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Improvement of the irrigation performance in Water User Associations integrating Data Envelopment Analysis and Multi-regression models

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Abstract

Irrigation performance assessment is particularly important in the Water Users Associations (WUAs) operating in Calabria (Southern Italy), where collective irrigation service suffers from poor performances both from an operative and economic point of view. For many years Data Envelopment Analysis (DEA) has been proposed for the diagnosis of Water Users Association performance; however, the number and type of related performance indicators must be selected with caution to avoid misleading and unrealistic results.

In this paper, we propose to apply DEA to a limited but significant set of performance indicators and to couple it to Multiple Regression Analysis by Principal Component Regression (PCR). The proposed methods were applied to evaluating the system operation and financial performances of ten of the eleven WUAs operating in Calabria (Southern Italy) to indicate potential improvements.

The analysis of the current performance indicators collected throughout five years (2011-2015) showed that in Calabrian WUAs the irrigation service is underutilised, and water delivered to crops is always in excess; the cost recovery of WUAs is very low, because of staff costs and low fee collection. DEA identified five inefficient WUAs and took the remaining five organisations as reference for performance improvement. The input-oriented DEA coupled to PCR has suggested reducing water usage, management and personnel costs and water fees, by increasing the irrigated area and the irrigation service coverage. The output-output oriented DEA coupled to PCR predicted a high increase of the cost recovery capacity of the inefficient WUAs, but in this case the improved scenario required an abnormal increase (10-fold) of the irrigated area, which may be basically unfeasible.

Overall, the integration of DEA with multi-regression models and their implementation in the case study, using a limited set of easy-to-survey performance indicators, appears to be a powerful and easy tool for decision makers in the irrigation sector.

Keywords: collective irrigation; performance indicators; Principal Component Regression; service efficiency; improved irrigation scenario; cost of the irrigation service.

1. INTRODUCTION

In many parts of the world, as, for instance, in Southern Italy and Spain, irrigation water is usually supplied from sources and delivered to farms by Water Users Associations (WUAs). The evaluation of performances in these collective irrigation systems is often neglected, also because it is considered a time-consuming and costly activity, whose results are appreciable only in the long term (Malano et al., 2004). The need for such assessment activities is particularly important in the WUAs operating in Calabria (Southern Italy); here, the collective irrigation service suffers from poor performances both from an operative and economic point of view in a region where agriculture is by far the most important economic sector (Zema et al., 2015). Farmers use large volumes of water to irrigate crops with low requirements or pump groundwater when water supplied from surface water sources is sufficient.

In such contexts, the evaluation of WUA performance is an important management tool to aid in providing a sound irrigation service, because it may support the system management in the identification of the strengths and weaknesses of an organisation and in the improvement of the organisation’s performance and productivity, taking into account its objectives (Alcon et al., 2017). One of the most widely-used tools for irrigation performance assessment is "benchmarking", a set of techniques able to identify the gaps between current and achievable performance and making changes to realise a higher standard of performance (Malano et al., 2004). Benchmarking techniques are often applied to Water Users Associations by calculating and processing the so called "performance indicators". These techniques consider different performance indicators, summarising the main management traits to describe and compare the management of the analysed WUAs (Soto-Garcia et al., 2013). Benchmarking of collective agencies managing irrigation services is relatively recent and some mathematical/statistical techniques, such as Principal Component Analysis (PCA), Agglomerative Hierarchical Clustering (AHC), Quality Index (QI) calculation, have been applied and validated in different areas worldwide for benchmarking. As regards the Mediterranean basin (which shares similar climatic and structural conditions with Italian agriculture), the following studies ~~of~~ can be cited: Zema et al. (2015) and Rodríguez-Dìaz et al. (2008) used PCA, AHC and QI in Calabria (Italy) and Andalusia (Spain), respectively; Còrcoles et al. (2010; 2012) applied AHC in WUAs of Castilla-La Mancha, Spain; Uysal and Atis (2010) and Koç and Bayazit (2015) processed the performance indicators.

However, if applied to collective irrigation just as a comparative assessment of performance indicators, benchmarking may provide an incomplete picture and such assessment may be difficult to interpret (Malano et al., 2004). Therefore, other tools are required, incorporating diagnostic analysis to identify those factors which majorly contribute to improving the levels of irrigation service performance.

Data Envelopment Analysis (DEA) is a non-parametric, linear programming method that works with input/output ratios to calculate relative efficiencies of organisations. This method has been proposed for benchmarking performance in service sectors, such as irrigation and drainage, because it has a number of advantages. Firstly, DEA has the ability to analyse several inputs and outputs simultaneously and derive an efficiency rating within a set of analysed units; secondly, DEA does not require the development of standards against which efficiency is measured; thirdly, it does not require predetermined production functions to relate inputs and outputs (Malano et al., 2004). However, DEA has so far found little application in irrigation, except for few literature studies (Rodríguez-Dìaz et al., 2008; Borgia et al., 2013; Frija et al., 2009). To summarise, in irrigation districts of Andalusia (Spain) Rodríguez-Dìaz et al. (2008) found by DEA great differences in terms of performance between districts with open channel and pressure water delivery systems; water use was more efficient in districts where users were charged per unit of irrigation water consumed. DEA and AHC applied by Borgia et al. (2013) in irrigation schemes of Mauritania demonstrated that, on a technical basis, large schemes performed similarly to small-scale schemes, while these latter showed greater variability of crop yield and technical efficiency, which may indicate a larger margin for improvement. The DEA by Borgia et al. (2013) also helped to identify the specific reference schemes for each low performing scheme. The use of DEA and a Tobit model in WUAs of Tunisia highlighted that management and maintenance are important tasks in determining the overall performance and efficiency (Frija et al., 2009).

Moreover, when applying DEA for benchmarking of irrigation performance, a degree of caution must be exercised in the number and selection of variables to be analysed and processed. As a matter of fact, the selection of variables must be closely related to the objectives of the study and the productive process being evaluated. In addition, there is the risk that the adoption of too many performance indicators would allow DEA to consider all or the majority of the analysed WUAs efficient and thus it would not provide any information about deviations of current situation from optimal management (Malana and Malano, 2006; Alcon et al., 2017). According to Soto-Garcia et al. (2013), the performance indicators should be: (i) easy to obtain from data routinely collected in the WUAs; (ii) mostly oriented towards aspects related to WUA management; and (iii) suitable for the purpose of each specific study. Therefore, a limited set of non-redundant performance indicators - but representative of as many as possible of the productive factors of WUAs - must be chosen for DEA application at the irrigation sector, in order to determine the relative efficiency of a WUA and its position in relation to the optimal situation. Other non-parametric techniques, such as multi-regression models, can be integrated to DEA and applied to the performance indicators not considered by DEA itself.

This paper proposes a novel approach to optimise WUA performance by benchmarking, applying DEA to a limited but significant set of performance indicators, and coupling it to Multiple Regression Analysis by Principal Component Regression (PCR), in order to improve the performance of ten WUAs operating in Calabria. The combination of these techniques is targeted to fully delineate the performances of the inefficient WUAs under an optimised management scenario, taking as reference a sample of efficient WUAs and using the values of a set of operation and financial performance indicators collected throughout five years. This aggregated diagnosis of current status and the prediction of future performance may be useful to the decision-makers to give them a concrete idea about the overall performance of an irrigation scheme vis-à-vis other irrigation schemes (Phadnis and Kuhlshrestha, 2013).

2. MATERIAL AND METHODS

2.1 Study area

The region of Calabria is located in the extreme southern part of Italian peninsula. Its climate can be classified as Csa (mild temperate, dry and hot summer, in coastal zones) and Csb (mild temperate, dry and warm summer, in internal areas), according the Koppen-Geiger classification (Kottek et al., 2006).

Agriculture in Calabria is practised both on the few plains and in the hills. The majority of the cultivated areas are irrigated. Farmers commonly use collective irrigation systems, managed by 11 WUAs (called in Italian "Consorzi di Irrigazione e Bonifica") operating in the territory of Calabria (Figure 1). Many of these WUAs are also involved in land reclamation, dealing with soil conservation and watershed management, but with a role limited to ordinary maintenance. Each WUA manages a part of the Calabrian territory ("administrated area") and controls all the irrigation systems within its own part (“command area”). Irrigation water is delivered only to the areas covered by crops ("irrigated area").

The ten investigated WUAs together cover over 86% of the irrigated territory of Calabria. Olive and citrus groves, and vineyards are the dominant tree crops, beside vegetables, corn and forage as herbaceous crops (Table 1).Water is supplied from small rivers and natural or artificial reservoirs (except for WUAs "BSCS", "AIRC" and "BIRC", exploiting also groundwater) and is distributed to farmers mainly by rotational systems (except "TCZ"); some WUAs have recently begun to turn to on-demand system (e.g. "ICZ"). Network conduits are mainly pressurised pipelines, but open canals still exist in many WUAs. The volume of irrigation water delivery (VIWD) varies from 2.7 ("TVV") to 105.3 ("BICS") Mm^3 yr^{-1} (on the average 24.3 Mm^3 yr^{-1}). From WUA bulletins, water for irrigation is usually sufficient for the entire season, even though occasionally some periods of shortage are recorded. Farmers use mainly surface and sprinkler irrigation systems, with a low percentage making use of micro-irrigation (mainly in WUA "BICS"). Water is charged to farmers on the basis of the irrigated area (often differentiating by crop); only in the WUA "ICZ" farmers pay irrigation volumes effectively consumed, thanks to the adoption of automated measuring devices (Table 1).

2.2 Performance indicators

For the quantitative analysis of WUA performance, Malano and Burton (2001) have proposed a set of performance indicators (*service delivery*, *productive efficiency* and *environmental performance*). The performance indicators used in this study were selected based on both the availability of input data at the investigated WUAs and findings of some Authors. In more detail, the indicators of agricultural productivity and economics were not considered, since data of agricultural production and gross/net margins are not easily available for each farm or irrigation district, but are aggregated only at provincial or regional scales. The calculation of the indicators related to the environmental performance was not possible, because the analysed WUAs do not evaluate the irrigation water quality parameters and use of fertilizers. However, Còrcoles *et al.* (2010) stated that it is possible to reduce the set of indicators by omitting just the *production efficiency* and *environmental indicators* without loosing too much information. Therefore, in this study the attention was mainly paid to the indicators of service delivery performance, which include: (a) the adequacy with which the organization manages the operation of the irrigation delivery system to satisfy the water required by users (*system operation*); and (b) the efficiency with which the organization uses resources to provide this service (*financial performance*). More specifically, service delivery indicators include aspects such as water distribution and irrigation areas, while financial indicators are related to distribution of the total *Management, Operation and Maintenance* (MOM) cost of the irrigation district (Còrcoles et al., 2016; Ghazalli, 2004). Most of these indicators have strong interrelations; for example, the main differences among some indicators lie in considering different types of unit areas (command or irrigated) and volume of irrigation water (supplied, delivered, consumed, required) (Còrcoles et al., 2010). Therefore, the service delivery indicators were properly selected, considering those related to the "size of the system", "water usage" and "financial and organisation aspects". These data concerned:

- as regards the "size of the system": *Administrative Area* (AA, ha), *Command Area* (CA, ha) and *Irrigated Area* (IA, ha), understood as the total area under the administration of each WUA, the area equipped with irrigation infrastructure and actual irrigated area during the five years covered, respectively; *Number of Users* (NU, -), the number of farmers who are members of each WUA and serviced by the collective irrigation system (for this service, water fees are invoiced and collected by the WUAs); *Average Irrigated Area per Farm* (AIA, ha).
- concerning the "water usage": annual *Volume of Irrigation Water Delivery* (VIWD, m^3 $year^{-1}$), calculated as the product of discharge (measured by weir) by distribution times in open canals or directly by counters in pipelines; annual *Volume of Irrigation Water Required* (VIWR, m^3 $year^{-1}$). This latter parameter was calculated for each WUAs as a weighted mean of covered areas by the net irrigation requirement of each crop (that is, the quantity of water exclusive of precipitation required for normal crop production). The net irrigation requirement was estimated using the software CROPWAT 8.0 (Clarke et al., 1998; FAO, 2009) and performing the daily water balance for each crop over the five years. The daily meteorological data required by CROPWAT (maximum and minimum temperatures, precipitation, relative humidity, wind speed and daylight) were measured selecting for each WUA a barycentric meteorological station. In relation to the crop data, the root depth and crop coefficients for calculating evapo-transpiration (estimated by Penman-Monteith model) were derived from FAO guidelines (Doorenbos and Kassam, 1986); the farm cultivation practices (i.e. dates and operations) were identified by

interviewing the WUAs' managers. Soil hydrological parameters, in the absence of direct measurements, were estimated using the Pedo Transfer Function of Saxton et al. (1986) on the basis of the soil texture reported by the Soil Map of the Calabria Region (ARSSA, 2003). The total irrigation requirement of each crop (henceforth indicated as "water required") was calculated from the net irrigation requirement, considering farm irrigation efficiency according to the methods commonly used in each cropped area: for sprinklers the value of 0.70 was assumed, while the values of 0.85 (sprayers) and 0.95 (drippers) were considered for micro-irrigation, in accordance with the CROPWAT guidelines (Clarke et al. 1998; FAO 2009). Finally, daily data of total irrigation requirement were aggregated at an annual scale.

- the following "financial and organisation variables": *Gross Revenue Invoiced* and *Gross Revenue Collected* (GRI and GRC, € year^{-1}), that is the annual revenues due from water users for provision of irrigation services and collected fee actually paid; annual *Management, Operation and Maintenance Costs* (MOMC, € year^{-1}), providing the service (staff, maintenance, energy, management and other costs, excluding capital expenditure and depreciation/renewals); *Number of Personnel employed in the provision of the Irrigation service* (NPI).

These input data allowed the computation of the following indicators regarding service delivery performance and WUAs’ financial performance (beside each indicator its meaning is explained):

- *Irrigated area/Command area Ratio (ICR, %,* equal to IA/CA*)*, which is an indicator of the coverage of the irrigation service over each WUA command area; it is also known as *Cropping Intensity*, since it represents the actual intensity of land utilisation during the year (Còrcoles et al., 2016).
- *Annual irrigation Water Delivery per unit of Irrigated Area (WDIA,* m^3 ha^{-1}*)*, the most important service delivery performance indicator (Malano et al., 2004; Frija et al., 2009).
- Annual *Relative Irrigation Supplied (RIS, %)*, calculated as the ratio between WDIA and VIWR, this latter divided by the irrigated area (IA); thus *RIS* < 100% indicates that the water supply is insufficient to satisfy full irrigation demand, while *RIS* > 100% indicates that an excess of water is applied. Therefore, RIS is a measure of the degree of irrigation requirement fulfilment.
- Annual *Management, Operation and Maintenance cost per unit Area (MOMA, €* ha^{-1}*)*, ratio between MOMC and IA, which standardizes the management costs on the irrigated area. MOMA can be calculated either including or not including the cost of personnel in

MOM; however, given that this cost is generally proportional to the staff size (the differences of salaries among employees being very low regardless of their jobs), already included in NPI and SUIA parameters, we have excluded the staff cost in calculating MOMA (henceforth indicated as "MOMA$^-$").

- *Cost Recovery Ratio (CRR, %),* calculated as the ratio between GRC and MOMC, which represents an index of the degree of financial self-sufficiency of the WUA. Hereafter CRR will be indicated as CRR$^+$, the superscript indicating that the cost of personnel was included in MOMC required by CRR.
- *Revenue Collection Performance (RCP, %),* calculated as the ratio between GRC and GRI, indicating the WUA's capacity of due fee collecting (Koc, 2007);
- *Staffing number per Unit Irrigated Area (SUIA, persons 100-ha^{-1}),* the ratio between NPI and IA). This indicator is also called *Personnel Intensity* by Yercan et al. (2009).
- *Cost of the Irrigation Service per unit of irrigated area* (CIS*, € ha^{-1}),* which is the unit fee paid by users to the WUAs for the irrigation service.

Note that CIS and MOMA measure different variables: while MOMA is the cost of the irrigation service incurred by a WUA, CIS is the price of the irrigation service provided by a WUA to the farmers; alone, this latter does not cover the MOM costs, since an important share of the WUAs' revenues is usually covered by regional funds.

For some of the indicators used in this study, literature (e.g. Bekisoglu, 1994; Vermillion, 2000; Nelson, 2002; Yercan et al., 2009) reports the following acceptance limits, to which the values detected in this study were compared:

- RCP and CRR, poor if < 40%, acceptable if in the range 40-60%, satisfactory if between 60-75% and good if > 75%;
- ICR, poor if < 30%, acceptable if in the range 30-40%, satisfactory if between 40-50% and good if > 50%;
- SUIA, poor if > 0.3 persons per 100 hectares, satisfactory if < 0.3 persons per 100 ha.

2.3 Data collection

The methodology was applied to ten of the eleven WUAs in Calabria; one of the WUAs did not provide data. A questionnaire was given to the managers and technicians in order to collect the input parameters needed to calculate the performance indicators. The questionnaire complemented the information contained in the annual reports produced by the WUAs. The collected data covered five years: 2011 to 2015.

2.4 Statistical Analysis

In order to identify possible mathematical structures between performance indicators and the related correlation coefficients, the Spearman correlation matrix was computed based on the current values of indicators surveyed in the analysed WUAs. Preliminarily, the indicators were standardised by converting data to zero mean and unit variance.

The benchmarking process of irrigation performance in the ten WUAs of Calabria was carried out by coupling DEA and PCR, as explained below. In order to reduce the number of the analysed variable, these techniques were applied only to the performance indicators (*ICR*, *WDIA*, *RIS*, CRR^+, $MOMA^-$, *RCP*, *SUIA* and *CIS)*, besides two other input parameters measuring the WUA size (that is, *IA* and *UN*), and not to all the variables (including the other input parameters) surveyed at the WUAs. This choice derives from findings of some Authors, who state that most of the indicators usually utilised in benchmarking the irrigation performance have strong interrelations with each other.

2.4.1 Data Envelopment Analysis

DEA, developed by Charnes, Cooper, and Rhodes in 1978, was previously applied in the irrigation sector (e.g. Rodriguez-Diaz et al., 2004a; 2004b; 2008; Borgia et al., 2013; Frija et al., 2009) to evaluate the efficiency of a given WUA compared to a group of representative WUAs (considered efficient and thus assumed as reference) and identify the optimal management scenario on a quantitative approach. DEA belongs to the set of efficient-frontier techniques, allowing the comparison of less efficient to more efficient organisations, these latter falling on the frontier (Malano et al., 2004). In DEA the frontier function is constructed using virtual units that are weighted combinations of observed most efficient Decision Making Units (DMUs) (Coelli et al., 2005).

In this study DEA was implemented by an "input oriented" (I-O) and an "output oriented" (O-O) model. The I-O model measures the ability of a DMU (in our case a WUA) to maintain the same capacity of production using a minimum of inputs (Cooper et al., 2004). Irrigated agriculture relies on finite and scarce water resources and in its current situation, agriculture in Europe does not need increased production, but rather a more efficient use of inputs (Rodriguez-Diaz et al., 2004a; Frija et al., 2009); therefore, in our study the use of I-O DEA was considered more appropriate to reduce inputs consumed in the production process

(Malana and Malano, 2006). IA is the constant output for the efficient WUAs; for the inefficient WUAs all the performance indicators related to WUA management efficiency (included IA) are optimised.

The O-O model refers to the capacity of a DMU to achieve the maximum volume of production output with the available inputs. In our study, since we want to maximize the financial performance of some inefficient WUAs, we adopted also an O-O DEA, using as input factors the same parameters as the I-O DEA, but we adopted CRR^+ as output. The O-O DEA predicts to what extent managers can increase the financial self-sufficiency (measured by CRR^+) of the inefficient WUAs by modifying the performance levels.

One of the analysis options in DEA is a choice between constant returns to scale and variable returns to scale (Frija et al., 2009). Since the scale of activity (that is, the size of the WUAs) has an important effect on its efficiency (Umetsu et al., 2005), we decided to adopt the variable return to scale. Increasing returns to scale indicate that an increase in the input resources produces more than proportionate increase in outputs. Similarly, decreasing returns to scale suggest a less than proportionate increase in the outputs in response to an increase in inputs (Malana and Malano, 2006).

2.4.2 Multiple Regression Analysis by Principal Component Regression (PCR)

Considering that DEA was applied to a limited set of performance indicators, it is necessary to estimate the values of the remaining indicators in the target scenarios for the inefficient WUAs. To this aim, predictive models were built between the five performance indicators used by DEAs (independent variables) and the remaining five indicators (dependent variables) to be predicted. Principal Component Regression (PCR, Massy, 1965) was used as predictive model. PCR is a combination of Principal Component Analysis (PCA) and Multiple Linear Regression (MLR, often an Ordinary Least Squares, OLS, regression), where the Principal Component (PC) scores are used as predictor variables and linear combinations are constructed between predictor and response variables. PCR is advised when the factors are many and highly collinear (Wold, 1975). As a matter of fact, many pairs of performance indicators adopted in our study were strongly correlated (as shown by the Spearman's correlation matrix) and therefore collinear. Since principal components (PC) are orthogonal, the multicollinearity problems of the original variables are removed (Carrascal et al., 2009).

PCR was implemented in the efficient WUAs as follows: (i) a PCA was applied to the five independent variables used by DEA; (ii) an OLS regression was run on the first two PCs; (iii) the dependent variables were calculated as a linear combination of the PCs, explaining most of the variance of the original independent variables; (iv) in these linear equations the scores of PCs were replaced by the scores calculated referring to the original independent variables (that is, those used by DEAs). PCR was calibrated for the efficient WUAs using the values of the five DEA performance indicators for the current scenario; the derived linear equations were applied to the inefficient WUAs in order to predict the target values of the remaining indicators based on the target values of performance indicators provided by DEA.

Figure 2 reports the conceptual scheme of coupling DEAs and PCR. To summarise, PCR provides a linear function "f(x)", which receives as input the five performance indicators used by DEA and predicts the remaining indicators ("y"); this funcion is calibrated on the efficient WUAs. The function "f(x)" is applied to the inefficient WUAs and provides the future values of the remaining indicators, receiving as input the values of the performance indicators optimised by DEA (in Figure 2 indicated as "g(x)" function).

PCR was performed using XLSTAT® software, while DEA was performed using the free software DEAP 2.1 (Coelli, 1996).

3. RESULTS

3.1 Main characteristics of WUAs

The WUA "BICS" has the largest command area (18685 ha) and irrigates 5335 farms, while the smallest WUA is "TVV" (CA of 676 ha and 150 associated farmers). The area effectively irrigated (IA) varies between 262 ("BIRC") and 10007 ("BICS") ha with an average value of 2609 ha and a low annual variability (see CV in Table 2) throughout the survey period. The average farm size (AIA) is 1.23 ha (Table 2).

As regards the water usage, the volume of irrigation water delivery (VIWD) varies from 2.7 ("TVV") to 105.3 ("BICS") Mm^3 yr^{-1} (on the average 24.3 Mm^3 yr^{-1}). The annual Volume of Irrigation Water Required (VIWR) is in the range 0.46 ("BIRC") - 32.49 ("BICS") Mm^3 year^{-1} with an average value of 7.72 Mm^3 year^{-1}.

Concerning the financial aspects of the analysed WUAs, the gross revenue amount collected from the users (GRC) (on average 341660 € yr^{-1}) is much lower than the amount invoiced (GRI) (mean value equal to 528070 € yr^{-1}); both revenues show a high variability among WUAs (Table 2). The MOMC (including the staff cost) is much higher compared to the revenues paid by users for the irrigation service, from 3-fold ("BICS") to about 13-fold

("BIRC") the GRC (Table 2). The size of the irrigation staff (NPI) is practically constant in time (as shown by the very low inter-annual CV), but is strongly variable among the WUAs: from 22 ("TVV") to 120 ("BICS") persons (with different roles and jobs, ranging from field workers to directive charges) are employed in the irrigation service (Table 2).

3.2 Analysis of performance indicators in the current status

This investigation reveals large differences in performance indicators and in technical efficiency among irrigation schemes. ICR shows a mean value of 27.9% and thus the cropping intensity is in general poor, in accordance with the literature limits reported above; this indicator varies widely among the WUAs: from poor values (8.0% in "TRC") to good levels (54.7%) recorded in "TVV" (Table 3). WDIA is in the range 6500 ("TCZ") - 14900 ("TRC") m^3 ha^{-1} yr^{-1} (on average 9500 m^3 ha^{-1} yr^{-1}) (Table 3). Based on the water volumes delivered to farmers and required by crops, a mean RIS equal to 417% was estimated with a peak as high as 978% ("TRC") (Table 3).

According to the acceptance limits reported above, mean RCP is satisfactory (70%). Only one WUA ("TRC") is able to fully collect the invoiced fees, while in some other WUAs (for example, "AIRC") payment evasion is very high (up to 60%) (Table 3). $MOMA^-$ (which excludes staff costs) is on average equal to 1445 € ha^{-1} yr^{-1} and highly variable among WUAs (Table 3). This variability is expected, considering that MOM costs vary according to different factors: the physical condition of a network, whether routine maintenance-repair works are carried out or not, organisation structure of the WUAs, collected irrigation fee revenue, size of irrigated area and rate of irrigated to command area, whether water is supplied by gravity or pumping, etc. (Koç, 2007; Zema et al., 2015). CRR^+ (considering personnel beside MOM) varies from 7.9% ("BIRC") to 34.5% ("BICS") with an average value of 17.5% (Table 3). SUIA is on average 5.2 persons per 100 ha of IA with a high variability among the WUAs (1.2 - 20.6 persons per 100 hectares) (Table 3). Finally, CIS of Calabrian WUAs is on average 262 € ha^{-1} yr^{-1}. However, this price is affected by a high variability among WUAs (from 118 € ha^{-1}, "TCZ", to even 611 € ha^{-1}, "BIRC"), but it is constant throughout the monitoring period (CV = 0, Table 3).

3.3 Correlations between performance indicators

The analysis of the Spearman matrix highlighted interesting correlations among pairs of performance indicators, measured by the coefficient of correlation ("r"). In more detail, the processing of performance indicators showed that (Table 4): (i) CRR^+ (directly, r = 0.758) as well as SUIA and CIS (inversely, r = -0.988 and -0.733, respectively) are fairly correlated with IA; (ii) furthermore, CRR^+ is inversely influenced by SUIA (r = -0.745); (iii) $MOMA^-$ is directly dependent on WDIA (r = 0.758) and inversely on ICR (r = -0.721); (iv) finally, high correlations between CIS and IA (inverse, r = -0.733) as well SUIA (r = 0.745) are found.

3.4. Analysis of WUA efficiency and performance improvement

3.4.1 Data Envelopment Analysis

Initially, we applied DEA to all the input performance indicators, considered as productive factors, except those indicators used as DEA output (IA for I-O and CRR^+ for O-O). These DEAs showed that all WUAs were unrealistically efficient; in this way, DEA did not provide any information about WUAs' performance and efficiency level. To avoid this, we ran DEAs (both I-I and O-O) with several combinations of a progressively reduced number of input parameters. Finally, only a selection of four indicators was used as input for DEA: (i) a parameter related to water delivery service (WDIA); (ii) the most important indicator of the financial aspects of management, operation and maintenance activities ($MOMA^-$), excluding personnel costs; (iii) the staff cost per unit area (SUIA); (iv) the direct impact of collective service on users, shown by CIS.

3.4.1.1 Input-Oriented DEA

I-O DEA considered five WUAs (BICS, IKR, ICZ, TCZ and TVV) as efficient and thus took them as reference, keeping constant all the performance indicators used. For the remaining WUAs (BSCS, BMCS, TRC, AIRC and BIRC, that is, the inefficient organisations) a mean level of efficiency equal to 65.9% was found; the most inefficient WUA was "TRC" (mean efficiency of 46.3%) (Table 5). A mean efficiency of about 45% implies that the same level of output could be produced with about 55% of the resources, if these units were performing on the frontier; in other words, 45% of overall resources could be saved by raising the performance of these WUAs to the highest level. In order to limit such inefficiency, DEA showed that IA would triple (+202.9%) by decreasing on the average the productive factors as follows: (i) WDIA by 35.0%; (ii) $MOMA^-$ by 59.0%; (iii) SUIA by 47.1%; and (iv) CIS by 53.1% (Figure 3a).

3.4.1.2 Output-Oriented DEA

O-O DEA considered the same WUAs to be efficient and inefficient as I-O DEA. The inefficient WUAs showed a mean efficiency equal to 49.7%; the most inefficient WUA was "BIRC" (mean efficiency of 23.0%) (Table 5). For the five inefficient WUAs, DEA provided an increase of CRR^+ on average of 135.0%, if the following average decreases of the input performance indicators were achieved: (i) WDIA of 10.8%; (ii) $MOMA^-$ of 35.9%; (iii) SUIA of 65.5%; and (iv) CIS of 45.0% (Figure 3b).

3.4.2 Multiple Regression Analysis (by Principal Component Regression)

Running PCR applied to the inefficient WUAs, the component sub-model PCA retained in the first two PCs (derivative variables) 85.7% (I-O DEA) and 86.2% (O-O DEA) of the total variance of the performance indicators (original variables). Figure 4 reports the loadings of the original variables on the first two PCs. The intercepts and coefficients of the linear equations provided by the predictive linear regression models of PCR together with their explanatory capacity (as measured by the regression coefficients) are instead reported in Table 6. Both models (I-O and O-O DEAs) gave r^2 always higher than 0.696 with a maximum of 0.999. The lowest explanatory capacity was achieved for the RIS (r^2 = 0.403-0.409) (Table 6).

I-O and O-O DEAs delineated two efficient scenarios for the previously inefficient five WUAs; compared to the current values of the corresponding performance indicators, the multiple regression models showed that (Figures 5a and 5b): (i) for the I-O DEA, RCP, RIS, ICR, NU and CRR^+ would increase on average by 3.6%, 21.0%, 55.3%, 1.2% and 35.7%, respectively; (ii) for the O-O DEA, on average a reduction of RCP is expected (of 0.1%) as well as an increase of RIS, ICR, NU and IA (of 1.6%, 284%, 235% and 1358%, respectively).

4. DISCUSSIONS

The collective irrigation networks in Calabria were strongly underutilised (with few exceptions), as shown by the value of the cropping intensity indicator, ICR). Although many of the NU (Numbers of Users) could potentially irrigate crops using the collective network of the CA, in reality a large proportion of NU get irrigation water from different sources, as confirmed by the low ICR (Table 3). Water usage varied noticeably among the monitored WUAs and this did not reflect the type of irrigated crop. In general, in some WUAs (e.g. "TVV" and "TCZ"), where the main crops had higher irrigation requirements (e.g. vegetables and fruit trees), the water delivered to farms was on average lower compared to other WUAs, in which wheat, maize and/or olives - requiring relatively little water - were mainly produced (e.g. "BSCS" and "BMCS"). WDIA in Calabria WUAs (9500 m^3 ha^{-1} yr^{-1}) is much higher than the values (between 1500 and 4300 m^3 ha^{-1} yr^{-1}) reported by Còrcoles et al. (2010, for maize, barley, alfalfa, onions, carrots, olive trees, vineyards and almond trees), Rodrìguez-Diaz et al. (2004a, for olive trees, wheat, sunflowers, maize and citrus fruits), Garcia-Vila et al. (2008, for winter cereals, sunflower, cotton, garlic, olive trees, sugar beet, maize, beans, asparagus, onions, pepper and potatoes), Camacho (2006, for olive trees, wheat, maize and citrus fruits) and Alcon et al. (2017, for citrus fruits, vegetables and cereals) in Spain. WDIA in collective irrigation of Calabria is more similar to the values measured in other agricultural contexts (Cakmak et al., 2004, Turkey, 9800-15000 m^3 ha^{-1} yr^{-1} for cotton, cereals, tobacco and vegetables; Uysal and Atis, 2010, Turkey, about 8000 m^3 ha^{-1} yr^{-1}, irrigated crops not specified; Ghazalli, 2004, Malaysia, 9400-34000 m^3 ha^{-1} yr^{-1} for rice).

In the analysed WUAs water delivered to crops was always in excess (as shown by the very high RIS) compared to the theoretical irrigation requirement; a RIS near 100% would be more desirable than a higher value (Molden et al., 1998). The mean RIS (417%, Table 3) is: (i) close to the maximum values reported by Córcoles et al. (2012) in Spain and Mateos et al. (2010) in Mauritania; (ii) higher than the range estimated by Lozano and Mateos (2008, 78-280%) in an irrigation scheme in Andalusia (Spain); and (iii) much higher than the value estimated by Rodrìguez-Dìaz et al. (2011, 24%) in Andalusia (Spain). Soto-García et al. (2013) reported a RIS ranging from 17% to 80% in the irrigated agriculture of Region de Murcia (Spain).

Concerning the financial performance of the studied WUAs, $MOMA^-$ (on average 1445 € ha^{-1} yr^{-1}, Table 3) is much higher compared to other studies, reporting MOMA in the range 21.7 (Yavuz et al., 2004, Turkey) - 1014 (Alcon et al., Spain) € ha^{-1} yr^{-1}. A key consideration with regard to the financial viability of the irrigation service in WUAs of Calabria is the relationship between the revenue received from farmers and the costs of operation and maintenance: total revenue should be equal to or greater than the costs of operation and maintenance (Koc, 2007). In our study, none of the analysed WUAs achieved a complete cost recovery (indicated by CRR$^+$) and fee collection capacity (explained by RCP), which are both parts of financial self-sufficiency (Yercan et al., 2009); therefore, their financial survival depended on external funds (mainly from Calabria Region). The very low self-sufficiency of the WUAs in Calabria was mainly due to the high incidence of staff costs. In fact, the cost recovery ratio was on average equal to 200%, if staff cost was not included in the analysis (Table 3). This means that WUAs should be able to fully cover MOM costs with water fees. It is imperative to devise water fees for irrigation in such a manner to meet, at least, the annual MOM costs to make the system self-sustainable: water fees should be such that minimum MOM costs are recuperated by revenue recovered (Phadnis and Kulshrestha, 2012); moreover, WUAs may provide additional revenues selling electrical energy produced by small hydro power plants integrated in the irrigation networks (Zema et al., 2016; 2017). Conversely, if personnel salaries are considered in CRR, the cost recovery (see CRR$^+$ values, Table 3) decreased to about 20% and became in general poor for the majority of the analysed WUAs. For CRR literature shows values between 28% (Molden et al., 1998, Sri Lanka) and 170% (Cakmak et al., 2009, Turkey).

As regards the personnel requirement, the values of SUIA detected in Calabrian WUAs (on average 5.2 persons per 100 ha of IA, Table 3) appears very high compared to the extreme values reported in literature studies (from 0.04, Ijir and Burton, 1998, USA, to 3.7 persons per 100 ha, Cornish, 2005, China) and, however, far from the acceptance limits reported in literature (below 0.3 persons per 100 ha). From the surveys in the Calabrian WUAs it has been noticed: (i) a large variability of staff in the investigated WUAs (due to the normal variations of labour productivity, service intensity and technology involved, as also observed by Koç, 2007); (ii) a practically constant number of employees devoted to management and financial activities; and (iii) a number of the field workers - directly utilised for irrigation service maintenance - not proportional to the irrigated area. In literature all the studies have shown that the personnel cost in MOM expenditure is much higher compared to other MOM expenditures (Koc and Bayazit, 2015), as also noticed in the Calabrian WUAs. Here, the reduced income was mostly used to cover fixed operational costs like salaries, while funding for maintenance (and minor works) was reduced (and this was also observed by Marre et al., 1998).

Another factor contributing to the poor financial performances was the limited capacity to collect the fees due from the associated farmers. Despite the average RCP being quite satisfactory, in some WUAs the fee evasion was high (45-60% of gross revenue invoiced). It is not to be excluded that the values of this indicator could be affected by the economic condition of the users and the degree to which the users feel the system is worth supporting (Yercan et al., 2009). This could confirm that, in general, in some WUAs of Calabria the satisfaction of farmers towards the irrigation service was low, since the capacity to collect due fees is a significant indicator of the level of acceptance of irrigation water delivery as a service to the associated users (Bos, 1997; Marre et al., 1998).

The irregular spatial distribution of the cost of the irrigation service was due both to problems in the water delivery system and the low financial performance of some WUAs: as a matter of fact, there was a large number of WUAs with a high incidence of maintenance works (mostly where there is widespread presence of free surface canals) and energy costs for groundwater pumping to the associated farms required a higher CIS. Also Alcon et al. (2017) stated that the use of groundwater increases the MOM costs of the irrigation service.

The correlations among pairs of performance indicators, shown by the Spearman matrix (Table 4), are interesting and somewhat expected (Còrcoles et al., 2010). First of all, the fair (direct or inverse) correlations of the cost recovery ratio (CRR^+) of the WUA, personnel requirement per unit serviced area (SUIA) and the irrigation service cost (CIS) on one hand, and the irrigated area (IA) on the other hand showed an evident scale effect of the extension of the irrigation service. In accordance with Alcon et al. (2017), who reported that the adoption of size growing policies allows obtaining economies of scale, this confirms the better financial and organisation performances as well as the lower costs of the irrigation service for the larger WUAs. The capacity to collect due fees (RCP) was not correlated with the irrigated area; conversely, an increase of this capacity with decreasing WUA size could be expected, considering that, presumably, the lower the number of associated users or the area is, the higher the control of the due fees is (Koç, 2007).

Another interesting inverse correlation was found between the cost recovery ratio (CRR^+) and the personnel intensity (SUIA), which can be explained by the fact that the lower the personnel cost, the higher the financial self-sufficiency of the WUAs. The mathematical dependencies between the MOM costs per unit irrigated area ($MOMA^-$) on one hand and the water usage (WDIA) - positive correlation - and cropping intensity (ICR) - negative correlation - means that high volumes of delivered water per unit irrigated area involve high MOM costs, which in their turn increase with low service coverage (ICR).

Moreover, a weak correlation was detected between $MOMA^-$ and IA, differently from findings of Rodriguez-Diaz et al. (2008), who stated that in irrigation districts of higher size general expenses are divided among larger areas and then the unit values weigh less. No correlation was found, however, between $MOMA^-$ and CRR^+, as opposed to what was detected by Phadnis and Kulshrestha (2012), who found that the greater the MOM costs, the lower the cost recovery ratio.

Finally, the high regression coefficient between the cost of the irrigation service (CIS) and IA evidenced that the water fees increase with decreasing serviced areas; this means that the farmers in smaller-sized associations pay considerably more than those in large units (accordingly to findings of Marre et al., 1998).

I-O DEA suggested that, in order to improve the performances of the five inefficient WUAs using more efficiently the productive factors, the managers should reduce water usage, MOM cost, personnel requirement and irrigation cost (Figure 3a). To get this greater efficiency, according to PCR, the collective organisations should enlarge the irrigated area (in order to benefit from the scale effect), keeping NU and CA constant (therefore without infrastructural works). In none of the WUAs the IA increase predicted by I-O DEA would exceed the CA, which means that this goal is practically achievable. This enlargement would lead to an increase of intensity of the irrigation service (ICR): for instance, this could be achieved by irrigating larger areas within the command area (thus, IA and ICR would increase, but CA and NU would remain constant). Furthermore, irrigation of larger areas would lead to a decrease of the excessive water delivery to users (detected in the inefficient WUAs), keeping constant the total irrigation water supplied by the system. Also, the financial performance would noticeably improve and this is confirmed by the increased capacity to collect fees (RCP) and, as a consequence, of the financial self-sufficiency (CRR^+) of the organisations. However, negative changes of the performance indicators may be possible in some WUAs, such as the slight worsening of the financial self-sufficiency (e.g. CRR^+ in "TRC") and the reduction of the capacity to collect fees (e.g. RCP in "BMCS", "TRC" and "BIRC") (Figure 5a). Moreover, DEA coupled with PCR models may predict for some performance indicator an unrealistic increase, as, for instance, of the already extremely high degree of irrigation requirement fulfilment (explained by RIS). Presumably, this may be due to the moderate explanatory capacity provided by the regression models (as also noticed for O-O DEA) of RIS, which could make its prediction not always realistic.

The O-O DEA was implemented to optimise the cost recovery capacity of the inefficient WUAs. This goal could be in general achieved for all the inefficient WUAs. O-O DEA predicted even a doubling of the cost recovery performance. This would lead to a significant decrease of water usage, personnel requirement, MOM costs and water fees (Figure 3b); however, PCR indicated that this improved scenario would require excessive changes of other performances, which is basically unrealistic in the current situation. For the five WUAs both associated farms and cropping intensity would need to increase three-fold, and the irrigated area would need to increase ten-fold; in four of the five analysed WUAs this latter would exceed the command area, thus this resizing of the irrigation schemes may be unfeasible for the WUAs (Figure 5b). Therefore, the results of the O-O DEA must be interpreted with care and, at the very least, the feasibility of the predicted scenario must be checked by other prediction models.

5. CONCLUSIONS

From the analysis of current performances of Calabrian WUAs, it emerged that the irrigation service is underutilised and water delivered to crops is always in excess compared to the theoretical irrigation requirement. From the financial point of view, the cost recovery of the WUAs is very low, with revenues from the water fees covering only MOM costs. This is mainly due to both the incidence of staff costs and the low fee collection capability.

DEAs allowed, firstly, the identification of the inefficient WUAs and the performance of the remaining collective organisations (considered as efficient) to be assumed as a reference. For the inefficient WUAs, an input-oriented DEA (coupled with PCR) showed that water usage, MOM and personnel costs could be reduced significantly with a consequent decrease of water fees and a significant increase (3-fold) of the irrigated area. Under this improved scenario, the multi-regression analysis predicted an enlarged irrigation service together with a high improvement in financial performance. An output-output DEA (coupled with PCR) suggested a high increase of the cost recovery capacity of the inefficient WUAs, but this scenario would require major improvement actions (for instance, a 10-fold increase of the irrigated area), which may be basically unsustainable for the collective organisations in the current situation and may also be unrealistic. This means that O-O DEA must be applied with care and, in any case, its results should be properly controlled before any implementation.

On the whole, the case study clearly demonstrated that irrigation is a complex process where every factor is important. The combination of DEA with multi-regression and their implementation in the case study, using a limited set of easy-to-survey performance indicators, may be a powerful and easy-to-use tool in irrigation sector management; by the implementation of these benchmarking techniques, the diagnosis of the crucial factors affecting the collective irrigation service and the simulation of improved scenarios may be carried out for strategic purposes and support the identification of the countermeasures for weak point removal in the collective irrigation sector. In this way, it is possible to determine which practices lead to better performance in a district and subsequently adapt these practices to irrigation districts that perform less efficiently; similarly, WUAs that perform more poorly will be able to determine which aspects are in need of improvement and take the necessary steps to achieve better performance.

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LIST OF ACRONYMS

Input parameters/performance indicators

CA: Command area
IA: Irrigated area
AIA: Average Irrigated Area per Farm
NU: Number of Users
VIWD: Annual Volume of Irrigation Water Delivery
VIWR: Annual Volume of Irrigation Water Required
GRI: Gross revenue invoiced
GRC: Gross revenue collected
MOMC: Total management, operation and maintenance cost
NPI: Total number of personnel engaged in irrigation service.
ICR: Irrigated area/command area ratio
WDIA: Annual irrigation water delivery per unit irrigated area
RIS: Annual relative water supply
MOMA: Total management, operation and maintenance cost per unit area
MOMA$^-$: Total management, operation and maintenance cost per unit area (without staff)
CRR: Cost recovery ratio
CRR$^+$: Cost recovery ratio (with staff costs)
RCP: Revenue collection performance
SUIA: Staffing numbers per unit of irrigated area
CIS: Cost of the Irrigation Service.

Water Users Associations

BCSC: Bacini Settentrionali del Cosentino
BMCS: Bacini Meridionali del Cosentino
ICS: Ionio Cosentino
IKR: Ionio Crotonese
TCZ: Tirreno Catanzarese
ICZ: Ionio Catanzarese
TVV: Tirreno Vibonese
TRC: Tirreno Reggino
AIRC: Alto Ionio Reggino

BIRC: Basso Ionio Reggino.

TABLES

Table 1 - Main characteristics of ten WUAs (Calabria, Southern Italy).

Characteristics/input parameters	**WUA**									
	BSCS	*BMCS*	*BICS*	*IKR*	*ICZ*	*TCZ*	*TVV*	*TRC*	*AIRC*	*BIRC*
Size of the system										
Administrative area (ha)	120295	135093	112948	139369	115280	85602	99997	96094	80795	108754
Command area (CA, ha)	8419 (0.00)	4794 (0.29)	18685 (0.00)	18529 (0.15)	11303 (0.28)	5746 (0.00)	676 (0.00)	8138 (0.26)	3700 (0.07)	3152 (0.58)
Irrigated Area (IA, ha)	2712 (0.00)	816 (0.68)	10007 (0.34)	5247 (0.82)	4000 (1.98)	1431 (0.00)	370 (0.00)	647 (13.55)	600 (3.45)	262 (0.87)
Number of associated users (NU, -)	2250 (1.01)	1224 (1.01)	5335 (0.56)	2501 (2.33)	2470 (2.55)	1200 (0.77)	150 (3.41)	1315 (1.25)	1600 (0.00)	900 (1.74)
Average farm size (AIA, ha)	1.21	0.67	1.88	2.10	1.62	1.19	2.47	0.49	0.38	0.29
Crops and irrigation infrastructure and management										
*Main crops**	Citrus (41%), vegetables (29%), olive (18%)	Vegetables (79%), olive (18%)	Citrus (40%), vegetables (38%), olive (19%)	Olive (22%), cereals (23%), forage (21%), fruits (25%)	Citrus (11%), vegetables (48%), olive (40%)	Citrus (8%), vegetables (53%), olive (37%)	Vegetables (98%)	Citrus (49%), fruits (15%), vegetables (15%), olive (18%)	Citrus (10%), fruits (23%), vegetables (48%), olive (13%)	Citrus (24%), fruits (26%), vegetables (22%), olive (23%)
Type of water distribution	Rotational schedule	Rotational schedule	Rotational schedule and on demand	Rotational schedule	Rotational schedule (60%) and on demand (40%)	Rotational schedule (20%) and on demand (80%)	Rotational schedule	Rotational schedule	Rotational schedule	Rotational schedule
Irrigation system	Sprinkler, surface	Sprinkler, surface	Sprinkler, surface	Sprinkler, surface	Sprinkler, surface	Sprinkler, surface	Sprinkler	Sprinkler, surface	Sprinkler, flowing	Sprinkler, surface, microirrigation
Water source	Surface water (40%), groundwater	Surface water	Surface water	Surface water	Surface water	Surface water	Surface water	Surface water	Surface water (50%), groundwater	Surface water (50%), groundwater

	(60%)								(50%)	(50%)
Irrigation water availability	Sufficient	Sufficient	Sufficient	Sufficient (occasionally not sufficient)	Sufficient	Sufficient	Sufficient	Sufficient	Sufficient	Sufficient
Method of water delivery	Gravity	Gravity (50%), in pressure (50%)	Gravity (40%), in pressure (60%)	Gravity	Gravity	Gravity (20%), in pressure (80%)	Gravity	Gravity (60%), in pressure (40%)	Gravity	Gravity
Water delivery infrastructure	Pressured pipeline (90%), open canal (10%)	Pressured pipeline (50%), open canal (50%)	Pressured pipeline (40%), open canal (60%)	Pressured pipeline (60%), open canal (40%)	Pressured pipeline (90%), open canal (10%)	Pressured pipeline (80%), open canal (20%)	Pressured pipeline	Pressured pipeline (50%), open canal (50%)	Pressured pipeline (80%), open canal (20%)	Pressured pipeline (80%), open canal (20%)
Type of revenue collection	Charge on crop type and irrigated area	Charge on crop irrigated area	Charge on crop type and irrigated area	Charge on crop irrigated area	Charge on crop irrigated area	Charge on crop irrigated area	Charge on crop irrigated area	Charge on crop type and irrigated area	Charge on crop irrigated area	Charge on crop irrigated area
Type of water control equipment	None	None	Automated with remote measuring system	None	None	Automated measuring device	None	None	None	None

Note: * % on the total irrigated area.

Table 2 - Input parameters for calculating the performance indicators of ten WUAs (Calabria, Southern Italy).

Characteristics/input parameters	**WUA**									
	BSCS	*BMCS*	*BICS*	*IKR*	*ICZ*	*TCZ*	*TVV*	*TRC*	*AIRC*	*BIRC*
Water usage										
VIWD ($Mm^3\ yr^{-1}$)	28.20 (6.09)	7.18 (28.19)	105.33 (2.91)	42.65 (4.13)	30.00 (4.86)	9.25 (16.21)	2.70 (2.48)	9.64 (6.20)	4.92 (22.78)	3.33 (28.31)
VIWR ($Mm^3\ yr^{-1}$)	11.86 (287.1)	4.24 (166.2)	32.49 (37.2)	14.15 (4.54)	8.37 (80.2)	2.51 (135.4)	0.85 (166.0)	0.99 (118.2)	1.26 (228.5)	0.46 (234.7)
Financial and organisation aspects										
GRC (*k€* yr^{-1})	286.8 (23.72)	103.8 (10.75)	1495.0 (13.82)	438.4 (20.11)	330.0 (16.38)	192.0 (17.20)	61.2 (8.58)	248.0 (31.45)	144.0 (34.10)	117.4 (13.06)
GRI (*k€* yr^{-1})	521.4 (3.60)	140.2 (3.45)	2300.0 (7.12)	626.3 (23.21)	550.0 (2.88)	320.0 (3.44)	68.0 (1.82)	248.0 (19.41)	360.0 (9.58)	146.8 (33.54)
MOMC (*k€* yr^{-1})	1683.0 (11.48)	975.7 (19.82)	4338.8 (27.57)	1995.0 (34.90)	1750.0 (26.80)	1235.0 (14.53)	558.0 (30.96)	995.0 (3.96)	1095.0 (11.77)	1480.7 (60.60)
NPI (persons)	57 (0.00)	35 (0.00)	120 (0.46)	73 (0.00)	62 (0.88)	44 (2.05)	22 (0.00)	34 (4.86)	37 (1.70)	54 (2.41)

Note: in brackets the inter-annual Coefficients of Variations are reported (in %).

Table 3 - Values of the performance indicators calculated in ten WUAs (Calabria, Southern Italy).

Performance indicator	**WUA**									
	BSCS	*BMCS*	*BICS*	*IKR*	*ICZ*	*TCZ*	TVV	TRC	AIRC	BIRC
Size and water usage of the system										
ICR (%)	32.2 (0.00)	17.0 (0.77)	53.6 (0.34)	28.3 (0.72)	35.4 (1.80)	24.9 (0.00)	54.7 (0.00)	8.0 (13.47)	16.2 (3.50)	8.3 (0.90)
WDIA (10^3 m^3 ha^{-1} yr^{-1})	10.4 (6.09)	8.8 (28.36)	10.5 (2.65)	8.1 (3.70)	7.5 (6.34)	6.5 (16.21)	7.3 (2.48)	14.9 (12.60)	8.2 (23.15)	12.7 (27.75)
RIS (%)	237.7 (33.86)	169.5 (5.35)	324.1 (6.99)	301.3 (26.96)	358.3 (3.02)	368.4 (64.38)	317.6 (187.91)	977.7 (10.60)	391.0 (6.50)	728.4 (13.74)
Financial and organisation aspects										
CRR^+ *(%)*	17.0 (23.02)	10.6 (27.89)	34.5 (38.91)	22.0 (28.20)	18.9 (15.80)	15.5 (14.41)	11.0 (56.14)	24.9 (30.12)	13.2 (38.34)	7.9 (53.84)
$MOMA^-$ *(€* ha^{-1} yr^{-1}*)*	620.5 (52.37)	1195.7 (3.01)	433.6 (10.81)	380.2 (13.72)	437.5 (16.40)	863.0 (42.82)	1508.1 (42.62)	1537.9 (27.02)	1825.0 (30.38)	5651.6 (49.80)
RCP (%)	55.0 (24.95)	74.0 (10.02)	65.0 (18.06)	70.0 (33.61)	60.0 (15.06)	60.0 (14.99)	90.0 (27.33)	100.0 (21.51)	40.0 (31.66)	80.0 (26.26)
SUIA (persons 100-ha^{-1}*)*	2.1 (0.00)	4.3 (0.68)	1.2 (0.32)	1.4 (0.73)	1.6 (2.23)	3.1 (2.05)	5.9 (0.00)	5.3 (8.26)	6.2 (4.73)	20.6 (1.97)
CIS (€ $ha^{-1}yr^{-1}$*)*	150 (0.00)	177 (0.00)	160 (0.00)	120 (0.00)	200 (0.00)	118 (0.00)	250 (0.00)	480 (0.00)	353 (0.00)	611 (0.00)

Note: in brackets the inter-annual Coefficients of Variations are reported (in %).

Table 4 - Spearman's correlation matrix among performance indicators in ten WUAs (Calabria, Southern Italy).

Performance indicators	*IA*	*NU*	*ICR*	*WDIA*	*RIS*	*CRR*$^{+}$	*MOMA*$^{-}$	*RCP*	*SUIA*	*CIS*
IA	**1**	**0.867**	0.479	-0.115	-0.358	**0.758**	-0.370	-0.383	**-0.988**	**-0.733**
NU		**1**	0.273	0.164	-0.139	**0.782**	-0.055	-0.450	**-0.806**	-0.394
ICR			**1**	-0.503	-0.648	0.236	**-0.721**	-0.182	-0.564	-0.455
WDIA				**1**	0.261	0.176	**0.758**	0.322	0.152	0.503
RIS					**1**	0.103	0.515	0.134	0.418	0.515
CRR^{+}						**1**	-0.152	-0.091	**-0.745**	-0.333
MOMA^{-}							**1**	-0.012	0.467	0.576
RCP								**1**	0.286	0.438
SUIA									**1**	**0.745**
CIS										**1**

Note: values in bold are statistically significant at p level < 0.05.

Table 5 - Working parameters in input-oriented (I-O) and output-oriented (O-O) DEA in ten WUAs of Calabria (Southern Italy).

WUA	**Efficiency**	**Frequency in the set of efficient WUAs**	**Benchmark ranking**
I-O DEA			
BSCS	0.80	0	6
BMCS	0.74	0	8
BICS	1.00	0	5
IKR	1.00	1	3
ICZ	1.00	2	2
TCZ	1.00	5	1
TVV	1.00	1	3
TRC	0.46	0	10
AIRC	0.79	0	7
BIRC	0.51	0	9
Mean	0.66*	-	-
O-O DEA			
BSCS	0.57	0	7
BMCS	0.40	0	9
BICS	1.00	5	1
IKR	1.00	1	3
ICZ	1.00	0	4
TCZ	1.00	2	2
TVV	1.00	0	4
TRC	0.72	0	6
AIRC	0.56	0	8
BIRC	0.23	0	10
Mean	0.50*	-	-

Note: * calculated only on the inefficient WUAs.

Table 6 - Coefficients of PCR models between performance indicators used in (a) input-oriented and (b) output-oriented DEAs in ten WUAs (Calabria, Southern Italy).

(a)

Model parameters		**Dependent variables (y)**				
		UN	ICR	RIS	RCP	CRR^+
Independent variables (x)	*WDIA*	465.071	4.264	-5.268	1.109	2.082
	SUAI	-234.151	2.744	3.474	1.749	-0.976
	$MOMA^-$	6.433	0.068	0.323	-0.056	0.038
	CIS	0.020	0.173	-0.157	0.117	-0.001
	IA	0.186	0.001	-0.002	0.000	0.001
Intercept		-1978.789	-38.704	380.157	39.801	0.576
Explanatory capacity (r^2)		0.993	0.983	0.409	0.698	0.998

(b)

Model parameters		**Dependent variables (y)**				
		UN	ICR	RIS	RCP	IA
Independent variables (x)	*WDIA*	493.442	4.350	-6.281	1.220	1040.294
	SUAI	-262.374	2.666	4.097	1.718	-590.875
	$MOMA^-$	4.461	0.060	0.328	-0.051	1.336
	CIS	0.638	0.175	-0.164	0.117	3.836
	CRR^+	78.251	0.305	-0.595	-0.076	158.358
Intercept		-2915.045	-42.286	391.538	39.917	-6502.018
Explanatory capacity (r^2)		0.993	0.984	0.403	0.696	0.999

FIGURE CAPTIONS

Figure 1 - Layout of the studied Water Users Associations (Calabria, Southern Italy).

Figure 2 - Scheme of Data Envelopment Analysis (DEA) and Principal Component Regression (PCR) coupling for benchmarking the performance of Water Users Associations (the subscripts refer to efficient, “eff”, or inefficient, “ineff”, WUAs)

Figure 3 - Changes (in %, compared to the current situation) of performance indicators evaluated by (a) input-oriented and (b) output-oriented DEA applied to ten WUAs of Calabria (Southern Italy).

Figure 4 – Loadings of performance indicators (WDIA, SUAI, $MOMA^{-}$, CIS) and IA (I-O DEA, chart "a"))/CRR+ (O-O DEA, chart "b") on the first two principal components (PC) (the percentage variation explained by the principal components is given in parentheses) in ten WUAs of Calabria (Southern Italy).

Figure 5 - Changes (in %, compared to the current situation) of performance indicators evaluated by multiple regression models (PCR) and not used by (a) input-oriented and (b) output-oriented DEAs in five inefficient WUAs of Calabria (Southern Italy).