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Application of Data Envelopment Analysis and Performance Indicators to Irrigation Systems in Thessaloniki Plain (Greece)

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Abstract**—**In this paper, a benchmarking framework is presented for the performance assessment of irrigations systems. Firstly, a data envelopment analysis (DEA) is applied to measure the technical efficiency of irrigation systems. This method, based on linear programming, aims to determine a consistent efficiency ranking of irrigation systems in which known inputs, such as water volume supplied and total irrigated area, and a given output corresponding to the total value of irrigation production are taken into account simultaneously. Secondly, in order to examine the irrigation efficiency in more detail, a cross – system comparison is elaborated using a performance indicators set selected by IWMI. The above methodologies were applied in Thessaloniki plain, located in Northern Greece while the results of the application are presented and discussed. The conjunctive use of DEA and performance indicators seems to be a very useful tool for efficiency assessment and identification of best practices in irrigation systems management.

Keywords**—**Benchmarking, D.E.A, Performance Indicators, Irrigation systems.

I. INTRODUCTION

PERFORMANCE of irrigation systems is a pivotal topic of interest that has aroused a great deal of attention from researchers, planners and managers of irrigation systems in the last decades. Due to the fact that irrigation systems in many countries are characterized by heterogeneity in different sections and also present a variety of technical characteristics, the comparison between them can become a difficult task.

The agricultural sector in Greece is the largest consumer of water since irrigation purposes account for 80% of water withdrawals [1, 2]. A significant variety of irrigation systems exist in regard to certain soil and climatic conditions, as well as crop requirements. In public networks, the conveyance of water is done mainly by means of earthen or concrete channels with a tendency to be replaced by pipelines [3]. However, due to inadequate water conveyance systems and lack of maintenance of irrigation systems, there are high water losses comprising the lion's share in rural water.

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In addition, non-adapted types of crops and farmer's lack of knowledge in irrigation practices complicate the current use of water for irrigation purposes. Therefore, the modernization and innovation in irrigation techniques is of major importance for reducing water distribution and application losses, enhancing agricultural productivity and contributing to socioeconomic development.

The purpose of the present study is to assess the efficiency of irrigation systems in the plain of Thessaloniki, in Northern Greece, and to determine irrigation systems that are technically inefficient and require irrigation improvements. As Thessaloniki plain presents intense agricultural activity that uses a significant portion of rural water for irrigation purposes, the comparison of the irrigation systems efficiencies could provide significant information on where the application of water produces the highest benefit and where irrigation practice is the most efficient.

In order to overcome the emerging difficulties in specifying the irrigations systems performance, the Data Envelopment Analysis (D.E.A.) approach could be considered as a useful and consistent benchmarking tool. Even if D.E.A. approach has been widely and successfully used in different areas, its application to irrigation water management is not quite often [4, 5]. Relevant research includes the efficiency studies of the water companies in the United Kingdom [6], the irrigation districts in Andalusia [7], and the reservoir system in the Paraguacu river basin [8].

This method is based on linear programming techniques that define the production function and determine the efficiency frontier of a set of decision-making units (DMUs). D.E.A. models evaluate the relative technical efficiency of each unit and allow for distinction to be made between efficient and inefficient DMUs. According to Farrell [9], the technical efficiency reflects the ability of a DMU to produce maximum output given a set of inputs, or alternatively to achieve maximum feasible reductions in input quantities when output values are given. In order to measure the efficiency of a selected DMU (i.e. irrigation system), D.E.A approach based on a number of inputs and outputs of the selected system assesses its relative technical efficiency or its production function, and determines its position in relation to the optimal situation [10]. Furthermore, this method appoints the optimal DMU and its efficiency can direct us to find out the best practices and the proper ways of utilizing the water resources so that the less efficient units will use them efficiently in future.

To achieve a more detailed analysis, a performance indicators framework was adopted for monitoring the irrigation water management of irrigation systems. Benchmarking based on performance indicators is an important management tool that allows us to compare the irrigation efficiency of agricultural systems [11, 12, 13]. A set of performance indicators was proposed by the International Water Management Institute (IWMI) in order to enable managers to conduct cross – system comparison [14]. Although D.E.A. approach is able to treat in a simultaneous way inputs and outputs, performance indicators can be used to complement and disambiguate the D.E.A. results through the examination of more aspects of irrigation systems (e.g. different crop water requirements).

This paper is structured as follows. The first section introduces and provides the main objectives of this work, while the second one describes the study area and the data elaborated. The third section presents the theoretical framework and the methodology adopted. The fourth section presents the results and discusses the major findings, while the concluding remarks are noted in the final section.

II. Study Area and Data

The region opted for evaluating the efficiency of irrigation systems was the plain of Thessaloniki which is located in northern Greece. It is one of the largest plains in Greece with gross cultivated area about 154,522 ha. The net cultivated area attains 110,000 ha, which approximately corresponds to 70% of gross area. The climate is predominantly Mediterranean with mild and wet winters, while the summers are quite dry. The average precipitation for the irrigation period is about 250-300 mm and rather inadequate to cover the water demand of crops, especially in summer. In this study, groundwater contribution is also taken into account for estimating the net irrigation water demands, since there is a high-elevated ground water table observed in Thessaloniki Plain, especially in littoral south-western region where the dominant crop is rice.

According to water resources supply, the plain of Thessaloniki can be divided into two main groups, the irrigation systems of Axios and Aliakmonas Rivers respectively, in which the climate conditions do not vary importantly. The main crops that prevail in Aliakmonas irrigation systems are fruits, corn and cotton, while in Axios irrigation systems, the dominant cultivations include rice in high intensity followed by cotton and corn. The cultivated region of Aliakmonas comprises irrigation systems with both pressurized and open networks, while water application in the field is made with a variety of methods including sprinkler, rain gun, localized techniques and furrows. In contrast, the irrigation districts of Axios River possess irrigation networks with open channels combined with surface irrigation methods, such as furrows and level basins in case of rice, which is the dominant crop in most districts.

The data used in this study refer to the year 2007 and cover 30 irrigation systems. The required data were obtained from the General Organization of Land Reclamation, which undertakes the general administration and management of irrigation systems in Thessaloniki plain. Available data include the volumes of water consumption and the total irrigated areas of each irrigation system. Specific information about general and technical characteristics of irrigation districts was derived directly from the respective Local Organizations of Land Reclamation. In addition, meteorological data were provided by the Land Reclamation Institute.

III. Methodology

A. Data Envelopment Analysis (D.E.A.)

The D.E.A is a non-parametric mathematical programming approach used to evaluate the technical efficiency of a group of similar process units. The concept of the relative technical efficiency based on a number of inputs and outputs was first introduced by Farell [9]. More explicitly, each DMU (i.e. irrigation system) is evaluated in relation to a group of similar units, and thus the efficiency estimated corresponds to the deviation of each unit in comparison with a set of optimal units.

The application of D.E.A method can be oriented in inputs or outputs. These two models set different objectives and especially the input–oriented model aims to continue producing the same outputs while minimizing the inputs, whereas the output–oriented model aims to maximize outputs using the minimum amount of inputs. In our study an input–oriented model is selected, since priority should be given to the sustainable management of water and land resources instead of the maximization of the total production.

Another classification of D.E.A models is made regarding the assumption of returns to scale. The first model, known as CCR [15], assumes constant returns to scale and as a result all DMUs operate on an optimal linear scale. The other model known as BCC [16] considers variable returns to scale due to the fact that real markets cannot operate in an ideal way.

The difference between the CCR and the BCC models is depicted in Fig. 1, where one input x is used to produce a single output y. In this case, the CCR frontier considers only one DMU as efficient, while the BCC model gives three possible solutions that define the curve of the optimum production function.

The program used in this study was the DEAP 2.1 freeware program and it was developed by Coelli [17].

Assuming that there are n DMUs, each with m inputs and s outputs the relative efficiency score of a test DMU_0 is obtained by solving the following model:

$$\max \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} \upsilon_i x_{i0}}$$

subject to :

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} \upsilon_i x_{ij}} \leq 1, \; j=1,\ldots,n$$

$$u_r, \upsilon_i > 0, \; i=1,\ldots,m \;\; \text{και} \;\; r=1,\ldots,s. \qquad (1)$$

where u_r is the weight given to output y_r, υ_i the weight given to input x_i, and y_{rj} and x_{ij} represent the values of the produced outputs and inputs y_r and x_i by DMU_j, respectively.
In case of an input oriented BCC approach, the final solution is derived from the dual linear programming problem, as follows (in vector form):

$$\begin{aligned} &\text{Minimize } \theta \\ &\text{Subject to:} \\ &-y_0 + Y\lambda \geq 0 \\ &\theta x_0 - X\lambda \geq 0 \\ &N1'\lambda = 1 \\ &\lambda \geq 0 \end{aligned} \qquad (2)$$

where θ is a scalar that corresponds to the efficiency and consequently the percentage of radial reduction to which each of the inputs is subjected, $\lambda \geq 0$ is a vector of n elements representing the influence of each DMU in determining the efficiency of DMU_0, Y and X are the vectors of outputs and inputs of all DMUs under study, y_0 and x_0 are the vectors of outputs and inputs of DMU_0, and N1 a nx1 vector of ones.

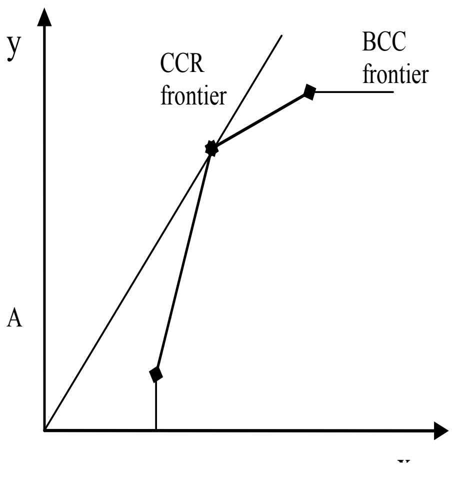

Fig. 1. Differences between CCR and BCC models

The model that was adopted in this paper was the input – oriented model with variable returns to scale (BCC), which matches better to the real market conditions. In this study we considered one output the total value of agricultural production (S.G.V.P) in euros (local prices), while the inputs are the total irrigated area in ha and the total volume of water applied to each irrigation network in m^3.

B. Performance Indicators

A minimum set of comparative indicators was applied in the study area to assess the performance of irrigation systems. These indicators were proposed by IWMI in order to examine the performance of irrigation water service, agricultural productivity and infrastructure adequacy. In this study seven performance indicators were considered: Output per irrigated area, Output per command area, Output per irrigation supply, Output per water consumed, Relative water supply, Relative irrigation supply and Water delivery capacity.

IV. Results – Discussion

Despite the fact that irrigation districts have different technical characteristics and crop patterns, initially all irrigation systems of the Thessaloniki Plain were included in the analysis. Fig. 2 shows the results of applying an input oriented BCC model to the whole of Thessaloniki plain for the year 2007. The mean technical efficiency of irrigation systems for the whole area is about 70%, meaning that, on average, irrigation systems could reduce their inputs by 30% and still maintain the same output level. It can be also observed in Fig. 2 that none of the irrigation systems supplied by Axios River (IDs 1 to 7) participated in the efficient frontier. First, this implies that irrigation systems of Aliakmon River outperform the ones of Axios River, and second that these two groups might be examined separately due to the important differences in crop patterns and irrigation methods.

As stated before, systems supplied by Axios River cultivate mainly rice, which requires high water demands. The current irrigation method is basins and the network consists of open channels. Therefore, at a second level, irrigation systems that have rice as a basic crop (IDs 1,2,3,4 and 7), or rice crop covers more than of 20% of their cultivate area (IDs 5 and 6), are grouped and analyzed separately from the rest of irrigation systems. The irrigation district Z. Tsekre (ID 30), although it is partially supplied by Axios River, it is not included in this group since rice crop percentage is very low and irrigation water is delivered to farms be means of closed conduits.

The results of this second-level analysis are presented in Fig. 3. As it was expected the technical efficiency scores of Aliakmon River irrigation systems are the same since they have established the efficiency frontier in the initial analysis. As shown in Fig. 3, Axios River irrigation systems present a quite similar technical efficiency with an average value of 0.93, meaning that in order to extract a more clear efficiency ranking among these systems they should be compared with another region with similar crop pattern (rice).

Concerning the group of Aliakmon River irrigation systems, the average technical efficiency is about 80% ranging from 0.315 to 1. A number of 17 (74%) of systems were found as technically inefficient, while nine of them (49%) have

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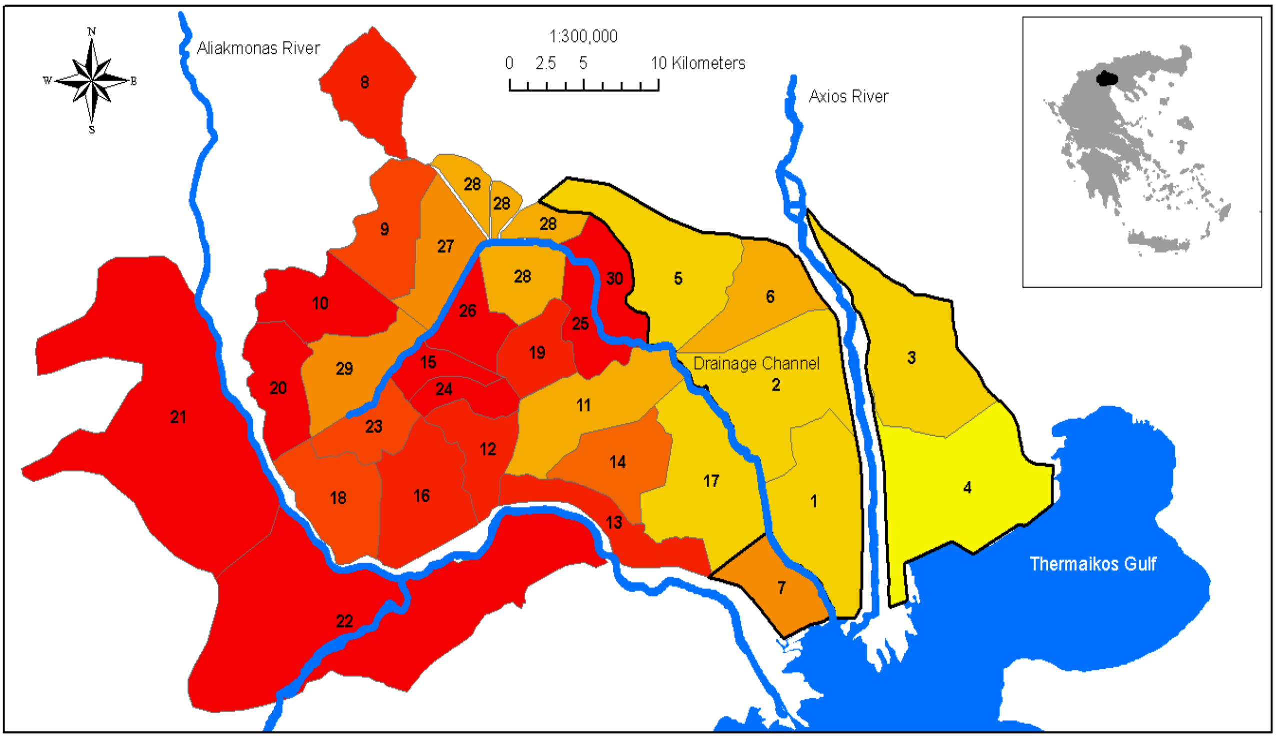
achieved scores below the average technical efficiency. The irrigation systems (IDs 10, 20, 21, 22, 24 and 30), which achieve the higher efficiency, have either pressurized networks and irrigation methods or open channel networks combined with irrigation methods consisting mainly of sprinkler and localized techniques. The main crops of the efficient systems are fruits (e.g. peaches), which have high prices in the local market, followed by cotton, maize and vegetables. It is also noted that irrigation systems with pipeline networks, in some cases, such as ID 29 have a quite low efficiency (0.6). This is mostly due to a number of reasons, such as the use of rainguns instead of localized techniques, water charges per area and not per volume (although networks are planned to work on demand - Clement's formula), and the moderate local price of the main crop (e.g. maize compared to other crops such as fruits, cotton, vegetables).



Irrigation Systems of Thessaloniki plain			
1. Malgara	9. Ag. Louka	17. Plateos	25. Nixoriou
2. Braxia	10. Arapitsa	18. Staurou	26. Sxoina Low
3. Ag. Athanasiou	11. Alexadreia	19. Sxoina High	27. Mpalitsa
4. Xalastra	12. Loutrou	20. Tripotamou	28. Giannitsa
5. Pella	13. Mylovou	21. Naousa	29.Krias Brisis
6. Xalkidona	14. Niseliou	22. Veroia	30. Z. Tsekre
7. Kleidi	15. Nisiou A'	23. Kavasila	
8. Aravissou	16. Kouloura	24. Nisiou B'	

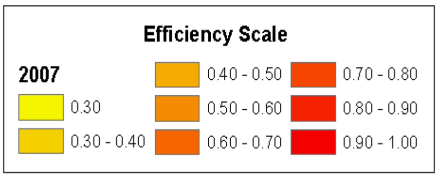


Fig. 2. Technical efficiency of irrigations systems in Thessaloniki plain – All irrigation systems are included in the same group

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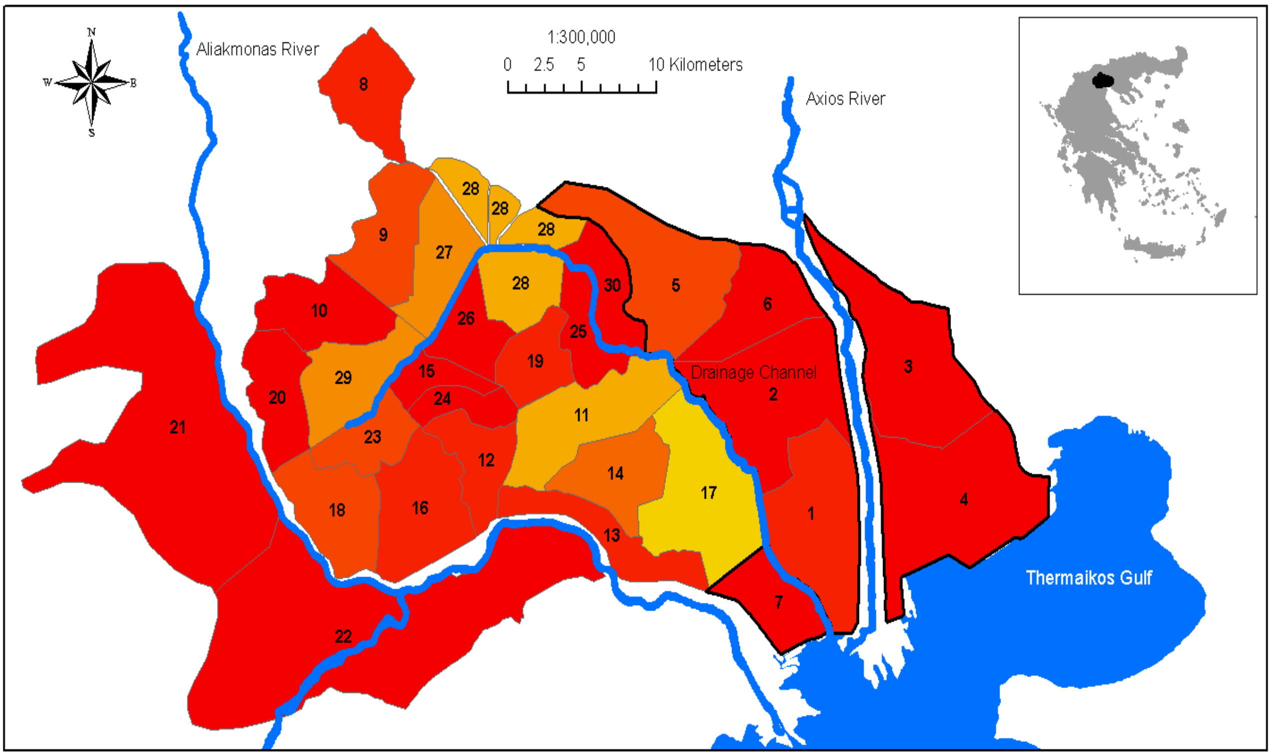

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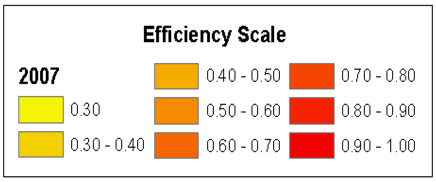

Fig. 3. Technical efficiency of irrigations systems in Thessaloniki plain – Irrigation systems are divided in two separated groups (Axios River group: IDs 1-7 and Aliakmon River group: IDs 8-30)

In order to supplement the DEA analysis and enhance the reliability of the results obtained, a performance indicators benchmarking analysis was conducted additionally for the two above- mentioned groups of irrigation systems and for the same period. Having applied the set of performance indicators, the average, maximum and minimum value of each indicator is calculated and presented in Fig. 4 and 5. Aliakmon River systems have a better average performance for all indicators compared to the one attained by Axios River Systems. This is consistent with the initial DEA analysis performed to the whole area.

Axios River systems (Fig. 4) reveal a more homogenous behavior, since they have a smaller fluctuation between maximum and minimum values of performance indicators. This can be explained by the fact that all irrigation systems have almost similar characteristics in terms of crop pattern, type of irrigation network and method of water application in the field. Low performance indicator values show that this group could improve its performance by ameliorating the production process and using more properly the available water resources. More specifically, Relative Water Supply (RWS) and Relative Irrigation Supply (RIS) indicators in these systems appear to have average values of 1.41 an 2.09 implying that the adequacy of total water supply in conjunction with flooding irrigation techniques (basins) leads to excessive water losses. Moreover, it could be pointed out that the crop of rice isn't as profitable as the other crops (e.g. fruits), since the productivity per unit irrigated area and the productivity per unit irrigation supply are relatively quite low. Another reason that contributes to the low efficiency and the high water losses is the mean operational time, which attains to fifty years.

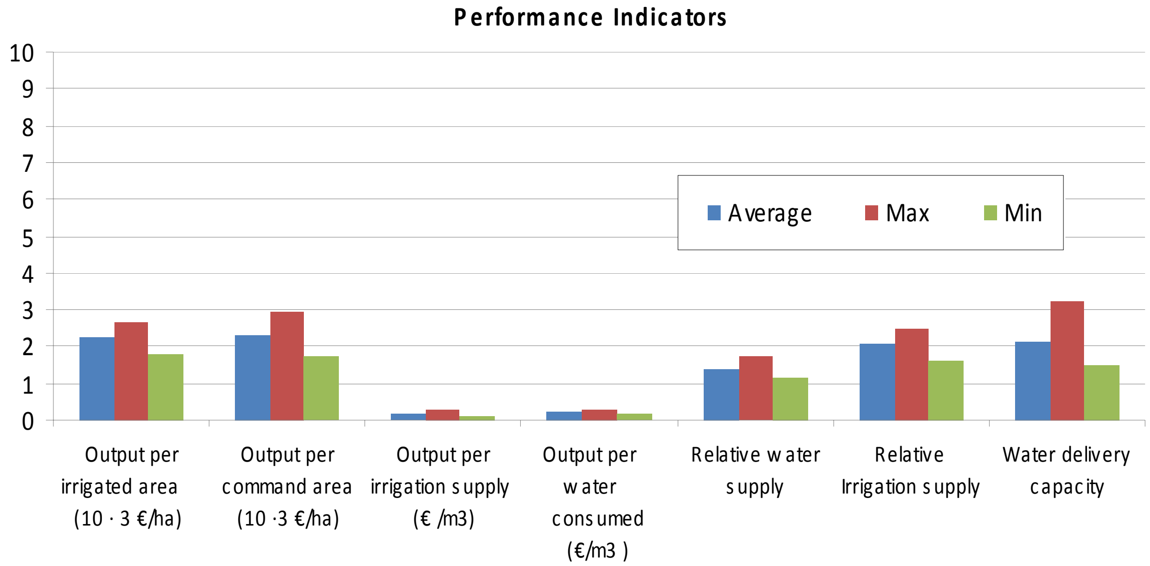

Fig. 4. Performance indicators of Axios River irrigations systems

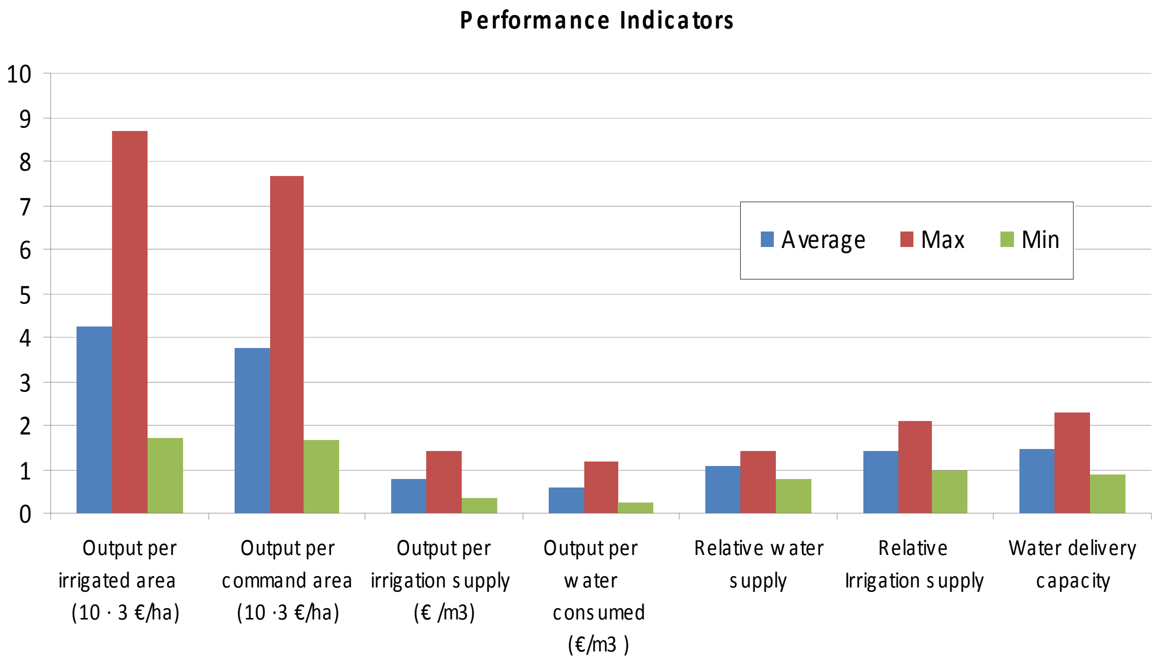

Fig. 5. Performance indicators of Aliakmon River irrigations systems

The Aliakmon River group of irrigation districts (Fig. 5) is quite heterogeneous due to the different types of irrigation systems and the variety of basic crops (fruits, cotton, maize). Performance indicators analysis shows that even if this group, in average, is more productive and efficient than the Axios group, there is a need for improvements and changes to be implemented. For example, a closer look at the average values of indicators RWS (1.06) and RIS (1.46) points out that water losses, even not as high as those occurred in Axios River systems, are also significant. The maximum values of the indicators "output per unit irrigated area" and "output per unit irrigation supply" occurs in districts where the dominant crop is fruit trees and irrigation water application in the field is effectuated by localized methods. Finally, the water delivery capacity of irrigation systems is considered as totally sufficient to carry the required flows in both Aliakmon and Axios River systems.

V. Concluding remarks

An input-oriented with variable returns to scale D.E.A. model was used for estimating technical efficiencies in the irrigation districts in Thessaloniki plain. The D.E.A. approach was selected as a highly diagnostic tool to determine the optimal efficient irrigation systems and at the same time to detect the lack of efficiency in the irrigation systems of the study area. Namely, DEA was able to provide a numerical quantification of the current best performance that should be considered as reference for the other districts.

Performance indicators were also computed for the irrigations districts in the plain of Thessaloniki for providing an integrated investigation of the potential factors that can influence the performance of irrigation systems. In this approach, even though inputs and outputs are treated independently without the existence of assigned weights, it allows the consideration of more factors and different local irrigation conditions.

This combined analysis (DEA and performance indicators) provided important information on the best practices and techniques that lead to enhancement in irrigation efficiency in order to apply them in less efficient systems. More specifically, results reveal that efficiency of some irrigation systems was substantially low. Therefore, it is obvious that it is crucial to increase the efficiency levels of the problematic irrigation systems by incorporating the appropriate features of the most efficient ones.

The present work could be used by authorities and policy makers in order to depict which irrigation methods can yield a more efficient use of water and improve the low efficient irrigation systems, seeking for a desirable overall agricultural performance. Improvements should aim to the general modernization in operational and managerial processes according to the type of irrigation system. Managers should be directed towards innovative production techniques in order to promote technology-intensive agriculture. Moreover, irrigation systems with low agricultural performance in a given irrigation district should be oriented to more profitable crops, and substitute the current ones in order to increase productivity. However, these reforms should be within the context of the European Common Agricultural Policy (CAP) and sustainable development, targeting to more efficient irrigation methods and more suitable agricultural practices, so as to reduce water losses and utilize water resources properly.

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