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Research article

# Eco-efficiency of agricultural water systems: Methodological approach and assessment at meso-level scale

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A B S T R A C T

This study presents a methodological framework for the meso-level eco-efficiency assessment of agricultural water systems using a life-cycle system-based approach. The methodology was applied to the *Sinistra Ofanto* irrigation scheme, located in Southern Italy, where about 28,165 ha are under irrigation. The environmental performance of the system was evaluated through a set of selected mid-point environmental impact categories while the economic performance was measured using the total value added to the system's final products due to water use and the adopted management practices. Both economic performance and environmental performance were measured at different stages and for each stakeholder in the value chain. A distinction was made between foreground and background systems referring, respectively, to the processes that occurred inside the water system boundaries and those used for the production of supplementary resources. The analysis revealed that the major environmental burdens are: i) the freshwater resource depletion (i.e. excessive groundwater pumping), ii) climate change (i.e. direct emissions due to fertilizer use and diesel combustion), and iii) eutrophication (as a result of excessive application of N and P fertilizers). A considerable impact was observed on the background system where energy, fuel and agrochemicals were produced thereby confirming the prominent role of background processes in the comprehensive eco-efficiency assessment. The presented methodology aimed at the quantitative assessment of the eco-efficiency level rather than at the identification of the most affected environmental category. Hence, the results can be used to compare the performance of the system from one year to the next, among different stakeholders (water users) and/or to assess the impact of adopting innovative technologies and management practices. Moreover, the presented approach is useful for comparing the performance among different agricultural water systems and also in respect to other meso-level water systems in a cross-sectorial analysis.



## 1. Introduction

The development of the agricultural sector greatly depends on irrigation especially in arid and semi-arid regions. Irrigation brings many benefits like stabilized crop production and farmer's revenue, increased food security, lower food prices, higher employment and more rapid social and economic development of agricultural areas (Stockle, 2002). However, intensive irrigation practices could induce numerous detrimental impacts on the environment and put unsustainable pressure on water resources (Tilman et al., 2002). Therefore, the performance assessment of agricultural water systems is increasingly important to safeguard the sustainability of irrigated lands.

The concept of eco-efficiency (EE) was used as a tool to analyze farm sustainability, i.e., to relate economic value of an activity to its impact on the environment (Rüdenauer et al., 2005). It is suitable to monitor progress in agricultural systems and to evaluate the uptake of eco-innovative technologies and practices that can contribute to environmental protection or to a more efficient use of natural resources (Levidow et al., 2014a).

Practical application of EE requires the definition of variables in the nominator and the denominator of EE ratio and the specification of created value added and corresponding environmental impact (Huppes and Ishikawa, 2005). Even though no standard indicators and measurement for economic and environmental values exist (Koskela and Vehmas, 2012), all international groups working on EE indicators use similar methodologies (Life Cycle

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Assessment, LCA and Life Cycle Costing, LCC) and calculate similar sets of ratios (Müller and Sturm, 2001).

The very simple indicators such as GDP over $CO_2$ emission or water use at macro-level, or units of output per unit of waste or environmental pressure at micro-level (Gomez-Limón et al., 2012; Koskela and Vehmas, 2012) cannot be used to analyze systemic changes and to interlink heterogeneous stakeholders across the entire value chain of a production/service process. Therefore, a meso-level assessment is needed to focus on the interconnection between the micro and the macro level and to address the dynamic behavior of a product/service system. The meso-level EE metric encompasses the entire value chain and all major stakeholders and can be used to analyze interdependencies and heterogeneity among different production systems, industries and actors (Levidow et al., 2015). On this basis, in the agricultural water sector, a continuous knowledge-exchange can be established to support more water-efficient management combining wider environmental benefits for the society with economic advantage for farmers (Levidow et al., 2014b).

This study presents a new methodological approach for the eco-efficiency assessment of meso-level agricultural water systems and its application to the *Sinistra Ofanto* irrigation scheme located in Southern Italy. The methodology was developed in the frame of the EcoWater project (FP7-ENV) aimed at the uptake of new technological solutions for the improvement of EE in the water sector at meso-level scale. The environmental performance was addressed by LCA using mid-point indicators, while the economic performance was measured using the total value added due to water use and adopted management practices. Our assessment identified the environmental impacts of specific stages/processes across the entire value chain and supported the stakeholders to improve the water system management and EE performance.

## 2. Materials and methods

### 2.1. Study area description

The “*Sinistra Ofanto*” irrigation scheme, located in Puglia region, covers a total area of 40,500 ha, out of which 38,815 ha are irrigable land and 28,165 ha are under irrigation. The study area has a semi-arid Mediterranean climate, with wet and mild winter and dry and hot summer. Average annual precipitation is about 520 mm and average annual temperature is 16.4 °C, ranging from 10.3 °C in January to 22.6 °C in July.

The irrigation scheme, constructed in the 80's and designed to operate “on-demand”, is managed by the water agency “*Consorzio Bonifica della Capitanata*” (CBC), which is in charge of the water withdrawal from Ofanto River, its conveyance, storage and distribution to the farms (Lamaddalena et al., 1995). CBC is a non-profit water user organization which covers the operational costs through the water tariffs paid by farmers. The system diverts water from Ofanto River and conveys it to three main sub-schemes (irrigation zones) including 14 operational districts of a size ranging from 456 ha to 4248 ha. In each irrigation zone, a farmers' association was established to deal with on-farm water distribution and management.

Irrigation zone 1 consists of three districts and covers a total area of 2900 ha. It is located along the left bank of Ofanto River and is supplied with water by the main Ofanto-Capacciotti conveyance pipe through three electrically powered lifting systems. In an average hydrological year, zone 1 receives about 3 $Mm^3$ from the CBC and a complement of its water requirements from Ofanto river (0.5 $Mm^3$) and the aquifer.

Irrigation zone 2 comprises about 7700 ha of irrigated land subdivided into four districts at higher elevations than zone 1. Through an electrically powered lifting plant water is delivered to daily regulation reservoirs and from there to the farmers by means of a gravity-fed pipe distribution network. In an average hydrological year, zone 2 receives about 11 $Mm^3$ of water from Ofanto river through the conveyance network and the rest from the aquifers.

Irrigation zone 3 extends over 20,400 ha subdivided into seven irrigation districts. Water is conveyed by the Ofanto-Capacciotti conduit to Capacciotti dam and then delivered to farms by the gravity-fed conduit and daily regulation reservoirs. Zone 3 receives, on average, about 25 $Mm^3$ of water from Capacciotti dam while the rest is pumped from Ofanto river (about 1 $Mm^3$) and aquifers. Water from river and aquifers is abstracted by diesel pumps directly managed by farmers.

### 2.2. Methodology framework

The methodology adopted in this work represents a system-based approach focusing on the estimation of the environmental impacts and the EE performance along the water value chain. Differently to other approaches (e.g. product-based) commonly applied in LCA studies (Brentrup et al., 2004; Pelletier et al., 2008), the presented methodology encouraged the selection of technologies and management solutions targeting to the improvement of the meso-level system as a whole and not to the improvement of a product or a specific production sector.

The methodology was based on a combination of the Life Cycle Assessment (LCA), according to ISO (2006), and the assessment of Life Cycle Costing (LCC) as illustrated in Fig. 1. In the proposed meso-level approach, the economic costs and benefits and environmental pressures were measured at different stages and considering different stakeholders in the value chain. The main stakeholders (CBC and farmers' associations in three irrigation zones, FA1, FA2 and FA3, respectively) were fully involved in the process of system mapping and interpretation of results. The analysis and all input data (related to climate, water distribution, cropping pattern, cultivation practices, market prices, etc.) referred to year 2007 representing the average hydrological conditions for the period 1989–2011. The eco-efficiency indicators (EEI) were

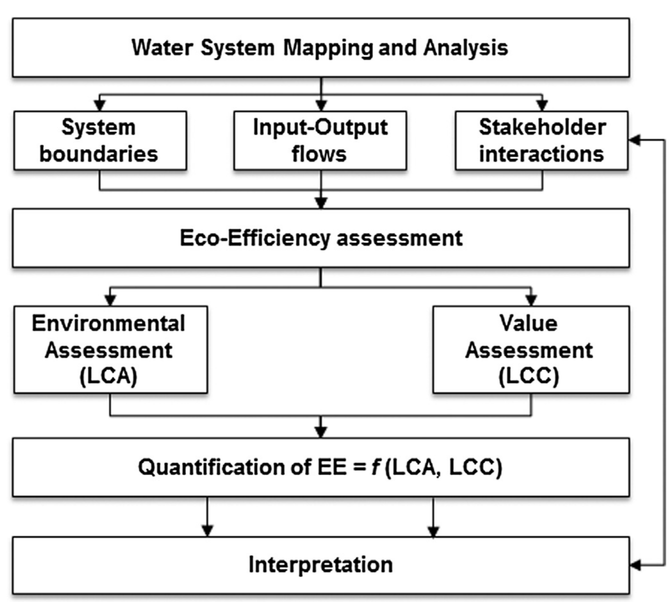


**Fig. 1.** Methodological steps of the eco-efficiency assessment adopted for a meso-scale irrigation scheme (EE: eco-efficiency; LCA: Life Cycle Assessment; LCC: Life Cycle Cost).