detail in methodological approach and the data set used for estimating these functions.

Table 10

Examples of annual operating and maintenance costs of sewer systems in Australia

	ANNUAL O&M COSTS (IN USD)[3*]
Gravity mains	$Cost = 2{,}872 - 1.13 * DN + 0.00024 * DN^2 * \mathbf{L}$
Rising mains	$Cost = 700 + 0.0005 * DN^2 * \mathbf{L}$
Sewage pumping stations	$Cost = 4{,}000 + 2{,}000 *$ ***No. of pumps***

* ***DN*** represents the pipe nominal diameter in millimetres and ***L*** represents the pipeline length in kilometres.

Source: Adapted from Hunter Water Corporation (2012).

Ugarelli et al. (2010) described the concept of **asset management** (AM) applied to sewage pipelines, addressing different aspects of AM and its limitations. Using the example of the sewage pipeline system of Oslo, the authors showed how to develop a life-cycle cost (LCC) based on asset management strategy. Several studies have developed methods for optimizing costs and further aspects of sewer networks.

Abraham et al. (1998) developed an integrated approach for **optimizing maintenance** costs over the entire life cycle of a wastewater system based on the current and predicted future condition of sewers. The proposed model, applied to the city of Indianapolis in the US, sought the optimal rehabilitation and maintenance strategy for minimizing life-cycle costs.

Rehan et al. (2013) proposed to simulate the behaviour of a wastewater management system over 100 years. This model takes into account information on water consumption, costs of pipe rehabilitation and maintenance, infiltration rates, duration of pipes in different condition, and grades and costs of sewage and wastewater treatment, all to assess **service level and financial sustainability**. A case study applying this methodology in Ontario, Canada concludes that different sources of financing may induce similar life-cycle costs, but lead to different consequences for service quality and the financial burden.

Table 11

Summary of the literature review on the costs of the sewer system and main issues

STUDY	APPROACH	MAIN FINDINGS OR REMARKABLE ASPECTS
Abraham et al., 1998	Discusses several aspects of integrated sewer systems management.	The study develops an integrated methodological approach to optimize maintenance costs over the entire life cycle of a wastewater system based on the current and predicted future condition of sewers. The outcome is the optimal rehabilitation and maintenance strategy for minimizing life-cycle costs. Application of the methodology to the city of Indianapolis.
Fenner, 2000	Reviews sewer maintenance and rehabilitation strategies in several countries.	This study concludes that a cost-effective maintenance strategy combines proactive and reactive approaches. Further, the authors claim that many countries lack sufficient information on the condition of sewer systems and pipes.
Tafuri et al., 2002	Provides an overview of technical aspects and research needs concerning wastewater collection systems in the US.	The study provides technical background knowledge on maintenance and repairs, as well as on the consequences of deterioration.
Breysse et al., 2007	Develops a mathematical model for optimizing costs of sewer systems.	The model proposes a solution for insufficient information on the condition of systems.
Yeh et al., 2008	Identifies cost functions for constructing sanitary sewer systems by means of open-cut or jacking techniques based on a sample of Taiwanese networks.	The study provides an overview of several previous studies that estimate the construction costs of sewer systems.
Bester et al., 2010	Estimates capital cost functions based on a sample of South African sewerage systems.	The study provides a simplified cost function for estimating construction costs for practical application during the planning stage.
Ugarelli et al., 2010	Describes the idea of asset management applied to sewage pipelines.	The study addresses methodologies for asset management of sewer systems and their limitations. The authors use the sewage pipeline system of Oslo to show how to develop an LCC-based AM strategy.
Dogot et al., 2010	Models the total unit costs for collective sewerage systems and wastewater treatment in the Walloon Region of Belgium.	The study describes statistics and costs functions on several cost elements. These include wastewater treatment plants, the collector and sewerage system, exploitation costs of collector systems and pumping stations.
Hunter Water Corporation, 2012	Proposes a guideline for estimating O&M costs of water and wastewater systems of Hunter Water.	Even though this report is aimed at estimating the company's costs, it may provide insights on the general cost structure of sewerage systems.
Rehan et al., 2013	Develops a methodology for parameterizing a system dynamic model for simulation of the behavior of a wastewater management system over 100 years.	This study concludes that different sources of financing may induce similar life-cycle costs, but lead to different consequences for service quality and the financial burden.

Several **appropriate technologies** involve **low-cost sanitation**. These consist of excreta-disposal systems that offer different degrees of user convenience, protection against the spread of diseases and water demand for their operation. The technologies can be classified in several ways, such as whether waste disposal is on-site or off-site.

On-site sanitation systems may consist of overhung[6] latrines, trench latrines, pit latrines, Reed Odourless Earth Closets (ROEC), ventilated improved pit (VIP) latrines, composting latrines, pour-flush latrines and septic tanks. Off-site sanitation systems include those in which excreta are collected from individual toilets and carried away; vault and cartage and bucket latrine are included in this category. Some of these systems involve the use of water and are therefore classified as wet systems. Other off-site sanitation systems disallow the use of water, even for hygienic purposes, and are therefore classified as dry systems. The **Economics of Sanitation Initiative** (ESI), launched in 2007, found the economic costs of poor sanitation and hygiene was over US$9.2 billion a year in Cambodia, Indonesia, Lao PDR, the Philippines and Viet Nam. Following success in East Asia, ESI studies were completed in Africa, South Asia, and Latin America. The global economic losses associated with inadequate water supply and sanitation are estimated at US$260 billion annually (Economics of Sanitation Initiative, 2014: *http://www.wsp.org/content/economic-impacts-sanitation).* In all cases, the high costs of inadequate water supply or no treatment of wastewater should justify measures to improve supply of safe water.

3.3.2 Cost of wastewater treatment

The existing literature on the costs of wastewater treatment is quite large. However, since it reflects a variety of methodological approaches and types of costs addressed, comparability of results is limited. While some studies take into account quality parameters (the quality of influent and effluent, or pollutants removed), for example, others only focus on the volume of wastewater treated. Some studies also estimate all cost drivers of operation and maintenance, while others approximate them by estimating only energy costs. Important is to identify common indicators which allow comparisons across scales (*Murray et al*. 2011). Some studies that estimate wastewater treatment costs based on an engineering approach are described below.

Rodríguez-Garcia et al. (2011) used an engineering approach to provide insight into the relationship between wastewater treatment costs and the volume of wastewater treated or the reduction of eutrophication. The authors assessed the **operational costs** of primary, secondary and tertiary treatment of six different kinds of WWTPs based on a sample of 24 treatment plants in Spain. They categorized WWTPs according to the requirements for the effluent's quality based on the type of destination area for discharge or the reuse purpose of the reclaimed water:

T1: WWTPs that remove organic matter (OM) and discharge treated wastewater to non-sensitive areas

T2: WWTPs that remove OM and nutrients and discharge treated wastewater to non-sensitive areas

T3: WWTPs that remove OM and nutrients and discharge treated wastewater to sensitive areas

T4: WWTPs reusing treated wastewater for irrigation in agriculture

T5: WWTPs reusing treated water for industrial purposes

T6: WWTPs reusing treated water for aquifer recharge

When eutrophication reduction was chosen as the objective of reference, there was less difference in operational costs between more advanced WWTPs and less advanced ones compared to when volume treated was chosen (Figures 3 and 4). This is particularly relevant where costs of greater action are compared with the cost of lesser action for supporting a transition to better objectives. Furthermore, choosing the volume treated revealed that removal of organic matter and discharges effluent to non-sensitive areas (estimated value: €0.13/m^3) is the most economic treatment system. Conversely, when eutrophication removal was chosen as the objective of reference, the treatment system that achieved the effluent quality required for aquifer recharge was the most economic option (€0.31/kg PO_4 equivalent removed).

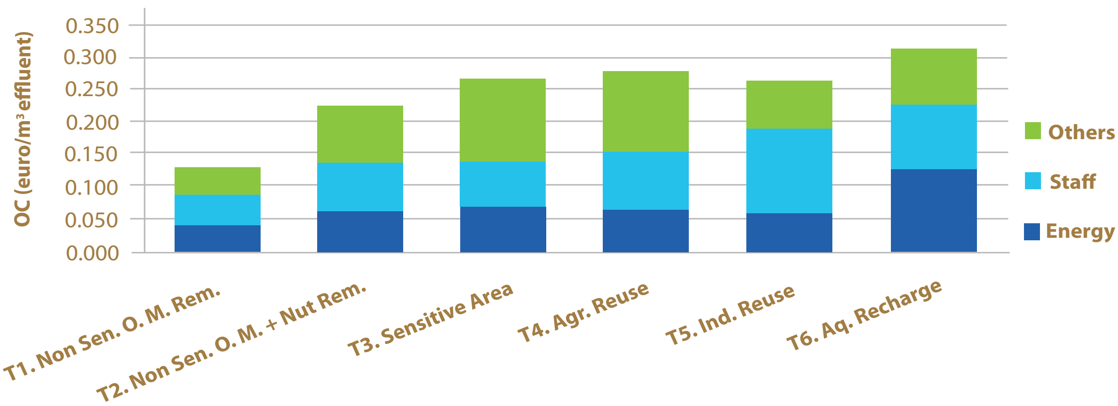
These results suggest that obtaining an effluent of higher quality (disinfected and with lower

6 A latrine sited in such a way that the excrete falls directly into the sea or other body of water.

eutrophication potential), increases both global warming potential and overall cost. Conversely, a minimal removal of organic matter led to the same eutrophication reduction in a more cost-effective way. In conclusion, for a wastewater treatment technology to be considered sustainable, it must comply with end-use objectives in terms of environmental, social and economic needs. Therefore, it is important to incorporate social variables with the already-developed approach to obtain a complete set of indicators of sustainability for each wastewater management action.

Figure 3

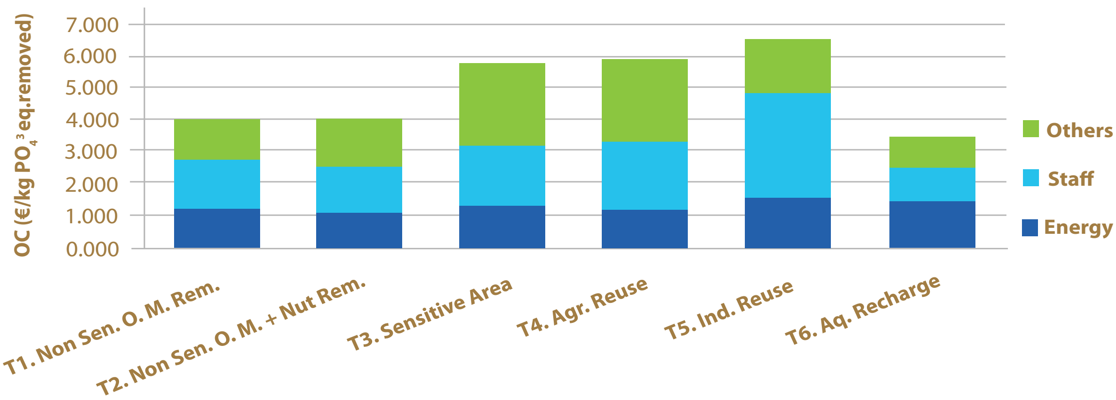
Operational cost of wastewater treatment per volume treated (€/m³)



Source: Adapted from Rodríguez-Garcia et al. (2011).

Figure 4

Operational cost of wastewater treatment per unit of eutrophication reduction (in €/kg PO_4 eq. removed)



Source: Adapted from Rodríguez-Garcia et al. (2011).

Venkatesh and *Brattebø* (2011) analyzed direct energy costs in operation and maintenance (O&M) of wastewater collection and treatment in Oslo from 2000 to 2006. On average, O&M required 0.67 kWh/m³ in 2000 and 0.82 kWh/m³ in 2006.

This increase of the specific energy consumption was due to rising consumption of electricity for aeration (for nitrogen removal), among other factors. In 2006, the annual per capita direct **energy costs of O&M** were approximately €0.8 for sewage pumping, €0.1 for wastewater pipelines and €3.8 for WWTPs.

In another study that provides insights into the energy use of WWTPs, *Lutz* (2005) analyzes energy consumption in secondary treatment using different types of aeration based on data from the US.

Molinos-Senante et al. (2010) provided information based on sample data of 22 Spanish WWTPs about their **total operating and maintenance costs** in five categories: i) energy; ii) staff; iii) reagents; iv) waste management; and v) maintenance. They identified the most important item as staff, representing one third of total costs. Maintenance and energy costs are the next in importance, representing 21 per cent and 18 per cent respectively. Waste management and reagent costs have similar percentage weights, contributing 15 per cent and 14 per cent respectively to total costs. They reported the average cost of plants with nutrient removal processes is €0.21/m^3, reducing to €0.18/m^3 if plants do not remove nutrients. Reagents are the only item in which costs differences between groups of plants that remove nutrients and those that don't are statistically significant.

Other studies have emphasized the assessment of costs based on the geographical area in which WWTPs are located. *Zessner et al*. (2010) investigated the costs of wastewater treatment in the Danube catchment for Austria, the Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria and Ukraine. They adapted existing cost functions for capital and operational costs for Austrian WWTPs for these countries using their national data. Investment costs for a WWTP able to **remove organic matter, phosphorus and nitrogen** (**CNDP**[7] plants) with a capacity of 100,000 population equivalent (p.e.) are about €250/p.e.

However, the cost for other countries is lower, 15 per cent in the case of the Czech Republic and 30 per cent for Ukraine. They also showed that investment costs for plants **without denitrification** are around 2 per cent lower. Operation costs for CNDP in Austrian WWTPs are about €11/p.e. year in larger plants (> 100,000 p.e.) and 16€/p.e. year in smaller plants (10,000 – 50,000 p.e.). In the other countries, operation costs are 18-30 per cent lower. Moreover, they also verified that annual costs of WWTPs with nitrification are 4-5 per cent lower compared to CNDP plants.

The authors conclude there are no significant differences in the annual costs of CN-plants and CND-plants.[8] Annual costs of plants with C-removal only are around 12 per cent lower compared to CNDP plants.

The assessment has shown that, for all plants in all countries, operational costs comprise 30-38 per cent of annual total costs.

Iglesias et al. (2010) analyzed the costs of suitable wastewater **treatment for water** reuse in Spain. The treatments considered in this study involve both secondary and tertiary treatment. According to the requirements of the Spanish legislation (RD 1620/2007), six wastewater treatments were defined as the following:

- **Type 1:** physical-chemical treatment with a lamella settling system[9], depth filtration[10], ultrafiltration[11] and disinfection
- **Type 2:** physical-chemical treatment with a lamella settling system, depth filtration and disinfection
- **Type 3:** filtration and disinfection
- **Type 4:** depth filtration
- **Type 5.a:** physical-chemical treatment with a lamella settling system, depth filtration, ultrafiltration, reverse osmosis and residual chlorine removal
- **Type 5.b:** Physical-chemical treatment with a lamella settling system, double depth filtration, electrodialysis[12] and disinfection. Table 12 shows investment and operation costs for each type of treatment train, calculated based on information from departments of water resources and operators of Spanish water reclamation plants. Ranges are due to the different sizes of water reclamation plants, climatic and geographical conditions and influent features.

7 Wastewater treatment plant equipped with facilities for carbon removal, nitrification, denitrification (nitrogen removal) and phosphorous removal.

8 CN plants: Wastewater treatment plant equipped with facilities for carbon removal and nitrification. CND plants: WWTP equipped with facilities for carbon removal, nitrification and denitrification (nitrogen removal).

9 Technology designed to remove particulates from liquids. It is often employed in primary water treatment using a series of inclined plates in place of conventional settling tanks.

10 This technology uses a porous filtration medium to retain particles. These filters are commonly used when the fluid to be filtered contains a high load of particles.

11 Filtration technology capable of removing very minute (ultra-microscopic) particles.

12 Technology designed to remove undesired ions from solution by means of a direct current passing between two electrodes, one on each side of the membrane.

Table 12
Establishment and operation costs for several wastewater treatment trains

TREATMENT TRAIN	ESTABLISHMENT COSTS (€/m^3 DAY)	OPERATION COSTS (€/m^3 DAY)
Type 1	185-398	0.14-0.20
Type 2	28-48	0.06-0.09
Type 3	9-22	0.04-0.07
Type 4	5-11	0.04-0.07
Type 5.a	416-736	0.35-0.45
Type 5.b	310-506	0.35-0.45

Source: Adapted from Iglesias et al. (2010).

A cost-benefit analysis of alternatives for introducing higher **standards for wastewater treatment** in Israel was developed by *Lavee* (2011). The analysis focused on the marginal costs and benefits of switching from current standards to more stringent ones. Three different standards of sanitary parameters were considered: basic, intermediate and stringent. Adoption of the intermediate standard increases costs by US\$0.10/m^3, while a stringent standard increases cost by US\$ 0.15/m^3.

Several other analyses have used the parametric approach to develop cost functions of wastewater treatment. These are based on the establishment of a functional relationship between the costs of wastewater treatment (dependent variable) and cost drivers (explanatory variables). The cost drivers considered vary among studies. For example, *Hernandez-Sancho et al.* (2011) provide a comprehensive approach for estimating cost functions of wastewater treatment. Based on Spanish data, they estimate costs (variable **C** in €/year) as a function of the volume of wastewater treated (variable ***V*** in m^3/year), the age of the plant (variable ***A*** in years) and the removal efficiency of the plants' pollutants (variables **SS**, **COD**, **BOD**, **N** and **P**) for removing suspended solids, organic components, nitrogen and phosphorus, respectively. The estimated cost functions for seven different treatment levels can be seen in Table 13.

Table 13
Examples of cost functions of different wastewater treatment systems

TECHNOLOGY	COST FUNCTIONS	R^2
Extended aeration without nutrient removal	$C = 169.4844V^{0.4540}\ e^{(0.0009A+0.6086SS)}$	0.61
Activated sludge without nutrient removal	$C = 2.1165V^{0.7128}\ e^{(0.0174A+0.15122SS+0.0372BOD)}$	0.68
Activated sludge with nutrient removal	$C = 2.518V^{0.7153}\ e^{(0.007A+1.455COD+0.15BN+0.243P)}$	0.73
Bacterial beds	$C = 17.3671V^{0.5771}\ e^{(0.1006A+0.6932COD)}$	0.99
Peat beds	$C = 1{,}510.84V^{0.2596}\ e^{(0.0171SS)}$	0.52
Biodisk[4*]	$C = 28.9522V^{0.4493}\ e^{(2.3771SS)}$	0.81
Tertiary treatment	$C = 3.7732V^{0.7223}\ e^{(0.6721COD+0.0195BN+0.7603P)}$	0.90

Source: Adapted from Hernandez-Sancho et al. (2011).

The cost functions presented in the table show the relationship for each technology between the cost of annual operation and volume treated together with the percentage of pollutants extracted and age of the plant (in some cases). The parameter that accompanies each explanatory variable illustrates the level of influence of this variable on the cost of operation. In all cases, the relevance of the treated volume is shown; the percentage of contaminants removed and the age of the plant have a very heterogeneous influence, depending on technology. Using these functions helps determine the most adequate technologies according to the volume of wastewater to be treated and the objectives set for removal of contaminants.

These results are consistent with some previous studies (*Renzetti*, 1999; *Wen* and *Lee*, 1999; *Friedler* and *Pisantly*, 2006; *Nogueira et al.*, 2009).

Using an integrated approach, *Dogot et al.* (2010) have modelled the costs of collective treatment of wastewater using both investment and operational costs. The model includes both WWTPs and collector and sewage networks. Two sets of data were compiled from the Walloon Region (Belgium). The first includes 111 WWTPs with a capacity between 250 p.e. to 390,000 p.e. and the second set of data includes 314 WWTPs (bigger than 390,000 p.e.). The authors show that both investment and operating costs are affected by **economies of scale**. In particular, the cost function obtained is given by the following relation:

$y = 10{,}027^{-0.34}$ ($R^2 = 0.75$) where y is the unit cost (per m^3 per year, say) and **x** is the nominal capacity in the same units.[13] Detailed information about investment costs was provided. In particular, equipment directly involved in wastewater treatment represents about 44 per cent of total investment costs; within this percentage, the secondary treatment alone counts for half of the costs. The same approach has been followed to estimate O&M costs. As reported by *Hernández-Sancho et al.* (2011), not only plant size but also treatment technologies have a significant impact on O&M costs. The mathematical adjustment including all WWTPs provided the following cost function:

$y = 899.8^{+0.44}$ ($R^2 = 0.59$) where y is again the unit cost and x is the nominal capacity.

In another contribution, *Tsagarakis et al.* (2003) estimate **life cycle cost** functions for wastewater treatment in Greece by means of the functional form. $y = ax^b$ The variable **y** represents costs of land use, construction and O&M costs and **x** represents the capacity of the WWTPs in terms of population equivalents. Costs of sludge management are also taken into account. Estimates are provided for three different types of primary and secondary treatment (Table 14).

13 The relationship is inverse; thus, a higher capacity implies lower cost per cubic meter.

Table 14
Examples of cost functions of wastewater treatment

WASTEWATER TREATMENT SYSTEM	COST OF LAND USE (L) (10^3 m^2)	CONSTRUCTION COST (CC) (106USD 10^{-3} p.e.)	ANNUAL O&M COSTS (C_a) (10^6USD 10^{-3} p.e.)
Conventional	$L = 0.839x^{0.722}$	$C_c = 0.116x^{0.954}$	$C_a = 0.022x^{0.672}$
Extended aeration with mechanical dewatering	$L = 0.764x^{0.810}$	$C_c = 0.206x^{0.775}$	$C_a = 0.0098x^{0.763}$
Extended aeration with air drying	$L = 1.001x^{0.820}$	$C_c = 0.153x^{0.727}$	$C_a = 0.0083x^{0.801}$

Source: Adapted from Tsagarakis et al. (2003).

Based on the indicator of total annual estimated economic costs (sum of costs for land use, construction and O&M costs), the authors found that extended aeration with natural air drying is the most economical system, followed by extended aeration with mechanical drying and conventional secondary treatment. The poor economic performance of conventional treatment in relation to extended aeration treatment is attributed to high energy costs.

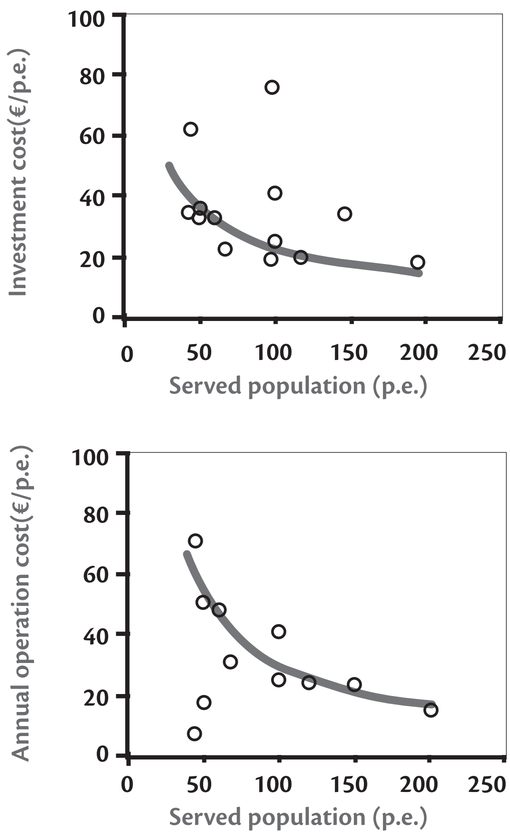
In a previous study, *Wen* and *Lee* (1999) applied a different empirical strategy. They used fuzzy regressions to estimate cost functions during the **planning stage** of WWTPs to account for uncertainty regarding actual and future costs. Estimates are based on data from municipal wastewater treatment systems in Taiwan. They indicate that total construction costs are proportional to design flow rate, treatment degree and capacity. O&M costs are only proportional to the treatment level and not to design flow or capacity. The impact of influent quality (in terms of BOD_5) on costs is reduced.

Costs of **small, decentralized, energy-saving wastewater treatment systems** are studied by *Nogueira et al.* (2009). Using data on 12 such plants that meet Portuguese standards for surface discharge, they estimate functions for investment and annual operation and maintenance costs per population equivalent.

As shown in Figure 5, both types of *per capita* costs decrease with the population size served, reflecting economies of scale.

Figure 5

Investment and operating cost in € per people equivalent



Source: Adapted from Nogueira et al. (2009).

More recently, *Molinos-Senante et al.* (2012b) collected cost functions (investment and operating and maintenance) published by *Tchobanoglous et al.* (2003), *Comas et al.* (2004) and *Ortega de Ferrer et al.* (2011). In contrast with previous studies, they focused on secondary treatment processes for small agglomerations (<2,000 p.e).

The study allows thorough comparison of costs of the selected technologies. Table 15 shows the different cost functions associated to eight wastewater treatment technologies. With respect to the cost functions for operation and maintenance, the exponent of the variable population equivalent is negative, reflecting economies of scale, i.e. a larger population equivalent means lower unit cost. These economies of scale are shown more clearly for the following technologies: trickling filter, sequencing batch reactor and pond systems. In the case of investment cost, the situation of different technologies is more heterogeneous.

PHOTO: © SUSANA SECRETARIAT

Table 15

Investment and operation costs of secondary wastewater treatment technologies (€/population equivalent)

SECONDARY TECHNOLOGY	O&M COSTS (€/p.e.)*	INVESTMENT COSTS (€/p.e.)*
Pond system	$y = 3\,897.7x^{-0.407}$; (R^2 = 0.998)	$y = 5.54x + 3\,127.5$; (R^2 = 0.991)
Intermittent sand filter	$y = 2\,115.5x^{-0.399}$; (R^2 = 0.992)	$y = 12.02x + 3\,518.9$; (R^2 = 0.992)
Constructed wetlands	$y = 947.3x^{-0.188}$; (R^2 = 0.991)	$y = 14.74x + 3\,645.1$; (R^2 = 0.994)
Trickling filter	$y = 12\,237.0x^{-0.487}$; (R^2 = 0.993)	$y = 13.50x + 6\,030.0$; (R^2 = 0.998)
Moving bed biofilm reactor	$y = 1\,187.0x^{-0.165}$; (R^2 = 0.991)	$y = 12.79x + 6\,031.0$; (R^2 = 0.985)
Rotating biological contactors	$y = 6\,931.4x^{-0.383}$; (R^2 = 0,998)	$y = 313.4x^{-0.435}$; (R^2 = 0.994)
Membrane bioreactor	$y = 5\,635.3x^{-0.352}$; (R^2 = 0.992)	$y = 30.15x + 13\,542.0$; (R^2 = 0.985)
Sequencing batch reactor	$y = 8\,258.9x^{-0.407}$; (R^2 = 0.970)	$y = 309.4x^{-0.389}$; (R^2 = 0.950)

***x** is p.e.; **y** is total cost expressed as €/p.e. and **R^2** is the determination coefficient.

Source: Adapted from Molinos-Senante et al. (2012b).

PHOTO: © NEIL PALMER (IWMI)

Molinos-Senante et al. (2013b) estimated the costs of sludge and waste management as functions of the volume of evacuated sludge, sand, solid waste and greases. They used information on 71 WWTPs with extended aeration in the Spanish region of Valencia. Sewage sludge from the WWTPs assessed in this study is used, by farmers for free, for agricultural purposes. The following cost functions are estimated:

Sludge treatment:

$C = 0.0378F - 2{,}883.4$

Waste management:

$C = 0.12585 + 0.03275F + 0.034801A + 0.01248B + 0.009358G$

Where the variable:

C indicates costs in €/year

F represents evacuated sludge in kg moisture content/year

A represents evacuated sand in kg/year

B indicates solid and similar wastes in kg/year

G represents evacuated grease in kg/year

The study concludes that sludge management is the most important cost factor in wastewater management. A ton of evacuated sludge imposes additional costs of between €32.8/year and €37.8/year.

The impact of other substances (evacuated sand, solid waste and grease) on the costs for wastewater management is of less relevance. The linear cost function indicates there are no economies of scale in wastewater and sludge management in WWTPs.

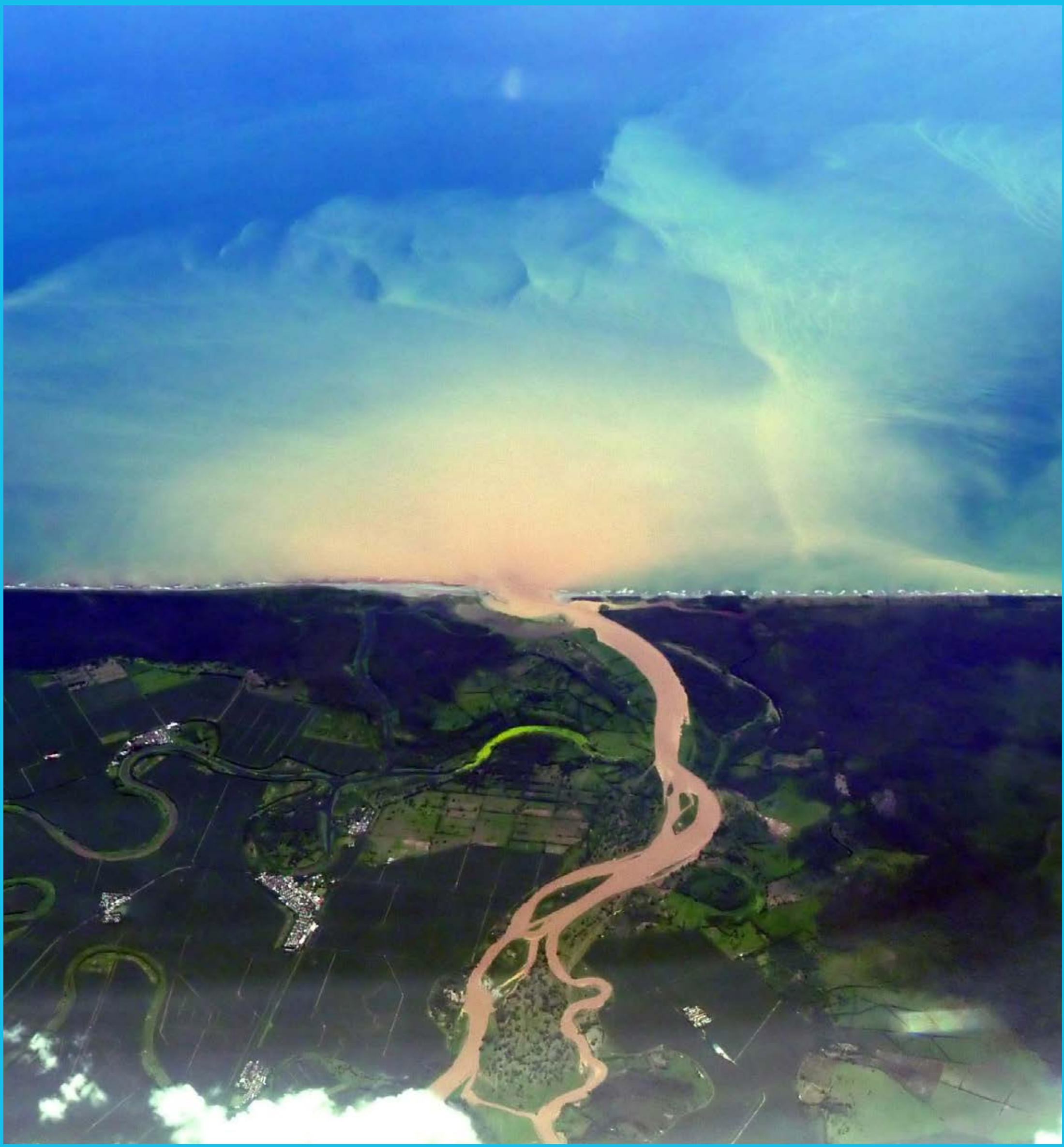
Table 16

Summary of the main findings, methods, functions and remarkable aspects about costs of wastewater treatment on the different approaches existing in the literature

STUDY	APPROACH	MAIN FINDINGS OR REMARKABLE ASPECTS
Renzetti, 1999	Estimates operational cost functions for water supply and sewage treatment based on Canadian data.	Investment and O&M costs are estimated based on input prices and a demand system.
Wen and Lee, 1999	Estimates cost functions for wastewater treatment systems in planning stage through fuzzy regressions.	Results indicate that total construction costs are proportional to design flow rate, treatment degree and collection area. O&M costs are only proportional to the treatment level and not to the design flow or collection area.
Tsagarakis, 2003	Estimates life-cycle cost functions of WWTPS in Greece. The study considers costs of sludge treatment and disposal.	Life-cycle cost functions are estimated separately for land usage, construction costs and O&M costs. Results indicate that the most cost-efficient system is extended aeration with natural air drying, while conventional systems are the least economical ones.
Renzetti and Kuschner, 2004	Provides full-cost accounting of water supply and wastewater treatment.	The assessed full costs include capital costs, energy costs, costs of raw water abstraction and costs of changes in water quality of receiving waters. A main conclusion is that full costs are underestimated since so-called social costs are not included in calculations.
Nogueira, et al., 2009	Estimates cost functions of investment and O&M costs of small decentralized energy saving wastewater treatment systems.	Results indicate the existence of economies of scale for O&M costs.
Rodriguez-Garcia et al., 2011	Analyzes cost of primary, secondary and tertiary treatment for six different types of WWTPs.	Operational costs depend on the choice of the objective of reference. When choosing eutrophication reduction as objective, the difference in operational costs between more advanced WWTPs and less advanced ones is lower than when choosing the volume treated.
Venkatesh and Brattebø, 2011	Analyzes energy costs in O&M costs of wastewater collection and treatment.	The study provides information on the electricity consumption of the water supply and wastewater treatment system of Oslo from 2000-2006.
Hernandez-Sancho et al., 2011	Estimates cost functions for seven different types of WWTPs based on Spanish data.	Total annual costs as a function of volume of wastewater treated, age of the WWTPS and pollutant efficiency removal are estimated.
Drechsel and Seidu, 2011	Comparing the costs and cost-effectiveness of treatment and non-treatment options for wastewater irrigation in Ghana.	On- and off-farm risk reduction options appear highly cost-effective, although only a few are likely to avert more than 80% of the disease burden.
Molinos-Senante et al., 2013b	Estimates cost functions for sludge and waste management in WWTPs.	Costs of sludge and waste management are modelled as a function of the volume of evacuated sludge, sand, solid waste and grease. Results show that sludge management is the most important cost factor in waste management.

4

COMPARISON OF COST OF ACTION AND COST OF NO ACTION



COMPARISON OF COST OF ACTION AND COST OF NO ACTION

4.1. Methodology

Estimates for the costs of action and no action (benefits not achieved) over the lifespan of the programme must account for the time component. Costs and benefits not achieved must be quantified for each year included in the analysis. As shown in Figure 6, the net present value (NPV) of the wastewater management project considers the first cost or investment cost at the very first stage of the life cycle; it considers that operating costs and benefits accrue during the lifespan; and it considers salvage value at the end of life of each facility. It is also assumed that most benefits are quantifiable, if the appropriate calculation is made.

Figure 6
Time location of costs of action and avoided benefits for no action

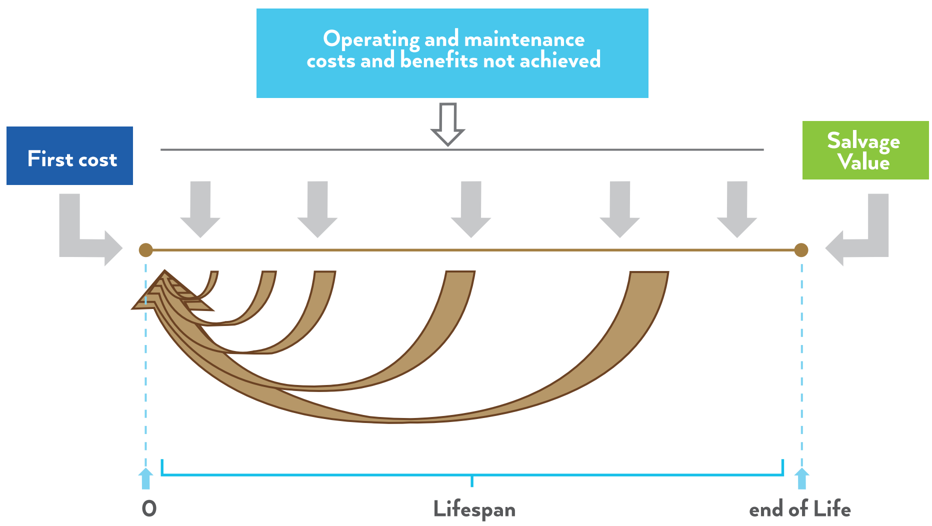
The NPV and, therefore, the economic feasibility of the project is calculated using Equation (1):

$NPV = \sum_{t=1}^{T} \frac{NP_t}{(1+r)^t}$ (1), where NPV is the net present value; NP_t is the net profit at time t; r is the discount rate and T is the project lifespan.

An intervention is economically feasible only if NPV >0, i.e. the intervention benefits outweigh the costs. If NPV <0, the costs exceed benefits, and the intervention is not economically feasible. Implementation may be justified by other factors, including social benefits, but not from an economic point of view. The best economic options offer the greatest NPV. A second choice for selecting the best alternative within a group is to produce a benefit–cost ratio; and the preferred option is the one with the highest benefit to cost (*Molinos-Senante et al.*, 2012a). Once the feasibility of the project has been justified, a financial analysis determines whether it can meet the costs of investment and under what conditions.

As it is known in Eq. (1), the NPV is estimated through the application of a discount rate. In this sense, the discount rate reflects that people generally prefer having money in the present rather than in the future. Thus, future costs have a lower value than those in the present. One difficulty in calculating the present value of an item is to obtain an appropriate value for the discount rate. The most used in the literature are 1 and 3 per cent.

Given that water reuse is a fundamental non-conventional water resource in water scarce areas, *Molinos-Senante et al.* (2011a) carried out a CBA of some water reuse projects developed in Spain.



Source: Elaborated from Termés-Rifé et al. (2013).

In doing so, and as a novel aspect, they considered in the assessment framework both market impacts and non-market impacts represented by environmental effects of the water reuse. An important conclusion of this study is that integrating only market impacts undermined the economic feasibility of some projects. However, if the external benefits (environmental benefits) are also incorporated, the economic feasibility analysis provided positive results for all water reuse projects evaluated. In addition, the robustness and reliability of the methodology applied for the quantification of environmental benefits is key to ensuring the credibility of the study.

Life-cycle cost (LCC) calculated for private investments considers discount rate values closely related to real market interest rate. In this way, it reflects opportunity costs in financial markets (*Howarth*, 1996); the main aim of LCC is to help decide whether a project is profitable. For projects that last a long time, common sense recommends using lower discount rates than in projects with a shorter lifespan. A long-term project may use a declining value for the discount rate at different time periods. Good discussions on discounting can be found in *Swarr et al*. (2011) and *Ciroth* (2011). *Pearce et al*. (2003) propose an alternative approach for a declining discount rate that replaces the exponential discount factor with a hyperbolic function.[14] This improves the viability of projects in which the costs occur early in the time horizon. Weitzman (2001) and *Guo et al*. (2006) provide more details about this approach. In another approach, *Almansa* and *Martínez-Paz* (2011) suggest a dual-rate discount rate that employs different discount rates for tangible and intangible goods. An appropriate discount rate can be determined by the Delphi method, i.e. consulting individually and anonymously a panel of experts (*Almansa and Martínez-Paz*, 2011).

A sensitivity analysis measures the impact of changing one or more key input values on the study result. As stated above, values in many components of costs and benefits may vary greatly due to uncertainty or lack of information about the future. Thus, the variability of items of the NPV in different scenarios should be analyzed to assess uncertainty and confidence in the final results. Different approaches can quantify uncertainty, such as Bayesian network models, Monte Carlo simulations or tolerance models, among others. In any case, the simplest approach is "ceteris paribus", in which all variables of the study remain constant, except the variable to be evaluated. *Molinos-Senante et al*. (2013b) analyze the economic feasibility of five technologies for wastewater treatment for small communities and show the discount rate is the most important source of uncertainty. They use the "ceteris paribus" approach with two discount rates, 2.5 per cent and 5.0 per cent, to assess the influence of uncertainty in the net profit of the projects.

14 It is a function of an angle expressed as a relationship between the distances from a point on a hyperbola to the origin and to the coordinate axes.

4.2. Comprehensive empirical applications

4.2.1 Extensive wastewater treatment: Cost of action vs cost of inaction in a hypothetical case

In the context of developing countries, extensive technologies[15] are generating interest as they are more environmentally friendly than intensive technologies (*Libhaber and Orozco-Jaramillo*, 2013). Moreover, the operation of extensive technologies requires fewer human resources and less energy consumption than intensive systems. Energy consumption is not only a key cost factor but also has environmental (emission of greenhouse gases) and risk implications especially in locations where electricity supply is not continuous (*Murray and Drechsel*, 2011). Hence, minimizing energy consumption in WWTPs is important for their functionality and ability to safeguard human health and the environment (*Molinos-Senante et al*., 2013b). In this sense, for many developing countries, extensive technologies are considered more suitable than intensive ones.

Pond systems (PS) and constructed wetlands (CW) are two of the commonly used extensive technologies. PS are artificial lagoons that treat wastewater by natural processes such as the influence of solar radiation, wind, microorganisms and algae. In a CW, wastewater is pre-treated by filtration and settling, followed by bacterial decomposition in (possibly natural-looking) lined marshes.

15 In extensive treatment processes, a long retention time ensures the purification; this requires more space compared to intensive technologies. However, extensive technologies are in general low-cost, low-energy and low-maintenance treatment processes.

The economic feasibility of the two extensive technologies previously described (PS and CW) is assessed in a hypothetical scenario using a CBA. This includes the economic value of the externalities associated with wastewater treatment, and the cost of action (investment and operation) estimated using cost functions. Externalities associated with wastewater treatment, both positive and negative, have been integrated into the economic assessment, where positive externalities are represented by environmental and health benefits, and GHG emissions are considered the negative externalities. The results of the CBA are expected to be of great use for decision makers regarding wastewater treatment systems in developing countries were water tariffs alone might not pay for the investment.

To provide general insights that may apply to other decentralized treatment opportunities in developing areas, the calculation assumes a population of 1,500 people equivalent (p.e) with an average flow rate of wastewater at 250 m^3/day.[16] The characteristics of the wastewater in this scenario might be adapted easily for the economic assessment at other scales. Designating the lifespan of a wastewater treatment system is always controversial because it depends on many factors, including maintenance of the facilities. Previous studies have not used any single model lifespan but rather different values based on technologies evaluated. Following *Molinos-Senante et al*. (2013b), and taking into account that technologies evaluated are extensive ones, a lifespan of 25 years has been assumed. Estimating the NPV of each alternative requires a discount rate for upgrading both costs and benefits. To minimize uncertainty, two discount rates (2.5 per cent and 5.0 per cent) have been used.

4.2.1.1 Cost of action

The cost of the action integrates three items: i) investment costs; ii) operation and maintenance costs; and iii) economic value of GHG emissions (public externality).

The market determines the two first costs, which have been estimated using the cost functions. As shown in the previous section, many studies have been developed in this topic so several options are available. For this case study, the cost functions reported by *Ortega de Ferrer et al*. (2011) and *Comas et al*. (2004) have been used since they were developed specifically for small communities and are adaptable to estimating wastewater treatment costs in developing countries. The cost functions used, shown in Table 17, allowed investment and maintenance costs to be quantified for the two technologies evaluated where y is the total cost expressed in €/p.e and x is p.e; investment costs and operating costs are in €.

Table 17

Cost functions for investment and operation costs

TECHNOLOGY	INVESTMENT COST	OPERATION COST
Pond system	$y = 3\,897.7x^{-0.407}$	$y = 5.543x + 3\,127.5$
Constructed wetlands	$y = 947.3x^{-0.188}$	$y = 14.749x + 3\,645.1$

Source: Ortega de Ferrer et al., (2011) and Comas et al., (2004.)

Following Molinos-Senante et al. (2013b), GHG emissions were assessed based on the energy demand of WWTPs. Using 100-year global warming potential coefficients (IPCC, 2007), GHG emissions were converted to equivalent CO_2 emissions. The market price of CO_2 emissions paid through the European Union's Emissions Trading System17 was used to translate CO_2 emissions (physical units) into monetary values. The market price of CO_2 was assumed to be €13.4/ton for the next 25 years, i.e. that the value of the externality represented by each ton of CO_2 emitted to the atmosphere would be €13.4.

Table 18 presents investment costs, operation and maintenance costs and GHG emissions costs with respect to the two discount rates for the two wastewater treatment systems assessed. This specific study illustrates that PS are more expensive than CW from the investment point of view, while operating costs are quite similar. Interestingly, the contribution of the cost of GHG emissions to operation costs is negligible (0.01%).

16 25 For developed countries, the typical flow rate for a population of 1,500 people equivalent is 400 m3/day. Since the empirical application has adapted for developing areas, a lower flow rate (250 m3/day) has been considered.

17 In the context of the Kyoto Protocol, a well-organized emissions trading system has been developed. In this study, data from the European trading system were used, although data from other markets might also be used.

Table 18
Investment costs, operation and maintenance costs and total costs for two discount rates

	COST OF ACTION		TOTAL COSTS FOR ALL LIFESPAN (€)	
TECHNOLOGY	INVESTMENT COST (€)	OPERATION COST (€/YEAR)	r = 2.5%	r = 5.0%
PS	205 000	28 000	838 000	756 000
CW	372 000	29 000	1 186 000	940 000

Source: Own calculations (F. Hernández-Sancho)

Once the cost of the action has been quantified, the next step is to calculate the costs of no action, equivalent to the benefits of treating wastewater. The net present value of wastewater treatment systems provides means for assessing the economic feasibility of the two wastewater treatment systems.

4.2.1.2 Cost of no action

The cost of no action integrates environmental and health effects arising from not treating wastewater. It is equivalent to the environmental benefits from preventing the discharge of pollutants into the environment. These were estimated based on the shadow price values obtained by Hernández-Sancho et al. (2010) (See Table 2). The total economic value of environmental benefits resulting from wastewater treatment (€/year) was based on the volume of pollutants removed by treatment (kg/year) and their shadow prices (€/kg). Taking into account the lifespan of the WWTPs (25 years) and the two discount rates (2.5 per cent and 5.0 per cent), the environmental benefits were expressed as a present value (€) (Table 19).

Table 19
Environmental benefits for the two wastewater treatment systems evaluated

	ENVIRONMENTAL BENEFITS (€/YEAR)					ENVIRONMENTAL BENEFITS FOR ALL LIFESPAN (€)	
	SS	COD	N	P	TOTAL	r = 2.5%	r = 5.0%
PS	100	5 000	35 000	14 000	54 500	1 200 000	920 000
CW	100	5 500	46 000	14 000	66 000	1 450 000	1 300 000

Source: Own calculations (F. Hernández-Sancho)

Economic valuation of the health effects associated with wastewater treatment used the approach reported by *Hutton* and *Haller* (2004) and related figures compiled by *Edwards* and *Cameron* (2011) on health benefits for sub-Saharan Africa from meeting the year 2015 MDG targets for sanitation. The authors estimated that annual health system and patient costs saved plus the value of time saved by reducing illness would be US$0.45 billion and US$0.72 billion (€0.33 billion and €0.53 billion) per year respectively for a population of 315 million people. Based on these figures and considering the case study assumes a wastewater treatment system for a 1,500-people agglomeration, total health benefits would be around US$5,500 per year (€4,100 per year)[18].

As was done for costs and environmental benefits, the value of the health effects is updated for the 25-year lifespan of the wastewater treatment project using the two discount rates. This yields estimated economic value for the health effects (benefits) of €77,000 at a discount rate of 2.5 per cent and €59,000 at 5.0 per cent.

Table 20 shows total benefits (costs of no action) associated with implementation of the two wastewater treatment systems evaluated. The main contributor to total benefits associated with wastewater is the environmental benefits. Nevertheless, as the size of the population increases, the health benefits will increase; environmental benefits will remain constant.

18 A more thorough valorization should be based in each case on national data

Table 20

Environmental, health and total benefits for implementing each of the wastewater treatment systems evaluated

	ENVIRONMENTAL BENEFITS FOR ALL LIFESPAN (€)		HEALTH BENEFITS FOR ALL LIFESPAN (€)		TOTAL BENEFITS FOR ALL LIFESPAN (€)	
	r = 2.5%	r = 5.0%	r = 2.5%	r = 5.0%	r = 2.5%	r = 5.0%
PS	1 200 000	920 000	77 000	59 000	1 280 000	980 000
CW	1 450 000	1 310 000	77 000	59 000	1 530 000	1 370 000

Source: Own calculations (F. Hernández-Sancho)

4.2.1.3 Economic feasibility

Once both cost of action and cost of no action (benefits) have been quantified and updated, the net present value associated with the two technologies evaluated can be calculated.

Table 21 shows the two technologies, PS and CW, are feasible since their net present value is positive. Therefore, applying the methodology to calculate the environmental benefits shows the feasibility of extensive technologies for treating wastewater from an economic point of view.

Table 21

Total benefits, total costs and net present value of implementing the two wastewater treatment systems evaluated

	TOTAL BENEFITS FOR ALL LIFESPAN (€)		TOTAL COSTS FOR ALL LIFESPAN (€)		NET PRESENT VALUE (€)	
	r = 2.5%	r = 5.0%	r = 2.5%	r = 5.0%	r = 2.5%	r = 5.0%
PS	1 280 000	980 000	838 000	756 000	442 000	224 000
CW	1 530 000	1 370 000	1 186 000	940 000	344 000	430 000

Source: Own calculations (F. Hernández-Sancho)

4.2.1.4 Conclusion and recommendations

The empirical application developed in this hypothetical study evaluates the economic feasibility of implementing two extensive technologies — pond systems and constructed wetlands — for treating wastewater from small settlements of developing areas, where extensive technologies are usually more suitable and cost effective. The results confirm that implementing either technology may be economically feasible with benefits of higher value than costs. Further studies will be required to assess economics of scale for such comparisons to provide more detailed information about both costs and benefits for various settlement sizes and other treatment options.

As is known, wastewater treatment is desirable since it provides environmental and health effects. However, and due to the difficulty of their quantification, economic arguments are not available to decision makers to support investments in sanitation and wastewater treatment. Methodologies that help quantify these externalities, especially environmental and health, should continue to be developed. They should be associated with the processes of wastewater treatment to ensure the feasibility studies of any investment will be realistic and reliable.

4.2.2. Case study about cost-benefit of wastewater for irrigation in Haroonabad, Pakistan

Farmers in urban and peri-urban areas of nearly all developing countries who need water for irrigation often have no other choice than wastewater (*Qadir et al.*, 2010; *Fuhrimann et al.*, 2014). This practice, however, can severely harm human health and the environment (*Qadir et al.*, 2007). Generally, farmers irrigating with wastewater have higher rates of parasite (i.e. helminth) infections than those using freshwater, but there are exceptions (*Trang et al.*, 2006). In addition, skin and nail problems may occur among farmers using wastewater (*Trang et al.*, 2007). Post-harvest contamination in markets can be an important factor affecting public

health, but the significance varies depending on the level of on-farm contamination (*Amoah et al.*, 2011; *Ensink et al.*, 2007). This makes it an often neglected of overseen issue in the wastewater discussion (*Qadir et al.*, 2010).

The case study analyzed by *Van der Hoek et al*. (2002) focused on Haroonabad (Pakistan). The assessment of costs and benefits of wastewater agriculture focused on a sample of 40 farms. Half of them used wastewater as their source of irrigation water and the other half used canal water and occasionally groundwater. This study showed that costs of irrigation water were higher for the canal-irrigators than for the wastewater irrigators mainly because of the high cost of pumping groundwater.

However, differences in costs for items such as seeds, land preparation or farmyard manure led to no significant difference in the total cost of either type of irrigation. Nevertheless, other studies developed for this country (*Buechler et al*., 2006; *Saravanan et al*., 2011) illustrated that farmers irrigating with wastewater earned between $US300-600 per year more than their counterparts who did not use wastewater. These results are in line with those obtained in Kumasi, Ghana, where farmers with access to (polluted) water earned about two to four times more than their counterparts who had no access to water (*Drechsel and Keraita*, 2014)

Van der Hoek et al. (2002) also highlighted that wastewater had levels of E. coli and worm eggs exceeding the international standards for irrigation and could pose a potential risk to human health. Usually, nutrients such as nitrogen, phosphorus and potassium are beneficial to plants. However, in this case study, the level of nitrogen in the wastewater was too high and could lead to excessive vegetation growth. This is an example of negative externality associated to the use of wastewater. Concentrations of other pollutants such as heavy metals in the soils of the wastewater-irrigated fields were found to be similar to those of normal soil; hence, they were unlikely to affect crop production. Other studies revealed that in Pakistan, overuse of wastewater with insufficient drainage — as with freshwater irrigation — produced signs of degradation of the soil structure and soil salinity; delays in emergence of wheat and sorghum may be due to excess nutrients (*Saravanan et al*., 2011).

Finally, the assessment of human health impacts revealed that members of families who were irrigating

their land with untreated wastewater around Haroonabad had a significantly higher occurrence of diarrheal diseases than those who irrigated their land with canal or tube-well water (*Van der Hoek et al*., 2002). In the same line, the case of Musi River in India revealed the transfer of metal ions from wastewater to cow's milk through grass fodder irrigated with wastewater. Milk samples were contaminated with different metal ions ranging 12-40 times above permissible levels (*Minhas and Samra*, 2004). These are some examples of negative externalities that should be quantified and incorporated in the cost-benefit analysis.

4.2.3. The economics of water reuse projects: some empirical applications

In Europe, *Verlicchi et al*. (2012) and *Heinz et al*. (2014) estimated costs and benefits associated to Italian and Spanish water reuse projects, respectively. *Verlicchi et al*. (2012) studied the feasibility of reusing reclaimed wastewater at the municipal treatment plant of Ferrara in the Po River basin in northern Italy. The economic valuation of the project focused on the following items: construction, operational and maintenance costs, and environmental and social benefits. Around 170 l/s of wastewater would be reused, and the treatment process involved rapid filtration, horizontal subsurface flow bed and lagooning. The project had four main benefits: (i) agricultural benefit derived from the reuse of reclaimed wastewater; (ii) environmental benefit for the quality of the Po di Volcano canal; (iii) financial benefit for the water management body through reduced energy consumption; and (iv) recreational benefits for the users of the park resulting from the creation of ponds for regenerating the wastewater. Table 22 shows construction, operation and maintenance costs for wastewater regeneration, as well as values of such benefits.

Table 22
Costs for regenerating wastewater and benefits of wastewater reuse at Ferrara WWTP

Construction costs	€15 310 000
Operation and maintenance costs	€361 000/year
Agricultural benefits	€1 106 100/year
Environmental benefits	€5 332 000
Financial benefits	€200 000/year
Recreational benefits	€3 485 000

Source: Verlicchi et al. (2012).

Assuming a discount rate of 5 per cent and the 20-year lifespan of all treatment stages, the estimated net present value is €40,000 and the benefit-cost ratio is 1.007. The feasibility of the project was not guaranteed as the value of the NPV is relatively small and therefore very sensitive to changes in assumptions. A Spanish case study evaluated by *Heinz et al.* (2014) was the water reuse project at the Llobregat Delta in Catalonia. It involved two WWTPs at El Prat de Llobregat (120 Mm^3/year) and Sant Feliu de Llobregat (26 Mm^3/year). Table 23 shows key data (costs and benefits) determined in this case study.

Table 23
Costs and benefits of water reuse project at the Llobregat Delta

CHARACTERISTICS	EL PRAT	SANT FELIU
Irrigated farmland (ha)	801	275
Effluent volume applicable for irrigated agriculture (Mm^3/yr)	13.0	7.3
ANNUAL COSTS...	**M€/YR**	**M€/YR**
Cost of new treatment units	1.09	0.08
Operation and maintenance cost of treatment	2.6	0.51
Cost of conveying effluents	0.12	0.20
Cost of conveying water released for urban use	1.43	0.81
Total cost of water reuse and exchange (A)	5.24	1.60
... and annual benefits		
Value added to agriculture	0.35	0.46
Value of water exchanged for city use	14.43	8.12
Total economic benefit of water reuse and exchange (B)	**14.78**	**8.58**
Total value added of water reuse and exchange (B-A)	**9.54**	**6.98**
Unit costs and benefits	€/m^3	€/m^3
Unit cost of water reuse and exchange	0.40	0.22
Unit total economic benefit for agriculture and city (€/m^3)	1.14	1.17
Unit cost/benefit ratio	**2.85**	**5.3**

Source: Heinz et al. (2014).

From this table we learn most reclaimed water on yields and sales revenues is dominant in the area of Sant Feliu de Llobregat. The main reason is the option to abandon rain-fed farming and to use reclaimed water instead. According to agricultural statistics, irrigated horticultural crops and tree crops render significantly more yields than rain-fed cultivations.

With regard to cost savings in pumping conventional waters, strong influences on the cost effectiveness of irrigation can be expected at the two sites. The use of reclaimed water would lead to a reduction of groundwater use by more than 50 per cent. In particular, the abandonment of the extraction of river water would particularly be a cost-effective option in the area of Sant Feliu de Llobregat.

The influence of using reclaimed water on cost savings in fertilization is less dominant compared to the impacts on sales revenues and freshwater pumping costs. Cost saving in fertilization contributes less than 10 per cent to the farmers' income at each of the sites. In terms of improved agricultural productivity, significant impacts resulting from use of reclaimed water can be expected in the area of Sant Feliu de Llobregat; in the most cost-effective strategy, reclaimed water could replace both river water and groundwater due to the considerable potential cost savings in freshwater pumping and fertilization alongside a high increase in sales revenues. In the area of El Prat de Lobregat, the impact on agricultural productivity will be moderate. At this site, cost savings in groundwater pumping plays the major role, whereas no significant increases in yields and sales revenues are expected.

Another Spanish case study was the Platja D´Aro area water reuse project (*Heinz et al.*, 2014). The Catalonian Water Authority planned to enlarge tertiary treatment capacity by 3.2 m^3/yr. This will be allocated as 39 per cent to agriculture, 10 per cent to municipalities, 20 per cent to the golf courses and 31 per cent as ecological water. Table 24 shows the potential economic benefit for agriculture and urban and other users.

Table 24

Costs and benefits of the water reuse project in the Platja d´Area area

Annual costs	**M€/yr**
Annual capital cost of new water-treating units, pumping stations, pipelines and reservoirs	0.60
Incremental O & M costs of treatment, pumping and conveyance	0.48
Total cost of water reuse and exchange (A)	**1.08**
Annual benefits	**M€/yr**
Increased farm-sales revenue due to expansion of farmland	0.87
Farmers' saving in pumping groundwater and fertilizing	0.14
Total added value in agriculture	**1.01**
Value of groundwater released for municipal and other users	1.03
Total economic benefit of water reuse and exchange (B)	2.04
Total added value of water reuse and exchange (B-A)	0.96
Unit costs and benefits	**€/m³**
Unit cost of water reuse and exchange	0.33
Unit benefit of water reuse and exchange	0.92
Unit cost/benefit ratio	3.1

Source: Heinz et al. (2014).

In this area, farmers are increasingly interested in replacing groundwater by reclaimed water as a cheaper and more productive source for irrigation. The prevention of yield losses and the expansion of farmland due to improved water availability can be the major causes. The increase in crop yields and sales revenue have a far greater economic significance than the reduction of fertilizer use. At the Platja d'Aro site, the economic net benefit remains positive due to the significant added value in agriculture caused by high increases in yields and cost savings in pumping conventional water. The option to save pumping cost and cost of fertilizing make reclaimed water an economically competitive resource for irrigation.

Heinz et al. (2014) studied the economics of a Mexican case (Durango City and Guadalupe Victoria irrigation module). The farmers agreed in 1999 to use effluent from the Durango WWTP for irrigation during times of drought. In 2000, a connecting pipe was built from the WWTP to convey 10 Mm^3/year of reclaimed water. The costs of such investment was €9.0 million, i.e. €0.57 million/year over a 15-year lifespan.

The costs of pumping reclaimed water to the field are considered insignificant because of the use of gravity irrigation. No investment cost for wastewater treatment arises as the quality requirements for the reclaimed water are the same as applied to regular discharge effluents. The use of reclaimed water increased production of corn, alfalfa and oats by about 30 per cent. The cost savings in fertilizer, which considerably surpass the total cost of reclaimed water, were estimated at €165,000/year. Additional benefits such as mitigating the overexploitation of aquifers should be considered as well.

4.2.4. Public perception about sanitation, wastewater treatment and water reuse

The study by Ali and Stevens (2009) summarized the experience of practical action in promoting water, sanitation, waste and hygiene-related infrastructure and services in the municipality of Faridpur, Bangladesh. The first step of the project was to identify people's priorities. As shown in Table 25, the top priorities were often to improve basic access to a safe water supply, environmental sanitation and proper waste collection.

Table 25
Priority needs in Faridpur, Bangladesh

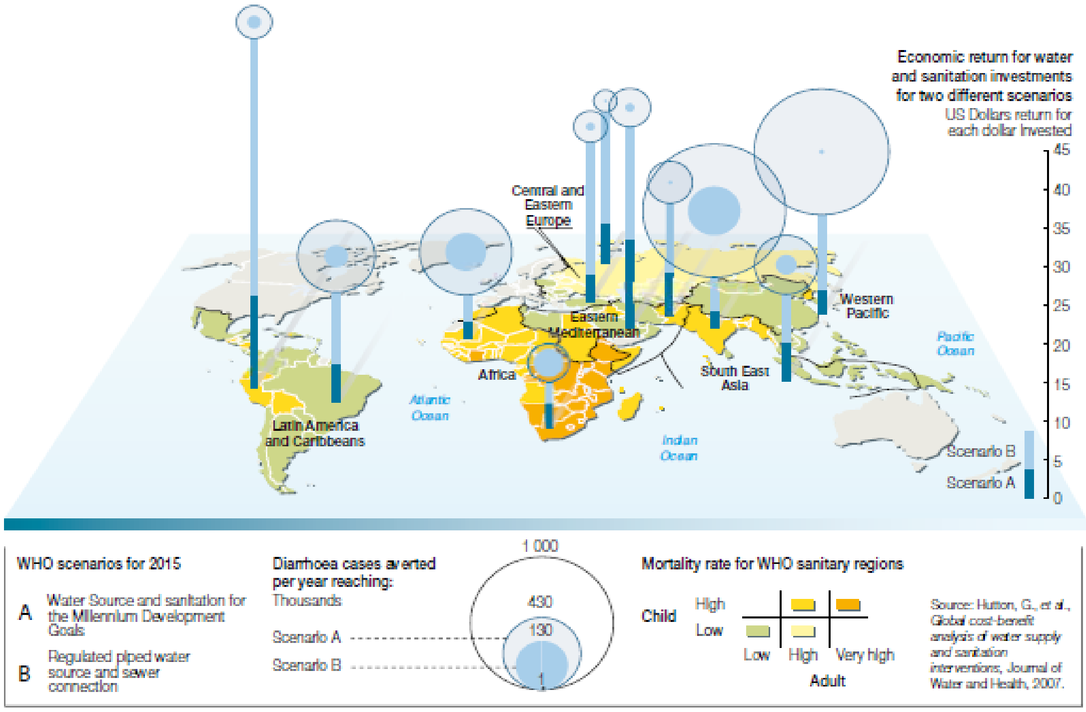
Priority need	Average score on scale 1–10
Safe water supply	9.4
Environmental sanitation	8.1
Waste disposal	6.0
Internal walkways	5.8
Lack of knowledge on hygiene	5.1
Unemployment	4.0
Water logging	3.8
Housing	3.3
Land tenure	2.8
Eviction	2.3
Municipal tax	0.9
Electricity	0.5
Education	0.4
Basic health services	0.1

Source: Ali and Stevens (2009).

Weldesilassie et al. (2009) used the contingent valuation method (CVM) to assess the value farmers from Ethiopia attach to safe use of wastewater for irrigation. The case study focused on two groups of farm households located around the city of Addis Ababa, namely wastewater and freshwater users. The CVM survey showed wastewater can have a significant return compared to freshwater in irrigation (WHO scenario A), and also have health benefits. A total of 415 sample households were included in the survey, of which 175 were freshwater farms and 240 were wastewater farms. They were given the choice between two government policy options. The first option would focus on advantages to the farmers by introducing a safe wastewater irrigation practice. The second option would address the polluters´ side by implementing a government programme to enforce existing anti-pollution laws. Averting diarrhoea cases and time saved (increased productivity) are shown in Figure 7.

Figure 7

Wastewater, health and human well-being: Investing in water supply and sanitation



Source: Data from Hutton et al. (2007).

Results of the survey by *Weldesilassie et al.* (2009) showed that farmers perceive the benefits of using wastewater for irrigation outweigh the health hazards. On the other hand, about 21 per cent of wastewater farmers and 31 per cent of freshwater farmers perceived that the irrigation water affected their health. Regarding the two policy options, the second ("forcing emitters to comply with existing environmental regulations") was the most preferred (40 per cent), while about 21 per cent of wastewater farmers preferred the first option ("awareness promotion on the methods of safe use of wastewater").

Finally, about 38 per cent of farmers preferred that both options were implemented jointly. Moreover, 90 per cent of wastewater farmers were willing to help improve the existing situation and make wastewater irrigation safer. On the other hand, 7.5 per cent of wastewater farmers responded negatively to the improvement programme.

Regarding the willingness to pay (WTP) for an improvement programme for wastewater reuse, the mean value was ETB19 39.57 per ha per year.

This means an average farm household was willing to pay 0.37 per cent of its annual farm income for the improvement programme. The total WTP of the wastewater and freshwater farm population in the study area for the policy programmes investigated was around ETB 92,965 per year.

Ndunda and *Mungatana* (2013) evaluated farmers' WTP for wastewater treatment by using a discrete choice experiment. There is a need for the municipality of Nairobi to invest in improved treatment of wastewater generated from Kibera informal settlements before it is discharged into Motoine-Ngong River.

The researchers selected a sample of 280 urban and peri-urban farmers from the area. Results illustrated that about 45 per cent of urban farmers were aware of health and environmental risks associated with wastewater irrigation. Also, about 36 per cent of farmers involved in urban wastewater irrigation have adopted low-cost measures to reduce associated health and environmental hazards.

Results revealed by *Ndunda* and *Mungatana* (2013) showed that urban and peri-urban farmers have positive WTP for an increase in treated wastewater quality, treated wastewater quantity and ecosystem

19 At the time of survey, US$1 = ca. 8.65 ETB.

restoration. In particular, average households are willing to pay Kshs[20] 51.0 monthly in municipal taxes to ensure that wastewater is treated before being released into the Motoine-Ngong River. Also, they are willing to pay about half (Kshs.22.18) as much to ensure the riverine ecosystem restoration.

These studies, which show a positive WTP for proper management of wastewater, indicate the awareness of stakeholders about the risks and negative impacts on health and the environment from untreated wastewater. These results place a value on the cost of no action from the stakeholders' point of view. Once this information is known, authorities should quantify the cost of the needed investments (cost of action) for wastewater treatment facilities. Although it is unlikely that the cost of action can be covered by the proposed "willingness to pay", the different value propositions of treatment with opportunities for recovering water, energy and nutrients while reducing pollution of surface water and groundwater, are in most cases exceeding the investment and operational costs (AQUAREC, 2006; *Hanjra et al.*, 2015).

However, a note of caution is needed. Many studies have shown that especially where risk perceptions are well established, early stakeholder involvement in any decision making on water reuse will be crucial for its acceptance, independently of any evidence of economic benefits or cost savings (*Guest et al.*, 2009).

20 At the time of survey, US$1 = ca. 82 Kshs.

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5
CONCLUSION

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CONCLUSION

To reverse current trends, and prevent and address the negative consequences from untreated wastewater, many countries should invest in wastewater management systems, especially developing countries. Several criteria could be adopted for decision making. However, the economic criterion, which considers overall costs and benefits for society, is needed to support public policy decisions for investments in this area.

Wastewater management is a socially desirable and economically rewarding option. It provides many public benefits, including those related to health and the environment, which must be considered in the decision-making process. Among the methodologies that can assess the economic feasibility of wastewater management projects, the cost of no action versus cost of action (CNA-CA) approach is expected to be useful for decision makers in developing countries.

PHOTO: © FASSEH SHAMS/IWMI

6
RECOMMENDATIONS

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RECOMMENDATIONS

1. **Pursue additional efforts to estimate both the cost of action and the cost of no action in developing countries.**

To promote wastewater management programmes in developing countries, their economic feasibility must be assessed. To that end, the general CNA-CA estimates should be adapted for each case study to take into account their peculiarities.

The proposed methodologies should not only be rigorous and credible; they must also be easily applied. Certainly, one major drawback to applying these methodologies is the potential difficulties associated with calculating the costs and benefits analyzed and the comparability of different valuation approaches. The design of a Decision Support System (DSS) could be an effective tool to develop feasibility studies of any proposed investment in the field of sanitation and wastewater management. Their results would assess not only the viability of individual projects, but also rank different proposals efficiently.

2. **Remove excess phosphorus and nitrogen from our waste streams and recover these nutrients for productive purposes.**

Excess phosphorus (P) and nitrogen (N) in rivers, seas and wetlands cause serious eutrophication problems and significantly reduce biodiversity by stimulating the growth of algae. More efforts should therefore focus on their elimination in order to increase environmental benefits. While in previous decades the removal of P from waste streams has been promoted, current technical options allow P recovery which adds multiple values to the environmental benefits as the treatment plant operators can reduce maintenance costs while recovering a valuable fertilizer.

3. **Collect domestic sewage and stormwater in separate networks.**

The combined sewer system (which treats both domestic sewage and stormwater) has been questioned because rainwater is not as polluted as wastewater. Rainwater thus requires less treatment before its discharge into a water body or its infiltration into the groundwater. Treating rainwater in wastewater treatment plants leads to unnecessary economic costs and fewer environmental benefits. To avoid such impacts, distinct sewer systems could be built to separate domestic sewage and stormwater, unless the rainwater is needed to flush the sewers.

4. **Encourage water reuse.**

Water recycling for potable and non-potable usages is an important component of sustainable water management and a typical example where especially in low-income countries the cost of action are usually higher than financial returns. However, the combined value of water and energy recovery, plus the environmental and social benefits of reuse can well exceed the operational or even investment cost. Important is however early stakeholder involvement to avoid that reuse projects are rejected for social reasons independently of their economic benefits,

5. **Consider extensive technologies with investment and maintenance cost requirements for wastewater treatment in developing countries.**

Where space is not a limiting factor, pond systems and constructed wetlands are two of the most common extensive technologies with significant cost advantage compared to the more energy demanding intensive systems like the activated sludge process. Since energy consumption is a main operational cost factor and electricity cuts a key risk factor for temporary or a lasting breakdown, minimizing energy consumption in WWTPs should be a key consideration in all countries with irregular electricity supply.

6. **Continue to develop methodologies that quantify externalities associated with wastewater treatment and reuse processes.**

Ever-increasing amounts of untreated or partially treated wastewater discharged into canals, rivers, lakes and seas affect human health, environmental quality and productive activities. Methodologies that help quantify and value these externalities continue to be needed. In particular, the environmental and health costs associated with wastewater treatment should be measured to capture the cost of no-action and ensure that feasibility studies of any investment will be economically sound.

7
GLOSSARY


PHOTO: © SUSANA SECRETARIAT

GLOSSARY

Aquatic ecosystem: an ecosystem in a body of water. Communities of organisms that depend on each other and on their environment live in aquatic ecosystems. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems.

Combined sewer system: sewer systems that collect both domestic sewage and storm water and transport it to a wastewater treatment plant.

Contingent valuation: a survey-based method widely used for placing monetary values of non-market goods and external costs and benefits.

Cost function: a tool to identify the most relevant variables in order to explain the cost of every process or activity.

Cost-benefit analysis: a systematic process for calculating and comparing total benefits and total costs of a project, decision or government policy, to see whether the benefits outweigh the costs, and by how much.

Economic valuation: a methodology to identify the monetary value of a good or activity.

Effluent: defined by the United States Environmental Protection Agency as "wastewater — treated or untreated — that flows out of a treatment plant, sewer or industrial outfall. Generally refers to wastes discharged into surface waters."

Electrodialysis: technology designed to remove undesired ions from solution by means of a direct current passing between two electrodes, one on each side of the membrane.

Extensive technologies: in extensive treatment processes, the purification is ensured thanks to long retention time, which requires more space compared to intensive technologies. However, extensive technologies are usually low-cost, low-energy and low-maintenance compared to other treatment processes.

Externality: positive or negative environmental, social or health trade-offs for another party who did not have a choice and whose interests were not taken into account.

Filtration: a technology that uses a porous filtration medium to retain particles. These filters are commonly used when the fluid to be filtered contains a high load of particles.

Functional form: different equations showing the relationships between a number of independent variables with the dependent variable.

Hyperbolic function: a function of an angle expressed as a relationship between the distances from a point on a hyperbola to the origin and to the coordinate axes.

Life-cycle analysis: a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave

Phytotoxicity: a toxic effect by a pollutant (trace metals, pesticides, salinity) on plant growth.

Pollution: the introduction of contaminants into the environment causing negative effects.

Population equivalent: the average amount of pollution load produced and introduced into wastewater by a permanently resident inhabitant within a day.

Pond systems: artificial lagoons in which wastewater is treated by natural processes such as the influence of solar radiation, wind, microorganisms and algae.

Shadow prices: the avoided costs resulting from removing pollutants during wastewater treatment.

Separate sewer systems: systems that collect domestic sewage and stormwater in separate networks.

Settling system: technology designed to remove particulates from liquids. It is often employed in primary water treatment using a series of inclined plates in place of conventional settling tanks.

Sludge: semisolid material generated by the wastewater treatment process.

Ultrafiltration: filtration technology capable of removing very minute (ultramicroscopic) particles.

Water reuse: use of reclaimed water for a direct beneficial purpose.

Wastewater: a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter.

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TABLE ENDNOTES

1* The shadow price of the nitrogen if discharged to wetlands is €-65.21/kg; for every kilogram of this nutrient not dumped into a wetland, the damage prevented, or the environmental benefit generated, equals €65.21.

2* The variable cost is the monetary value in ZAR; L is the total length of the pipeline in metres; D is the nominal pipe diameter in millimetres.

3* ***DN*** represents the pipe nominal diameter in millimetres and ***L*** represents the pipeline length in kilometres. The conversion rate between USD and EURO was in this example approximately $1 = €0.74.

4* Treatment system consisting of a tank filled with wastewater with a set of semi-submerged vertical discs slowly turning around a central axis.

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This book presents the results of an analytical study on the economic valuation for wastewater, comparing the cost of no action versus the cost of effective wastewater management.

Although economic valuation of wastewater management is complex, it remains an important tool to guide policymakers and investors to take informed decisions. A financial analysis of wastewater management looks at its private costs and benefits and can underpin decision making from a business or treatment plant operator standpoint. Economic analysis looks at the broader costs and benefits for society, providing information for public policy decisions to support improvements in wastewater management. Adequate wastewater collection, treatment, and safe use or disposal can lead to significant environmental and health benefits. However, because some of these benefits do not have a market price, they have not traditionally been considered in the financial analysis of wastewater treatment projects, therefore underestimating total benefits.