A web-based Toolbox to support the systemic eco-efficiency assessment in water use systems

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(7641 words)

Abstract

The eco-efficiency assessment of a water use system at the meso level, as well as the estimation of the anticipated eco-efficiency improvements as a result of innovative practices/technologies, is a conceptually and methodologically challenging issue. A systemic approach is required to capture the complexity of all interrelated aspects and the interactions among the heterogeneous actors involved in the system. This involves mapping the behaviour of the system into representative models, structuring the analysis in easy to understand procedures and developing versatile software tools for supporting the analysis.

This paper presents a web-integrated suite of tools and resources (EcoWater Toolbox) for assessing eco-efficiency improvements from innovative technologies in water use systems. Equipped with a continuously updated inventory of currently available technological innovations as well as a repository of eco-efficiency indicators and their evaluation rules, the EcoWater Toolbox supports a comprehensive four-step eco-efficiency assessment of a water use system: (1) allows the users to frame the case study by defining system boundaries, describing the water supply chain and value chains and including all the actors; (2) helps the users to establish a baseline eco-efficiency assessment, using the integrated modelling tools; (3) supports the users in identifying both sector-specific and system-wide technologies and practices to suit their situation, through the integrated technology inventory; and (4) enables the users to assess innovative technology solutions by developing predictive technology scenarios and comparing these with baseline results.

At the core of the Toolbox are two modelling tools, which combine both economic and environmental viewpoints into a single modelling framework. The "Systemic Environmental Analysis Tool" (SEAT), assists in building a representation of the physical system, its processes and interactions and forms the basis for evaluating the environmental performance of the system. The "Economic Value chain Analysis Tool" (EVAT), addresses the value chain and focuses on the economic component of the eco-efficiency. Both tools provide a graphical model construction interface that is implemented in client-side and incorporate advanced features such as model scripting.

The methodology adopted and the operational aspects of the EcoWater Toolbox are presented and demonstrated through the assessment of the eco-efficiency performance associated with the water value chain in the case of a milk production unit of a dairy industry.

Keywords: web-based modelling; eco-efficiency; water use system; value-chain; environmental assessment; eco-innovation

1. INTRODUCTION

In a typical water use system, freshwater is abstracted from a source (surface water or groundwater), purified and distributed for different water uses. Each use consumes water of a specific quantity and quality, along with other resources (energy, raw materials, etc.), for the provision of goods or services (both of which are denoted as "products"). Wastewater from uses is collected and treated before being disposed into the environment. In order to monitor the progress of water use systems towards sustainable development, methods and tools are required, which may help quantify and compare their performance. Recent policy frameworks, such as the Europe 2020 strategy, widely promote the concepts of resource efficiency (minimizing the resources used for the provision of products) and resource productivity (the efficiency of economic activities in generating added value from the use of resources) for transforming economy into a sustainable one (O'Brien, et al., 2011). Eco-efficiency is nowadays recognized as a key instrument for promoting fundamental changes in the way societies produce and consume resources, and thus for measuring progress towards sustainability (UN-ESCAP, 2010).

The aim of the eco-efficiency assessment of a water use system is twofold: to analyse the system and its environmental and economic exchanges (attribution analysis) and/or to describe how the environmental and economic exchanges of the system can be expected to change as a result of innovative practices, including technology adoption (consequential analysis) (Rebitzer, et al., 2004). An EU-funded research project, EcoWater, has been systematising those concepts in order to develop a methodology for the assessment of eco-efficiency in water use systems at the meso-level and of the potential eco-efficiency improvements from the implementation of innovative technologies. The meso-level encompasses the water supply and water use chains and entails the consideration of the interactions among all the involved heterogeneous actors, e.g. between water service providers and users.

Interventions in a water use system at the meso-level may have synergies. For example, process upgrading can reduce the concentration of pollutants in the effluents, in turn facilitating improvements in the water use chain, e.g. through in-house waste water treatment, reuse, recycling, etc. On the other hand, they may lead to trade-offs between economic and ecological parameters since innovative practices can incur economic costs for an actor lacking a clear incentive or responsibility to make such an investment for environmental benefits of the overall system. Due to the complexity of the interrelated aspects relevant to environmental and economic behaviour and the interactions among the actors, the eco-efficiency analysis of a meso-level water use system is not trivial. This complexity may be resolved by mapping the behaviour of the system into representative models and structuring the analysis in easy to understand procedures. Many software tools for easing this process are available (EcoWater, 2012), like Umberto NXT LCA (IFU Hamburg, 2015), Gabi (PE International, 2013), SimaPro (Goedkoop, et al., 2013) and STAN (Cencic. & Rechberger, 2008). Umberto software enables material and energy flow analyses, life cycle assessment and life cycle costing to be conducted. Thanks to this, it is possible to calculate the eco-efficiency of a product (Czaplicka-Kolarz, et al., 2014). SimaPro and GaBi are widely used tools for life cycle assessment (Herrmann & Moltesen, 2015). These tools are not specific for water flows, neither for eco-efficiency, because they focus on the environmental aspects of a production system and their capabilities for simultaneously analysing economic features are limited. However, they can be applied to a variety of systems, including water use systems and they are usually combined with a life cycle cost approach to calculate the eco-efficiency of products and services (Michelsen, et al., 2006; Aranda Usón, et al., 2011). Tools considering the economic value chain of water use systems have also been presented, such as the WaterStrategyMan DSS (Manoli, et al., 2001) that provides cost-benefit assessments of water allocation schemes, water management options and integrated scenarios, combining changes in water availability, demands and infrastructure; and the City Water Economics (NTUA, 2011) for the assessment of institutional arrangements and alternative cost allocation schemes for urban water services. However, by assigning costs or revenues to the energy or material flows of the water supply and use chains, monetary cost accounting can be added to the environmental assessment. In order to go one step further and include the meso-level effects of technology decisions, models and tools that combine both economic and environmental perspectives should be developed. This would help analysing more complex issues, such as the distributional effects among the actors involved in the system under study.

Simulation and modelling tools are generally designed to be run purely on an end-user operating system. With the expansion of the Internet and the ubiquity of the World Wide Web, new possibilities to harness this communication technology and platform to develop rich collaborative modelling tools have become available. Web-based modelling can be defined as the use of resources and technologies offered by the World-Wide-Web for interaction with client and server tools. Compared to classical desktop systems, several advantages with web-based systems can be identified (Syberfeldt, et al., 2013; Fortmann-Roe, 2014): (i) accessibility – a web-based system is accessible from anywhere with an internet connection and outside normal business hours, (ii) portability – a web-based system can be run in any web browser on any operating system and it can be run on any device that has a web, (iii) maintenance – the maintenance of web-based systems is easier, since they do not have to be installed in each client's computer, and (iv) controlled access – through user logins, a web-based system allows for the configuration of user groups with different privileges based on work tasks. One major review of the opportunities, categories, and issues faced when utilizing web-based modelling tools has been presented by Byrne et al. (2010).

The scope of this paper is the presentation of an integrated suite of on-line tools and resources (EcoWater Toolbox) for assessing eco-efficiency improvements from the implementation of innovative technologies in water use systems at the meso-level. The Toolbox integrates a technology inventory, a repository of indicators and a pair of modelling tools, the "Systemic Environmental Analysis Tool" (SEAT) and the Economic Value chain Analysis Tool" (EVAT), which combines both economic and environmental viewpoints into a single modelling framework. The web platform that provides content management services, integrates resources and tools and guides the user through the eco-efficiency assessment methodology as well as the client side modelling tools have been developed, tested and validated by the authors in the context of the EcoWater research project. A description of the operational aspects of SEAT and EVAT tools has been presented by Arampatzis et al. (2014). The present paper provides detailed information on the structure and the functionalities of the Toolbox as well as the methodologies of the tools.

The remainder of the paper is organized as follows. Section 2 presents the context of the analysis, providing a concrete model of a water use system and the factors affecting its eco-efficiency assessment at a meso-level. The architecture of the Toolbox is presented in Section 3 while Section 4 details the main functionalities provided by the Toolbox. The two modelling tools provided by the Toolbox (SEAT and EVAT) are presented in Sections 5 and 6 respectively. The methodology adopted and the operational aspects of the EcoWater Toolbox are demonstrated through the assessment of the eco-efficiency performance associated with the water value chain in the case of a milk production unit of a dairy industry in Section 7. Finally, Section 8 summarizes the conclusions from the study.

2. CONTEXT OF THE ANALYSIS

A generic system, which models the typical meso-level water use system, is presented in Figure 1. The system combines the typical water supply chain (horizontal chain) with the corresponding water use chain (vertical chain) and is represented as a network of unit processes grouped into stages. Each process represents an activity, implementing one or more technologies, where generic materials (water, raw materials, energy and other supplementary resources) are processed and transformed into other materials, while releasing emissions to the environment (air, land, water).

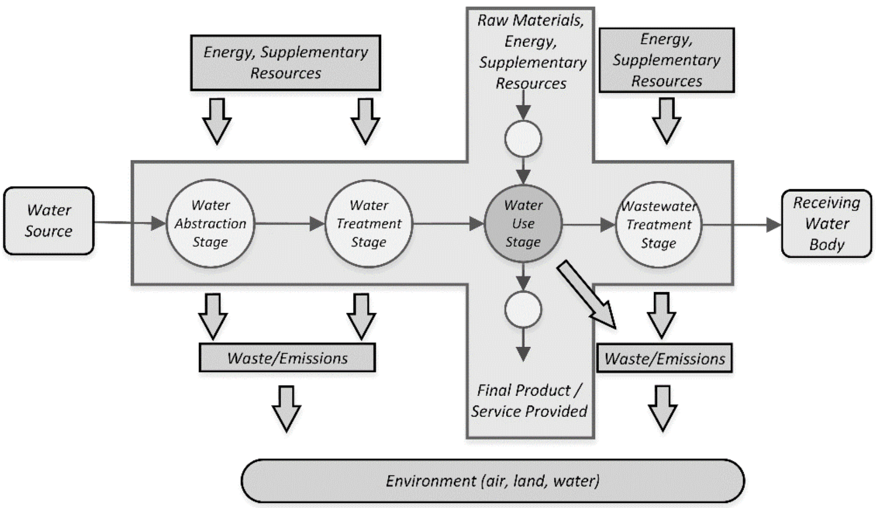

Figure 1. The water supply and water use chains of a water use system.

The economic analysis of the system also entails the consideration of the interdependencies and the economic interactions of all the heterogeneous actors involved in the water supply and use chain. It involves the sharing of resources, services and by-products among the actors in order to add value and reduce costs. As a result, the meso-level water use system has another significant component, the water value chain, as presented in Figure 2.

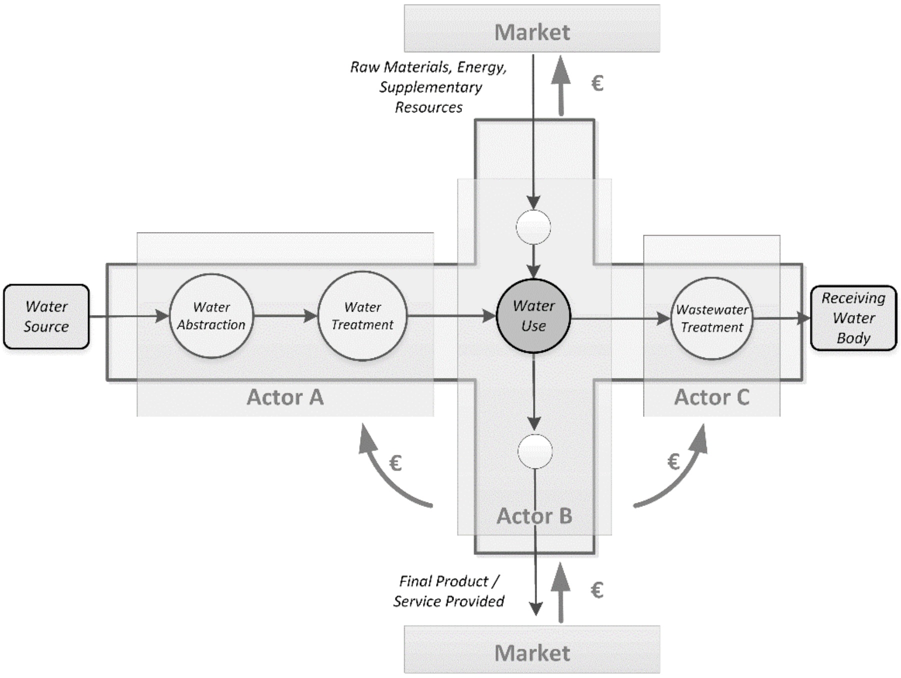

Figure 2. The water value chain of a meso-level water use system.

Eco-efficiency has recently become a critical part of environmental policy making as it is a concept that combines resource efficiency (the minimization of resources used in producing a unit of output) and resource productivity (the efficiency of economic activities in generating added value from the use of resources). An eco-efficiency indicator can be expressed quantitatively by the “eco-efficiency equation” shown in Figure 3. In the numerator is the economic output (benefit) provided by the system and in the denominator are the environmental impacts (costs) associated with that (UN-ESCAP, 2010). Thus, an increase in the eco-efficiency could either result of improved economic performance, result of reduced environmental impact or even both. However, since the concept has not been widely applied in real case studies, there are no benchmarks for their values and decisions cannot be easily based on the results. On the contrary, the eco-efficiency indicators can be used to compare alternative configurations of the same system. An appropriate set of eco-efficiency indicators should be selected for each system, tailored to the goal and scope of the analysis. Indicative criteria for their selection include: (a) relevance to the goal of the analysis, (b) comprehensiveness and relevance to the examined system, (c) reliability, simplicity and comparability and (d) importance for supporting system-wide decisions.

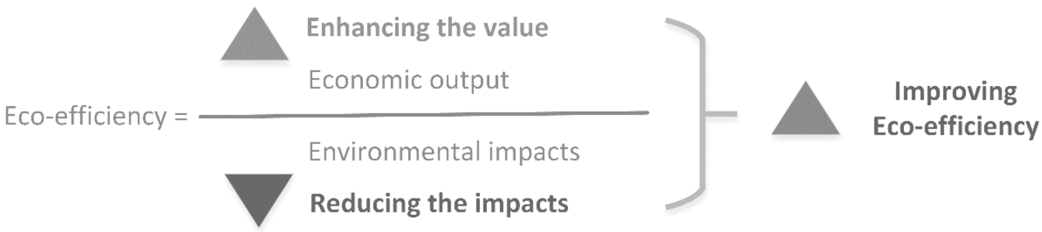

Figure 3. The eco-efficiency “equation”.

In order to assess the eco-efficiency of a meso-level water use system, a comprehensive four step methodology has been developed in the EcoWater project. The first step leads to a clear, transparent mapping of the system at hand and the respective value chain. The second step provides the means to assess its eco-efficiency. The third step includes the selection of innovative technologies, which are assessed in the last step and combined with mid-term scenarios to determine the feasibility of their implementation. The essential aspects of this methodology, presented in Angelis-Dimakis et al. (2014), are the following:

Step 1. System Framing - This step involves the definition of the system boundaries as well as the mapping and description of the water supply chain (stages, processes and existing technologies) and value chain (actors involved and their interrelations).

Step 2. Baseline Eco-efficiency Assessment - There is a wide spectrum of indicators that could measure the environmental performance of the water use system. The developed methodology follows a life-cycle oriented approach (ISO 14045, 2012) using a standard list of midpoint impact categories (JRC, 2010) (including the impacts from the background systems), which make it possible to characterize different environmental problems, such as climate change, ozone depletion, photochemical ozone formation, acidification, eutrophication and resource depletion (Guinée, et al., 2001). The most relevant economic output indicator in the meso-level water use system is the so called Total Value Added to the product due to water use, expressed in monetary units. “Total” denotes the economic value added minus various costs of water abstraction, treatment, wastewater treatment, etc. as well as other resource inputs. Hence, evaluating eco-efficiency requires information about the physical system, in terms of elementary flows as well as financial information, in terms of product prices, investment costs, cost of materials and other operational and maintenance costs.

Step 3. Identification of Technologies - Following the assessment of the baseline situation, alternative ways are sought in order to upgrade the water use system through: (i) process upgrading, (ii) product upgrading, (iii) functional upgrading or (iv) improvement of the organizational procedures. Such actions may include not only technical interventions but also management or behavioural changes. However, for the purposes of the EcoWater project, the upgrading the water use system was based only on the introduction of new and innovative technologies.

Step 4. Technology Scenario Assessment - Each of the selected technologies in step 3, is modelled by identifying the parameters of the water supply and value chains that are affected by its implementation. The estimation of the eco-efficiency indicators can be repeated for each different technology or combination of technologies.

3. SYSTEM ARCHITECTURE

The EcoWater Toolbox is a web-based platform, which contains the resources and tools necessary for the eco-efficiency assessment of different technologies. The Toolbox provides a number of different services that both mirror what would be found in a traditional desktop application (such as model construction and simulation) but also extend beyond into areas more specific to a web environment (such as user account management and model searching and sharing). The platform is designed to serve multiple users simultaneously, in order to support a context in which different beneficiaries perform various tasks at the same time. Access to the various functions is controlled and a command can only be executed if the user has the privileges to do so.

Figure 4 illustrates the architecture of the Toolbox. The application uses a client–server architecture, where clients are connected to the server over the Internet. Users may use the web browser on their machine to connect to the server and load the modelling tools. The core server-side components are responsible for managing case studies, implementing specific technologies (scenario management) and defining indicators to be used for the eco-efficiency assessment. The analysis and the evaluation of the results are also performed on the server using the data stored in the database. The client-side components provide model construction capabilities through the SEAT and EVAT tools. Clients do not communicate with one another directly and instead all communication happens through the centralized server. The server-side is also equipped with a continuously updated inventory of currently available technological innovations as well as a dynamic repository of eco-efficiency indicators.

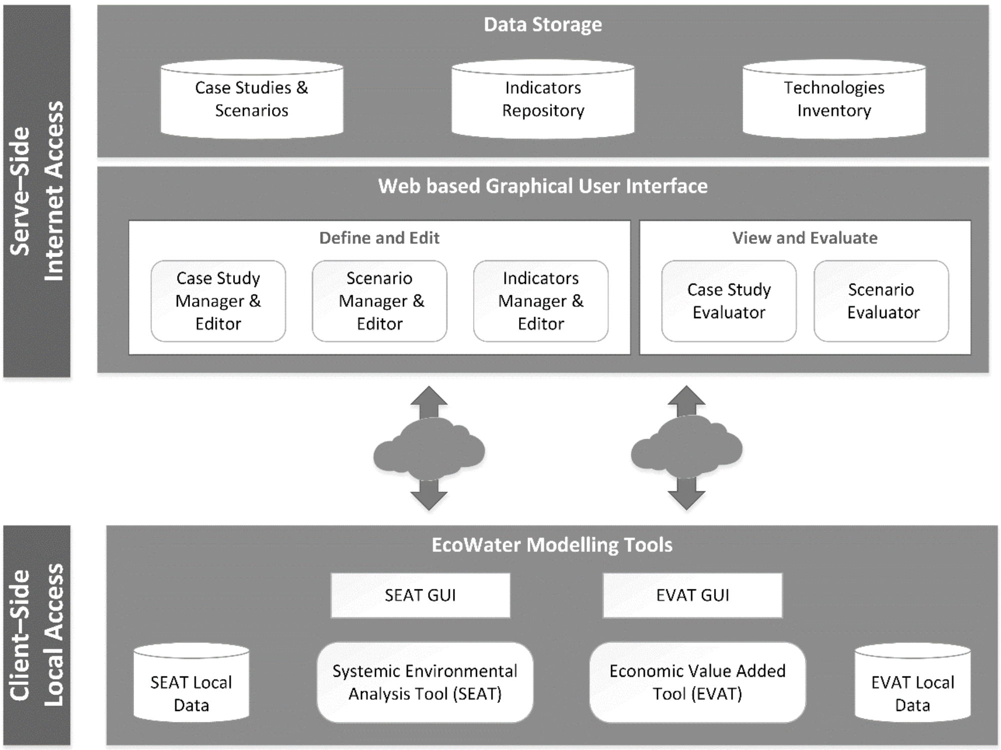

Figure 4. Architecture of the EcoWater Toolbox.

User groups are used by the Toolbox to control the access to the functionalities provided. There are six system-wide user groups and three case study-specific user groups, presented in Table 1.

Table 1. User groups and their roles.

User Group	Description / Role
Public (all users)	All users that visit the web site. Able to view basic information about the Toolbox and request registration to the system.
Registered Users	The users that have been registered and logged into the system. Able to view general and case study information.
System Administrators	The users who are responsible for setting up and maintaining the system. Responsible for managing user accounts and authorizing users to enter/edit information to the system.
Case Study Providers	The users that have the right to create a new case study.
Technology Providers	The users that have the right to create a new technology.
Indicator Providers	The users that have the right to create a new indicator.
Case Study Stakeholders	The users that are allowed to view all case study (public and private) information.
Case Study Collaborators	The users able to enter and edit case study information.
Case Study Administrators	Responsible to authorize users to enter case study information.

4. THE ECOWATER TOOLBOX ASSESSMENT APPROACH

The EcoWater Toolbox has been designed to support the comprehensive four-step eco-efficiency assessment methodology presented in Section 2. A brief description of the role of the EcoWater Toolbox in supporting these four steps, is presented in the following sub-sections.

4.1 Step 1 – System Framing

This step involves the definition of all system properties and it is achieved both through a narrative way (users may enter descriptions, links and documents relevant to case study) and in a more structured way by uploading the relevant models of the water supply and value chain constructed by the SEAT and EVAT tools.

4.2 Step 2 – Baseline Eco-Efficiency Assessment

The environmental impact for the impact category *c* is expressed as a score (ES_c) based on the concepts of classification and characterization (Guinée, et al., 2001):

$$ES_c = \sum_r cf_{r,c} \times f_r + \sum_e cf_{e,c} \times f_e \quad (1)$$

where ($cf_{r,c}$, $cf_{e,c}$) are the characterization factors that quantify the extent to which each resource *r* (energy, raw materials and supplementary resources) or emission *e* contributes to the impact category *c* and (f_r, f_e) are the corresponding elementary flows of resources and emissions (calculated in SEAT as described in Section 5). The characterization factors for the foreground system, included in the indicators inventory, are extracted from the CML-IA database (Guinee, et al., 2001). The background environmental impacts are evaluated using data from several open access LCA databases (ELCD, 2013; USLCI, 2012) which contain inventory data of many basic materials, energy carriers, waste management and transport services.

The economic performance of the water use system is measured using the Total Value Added to the product due to water use, calculated by the EVAT tool (see section 6).

The Eco-Efficiency Indicators (*EEI*) of the meso-level water use systems are estimated as ratios of the economic performance to the environmental performance of the system (environmental impacts):

$$EEI_c = \frac{TVA}{ES_c} \tag{2}$$

This step also supports the interpretation of the baseline eco-efficiency assessment results through:

- Calculation of the contribution of foreground and background systems to the environmental performance indicators, highlighting the most significant environmental impacts;
- Breakdown of the environmental impact per stage of the foreground system, indicating the environmental weaknesses of the system; and
- Estimation of the Net Economic Output for each directly involved actor.

All calculations as well as the presentation of results are executed remotely at the server, based on the results of the modelling tools and a dynamic repository of eco-efficiency indicators with their evaluation rules.

4.3 Step 3 – Identification of Technologies

The Toolbox integrates a technology inventory (Figure 5), with detailed information on the possible technologies and practices for the eco-efficiency improvement of the water system. The technology inventory was initially populated based on the existing Best Available Techniques (BAT) Reference documents (BREFs) developed under the IPPC Directive and the Industrial Emissions Directive (IED). It was further enriched with case-specific technologies, concerning the eight water use systems examined during the EcoWater project (agricultural, urban and industrial systems), by the case study developers after consultation with local stakeholders.

During this step, technologies can be selected from the inventory for implementation either throughout the water supply and wastewater treatment stages (common for all water use sectors) or within the water use processes (sector specific technologies). The technologies are also classified in three categories, based on the three main axes of the current European research framework, according to their objective of their implementation:

- Resource efficient technologies, focusing on water, energy or material savings.
- Pollution preventing technologies, aiming to reduce the emissions to air, to water and to soil.
- Technologies enhancing circular economy, such as reuse, recycle or recovery.

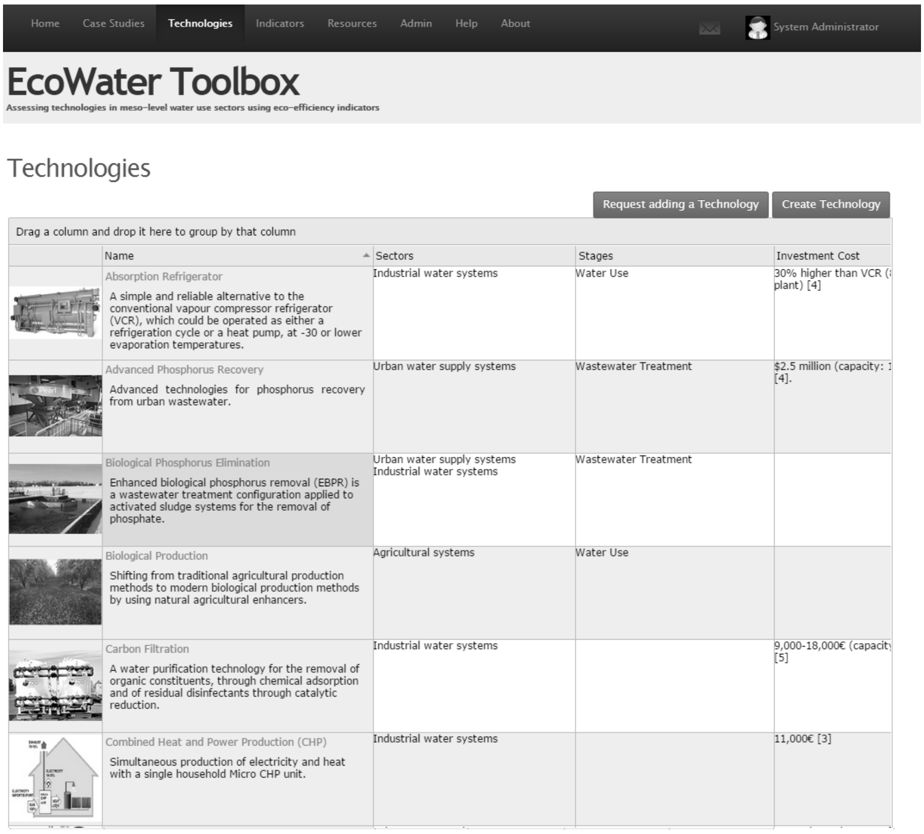

Figure 5. The Technology Inventory.

4.4 Step 4 – Technology Scenario Assessment

The Toolbox enables the assessment of innovative technologies by supporting the development of technology scenarios and providing the SEAT and EVAT tools for modelling the impacts on the water system from the technology implementation. A technology scenario can be defined as "the implementation of (at least) one innovative technology in the system under study, assuming that all other parameters remain the same".

The Toolbox also facilitates the comparison of technology scenarios to the baseline results both per actor and for the entire system studied (Figure 6). The eco-efficient technologies are identified and then ranked on the basis of their performance measured by the eco-efficiency indicators. Different ranking sets may be produced based on the classification of technologies according to the objective of their implementation: (a) pollution prevention, (b) resource efficiency and (c) circular economy.

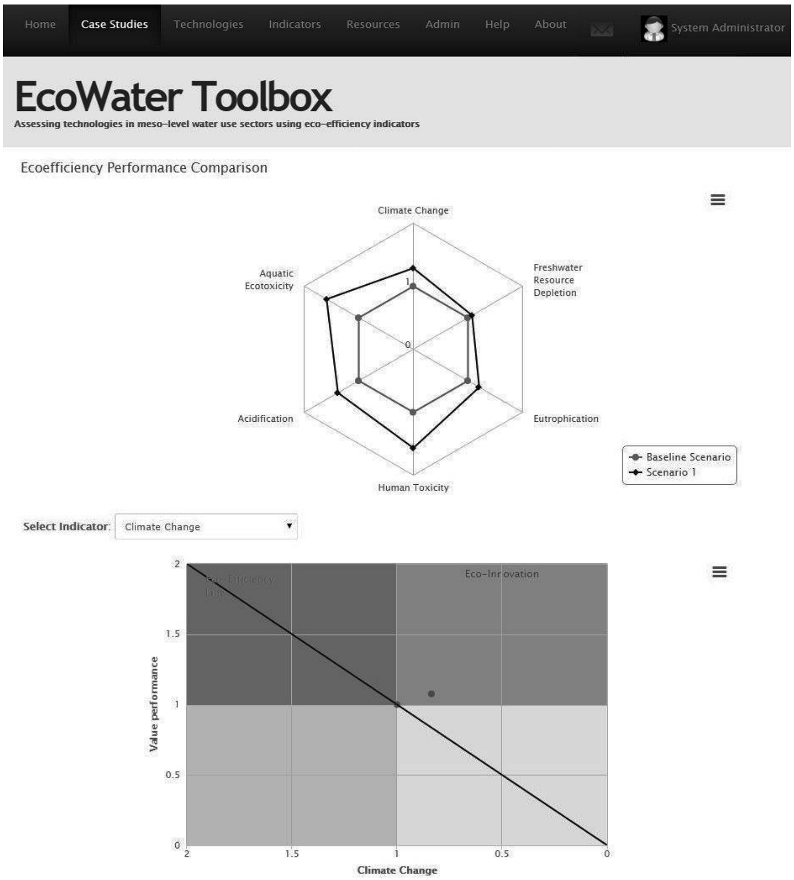

Figure 6. Comparing technology scenarios.

5. SYSTEMIC ENVIRONMENTAL ANALYSIS TOOL

5.1 Scope and objectives

SEAT is the core modelling tool of the EcoWater Toolbox that assists in building a representation of a meso-level water use system, its processes and interactions. This model forms the basis for evaluating the midpoint impact indicators, used to measure the environmental performance of the system. A SEAT model provides the elementary flows of resources and emissions that are necessary for evaluating the environmental impacts. It also provides the flows of water, products and other materials that allow the estimation of the costs and incomes generated by the system and quantify the interactions among the actors. Therefore, the system's model is built in SEAT and its results are the main input to the EVAT tool. All flows calculated by SEAT refer to a time period of one year in order to be consistent with the yearly costs calculated in EVAT.

5.2 Operational aspects

SEAT operates as an interactive graphical modelling environment (Figure 7) providing the following core functionalities:

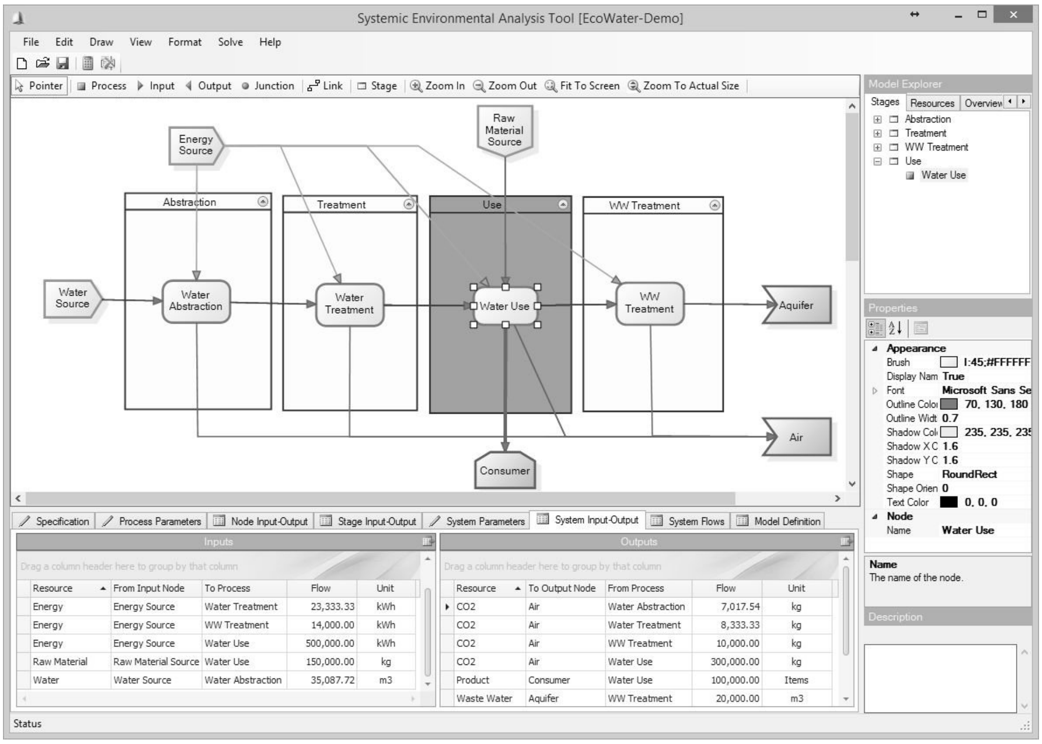

Figure 7. The SEAT modelling environment.

- Design of a model representation of the analysed physical system. A graphical approach is followed, where the user specifies the stages and the processes of the water use system by actually drawing the elements on a canvas.
- Mapping of the stages and the production processes in the water supply and use chains. This is the core modelling step where the user specifies the flow of materials to and from processes, as well as the relationships between input and output flows.
- Automatic calculation of the material flows for each process and stage, using the input-output relations defined in the previous step, when at least one reference flow is specified.
- Presentation and reporting of the results. The software supports the tabular representation of the calculated flows per link, process, stage, and for the entire system. It also allows exporting the results in common format for further processing and graphing.

5.3 Methodology

The modelling approach adopted in SEAT is based on the principles of Material Flow Analysis (Huang, et al., 2012) and Material Flow Networks (MFN) (Wohlgemuth, et al., 2006; Page, et al., 2008) which model material and energy flows in production chains. According to this approach, SEAT networks are graphs with two different types of vertices called processes and places, connected with links. Processes represent single activities in which materials are processed and transformed to other materials. Places represent store and/or transfer nodes for materials within the network and are distinguished as input nodes (the initial sources of materials flowing towards processes) and output nodes (the target sinks of materials flowing from processes). Junctions are special type of places, connecting processes and acting as output nodes for one process and input nodes for the other process. Links represent a way by which materials can flow between nodes. Finally, processes can be grouped into stages that serve as containers for network nodes.

The principal entities of the network are the processes, which describe activities that are entered by all the required materials (input) and, as a result, generate new or modified materials (output). The most important modelling step is the specification of a process. This involves the definition of the input and output materials as well as the relations between input and output flows.

A typical process has NPF_{in} in-flows (flows emanating from input nodes and enter the process) and NPF_{out} out-flows (flows emanating from the process and enter output nodes). In total, there are $NPF = NPF_{in} + NPF_{out}$ flows related to a process. The relation between in-flows and out-flows is defined on the basis of scaling factors $\left(s_i, i = 1, NPF\right)$. These are numbers representing linear relationship between flows $\left(f_i, i = 1, NPF\right)$. Given the scaling factors, the following analogies apply:

$$\frac{f_1}{s_1} = \frac{f_2}{s_2} = \ldots = \frac{f_{NPF}}{s_{NPF}} \tag{3}$$

The solution of a process involves the calculation of all in- and out- flows (f_i). There are *NPF* flows to be specified and *NPF*−1 equations defined via the scaling factors (Eq. 3). Therefore:

Precondition: The process can be solved when at least one flow (input or output) is known and all scale factors are specified.

Calculation Procedure: Denoting the index of the known flow by *ref*, the unknown flows can be calculated as:

$$f_i = f_{ref}\frac{s_i}{s_{ref}} \qquad i = 1, NPF \quad \text{and} \quad i \neq ref \tag{4}$$

Exceptions: If more than one flow is known then the known flows are first checked when they are in agreement with their scaling factors (if Eq. 3 holds). If yes, then Eq. (4) is used to calculate the remaining flows. Otherwise, the process (as well as the network) is considered over-defined.

In a typical junction, *NJM* materials are entered (and exited). For each material *m*, there are $NJF_{m,\mathrm{in}}$ in-flows (flows emanating from processes and enter the junction) and $NJF_{m,out}$ out-flows (flows emanating from the junction and enter processes). A junction obeys the concept of strict material conservation. Therefore, the following equation applies for each material:

$$\sum_{i_{in}=1}^{NJF_{\mathrm{m},in}} f_{i_{in}} = \sum_{i_{out}=1}^{NJF_{\mathrm{m},out}} f_{i_{out}} \qquad r = 1, NJM \tag{5}$$

The solution of a junction is performed for each material (*m*) independently. Therefore:

Precondition: The junction can be solved when there is only one unknown flow.

Calculation Procedure: Denoting the index of the unknown flow *i*, it can be calculated as:

$$f_i = \begin{cases} \sum_{i_{in}=1}^{NJF_{r,in}} f_{i_{in}} - \sum_{i_{out}=1}^{NJF_{r,out} \text{ and } i_{out} \neq i} f_{i_{out}} & \text{if } f_i \text{ is an out-flow} \\ \sum_{i_{out}=1}^{NJF_{r,out}} f_{i_{out}} - \sum_{i_{in}=1}^{NJF_{r,in} \text{ and } i_{in} \neq i} f_{i_{in}} & \text{if } f_i \text{ is an in-flow} \end{cases} \quad (6)$$

The overall network solution algorithm is an iterative procedure using the following steps:

1. The Network can be solved only when one or more flows are specified (reference flows).
2. For each process in the Network:
   2.1. Check if the process can be solved using the process precondition.
   2.2. If the process can be solved, then apply the process calculation procedure.
3. For each junction in the Network and each material *m* appearing in the junction:
   3.1. Check if the junction can be solved using junction precondition.
   3.2. If the junction can be solved, then apply the junction calculation.
4. Repeat from step 1 until one of the following condition met:
   4.1. All flows have been successfully calculated (the network has been solved successfully), or
   4.2. No new flows have been calculated during the last step (the network is under-defined and cannot be solved), or
   4.3. An exception is thrown when calculating a process (the network is over-defined and cannot be solved).

6. ECONOMIC VALUE CHAIN ANALYSIS TOOL

6.1 Scope and objectives

EVAT supplements the analysis of SEAT by addressing the value chain, its actors and their interactions. The value chain monitors the value added to the final product due to water use from stage to stage and can be described using monetary quantities. EVAT also provides the allocation of costs and incomes among the chain stages and actors that forms the basis for the analysis of potential distributional effects involved in the studied systems.

The main output from EVAT is the monetary flows that can be used to estimate the total value added (*TVA*) to the product from water use, defined as:

$$TVA = EVU - TFC_{WS} - TFC_{WW} - TIC \quad (7)$$

In Equation (7), *EVU* represents the economic value-added from water use, TFC_{WS} is the cost related to water supply provision for rendering the water suitable for the specific use, TFC_{WW} is the cost related to wastewater treatment. *TIC* is valid (non-zero) when the implementation of a technology is examined and represents the equivalent annual total investment cost and the additional annual operational costs, from upgrading the system's value chain. *EVU* refers to the total benefits from direct use of water and is estimated using the residual value approach:

$$EVU = TVP - EXP_{NW} \quad (8)$$

where TVP is the total market value of product(s) and EXP_{NW} are the non-water related expenses in the water use stage. All terms in equations (7) and (8) are expressed in Euros per year.

EVAT is also used to calculate the net economic output of each actor i (NEO_i), defined as:

$$NEO_i = WS_i + VP_i - FC_i - IC_i \qquad (9)$$

The term WS_i represents the net revenues of the actor from the water services (incomes from services provided to other actors minus expenses from services received by other actors), while VP_i, FC_i and IC_i are the value of product(s), financial costs and annual investment costs, respectively, incurred in the pertinent stages of actor.

6.2 Operational aspects

EVAT operates on a similar to SEAT interactive environment, based on the network representation of the physical model. The core functionalities provided are:

- Management of the relevant actors, e.g. the specification of the actors involved in the water system and the assignment of the relevant stages to each actor.
- Specification of financial costs incurred in the system's processes and the incomes generated from products or services.
- Analysis of economic interactions among actors by identifying and quantifying the water services between actors.
- Calculation, presentation and reporting of the results. The software calculates the total value added from water use and the net economic output per actor. All economic results are broken-down either per stage or per actor.

6.3 Methodology

The approach adopted for the development of EVAT is based on the concept of inheritance used in object oriented design patterns. EVAT builds on the model developed in SEAT, inheriting the basic elements described in Section 4.3, and extending it to include economic information, necessary for the estimation of total value added and the net economic output of actors according to Eqs. (7-9). Two complementary views (modes) of EVAT operation permit the specification of the different financial elements in the value chain in an organized manner.

The "stages view" provides the context for defining the cost elements incurred in each stage of the water supply and use stages, as well as the incomes generated from product in water use stage. On the other hand, the "actors view" permits the specification of water services between actors, necessary to calculate the net economic output of actors.

Equivalent annual investment cost (from the upgrade of the value chain) is calculated by specifying the total investment cost, the life time of the implemented action and an interest rate. Operations and maintenance cost are composed by a fixed part plus the cost of productive inputs (resources) and/or any taxes paid for the emissions. The unit costs of resources and emissions are specified in the stages view and the actual costs are calculated using the corresponding flows from the SEAT model. A similar procedure is followed for the specification of incomes.

The "actors view" mode of EVAT operation is shown in Figure 8. Any type of water tariff structure can be specified by defining a flat rate and a volumetric tariff. The latter may be a fixed volumetric rate or a more complex block tariff (increasing or decreasing). Expenses and incomes from water services are calculated by combining the tariffs defined in EVAT with the water flow calculated in SEAT model.

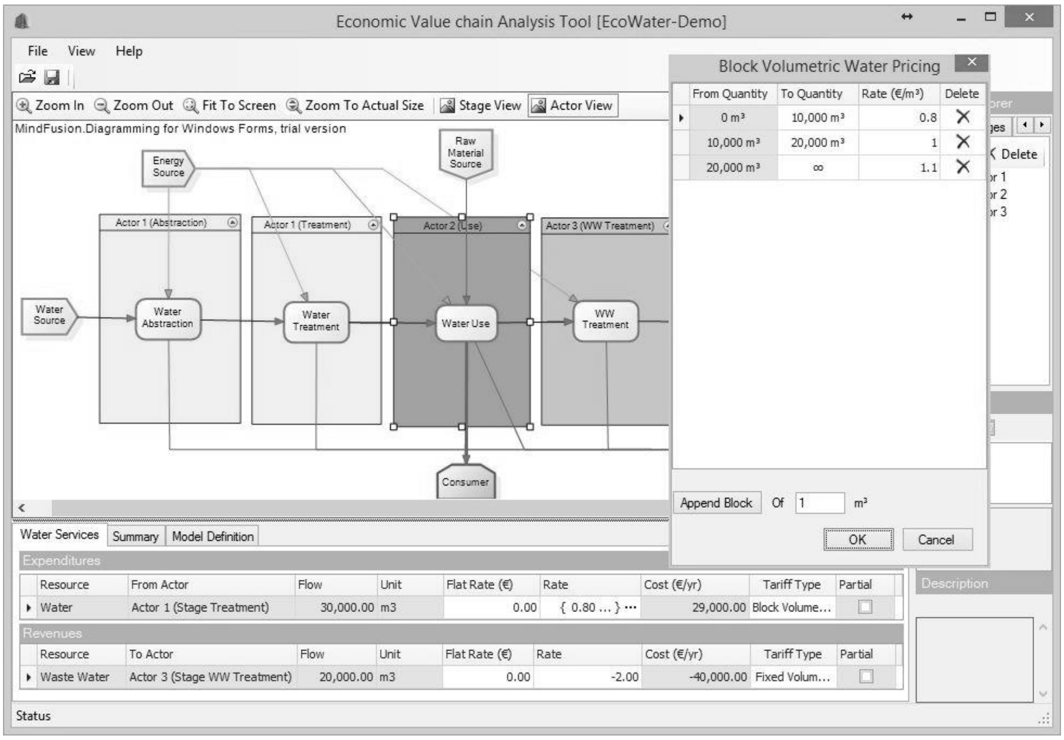

Figure 8. Actor view of the EVAT modelling environment and the specification of a block volumetric water tariff structure

7. DEMONSTRATION OF THE TOOLBOX

The operational aspects of the SEAT and EVAT modelling tools are illustrated through the assessment of the environmental impacts and the eco-efficiency performance associated with the water value chain in the case of a milk production unit of a dairy industry. An attempt to upgrade the value chain through the introduction of two innovative technologies is investigated and the eco-efficiency improvement of the system is evaluated.

7.1 System framing

The analysis of the dairy industry encompasses the whole water value chain starting from its origin as a natural resource and ending to a receiving water body after its environmental degradation in the production process. The main stages of the water value chain include the water supply, treatment and distribution systems, the use stage where water is used in the milk production process and the final stage were wastewater is treated before being discharged in a water body. Figure 9 presents the model of the physical system in the SEAT tool.

Each stage has been defined in such way that encloses the relevant actors involved in the system and the interactions among them. The actors involved in this case are:

- The Water Supply and Sewerage Company (OPERATOR) which has the responsibility for water supply in the industrial sector and the wastewater treatment facilities.
- The Milk Production Unit (INDUSTRY).

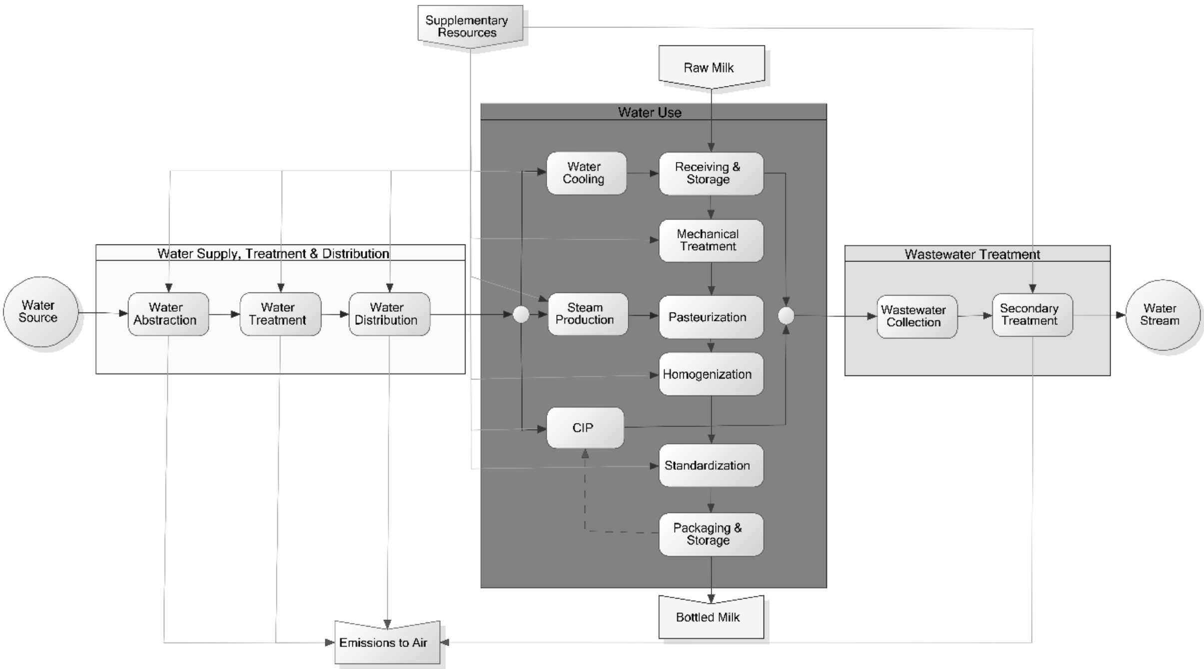

Figure 9. SEAT Model of the water use system in the dairy industry.

7.2 Baseline Eco-efficiency Assessment

7.2.1 Environmental assessment

The annual average milk production is estimated to be 190,000 m^3 of milk and the annual water requirements are assumed to be:

- 0.3 m^3 of water per m^3 of milk, for cooling;
- 1.25 m^3 of steam per m^3 of milk, for pasteurization; and
- 3.2 m^3 of water per m^3 of milk; for cleaning purposes.

Steam is produced using a natural gas fed boiler with average efficiency of 60%. All other energy requirements of the industrial unit are satisfied using electricity, bought from the grid. It is also assumed that each m^3 of milk requires 6 kg of sugar at the standardization process.

In the water supply chain, the total electricity requirements for abstraction, treatment and distribution processes are 0.29 kWh/m^3 of water abstracted and 3.5 gr of chemicals are required for treating 1 m^3 of water. Before being discharged to the water stream, wastewater is being treated in a WWTP with COD removal efficiency 97% and average electricity consumption of 0.25 kWh/m^3 of wastewater treated.

The environmental performance of the system is assessed through seven environmental impact categories. The characterization factors included in the CML-IA database are used for the calculation of the environmental impacts and the results are presented in Table 2 (Columns 3 and 4, per m^3 of water abstracted and per m^3 of milk produced, respectively).

Table 2. Environmental and eco-efficiency indicators.

Midpoint Impact Category	**Unit**	**ES_C (Unit/m^3 water)**	**ES_C (Unit/m^3 milk)**	**EEI_C (in €/Unit)**
Climate change	$kgCO_{2,eq}$	30.4	183	1.50
Eutrophication	$kgPO_4^{3-}{}_{,eq}$	0.01	0.04	7461
Acidification	$kgSO^{2-}{}_{,eq}$	0.28	1.69	162
Human toxicity	$kg1,4DCB_{,eq}$	1.36	8.18	33.5
Photochemical ozone formation	$kgC_2H_{4,eq}$	0.01	0.07	3771
Fossil fuels depletion	TOE	0.01	0.08	3.43
Freshwater depletion	m^3	0.17	1.05	260

7.2.2 Economic Assessment

The total value added to the milk from the use of water is calculated based on the unit costs of supplementary resources presented in Table 3. In addition to that it is assumed that the dairy industry sells the product (bottled milk) for 400 €/m^3. Regarding the expenses for water services, the dairy industry buys water from the water utility operator for 1.5 €/m^3 and pays as a fee 1 €/m^3 for wastewater collection and treatment. Finally, the annual O&M costs of the industrial unit have been assumed to be equal to 1M€.

Table 3. Unit costs of supplementary resources.

Resource	**Unit Cost**
Raw milk	200 €/m^3
Sugar	400 €/kg/tonne
Cleaning Chemicals	0.32 €/kg
Electricity	86 €/MWh
Natural Gas	0.5 €/m^3

Table 4 summarizes the economic results for both actors involved. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 52,101,706 €/yr (or 274 €/m^3 milk produced).

Table 4. Economic results for system actors (all values in €/*yr*.).

Actor	**Annual O&M Cost**	**Gross Income**	**Revenues from Water Services**	**Net Economic Output**
Industry	-42,780,247	95,000,000	-2,189,750	50,030,002
Operator	-118,046	0	2,189,750	2,071,704
Total Value Added:				52,101,706

7.2.3 Eco-efficiency Assessment

Based on the environmental and value assessment, the seven relevant eco-efficiency indicators are calculated and presented in Table 2 (last column). However, only for four of them (climate change, fossil fuels depletion, freshwater depletion and eutrophication), the contribution of the foreground system is significant enough (>30%), so that a technological intervention in the water value chain could affect the performance of the whole system. Furthermore, by comparing the values of the eco-efficiency indicators with similar values of other representative industrial water values chains (Angelis-Dimakis et al, 2014), it can be pointed out that the value for eutrophication is too high to be considered an environmental threat. Thus, the upgrading of the system through innovative technologies should aim at improving these three key indicators (climate change, fossil fuels depletion, freshwater depletion).

7.3 Identification of Technologies

To identify possible improvements in the water value chain and assess the environmental performance by applying alternative technologies, two scenarios are investigated and compared on the basis of the eco-efficiency indicators.

The technologies analysed are:

- Installation of a company owned water treatment plants with simultaneous recycling of wastewater discharged from the production process and diversion to CIP process (Scenario 1). This change in the water supply chain will result to water saving of 75% and the required installation cost reaches 500,000 € with a technology lifetime of 10 years.
- Replacement of the existing gas boiler (efficiency 60%) by a more efficient (80%) in the Steam Production process (Scenario 2). The investment cost is assumed to be 100,000€ and the boiler lifetime 30 years.

7.4 Technology Scenario Assessment

Figure 10 presents the relative change in the seven eco-efficiency indicators of the upgraded system compared to those of the current situation (baseline scenario). The *TVA* from water use in the two alternative scenarios is:

- 52,034,413 € or 273 €/m^3 milk produced (Scenario 1)
- 52,671,706 € or 277 €/m^3 milk produced (Scenario 2)
- The application of a CIP system significantly improves the freshwater resource depletion indicators, as it is expected. However, all other eco-efficiency indicators are not affected since a minor improvement is counterbalanced by the slight decrease of the TVA. On the other hand, the installation of a more efficient boiler leads to a more balanced improvement of all 7 eco-efficiency indicators, which is further enhanced by the increase on the overall *TVA*.

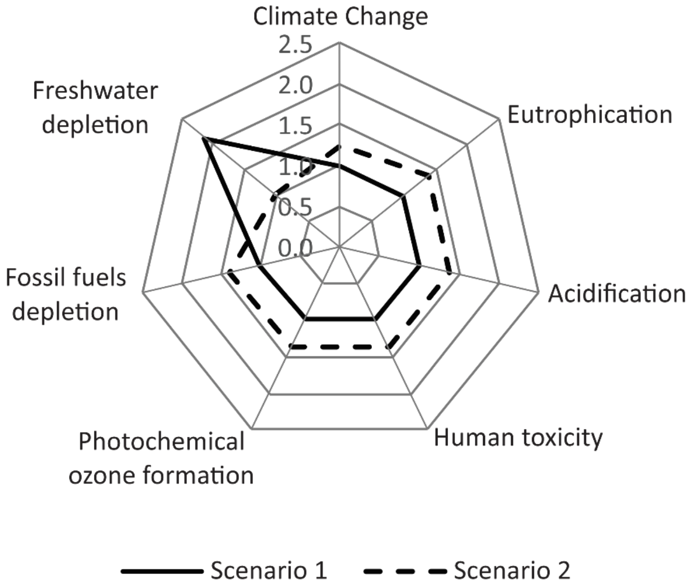

Figure 10. Comparison of eco-efficiency indicators in the three scenarios

8. CONCLUSIONS

The EcoWater Toolbox, an integrated suite of on-line tools and resources for assessing eco-efficiency improvements from innovative technologies in water use systems at the meso-level, was presented in this paper. The Toolbox has been designed to support the methodological approach developed in EcoWater project and integrates a technology inventory, an indicators repository and a pair of modelling tools which combines both economic and environmental viewpoints into a single modelling framework.

The methodological and operational aspects of the Toolbox and the integrated tools were analysed and tested through a simple case study concerning a milk production unit of a dairy industry. The case study demonstrates the capability of the Toolbox to support four steps of eco-efficiency assessment methodology developed in the context of EcoWater project. The upgrade of the value chain through the introduction of two innovative technologies was also analysed and the eco-efficiency improvement of the system was evaluated.

The EcoWater Toolbox has been successfully tested in eight case studies, in three different sectors of water use. Two of the case studies focused on agricultural water service systems, two case studies on urban water supply systems, while four of them focused on industrial uses. One argument that has been raised during its application, is that due to lack of similar studies, there do not exist known and validated benchmarks for the majority of the indicators used. Thus, policy makers cannot base a decision solely on the assessment of the baseline conditions of a given system. For that reason, the Toolbox should be considered as an open access repository of case studies with the aim to estimate a range for all the eco-efficiency indicators and to even identify reference values for normalizing them.

One of the strength of the Toolbox is the provision of decision support when comparing two or more alternative configurations of the same system. However, the Toolbox does not necessarily dictate the most eco-efficient option that should be definitely applies, but provides all the necessary input to assess the trade-offs between environmental and economic performance, in order to prioritize and target policy actions.

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