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Efficient water management: an analysis for the agricultural sector

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Abstract

Efficient water use in agriculture depends on a number of variables, from the farmers' perceptions of these concerns, to the socioeconomic dimensions. In any case, it is important to bring about more insight into these fields, specifically to stimulate the design of adjusted management plans and policies which increase water efficiency on farms. These are relevant motivations to perform more research in these fields. In this framework, the main objective of this study is to analyse the water management efficiency of the agricultural sector in the regions (NUTS 2) and countries in the European Union. For this purpose, statistical information from the Eurostat was considered and an approach based on the Cobb–Douglas theory of production was used which combines DEA (data envelopment analysis) with factor and cluster analysis. Also performed was qualitative analysis with the Atlas.ti software. This approach that combines qualitative analysis with DEA–factor-cluster analysis brings new outcomes to the literature. The insights obtained from this study reveal that it is possible to improve water management without compromising the agricultural output and while still improving farmers' profit. For example, in some French regions, almost 100% of the surface water withdrawal for agricultural irrigation could be saved.

Keywords: Cobb–Douglas theory of production; Data envelopment analysis; European Union regions and countries; Factor and cluster analysis

1. Introduction

Water shortage has become a concern for several stakeholders related to water use and management, from the policymakers to the end consumer. However, sometimes, it is not easy to implement any strategy to save freshwater, either due to the perceptions of the different stakeholders, or the lack of adjusted plans and strategies to improve efficiency (Marston & Cai, 2016).

Specifically, in the agricultural sector, these questions related to efficient freshwater management hold special relevance, not only for environmental and sustainability problems, but, also, in reducing

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farmers' costs. Public institutions and policymakers have a determinant role to play here, namely, in the framework of the Common Agricultural Policy (CAP) inside the European Union (Salmoral *et al.*, 2017).

In fact, across the world, water withdrawal by the agricultural sector (around 2010) was about 70%. This question assumes special relevance in Africa and Asia (81%) and Oceania (65%). In European and American countries, the situation is not so problematic (25% and 48%, respectively), but deserves also special attention, namely, in the southern countries (Aquastat, 2019).

To increase the effectiveness of the implementation of any plan or strategy to promote efficiency in water use on farms, it is fundamental to involve several stakeholders, namely, farmers, in the design and implementation process. This will improve farmers' perceptions and will allow for adjustments based on the stakeholders' experiences, problems and concerns (Esteban *et al.*, 2018).

In this way, it is crucial to bring more insight regarding these aspects associated with efficient water management in the agricultural sector of the European Union regions and countries. In this context, the main objective of the research presented here is to analyse the efficiency of water management by the agricultural sector within the European Union. For the literature survey, mainly the whole databases from the Web of Science (2019) were considered. To organize the literature review the Atlas.ti (2019) software was taken into account. Following this, an analysis of the data, obtained from Eurostat (2019), was carried out (other databases could be considered, however the information available in the Eurostat seems to be more adjusted to the objectives proposed in this research), and this statistical information was explored through an approach that combined factor and cluster analysis with data envelopment analysis (DEA). The factor and cluster analysis was considered to find more homogeneous decision making units (DMUs). With more homogeneous groups of European Union regions and countries, the intention was to reduce the influence, in the efficiency analysis, from national and regional specific characteristics. Before the cluster analysis, factor analysis was used to avoid problems of collinearity between the variables. After the factor and cluster analysis, considering Stata (2019) and Torres-Reyna (n.d.) procedures, the DEA through the DEAP (2019) software was performed. For the DEA the Cobb & Douglas (1928) model from the theory of production was considered as the base. This research follows studies such as, for example, Ali & Klein (2014), Xiang *et al.* (2016), Martinho (2017) and Suárez-Varela *et al.* (2017). These authors considered the DEA methodologies so as to analyse the issues related to the sustainable use of resources, including water. Approaches combining qualitative analysis, with factor-cluster analysis and DEA seem to be a field where there are issues to be explored, namely, those related to water efficiency.

This study delivers a systematic analysis about the literature related to efficient water management in the agricultural sector and highlights the potentialities of water savings in European countries and regions. These are relevant insights for the several operators related to water use and management (farmers and policymakers), based on new approaches that combine qualitative analysis (considering the Atlas.ti software) with the DEA–factor-cluster analysis.

2. Literature analysis

To better organize the literature analysis, first a qualitative analysis will be done considering the Atlas.ti software and 50 of the 54 scientific documents obtained from the Web of Science databases related to the topics: 'efficient water management'; agriculture. Only 50 were considered because the

Atlas.ti was unable to import information for the following studies: Cassel *et al*. (1978), Barrett & Skogerboe (1980), Rahman *et al*. (1981) and Hundal & Dedatta (1984).

Figure 1 presents the main words in the 50 scientific documents related to efficient water management by the agricultural sector. It is proposed that the following three groups can be considered: irrigation efficiency, water shortage, water quantification. In the following subsections, these three groups will be explored in depth, through a literature survey, and several studies are considered here.

2.1. Irrigation efficiency

Efficient water management in irrigation practices depends on several factors (Koscielniak *et al*., 2005), as those related to the political, economic, social, technological, legal and environmental contexts (Nazari *et al*., 2018). Among these factors, the depth of application, for instance, may have relevance in these contexts, as well as adjusted drainage systems (Chandio *et al*., 2013). In turn, the irrigation practices are interrelated with other agricultural techniques, such as soil management approaches (Rahman & Islam, 1991; Lee *et al*., 2018) or energy consumption (Yuan *et al*., 2018). In fact, the way in which irrigation is performed can have a significant impact on water management efficiency, namely, in surface irrigation (Castanedo *et al*., 2013), on agricultural production (Ismail *et al*., 2008) and soil productivities (Kim *et al*., 2018). It also has implications on farms' economic indicators

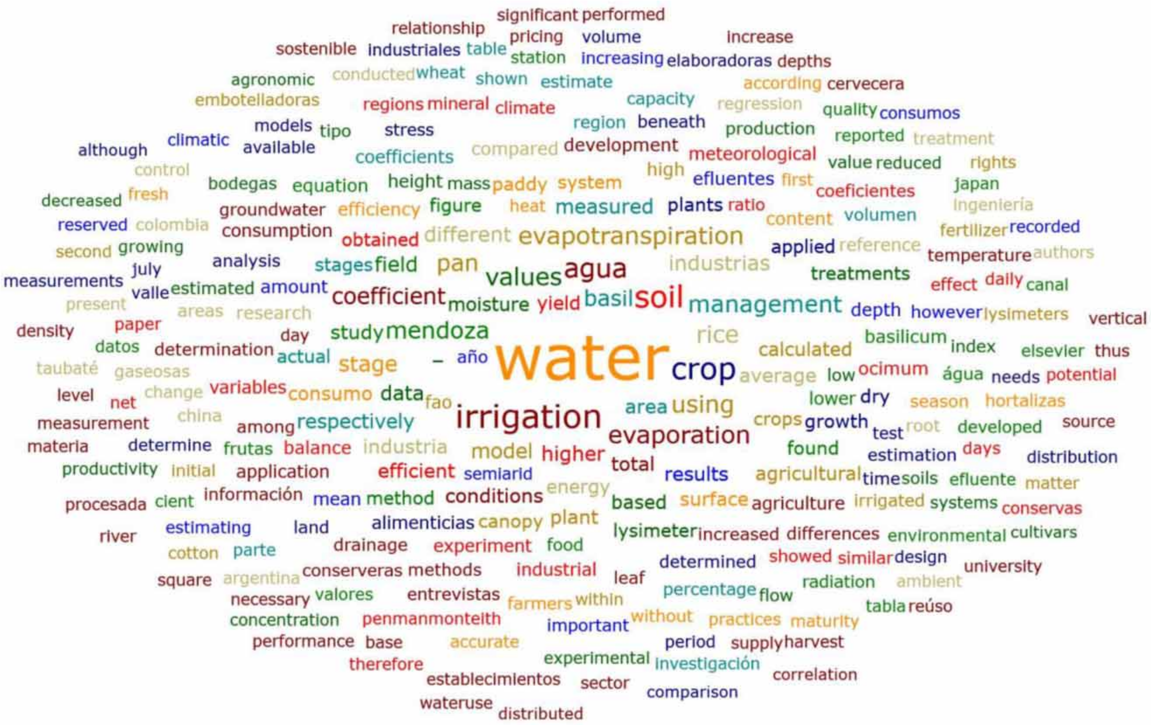

Fig. 1. Cloud words for the works obtained from the Web of Science related to the topics: 'efficient water management'; agriculture.

(Kumar *et al.*, 2009) and on the morphology and spatial distribution of the roots from permanent crops (Deng *et al.*, 2017).

In the framework of the European Union requirements (e.g., WFD, 2000) for efficient water management, the water pricing systems, namely, those which charge farmers for the costs produced, in some circumstances may bring negative environmental externalities, such as putting more pressure on the demand for alternative water sources (Dono *et al.*, 2010). These findings show the importance of monitoring and assessing the several policy instruments before and after their application (Kahil *et al.*, 2015), to better achieve the objectives proposed and to be able to choose the best adjusted strategies (Kumar & Singh, 2003).

Farmers' involvement in the whole design process of policy and water management plans improves the efficacy of their implementation. Another important aspect is to support farmers in choosing the best practices to improve the efficiency in water management with benefits for both the environment and the farmers' income (Levidow *et al.*, 2014).

In any case, water management efficiency has significantly improved around the world, thanks to developments in the technologies and techniques of irrigation or due to farmers' options and decisions being more adjusted (Roth *et al.*, 2013); nevertheless, it is still important to improve upon this (van Steenbergen *et al.*, 2015).

2.2. Water shortage

Water scarcity is and will be one of the biggest challenges for the several stakeholders concerned with sustainable development, namely, for the water managers and policymakers. Considering water scarcity and its importance as a resource for the agricultural sector (Zhang *et al.*, 2014a), the reuse of treated water may be an interesting approach towards dealing with this environmental and sustainability problem (Alcon *et al.*, 2010), namely, reutilizing water from food industry effluent (Duek, 2016). The shortage of water will increase in the future because of climate change and global warming, with significant impacts on the percentage of irrigated land (D'Agostino *et al.*, 2014) and promoting persistent dry seasons (Jin *et al.*, 2018). The global increased demand for food and bioenergy sources also puts pressure on the availability of water (Graveline & Merel, 2014), such as with soil and water pollution (Muttamara & Sales, 1994).

Another relevant way to deal with the water shortage is to design an optimal allocation of irrigation to each stage of crop evolution, reducing hydric stresses and improving farmers' profit (Fatemi *et al.*, 2011). Another such aspect concerns the choice of cultivars (turf industry) having a lower need for water (Githinji *et al.*, 2009). Efficient water management plans here make a determinant contribution.

Viticulture and wine production is a particular sector where water scarcity brings and will bring serious challenges, namely, in maintaining the specific characteristics of the certified wine, and where it is crucial for adjusted hydric stress management (Lanari *et al.*, 2014). Rice cultivation is another agricultural production where water scarcity raises special concerns (Mostafa & Fujimoto, 2014) and where it is fundamental to implement efficient water management practices (Sharma & Rajput, 1990), such as mulching, for example (Totin *et al.*, 2013). Mulching practice also has its application and use in other agricultural sectors, namely, when combined with surface irrigation (Zhang *et al.*, 2014b), because, indeed, there are other farming sectors that may be affected by the water shortage, as, for example, maize, vegetable and fruit crops (including dry fruits).

2.3. Water quantification

This subsection intends to highlight methodologies, in general, considered to quantify the water availability and to present approaches that, in some contexts, may be considered as alternatives to those explored in this study. For example, to understand the water dynamics, it is important to analyse subsurface water movement (Shaw *et al*., 2001) and the relationships between the various water reservoirs, which may highlight important insights for the several stakeholders and it is here where methodologies such as oxygen-18 (180) and deuterium isotopes may produce relevant outcomes (Aly *et al*., 1993). Another interesting approach is the surface energy balance algorithm for land (SEBAL) for evapotranspiration analysis (Atasever & Ozkan, 2018), or METRIC (mapping evapotranspiration at high resolution using internalized calibration) (Chavez *et al*., 2009), or nonparametric approaches such as random regression forest models (RRFM) (Gonzalo-Martin *et al*., 2017), wireless in-field sensing and control (WISC) software (Kim *et al*., 2008; Kim & Evans, 2009), decision support systems for canal water release (CWREDSS) (Rao & Rajput, 2009), or surface renewal (SR) methodology (Rosa & Tanny, 2015).

Other important questions relate to the calculation of water requirements for plants (or the levels of evapotranspiration) and the availability of water, namely, in the soil (Wijewardana & Galagedara, 2010). Here, some indicators/indices such as the crop coefficient, or field capacity (Constanza Daza-Torres *et al*., 2017), or the leaf area index (Gassmann *et al*., 2011), or trunk sap flow (Liu *et al*., 2009) may be useful for the design of adjusted plans for water management (Haofang *et al*., 2017).

In any case, each approach needs to be validated for its location relative to specific conditions of each context (Otero *et al*., 2012) and farming production (Yang *et al*., 2016), namely, in the decision support systems, to avoid bias results and rejections by the several stakeholders related to water management (Kinzli *et al*., 2015).

To design better water management practices, it is important to quantify evapotranspiration and the water requirements of plants and it is here where new information technologies and communication and mathematical models may provide useful support (Kumar *et al*., 2012; Kumar, 2013). The real-time assessment of soil quality and water requirements and automated irrigation approaches with multi-sensors has gained increasing importance over the last few years (Miller *et al*., 2014).

3. Data analysis

Unfortunately, data about water use/withdrawal are not abundant in the international mainstream databases and less specifically for the agricultural sector. In any case, it was possible to obtain statistical information from the Eurostat for some European Union regions and countries, presented in Tables 1–3, with a robust time series for the period 2010–2012. Considering the approaches used here (the DEA), averages over this period for cross-section analysis were obtained.

The countries presented in Table 1 were selected due to the availability of data and this statistical information shows that Spain is where more fresh surface and groundwater is withdrawn for irrigation in the agricultural sector (about 22,394 million cubic metres) followed by France (about 10% of that of Spain), next Bulgaria (796.11 million cubic metres) and Romania (310.33 million cubic metres).

Table 1. Water abstraction for agriculture irrigation, on average, over the period 2010–2012 (million cubic metres), at a national level.

European Union countries	Fresh surface and groundwater	Fresh surface water	Fresh groundwater
Bulgaria	796.11	790.35	5.76
Czechia	22.20	21.83	0.37
Denmark	173.33	2.30	171.00
Spain	22,394.33	17,486.33	4,908.00
France	2,994.03	1,843.79	1,150.24
Cyprus	160.67	37.67	123.00
Lithuania	1.04	0.25	0.79
Hungary	115.73	90.46	8.74
Malta	24.08	0.00	24.08
Netherlands	62.13	14.77	47.36
Poland	79.43	79.43	0.00
Romania	310.33	307.00	3.33
Slovenia	2.34	2.09	0.25
Slovakia	13.33	11.37	1.97
United Kingdom	90.23	49.53	40.70

Table 2. Water abstraction for agriculture irrigation, on average, over the period 2010–2012 (million cubic metres), at national and regional level (fresh surface water).

European Union countries	European Union regions	Fresh surface water
Bulgaria	Bulgaria	790.35
Bulgaria	Severozapaden	2.20
Bulgaria	Severen tsentralen	23.81
Bulgaria	Severoiztochen	71.32
Bulgaria	Yugoiztochen	176.27
Bulgaria	Yugozapaden	9.01
Bulgaria	Yuzhen tsentralen	507.75
Czechia	Czechia	21.84
Czechia	Praha	0.02
Czechia	Strední Cechy	5.85
Czechia	Jihozápad	0.01
Czechia	Severozápad	1.75
Czechia	Severovýchod	0.49
Czechia	Jihovýchod	13.63
Czechia	Strední Morava	0.09
Czechia	Moravskoslezsko	0.00
France	France	
France	Île de France	1.42
France	Champagne-Ardenne	0.82
France	Picardie	1.75
France	Haute-Normandie	0.22
France	Centre	28.20

(*Continued.*)

Table 2. (*Continued.*)

European Union countries	European Union regions	Fresh surface water
France	Basse-Normandie	0.66
France	Bourgogne	4.84
France	Nord – Pas-de-Calais	0.50
France	Lorraine	0.02
France	Alsace	7.48
France	Franche-Comté	0.09
France	Pays de la Loire	95.68
France	Bretagne	5.53
France	Poitou-Charentes	52.21
France	Aquitaine	183.60
France	Midi-Pyrénées	285.64
France	Limousin	1.99
France	Rhône-Alpes	151.13
France	Auvergne	27.91
France	Languedoc-Roussillon	316.35
France	Provence-Alpes-Côte d'Azur	626.04
France	Corse	51.73
Cyprus	Cyprus	37.67
Cyprus	Kypros	37.67
Lithuania	Lithuania	0.25
Lithuania	Lietuva	0.00
Hungary	Hungary	98.82
Hungary	Közép-Magyarország	0.63
Hungary	Közép-Dunántúl	1.65
Hungary	Nyugat-Dunántúl	6.10
Hungary	Dél-Dunántúl	1.62
Hungary	Észak-Magyarország	0.77
Hungary	Észak-Alföld	55.51
Hungary	Dél-Alföld	32.55
Poland	Poland	79.42
Poland	Lódzkie	1.21
Poland	Mazowieckie	26.39
Poland	Malopolskie	0.00
Poland	Slaskie	0.00
Poland	Lubelskie	3.96
Poland	Podkarpackie	3.08
Poland	Swietokrzyskie	0.00
Poland	Podlaskie	1.20
Poland	Wielkopolskie	16.64
Poland	Zachodniopomorskie	0.87
Poland	Lubuskie	1.21
Poland	Dolnoslaskie	0.35
Poland	Opolskie	0.21
Poland	Kujawsko-Pomorskie	8.16
Poland	Warminsko-Mazurskie	8.84
Poland	Pomorskie	7.32

Table 3. Water abstraction for agriculture irrigation, on average, over the period 2010–2012 (million cubic metres), at national and regional level (fresh groundwater).

European Union countries	European Union regions	Fresh groundwater
Bulgaria	Bulgaria	5.77
Bulgaria	Severozapaden	0.04
Bulgaria	Severen tsentralen	0.18
Bulgaria	Severoiztochen	1.75
Bulgaria	Yugoiztochen	0.00
Bulgaria	Yugozapaden	0.34
Bulgaria	Yuzhen tsentralen	3.46
France	France	
France	Île de France	18.62
France	Champagne-Ardenne	21.90
France	Picardie	36.90
France	Haute-Normandie	3.05
France	Centre	251.75
France	Basse-Normandie	2.41
France	Bourgogne	8.12
France	Nord – Pas-de-Calais	6.88
France	Lorraine	0.11
France	Alsace	67.81
France	Franche-Comté	1.46
France	Pays de la Loire	88.33
France	Bretagne	4.04
France	Poitou-Charentes	124.23
France	Aquitaine	317.34
France	Midi-Pyrénées	41.65
France	Limousin	0.21
France	Rhône-Alpes	85.42
France	Auvergne	13.91
France	Languedoc-Roussillon	17.96
France	Provence-Alpes-Côte d'Azur	38.14
France	Corse	0.00
Cyprus	Cyprus	123.00
Cyprus	Kypros	123.00
Lithuania	Lithuania	0.79
Lithuania	Lietuva	1.00
Hungary	Hungary	8.73
Hungary	Közép-Magyarország	0.27
Hungary	Közép-Dunántúl	0.62
Hungary	Nyugat-Dunántúl	1.80
Hungary	Dél-Dunántúl	0.18
Hungary	Észak-Magyarország	1.61
Hungary	Észak-Alföld	0.87
Hungary	Dél-Alföld	3.38
Malta	Malta	24.08
Malta	Malta	24.33

On the other hand, a great part of the water withdrawal was surface water in the majority of the European Union countries considered, except for Denmark, Cyprus, Lithuania, Malta, the Netherlands (where there is the inverse), France and the United Kingdom (where the values are almost the same).

At national and regional levels (NUTS 2), Tables 2 and 3 show a similar pattern to that presented in Table 1 in the relationships between surface and groundwater withdrawal. However, it is important to stress the great diversity of relationships for the French regions (the database does not present values for France, as a country, in the data disaggregated at regional level) when it is compared for surface and groundwater withdrawal. For example, in the Centre (French region) the greatest volume of water withdrawal was from groundwater (251.75 million cubic metres from groundwater and 28.20 million cubic metres from surface) and the inverse happens for Provence-Alpes-Côte d'Azur (626.04 million cubic metres from surface and 38.14 million cubic metres from groundwater).

In turn, within each country, there is also a diversity of realities, showing that the contexts between regions of the same country, with regards to water withdrawal for agricultural irrigation are different and the cluster analysis makes good sense.

For example, concerning water withdrawal from the surface (Table 2), the values for the region Yuzhen Tsentralen in Bulgaria represent almost 65% of the total and for the region Severozapaden only 0.3%. The same may be verified for the French context, where Provence-Alpes-Côte d'Azur reveals the highest values. The same disparities occur for the Hungarian and Polish frameworks.

For water withdrawal from groundwater (Table 3), the differences in the values between European Union regions, within each country, should also be taken into account in the analyses performed in the next section. For example, among the French regions, Centre and Aquitaine withdrawal alone accounts for almost half of the used water for agricultural irrigation.

4. Factor and cluster analysis

To better organize the research presented here, namely, so as to avoid presenting too many tables, and considering the availability of data, in this and the next section, only statistical information for fresh surface water at national and regional level and for the year of 2010 will be explored. Fresh groundwater also is important in some European Union countries, as stressed before, but this may be considered in a future study considering the approaches covered here.

To improve understanding about the results presented in this section, Figure 2 shows the evolution of the standard output, utilized agricultural area and labour force across the European Union countries explored in this part of the study. This figure reveals that France and Poland, among the countries considered, are the member-states with higher standard output and utilized agricultural area; however, it stresses the comparatively (considering the values for the standard output and utilized agricultural area) low values for the labour force in France.

The factor and cluster analysis were performed following the Stata (2019) and Torres-Reyna (n.d.) procedures. To avoid problems of multicollinearity, before the cluster analysis the variables through factor investigation were also explored. For factor analysis, variables such as the standard output, utilized agricultural area, directly employed labour force and fresh surface water were considered. For the consideration of these variables, the Cobb–Douglas theory of production developments was taken into account as well as the design of the model for the DEA approach in the next subsequent section, for example, Martinho (2017).

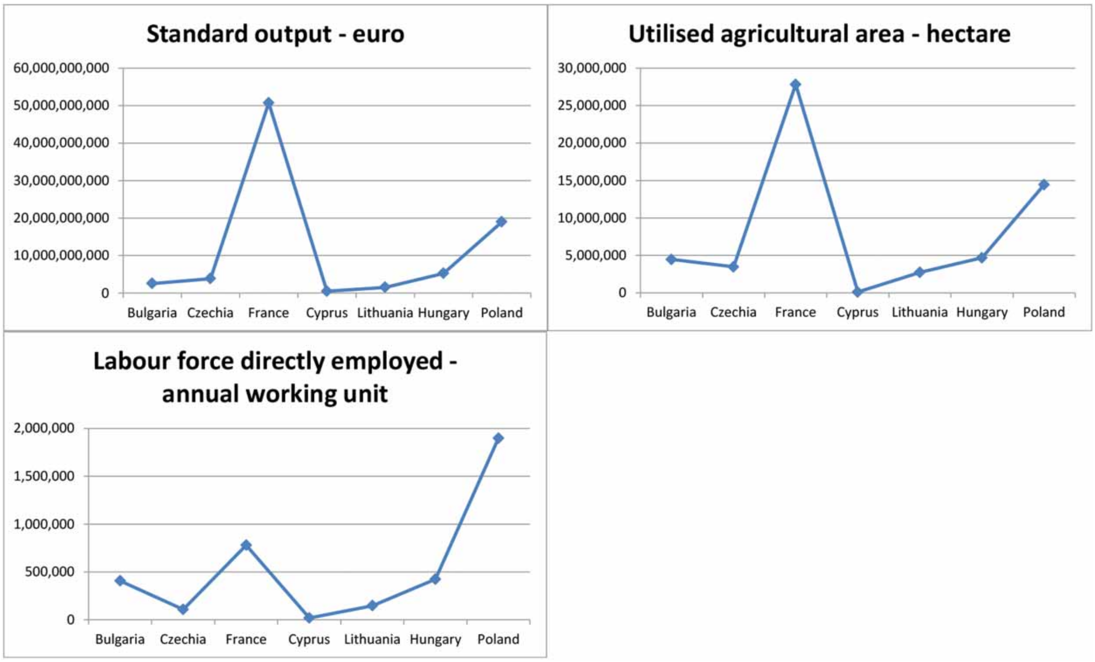

Fig. 2. Standard output, utilized agricultural area and labour force, for the year 2010, at national level.

By performing factor analysis the two factors presented in Table 4 were obtained. The main objective of the factor analysis is to find variables (factors) without having potential problems of multicollinearity to be considered for the cluster analysis. In Table 4 'variance' is the total variance in the data explained by each factor, 'difference' is the difference between one variance and the next, 'proportion' is the per cent of total variance explained by each factor and 'cumulative' is the amount of variance explained by the current and all previous factors. In Table 5, the values for factor1 and factor2 show the relevance of each variable for the respective factor. For example, the correlation between the variable standard output for factor1 is 0.937 (values close to 1 represent a higher correlation). The uniqueness reveals the variance of the variable not related with the factors. It is expected to find lower uniqueness (Torres-Reyna, n.d.). In Table 6, the KMO (Kaiser-Meyer-Olkin) test is presented, and for this test, values of at least higher than 0.5 are expected (Filho & da Silva Júnior, 2010).

Table 4 shows that factor1 explains 99% of the total variance verified and Table 5 reveals that this factor1 is mainly defined by the standard output, utilized agricultural area and labour force. The fresh surface water little defines factor1 and the value for the uniqueness of this variable confirms the lower relevance of it for the explanation of the factors obtained. The sampling adequacy analysed

Table 4. Factor analysis through principal factors with rotation (orthogonal varimax (Kaiser off)).

Factor	Variance	Difference	Proportion	Cumulative
Factor1	2.732	2.654	0.994	0.994
Factor2	0.079		0.029	1.023

Table 5. Rotated factor loadings (pattern matrix).

Variable	Factor1	Factor2	Uniqueness
Standard output	0.937	−0.058	0.119
Utilized agricultural area	0.978	0.108	0.032
Labour force	0.937	0.033	0.121
Fresh surface water	0.141	0.250	0.918

Table 6. Kaiser-Meyer-Olkin measure of sampling adjustment.

Variable	KMO
Standard output	0.767
Utilized agricultural area	0.639
Labour force	0.771
Fresh surface water	0.393
Overall	0.711

in Table 6 also confirms the lower relevance of the fresh surface water for the factor analysis. In any case, the overall Kaiser-Meyer-Olkin for all the variables is 0.711 (acceptable for this test).

Figure 3 obtained through cluster analysis, considering the factor1 as variable, shows that several European Union regions considered in this study may be grouped into three main clusters. In this figure ‘G’ represents the group and ‘n’ the number of observations in each group.

The results presented in Table 7, obtained following Stata (2019) procedures for cluster analysis, for the three clusters already identified reveal that in cluster 1 it is possible to find Bulgaria, the Czech Republic, Lithuania, Hungary and some regions from France and from Poland. Poland appears alone in cluster 2, showing a context which is different to the other regions and countries.

In cluster 3 it is possible to find Cyprus, the regions from Bulgaria, the Czech Republic and Hungary and the remaining regions from France and Poland.

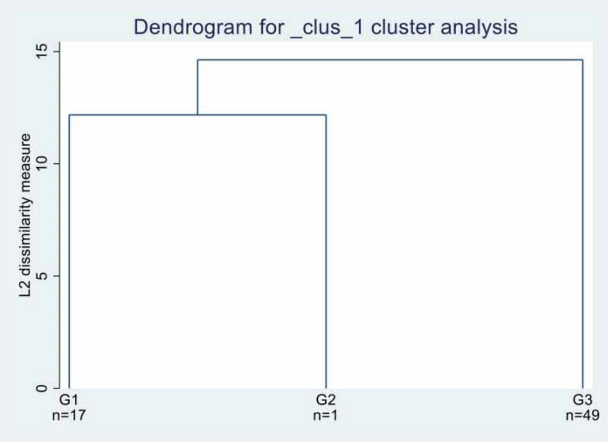

Fig. 3. Dendrogram to identify the number of main clusters.

Table 7. Cluster obtained for the countries and regions considered in this study.

Country	Region	Standard output	Utilized agricultural area	Labour force directly employed	Fresh surface water	Clusters
Bulgaria	Bulgaria	2.54×10^{9}	4,475,530	406,520	749.600	1
Czechia	Czechia	3.85×10^{9}	3,483,500	107,990	19.440	1
France	Champagne-Ardenne	4.36×10^{9}	1,536,950	38,740	0.970	1
France	Centre	3.00×10^{9}	2,311,400	37,380	29.070	1
France	Bourgogne	2.59×10^{9}	1,762,610	34,370	4.720	1
France	Pays de la Loire	5.18×10^{9}	2,103,390	64,460	108.990	1
France	Bretagne	5.83×10^{9}	1,639,840	57,390	7.090	1
France	Poitou-Charentes	2.76×10^{9}	1,721,280	36,010	58.690	1
France	Aquitaine	3.91×10^{9}	1,477,320	72,720	184.070	1
France	Midi-Pyrénées	2.77×10^{9}	2,540,090	60,580	286.350	1
France	Rhône-Alpes	2.41×10^{9}	1,516,680	58,410	142.650	1
Lithuania	Lithuania	1.53×10^{9}	2,742,560	146,770	0.300	1
Lithuania	Lietuva	1.53×10^{9}	2,742,560	146,770	0.000	1
Hungary	Hungary	5.24×10^{9}	4,686,340	423,490	82.470	1
Poland	Mazowieckie	2.80×10^{9}	1,834,790	285,900	23.960	1
Poland	Lubelskie	1.55×10^{9}	1,356,740	235,220	3.000	1
Poland	Wielkopolskie	2.98×10^{9}	1,722,000	181,910	16.560	1
Poland	Poland	1.90×10^{10}	14,447,290	1,897,240	75.070	2
Bulgaria	Severozapaden	4.25×10^{8}	881,670	50,720	1.300	3
Bulgaria	Severen tsentralen	4.62×10^{8}	806,130	51,890	16.920	3
Bulgaria	Severoiztochen	4.55×10^{8}	804,550	53,140	67.130	3
Bulgaria	Yugoiztochen	4.87×10^{8}	874,260	59,340	130.770	3
Bulgaria	Yugozapaden	2.04×10^{8}	480,870	64,610	6.170	3
Bulgaria	Yuzhen tsentralen	5.04×10^{8}	628,040	126,810	527.310	3
Czechia	Praha	23034070	11,100	340	0.030	3
Czechia	Strední Cechy	6.47×10^{8}	554,520	15,410	6.140	3
Czechia	Jihozápad	7.26×10^{8}	732,170	19,950	0.010	3
Czechia	Severozápad	2.41×10^{8}	318,850	7,050	1.760	3
Czechia	Severovýchod	6.39×10^{8}	559,120	19,410	0.540	3
Czechia	Jihovýchod	9.81×10^{8}	714,590	26,200	10.860	3
Czechia	Strední Morava	3.95×10^{8}	384,990	12,770	0.100	3
Czechia	Moravskoslezsko	2.01×10^{8}	208,150	6,860	0.000	3
France	Île de France	8.09×10^{8}	568,840	9,000	1.450	3
France	Picardie	2.31×10^{9}	1,328,370	22,720	1.460	3
France	Haute-Normandie	1.22×10^{9}	774,550	14,920	0.220	3
France	Basse-Normandie	1.99×10^{9}	1,210,810	30,700	0.740	3
France	Nord – Pas-de-Calais	1.85×10^{9}	817,990	22,840	0.500	3
France	Lorraine	1.29×10^{9}	1,138,400	18,300	0.000	3
France	Alsace	1.04×10^{9}	336,770	16,640	7.290	3
France	Franche-Comté	8.09×10^{8}	667,190	14,040	0.190	3
France	Limousin	7.08×10^{8}	838,760	19,160	1.950	3
France	Auvergne	1.33×10^{9}	1,469,490	31,840	21.440	3
France	Languedoc-Roussillon	1.74×10^{9}	956,590	41,980	297.880	3
France	Provence-Alpes-Côte d'Azur	1.84×10^{9}	815,450	39,290	630.650	3
France	Corse	1.81×10^{8}	179,940	4,050	45.140	3

(*Continued.*)

Table 7. (*Continued.*)

Country	Region	Standard output	Utilized agricultural area	Labour force directly employed	Fresh surface water	Clusters
Cyprus	Cyprus	4.72×10^8	118,400	18,590	36.400	3
Cyprus	Kypros	4.72×10^8	118,400	18,590	36.400	3
Hungary	Közép-Magyarország	2.77×10^8	259,570	33,020	0.300	3
Hungary	Közép-Dunántúl	6.08×10^8	531,170	42,140	0.360	3
Hungary	Nyugat-Dunántúl	6.13×10^8	524,370	44,350	1.190	3
Hungary	Dél-Dunántúl	7.59×10^8	689,440	54,050	0.650	3
Hungary	Észak-Magyarország	4.25×10^8	523,270	48,640	0.120	3
Hungary	Észak-Alföld	1.17×10^9	1,051,090	95,470	57.360	3
Hungary	Dél-Alföld	1.39×10^9	1,107,420	105,820	22.490	3
Poland	Lódzkie	1.42×10^9	957,060	165,820	1.730	3
Poland	Malopolskie	7.78×10^8	565,200	188,440	0.000	3
Poland	Slaskie	5.45×10^8	357,310	65,530	0.000	3
Poland	Podkarpackie	6.04×10^8	569,520	152,160	3.600	3
Poland	Swietokrzyskie	6.72×10^8	503,000	126,250	0.000	3
Poland	Podlaskie	1.26×10^9	1,031,750	110,840	1.060	3
Poland	Zachodniopomorskie	9.49×10^8	897,290	37,970	0.790	3
Poland	Lubuskie	4.51×10^8	417,700	25,350	1.130	3
Poland	Dolnoslaskie	8.97×10^8	909,470	68,700	0.340	3
Poland	Opolskie	6.02×10^8	509,060	37,520	0.040	3
Poland	Kujawsko-Pomorskie	1.52×10^9	1,055,670	98,040	6.830	3
Poland	Warminsko-Mazurskie	1.12×10^9	1,028,820	60,960	8.760	3
Poland	Pomorskie	8.32×10^8	731,930	56,640	7.270	3

Note: Standard output in euros; utilized agricultural area in hectares; labour force directly employed in annual work unit; fresh surface water in million cubic metres.

5. Efficiency investigation through DEA

The DEA in this section was performed through DEAP (2019) software, considering a model based on the Cobb–Douglas developments, where the output is the standard output (euros) and the inputs are the utilized agricultural area (in hectares and as a proxy for the capital), the labour (annual work units) and the fresh surface water withdrawal (million cubic metres) for farming irrigation (to analyse the possibility of efficient savings for agricultural research). All these variables were considered disaggregated at national and regional level and only to 2010 (for better compatibility of several series). The selection of the countries and regions was also constrained by the availability of data in the mainstream databases.

The mathematical formulation to perform the DEA analysis based on the Cobb–Douglas model described before is well described, for example, in Coelli (1998).

This analysis will only apply to clusters 1 and 3 identified in the previous section, because for cluster 2 there was only Poland found as DMU. An analysis oriented input was considered, with variable returns to scale and DEA multi-stage.

Table 8 demonstrates that it is possible to improve the output of Bulgaria, the Czech Republic, Lithuania and of regions from France (Poitou-Charentes, Midi-Pyrénées, Rhône-Alpes). For example, in Rhône-Alpes it is possible to efficiently improve the standard output by about 70%. On the other hand, the French regions of Champagne-Ardenne, Bourgogne, Bretagne, Aquitaine and the Polish region of Lubelskie seem to be those which are more efficient in cluster 1. Specifically for the surface water withdrawal for agricultural irrigation, the situation is more critical for the French region; Centre, Pays de la Loire, Poitou-Charentes and Midi-Pyrénées where almost 100% of the water withdrawal could be saved (since the projected values are almost 0% of the original values). It is worth noting that the Bulgarian and Hungarian global contexts deserve special attention from the several stakeholders. In general, the frameworks for the utilized agricultural area and labour force follow a similar pattern and are not so problematic as those shown for fresh surface water. In any case, the Bulgarian, Czech and Hungarian contexts, for example, reveal that it is potentially possible to improve significantly the efficiency in the area and labour use.

For cluster 3, Table 9 shows that two regions from the Czech Republic (Praha and Moravskoslezsko), several regions from France, Cyprus and two Polish regions (Malopolskie and Slaskie) are the most efficient DMU. Concerning water withdrawal for agricultural irrigation the more dramatic cases are those from the Bulgarian regions (as it is for the other inputs, confirming the findings stressed for Table 8), some regions from Czech Republic (Strední Cechy and Severozápad, for example), some French regions (Auvergne, Languedoc-Roussillon, Provence-Alpes-Côte d'Azur and Corse) and the Hungarian regions of Észak-Alföld and Dél-Alföld. As referred to before, for cluster 1, in general, the contexts for the utilized agricultural area and labour force display a similar picture and are not so problematic as those presented for surface water; however, in some cases, the potentialities for savings in the labour force are more relevant, namely, in the Hungarian and Polish regions. This is also observable in Table 8 and in Figure 2.

Table 8. Percentages (%) between the projected values by DEA and the original (cluster 1).

Country	Region	Standard output	Utilized agricultural area	Labour force directly employed	Fresh surface water
Bulgaria	Bulgaria	121	32	32	16
Czechia	Czechia	110	44	44	44
France	Champagne-Ardenne	100	100	100	100
France	Centre	100	74	95	13
France	Bourgogne	100	100	100	100
France	Pays de la Loire	100	76	76	4
France	Bretagne	100	100	100	100
France	Poitou-Charentes	111	99	99	6
France	Aquitaine	100	100	100	100
France	Midi-Pyrénées	143	62	62	1
France	Rhône-Alpes	170	99	99	73
Lithuania	Lithuania	151	88	80	88
Lithuania	Lietuva	100	100	100	100
Hungary	Hungary	100	34	13	34
Poland	Mazowieckie	100	78	52	78
Poland	Lubelskie	100	100	100	100
Poland	Wielkopolskie	100	84	74	84

Table 9. Percentages (%) between the projected values by DEA and the original (cluster 3).

Country	Region	Standard output	Utilized agricultural area	Labour force directly employed	Fresh surface water
Bulgaria	Severozapaden	100	21	11	21
Bulgaria	Severen tsentralen	100	19	14	19
Bulgaria	Severoiztochen	100	18	18	14
Bulgaria	Yugoiztochen	100	17	17	8
Bulgaria	Yugozapaden	100	16	5	16
Bulgaria	Yuzhen tsentralen	100	21	15	7
Czechia	Praha	100	100	100	100
Czechia	Strední Cechy	100	52	52	3
Czechia	Jihozápad	100	86	86	90
Czechia	Severozápad	100	39	39	7
Czechia	Severovýchod	100	50	41	50
Czechia	Jihovýchod	100	53	53	32
Czechia	Strední Morava	100	67	67	67
Czechia	Moravskoslezsko	100	100	100	100
France	Île de France	100	81	89	36
France	Picardie	100	100	100	100
France	Haute-Normandie	100	100	100	100
France	Basse-Normandie	100	100	100	100
France	Nord – Pas-de-Calais	100	100	100	100
France	Lorraine	100	100	100	100
France	Alsace	100	100	100	100
France	Franche-Comté	100	75	75	75
France	Limousin	100	42	42	16
France	Auvergne	100	46	46	3
France	Languedoc-Roussillon	100	79	52	0
France	Provence-Alpes-Côte d'Azur	100	99	58	0
France	Corse	100	51	51	0
Cyprus	Cyprus	100	100	100	100
Cyprus	Kypros	100	100	100	100
Hungary	Közép-Magyarország	100	47	11	47
Hungary	Közép-Dunántúl	100	51	18	51
Hungary	Nyugat-Dunántúl	100	50	18	50
Hungary	Dél-Dunántúl	100	48	17	48
Hungary	Észak-Magyarország	100	50	50	50
Hungary	Észak-Alföld	100	39	18	11
Hungary	Dél-Alföld	100	49	18	19
Poland	Lódzkie	100	64	11	64
Poland	Malopolskie	100	100	100	100
Poland	Slaskie	100	100	100	100
Poland	Podkarpackie	100	43	5	43
Poland	Swietokrzyskie	100	94	94	100
Poland	Podlaskie	100	54	14	54
Poland	Zachodniopomorskie	100	47	31	46
Poland	Lubuskie	100	46	23	46
Poland	Dolnoslaskie	100	51	51	51

(*Continued.*)

Table 9. (*Continued.*)

Country	Region	Standard output	Utilized agricultural area	Labour force directly employed	Fresh surface water
Poland	Opolskie	100	86	86	85
Poland	Kujawsko-Pomorskie	100	59	21	48
Poland	Warminsko-Mazurskie	100	42	26	42
Poland	Pomorskie	100	43	21	43

6. Discussion

Of course, despite cluster analysis being done to obtain homogeneous DMUs, following, for instance, Martinho (2020), there are still significant differences between the regions and countries considered in each cluster. In any case, the results presented and discussed here may provide an interesting base for the several stakeholders, namely, farmers and policymakers, in line with that argued, for example, by Salmoral *et al.* (2017). These findings may allow implementation of new and adjusted strategies to improve water withdrawal for agricultural irrigation, with relevant positive externalities for the environment and economic sustainability for farms.

Indeed, the amount of water withdrawal for agricultural irrigation and how effectively it is used, as shown in the statistics from the Eurostat, should be a motive for concern, as stressed by the Aquastat (2019). In general, the surface water and, in some cases, the labour force, are used less efficiently in the agricultural sector than, for example, the utilized agricultural area. The efficient use of water depends, in fact, on several factors, as stressed by Nazari *et al.* (2018).

The more dramatic cases are those from some French regions and from the Bulgarian and Hungarian contexts. The French context is paradoxical, because it has the most and less efficient regions, for surface water use for agricultural irrigation. Nonetheless, the French efficiency weaknesses are more focused on the surface water withdrawal and the Bulgarian and Hungarian fragilities are more scattered over the farm structures, involving the area and the labour management. This context highlights the diversity of realities inside the European Union, as shown by Martinho (2017).

7. Conclusions

The main objective of this study was to analyse the efficiency in water withdrawal for agricultural irrigation in the regions and countries of the European Union. For this, qualitative analysis of the literature was performed and statistical information from the Eurostat was considered over the period 2010–2012. These data were analysed through DEA, after factor and cluster analysis. The factor analysis allowed factors to be obtained without presenting problems of multicollinearity and the cluster analysis allowed for finding groups of more homogeneous DMUs (important aspects for the efficiency of the investigation). The variables considered were the standard output (as output), the utilized agricultural area, the labour and the water withdrawal. For water withdrawal, two series were considered, one for the fresh surface water and the other for fresh groundwater. Considering the difficulties in finding robust series for the water withdrawal, the factor, cluster and DEA analyses were performed only considering fresh surface water, for the year of 2010 and for the countries and regions with statistical information in the Eurostat. In fact, it will be important that public institutions improve the availability of statistical information concerning water withdrawal and its use by the agricultural sector.

The literature review, complemented with bibliometric analysis through the Atlas.ti software, highlights the following three main topics about efficient water management in the agricultural sector: irrigation efficiency, water shortage and water quantification. In fact, it is fundamental to improve irrigation efficiency, namely, with new approaches and technologies, where farmers have a determinant role. The questions regarding improvements in water efficiency gain more relevance when the water scarcity or shortage increases due to climate change and global warming. The new approaches for water quantification may also provide an important contribution.

It is important to highlight in this section that the data analysis shows that a relevant part of the water withdrawal for agricultural irrigation is from fresh surface water and that the factor and cluster analysis allowed identification of three clusters for the countries and regions considered in this study (the selection was constrained by the availability of statistical information in the mainstream databases).

Finally, the data envelopment analysis reveals that there are interesting cases of efficiency (including water withdrawal efficiency) that should be considered as references in a process of benchmarking that could be performed within the European Union, considering the specificities of the agricultural sector and the importance of an efficient management of water. On the other hand, there are some cases that deserve special attention, such as those, for example, from Bulgaria and some French regions, where, in some circumstances, almost 100% of the water withdrawal could be saved (of course, in an optimized perspective).

This study highlighted the main aspects related to efficient water management in the agricultural sector, making it possible to identify European countries and regions that may be considered as benchmarks for the less efficient regions and quantifying the potential possibilities of savings in the area, labour and farm water use. The main limitation of this work is related to the availability of statistical information in the mainstream databases. In future research, the approaches presented in this study may be applied to other parts of the world outside the European Union, by benchmarking the results obtained with those demonstrated here.

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