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Comparative analysis of energy efficiency in water users associations

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Abstract

The government of Spain has developed an energy strategy that includes a campaign of energy audits in water users associations (WUAs) in order to improve energy efficiency in irrigation. A guideline for energy audits has been developed, standardizing the audit process in WUAs. This guideline has been implemented in 22 WUAs in the Castilla-La Mancha, Valencia, and Murcia Regions. In this paper, an analysis of the indicators proposed in the guideline is performed, and the indicators that most represent energy efficiency of WUAs are identified. Also, the suitability of the proposed indicators and classifications under different conditions are discussed. In addition, a cluster analysis is performed on WUAs to classify them according to their energetic aspects. Results show that indicators global energy efficiency (GEE) and active energy consumed per hectare (EacSr) are not adequate for analysing the evolution of energy consumption in a WUA. The most representative energy indicators are those expressing ratios between energy consumption and water volume supplied to the users as the indicators active energy consumed per volume unit (EacVs) and energy cost per volume unit (CENVs). It is conclude that using the current methodology for calculate the supply energy efficiency indicator (SEE), GEE is not an adequate indicator for energy classification of WUAs, and also that the results of the energy analysis must be used to propose measures for energy conservation and energy cost reduction.

Additional key words: energy indicators; irrigation energy efficiency.

Resumen

Estudio comparativo de eficiencia energética en comunidades de regantes

El gobierno de España ha desarrollado una estrategia de ahorro y eficiencia energética que incluye una campaña de realización de auditorias energéticas en Comunidades de Regantes para la mejora de la eficiencia energética en el sector del regadío. Con este fin se desarrolló un protocolo de auditorias energéticas que estandariza el proceso de auditoría en Comunidades de Regantes. Este protocolo se ha implementado en 22 Comunidades de Regantes de Castilla- La Mancha, Valencia y Murcia. En este artículo se presenta un análisis de los indicadores propuestos en el protocolo, identificando los que mejor representan la eficiencia energética de las comunidades de regantes, se analiza la idoneidad de los indicadores y clasificaciones propuestas y se realiza un análisis cluster sobre las Comunidades de Regantes analizadas, clasificándolas respecto a variables de tipo energético. Los resultados muestran que la eficiencia energética general (GEE) y la energía activa consumida por hectárea (EacSr) no son indicadores adecuados para estudiar la evolución del consumo de energía en una comunidad de regantes. Los indicadores energéticos más representativos son el consumo de energía activa por unidad de volumen (EacVs) y el coste de energía por unidad de vo-

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Abbreviations used: CENSr (energy cost per hectare), CENVs (energy cost per volume unit), EacSr (active energy consumption per hectare), EacVs (active energy consumed per volume unit), EDI (energy dependence index), GEAWUAs (guideline for energy audit of water users associations), GEE (global energy efficiency), GPS (global positioning system), IDAE (Instituto para la Diversificación y Ahorro de la Energía), PEE (pumping energy efficiency), SEE (supply energy efficiency), WUA (water users association).

lumen (CENVs). Finalmente se concluye indicando que con la metodología actual de cálculo de la eficiencia de suministro energético (SEE), GEE no es un indicador adecuado para calificar energéticamente las comunidades de regantes, así como que los resultados de los análisis energéticos se deben tener en cuenta para proponer medidas de ahorro energético y económico.

Palabras clave adicionales: eficiencia energética del riego; indicadores energéticos.

Introduction

The European Union Directive 2006/32/EC, on energy end-use efficiency and energy services is implemented in Spain through the Governmental Action Plan PAE4+ «Energy Conservation and Efficiency (2008-2012)» (Ministerio de Industria, Comercio y Turismo, 2007). Performing energy audits in water users associations (WUAs) is one of the main PAE4+ measures for improving energy efficiency in the irrigation sector. A subsidy for the development of energy audits in WUAs was established by the government, together with additional subsidies for the specific energy saving measures identified in the audits. As a consequence, a large number of energy audits have been performed in different irrigated areas of Spain during the last years.

The guideline for energy audit of WUAs (GEAWUAs), published by the «Instituto para la diversificación y ahorro de la energía» (IDAE), Ministry of Industry of Spain (Abadía *et al.,* 2008a), presents a number of specific energy indicators. These indicators were compiled from previous works by different authors (Malano and Burton, 2001; Rocamora *et al.,* 2008; Rodríguez *et al.,* 2008). An energy classification is proposed in the GEAWUAs based on the global energy efficiency (GEE) and active energy consumption per hectare (EacSr) indicators.

The GEE of an irrigation distribution network includes both the pumping energy efficiency (PEE), which depends on the functioning of the pumping stations, and the supply energy efficiency (SEE), that depends on the system's spatial distribution and layout (Abadía *et al.,* 2008b). PEE represents the energy efficiency of the pumping system, while SEE represents the ratio between the energy demanded by the irrigation system and the supplied energy. Similar analyses of energy efficiency for water distribution network have been presented by several authors. Pelly and Hitz (2000) calculated the global efficiency, applied to urban systems, as the ratio between the minimum energy required to supply the demanded head to the users and the total energy actually consumed during one year. In this study it was not possible to identify the individual contribution of the pumping energy efficiency and supply energy efficiency to the global energy efficiency of the system. Luc *et al.* (2006) proposed a set of performance indicators for irrigation pumping stations based on pumping energy efficiency, which include the pump efficiency, the transmission efficiency and the electric motor efficiency. However, these authors did not consider the influence of the supply energy efficiency on the global efficiency.

The rating scale described in the GEAWUAs establishes five ratings, depending on the GEE value, as shown in Table 1. Regarding consumption of energy per unit of irrigated area (EacSr), five groups are also established, as shown in Table 2.

The values for rating the GEE and EacSr of WUAs were established by IDAE. These ratings were not contrasted with real field data at the time. It is therefore necessary to classify a real data set in order to assess their suitability and to propose improvements reflecting better adaptation to current energy efficiency standards. Two additional indicators provide information about energy management in the WUA: 1) active energy consumed per volume unit (EacVs), also known as specific energy consumption (kWh m^{-3}); and 2) energy cost per volume unit (CENVs), also known as specific energy cost (in € m^{-3}). The first one is useful for analysing the evolution of seasonal energy consumption in the WUA, as well as for establishing comparisons between WUAs with similar productive orientations. The second indicator evaluates the success in selecting periods of low energy tariff, and is useful for compa-

Table 1. Energy rating scale for evaluating the energy efficiency of a WUA (GEE)

Rating	Description	GEE (%)
A	Excellent	GEE ≥ 50
B	Good	40 ≤ GEE < 50
C	Normal	30 ≤ GEE < 40
D	Acceptable	25 ≤ GEE < 30
E	Unacceptable	GEE < 25

WUA: water user association. GEE: global energy efficiency.

Table 2. Rating regarding active energy consumption per irrigated hectare (EacSr)

Group	Description	EacSr (kWh ha^{-1} year^{-1})
1	Non consumer	EacSr = 0
2	Low consumer	0 < EacSr ≤ 300
3	Medium consumer	300 < EacSr ≤ 600
4	Consumer	600 < EacSr ≤ 1,000
5	High consumer	EacSr > 1,000

ring WUAs with similar specific energy consumption. These two indicators are not linked to water availability in the WUA, and their value is indicative of energy consumption and cost.

Following the energy analysis, the next goal of an energy audit is to propose measures promoting energy conservation and economic performance, but this phase is not the aim of this work and can be found in related papers (Moreno *et al.,* 2007a, 2009).

This paper aims to present the experience of two research groups on energy audits in irrigation, under a common context of sustainable use of water and energy resources. The results of 22 WUA audits are analysed, and the suitability of the proposed indicators and classifications under different conditions are discussed. In addition, based on the analyzed indicators, WUAs have been classified into homogenous groups by considering energy demand criteria.

Material and methods

The description and calculation method of the nine indicators used in this study is presented in Table 3, adapted from Abadía *et al.* (2008a). In order to compute these indicators in each WUA it was necessary to obtain data from the irrigation network managers and from the WUA databases. In addition, specific data needed to be obtained during the audit using electric, hydraulic, and topographic equipment. All data corresponded to the 2007 irrigation season. The required data included:

— Data obtained from managers: network hardware and management, energy costs, and water delivery.

— Measured hydraulic data: discharge of all the pumps (wells and pumping stations), by installing a portable ultrasound flowmeter (2.5% accuracy) at the pumping pipe, and the pumping head, by installing a pressure transducer (1% accuracy), following the methodology proposed by Moreno *et al.* (2007a).

— Electrical parameters measured at the pumping station: current, voltage, power factor, and absorbed power. Those parameters were measured with an electrical network analyzer (1.5% accuracy) (Moreno *et al.,* 2007a).

— Frequency distribution of discharge at the pumping stations: obtained following the methodology proposed by Moreno *et al.* (2007a) and Rocamora *et al.* (2008).

— Elevation of all hydrants and singular network points (pumping station, valves, etc.): measured by a global positioning system (GPS) with relative accuracy between points higher than 0.01 m.

Hydraulic network simulation models contribute to the energy analysis of irrigation networks. EPANET (Rossman, 2000) was applied to all of investigated networks to evaluate their performance taking into consideration their managing conditions.

In order to determine the energy efficiency of the pumping stations, the MAPEE (model for energy analysis of pumping stations) was used (Moreno *et al.,* 2007b). This model calculates efficiency under different types of regulations and by considering the frequency of different discharge ranges during the irrigation season (Moreno *et al.*, 2007a).

The general characteristics of the 22 analyzed WUAs are presented in Table 4. This table shows the denomination of each WUA, the irrigable area, the volume of water invoiced, the index of energy dependence (EDI, percentage of pumped volume to total supplied volume), the number of pumping stations, the maximum difference in elevation within the irrigable area, and the type of irrigation system. The denomination of each WUA is made up of two numbers: the first makes reference to the Region and the second to the WUA, being region 1 Castilla-La Mancha, 2 Comunidad Valenciana, and 3 Región de Murcia.

With regard to the type of irrigation system, as shown in Table 4; «Surface» refers to water users associations where pumps supply water at atmospheric pressure, either directly to channels for surface irrigation, or to reservoirs where different irrigation systems are then supplied (surface and drip irrigation systems). «Drip» and «Sprinkler» refer to pumps that directly pump water into the distribution network to supply these irrigation systems, while «Desalination» refers to pumps that supply pressure to desalination plants. The combination «Surface/drip» refers to water users associations that supply drip irrigation systems and non pressurized systems.

Table 3. Description of analyzed indicators

Indicator name	Abrev	Description	Calculation
Present active energy consumed (kWh)	Eac	Annual energy consumed in the whole of the WUA.	
Energy consumed per unit of irrigated area (kWh ha^{-1})	EacSr	This is the quotient between active energy consumed and present irrigation surface of the WUA.	$\frac{\text{Energy consumed}}{\text{Irrigated area}}$
Specific energy (kWh m^{-3})	EacVs	This is the quotient between active energy consumed and total volume of water supplied to users.	$\frac{\text{Energy consumed}}{\text{Water volume supplied to the users}}$
Energy cost per irrigated area (€ ha^{-1})	CENSr	This represents the total turnover of energy divided by the present irrigated area of the WUA.	$\frac{\text{Invoiced energy cost}}{\text{Irrigated area}}$
Energy cost per m^3 supplied to users (€ m^{-3})	CENVs	This represents the total turnover of energy divided by the total volume of water supplied to users.	$\frac{\text{Invoiced energy cost}}{\text{Water volume supplied to users}}$
Energy load index (m)	ELI	This represents the average manometric height supplied by pumping, including supply points that don't need pumping.	$\frac{\sum V_i H_i}{\text{Volume of water that enters the system}}$ V_i and H_i being the volume and manometric height supplied by pump *i*.
Pump energy efficiency (%)	PEE	This represents the energy efficiency of all the pumping in the WUA.	$\text{PEE} = 0.002725 \frac{\sum V_k H_k}{\sum kWh_{k\ invoiced}} \cdot 100$ V_k being the pumped volume for each pump; H_k manometric height supplied by each pump; and $kWh_{k\ invoiced}$ the kWh consumed per pump.
Energy supply efficiency (%)	SEE	This represents the relation between the energy required and the energy actually supplied by the pumps.	$\text{SEE} = \frac{(V_T \frac{\sum S_j(z_j + H_{dj})}{S_T} - \sum V_i z_i)}{\sum V_k H_k}$ V_T being the total volume of water that enters the Irrigation Society; S_j the surface of the farming area at z_j elevation; H_{dj} the design pressure at the irrigation inlets; S_T total surface of irrigable area; V_i volume contributed by each water supply point; z_i the elevation of each supply point; V_k the volume pumped by each pump; and H_k the manometric height supplied by each pump.
General energy efficiency (%)	GEE	This represents the global energy efficiency of the WUA.	$\text{GEE} = \text{PEE} \cdot \text{SEE}$

The energy dependence of the analyzed WUAs varies depending on the initial energy of the water. For example, WUA.3.2 only needs to pump 22% of the total amount of water invoiced due to a favourable water elevation in relation to the irrigable area. In most of the WUAs showing EDIs of 100%, groundwater is the only source of water.

In order to determine the similarity between WUAs and energy indicators, a cluster analysis was performed. This multi-variant statistical method, commonly used in benchmarking processes (Rodríguez *et al.,* 2008), aims at classifying elements into homogenous groups, based on a defined set of variables (Peña, 2000). Cluster analysis is an exploratory technique, which does not

Table 4. General characteristics of the analyzed water users associations

Denomi-nation	Irrigated area (ha)	Volume water invoiced (m³)	EDI[1] (%)	Number of pumps	Maximum elevation difference (m)	Number of hydraulic sectors	Type of irrigation system
WUA 1.1	515.09	958,041	100	1	100	1	Drip
WUA.1.2	107.46	128,037	100	2	9	1	Drip
WUA.1.3	245.10	1,762,153	100	7	10	2	Drip
WUA.1.4	103.78	100,058	100	2	5	1	Drip
WUA.1.5	1,646.60	11,389,385	100	12	22	3	Sprinkler
WUA.1.6	551.37	509,090	100	2	125	1	Drip
WUA.1.7	136.16	120,996	100	2	6	1	Drip
WUA.1.8	779.56	3,595,615	100	14	85	4	Sprinkler
WUA.1.9	274.70	927,084	100	9	15	3	Sprinkler/Drip
WUA.1.10	123.30	142,771	100	2	15	1	Drip
WUA.1.11	388.92	2,243,581	100	5	31	1	Sprinkler
WUA.1.12	590.41	2,939,572	100	13	50	7	Sprinkler
WUA.1.13	1,732.40	1,304,215	100	4	100	1	Drip
WUA.1.14	951.23	5,047,527	100	11	36	2	Sprinkler
WUA.1.15	675.78	618,174	100	6	25	3	Drip
WUA.2.1	3,332.50	3,840,050	51.72	3	115	2	Surface/Drip
WUA.2.2	1,747.00	2,237,559	100	6	120	1	Desalination/Surface
WUA.2.3	778.37	947,700	100	3	93	1	Desalination/Surface
WUA.2.4	656.31	2,050,200	97.33	3	88	3	Surface
WUA.2.5	766.07	1,458,025	100	3	180	1	Surface
WUA.3.1	12,728.00	44,946,447	81.72	12	155	3	Surface/Drip
WUA.3.2	6,745.00	7,675,533	22.03	3	157	4	Surface
Total	35,330.01	93,179,660		125			

[1] EDI (energy dependence index) represents the relation between volume of pumped water and total volume of water supplied.

impose restrictions through statistical models (Figueras, 2001). This methodology was applied using the MatLab® software. Among the different existing grouping methods (Peña, 2000), a hierarchical aglomerative cluster was used, since the number of WUAs to be classified was high. Similarity was determined using correlation coefficients. This is a common method when the classification variables have different measurement units. The simple link criterion, based on the minimum distance between objects, was adopted. For the determination of correlation (Dc), the following equation was used:

$$Dc = 1 - \left(\frac{\sigma_{ab}}{\sigma_a \cdot \sigma_b} \right) \quad [1]$$

where: σ_{ab} is the covariance between WUAs a and b or between indicators a and b (depending on whether WUAs or indicators are grouped); σ_a is the standard deviation of WUAs or indicator a; σ_b is the standard deviation of WUAs or indicator b.

The indicators used for grouping WUAs and the indicators themselves were: EacSr, EacVs, CENSr, CENVs, ELI, and PEE. Indicators formulated as absolute values were not considered in this analysis. This is the case of the volume supplied to users or the total energy consumed. In fact, these indicators can introduce differences due to scale factors. Furthermore, indicators SEE and GEE were not considered, due to the problems detected in SEE determination as discussed in the following section.

Results and discussion

Table 5 presents the value of the analysed indicators for each WUA. GEE and EacSr are not totally reliable and their use for analysing the evolution of energy consumption in a WUA in successive irrigation seasons, as well as for comparing different WUAs, can lead to interpretation errors, as discussed in the following paragraphs.

Regarding GEE, it can be determined as the product of SEE and PEE. SEE is closely linked to the topography of the irrigable area: it presents low values in

Table 5. Value of analysed indicators

	EacSr (kWh ha^{-1})	EacVs (kWh m^{-3})	CENSr (€ ha^{-1})	CENVs (€ m^{-3})	ELI (m)	PEE (%)	SEE (%)	GEE (%)
WUA.1.1	601.61	0.323	63.77	0.030	53.8	52.4	24.1	12.6
WUA.1.2	1,467.63	1.186	121.85	0.102	146.6	48.8	93.4	45.5
WUA.1.3	4,735.68	0.659	359.24	0.050	105.4	57.2	88.1	50.4
WUA.1.4	1,047.19	1.046	87.34	0.090	154.0	58.2	96.4	56.1
WUA.1.5	4,584.20	0.663	315.35	0.046	136.4	59.7	98.1	58.0
WUA.1.6	938.33	1.031	68.55	0.074	135.3	36.3	74.3	27.0
WUA.1.7	823.43	0.927	69.19	0.079	143.0	53.5	90.7	48.5
WUA.1.8	6,098.90	1.322	410.17	0.090	251.3	57.3	95.9	55.0
WUA.1.9	3,428.16	1.016	295.01	0.087	123.5	51.7	95.6	49.5
WUA.1.10	1,185.00	1.023	114.92	0.099	166.7	69.4	91.1	63.2
WUA.1.11	6,229.90	1.080	543.35	0.094	233.1	60.8	90.7	55.1
WUA.1.12	4,978.87	0.754	287.71	0.058	131.0	50.6	93.7	47.5
WUA.1.13	617.94	0.821	55.57	0.074	115.8	45.2	51.2	45.2
WUA.1.14	5,749.50	1.083	428.29	0.081	167.1	52.4	91.7	48.0
WUA.1.15	859.70	0.940	70.84	0.077	155.3	61.7	100.0	61.7
WUA.2.1	335.06	0.211	28.17	0.024	46.9	54.4	0.0	0.0
WUA.2.2	801.19	0.589	87.57	0.068	71.9	45.4	22.5	10.2
WUA.2.3	3,364.87	2.563	346.34	0.264	171.9	47.2	47.4	22.3
WUA.2.4	1,618.64	0.518	189.00	0.060	102.1	53.9	55.0	29.6
WUA.2.5	2,373.24	1.228	245.98	0.129	96.9	55.8	49.2	27.5
WUA.3.1	880.20	0.245	62.74	0.018	52.6	53.1	77.3	41.0
WUA.3.2	92.32	0.080	10.67	0.009	14.2	49.8	80.5	39.6

WUAs where the difference in elevation is large, and vice-versa. Figure 1 presents a clear relation between maximum difference in elevation and SEE. In irrigable areas with high elevation difference overpressures appear at the lower parts of the network when the target pressure is supplied at the upper part of the network. Therefore, more energy is supplied than the theoretically necessary, thus resulting in low SEE and therefore GEE. Nevertheless, GEE has not been considered as an indicator for rating the energy efficiency of a WUAs. This is because when two or more water inputs exist at different locations and elevations, the SEE calculation can result in interpretation errors (Abadía *el al.*, 2008a). For instance, WUA 2.1 has a zero value for SEE (Fig. 1). In this WUA, EDI is 51.72% (Table 4), indicating that more than half of the water resources

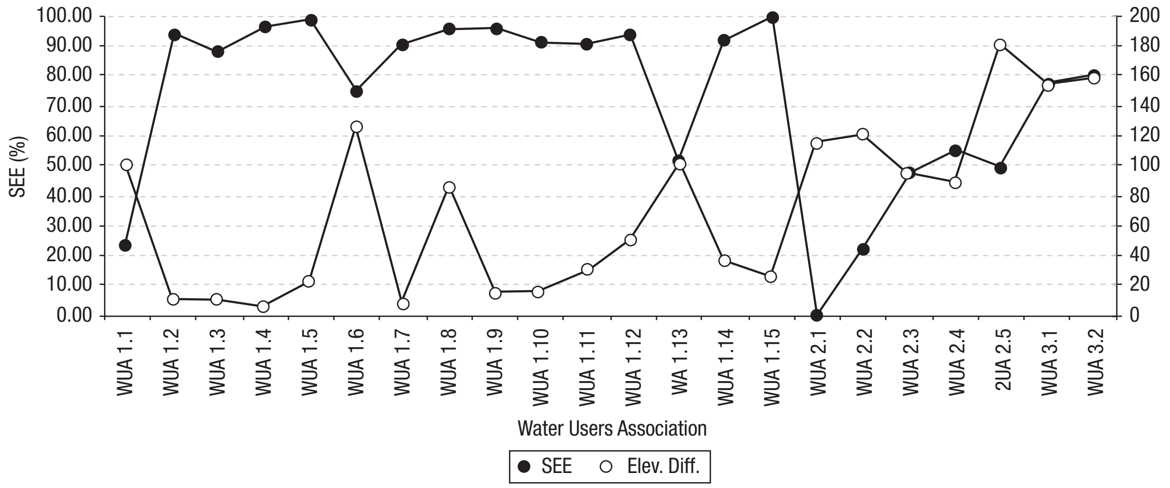

Figure 1. Relation between SEE and maximum elevation difference in the anaysed WUAs.

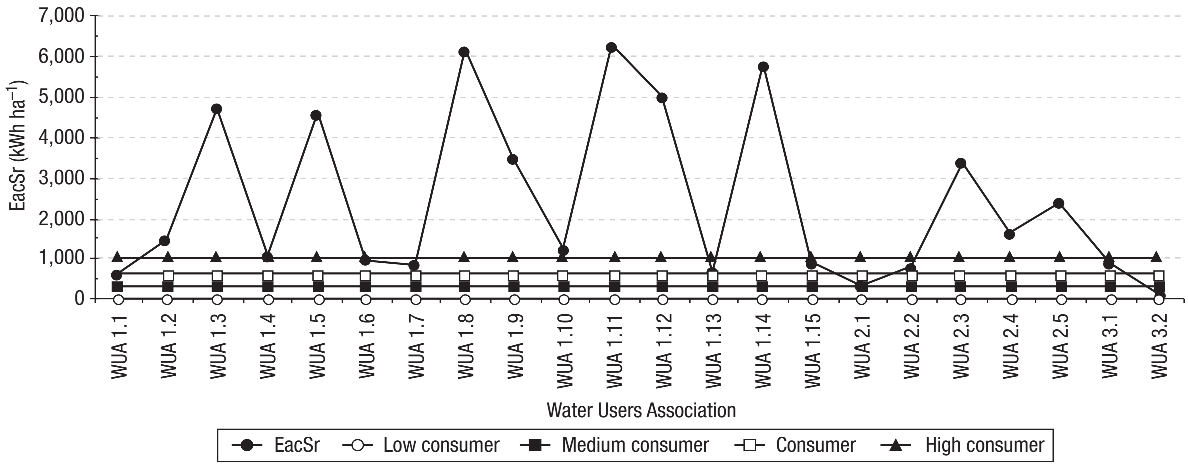

Figure 2. Active energy consumed per hectare in the analysed WUAs. The groups described in Table 2 are indicated in the Figure.

are pumped. Additionally, the water that requires pumping enters the systems at elevation below of irrigable area, while the water that does not require pumping enters the system at a very high elevation. Under these conditions energy input is higher than the energy requirement (Table 3). Although this would indicate that overall pumping is not required, and therefore SEE and GEE would have a zero value, pumping is locally necessary at low elevation water input. This is because with the actual method of SEE calculation, the extra energy of water enters at very high elevation, sums the low energy of water at low elevation and the total energy is higher than the required one, despite the real situation where that extra energy is not useful for water input at low elevation. This suggests that the calculation method of SEE as formulated by Abadía *et al.* (2008b), must be reformulated to become representative of different configurations of irrigation districts.

EacSr is linked to water consumption in the irrigable area; its value depends on water availability, irrigation requirements and irrigation management. In the same WUA, if the energy consumed per hectare in a determined year is high compared to another year, this may be because more water has been consumed, and not because the energy consumption has been more or less efficient. Therefore, this indicator can only serve the purpose of measuring energy consumption and not energy efficiency, because its value is depending on water and energy consumption jointly.

Figure 2 presents EacSr in the analysed districts along with the consumption thresholds established in Table 2. A total of 13 WUAs are rated as high consumers, 7 as consumers, 1 as average consumer, and 1 as low consumer. These values are similar to those obtained by Blanco *et al.* (2009) in Andalucia Region where 5 of a total of 10 WUAs analysed were rated as high consumers, 4 as consumers and 1 as average consumer. These values suggest that the rating thresholds should be revised once there are a wide range of WUAs analyzed all over Spain with different topology and irrigation systems, because with the actual rating, most of then are rated as high consumers.

As a result of the cluster analysis of indicators, the formation of groups corresponding to the indicators related to area (EacSr and CENSr) and those related to the volume supplied (EacVs and CENVs) can be observed in Figure 3. The fact that there are no differences between EacVs and CENVs shows that electricity is generally contracted in a similar way in different areas, although there may be specific cases where these diffe-

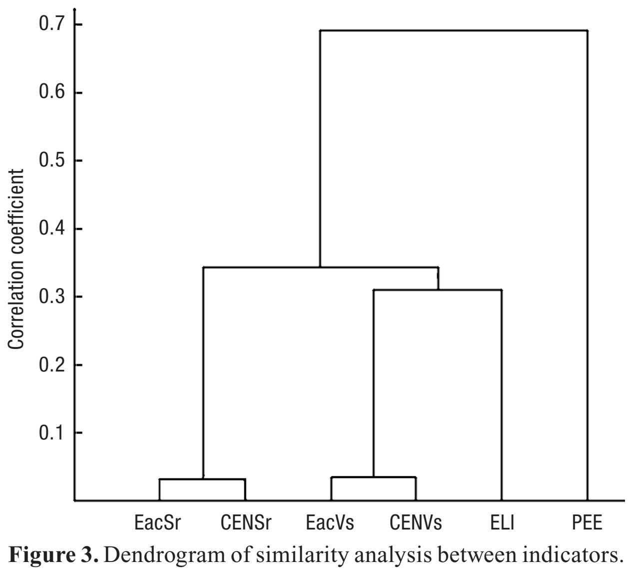

Figure 3. Dendrogram of similarity analysis between indicators.

rences are greater due to an inadequate energy contract. ELI is more closely linked to the indicators related to the volume supplied than to those related to the area. The PEE indicator presents high differences with respect to other efficiency indicators. This seems to be primarily due to the low variability reported for this indicator.

Figures 4 and 5 present the results of applying cluster analysis techniques to the 22 WUAs. Clear differences were found between WUA 3.2 and the rest, since the energy dependence of this WUA is 24% (Table 4), with an ELI of only 14.2 m and an EacVs of only 0.08 kWh m^{-3} (Table 5). Furthermore, important differences can also be observed between 2.1 and the other WUA. In order to establish groups out of the rest of the irrigable areas, Figure 5 broadens the scale of the dendrogram so as to be able to further analyse the groupings.

A group formed by the WUAs with sprinkler irrigation in Castilla-La Mancha is clearly observed (from 1.9 to 1.8 in Fig. 5). This sprinkler irrigation group is closely linked to WUA 2.3 and 2.5, which form a group. These two WUAs are important energy consumers (just like the sprinkler irrigation group), but mostly use surface irrigation. Linked to these two groups appears surface irrigated, energy intensive WUA 2.4. Another group formed by WUA 1.1 and 2.2 can also be observed in spite of they have very different characteristics (Table 4). However, although the sum of the energy needed for extraction, transportation and distribution is similar in 1.1 and 2.2, the energy necessary for each individual process may be different. This fact calls for the generation of new indicators determining energy efficiency at the different levels: such as extraction, desalination, transportation, and distribution, so

Figure 4. Dendrogram of similarity analysis between WUAS.

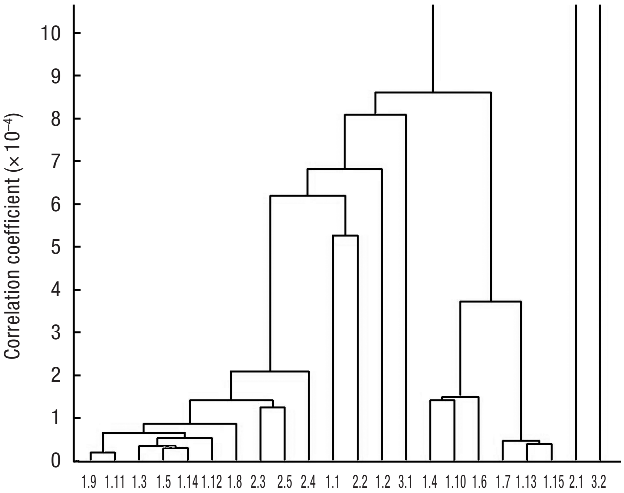

Figure 5. Extended dendrogram of similarity analysis between WUAs.

that further differences can be established among WUAs. Those indicators could be similar to PEE, EacVs, CENVs, as they are defined in Table 3, but knowing the energy consumption, and water volume in each individual process of extraction, desalination, transportation, and distribution.

Two groups of drip irrigated WUAs from Castilla La Mancha are linked to the former groups. On the right in the dendrogram, a group is formed by drip irrigate WUAs of Castilla-La Mancha. The WUAs 1.1 and 1.2 does not belong to this group because WAU 1.1 has an ELI much lower than the others WUAs with drip irrigation in CLM and WUA 1.2 has a very high energy consumption for this type.

Córcoles *et al.* (2009) obtained similar results by using 37 energy indicators on 7 WUAs in Castilla-La Mancha Region during three irrigation seasons. Two main groups of WUAs were obtained, separating sprinkler and drip irrigated areas. These authors also found that drip irrigated WUAs were more heterogeneous than sprinkler irrigated WUAs. The same conclusion was obtained for WUAs with low ELI, which usually form an independent group. The findings of Córcoles *et al.* (2009) are consistent with the results reported in this paper. However, more WUAs are required to validate the groups and to establish specific energy analysis methodologies for each group. Such methodological approach could be more efficient and report more benefits for the concerned WUAs and for the public interest. Moreno *et al.* (2010) analysed energy conservation and economic performance improvements resulting from the implementation of different measures. The estimation of energy savings in the 22 WUA was 14.1%, and the economic saving was 20.0%.

Conclusions

— The methodology used to estimate the SEE indicator must be reformulated to become representative of all the different configurations of the irrigation districts. Using the current methodology for SEE, GEE is not an adequate indicator for energy classification of WUAs.

— EacSr is adequate for determining energy consumption and not energy efficiency because its value is depending on water and energy consumption jointly.

— EacSr values for group ratings should be revised, for which it would be necessary to broaden the study of this indicator to all the irrigation areas of Spain.

— The most representative indicators of energy efficiency in the WUAs are those relating energy costs and energy consumed to the volume supplied to users (CENVs and EacVs), instead of those relating these parameters to the irrigated area.

— In order to be able to compare WUAs with different characteristics, it is necessary to take into account new indicators, similar to PEE, EacVs and CENVs but distinguishing among energy and volume using in extraction, desalination, transportation, and distribution.

— The energy indicators must be applied to propose corrective measures on energy and economic savings.

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References

ABADÍA R., ROCAMORA C., RUIZ A., 2008a. Protocolo de auditoría energética en comunidades de regantes. Instituto para Diversificación y Ahorro de la Energía, IDAE. Serie Divulgación Ahorro y Eficiencia Energética en Agricultura. 10. Ministerio de Industria, Turismo y Comercio, Madrid. [In Spanish].

ABADÍA R., ROCAMORA C., RUIZ A., PUERTO H., 2008b. Energy efficiency in irrigation distribution networks I: Theor Biosyst Eng 101(1), 21-27.

BLANCO M., CAMACHO E., RODRÍGUEZ J.A., 2009. Análisis de la eficiencia energética en el uso del agua de riego en comunidades de regantes de Andalucía. XXVII Congreso Nacional de Riegos, Murcia, Spain. Junio 2009. [CD-ROM]. [In Spanish].

CÓRCOLES J.I., DE JUAN J.A., MORENO M.A., MORALEDA D.A., ORTEGA F., TARJUELO J.M., 2009. Evaluación de zonas regables en Castilla-La Mancha mediante técnicas de benchmarking. V Congreso Nacional y II Congreso Ibérico de Agroingeniería, 28-30 septiembre, Lugo, Spain. [CD-ROM]. [In Spanish].

FIGUERAS M., 2001. Estadística: análisis de conglomerados o cluster [on line]. Available in http://www.5campus.org/leccion/cluster [11 Jan, 2009].

LUC J.P., TARHOUNI J., CALVEZ R., MESSAOUD L., SABLAYROLLES C., 2006. Performance indicators of irrigation pumping stations: application to drill holes of minor irrigated areas in the Kairouan plains (Tunisia) and impact of malfunction on the price of water. Irrig Drain 55, 85-98.

MINISTERIO DE INDUSTRIA, COMERCIO Y TURISMO, 2007. Estrategia de ahorro y eficiencia energética en España. Plan de acción 2008-2012 (PAE4+). Madrid. [In Spanish].

MALANO H., BURTON M., 2001. Guidelines for benchmarking performance in the irrigation and drainage sector. International Programme for Technology and Research in Irrigation and Drainage (IPTRID), Rome, Italy.

MORENO M.A., CARRIÓN P., PLANELLS P., ORTEGA J.F., TARJUELO J.M., 2007a. Measurement and improvement of the energy efficiency at pumping stations. Biosyst Eng 98(4), 479-486.

MORENO M.A., PELAYO J., CÓRCOLES J.I., PLANELLS P., CARRIÓN P.A., TARJUELO J.M., 2007b. Model for analysis of energy efficiency at pumping stations. Tenth Inter-Regional Conference on Water and Enviroment (Envirowat 2007), Nueva Delhi. [CD-ROM].

MORENO M.A., ORTEGA J.F., CÓRCOLES J.I., MARTÍNEZ A., TARJUELO J.M., 2010. Energy analysis of irrigation delivery systems: monitoring and evaluation of proposed measures for improving energy efficiency. Irrig Sci 28, 445-460.

PELLI T., HITZ H.U., 2000. Energy indicators and savings in water supply. J Am Water Works Ass 92(6), 55-62.

PEÑA D., 2000. Estadística: modelos y métodos 2. Modelos lineales y series temporales. Ed Alianza Editorial, SA, Madrid.

ROCAMORA C., ABADÍA R., RUIZ A., PUERTO H., PUERTO H., MELIAN A., 2008. Energy efficiency in irrigation: energy audits and qualification of water user's associations. International Conference on Agricultural Engineering. AGENG 2008. Hersonissos-Crete (Greece). [CD-ROM].

RODRÍGUEZ J.A., CAMACHO E., LÓPEZ R., PÉREZ L., 2008. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: an application in Spain. Agric Syst 96, 250-259.