# COST-EFFECTIVENESS ANALYSIS FOR SUSTAINABLE WASTEWATER ENGINEERING: A CASE STUDY AT MINHO-LIMA'S RIVERS BASINS (PORTUGAL)

S. Costa[1*], L. Coutinho[1*], R. Nogueira[1], A.G. Brito[1], J.J. Salas[2], C. Póvoa[3]

[1] IBB-Institute for Biotechnology and Bioengineering. Centre for Biological Engineering, University of Minho, Campus de Gualtar 4710-057 BRAGA, Portugal. Email: agbrito@deb.uminho.pt.

[2] Centre for New Water Technologies (CENTA). Av Américo Vespucio 5-1, Pl. 2ª Mód. 10, E-41092, SEVILLE, Spain. Email: jjsalas@centa.org.es .

[3] AdP – Águas de Portugal. Av. da Liverdade, nº 110, 7º Piso, 1296-042 LISBOA, Portugal.Email: c.povoa@adp.pt

**Abstract**

The present work was focused on a methodological assessment for defining cost-effective measures regarding to wastewater sanitation in rural areas and was carried out within the project *AQUA Project – Preliminary Studies for the Water Framework Directive Implementation at the Minho and Lima's Rivers Basins.* In order to assure a good ecological and chemical *status* in water bodies according to Water Framework Directive, a set of priority and complementary actions combined with a cost-effectiveness analysis was used to select a wastewater treatment strategy to increase public attendance. Using geoprocessing methodologies and geographic information multicriteria analysis (e.g.: soil, land use, topography), locations with high potential for implementation of low-energy wastewater treatment systems were identified and worked out with cost-functions. The results show that a combination of centralized and decentralized plants allow a cost-effectiveness attendance of 1,51 k€/equivalent inhabitant in Minho and Lima's river basins. The approach indicates that low-energy wastewater treatment plants are interesting options with a promising cost-effectiveness potential in rural areas.

**Keywords:** Cost-effectiveness analysis, decentralized wastewater treatment; water economic analysis, Water Framework Directive.

## Introduction

One of the Water Framework Directive (WFD) guidelines addresses the establishment of the best cost-effectiveness combination of intervention measures, in order to accomplish the water quality and quantity goals and evenly distribute the recovery of water management costs among the different users. This principle comprises the development basis of a joint venture between *Águas do Minho e Lima* (AdML) and *Augas de Galiza*, designated as *AQUA Project – Preliminary Studies for the Water Framework Directive Implementation at the Minho and Lima's Rivers Basins*). Therefore, this communication aims to present the methodology and results of a simplified cost-effectiveness

[*] Sérgio Costa and Luciana Coutinho are currently working at SIMBIENTE – Environmental Engineering and Management, Ltd., a spin-off company of University of Minho, Praça Paulo Vidal, n.º21, 4710-245 BRAGA, Portugal. Email: sergio.costa@simbiente.com

analysis, regarding decentralized wastewater treatment implementation over the AdML intervention area (Figure 1).

One of the main environmental difficulties at the Minho and Lima's rivers basins regards to the wastewater drainage and subsequent treatment. In fact, in 2005 the drainage services were quite unsatisfactory (according to AdML (AdML, 2005), only 32% of the population of this region was supplied by these services). Regarding the water supply services, the attendance was never higher than 50%, and in most of the cases, was even lower than 20%. Concerning the risk of quality deterioration of water bodies, especially in surface waters (acknowledged that these are usually the most affected by different usage pressure), this scenario has a significant contribution to increase that risk.


*Figure 1. Águas do Minho e Lima intervention area*

## Methods

The present study was organized in three stages: (1) Characterization baseline of the Minho and Lima´s rivers basins, and determination of the trends of water usage, specifically regarding the wastewater production and wastewater drainage and treatment supply levels; (2) Definition of strategic and operational environmental objectives, addressing several thematic areas and assuming 2015 as deadline for their accomplishment; (3) Establishment of Programme of Measures, according to the relevant thematic areas and based on the related rivers basins management plans, focusing on the measures and actions more relevant for the environmental objectives achievement. Their structure was built in order to consider a set of indicators, according to a Pressure-State-Response model, as well as to consider their implementation and potential impacts monitoring. Once the objectives were established and their associated Programme of measures were defined, it was performed an exploratory analysis to a set of analysis tools, concerning the definition of high-priority measures and complementary actions, as well as the assessment of the consequent impacts on the ecosystems, based on cost-effectiveness criteria. Figure 2 illustrates this general methodological scheme.

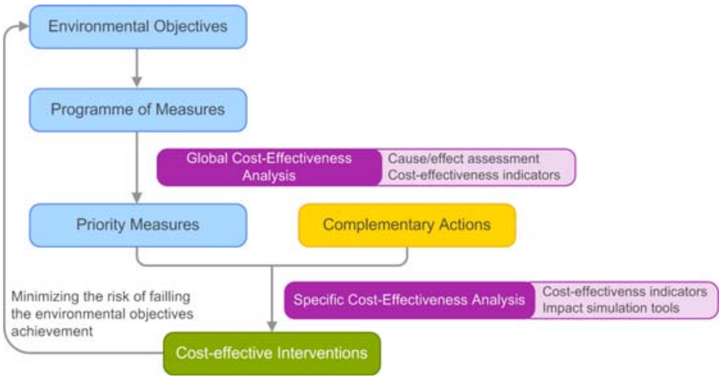


*Figure 2. Cost-effectiveness analysis components*

Regarding the cost-effectiveness global analysis, the aim of the methodology applied to the several measures was the definition of strategic priorities. These priorities were identified through a cause/effect matrix and a Global Effectiveness Index (EI) calculation (Figure 3 and Table 1):

$$EI = \sum_{c=1}^{4} \left( \frac{\sum_{i=1}^{n} a_i}{n} \right)_c ?\ gr_c$$

Legend: EI: Effectiveness Index; c: quality components (c=1: biological elements; c=2: hydromorphological elements; c=3: physical-chemical elements; c=4: socioeconomic elements), a: assessment indicators classification for each quality component; n: number of assessment indicators for each quality component: gr: relevance of each quality component.

*Figure 3. Global Effectiveness Index formula*

*Table 1. Classification scale of the Global Effectiveness Index*

| EI value range | Effectiveness assessment | Priority |
|---|---|---|
| 1<EI<10 | Low | 1 |
| 11<EI<20 | Medium | 2 |
| 21<EI<30 | High | 3 |

Several quality components already defined in the Water Framework Directive's Annex V were considered, specifically regarding to biological, hydromorphological, physico-chemical and socioeconomic elements. Additionally, several indicators were identified and defined based on their relevance in the scope of the quality of the mentioned components. Finally, and in regard to the reduction of the measures pressures, an effectiveness classification for each measure was defined.

In order to achieve more demanding quality goals, additional Complementary Actions for the high-priority measures were proposed. In this context, the methodology applied was based on two sub-methodologies: (1) Analysis of specific cost-effectiveness indicators, targeting the pressure components that are associated with different response types; (2) Demonstration of the impact assessment on environmental systems (using a decision support system based on several tools, e.g.: STELLA, AQUASIM, Dashboard of Sustainability). The last step consisted in a comparative analysis between the actions included in the Programme of Measures and their respective Complementary Actions.

The specific Complementary Action "Construction of 10 decentralized low-energy wastewater treatment plants" (that intended to mitigate the unsatisfactory wastewater drainage and treatment services in the Minho and Lima's rivers basins) integrated a base study in order to understand the best approach for the implementation of these systems. The state of the art regarding to this subject demonstrate that the implementations of these plants should be critical for areas with significant environmental risks (for example, locations with a relatively low population dimension that, isolated or cumulatively, will not be served by the centralized wastewater drainage and wastewater treatment plant systems). Once the potentially suitable sites for the decentralized plants implementation were identified, the next step consisted in the comparison of the locals against the territory spatial edafoclimatic characteristics (e.g. climatic limitations, depth until the water table, slope and soil permeability). This methodology led to a preliminary identification of sites with suitable target profile for this Complementary Actions, as well as the most suitable technology to apply in each case. On the other hand, the cost-effectiveness estimative for this Action assumed several cost functions related to decentralized wastewater treatment plants (Table 2). It is important to refer that these functions were estimated taking based on the performance of other similar plants (portuguese and spanish case studies). The variables accounted were investment costs, population equivalents (p.e.) and treated wastewater flow. Additionally, values of average investment costs were estimated based on budget criteria from rivers basins plans (AGRIPRO AMBIENTE *et al*, 2000; HIDRORUMO *et al*, 1999). Complementary data from equipment suppliers was also considered: 1000 €·p.e.$^{-1}$ until 3000 p.e.; 750 €·p.e.$^{-1}$ between 300 and 400 p.e.; 600 €· p.e.$^{-1}$ between 400 e 500 p.e.; 500 €· p.e.$^{-1}$ for more than 500 p.e.. At last, a comparative study of the impact of adding up the Complementary Actions to the previous defined measure was made.

*Table 2. Cost functions for decentralized wastewater treatment systems*

| TYPE OF TECHNOLOGY | INVESTIMENT COSTS | | OPTIMIZED RANGE (p.e.) | REMOVAL RATE (%) | | |
|---|---|---|---|---|---|---|
| | Construction and Equipment Costs | Operation Costs | | $DBO_5$ | TSS | P |
| Slow Rate Irrigation Systems | $y = 32{,}567e^{-0{,}0025x}$ | $y = 4{,}9627e^{-0{,}0019x}$ | 0 – 500 | 90-95 | 90-95 | 75-85 |
| Peat Filters | $y = 333{,}05e^{-0{,}0002x}$ | $y = 13{,}183e^{-0{,}0002x}$ | 1000 – 2000 | 80-85 | 95-99 | 10-30 |
| Aerated Lagoon Systems | $y = 131{,}48e^{-0{,}00006x}$ | $y = 20{,}054e^{-0{,}00003x}$ | 1500 – 12000 | 80-95 | 70-90 | 40-60 |
| Constructed Wetlands | $y = 371{,}32e^{-0{,}001x}$ | a.d. | 150 – 800 | 98 | 99 | 81 |

Units:

**Investiment Costs:** y – Investiment cost/Equivalent Population (€·p.e.$^{-1}$); x – Population (p.e.).

**Exploration Costs:** y – Exploration costs/ Equivalent Population (€·p.e.$^{-1}$); x – Population (p.e.).

## Results and discussion

The described methodology allowed the identification of five "high priority" measures (Table 3) for which were established Complementary Actions. Focusing the analysis on the "*Pollutants discharges assessment and control*" measure (due to it particular role for the Minho and Lima's rivers basins management), a Complementary Action was set regarding to the "*Construction of 10 decentralized low-energy wastewater treatment plants*", which location and most suitable technology to apply in each case were preliminary identified based on a cross-comparison between the mentioned edafoclimatic data and economic criteria (results can be seen in Figure 4).

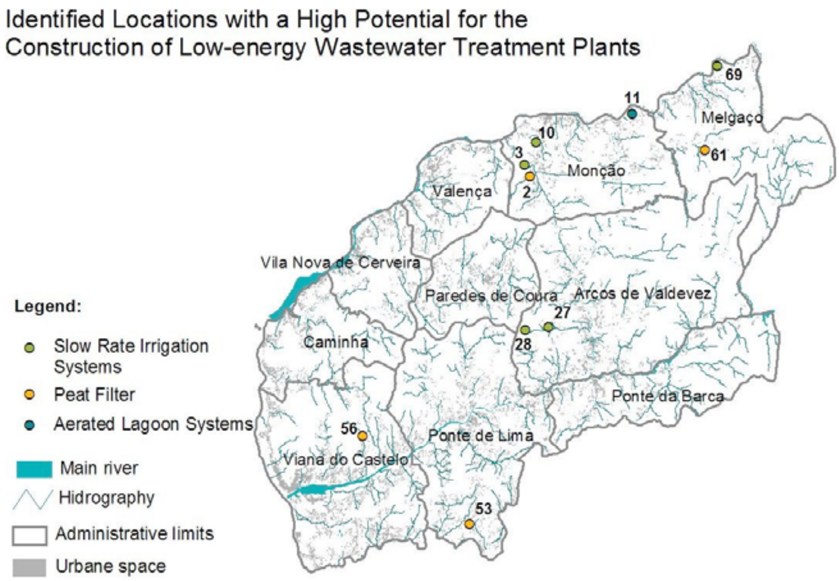


*Figure 4. Map with the potential sites for the implementation of decentralized low-energy wastewater treatment plants*