Water Re-Use

Sustainable waste water reuse technologies for irrigated land in NIS and southern European states

Project no. 516731

WATER REUSE

Sustainable waste water recycling technologies for irrigated land in Nis and Southern European States

INCO-2003-D1 Environmental protection

DELIVERABLE 27: Report on comprehensive comparative analysis of water saving technique performances and prospects, also addressing prevailing and predictable future socio-economic, cultural and policy-driven factors at the local regional and trans-boundary level

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Contents

1 Introduction

Agriculture is one of the largest consumers of available fresh ground and surface water; of the fresh water that is being used by man worldwide, an average of 70% is being consumed by Agriculture, followed by 22% used by industry and 8% for domestic use (source: World Business Council for Sustainable Development). Of this 70% that is being used in agriculture, only 13-18% is being used efficiently in eg. semi-arid areas (about 30% is lost by storage and conveyance, 44% is being lost by surface runoff and drainage into deeper soil layers and 8-13% is being lost by evaporation from the bare soil or from ponding). (Wallace and Batchelor, 1997 – Falkenmark et al, 1998). When looking at these numbers, it should be clear that the irrigation efficiency can be largely improved by looking closely at the different sources of water loss stated above. Besides increasing the irrigation efficiency when using fresh ground or surface water, another source of water can also be considered; (partially) treated waste water. An prominent mechanism in irrigation water drainage is caused by water repellency of soils. The soil surface and profile is unable to be wetted evenly and water tends to move in vertical flowpaths, causing accelerated drainage into deeper layers and wet and dry pockets in the root zone.

In irrigated areas in the New Independent States (NIS) and southern European States, the on-site inefficient use of conventional fresh water resources occurs through most of the mechanisms described above; surface runoff, ponding and subsequent evaporation, incomplete wetting of soils, which causes accelerated runoff and preferential flow, and also through excessive evaporation associated with unhindered capillary rise. Furthermore, in these regions, a largely unexploited potential exists to save conventional irrigation water by supplementation with organic-rich waste water, which, if used appropriately, can also lead to improvements to soil physical properties and soil nutrient and organic matter content (e.g. Lazarova and Asano, 2005).

The Water Reuse project aimed to (a) reduce irrigation water losses by developing, evaluating and promoting techniques that improve the wetting properties of soils and preventing water loss by conventional irrigation methods, and (b) investigate the use of organic-rich waste water as a non-conventional water resource in irrigation and, in addition, as a tool in improving soil physical properties and soil nutrient and organic matter content.

In this deliverable the findings of the Water Reuse Project are discussed in relationship to human-environmental conditions. The objective is to identify where the strategies tested on plot scale, may be applicable or not on a field and/or regional scale, and why – in terms of the land conditions that are dependent on socio-economic, cultural and policy-driven factors in the studied regions in Greece, Spain, Russia and Ukraine.

The report is structured in three main parts. Chapter 2 sketches the human environment in which the water saving strategies were tested, and the importance of each condition for the applicability of the water saving strategies. Chapter 3deals with stakeholder groups which are relevant to the possible adoption of water saving strategies in the study areas, their influence on the adoption of strategies, and their assignments of importance to economic, environmental and socio-cultural indicators of water saving strategies. This information may be used to identify suitable areas in the NIS and Mediterranean in terms of land use, legislative and socio-economic conditions for the implementation of the tested water saving techniques. Finally, in chapter 0, the performance of water saving strategies from an economic, ecological and socio-cultural point of view was evaluated for two of the study regions using a simple multi-objective decision support system. Chapter 5 provides prospects on the potential human-environmental conditions for the implementation of water saving strategies and associated recommendations, which are likely to support the project's objectives to reduce irrigation losses and to save fresh water resources.

2 Human-environmental conditions in the regions where the water saving strategies were tested

2.1 Methods

The information on human-environmental conditions in the study areas was collected by the research teams based on previous work for deliverable 6[1], their experience in the study region, and based on consultations with socio-economic experts of their research institutions, and on interviews with land users.

The human-environmental characteristics investigated in paragraphs 2.3 till 2.12 were derived from the WOCAT questionnaire on technologies for sustainable land management (WOCAT, 2008). This questionnaire was developed as part of a framework for the documentation and evaluation of strategies for sustainable land management, and has been tested and evaluated worldwide in collaboration with land users, other stakeholders and scientists in the past 15 years. It is recognised in the environmental scientific community as the standard for documenting, monitoring, evaluating, sharing and using knowledge on sustainable land management. The framework was considered useful for documenting the biophysical and human-environmental context of the water saving strategies tested in the Water Reuse project because of the correspondence between water and land management, realizing that water in soil and crops/plants is considered part of ‘land’ by scientists in the field of sustainable land management.

2.2 General human-environmental context of the study regions with regard to water saving strategies by country

2.2.1 Spain

In Spain, the Water Law Text applies to irrigation management (Water Law Refunded Text. RDL1/2.001. BOE nº 176, July 24, 2001). Apart from this legislation, a Hydrologic Basin Plan for the Júcar Basin describes the characteristics of the aptitude of water destined to agricultural use (UMH, 2006). The current developments with regard to water management at the national level in Spain include the Program A.G.U.A. (Actions for the Management and the Utilization of the Water). This program aims to reorient the water policy, by diffusing concrete actions designed to guarantee the availability and the quality of water in each region. This entails the modernization of the hydraulic infrastructures in the irrigated zones in several regions, (among which Alicante) with the purpose to improve the irrigation efficiency, and the replacement of traditional irrigation techniques by new techniques like drip irrigation, that are well-known for their potential to considerably save water (e.g. Banedjschafie et al. 2008).

Currently, the use of wastewater for irrigation is important in the province of Alicante due to freshwater scarcity and the improvements in wastewater treatment techniques. Current tendencies in irrigation include the use of wastewater and desalinized water for irrigation, and the use of irrigation techniques that optimize the use of water (mainly spatially). The use

[1] Database on socio-economic and legislative parameters for the selected sites.

of wastewater for the irrigation of golf courses has increased in recent years due to the construction of an increasing number of golf courses.

The scarcity of available water resources in Spain, mainly in the east and south (e.g. Alicante Province) requires the introduction of alternative water resources for irrigation in agriculture, like wastewater (UMH, 2006). However, a large ignorance among land users and other stakeholders was observed on the practices and benefits of the use of wastewater for irrigation. This relates to the limited information sources available and limited communication from responsible authorities. Apart from that, there are gaps in the legislative framework for wastewater use. The Water Law Text(Water Law Refunded Text. RDL1/2.001. BOE nº 176, July 24, 2001) applies indicates the Legal State of the use of wastewater. A draft Regulation of the Hydraulic Public Domain prescribes the basic conditions for the use of wastewater. However, the draft still needs approval from the National Council of Water and subsequently by the Cabinet (UMH, 2006). Due to the lack of decisive legislation on the use of wastewater, and despite the long history in the use of wastewater in agriculture (40 years), there is a large distrust about the use of wastewater for irrigation among land users. The current reuse of wastewater in irrigated agriculture corresponds to approximately 50% of the wastewater produced in Alicante Province. However, this share should be increased to meet the high water demand in this region .

2.2.2 Russia and Ukraine

In Russia and Ukraine, only recently the process of the reorganisation of the irrigation sector started in response to the transition from a central planning economy to a market economy. Under the Soviet Union, the SU Ministry of Land Melioration and Water Sector (Minvodkhoz) functioned at the level of the Soviet Union, and the RF Ministry of Land Melioration and Water Sector at the level of Russian Federations. After the ending of the Soviet Union, both ministries were dissolved. After the ending of the Soviet Union the first Ministry was dissolved and the activities of the RF Ministry of Land Melioration and Water Sector were divided into two branches – Water Resources and Land Reclamation. The Water Resources branch was headed by the RF Committee of Water Sector, which was organized after 2002 in the Federal Agency of Water Resources of the RF Ministry of Natural Resources. The Land Reclamation branch was headed by the Department of Land Amelioration of the RF Ministry of Agriculture.

After the adoption of the new Water Code of the Russian Federation in 2006, which was based on the Water Basin approach, the territory of the Russian Federation was divided into 14 Hydrographical Units in 2007. Water objects in these Hydrographical Units were assigned to either the Federation or Territory. The water objects in the Territories are managed by Water Basin Units at the Federal level, governed by the Federal Agency of Water Resources. All Territorial water objects at the border of Hydrographical Units are managed by specific administrative organs (84 at 01.01.2010) of the Russian Federation. These territorial organs are carrying out their own water administration policy in concordance with federal organs.

However, in both contemporary Russia and Ukraine, Land Melioration (Irrigation, Drainage, Agricultural Water Supply) management Units are part of the government, and have top-down administration systems, with control from the central government. The infrastructure for water transportation to the field is owned by the state, but the irrigation infrastructure at the field is owned by agricultural producers. Maintenance of irrigation water transportation systems is financed by a central state budget. The costs of water pumping are partly paid by regional budgets and users. In restructuring irrigation management in the new post-soviet socio-economic framework, the national agricultural policies of these countries must consider the importance of the irrigation sector for food security, for agrarian market developments, but also for the general economic development of the countries (Zhovtonog, 2005). Russia and Ukraine both have a long history of scientific research in agronomy and agricultural water management.

In the Saratov Region, Russia, agriculture is very dependent on irrigation. The agricultural sector is the main water user. In total, the current region's consumption of water for irrigation and agricultural water supply amounts to 1.5 million m^3 per year (about 1/3 of the level during the last years of Soviet Union). Water management in the Saratov Region has developed since 1936, when the first small irrigation areas (Pygachevskay and Tolstovskaya) were established. Nowadays irrigation in the region has an extensive character, and is applied to fodder-grain and vegetable crop rotations. Due to the deteriorating economic situation since the end of the Soviet Union and a period of low crop yields on irrigated land without drainage, the area equipped for irrigation decreased, and the conditions of large-scale irrigation systems like the Privolghskaya and Komsomolskaya irrigating systems deteriorated, with subsequent dismantling of the systems (MSUEE, 2006).

The decrease in crop yields on irrigated land of the Regions NigneePovolgie, Volgograd and Astrakhan, situated downstream of Volga River, was partly caused by secondary salinization/alkalinisation and by the rise of ground water due to improper irrigation and fluctuation of the Caspian Sea level. This process has affected 719 000 ha of irrigated land and 563 000 ha of drained land in the Regions of Astrakhan, Volgograd, Saratov and Samara. The causes of the rise of the Caspian Sea level have not yet been explained.

The use of wastewater for irrigation developed in Russia in the period 1950-1990. There is substantial scientific knowledge of the ecological and economic effects of wastewater irrigation, and national standards for wastewater quality are available. After the period of economic crises in the 1990s, the use of wastewater in irrigated agriculture now receives serious renewed attention from the state in the form of federal target programs or regional programs.

In Ukraine, wastewater irrigation has a long tradition. It is mainly applied to field and fodder crops. The water is derived from various sources: household, industry, cattle breeding and pig farms. The long record of scientific experimental research on wastewater use for irrigation points to positive effects on yields of field and fodder cultures and on the enrichment of soils by mobile soil nutrients and an increase in biological activity. In general, negative effects on soil properties were weak. Also, in Ukraine, wastewater is usually not heavily polluted with heavy metals above the national health standards, except for water coming from cellulose-paper factories. Therefore, considering that the southern and south-eastern parts of Ukraine are subject to drought, the use of wastewater can be seriously considered as an alternative option for irrigation using fresh water.

2.2.3 Greece

In Greece, the state implements and manages irrigation networks. Greece has no history of wastewater use in irrigated agriculture, though the irrigated area is expanding, and water scarcity is expected in the 21st century due to increased demands from various economic sectors and climate change (EEA, 2009; EC, 2009; EC, 2010a). Also, there is a lack of fresh water in some coastal regions, like the study region in the southern part of the Prefecture of

Xanthi (DUTH, 2006). In 2007, the Ministry of Planning, Public Works and the Environment commissioned the development of a drought master plan for Greece and an immediate drought mitigation plan (Karavitis, 2008). However, at least up till the delivery date of the socio-economic survey of deliverable 6 in 2006, there were no state programs to develop the use of wastewater in agriculture, and there no examples of participation from industries in the development of wastewater programs. Treated wastewater is routinely disposed to local streams and rivers. This water is then used for irrigation downstream. There is no organized network to transport treated wastewater to agricultural land.

Recently in 2008, a modification of the Joint Ministerial Decision for Wastewater Disposal was published, which included guidelines for unrestricted reuse of treated wastewater in agriculture. However, there is no financial support yet for using wastewater to farms and farmers. On the other hand, a lot of scientific research is devoted to the treatment of wastewater and its potential use for irrigation of agricultural and recreational landscapes (e.g. Tsagarakis et al., 2001; Tsagarakis et al., 2004; Tsobanoglous and Angelakis, 1996), and the country has substantial facilities for research and monitoring and control of wastewater and agricultural products resulting from its use.

2.2.4 Summary of human-environmental context for irrigation using wastewater

In all studied countries except for Greece, wastewater use for irrigation has been practiced for a long time, from 30 till 70 years (ISSAR, 2007; del. 7). The largest surfaces are in the Russian Federation (up to 170.000 ha) and Ukraine (about 100.000 ha). However, due to the collapse of the agricultural sectors after the end of the Soviet regime and subsequent land privatization, the area irrigated with wastewater has shrunk. Wastewater is for a large part conveyed through the Volga River, which receives 45% of all the sewage water generated in the Russian Federation. However, due to the recession, industrial activity has decreased in recent years, resulting in less sewage water (MSUEE, 2006) .

At the same time the legislative mechanisms of recycling and using wastewater on private land are not settled. In Greece, irrigation using wastewater is not stimulated by the government. In Spain, the use of wastewater for irrigation is stimulated by the government, and even applied to other land uses (like turf grass on golf courses). In Ukraine, despite the availability of standards for using wastewater and considerable scientific knowledge on the composition of wastewater and its effects on soils, crops and human health, in practice wastewater is used without any chemical cleaning (only mechanical) (ISSAR, 2006).

Wastewater is used for many annual field crops, except for vegetables, on which the use of wastewater is prohibited in all studied countries, and in Spain also for grapes, fruit and olive trees, meadows and pastures. Wastewater is delivered on fields in the diversified ways: in open channels and pipes, and subsequently by sprinkler or flow irrigation. Technologies for cultivating crops irrigated with wastewater do not differ from those applied using fresh water. Wastewater is applied in 2-3 times per growing season by dozes of 300-400 m^3/ha for grain crops, 500-660 m^3/ha for food crops and 700-800 m^3/ha for forage crops. The control of water delivery over fields is carried out in Russia and in Ukraine partly by hydro-counters, and partly by pump power ness. In Spain and in Greece no sensors are used for irrigation scheduling.

The studied regions have in common that the populations mistrust the use of wastewater for irrigation due to ignorance of the effects on crops, environment and human health.

There is a lack of communication from (national and regional) governments towards the population on these effects and a lack of experimental evidence to support this communication. This is especially the case in the former Soviet countries. This is supported by the observation in this deliverable that stakeholders assign large importance to the socio-cultural indicators of education and training of land users, the acceptability of using wastewater for irrigation, and farmer health and safety. On the other hand, in the Russian federation at least, industrial enterprises and community facilities have interest in the use of wastewater as an alternative for fresh water in agriculture.

In all countries except Spain, where regional programs for wastewater use in agriculture are in development, there is limited participation by the national governments in the development of wastewater use programs. The role of governments is in most cases limited to some support to scientific research and several training programs for farmers, but large-scale support to the implementation of institutional frameworks, infrastructure and policy is missing. For example in Ukraine, there is an active discussion on the rehabilitation of wastewater irrigation in agriculture up to the level of 1990 (2.5-3 millions of ha) for the southern regions, which suffer most from drought.

There is a long record of field experimental evidence in the literature of the use of wastewater for irrigation in all studied countries, dating from the 1960s. The records indicate overall positive results with regard to crop yield and crop quality, with crop yields being improved or at least not decreased compared to the use of fresh water or river water for irrigation. Based on these records, effects on the environment were not found to be severe. For example, in the Saratov region, analyses show that wastewater use has not increased heavy metal contents in soils and crops (P.Bednov, Reshetov, A.I. Sobolev, 1998), though there is no information on the long term effects of wastewater use on heavy metal contents.

The wastewater used in the different countries is usually of municipal origin, comes from cattle-breeding complexes or industrial enterprises or mines. Most water is mixed with fresh water. In Greece municipal wastewater is drained off to surface waters or reservoirs. The clearing of such effluents is carried out in centralized wastewater treatment plants or filtration fields by means of dilution or filtration or neutralization, biological processing, and by chemical amendments. New water treatment technologies like the processing of water using membranes are also applied. The water quality parameters monitored include the conventional pollution parameters like pH, heavy metal contents, also pollutions of a biochemical and sanitary-and-epidemiologic origin are monitored. In Russia and in Ukraine there is a system of national standards. In Spain standards only refer to part of the pollution parameters, and in Greece standards have been recently developed (2008).

2.3 Demographic context of the study regions

The study regions are all situated in rural areas with a low population density (Table 2-1). In the regions in Greece, Ukraine and the Russian Federation the population is decreasing or remaining stable, but in the Spanish region the population is increasing. This trend is probably linked to the growth of the industrial and tourism sectors; traditional activities like agriculture are in a clear backward movement process (UMH, 2006).

Table 2-1 Demographic characteristics of the study regions.

Study region	Population density (persons/km2)	Annual population growth, inclusive migration (%)
Alicante, Spain	10-50 (village of Biar; 38) >500 (Alicante town; 1663)	>4 (Comunidad Valenciana (10.90%)
Saratov Region, Russian Federation	<10	Negative
Kharkivs'ka oblast, Ukraine	10-50	<0.5
Maggana, Greece	<10 (rural hotspot region)	Negative

2.4 Potential land users

A typology of the land users having the potential to apply the water saving strategies in the regions in Spain, the Russian Federation, Ukraine and Greece where the water saving strategies were tested is given in Table 2-5 till Table 2-3.

The results show that almost all strategies in the three regions are likely to be implemented by individuals and groups, being either the community or a cooperative. With regard to the scale of the land users, irrigation scheduling is likely to be applied by any type of land user (small, medium and large). Irrigation with waste water is restricted to medium and large scale land users in Spain and Ukraine. This is probably explained by the high initial capital costs for constructing the wastewater treatment and delivery system (e.g. Morris et al., 2005), which makes these systems likely to be available to medium and large scale land users only. Also, the absence of pricing on fresh water resources does not stimulate the use of wastewater in irrigation in these regions (Medvedev, Laktionova and García Orenes, pers. comm.; Valsecchi et al., 2009; EC, 2010a).

However, in Saratov Region in the Russian Federation, large and medium-scale land users applying irrigation in general have access to fresh water in the water transportation channels due to rules of land privatization. Therefore they are not so interested in other sources of water. Apart from that, the quantities of treated wastewater from municipal sources currently available in the region are not high enough to encourage large- and medium-scale land users to build infrastructure for transport and storage.

In contrast, individual householders having small-scale enterprises in Saratov Region are likely to implement wastewater irrigation strategies. The reason is that the same processes of land privatization in Saratov Region, in which former farms were divided, prevent access to fresh water channels for these land users, a process that also resulted in the deterioration of irrigation system integrity in Ukraine(Zhovtonog et al., 2005). Therefore these land users are interested in other water resources for irrigation, and potentially would be interested by transportation of wastewater to their fields.

Small-scale users are also the main potential type of land users to implement wastewater irrigation using effluents from olive mills in Maggana region in Greece due to the absence of large-scale infrastructure and a regulatory framework.

Mulching is typically a water saving strategy that would be applicable by small scale land users, because of the ease of implementation and low costs (e.g. Morgan, 2005; WOCAT, 2007). However, it is estimated to be potentially applied also by medium-scale land users in

Spain and Ukraine. The potential application by large-scale land users in Ukraine is probably explained by the dominance of these land users in the region.

The degree of privilege of land users appears not to be very critical to the potential adoption of water saving strategies, based on the result that all tested water saving strategies are estimated to be potentially adopted by common or average land users in this respect, not necessarily by privileged users. The potential use of surfactant in Greece by leading and privileged land users is an exception to this observation, probably due to the fact that many land users are still unaware of the potential of surfactants to improve the wettability of soils.

In the studied regions in Greece, Spain and Ukraine, mainly men will be potentially applying water saving strategies in agriculture, or deciding on their application. This is probably due to the fact that even in the more developed agricultural sectors of Spain and Greece, entrepreneurs in agriculture are mainly men. However, in the region in the Russian Federation also women are considered as potential land users for the application of water saving strategies.

Table 2-2Potential land users for application of the water saving strategies in Alicante, Spain.

Main categories of water saving strategies	Type of individual or group	Scale	Degree of privilege	Gender
Irrigation scheduling	Individual cooperative	Small-Medium	Common/average land users	Mainly men
Irrigation with waste water	Individual cooperative	Medium-Large	Common/average land users	Mainly men
Mulching	Individual	Small-Medium	Common/average land users	Mainly men
Use of surfactant				
Claying				

Table 2-3Potential land users for application of the water saving strategies in Saratov Region, Russian Federation.

Main categories of water saving strategies	Type of individual or group	Scale	Degree of privilege	Gender
Irrigation scheduling	Cooperative, irrigation water supply company	Small, medium and large scale land users	Average users	mixed
Irrigation with waste water	Individual, householders	Small scale land users	Average users	mixed
Mulching				
Use of surfactant				
Claying				

Table 2-4Potential land users for application of the water saving strategies in Kharkivs'ka oblast, Ukraine.

Main categories of water saving strategies	Type of individual or group	Scale	Degree of privilege	Gender
Irrigation scheduling	Individual and groups for Steppe zone. Only groups – in Forest Steppe.	Large and medium scale land users	All users in the Steppe, and leaders and common/average land users in the Forest Steppe	Mainly men
Irrigation with waste water	Individual and groups for Steppe zone. Only groups – in Forest Steppe.	Large and medium scale land users	All users in the Steppe, and leaders and common/average land users in the Forest Steppe	Mainly men
Mulching	Individual and groups for Steppe zone. Only groups – in Forest Steppe.	Large and medium scale land users	All users in the Steppe, and leaders and common/average land users in the Forest Steppe	Mainly men
Use of surfactant	-	-	-	-
Claying	-	-	-	-

Table 2-5Potential land users for application of the water saving strategies in Maggana, Greece.

Main categories of water saving strategies	Type of individual or group	Scale	Degree of privilege	Gender
Irrigation scheduling				
Irrigation with waste water	Community	- Large-scale for treated municipal wastewater (ww) - Small-scale for olive mill ww	Common/average land users	Mainly men*
Mulching				
Use of surfactant	Individual	Medium-scale	Privileged land users	Mainly men
Claying	Individual	Small-scale	Common/average land users	Mainly men

*In Greece it is mainly men that are involved in land cultivation.

2.5 Wealth indicators of land users applying the water saving strategies

The wealth of land users already applying water saving strategies in the regions is indicated in Table 2-6 and Table 2-8, based on local standards for wealth. The results show that land users applying water saving strategies belong mostly to average wealth category, and manage a large part of the agricultural land area, except for the region in Russia, where they only manage 5% of the agricultural land. The land users applying mulching in Ukraine belong to the same or a 'richer' wealth category, but are smaller in number, and their agricultural activities cover a smaller part of the land. No data were shown for the study region in Greece, because water saving strategies are not yet applied in the region.

Table 2-6 Wealth indicators of land users applying water saving strategies in Alicante, Spain.

Main categories of water saving strategies	Wealth category of current land users	% of land users in the area in this wealth category	% of total land area owned by wealth category
Irrigation scheduling	average	>50%	>50%
Irrigation with waste water	average	>50%	>50%
Mulching	average	>50%	>50%
Use of surfactant			
Claying			

Table 2-7 Wealth indicators of land users applying water saving strategies in Saratov Region, Russian Federation.

Main categories of water saving strategies	Wealth category of current land users	% of land users in wealth category	% of total land area covered by wealth category
Irrigation scheduling	average	20%	5%
Irrigation with waste water	n/a		
Mulching	n/a		
Use of surfactant	n/a		
Claying	n/a		

Table 2-8 Wealth indicators of land users applying water saving strategies in Kharkivs'ka oblast, Ukraine.

Main categories of water saving strategies	Wealth category of current land users	% of land users in the area in this wealth category	% of total land area owned by wealth category
Irrigation scheduling	Average	50	40-50
Irrigation with waste water	Average	20-30	?
Mulching	Rich and average	15-20	30-40 (in the Steppe)
Use of surfactant			
Claying			

2.6 Significance of off-farm income

Land users applying water saving strategies are very dependent on off-farm income in Spain, but less so in Ukraine and the Russian Federation (Table 2-9). This difference may reflect the dominance of the agricultural sector in the regions in Ukraine and the Russian Federation, versus the increasing influence of other sectors in Spain. No data were shown for the study region in Greece, because water saving strategies are not yet applied in the region.

Table 2-9 Significance of off-farm income for land users who already apply the water saving strategies. - :land users do not yet apply the strategy.

Main categories of water saving strategies	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine
Irrigation scheduling	>50%	10-50%	<10%
Irrigation with waste water	>50%	-	<10%
Mulching	>50%	-	<10%
Use of surfactant	-	-	-
Claying	-	-	-

2.7 Access to services and infrastructure

The access to various types of services and infrastructure is an important condition for the implementation of water saving strategies (e.g. Morris et al., 2005). Overall, the access to services and infrastructure is moderate to high in the study regions in Greece and Spain, and moderate to low in Ukraine and the Russian Federation (Table 2-10). Access to services in Ukraine is hampered by the high prices of services and resources.
Access to treated irrigation water and waste water is a prerequisite to introducing irrigation scheduling and irrigation with waste water. This is low to moderate in Greece, Ukraine and the Russian Federation. In contrast, access to these water sources is high in the region in Spain, where subsidies apply to irrigated agriculture (Valsecchi et al., 2009), and the use of waste water for irrigation has been practiced for some time (UMH, 2006).

Table 2-10 Level of access to services and infrastructure related to water saving strategies in the study regions.

Service/infrastructure	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine	Maggana, Greece
Health	high	Moderate	moderate	High
Education	high	Moderate	moderate	High
Technical assistance	moderate -high	Low	moderate	Low
Employment (eg off-farm)	moderate	Low	low	Moderate
Market	moderate	Moderate	moderate	High
Energy	high	Moderate	moderate	High
Roads & transport	high	Moderate	moderate	High
Drinking water and sanitation	high	Low	moderate	High
Financial services	moderate	Moderate	low	High
Irrigation water (treated)	moderate -high	Moderate	moderate	Low
Waste water	moderate -high	Low	low	Low

2.8 Land ownership

Land ownership(or the type of land possession) varies between the study regions. In Greece, land is owned by individuals on a titled base. In the regions in Spain and Ukraine, also not titled individual ownership occurs, and ownership by the community or village. In Ukraine and the Russian Federation, the state is an important land owner. Types of land possession are most varied in the Russian Federation.

Land ownership	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine	Maggana, Greece
State		X	X	
Company		X		
Communal/village	X	X	X	
Group				
Individual, not titled	X	X	X	
Individual, titled	X	X		X
Other (specify)				

2.9 Land and water use rights

Land use rights refer to the access to land. The type of access is important to estimate the potential for the adoption of water saving strategies. Rights of use by a single user (individual) occur in all study regions, except for the Russian Federation (Table 2-11). In Spain and Ukraine, also communal (organised) land use rights occur, which implies that the access to land is subject to community-agreed management rules (WOCAT, 2008). Land use rights in the form of lease occur in the Ukraine and Russian regions.

Table 2-11 Land use rights in the study regions.

Rights	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine	Maggana, Greece
Open access (unorganized)				
Communal (organized)	X		X	
Leased		X	X	
Individual	X		X	X
Other (specify)				

Water use rights are essential to developing projects using the strategies based on irrigation scheduling and irrigation with waste water. This is because the rights allocated by states can promote water saving strategies or form an obstacle to the introduction of strategies (e.g. Rosenblum, 2005). A water right is a right to use water and in many cases does not actually involve the ownership of the water itself (EPA/USAID Guidelines for Water Reuse, 1992; in Rosenblum, 2005). In the study region in Greece, water rights are unorganized, and water can be used freely (Table 2-12). In Spain, Ukraine and the Russian Federation water use is subject to community-agreed management rules. Similar to the type of rights to land, water use rights in the form of lease occur only in Ukraine and the Russian Federation.

Table 2-12 Water use rights in the study regions.

Rights	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine	Maggana, Greece
Open access (unorganized)				X
Communal (organized)	X	X	X	
Leased		X	X	
Individual			X	
Other (specify)				

2.10 Agricultural production systems

Characteristics of the agricultural production systems determine conditions for the introduction of water saving strategies in terms of infrastructure required, timing of water applications through the year, and the economic potential of agricultural enterprises to invest in water saving strategies. The agricultural production systems in the study regions include olive growth in Greece and Spain, grapevine and pumpkin in Spain, winter wheat in Ukraine and alfalfa and corn in the Russian Federation (Figure 2-1).The systems are partly producing for self-supply, and partly for the market. The production is subsidized in Spain and Ukraine, and highly subsidized in the Russian Federation, where agriculture is one of the key supported sectors in the economy, but not in Greece. Land cultivation is mechanised, except for olive growth in Greece and Spain.

The type of cropping system determines the irrigation demand during the year. Olive trees require some irrigation during the dry time of the year. This is also the case for winter wheat. In order to use clay or surfactant to reduce water repellency of the soils, irrigation is also required.

The size of the cropland area per enterprise varies widely, from 0.5-1.0 ha for olive growth in Greece to up till 10.000 ha on agricultural enterprises in the Russian Federation. In Saratov region, agricultural land covers 84% of the area, and is mainly in use for field crops (71%) MSUEE, 2006).

Manual application of surfactants and clay is possible in small production units like in the olive orchards in the Maggana region in Greece. For irrigation with waste water in vineyards in Spain, wheat fields in Ukraine and fields with corn and alfalfa in Russia infrastructure is required that is able to distribute irrigation over larger areas (e.g. sprinkler systems).

Table 2-13 Properties of agricultural production systems in the study regions as part of which the water saving strategies were applied.

Region	Crop land use type	Market orientation	Production subsidized?[2]	Method of land cultivation	Type of cropping system and major crops	Water supply	Size of cropland area per enterprise (ha)
Alicante, Spain	grapevine	Commercial/ market	Yes, moderately	mechanised	Tree/shrub	Mixed rainfed-irrigated	15-50
	pumpkin	Commercial/ market	Yes, little	mechanised	annual	Mixed rainfed-irrigated	5-15
	Olive tree	Mixed[3]	Yes, moderately	Manual labour	Tree	Mixed rainfed-irrigated	50-100
Saratov Region, Russian Federation	alfalfa	Mixed	Yes, highly	Mechanized	Perennial cropping	Mixed rainfed-irrigated	1000-10000
	corn	Mixed	Yes, highly	Mechanized	Annual cr opping	Mixed rainfed-	1000-10000

2 Subsidy: a subsidy is an instrument used by the state or by private actors to reduce the costs of a product or increase the returns from a particular activity (Kerr, 1994). It may be provided in cash or in kind and usually serves a specific purpose.
3 Commercial and subsistence

Region	Crop land use type	Market orientation	Production subsidized?[2]	Method of land cultivation	Type of cropping system and major crops	Water supply	Size of cropland area per enterprise (ha)
						irrigated	
Kharkivs'ka oblast, Ukraine	Winter wheat	Mixed	Yes, little	Mechanized	Annual, perennial, winter wheat	Mixed rainfed-irrigated	800 (on agricultural enterprise)
Maggana, Greece	Olive orchard	Subsistence4	no	manual	Tree	Mixed rainfed-irrigated	0.5-1.0

Figure 2-1Wheat cultivation in Saratov Region, Russia.

2.11 Water supply

The way of water supply to all production systems in which the strategies were tested is mixed-rainfed. This implies that limited amounts of water are applied to the crop when rainfall fails to provide sufficient water for plant growth, to increase and stabilise yield. However, the additional water alone is inadequate for crop production. This implies that water saving strategies must be well tuned to the intra-annual rainfall variability and amounts in the area. Average annual rainfall is comparable between the studied regions (ranging from 400 mm in the Russian Federation to 550 in Greece), but the length of the dry period differs from 2 months in Ukraine and the Russian Federation up till 4-5 months in Greece and Spain. Considering that all studied cropping systems are tree crops or annual crops, irrigation should be tailored to the period in which the growing season coincides with dry periods in the year.

4 Self-supply.

Table 2-14 Ways of water supply in regions where water saving strategies were tested.

Main categories of water saving strategies	Alicante, Spain	Saratov Region, Russian Federation	Kharkivs'ka oblast, Ukraine	Maggana, Greece
Irrigation scheduling	Mixed rainfed - irrigated	Mixed rainfed - irrigated	Mixed rainfed - irrigated	
Irrigation with waste water	Mixed rainfed - irrigated		Mixed rainfed - irrigated	Mixed rainfed – irrigated
Mulching	Mixed rainfed - irrigated		Mixed rainfed - irrigated	
Use of surfactant	Mixed rainfed - irrigated			Mixed rainfed – irrigated
Claying	Mixed rainfed - irrigated			Mixed rainfed – irrigated

In the province of Alicante, an important increase was observed in the quantity of wastewater directly reused in agriculture and nature management since 2001, despite the fact that the quantity of fresh water used remained almost constant in this period (UMH, 2006). The land users in the community of Biar occasionally request water produced in the tertiary processing of the waste water treatment plant of Biar to satisfy their water requirements. In spite of these occasional demands, the use of wastewater for irrigation is not widely accepted by the land users, partly due to the lack of information on the potential benefits of wastewater use for the irrigation of crops (UMH, 2006).

2.12 Non-agricultural land use types for the application of water saving strategies

Some of the tested water saving strategies are already applied in other land use types than agricultural land use in Spain and Ukraine (Table 2-15). Irrigation scheduling is already applied in recreational areas and in gardens. Irrigation with waste water is applied in gardens, golf courses and road borders. Mulching is applied in gardens.

The use of the tested water saving strategies for other land use types than agriculture is also reported in the literature. Waste water is widely used for landscape and turf grass irrigation in many parts of the world (e.g. Sheikh, 2005).

Table 2-15 Application of wastewater irrigation in non-agricultural land use.

Main categories of water saving strategies	Alicante, Spain	Kharkivs'ka oblast, Ukraine
Irrigation scheduling	Recreational areas	Gardens, recreational areas
Irrigation with waste water	Gardens, borders of road and railways and golf courses	Golf courses, strip protective along a highways and railways
Mulching	gardens	Gardens, vineyard, berry plantation
Use of surfactant		
Claying		

3 Stakeholder views on economic, environmental and socio-cultural indicators of water saving strategies

Stakeholder views on water saving strategies are of paramount importance in the development of sustainable land and water management programs (e.g. Loucks, 2000; Reed, 2008; Blomquist et al., 2010). Sustainable water management attempts to deal with water in a holistic fashion, taking into account the various sectors affecting water use, including political, economic, social, technological and environmental considerations (International Hydrological Programme, UNESCO).Economic and environmental indicators may be used to inform on the efficiency and competitiveness of sustainable water management programs. In addition, the development of such programs needs to include an understanding of the social and cultural aspects of water saving strategies (Lazarova, 2005). The drivers that promote involvement in water saving strategies will vary between stakeholders in the supply and use of water.

In the Water Reuse project, indicators were selected to assess the economic, environmental and socio-cultural performance of water saving strategies with regard to the main objectives of the project to reducing water loss in irrigated agriculture and saving fresh water by improving the wettability and fertility of soils, and by using treated waste water.

3.1 Methods

The project research teams were asked to indicate the relevance of stakeholders for enabling or hindering adoption of the tested water saving strategies in the study regions. The impact of stakeholders was rated according to the following scale:

1- very little impact
2- some impact
3- significant impact
4- very influential
5- must have support

Questionnaires were sent to representatives of the stakeholder groups with high relevance to obtain information on their assignment of importance to the economic, environmental and socio-cultural aspects related to the adoption of water saving strategies in the region. Within the scope of the project, the number of respondents from each stakeholder group was restricted to 1 or 2.

The economic, environmental and socio-cultural aspects were pre-defined in indicators of the performance of water saving strategies. The indicators were selected on the condition to be usable for the assessment of the main objectives of the project. These were to:

1. Reduce irrigation water losses by developing, evaluating and promoting techniques that improve the wetting properties of soils, and
2. Investigate the use of organic-rich waste water as a non-conventional water resource in irrigation and, in addition, as a tool in improving soil physical properties and soil nutrient and organic matter content.

This yielded some of the economic and environmental indicators. The set of socio-cultural indicators was selected likely to be related to the adoption of water saving strategies in the studied regions based on literature research, information from deliverable 6, and expert judgment from a business expert in water saving strategies.

The indicator sets for each category are shown in Table 3-1, Table 3-2 and Table 3-3.

Table 3-1 Economic indicators of the performance of water saving strategies.

Economic indicators		
Nr	**Indicator**	**Definition**
EC-1	Crop yield in treated area	mass of harvestable crop per ha per growing season
EC-2	Farm Gross Margin	Gross farm income of a given crop per ha growing season minus variable costs
EC-3	Irrigation use efficiency	crop yield per ha and per mm of irrigation per growing season
EC-4	Water use efficiency	(aboveground biomass in treatments aboveground biomass in control situation)/total rainfall per ??
EC-5	Total Available Water	Potential Total Available Water in rootable part of soil profile
EC-6	Green water use efficiency	plant transpiration/(precipitation+irrigation) per year
EC-7	Establishment costs	total costs of establishment of the strategy per ha, including labour, investment costs, material costs, transport costs, infrastructure costs
EC-8	maintenance costs	total costs of maintenance of water saving strategy per ha and per year, including labour, re-investment costs, material costs, transport costs, infrastructure costs
EC-9	subsidy (or production aid)	total subsidy for applying water saving strategy per ha and per year

Table 3-2 Environmental indicators of the performance of water saving strategies.

Ecological indicators		
Nr	**Indicator**	**Definition**
ENV-1	Soil water repellency	repellency of soil matrix to water penetration in field moist condition
ENV-2	Soil structural stability	stability of soil structure under water saving strategy, including susceptibility to soil sealing and crusting
ENV-3	Bulk density	bulk density
ENV-4	Heavy metal content	heavy metal contents of soil
ENV-5	soil alkalinity	degree of Mg, Na, Ca and K salts in soil
ENV-6	soil salinity	degree of Mg, Na, Ca and K salts in soil
ENV-7	Soil organic matter content	organic matter (or carbon) content in topsoil

Table 3-3 Socio-cultural indicators of the performance of water saving strategies.

Socio-cultural indicators		
Nr	**Indicator**	**Definition**
SOC-1	legal restrictions	degree to which laws or regulations hamper the implementation and/or use of water saving strategies
SOC-2	education and training of farmers	education and training of farmers
SOC-3	acceptability of using waste water for irrigation	degree of concern about use of waste water for irrigation
SOC-4	historical adoption of new technologies	degree to which new technologies have been adopted historically
SOC-5	likelihood of adoption of new technologies from Water Reuse	likelihood that a farmer will adopt a strategy from the Water Reuse project
SOC-6	incentives required to change behavior	level of positive or negative incentive that motivates change

SOC-7	farmer health and safety	farmer health and safety, related to the use of waste water for irrigation

3.2 Impact of stakeholders

The impact of stakeholder groups in the study regions in Spain, the Russian Federation, Ukraine and Greece is shown in Figure 3-1.**Error! Reference source not found.** Red colors denote high impact, green colors low impact, white fields indicate no response or no data. Almost all stakeholder groups are estimated to have some impact on the adoption of water saving strategies in the studied regions, though their impact varies. Exceptions are civilians in the Spanish region (low impact), distant consumers and educators in the Russian region, other land users and land owners in the Greek and Spanish regions, and policy makers in the Russian and Ukraine regions.

Civilians are considered very influential or to must have support to water saving strategies in all study regions except the Spanish region (Figure 3-1). The non-importance of civilians in the Spanish region may be explained by the limited access of the population to information sources on water management in relation to agricultural production (UMH, 2006).

The impact of policy makers is very different between the regions. In Greece, policy makers are rated as very influential at all levels from local to the EU, whereas in Spain, their impact decreases when moving from the local scale to larger administrative areas. This is a surprising result, as it is known that the use of irrigation water in Spain is still stimulated by coupled CAP subsidies on the production of agricultural commodities requiring irrigation (Valsecchi et al., 2009). However, the CAP Health Check in 2008 has strengthened the environmental requirements for obtaining the production-coupled subsidies, including water management (Aldaya et al., 2009). In Ukraine and the Russian Federation, policy makers are not very influential compared to other stakeholder groups, independent of the level of administration. This is explained by the low confidence of land owners, land users and interest groups in politicians (Laktionova, pers. comm.).

Water authorities and water suppliers have a very large impact on the adoption of water saving strategies in Spain. In Greece and Russia, water authorities are very influential, but water suppliers are less. This points at a strong regulation of water management in the region. In Ukraine, water authorities and suppliers have some impact on the adoption of water saving strategies. Their influence is expected to increase in the future with anticipated water scarcity problems due to climate change, especially if they will establish reasonable prices on water. Water authorities and suppliers can promote the development of new technologies in irrigated agriculture, but at the same time determine the pricing of water. Currently the water prices limit the use of fresh water for irrigation.

Stakeholder Group	Alicante, Spain	Saratovsky Region, Russia	Kharkivs'ka oblast, Ukrain	Maggana, Greece
Agricultural advisors and consultants	5	4	2	**4**
Civilians	1	5	5	4
Consumers – distant	3	1	5	3
Consumers – local	4	3	2	4
Educators	3	1	2	2
Land users – farmers	5	3	5	4
Land users - other	3	5	5	
Farmers organizations	5	3	5	4
Industry - as source of supply	3	3	2	3
Irrigation equipment companies	4	2	2	2
Landowners - agricultural land	5	5	5	4
Landowners - nonagricultural land	1	1	1	2
Policy makers EU	1	1	1	4
Policy makers local	2	2	1	4
Policy makers national	3	1	2	4
Policy makers regional	4	1	1	4
Water authorities	5	4	2	4
Water suppliers	5	3	2	2

1-very little impact
2-some impact
3-significant impact
4-very influential
5-must have support.

Figure 3-1Impact of stakeholders for adoption of water saving strategies in the studied regions, sorted by stakeholder group and by region.

Figure 3-2shows the impact of stakeholder groups as estimated by the research teams cumulated by group. Considering all four regions, the following groups are rated as very influential for enabling or hindering the adoption of water saving strategies: agricultural advisors and consultants, land users (farmers, but could also be pastoralists), farmers organizations, owners of agricultural land and water authorities. Least impact in all three regions is expected from educators and policy makers at EU level. The latter observation is striking, since the EU has taken several actions to address water scarcity and droughts in the European Union in recent years with the implementation of the Water Framework Directive, the assessment of water scarcity and droughts in the European Union, and the presentation of an initial set of policy options to increase water efficiency and water savings (COM/2007/0414 final) published in July 2007. Recently actions were directed to the review and further development of the water scarcity and drought policy by 2012 (http://ec.europa.eu/environment/water/quantity/scarcity_en.htm).

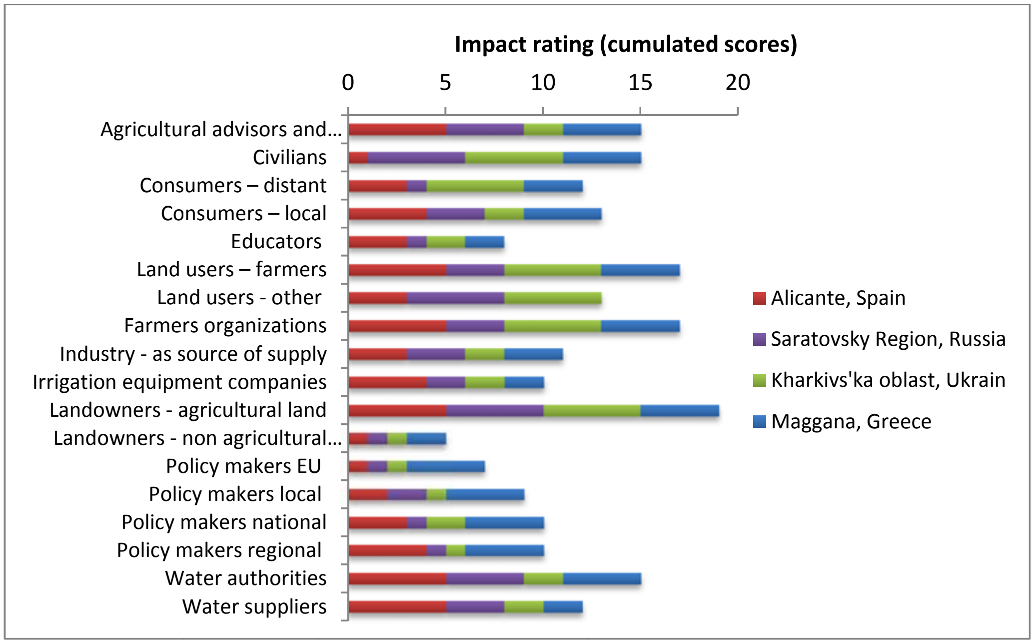


Figure 3-2 Impact of stakeholders for adoption of water saving strategies in the studied regions, sorted by stakeholder group.

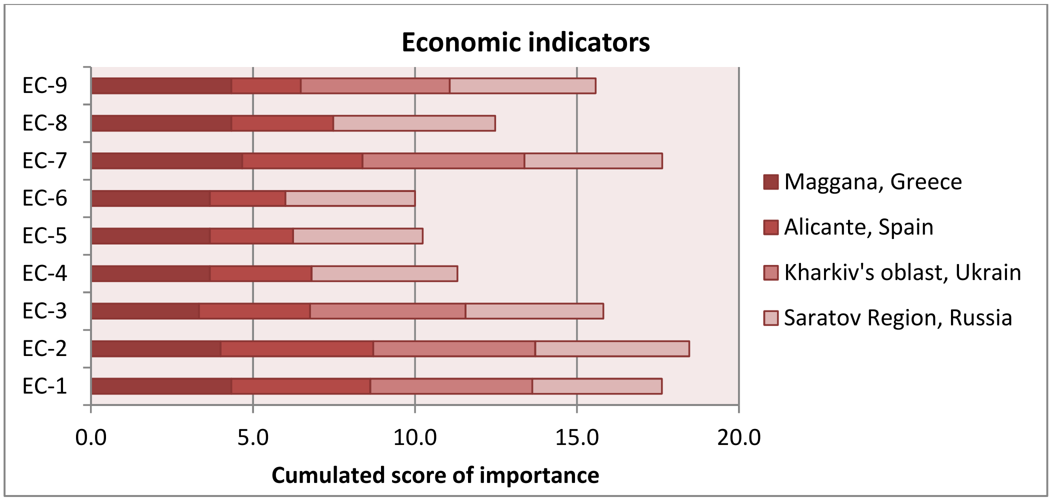
3.3 Importance of indicators according to stakeholders

The importance assigned to the economic, environmental, and socio-cultural indicators by the representatives of stakeholder groups in the regions in Greece, Spain, Ukraine and the Russian Federation is shown in figures Figure 3-3, Figure 3-4andFigure 3-5.

Of the economic indicators, the crop yield and farm gross margin are considered most important by stakeholders in all four regions. Costs for establishment and maintenance, and subsidies on applying the technologies are also considered important in Greece, Ukraine and Russia, but not that much in Spain. The indicators expressing the efficiency of water use do not receive high assignments of importance by stakeholders, except for the stakeholders consulted in the Saratov region, Russia. This may indicate that not all stakeholders are familiar with these indicators, despite the descriptions given in the questionnaire. In Russia there is a long record of agronomic research in society since the 19^{th} century. This may explain that the different stakeholder groups in this country recognise the importance of indicators expressing the efficiency of water use in irrigated agriculture.

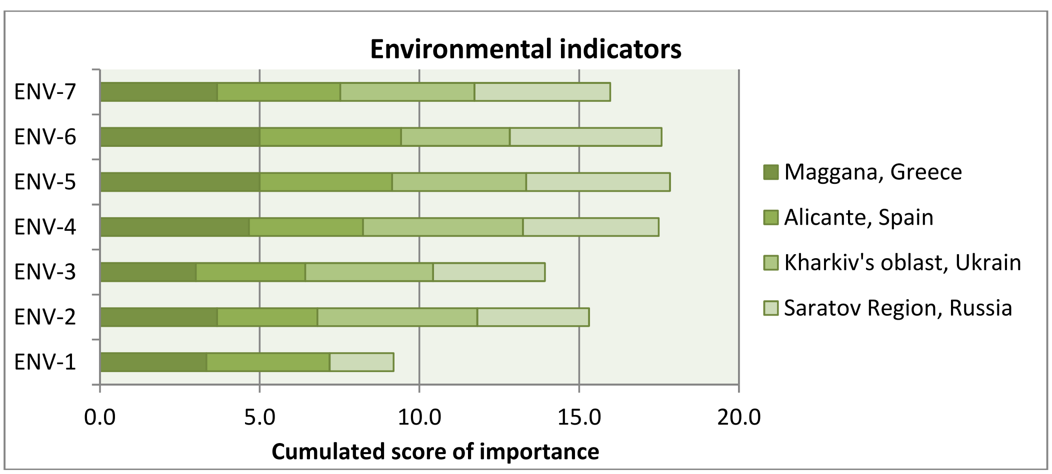
In the group of environmental indicators, stakeholders seem to be most concerned with effects of water saving strategies on heavy metal contents, soil alkalinity and soil salinity. A relatively low or no importance was assigned to soil water repellency. This may indicate that stakeholders are not aware of this phenomenon or unfamiliar with the concept in their regions.

Of the socio-cultural indicators, legal restrictions, the education and training of farmers, the acceptability of using wastewater for irrigation, and the political or financial incentives required to change the behaviour of land users were considered the most important factors for enabling or hindering the adoption of water saving strategies in all three regions.



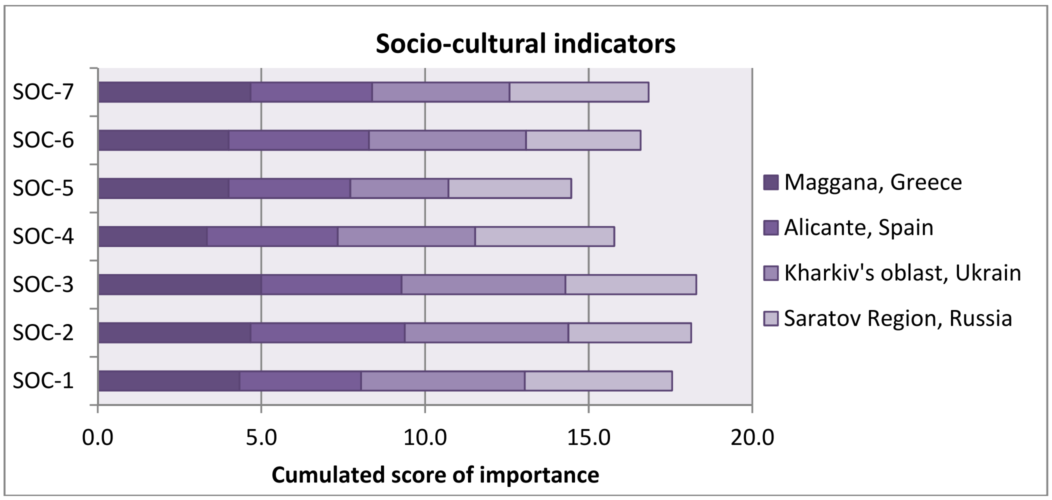
EC-1	Crop yield in treated area
EC-2	Farm Gross Margin
EC-3	Irrigation use efficiency
EC-4	Water use efficiency
EC-5	Total Available Water
EC-6	Green water use efficiency
EC-7	Establishment costs
EC-8	maintenance costs
EC-9	subsidy (or production aid)

Figure 3-3 Assignment of importance by stakeholders to economic indicators of the performance of water saving strategies in the studied regions – average scores for all stakeholder groups consulted.



ENV-1	Soil water repellency
ENV-2	Soil structural stability
ENV-3	Bulk density
ENV-4	Heavy metal content
ENV-5	soil alkalinity
ENV-6	soil salinity
ENV-7	Soil organic matter content

Figure 3-4 Assignment of importance by stakeholders to environmental indicators of the performance of water saving strategies in the studied regions – average scores for all stakeholder groups consulted.



SOC-1	legal restrictions
SOC-2	education and training of farmers
SOC-3	acceptability of using waste water for irrigation
SOC-4	historical adoption of new technologies
SOC-5	likelihood of adoption of new technologies from Water Reuse
SOC-6	incentives required to change behavior
SOC-7	farmer health and safety

Figure 3-5 Assignment of importance by stakeholders to socio-cultural indicators of the performance of water saving strategies in the studied regions – average scores for all stakeholder groups consulted.

Detailed information on the assignment of importance to indicators of water saving strategies in the regions in Greece, Spain and Ukraine is given below.

3.3.1 Importance of criteria according to stakeholders in Maggana region, Greece

Stakeholder preferences in Maggana region, Greece, show that the representatives of the civilian group attribute intermediate importance to indicators in each category, whereas the importance attributed by the environmental engineer varies much more between indicators, also within categories. The low scores of the environmental engineer on economic indicators showing the efficiency of water use by the strategies (irrigation use efficiency, water use efficiency, total available water in the root zone and green water use efficiency) are surprising, assuming that improving the efficiency of water use is among the objectives of engineering practices in sustainable water management (e.g. Lazarova, 2005). In contrast, the environmental engineer attached more importance to direct indicators of economic value, like the Farm Gross Margin and establishment and maintenance costs. For both stakeholder groups, socio-cultural indicators directly related to the well-being of the farmer or land user: education and training (SOC-2) and farmer health and safety (SOC-7).

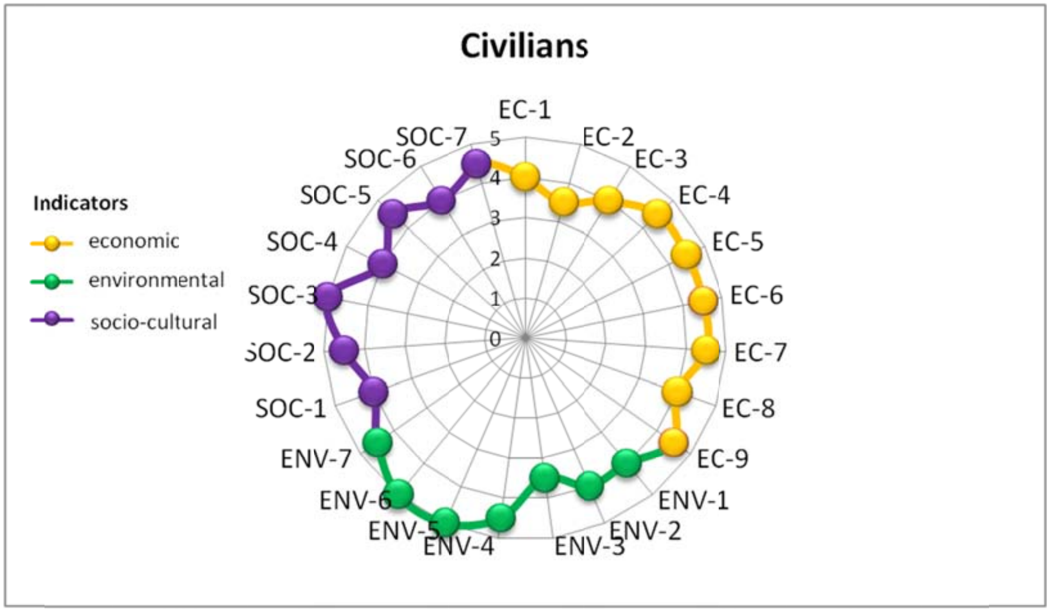


Figure 3-6 Assignment of importance to performance indicators of water saving strategies by stakeholders: civilians in Maggana region, Greece.

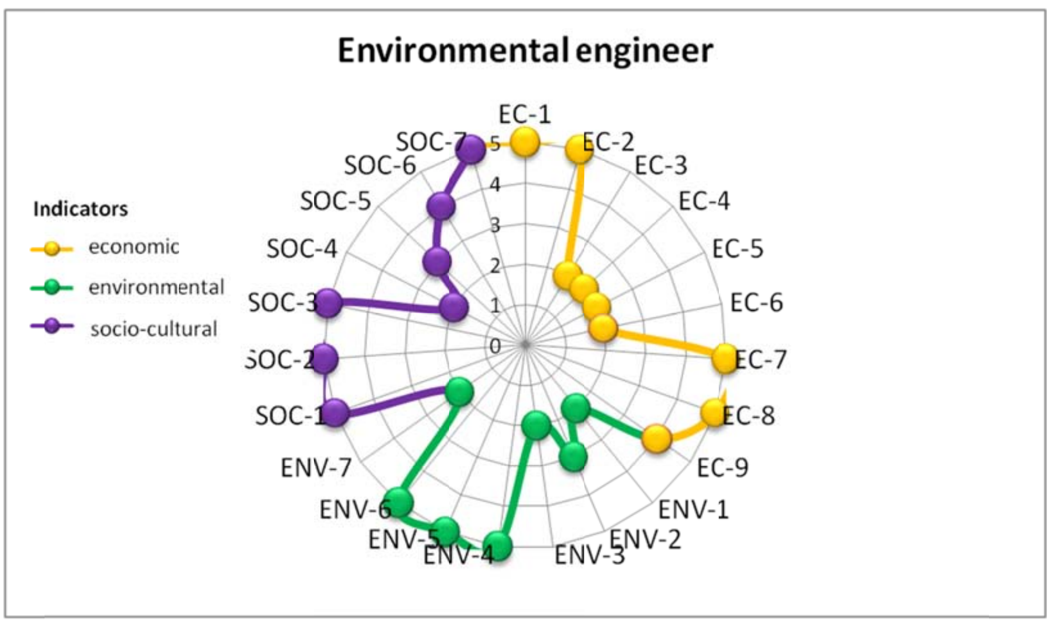
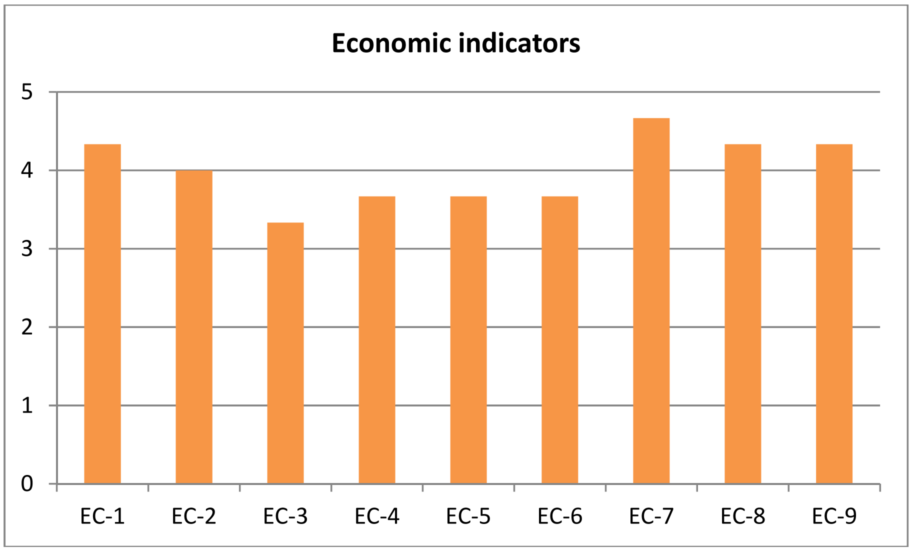


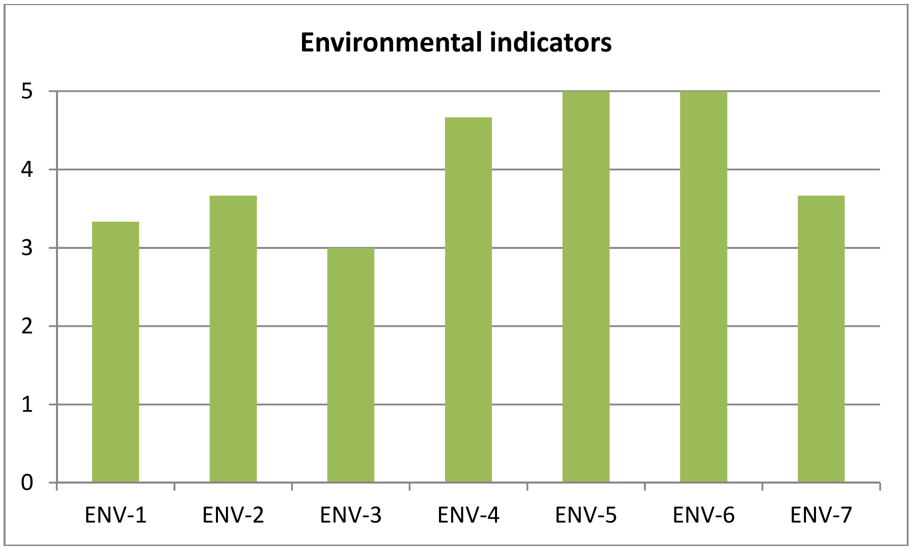
Figure 3-7 Assignment of importance to performance indicators of water saving strategies by stakeholders: environmental engineer in Maggana region, Greece.

The average importance assigned to performance indicators by stakeholders in the Greek region is indicated in Figure 3-8, Figure 3-9 and Figure 3-10. Stakeholders assigned a high importance (score>4) to indicators in each category. For the economic indicators, crop yield, costs and subsidies of water saving strategies were found most important. In the category of environmental indicators, heavy metal contents, soil alkalinity and soil salinity were assigned the highest importance. In the category of socio-cultural indicators, the number of legal restrictions, education and training of farmers, and the acceptability of using waste water were found most important, together with farmer health and safety.



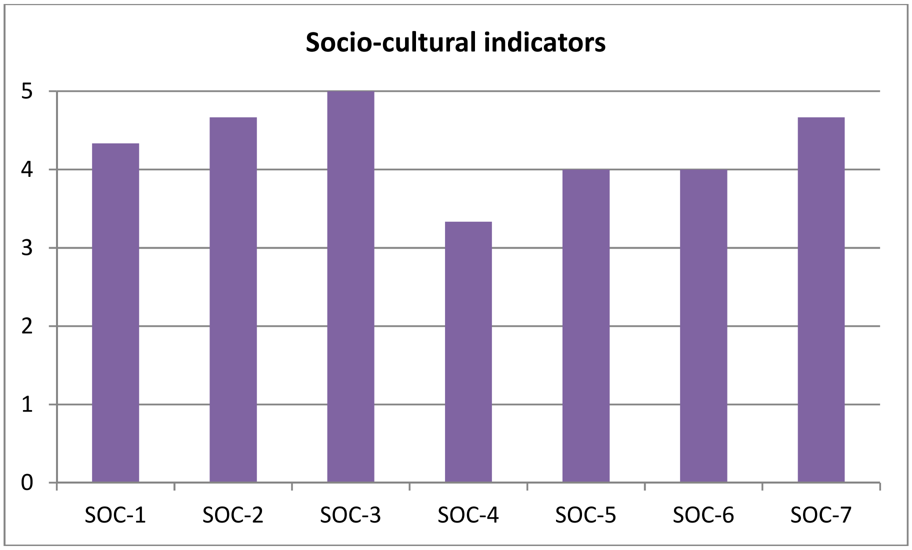
EC-1	Crop yield in treated area
EC-2	Farm Gross Margin
EC-3	Irrigation use efficiency
EC-4	Water use efficiency
EC-5	Total Available Water
EC-6	Green water use efficiency
EC-7	Establishment costs
EC-8	maintenance costs
EC-9	subsidy (or production aid)

Figure 3-8Average importance of economic indicators of the performance of water saving strategies according to all stakeholders consulted in Maggana region, Greece.



ENV-1	Soil water repellency
ENV-2	Soil structural stability
ENV-3	Bulk density
ENV-4	Heavy metal content
ENV-5	soil alkalinity
ENV-6	soil salinity
ENV-7	Soil organic matter content

Figure 3-9Average importance of environmental indicators of the performance of water saving strategies according to all stakeholders consulted in Maggana region, Greece.



SOC-1	legal restrictions
SOC-2	education and training of farmers
SOC-3	acceptability of using waste water for irrigation
SOC-4	historical adoption of new technologies
SOC-5	likelihood of adoption of new technologies from Water Reuse
SOC-6	incentives required to change behavior
SOC-7	farmer health and safety

Figure 3-10Average importance of socio-cultural indicators of the performance of water saving strategies according to all stakeholders consulted in Maggana region, Greece.

3.3.2 Importance of criteria according to stakeholders in Alicante province, Spain

Figures Figure 3-11 till Figure 3-15show the assignment of importance to criteria for enabling or hindering the adoption of water saving strategies according to stakeholders in Alicante province, Spain. Overall, the respondents from industry and education assigned higher importance to the criteria compared to the other stakeholders, especially for the economic and socio-cultural indicators. This is surprising considering that the respondents from the other stakeholder groups would have more direct interest or involvement in the implementation of water saving strategies.

Socio-cultural indicators received the highest rating of importance from stakeholders (4.2 on average, versus 3.4 and 3.8 respectively for economic and environmental indicators). This indicates that these aspects require due attention in the implementation of water saving strategies in the region.

The respondents from farmers' organizations assigned the highest importance to economic indicators expressing economic profit (crop yield EC-1 and farm gross margin EC-2) and efficient water use (irrigation use efficiency EC-3 and water use efficiency EC-4). The education and training of farmers and the level of incentives required to change behaviour were also considered importance for enabling of hindering the adoption of water saving strategies by the respondents from the farmers organizations. Environmental indicators were considered less important, except for soil salinity. The results from the field trials indicate that this concern is justified, since the use of municipal waste water from secondary treatment was observed to induce soil salinity and to reduce crop growth and yield.

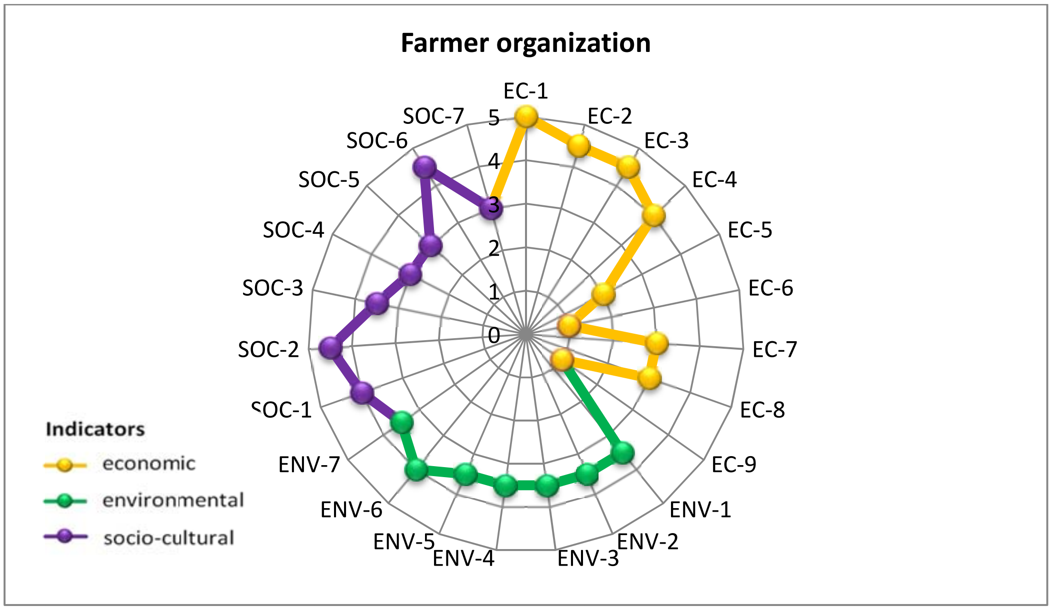


Figure 3-11 Assignment of importance to performance indicators of water saving strategies by stakeholders: farmer organization in Alicante, Spain.

The respondent from the land users attributed the highest importance to socio-cultural indicators, except for the indicator expressing the likeliness that farmers will adopt new water saving strategies like those proposed in the Water Reuse project. According to the land user, environmental indicators were also important for enabling or hindering the adoption of water saving strategies, except for indicators expressing the soil physical condition of the soil (soil structural stability EC-2 and bulk density EC-3). This results stands out, since the protection of the structural stability of the soil surface was one of the main objectives of the water saving strategies trialled in the Water reuse project. The results also showed that traditional irrigation techniques caused a decay of soil structural stability, and that this could be well remediated by irrigation scheduling and mulching.

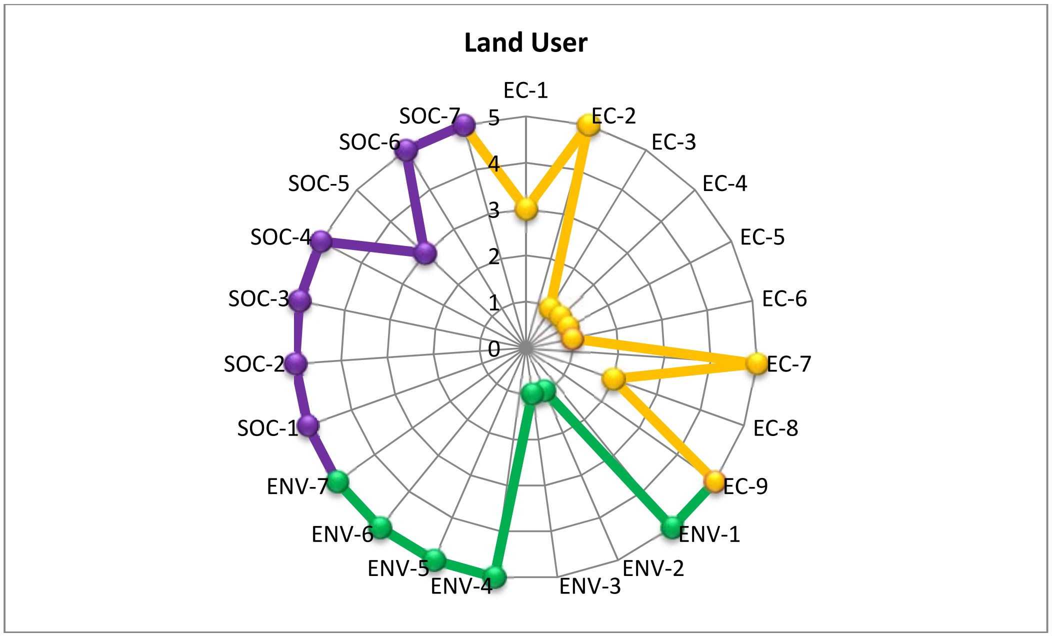


Figure 3-12 Assignment of importance to performance indicators of water saving strategies by stakeholders: land user in Alicante, Spain.

For the respondents from the public management water enterprise, the farm gross margin 9EC-2), education and training of farmers (SOC-2), and the acceptability of using waste water for irrigation stand out as the most important criteria enabling or hindering the adoption of water saving strategies in the region. It is surprising that the criteria expressing the efficiency of water use (EC-3, 4 and 6) were not considered important by the respondents from the public management water enterprise, considering that the objectives of this organization are probably to sustainably manage and convey water resources in the region.

The respondents from the public management water enterprise considered all environmental indicators important, except for soil water repellency. This is justified by the observation from the field experiments that the use of waste water did not produce water repellency in the soils.

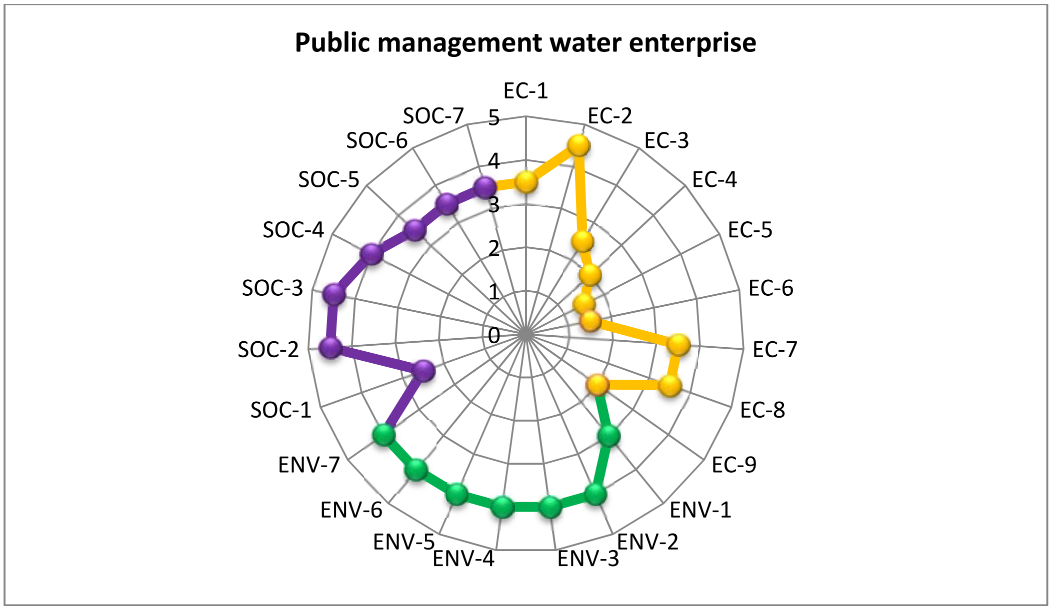


Figure 3-13 Assignment of importance to performance indicators of water saving strategies by stakeholders: public management water enterprise in Alicante, Spain.

The respondent from the industry assigned an overall high importance to economic, environmental and socio-cultural indicators (respectively 4.5, 4.3 and 4.4 on average). This reflects the awareness of the relevance of each of the three subject fields for the introduction of water saving strategies. Among the indicators rated as important, most important were considered the indicators of economic profit or costs (crop yield and farm gross margin, establishment costs), but also the total available water in the root zone of the soil was considered important for enabling the introduction of water saving strategies in the region. The latter may explained by the fact that the respondent from industry was also a land user. Among the environmental indicators, the soil bulk density and salinity were considered most important. Of the socio-cultural indicators, indicators directly related to the interests and well-being of land users were considered most important, like the education and training of farmers, the incentives required to change behaviour and aspects of health and safety. Also these preferences may be explained by the fact that the respondent from industry was also a land user.

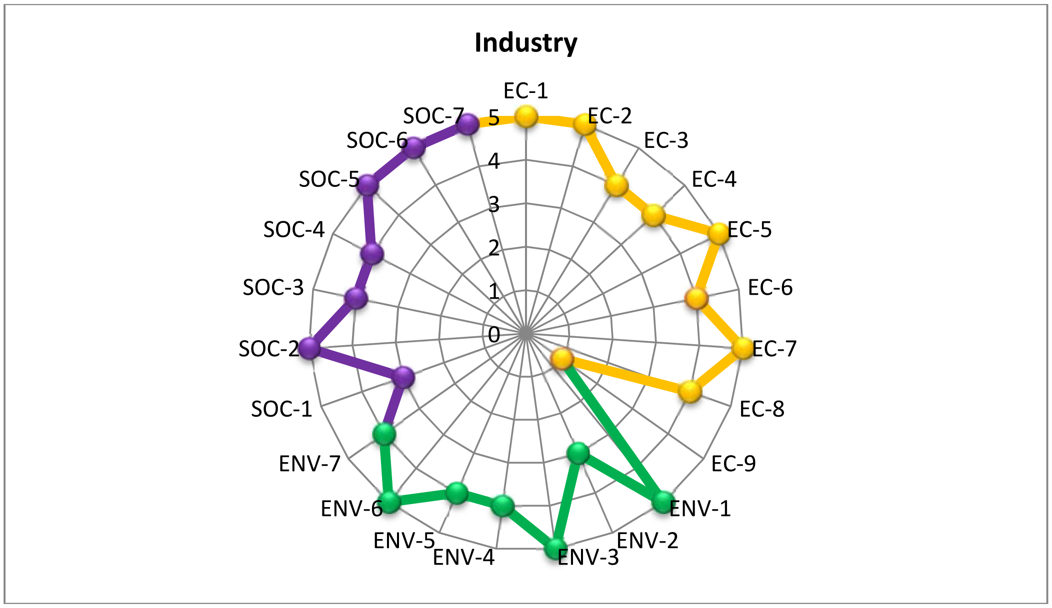


Figure 3-14 Assignment of importance to performance indicators of water saving strategies by stakeholders: industry in Alicante, Spain.

The respondent from the stakeholder group ‘educators’ (at university level) assigned a high importance to economic and socio-cultural indicators, but less importance to environmental indicators. An exception to this observation were the soil organic matter content and soil salinity, which were considered as very important for enabling or hindering the adoption of water saving strategies in the province.

For the economic indicators, the scores were relatively low for indicators directly related to the costs of implementation (EC-7, 8 and 9). Among the socio-cultural indicators, farmer health and safety was not assigned a large importance.

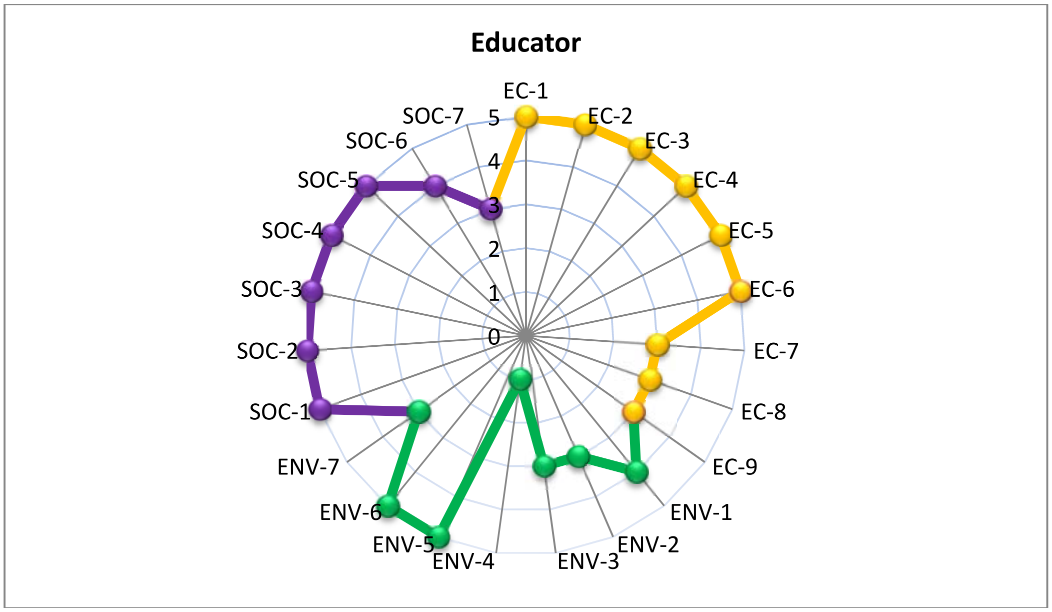
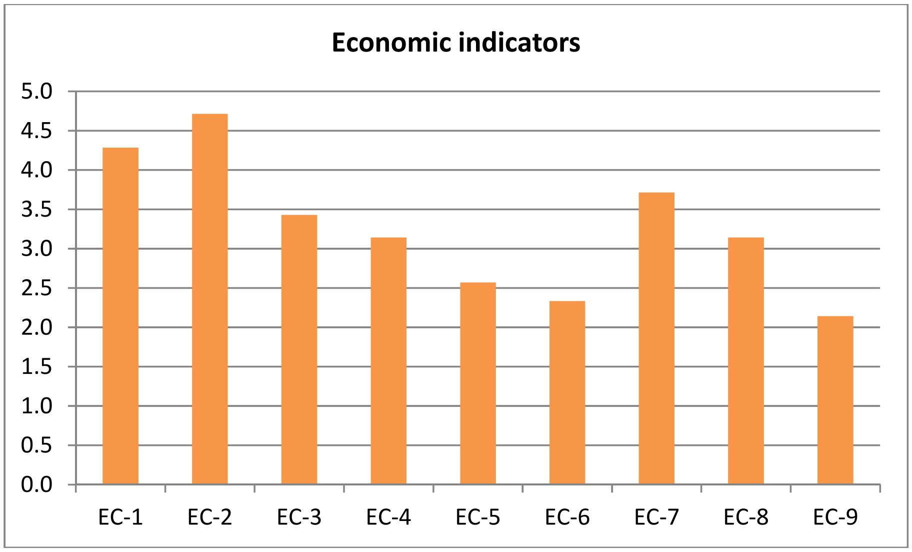


Figure 3-15 Assignment of importance to performance indicators of water saving strategies by stakeholders: educator in Alicante, Spain.

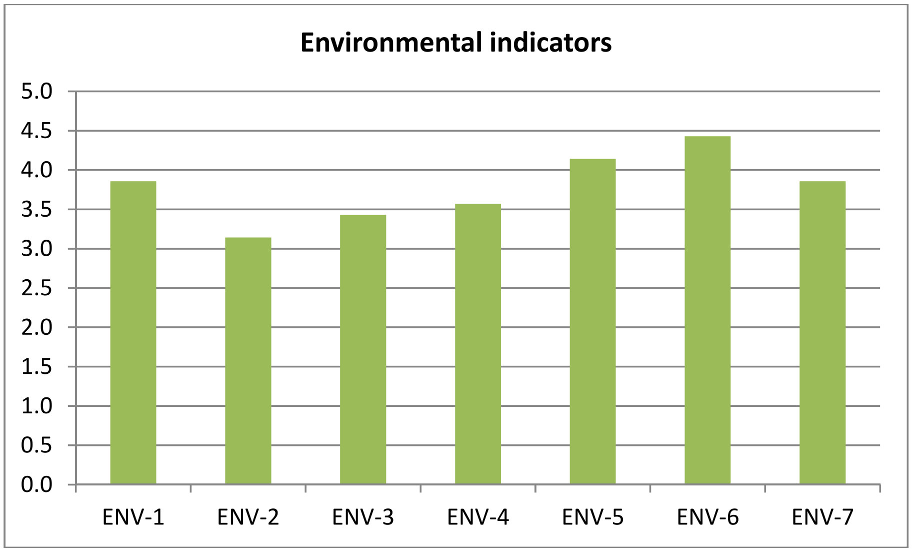
Looking at the assignment of importance to individual criteria in each group, for the economic indicators crop yield (EC-1) and farm gross margin (EC-2) received the highest scores (Figure 3-16). The low rating of the importance of green water use efficiency (EC-6) may be due to the fact that 'green water' is a relatively new concept in environmental science, and that stakeholders may not be familiar with it, despite the description given. The granting of subsidies for applying water saving strategies is considered not very important for enabling the adoption of water saving strategies by the stakeholder groups. This may be explained by the fact that land users and land owners currently receive CAP related subsidies for the production of some agricultural commodities (Valsecchi, C., ten Brink, P., Bassi, S. et al., 2009).



EC-1	Crop yield in treated area
EC-2	Farm Gross Margin
EC-3	Irrigation use efficiency
EC-4	Water use efficiency
EC-5	Total Available Water
EC-6	Green water use efficiency
EC-7	Establishment costs
EC-8	maintenance costs
EC-9	subsidy (or production aid)

Figure 3-16 Average importance of economic indicators of the performance of water saving strategies according to all stakeholders consulted in Alicante province, Spain.

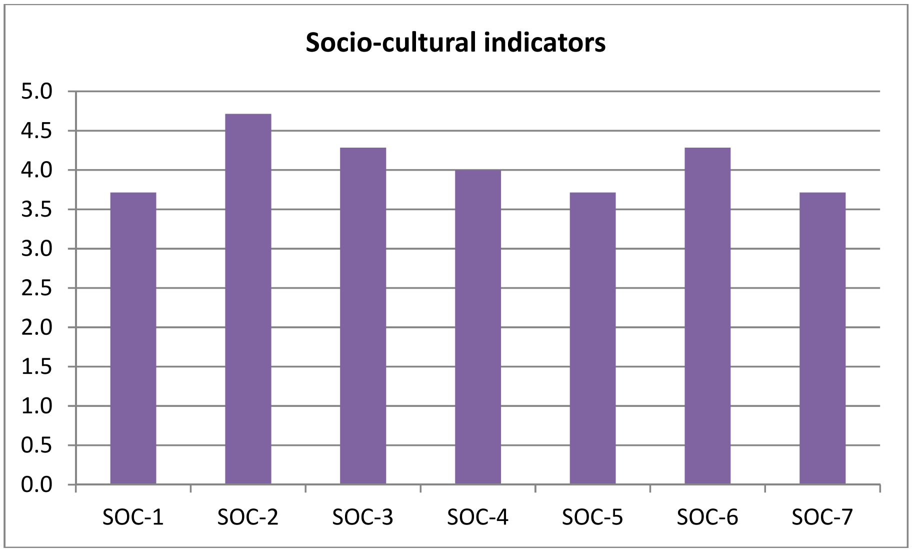
Of the environmental indicators, soil salinity induced or relieved by water saving strategies was considered most important for enabling or hindering the adoption of water saving strategies in Alicante by the consulted stakeholder groups (Figure 3-17). This may be explained by the fact that soil salinity is reported as one of the major forms of land degradation in the region by researchers and land users independent of water saving strategies. In addition, the importance assigned to soil salinity may be explained by the awareness that irrigation with waste water intrudes salts in the soil.



ENV-1	Soil water repellency
ENV-2	Soil structural stability
ENV-3	Bulk density
ENV-4	Heavy metal content
ENV-5	soil alkalinity
ENV-6	soil salinity
ENV-7	Soil organic matter content

Figure 3-17 Average importance of environmental indicators of the performance of water saving strategies according to all stakeholders consulted in Alicante province, Spain.

Of the socio-cultural indicators of the performance of water saving strategies, the education and training of farmers was considered most important by the stakeholder groups consulted (Figure 3-18). This indicates that this aspect should receive attention when implementing water saving strategies in the area.



SOC-1	legal restrictions
SOC-2	education and training of farmers
SOC-3	acceptability of using waste water for irrigation
SOC-4	historical adoption of new technologies
SOC-5	likelihood of adoption of new technologies from Water Reuse
SOC-6	incentives required to change behavior
SOC-7	farmer health and safety

Figure 3-18 Average importance of socio-cultural indicators of the performance of water saving strategies according to all stakeholders consulted in Alicante province, Spain.

3.3.3 Importance of criteria according to stakeholders in Kharkiv region, Ukraine

In Kharkiv region, Ukraine, respondents from agricultural advisors/consultants, water suppliers and water authorities were asked to assign scores of importance to performance indicators of water saving strategies (Figure 3-19, Figure 3-20 and Figure 3-21). Typically, the groups did not assign scores to indicators expressing the efficiency of water use (EC-4, 5 and 6), maintenance costs (EC-8) and soil water repellency (ENV-1) (Figure 3-22 and Figure 3-23). It is not clear why the stakeholder groups did not rate these indicators. With regard to soil water repellency, this was not observed in the field trials (del 25, Moore et al., 2010). Unfamiliarity with soil water repellency may also explain the absence of ratings for this indicator. However, this does not explain the omission of scores for the other indicators, as these are in the domain of expertise of the stakeholder groups consulted. Overall, the ratings of importance are very similar between the groups, with high importance assigned to crop yield, farm gross margin and irrigation efficiency, establishment costs and subsidies (Figure 3-19, Figure 3-20 and Figure 3-21). Furthermore ratings for environmental indicators are lower for all three groups, with only soil structural stability and heavy metal contents receiving high scores (Figure 3-22, Figure 3-23 and Figure 3-24). The high scores for soil structural stability (EC-2) are surprising, since the negative effects of the deterioration of soil structure are often not known to stakeholders other than land users and soil scientists. Of the socio-cultural indicators, legal restrictions, education and training of farmers, the acceptability of using waste water and incentives to change farmer behaviour are considered very important by all three stakeholder groups.

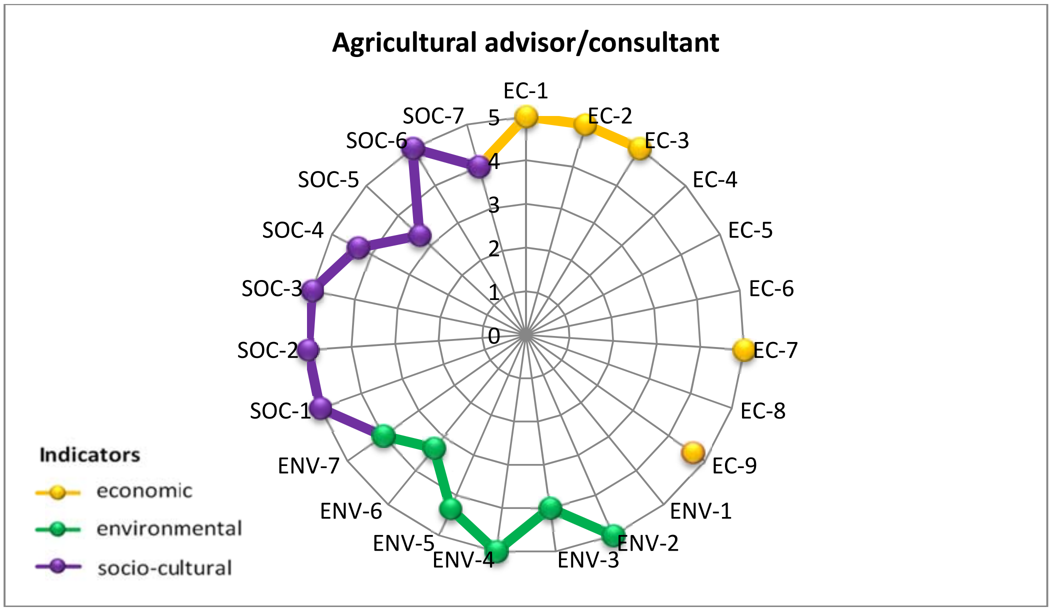


Figure 3-19 Assignment of importance to performance indicators of water saving strategies by stakeholders: agricultural advisor/consultant in Kharkiv region, Ukraine.

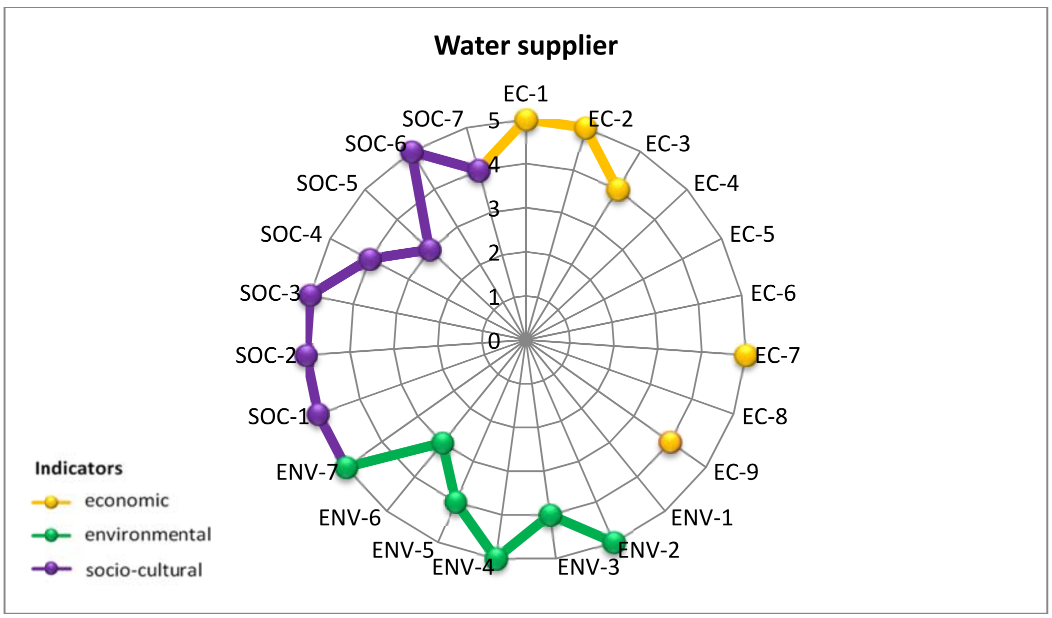


Figure 3-20 Assignment of importance to performance indicators of water saving strategies by stakeholders: water supplier in Kharkiv region, Ukraine.

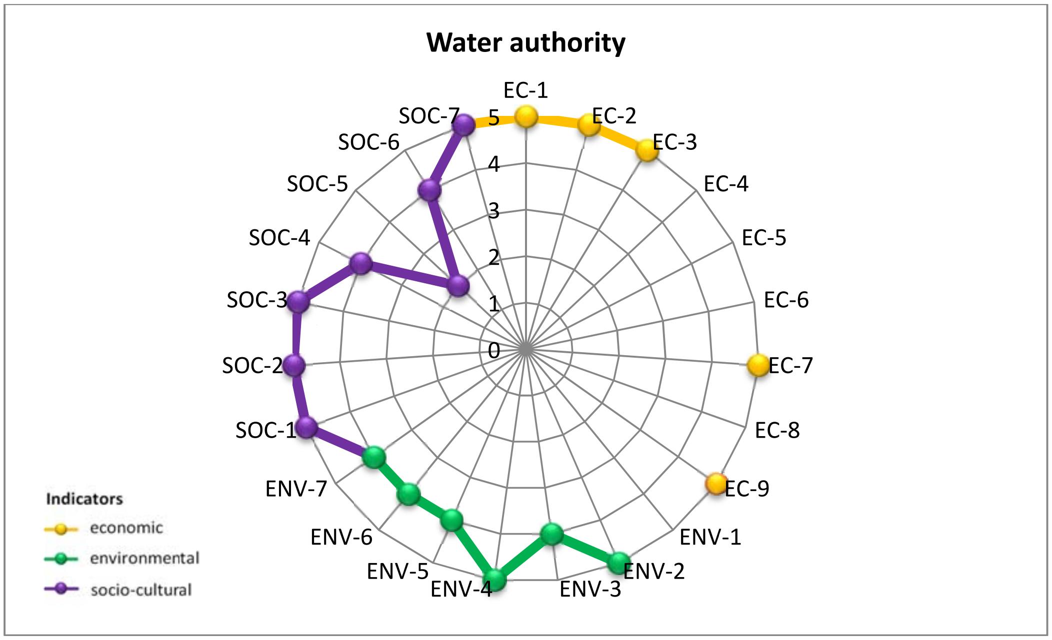
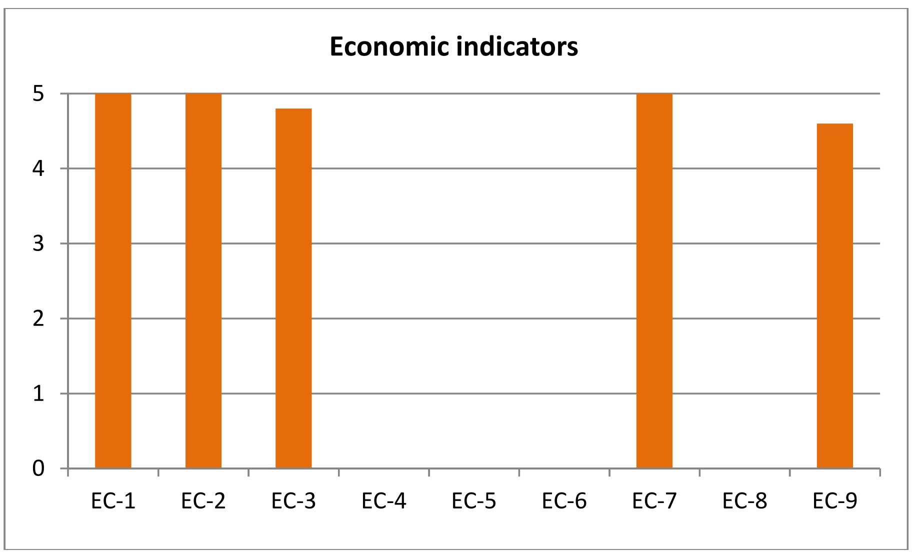
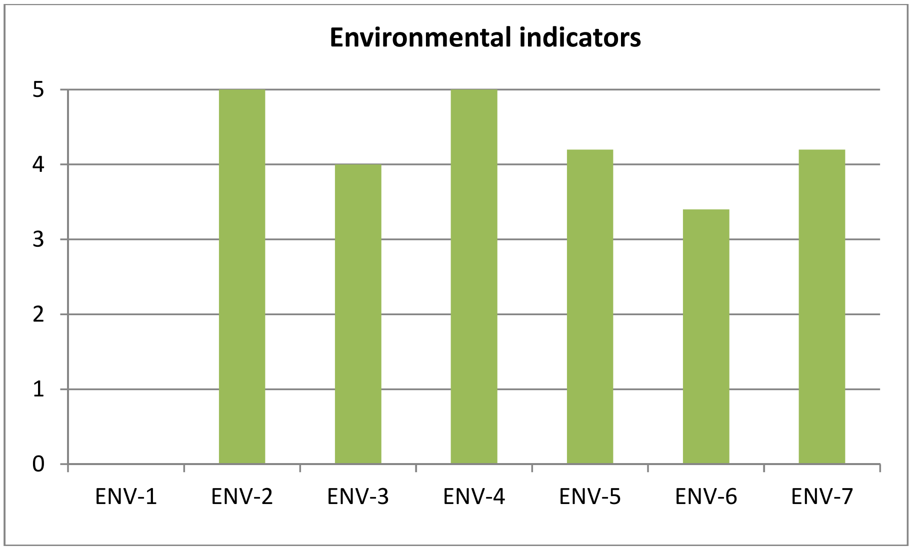


Figure 3-21 Assignment of importance to performance indicators of water saving strategies by stakeholders: water authority in Kharkiv region, Ukraine.



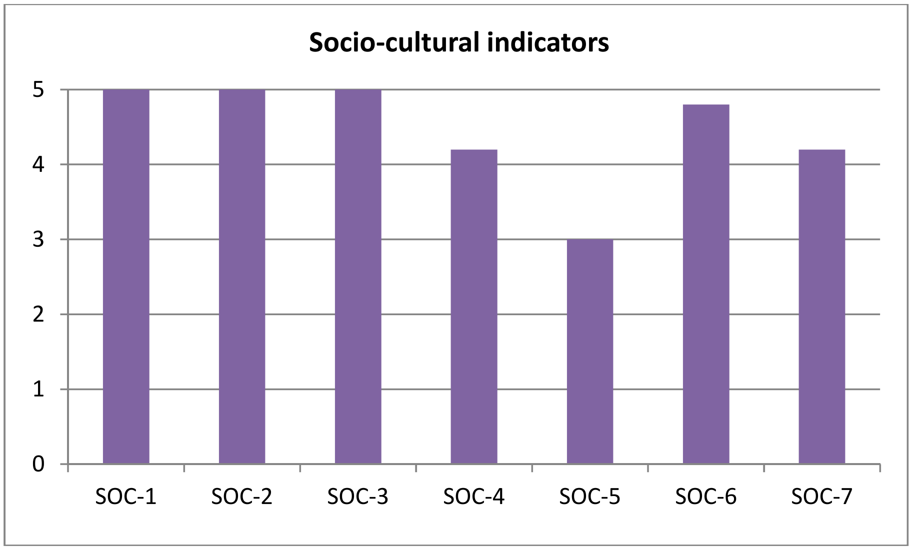
EC-1	Crop yield in treated area
EC-2	Farm Gross Margin
EC-3	Irrigation use efficiency
EC-4	Water use efficiency
EC-5	Total Available Water
EC-6	Green water use efficiency
EC-7	Establishment costs
EC-8	maintenance costs
EC-9	subsidy (or production aid)

Figure 3-22 Average importance of economic indicators of the performance of water saving strategies according to all stakeholders consulted in Kharkiv region, Ukraine.



ENV-1	Soil water repellency
ENV-2	Soil structural stability
ENV-3	Bulk density
ENV-4	Heavy metal content
ENV-5	soil alkalinity
ENV-6	soil salinity
ENV-7	Soil organic matter content

Figure 3-23 Average importance of environmental indicators of the performance of water saving strategies according to all stakeholders consulted in Kharkiv region, Ukraine.



SOC-1	legal restrictions
SOC-2	education and training of farmers
SOC-3	acceptability of using waste water for irrigation
SOC-4	historical adoption of new technologies
SOC-5	likelihood of adoption of new technologies from Water Reuse
SOC-6	incentives required to change behavior
SOC-7	farmer health and safety

Figure 3-24 Average importance of socio-cultural indicators of the performance of water saving strategies according to all stakeholders consulted in Kharkiv region, Ukraine.

3.3.4 Importance of criteria according to stakeholders in Saratov region, Russia

The stakeholder groups consulted in Saratov region, Russia, comprised representatives from the regional water authority, from the Ministry of Agriculture, an agricultural advisor, and a land user (farmer). Overall, they assigned a moderate to very high importance to all indicators, with averaged scores per indicator over the stakeholder groups of at least 3.5 on a scale of 5 (Figure 3-29, Figure 3-30 and Figure 3-31). The only indicator receiving a lower average score was the soil water repellency (ENV-1) (average score 2.0) (Figure 3-30), pointing to an irrelevance of the phenomenon. This is confirmed by the results of the field trials (see deliverable 25, Moore et al., 2010). Unfamiliarity with the phenomenon of soil water repellency by stakeholders may also explain the low scores.

The respondents from the water authority, the regional policy makers and the land user assign the largest importance to economic indicators, whereas the agricultural advisor attributed higher importance to environmental and socio-cultural indicators (Figure 3-25 to Figure 3-28).Socio-cultural indicators were found more important by the agricultural advisor and the land user than by the water authority and the policy maker.

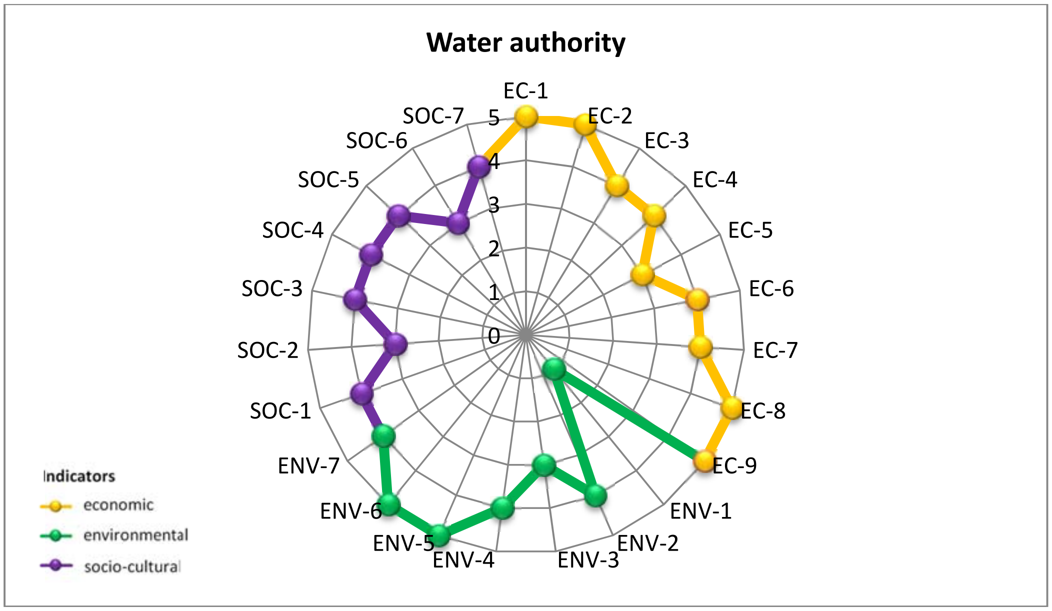


Figure 3-25 Assignment of importance to performance indicators of water saving strategies by stakeholders: water authority in Saratov Region, Russia.

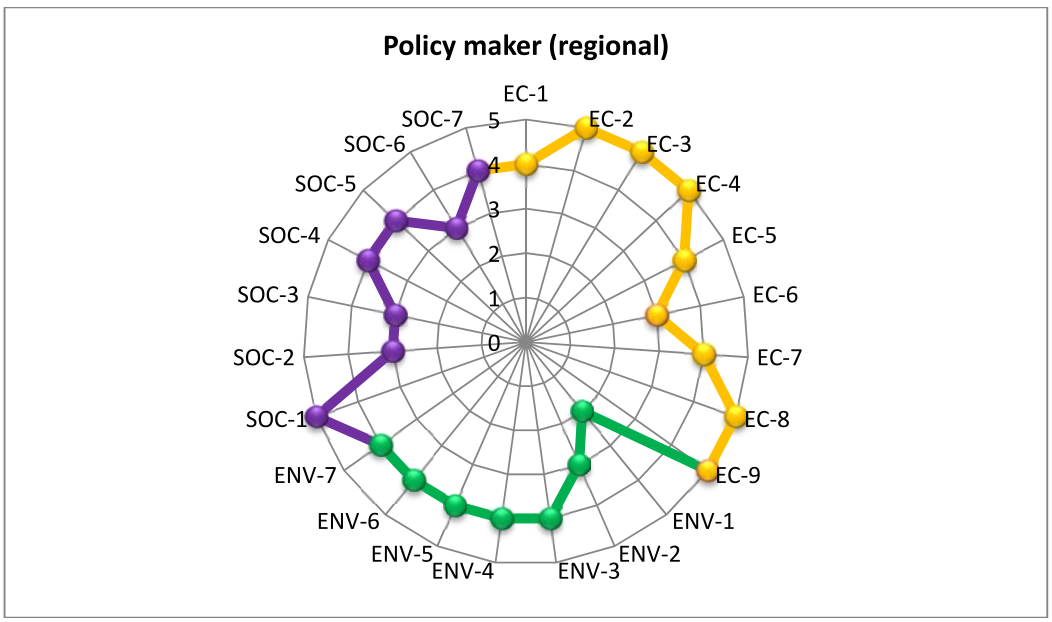


Figure 3-26 Assignment of importance to performance indicators of water saving strategies by stakeholders: regional policy makers in Saratov Region, Russia.

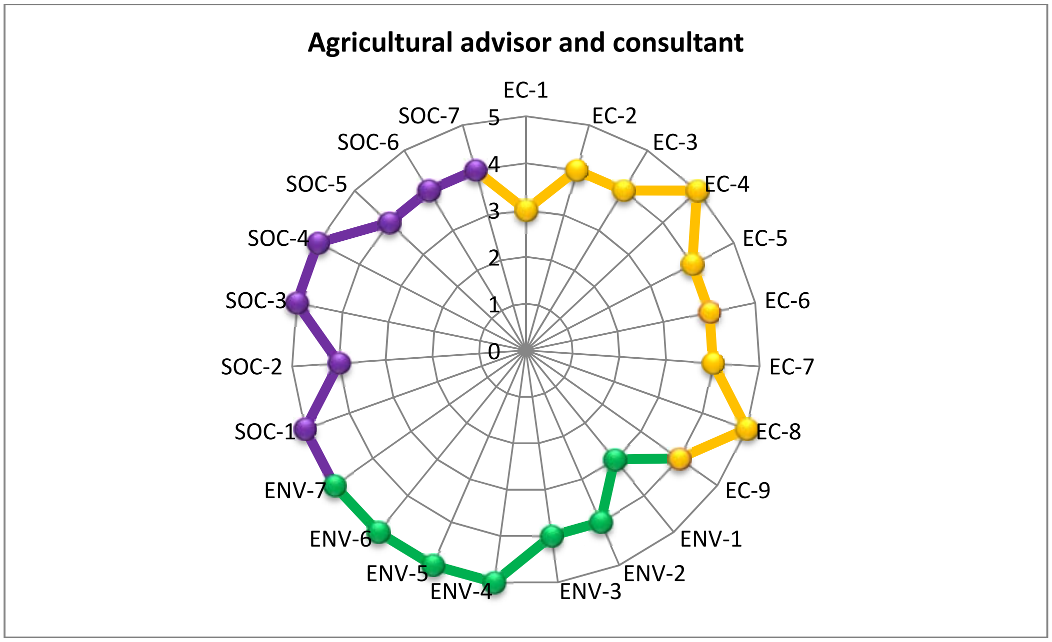


Figure 3-27 Assignment of importance to performance indicators of water saving strategies by stakeholders: agricultural advisor and consultant in Saratov Region, Russia.

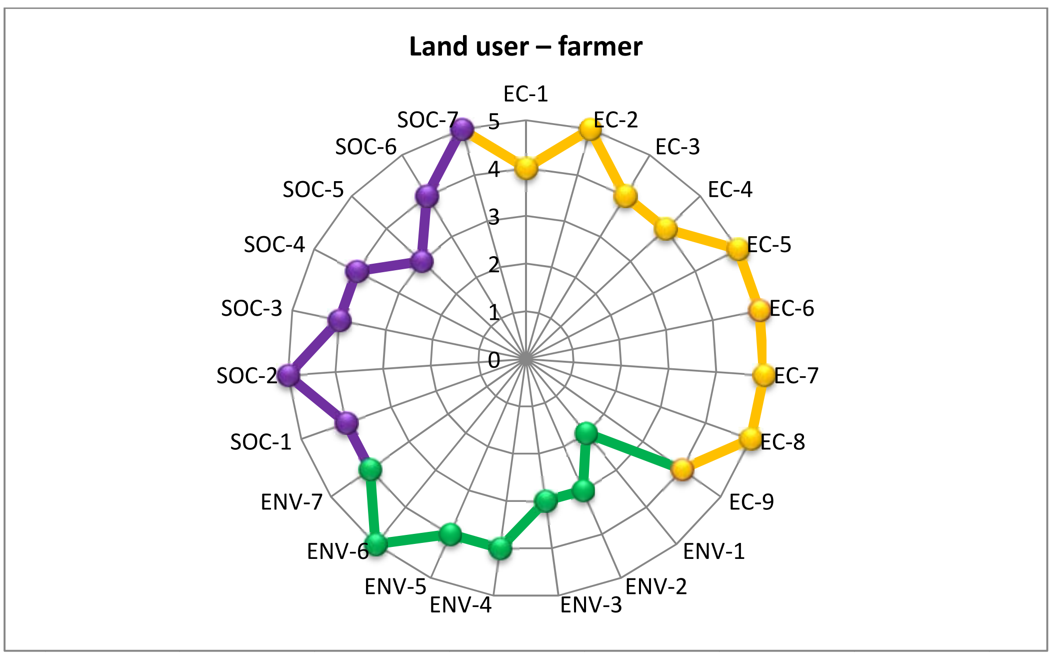
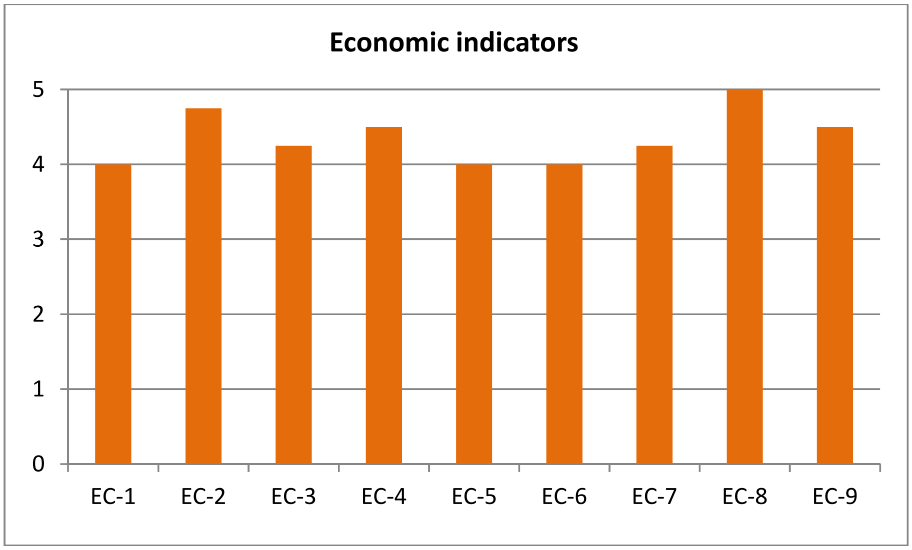


Figure 3-28 Assignment of importance to performance indicators of water saving strategies by stakeholders: land user-farmer in Saratov Region, Russia.

Of the economic indicators, the farm gross margin (EC-2) and the maintenance costs (EC-8) received the highest scores of importance averaged over the stakeholder groups (Figure 3-29). The importance assigned to maintenance costs may be explained by the large-scale nature of the irrigation systems in the Russian Federation, which consist of large systems of canals in combination with large-scale, energy-consuming pressure systems with sprinklers(http://www.icid.org/cp_russia.html; MSUEE, 2006; Zhovtonog et al., 2005).

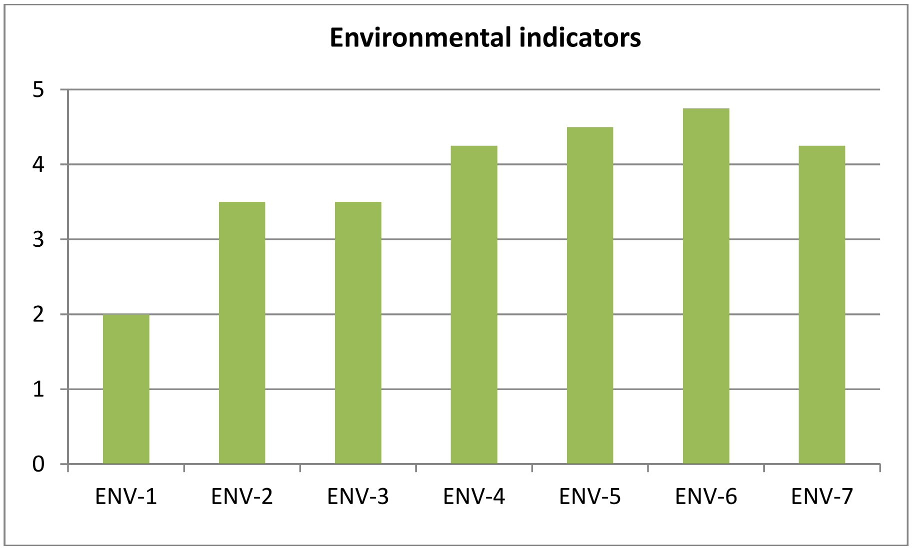


EC-1	Crop yield in treated area
EC-2	Farm Gross Margin
EC-3	Irrigation use efficiency
EC-4	Water use efficiency
EC-5	Total Available Water
EC-6	Green water use efficiency
EC-7	Establishment costs
EC-8	maintenance costs
EC-9	subsidy (or production aid)

Figure 3-29 Average importance of economic indicators of the performance of water saving strategies according to all stakeholders consulted in Saratov Region, Russia.

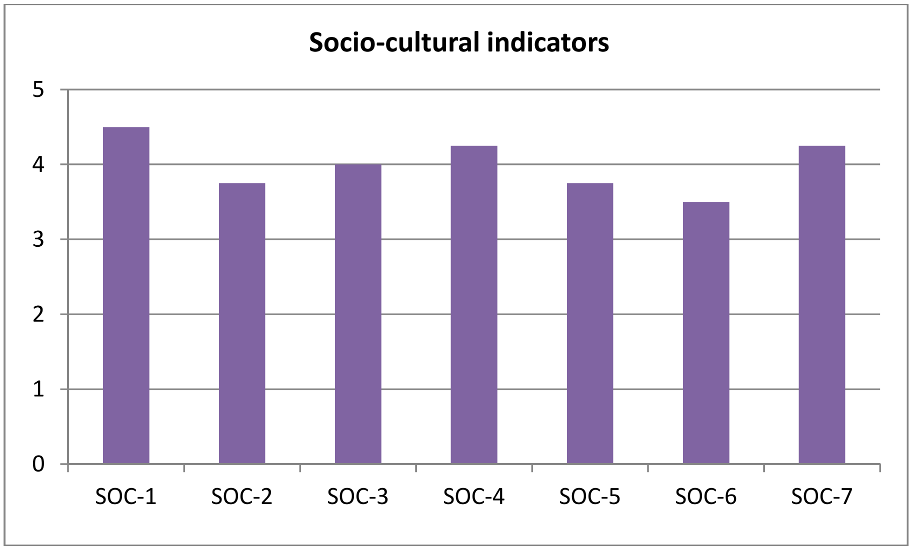
Most concern from the stakeholders with regard to environmental indicators of the performance of water saving strategies is with the effects on soil alkalinity and soil salinity. These phenomena have long been recognised as negative environmental side-effects of irrigation in the region (Gabchenko, 2008), which explain the high ratings by the stakeholders.

With regard to socio-cultural indicators, legal restrictions were considered to be most important in enabling or hindering the adoption of water saving strategies in the region. This may be related to the dominant orientation of the state policy and legislation in Russia towards an increase of more governmental influence on operation and maintenance or rehabilitation in the irrigation sector. Examples are the Russian federal programme ''Soil fertility improvement in Russia in 2002–2005'' and the programme ''Re-establishment for agricultural lands and agro landscapes of Russia in 2002–2010''. This orientation is illustrative of the absence of a clear transformation policy and strategy during the transition to a market economy (Zhovtonog et al., 2005). Following this explanation, the low importance assigned to incentives required to change farmer behaviour (SOC-6) may also be explained, since the strong influence of the regional governments on irrigation management could make incentives to change the behaviour of land users in irrigated agriculture unnecessary.



ENV-1	Soil water repellency
ENV-2	Soil structural stability
ENV-3	Bulk density
ENV-4	Heavy metal content
ENV-5	soil alkalinity
ENV-6	soil salinity
ENV-7	Soil organic matter content

Figure 3-30 Average importance of environmental indicators of the performance of water saving strategies according to all stakeholders consulted in Saratov Region, Russia.



SOC-1	legal restrictions
SOC-2	education and training of farmers
SOC-3	acceptability of using waste water for irrigation
SOC-4	historical adoption of new technologies
SOC-5	likelihood of adoption of new technologies from Water Reuse
SOC-6	incentives required to change behavior
SOC-7	farmer health and safety

Figure 3-31 Average importance of socio-cultural indicators of the performance of water saving strategies according to all stakeholders consulted in Saratov Region, Russia.

4 Performance evaluation of water saving strategies

4.1 Introduction

In the Water Reuse project, new and existing water saving strategies were tested in the southern Mediterranean area and in NIS states with the objectives to (a) reduce irrigation water losses by developing, evaluating and promoting techniques that improve the wetting properties of soils and preventing water loss by conventional irrigation methods, and (b) investigate the use of organic-rich waste water as a non-conventional water resource in irrigation and, in addition, as a tool in improving soil physical properties and soil nutrient and organic matter content. An evaluation of the performance of the tested water saving strategies is required In order to evaluate the appropriateness of the tested water saving strategies with regard to the project's objectives. This evaluation on the one hand relates to the biophysical performance of the strategies on environmental aspects, regarding the efficiency of water use in irrigation and its effects on the wetting properties and soil physical and chemical properties. On the other hand, an evaluation of water saving strategies on economic and socio-cultural aspects is required, which inform on the feasibility to introduce water saving strategies in an area, like crop yield, legal restrictions, needs for communication and training, or effects on health. The performance of water saving strategies can be evaluated by measuring their 'scores' on the economic, environmental and socio-cultural indicators selected in chapter 3. In the Water Reuse project, these scores were partially derived from the field experiments, partly from literature and partially from interviews with land managers and land users. Apart from these scores, stakeholder views upon the water saving strategies are required to support the identification of water saving strategies for an area, and to support decisions on which strategies to implement. The measured scores on performance indicators and assignments of importance to the indicators by stakeholders can be evaluated together in a multi objective decision support system in order to identify preferred management options.

As part of the comprehensive comparative analysis of water saving technique performances and prospects in deliverable 27, the objective of this chapter was to identify potential water saving strategies based on scores on economic, environmental and socio-cultural indicators and stakeholder preferences for two of the study areas. This will show how participation by stakeholders can be incorporated in research on water saving strategies in a simple way, and how measured data, simulation model results and expert opinions can be accommodated in the decision making process on water saving strategies.

4.2 Methods

The research sites in Alicante province, Spain, and Kharkiv region, Ukraine, were selected for the evaluation of water saving strategies from an economic, ecological and socio-cultural point of view based on stakeholder preferences. Water saving strategies for the Alicante province in Spain were selected with the aims to:

1) to optimize the irrigation dose to crop requirements,
2) to improve the wetting properties of soils by preventing formation of water repellency,
3) to prevent water loss due to evaporation, and

4) to investigate the use of waste water as a non-conventional water resource in irrigation, saving fresh surface and ground water.

For Kharkiv region, aims 1), 3) and 4) guided the selection of water saving strategies. Aims 1) till 3) contribute to the first objective of the Water Reuse project, while aim 4) contributes to the second objective (see chapter 4.1).

The method chosen for the performance evaluation of water saving strategies consists of the following steps (Figure 4-1):

1. Selection of water saving strategies for the area potentially capable to reduce irrigation water losses (Water Reuse project objective 1) to provide an alternative water resource to fresh water by using wastewater, and to improve soil physical properties, soil nutrient content and soil organic matter content (Water Reuse project objective 2).;
2. Select indicators of the performance of water saving strategies from an economic, environmental and socio-cultural perspective ;
3. Measure scores of each water saving strategies on the indicators using field experiments, literature research and stakeholder consultation;
4. Consult stakeholders on their assignment of importance to the performance indicators;
5. Identify preferred water saving strategies consistent with the scores on the indicators and the ranking of the performance indicators by stakeholders.

Step 1 was performed based on ex-ante field experiments and water balance modelling using the SWAP model as part of the Water Reuse project (deliverable 21). The selected water saving strategies are shown in Table 4-1 and Table 4-2.

Table 4-1 Water saving strategies selected for performance evaluation for Alicante province, Spain.

Water saving strategy	Description
Strategy 1 S1	**Soil irrigated with fresh water (control)**
Strategy 2 S2	**Soil irrigated with waste water from secondary treatment**
Strategy 3 S3	**Soil irrigated with waste water from tertiary treatment**
Strategy 4 S4	**Soil irrigated with fresh water (control) + Mulch**
Strategy 5 S5	**Soil irrigated with waste water from secondary treatment + Mulch**
Strategy 6 S6	**Soil irrigated with waste water from tertiary treatment + Mulch**

Table 4-2 Water saving strategies selected for performance evaluation for Kharkiv region, Ukraine.

Water saving strategy	Description
Strategy 1 S1	**No irrigated soil (boghara)**
Strategy 2 S2	**Soil irrigated with fresh water (control)**
Strategy 3 S3	**Soil irrigated with municipal waste water**
Strategy 4 S4	**Soil irrigated with waste water from pig farm**
Strategy 5 S5	**Soil irrigated with fresh water + Mulch**
Strategy 6 S6	**Soil irrigated with municipal waste water + Mulch**

Step 2 is documented in chapter 3.1. Step 3 was performed through field experiments, literature research and stakeholder consultation as reported in deliverables 23, 24 and 25. Interviews with 5 land users in the region were used to supplement the scores on socio-cultural indicators. Step 4 is documented in chapters 3.2 and 3.3 of this report. Step 5 was performed using a multiple objective decision support system (MODSS). The MODSS used was Facilitator (facilitator.sourceforge.net). The facilitator software uses decision rules, a hierarchical system for ranking criteria, score functions and linear programming to identify preferred management option consistent with the ranking of the decision criteria. Results are displayed as horizontal bars with best and worst composite scores; the length of the bars representing the sensitivity of the water saving strategy to the individual ordering of the performance indicators (e.g. Figure 4-4).

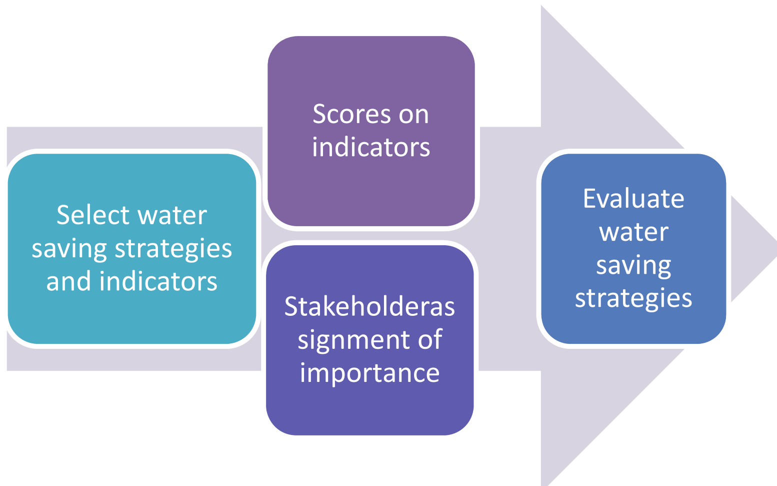


Figure 4-1 Work flow in the performance evaluation and identification of preferred water saving strategies.

The set-up of the MODSS for the performance evaluation and identification of preferred options requires the following activities:

a. Defining a matrix of water saving strategies versus performance indicators. This was done based on the water saving strategies and performance indicators selected in steps 1 and 2 of the performance evaluation as outlined above.
b. Populating the matrix with measures of the scores of water saving strategies on indicators, using the results from the field experiments, literature research and stakeholder consultation (step 3 in the performance evaluation). The matrix should contain a score for every strategy on every indicator, otherwise the MODSS cannot run the analysis.
c. Ranking the performance indicators, performing runs, and analyzing the results. The ranking of indicators was provided by the consultation of stakeholders as outlined in step 4 of the performance evaluation.

The multi criteria analysis performed by the MODSS performs a normalization of the scores of water saving strategies on performance indicators. The normalization of scores requires information on their type (cost or benefit) minimum and maximum values, measurement unit, and value function. This information was entered into the MODSS in step a. Minimum and maximum values of indicators were obtained from the databases of soils and crops established in the Water Reuse project (deliverables 23 and 24) or from available data sources on indicators for the region (e.g. FAOSTAT for crop yield). The type of function determines the translation of scores on indicators into normalized values of cost or benefit on a scale of 0 to 1. For example, for the indicator ‘crop yield’, a non-linear value function was chosen, based on the supposition that growth in height does not translate directly into yield. But for the indicator ‘irrigation use efficiency’ a linear value function was chosen to express that an increase in irrigation use efficiency immediately translates in a benefit. Details on the configuration of the performance indicators are given in Appendix I for Alicante region, and in Appendix II for Kharkiv region.

Stakeholders were asked to assign importance to all key performance indicators, but scores for a selection of indicators only were available (Table 4-3 and). In order to run the MODSS, scores must be available for each indicator. For Alicante region, Spain, the analysis was limited to the results of all six water saving strategies based on the restricted set of indicators for which scores are available for all strategies are available. For the Kharkiv region, Ukraine, for none of the indicators all scores were available. A set of indicators was selected with in each group scores available for at least one relevant indicator (e.g. crop yield in the group of economic indicators). This set was complete for strategies S2, S3 and S4.

Table 4-3 Availability of scores on performance indicators for the multi-criteria analysis on the dataset of Alicante, Spain. Non-shaded indicators were available for all strategies tested.

Nr	Indicator	Available in analysis
EC-1	Crop yield in treated area	
EC-2	Farm Gross Margin	
EC-3	Irrigation use efficiency	
EC-4	Water use efficiency	
EC-5	Total Available Water	
EC-6	Green water use efficiency	
EC-7	Establishment costs	
EC-8	maintenance costs	
EC-9	subsidy (or production aid)	
ENV-1	Soil water repellency	
ENV-2	Soil structural stability	
ENV-3	Bulk density	
ENV-4	Heavy metal content	
ENV-5	soil alkalinity	
ENV-6	soil salinity	
ENV-7	Soil organic matter content	
SOC-1	legal restrictions	
SOC-2	education and training of farmers	
SOC-3	acceptability of using waste water for irrigation	
SOC-4	historical adoption of new technologies	
SOC-5	likelihood of adoption of new technologies from Water Reuse	
SOC-6	incentives required to change behaviour	
SOC-7	farmer health and safety	

Table 4-4 Availability of scores on performance indicators for the multi-criteria analysis on the dataset of Kharkiv region, Ukraine. Non-shaded indicators were available for selected strategies S2, S3 and S4.

Nr	Indicator	Available in analysis
EC-1	Crop yield in treated area	
EC-2	Farm Gross Margin	
EC-3	Irrigation use efficiency	
EC-4	Water use efficiency	
EC-5	Total Available Water	
EC-6	Green water use efficiency	
EC-7	Establishment costs	
EC-8	maintenance costs	
EC-9	subsidy (or production aid)	
ENV-1	Soil water repellency	
ENV-2	Soil structural stability	
ENV-3	Bulk density	
ENV-4	Heavy metal content	
ENV-5	soil alkalinity	
ENV-6	soil salinity	
ENV-7	Soil organic matter content	
SOC-1	legal restrictions	
SOC-2	education and training of farmers	
SOC-3	acceptability of using waste water for irrigation	
SOC-4	historical adoption of new technologies	
SOC-5	likelihood of adoption of new technologies from Water Reuse	
SOC-6	incentives required to change behaviour	
SOC-7	farmer health and safety	

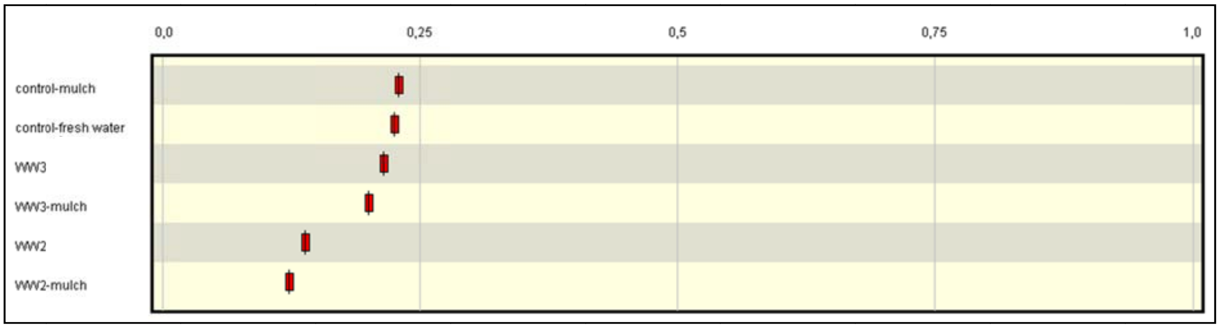
4.3 Results for Alicante region, Spain

4.3.1 Scores of water saving strategies on performance indicators (step b)

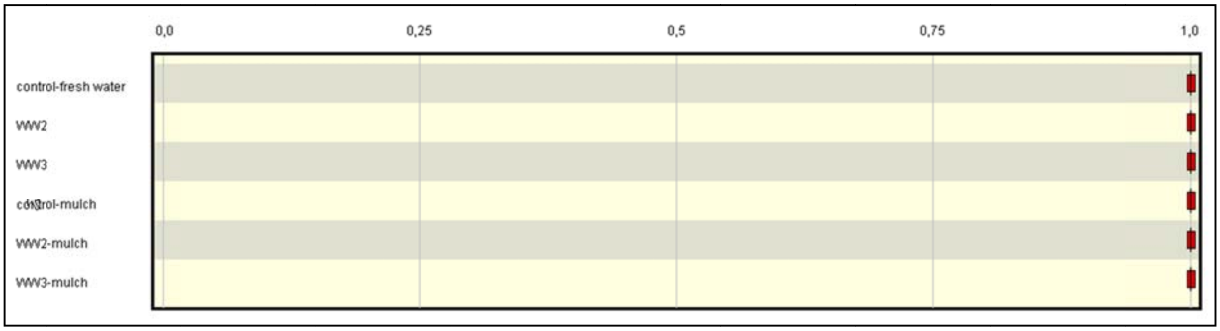
The scores of the water saving strategies on the performance indicators (step b in the set-up of the MODSS) are displayed in Figure 4-2. The scores are normalized to values between 0 and 1 based on the minimum and maximum values entered in the MODSS for each indicator. For each indicator, the water saving strategies are ordered from top to bottom according to their score on that indicator.

The scores on plant height are low for all strategies (<0.25) due to the small age of the vine grapes in the field experiment (first year of harvest). For soil water repellency, the scores for each strategy are maximal, indicating that soil water repellency was not observed in the field experiments.

Plant height

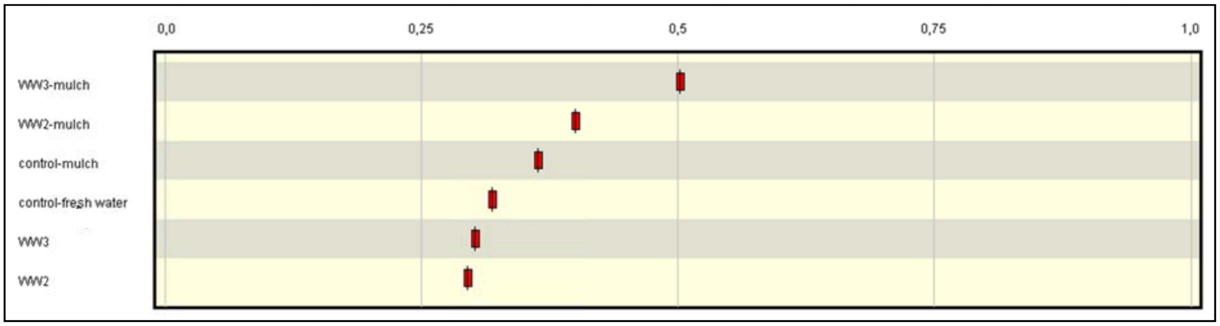


Soil water repellency

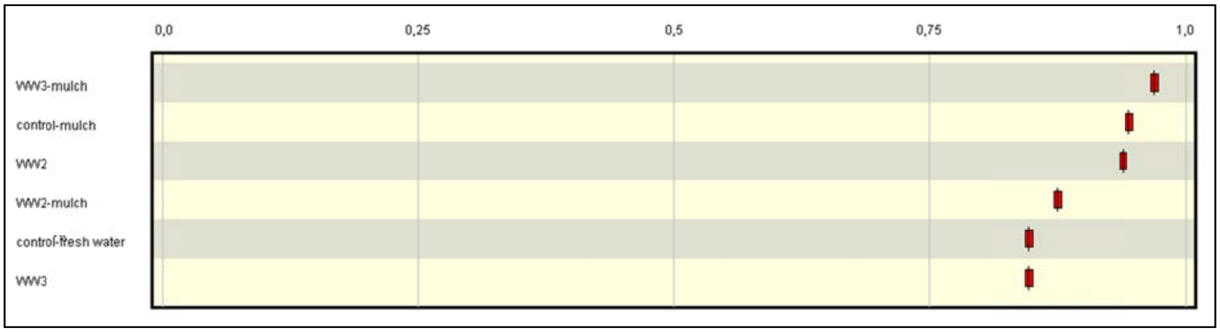


The soil structural stability was highest for the water saving strategies using mulch, indicating that mulch is a good strategy to maintain the structural stability of the soil surface. Without mulch, fresh water ensures a better stability of the soil surface than wastewater. The scores on secondary treated wastewater (WW2) are smaller than for tertiary treated wastewater due to the high content of salts in the wastewater from the secondary treatment. The water saving strategies had high scores on soil bulk density, indicating that this indicator was not negatively affected by any of the strategies.

Soil structural stability

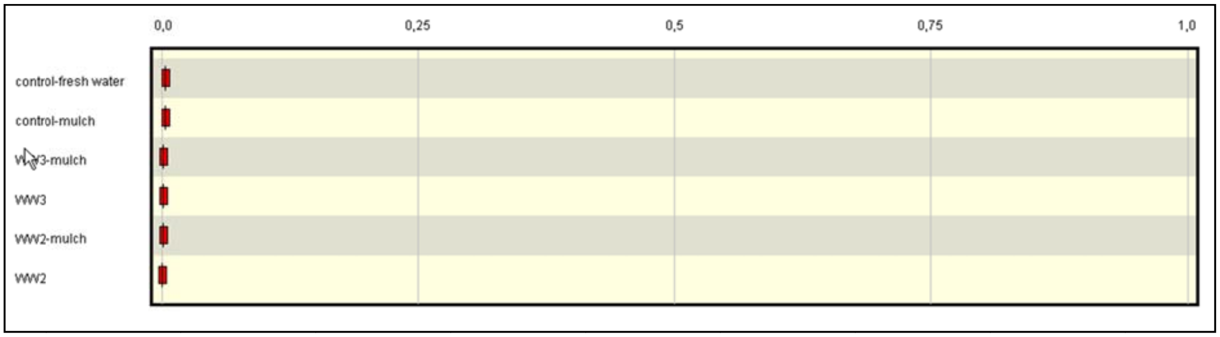


Bulk density

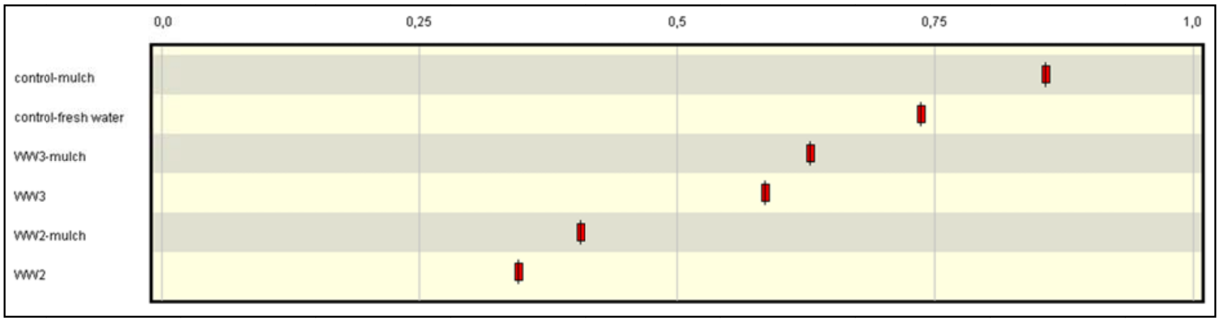


The water saving strategies had low scores on soil alkalinity, due to the fact that no significant effect of the water saving strategies on the pH of the soil solution was observed. Soil salinity in contrast was strongly increased by the use of wastewater, especially from secondary treatment, due to the high salt content.

Soil alkalinity

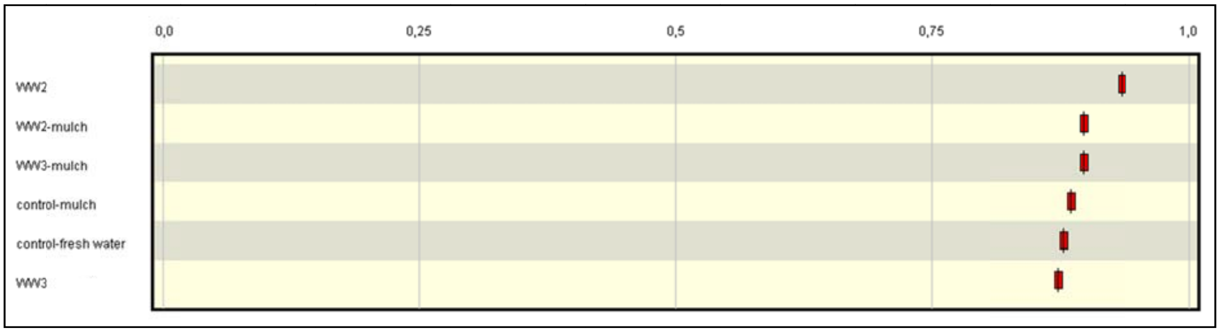


Soil salinity



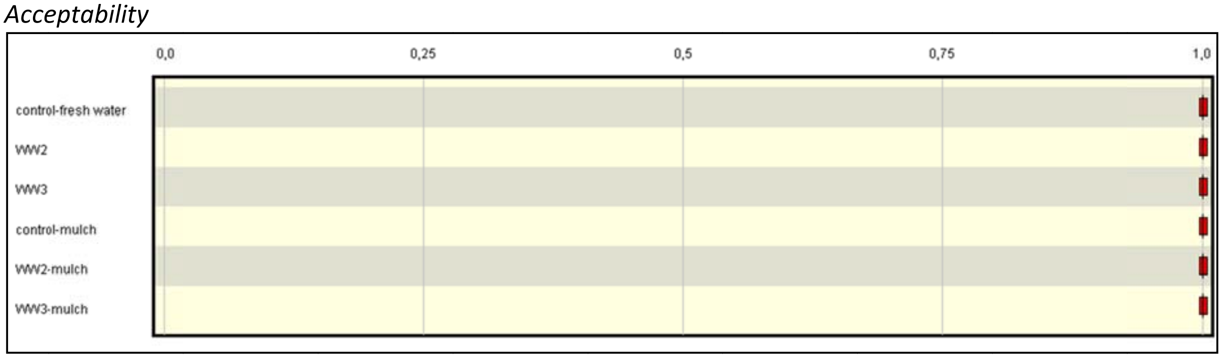
The high scores on soil organic matter for all water saving strategies indicate that soil organic matter was not negatively influenced by the strategies, and even improved by the use of wastewater compared to fresh water.

Soil organic matter

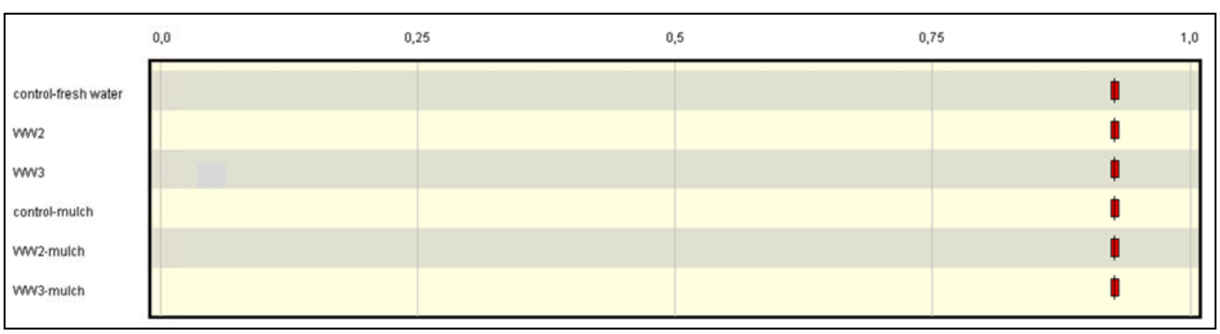


All water saving strategies scored high on the acceptability of the strategies, the historical adoption of similar new technologies in the area, the likelihood that the strategy would be adopted in the area, farmer health and safety and the number of legal restrictions applicable to water saving strategies. This indicates that the socio-cultural setting of the Alicante province offers a potentially receptive environment for the tested water saving strategies. However, the level of incentives required to change current land users' behavior and practice in water management was observed to be high (low score of performance) for all water saving strategies. This indicates that although the socio-economic context may be suitable for the strategies, the process of governance in the region to enable adoption of the strategies would require due attention.

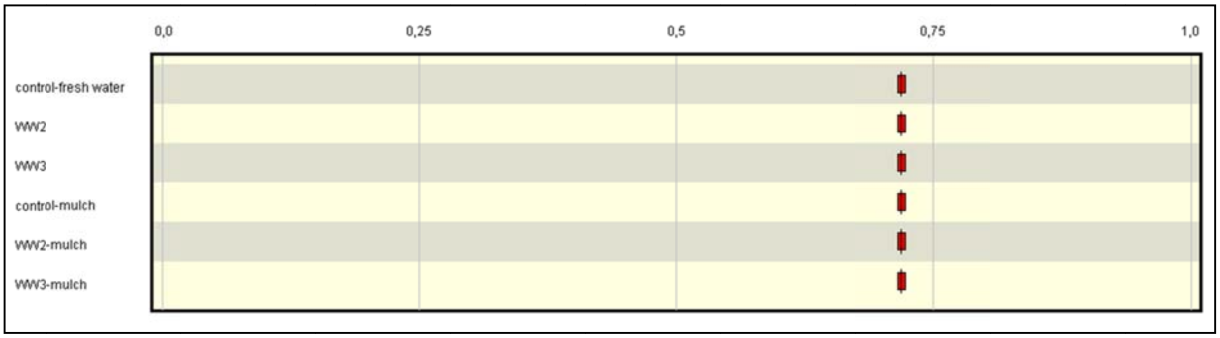
Acceptability



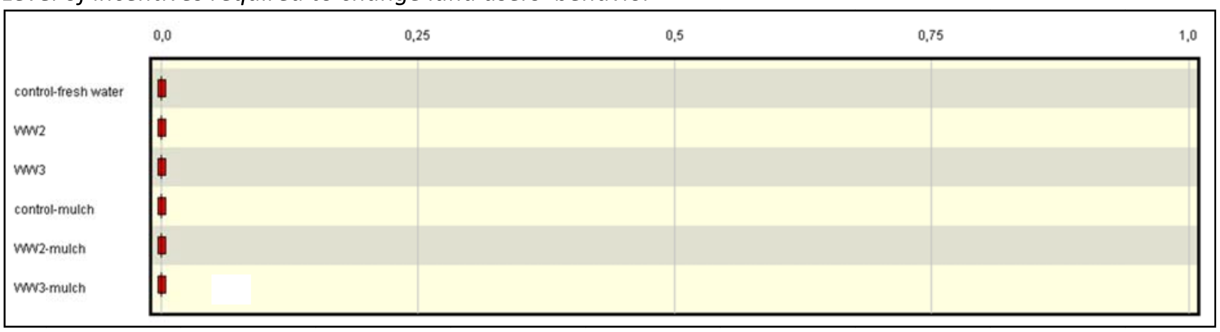
Historical adoption of new technologies in the area



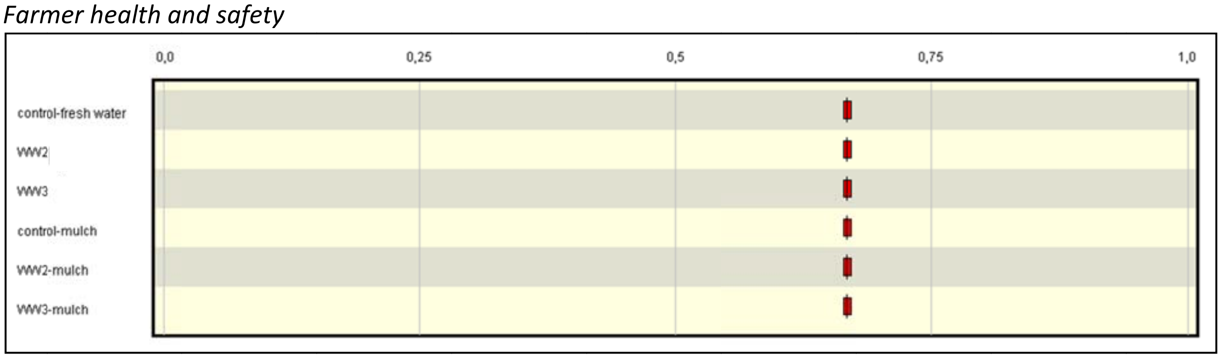
Likelihood of adoption of strategies from Water Reuse



Level of incentives required to change land users' behavior



Farmer health and safety



Legal restrictions

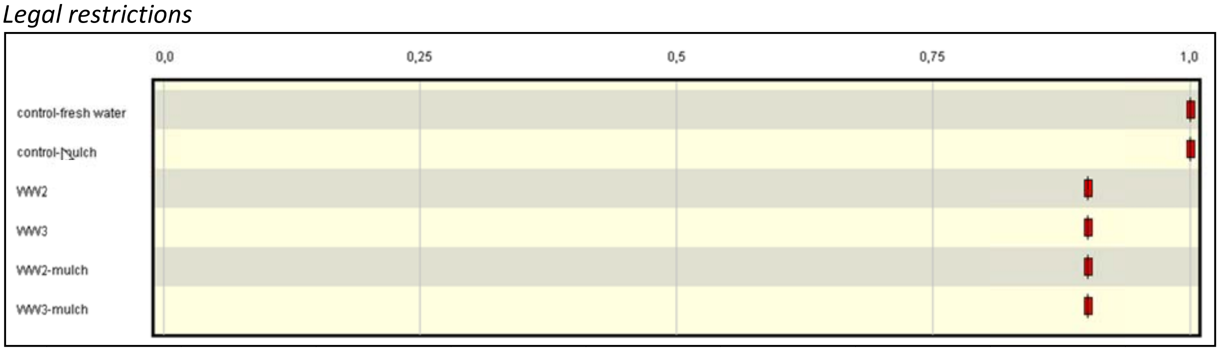


Figure 4-2 Scores of water saving strategies on performance indicators.

4.3.2 Stakeholder ranking of performance indicators and multi-criteria analysis (step c)

This paragraph describes the stakeholders' perception of the importance of the various performance indicators listed, in other words: what the different stakeholder groups think are the most important criteria to look at in evaluating different strategies.

On one hand this shows that it matters who you ask to evaluate certain strategies; one group has different criteria than another group might have. On the other hand, it also shows that in order to come to a balanced choice of a certain strategy, not only the physical performance of a strategy should be evaluated, but also consensus should be reached among all people involved in implementing certain strategies.

The relevant stakeholder groups for water saving strategies in Alicante province are mentioned in Table 4-5, together with the number of representatives consulted. The number of representatives consulted is low, because a formal stakeholder consultation was not the intention of the Water Reuse project, which was more directed to the experimental investigation of biophysical effects of water saving strategies. Scores of representatives from the same stakeholder group were averaged.

Table 4-5 Relevant stakeholder groups for water saving strategies in Alicante province and number of representatives.

Stakeholder group	Nr of representatives
farmers' organizations	2
land users	1
public management water enterprise	3
industry	1
educators	1

The ranking of indicators by the stakeholder groups is illustrated in the form of hierarchical trees (e.g. Figure 4-3). The higher the vertical position of an indicator in the ranking tree, the larger their importance according to the stakeholder groups. Indicators connected by a blue bracket have the same importance.

The ranking of indicators and resulting evaluation of water saving strategies are given below for each stakeholder group.

Farmers' organizations

The representatives from farmer organizations ranked crop yield (represented by plant height) and the level of incentive required to change farmers' behavior with regard to water management as the most important criteria for the adoption of water saving strategies in the area (Figure 4-3). Environmental criteria related to water and soil were ranked in intermediate positions. Socio-cultural criteria were attributed less importance, except legal restrictions.

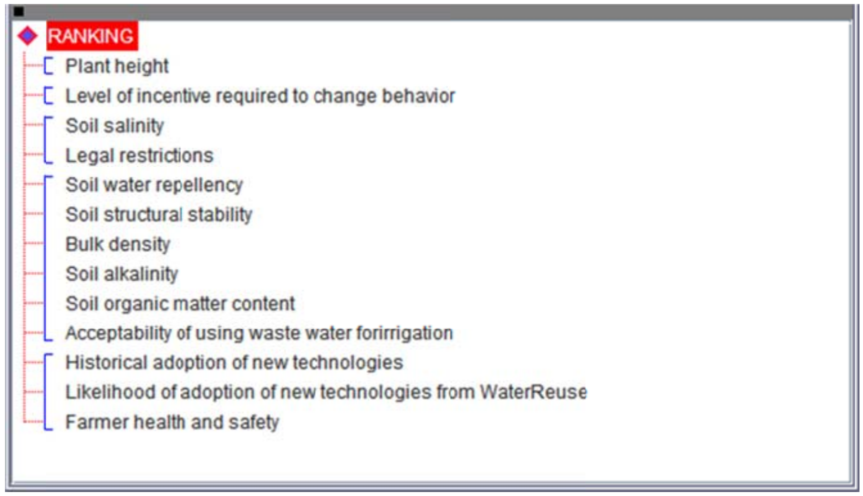


Figure 4-3 Ranking of indicators of water saving strategies in Alicante province by farmer organizations.

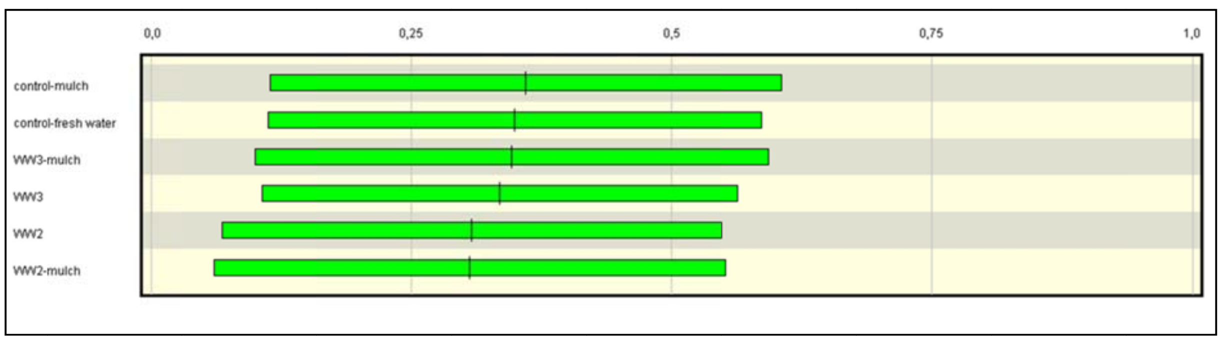


Figure 4-4 Identification of preferred water saving strategies from the viewpoint of farmers' organizations in Alicante province, Spain. Control: irrigation with fresh water; WW2: irrigation with wastewater from secondary treatment; WW3: irrigation with wastewater from tertiary treatment.

Based on the scores of the water saving strategies on the criteria, and the assignment of importance to the decision criteria from the point of view of the representatives of the farmers' organizations, the performance of the strategies shows little differentiation (Figure 4-4). The length of the bars indicates that there is a large uncertainty in the composite scores on each of the strategies, depending on the ordering of the criteria as expressed by the farmers' organizations. This implies that the ranking of the strategies is rather sensitive to the ordering of the criteria.

The strategies using fresh water perform slightly better than the strategies using waste water. In interpreting this result, one should realize that only one economic criterion was included in the evaluation matrix (plant height, as a substitute for crop yield). The economic criteria indicating monetary effects of the strategies, like farm gross margin, establishment costs, maintenance costs and subsidy (or production aid) were not included in the evaluation matrix, because data were not available. Though irrigation with reclaimed waste water is still faced with a number of technical, social, regulatory and institutional challenges, there are numerous examples of the potential economic benefits and financial performance of using waste water in irrigated agriculture (e.g. Lazarova and Bari, 2005; Scott et al., 2004).

Therefore it is likely that inclusion of these criteria may result in a better performance of the strategies using waste water.

While the use of mulch is able to increase the performance of the strategies using fresh water and wastewater from tertiary treatment, it did not improve the performance of the strategy using wastewater from secondary treatment. The field trials showed that the use of mulch improved the aggregate stability of the soil significantly when waste water from a secondary treatment was used. It is possible that the lower performance of the strategy using mulch and wastewater from a secondary treatment is due to the high assignment of importance to the soil salinity indicator (3^{rd} rank, Figure 4-3), which has low scores for the strategy using secondary treated waste water (Figure 4-2).

Land user

The land user ranked almost all socio-cultural criteria as the most important for the adoption of water saving strategies in the region (Figure 4-5). Indicators of soil fertility (soil organic matter content) and soil alkalinity, soil salinity and soil water repellency were judged equally important.

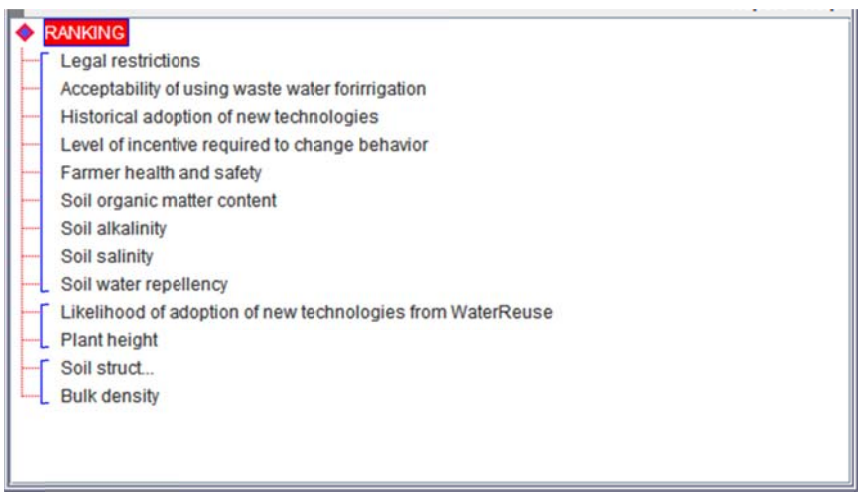


Figure 4-5 Ranking of indicators of water saving strategies in Alicante province by a land user.

The difference between alternatives in their performance according to the representative of the land users group is not large (Figure 4-6), though the outcomes are less sensitive to the ranking of criteria than for the representatives of the farmers' organizations. The strategies using fresh water (control) have the highest score for performance according to the land user, followed by the strategies using waste water from a tertiary treatment. The strategies using waste water from a secondary treatment have the lowest score for performance. This is probably due to their negative effect on the soil salinity indicator through the high electric conductivity of the water. The use of mulch improves the performance of strategies with each type of water.

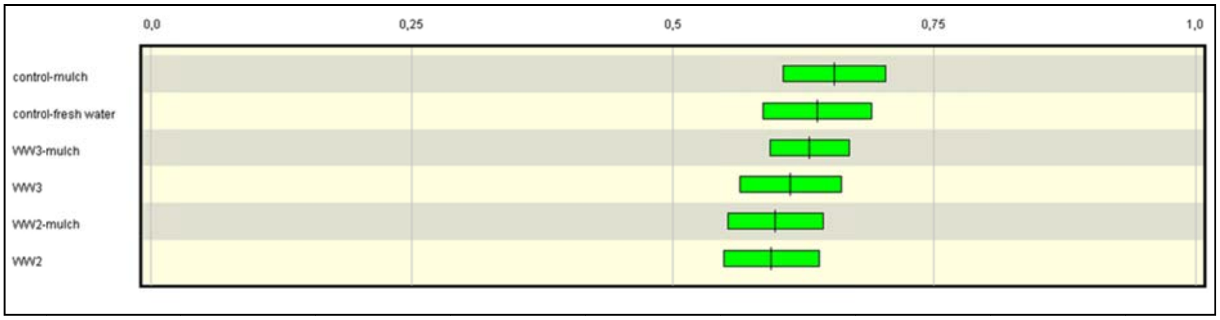


Figure 4-6 Identification of preferred water saving strategies from the viewpoint of a land user in Alicante province, Spain. Control: irrigation with fresh water; WW2: irrigation with wastewater from secondary treatment; WW3: irrigation with wastewater from tertiary treatment.

Public management water enterprise

Two respondents from a public management water enterprise provided their ranking of the decision criteria. They ranked acceptability of using waste water for irrigation as the most important criterion for the successful introduction of water saving strategies in the region, followed by the historical adoption of new technologies and the soil quality related indicators. All other socio-cultural indictors were attributed less importance. Also, crop yield as an economic indicator was assigned less importance.

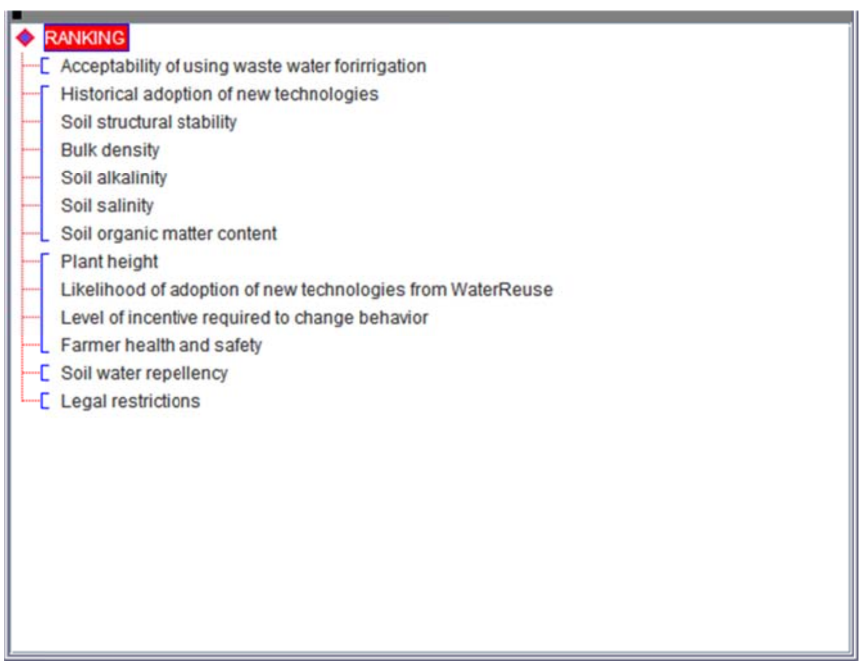


Figure 4-7 Ranking of indicators of water saving strategies in Alicante province by a public water management enterprise.

The results of the multi-criteria analysis show that the water saving strategies differ only slightly in performance based on the scores and the ranking of indicators by the public water management enterprise, given the slight difference in mean scores and their large sensitivity to the ranking of indicators, as expressed by the width of the bars. The strategies using mulch have the highest mean scores. Strategies using fresh water rank slightly higher than those using waste water.

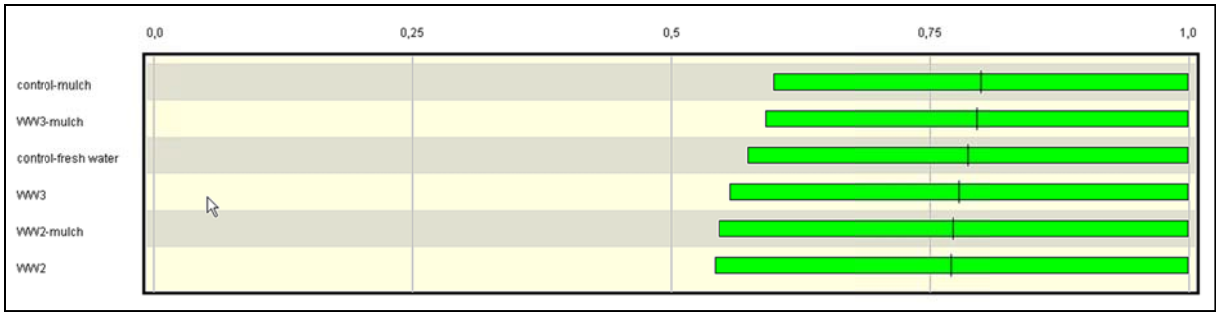


Figure 4-8 Identification of preferred water saving strategies from the viewpoint of a public water management enterprise in Alicante province, Spain. Control: irrigation with fresh water; WW2: irrigation with wastewater from secondary treatment; WW3: irrigation with wastewater from tertiary treatment.

Industry

The representative of the agro-industry assigned the highest importance to a combined set of economic, environmental and socio-cultural indicators (Figure 4-9). Legal restrictions were assigned the lowest importance, in contrast to the ranking assigned by the land user. This may indicate that legal restrictions to the use of waste water do not affect the agro-food industry in the region.

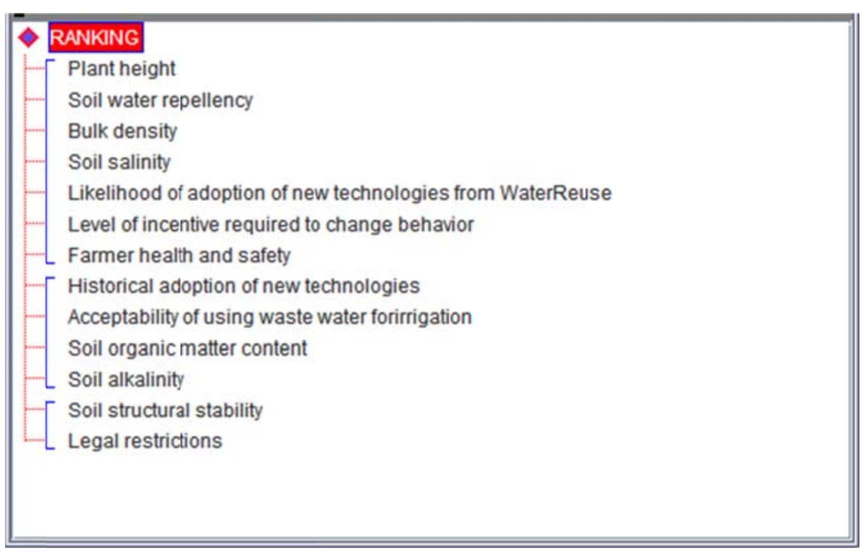


Figure 4-9 Ranking of indicators of water saving strategies in Alicante province by an industrial enterprise.

The strategy using fresh water for irrigation and mulch performed best according to the ranking of decision criteria by the representative of the industry, followed by the strategy using waste water from a tertiary source and mulch, and the strategy using fresh water for irrigation (Figure 4-10). The strategies using secondary treated waste water had the lowest scores. The scores are not very sensitive to the ranking of criteria compared to the scores from the viewpoint of the farmers' organization and the public management water enterprises. Mulch does not increase the overall performance of the water saving strategy in this case.

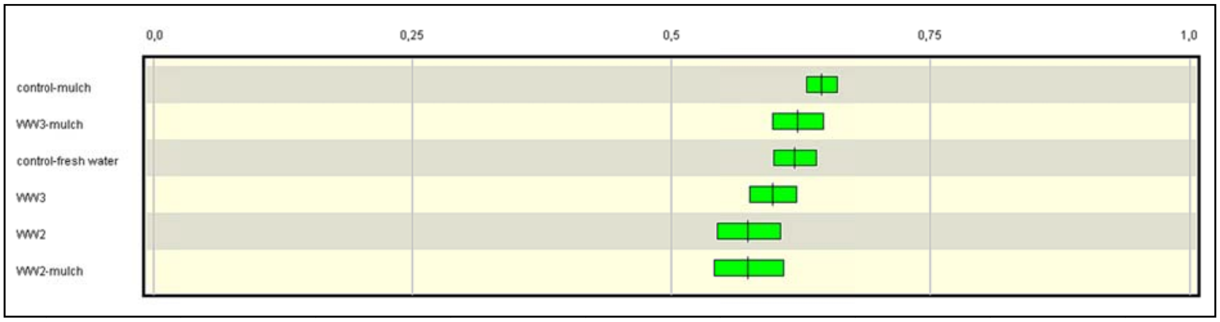


Figure 4-10 Identification of preferred water saving strategies from the viewpoint of an industrial enterprise in Alicante province, Spain. Control: irrigation with fresh water; WW2: irrigation with wastewater from secondary treatment; WW3: irrigation with wastewater from tertiary treatment.

Educator

From the viewpoint of the representative of education, a combination of economic, environmental and socio-cultural indicators is most important to the successful introduction of water saving strategies in the region (Figure 4-11). Indicators related to physical and chemical soil quality are assigned little importance, except for soil alkalinity and soil salinity. Farmer health and safety is not considered an important factor for introducing water saving strategies using waste water according to the educator.

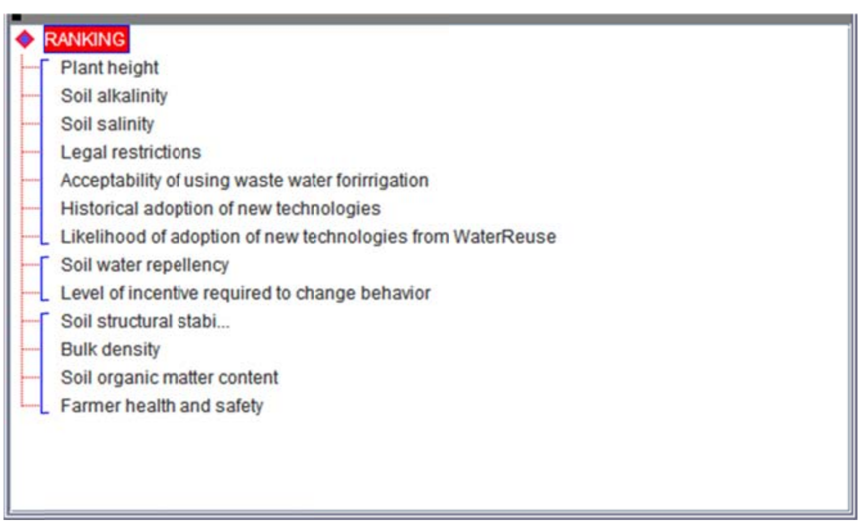


Figure 4-11 Ranking of indicators of water saving strategies in Alicante province by an educator.

Based on the scores of the water saving strategies on the performance criteria, and the ranking of the criteria from the viewpoint of the educator, the strategies using fresh water for irrigation perform best for the region (Figure 4-12). The strategies using waste water from a secondary treatment perform worst. Mulch increases the performance of each water type.

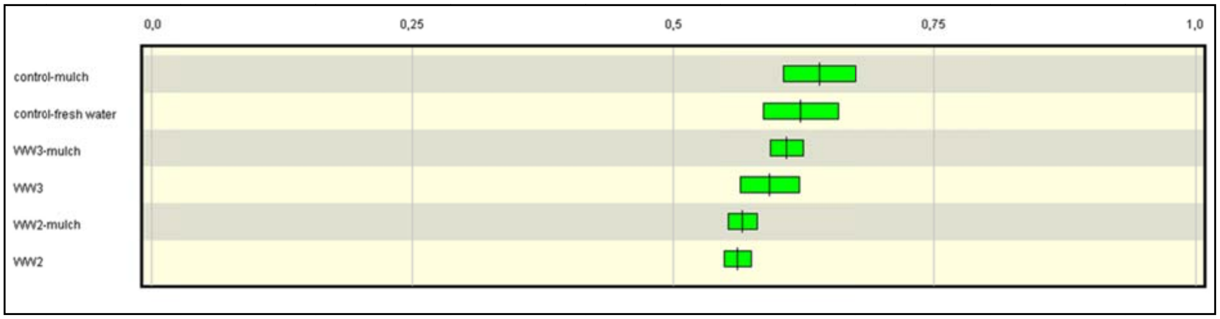


Figure 4-12 Identification of preferred water saving strategies from the viewpoint of an industrial enterprise in Alicante province, Spain. Control: irrigation with fresh water; WW2: irrigation with wastewater from secondary treatment; WW3: irrigation with wastewater from tertiary treatment.

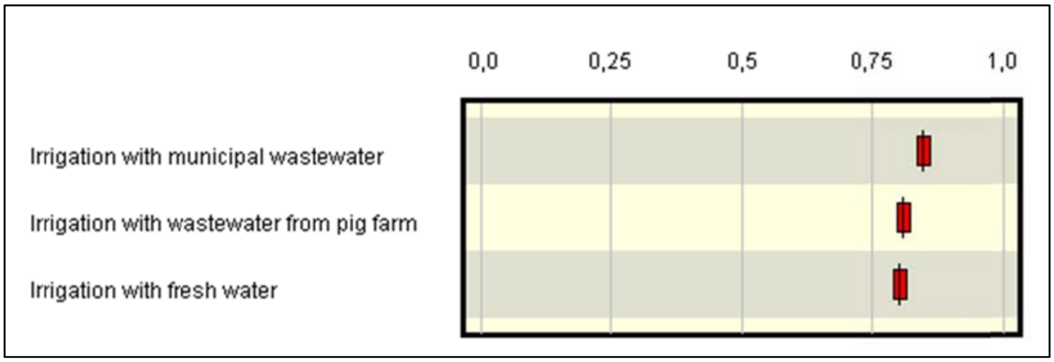
4.4 Results – Kharkiv region, Ukraine

4.4.1 Scores of water saving strategies on performance indicators (step b)

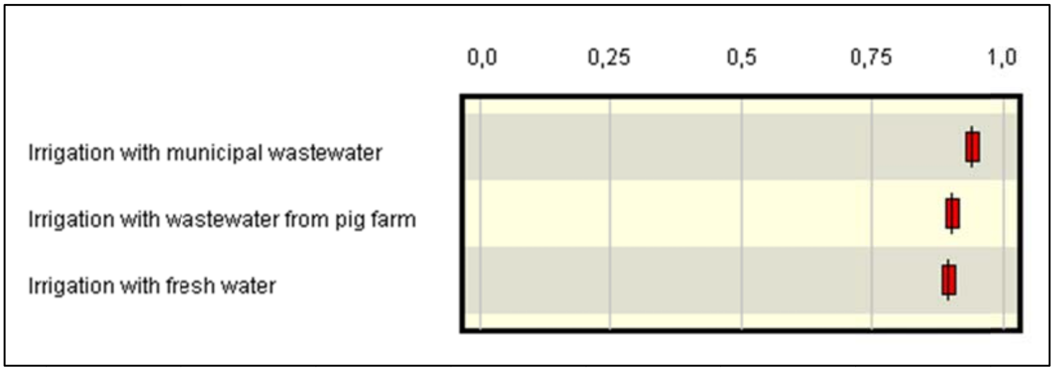
The scores of the water saving strategies on the performance indicators (step b in the set-up of the MODSS) are displayed in Figure 4-2. The scores are normalized to values between 0 and 1 based on the minimum and maximum values entered in the MODSS for each indicator. For each indicator, the water saving strategies are ordered from top to bottom according to their score on that indicator.

In the group of economic indicators, the scores on crop yield and irrigation use efficiency are slightly higher for the strategies using wastewater for irrigation than the freshwater strategy, suggesting a slightly better performance (Figure 4-13). However, it should be noted that the scores on both indicators are already high compared to the reference values for crop yield for Ukraine used for all strategies, including the use of fresh water for irrigation. For maintenance costs, the strategy using fresh water for irrigation had the best score, due to the lower maintenance costs involved. The higher costs for the strategies using wastewater relate to the lack of maintenance and investment in infrastructure due to the economic crisis following the transition from the Soviet regime to a market economy.

Crop yield



Irrigation use efficiency



Maintenance costs

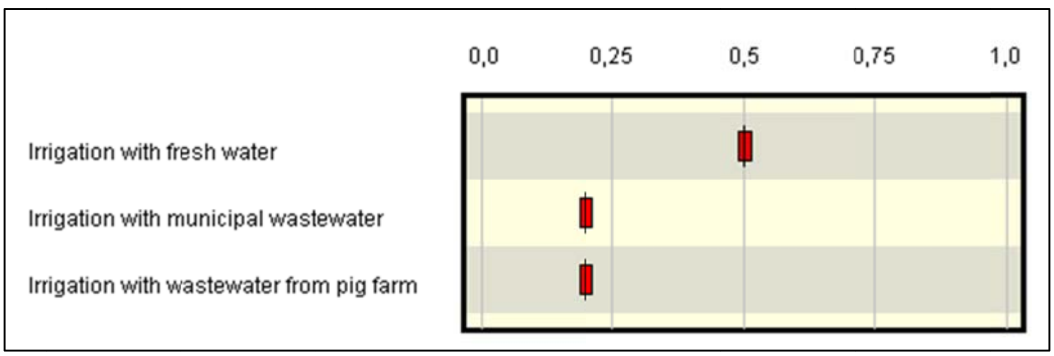
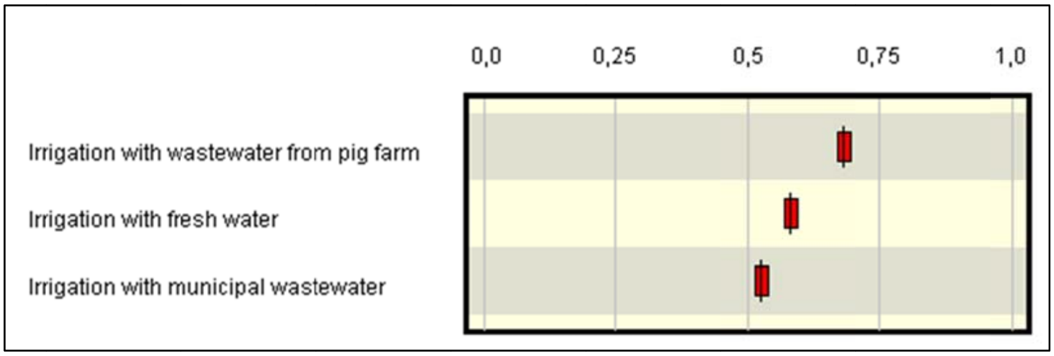


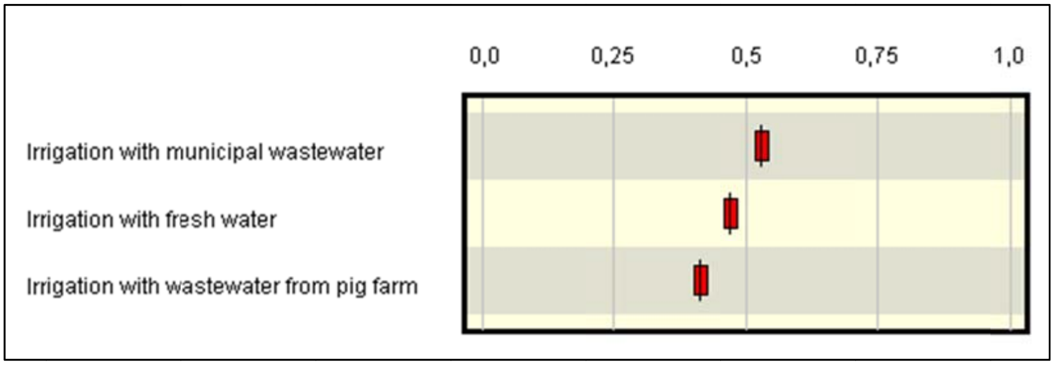
Figure 4-13 Scores of water saving strategies on economic performance indicators.

The strategy using wastewater from a pig farm for irrigation performed best with respect to the environmental performance indicator bulk density, followed by the strategy using fresh water and the strategy using municipal wastewater (Figure 4-14). This effect is not related to the organic matter content of the wastewater, since the strategy using wastewater from the pig farm had the lowest score on soil organic matter content.

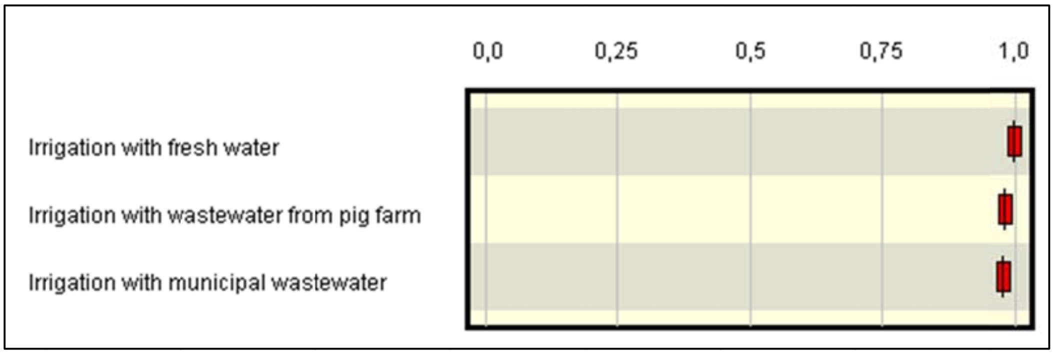
Soil bulk density



Soil organic matter content



Soil alkalinity



Soil salinity

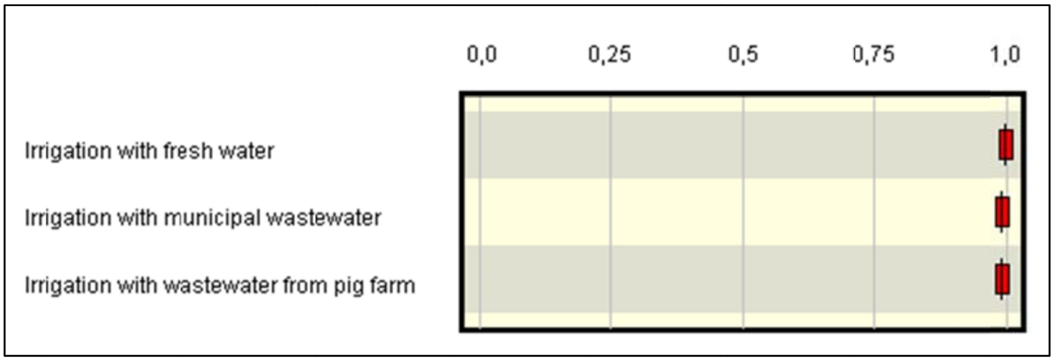


Figure 4-14 Scores of water saving strategies on environmental performance indicators.

The performance of water saving strategies was comparably good with respect to the environmental indicators soil alkalinity and soil salinity, with high scores for all three strategies. This proved that the use of wastewater from either source did not result in increased pH or salt concentrations of the soil solution compared to the use of fresh water.

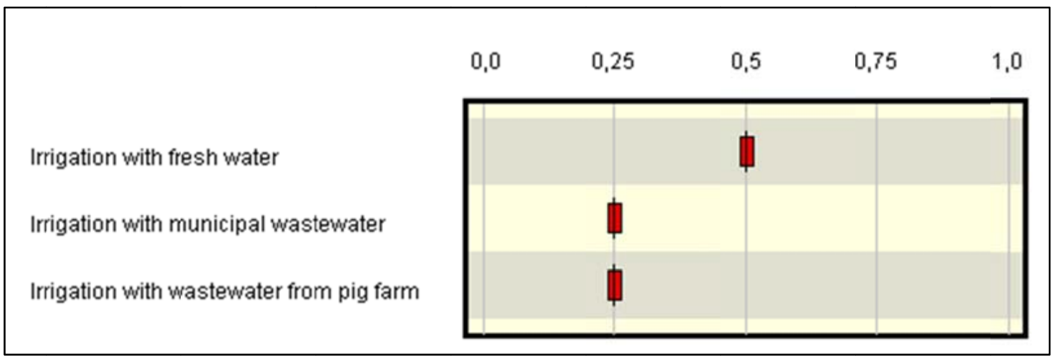


Figure 4-15 Scores of water saving strategies on the socio-cultural performance indicator 'legal restrictions'.

The scores on the performance indicator 'legal restrictions' are lower for the water saving strategies using wastewater for irrigation, due to the larger number of legal restrictions operative. This is a limiting factor for the adoption of irrigation of wastewater by land users.

4.4.2 Stakeholder ranking of performance indicators and multi-criteria analysis (step c)

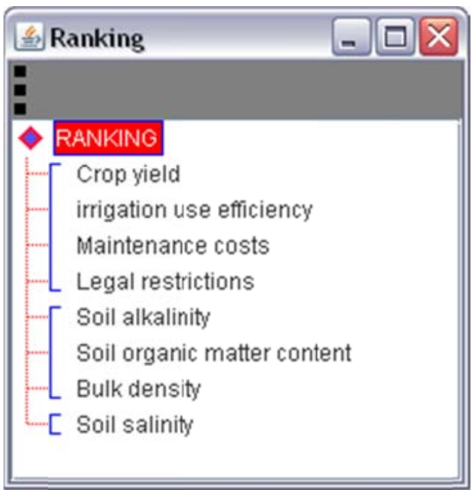
The relevant stakeholder groups for water saving strategies in Kharkiv region are mentioned in Table 4-5, together with the number of representatives consulted. The number of representatives consulted is low, because a formal stakeholder consultation was not the intention of the Water Reuse project, which was more directed to the experimental investigation of biophysical effects of water saving strategies. Scores of representatives from the same stakeholder group were averaged.

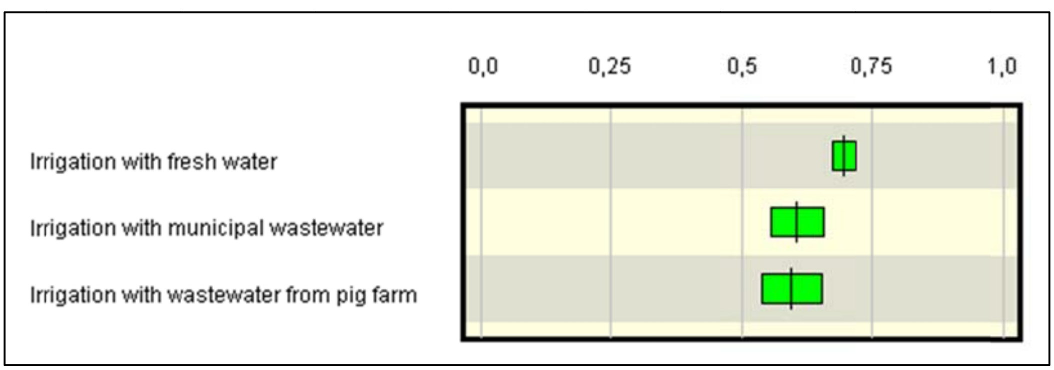
Table 4-6 Relevant stakeholder groups for water saving strategies in Alicante province and number of representatives.

Stakeholder group	Nr of representatives
Agricultural advisor/consultant	3
Water supplier	1
Water authority	1

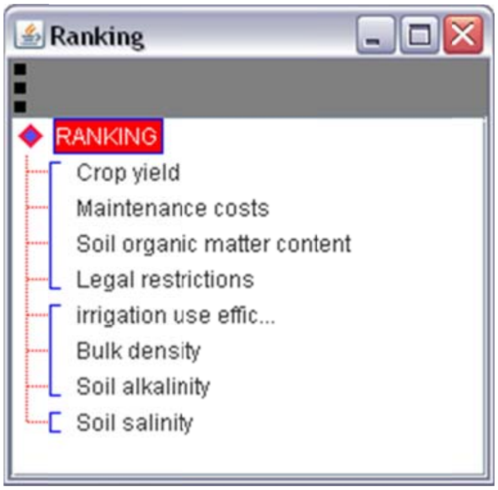
The ranking of indicators and resulting evaluation of water saving strategies are given below for each stakeholder group.

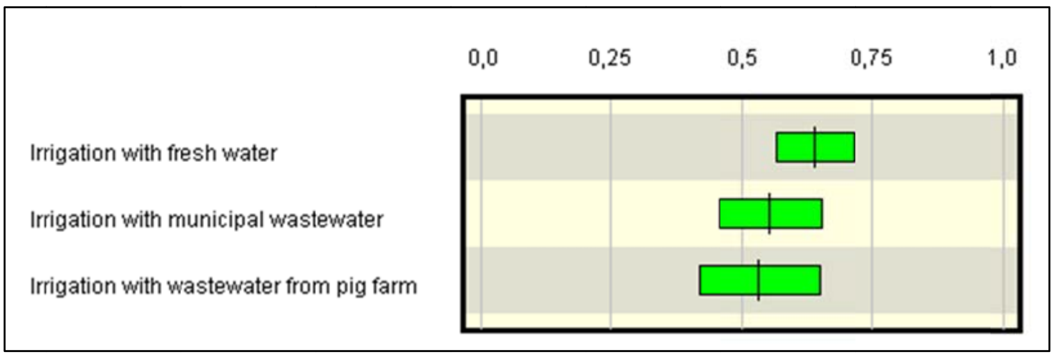
Agricultural advisor/consultant



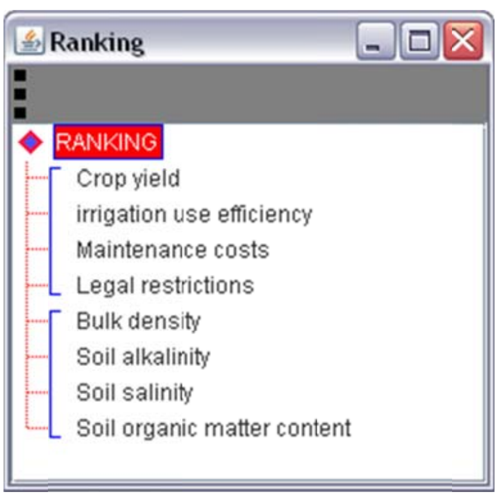


Water supplier





Water authority



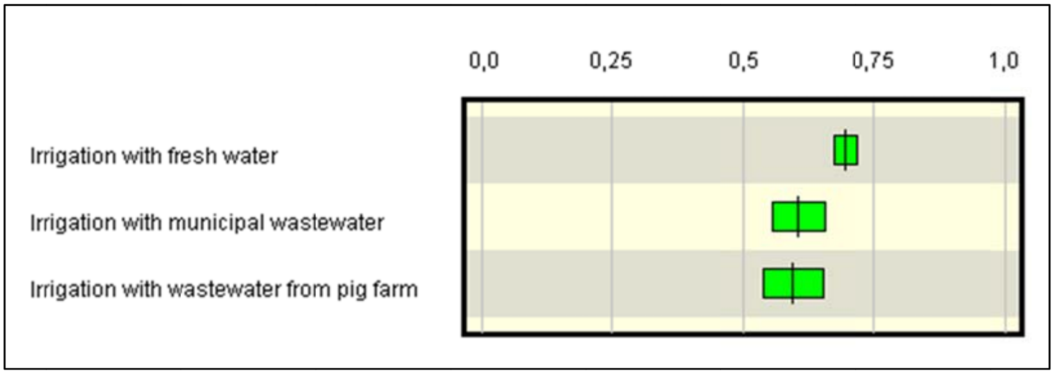


Figure 4-16 Ranking of performance indicators by stakeholder groups and composite scores of water saving strategies on indicators.

All stakeholder groups ranked the indicators crop yield, maintenance costs and legal restrictions as the most important indicators hindering or enabling the adoption of water saving strategies in the region. Due to the significantly better performance of the strategy using fresh water for irrigation on maintenance costs and legal restrictions, this explains why, based on the scores of the strategies on the indicators, and the ranking of the importance of the indicators by the stakeholder groups, the strategies using wastewater perform worse than the strategy using fresh water for irrigation. This slightly higher performance of the strategies using wastewater with regard to the indicators crop yield and irrigation use efficiency are not sufficient to off-set the lower performance of these strategies on maintenance costs and legal restrictions. In other words, although the use of wastewater was shown to be able to increase the crop yield and efficiency of irrigation water use, the costs for maintenance and the number of legal restrictions still too high to suggest the use of wastewater as a preferred management option.

4.5 Discussion

The performance of water saving strategies tested in the Water Reuse project was evaluated in a vine growing area in Alicante, Spain, and a region with winter wheat in Kharkiv region, Ukraine, using fresh water and waste water from secondary and tertiary treatments, a pig farm and municipal wastewater in combination with mulching, based on results from field experiments and a socio-economic survey among various stakeholder groups. The performance was measured for economic, environmental and socio-cultural indicators selected based on literature research and expert judgment.

The results of the multi criteria analysis for Alicante region, Spain, show that the water saving strategies differed only slightly in their performance with regard to the selected economic, environmental and socio-economic criteria. The strategy using fresh water and mulch obtained the highest overall performance score based on the experimental results and the assignment of importance to the indicators by the different stakeholder groups. The strategies using waste water performed slightly less than strategies using fresh water.

This result may be explained by the overall higher scores of strategies using fresh water on several indicators, which also received high assignments of importance from stakeholders: plant height (as a substitute of crop yield) and soil salinity. For the soil structural stability, bulk density and soil organic matter the strategies using waste water performed better than those using fresh water. The performance of strategies on socio-cultural indicators was equal for all strategies, except for legal restrictions, where strategies using fresh water performed better because no legal restrictions were reported (Figure 4-2).This indicates that the socio-cultural setting of the Alicante province offers a potentially receptive environment for the tested water saving strategies. However, the level of incentives required to change current land users' behavior and practice in water management was observed to be high (low score of performance) for all water saving strategies. This indicates that although the socio-economic context may be suitable for the strategies, the process of governance in the region to enable adoption of the strategies would require due attention.

The use of mulch in Alicante region, Spain, improved the performance of strategies for fresh water and waste water from a tertiary treatment, but not when waste water from a secondary treatment was used. This is probably due to the low score on this strategy on the soil salinity indicator, resulting from the high electrical conductivity of the waste water from the secondary treatment during some months of the year (2000-2500 µS/cm compared to 500-700 for the control treatment and 1000-1500 µS/cm for the WW3 treatment) (UMH, 2009).

The literature on the use of waste water for irrigation reports many examples of economic benefits and financial performance of using waste water in irrigated agriculture (e.g. Lazarova and Bari, 2005; Scott et al., 2004). The lower performance of strategies using waste water in the test site in Alicante region, Spain, may be firstly explained by the low scores on the indicators of economic performance compared to the maximum potential scores for the region. These are related to the low crop yield in the experiments, and to the lack of data on essential indicators of economic costs and benefits of water saving strategies for the multi-criteria analyses (establishment and maintenance costs, subsidy or production aid). The crop yield was highest under irrigation with fresh water, and lowest under irrigation with waste water from a secondary treatment. However, the differences of means are statistically non-significant according to analysis of variance. The results must be interpreted with care since they were obtained on the first harvest of the grapevines, and the number of plants and grapes were low. The low yield for the waste water from secondary treatment can be explained by the high electrical conductivity, which is known from the literature to have detrimental effects on crop growth (UC, 2002). The low crop yield influenced the scores of the three economic indicators used (crop yield, irrigation use efficiency, water use efficiency).

Secondly, the observation that strategies using fresh water perform slightly better than the strategies using waste water for the test site in Spain should be considered in view of the fact that only one economic criterion was included in the evaluation matrix (plant height, as a substitute for crop yield). The economic criteria indicating monetary effects of the strategies, like farm gross margin, establishment costs, maintenance costs and subsidy (or production aid) were not included in the evaluation matrix, because data were not available. A wider evaluation of economic indicators is required to provide a more balanced assessment of the potential of water saving strategies to meet the objectives of reducing water loss and using alternative water resources for irrigation.

For the Kharkiv region, Ukraine, similar results were obtained in that irrigation with fresh water still outperforms irrigation using wastewater. The reasons however differ from the case in Spain, and relate to the insufficient gain from using wastewater for irrigation in the slightly improved crop yield and irrigation use efficiency to off-set the higher maintenance costs and larger number of legal restrictions associated with wastewater irrigation.

The examples given in this chapter regarding the evaluation of water saving strategies with respect to physical performance and socio-economic criteria, shows that selecting certain strategies based on physical performance alone is not sufficient. The perception of the performance of certain strategies, the social acceptance of these strategies, history of a certain region with regard to acceptance of land management changes, trust of authorities, are just as or perhaps even more important factors determining the success of implementation than the physical performance of a certain strategy alone. This conclusion should be taken into account when looking for solutions for improving irrigation efficiency in agriculture.

Many studies have already addressed combinations of technical and socio-economic, quantitative and qualitative methods in studies on irrigation management, but there is a need for frameworks leading to concrete formulations of recommendations. Such frameworks are available in for example the DESIRE decision support system for sustainable land and water management (Schwilch et al., 2009) and the Sustainable Livelihoods Approach, which was proposed for wastewater management by Buechler(2004). In the DESIRE decision support system, stakeholders and researchers together identify, document and evaluate and negotiate strategies for sustainable land and water management. The system uses the Learning for Sustainability approach, the WOCAT questionnaires for Technologies and Approaches (WOCAT 2008; www.wocat.net), and the multi-objective decision support system that was also used in this study. The Sustainable Livelihoods Approach (DFID, 2003, in: Buechler, 2004) is actor-centered, multi-disciplinary and oriented towards change. It puts a focus on actors involved in irrigation (or wastewater) management at various levels, thereby generating knowledge tailored to the needs of different stakeholders and institutions using and managing irrigation or wastewater, and to the different contexts of irrigated agriculture. The approach considers livelihood assets (human, natural, financial, social and physical) in a context of vulnerability (due to for example shocks, trends of seasonality). Policies, institutions and processes influence the vulnerability context and the livelihood assets, and result in strategies, like the ones proposed in the Waterreuse project. The strategies in turn determine the outcomes for livelihoods, which again influence and provide access to the livelihood assets.

5 Prospects of water saving strategies in terms of human-environmental conditions

5.1 General human-environmental conditions sketching prospects for water saving strategies

The Water Reuse project was motivated by the growing imbalance over the past decades between water demand and water availability in the agricultural sector in the regions of the Mediterranean and NIS countries studied. The imbalance is driven by different factors in the studied regions. In the regions in Russia and Ukraine, the increasing dependency on irrigation of the agricultural sector is an important driver, while at the same time the capacity of existing irrigation systems has been deteriorating, and the institutional framework is in transition to be re-equipped to improve the situation. Populations are stable or declining in these regions. The introduction of water saving strategies in these regions could give an impetus to the renewed development of the agricultural sector and to increasing economic development and repopulation.

In Spain, climate change and an increasing demand for water from an increasing population, a substantial agricultural export market (Spain is Europe's largest producer and exporter of oranges and mandarins) and the growing tourism sector is driving an increasing water scarcity. The national and regional governments are active in setting up programs to guarantee the availability and the quality of water in the regions, including innovative technologies. In Greece, the irrigated area is expanding, and water scarcity is expected in the 21st century due to increased demands from various economic sectors and climate change, especially in coastal zones.

Individuals and groups are the most likely types of land owners or land users to be targeted in initiatives to introduce water saving strategies in the studied regions. Of the individuals and groups having access to the land (i.e. having land use rights), communal, leased and individual land use rights prevail in the study regions, implying that both organizations and individual land users should be involved in water management programs aimed at the introduction of water saving strategies. Land use rights are most diversified in Spain and Ukraine, whereas in Russia and Greece one type of land use rights is dominant. The groups having access to the land may include either communities or cooperatives. With regard to the individual types of land users likely to implement the water saving strategies, irrigation scheduling can be implemented by any type of land user, independent of the size of the enterprise. Irrigation with waste water is restricted to medium and large scale land users in Spain and Ukraine. Explanations are high initial capital costs for constructing the wastewater treatment and delivery system and the absence of water pricing systems providing incentives for the use of wastewater in irrigated agriculture. In Russia, irrigation with wastewater is potentially implemented only by small-scale land users, because due to land privatization, they do not have access to fresh water transportation channels, in contrast to large and medium-scale land users. Apart from that, the quantities of treated wastewater from municipal sources currently available in the region are not high enough to encourage large- and medium-scale land users to build infrastructure for transport and storage.Mulching can be applied by small- and medium-scale land users.

Land ownership (or the type of land possession) varies widely between the study regions, indicating that the introduction of water saving strategies must be fine-tuned to address many different land owners. Types of land possession are most varied in the Russian Federation.

In identifying target groups of land users for the introduction of water saving strategies, not necessarily the wealthiest land users need to be addressed as the most likely to be willing and able to adopt water saving strategies. In the Water Reuse project, it was found that land users likely to apply water saving strategies belong mostly to the average wealth category, and manage a large part of the agricultural land area. This offers good perspectives for initiatives to introduce water saving strategies in regions similar to the ones tested. An exception is Saratov Region in Russia, where average wealthy land users only manage 5% of the agricultural land. The dependency on off-farm income of land users in Spain may decrease their interest in taking entrepreneurial risks by investing in water saving strategies in agriculture.

The degree of privilege of land users appears not to be very critical to the potential adoption of water saving strategies. The potential use of surfactant in Greece by leading and privileged land users is an exception to this observation, probably due to the fact that many land users are still unaware of the potential of surfactants to improve the wettability of soils. Although the benefits of using surfactants for improving soil wettability have been demonstrated since the 1960s (Morgan et al. 1966, Moore et al. 2010), this obviously calls for better communication and dissemination of experimental evidence of increased water use efficiency and production to land users. The experimental results from the Water Reuse project may be used for this purpose, for example by active dissemination of the extension bulletins in deliverable 28.

Water use rights are essential to developing projects using the strategies based on irrigation scheduling and irrigation with waste water. This is because the rights allocated by states can promote water saving strategies or form an obstacle to the introduction of strategies (e.g. Rosenblum, 2005). The most prevailing water rights in the study regions are communal, organized water rights. This indicates that the organizations having agreed on the management rules of water use should be targeted in programs aimed at introducing water saving strategies in the study regions. In Greece, water rights are unorganized. This situation increases the risk of water scarcity, because there is no other control on the use of water apart from water pricing mechanisms. Recommendations towards the introduction of water saving strategies therefore include the organization of water rights or the establishment of water pricing mechanisms to enable the adoption of water saving strategies, as was also suggested in recent studies from the OECD on the sustainable management of water resources in agriculture (OECD 2010a, b). The stakeholder consultation in Greece confirmed that incentives required to change behavior of land and water users were among the important factors enabling the introduction of water saving strategies in the studied region. However, the implementation of incentive-oriented policy instruments would perform best when agricultural market scenarios and policy scenarios are considered in the design of such instruments (Viaggi et al., 2010).

Initiatives to introduce water saving strategies should take into account that the provision of access to services (water supply, energy, insurance) and infrastructure is currently moderate to low in the regions in Russia and Ukraine studied. In the Mediterranean countries these conditions are better established. Access to treated irrigation water and waste water is low to moderate in Greece, Ukraine and the Russian Federation. In contrast, access to these water sources is high in the region in Spain, where subsidies apply to irrigated agriculture (Valsecchi et al., 2009), wastewater may be used without charge, and the use of waste water for irrigation has been practiced for some time (UMH, 2006).

In most studied regions, the state is responsible for the construction of irrigation networks and other installations required for the implementation of water saving strategies. For those strategies requiring infrastructure to cover large-scale production units, the initiative, investment and involvement of the state or decentralized governments is indispensable for the implementation of water saving strategies. This is would be the case for irrigation scheduling in the studied regions in Ukraine and Russia, and for the use of wastewater in all studied regions, except for the olive tree cultures in Greece, in which wastewater can be supplied and distributed by manual labor, at least in the production units addressed in the experiments for this project.

Over the studied regions, the Water Reuse project addressed a wide variety of agricultural cropping systems in the testing of water saving strategies in terms of the cultures and size of the cultivated area per enterprise. Overall, the results were promising for each of the systems (see deliverable 25), indicating a large potential of the strategies for various forms of irrigated agriculture. The systems are both self-supplying and market oriented, indicating that interests at the level of farm business units as well as market developments will influence the adoption of water saving strategies by land users in the regions.

The agricultural cropping systems investigated in the Water Reuse project all depend on water supply from rainfall supplemented by irrigation. This implies that the water saving strategies must be well tuned to the occurrence and length of the dry period in the target region.

A point of attention is the provision of subsidies to the production of agricultural commodities. Where this is the case for irrigated agricultural production (Russian Federation, Ukraine, Spain), these may hamper the adoption of water saving strategies, or even increase water scarcity (e.g. Valsecchi et al., 2009). This applies particularly to Spain, where the stakeholder consultation pointed out that on average, stakeholders did not consider the provision of subsidies (e.g. on the use of wastewater for irrigation instead of fresh water) as an important factor enabling or hindering the adoption of water saving strategies.

In Spain and Ukraine, irrigation scheduling, irrigation with wastewater and mulching are already successfully applied in other land use types besides agricultural land use, like gardens, parks, road borders and golf courses. This offers scope for the wider application of the tested water saving strategies beyond the agricultural sector.

5.2 Specific remarks on the use of wastewater in irrigated agriculture

In all studied countries except for Greece, wastewater use for irrigation has been practiced for a long time, from 30 till 70 years (ISSAR, 2007; del. 7). At the same time the legislative mechanisms of recycling and using wastewater on private land are not or only partly established. In all countries except Spain, where regional programs for wastewater use in agriculture are in development, there is limited participation by the national governments in the development of wastewater use programs. The studied regions have in common that the populations mistrust the use of wastewater for irrigation due to ignorance of the effects on crops, environment and human health. There is a lack of communication from (national and regional) governments towards the population on these effects and a lack of experimental evidence to support this communication.

The results on the economic performance indicators of the use of wastewater for irrigation in Russia and Ukraine suggest that the strategy is promising, because fresh water is saved while crop yield may be increased. There is also other evidence from several field experiments from dry areas in the steppe zones of Russia and Ukraine. For example, a 4-year study on the experimental field stations of Moscow State University of Environmental Engineering and Saratov State Agrarian University, using wastewater from biologically cleared drains of an oil refining factory. The field-moist weight of corn of 55,5 t/ha and Lucerne of 62,2 t/ha compared to respectively 50,5 and 57,2 t/ha under fresh water irrigation. For Ukraine evidence is available from the Donetsk irrigating system, collected during a 6-year experiment using wastewater in Mariupol region on fodder beets. Crop yields amounted to 65,0 t/ha, compared to 58,5 t/ha under fresh water irrigation, and 16,5 t/ha without irrigation. The crop was of good quality (ISSAR, 2006).
In the Russian federation the awareness and willingness is growing among industrial enterprises and community facilities that the uncontrolled discharge of sewerage water into the Volga should be remediated, and that the water quality should be improved. One of the options recognised by stakeholders is to use the (treated) water for agricultural purposes. Consultations among stakeholders dealing with irrigation and environmental management at local and regional level in the Volga Region (representatives of the water authority, regional policy makers, agricultural advisors and land users) revealed that investments to adapt existing irrigation systems are the most important requirements to realize wastewater use in irrigated agriculture (Anatoly Zeiliguer, pers. comm. and MSUEE (2010)).

In the Spanish region, the shortage of water resources constitutes a serious problem because of the population growth and the shortage of rainfall, which is also irregularly distributed in time. This causes the gradual depletion of groundwater resources. For these reasons, and because agriculture in this region depends almost absolutely on irrigation, the use of wastewater in agriculture constitutes a necessary and interesting alternative to the use of freshwater resources. Based on the ignorance of land users and other stakeholders in Alicante province on the practices and benefits of the use of wastewater for irrigation , the general mistrust and the absence of a decisive legislative framework for wastewater use in irrigation, it is recommended to increase the scientific evidence of the benefits and restrictions of wastewater use in agriculture, and its dissemination towards the relevant stakeholder groups. The results collected in the Water Reuse project contribute to this. In addition to this effort, the use of wastewater in agriculture could be promoted by the provincial authorities through subsides and the improvement of infrastructure.

The literature on the use of waste water for irrigation reports many examples of economic benefits and financial performance of using waste water in irrigated agriculture (e.g. Lazarova and Bari, 2005; Scott et al., 2004). The Water Reuse project has confirmed that treated wastewater use in agriculture is a promising water saving strategy. The negative effects on soils often reported in the literature were not confirmed by the Water Reuse project, neither were negative effects on crop quality. However, there are several restrictions to the use of wastewater in agriculture, which should be considered in the design and implementation of wastewater use programs.

- Monitoring and control of wastewater quality require more attention in the Russian Federation and Ukraine, especially for wastewater originating from the cellulose-paper industry, mines and thermo-electric power stations, for which insufficient information on the wastewater composition is available.

- The use of wastewater for irrigation may induce salinization and alkalinisation of soils, as was observed in the field experimental trials in Spain, Russia and Ukraine, even for soils with heavy textures.
- The use of wastewater for irrigation may induce water repellency, when the water contains high concentrations of organic material (this was proven in the Spanish case, where measurements were done on a site where untreated water was used for many years) (Morúgan, 2008).
- Under conditions of shallow groundwater levels, irrigation using wastewater is best performed using drainage and soil improvements.
- The positive results on crop yield and quality and absence of negative results on soil properties apply to treated wastewater. The use of untreated water can cause the accumulation of nitrates in soil and groundwater.

5.3 Impacts of stakeholders on enabling or hindering the adoption of water saving strategies

An inventory among several stakeholder groups in the studied regions showed that agricultural advisors and consultants, land users (farmers, but could also be pastoralists), farmers organizations, owners of agricultural land and water authorities are rated as very influential for enabling or hindering the adoption of water saving strategies. The stakeholder inventory was based on a limited number of responses. Therefore the results should be interpreted with caution. However, some general observations on the stakeholder response may be made.

Least impact in all regions was expected from educators and policy makers at EU level. The latter observation is striking, since the EU has taken several actions to address water scarcity and droughts in the European Union in recent years. Civilians were considered very influential in all study regions except the Spanish region. The non-importance of civilians in the Spanish region may be explained by the limited access of the population to information sources on water management in relation to agricultural production (UMH, 2006). Both the importance and non-importance of civilians as stakeholders in water saving strategies call for attention to the communication and dissemination on the benefits and requirements of water saving strategies in the regions.

The impact of policy makers is very different between the regions, and should be taken into account in the development of policy frameworks addressing water scarcity in the regions. In Greece, policy makers are rated as very influential at all levels from local to the EU, whereas in Spain, their impact decreases when moving from the local scale to larger administrative areas. In Ukraine and the Russian Federation, policy makers are not very influential compared to other stakeholder groups, independent of the level of administration. This is explained by the low confidence of land owners, land users and interest groups in politicians (Laktionova, pers. comm.).

At the watershed level, collaborative watershed partnerships provide possible assemblies of a diverse array of stakeholders to address by practitioners and policy makers for promoting water saving strategies. It should be noticed however that watershed groups often rely on government support for their operational and project budgets, and therefore are subject to the guidance of granting institutions (Hardy, 2010). Hardy (2010) observed that if government policies and agencies providing financial and technical resources to watershed groups would give them more flexibility with the use of financial resources and greater availability of human and technical resources, watershed groups would be better equipped to capitalize on their professional strengths and social networks. Also, local knowledge and perspectives on watershed management would become more effective. The composition of watershed groups is equally important in the promotion of water saving strategies. Rural groups tend to concentrate on the protection of land resources from development pressures (like contamination by wastewater), whereas groups found in urban environments focus on reducing storm water runoff and achieving compliance with federal water resource policy (Hardy, 2010). Understanding the goals, activities, and outputs of watershed partnerships helps policy makers and practitioners to tailor their support to best fit the opportunities for water saving strategies in watersheds.

5.4 Stakeholder views on prospects of water saving strategies

The crop yield and farm gross margin achieved by water saving strategies in agriculture were considered most important by stakeholders in all four regions. The indicators expressing the efficiency of water use did not receive high assignments of importance by stakeholders. This is possibly caused by the fact that not all stakeholders are familiar with these indicators, despite the descriptions given in the questionnaire. This calls for a better dissemination of information on water demand, supply and use in the agricultural sector to stakeholders in regions with large shares of irrigated agricultural land.

With regard to the environmental performance of water saving strategies, stakeholders seemed to be most concerned with effects of water saving strategies on heavy metal contents, soil alkalinity and soil salinity. A relatively low or no importance was assigned to soil water repellency. This may indicate that stakeholders are not aware of this phenomenon or unfamiliar with the concept in their regions, and calls for better communication on this phenomenon to stakeholders directly involved in land management.

In socio-cultural terms, the education and training of farmers, the acceptability of using wastewater for irrigation, and the political or financial incentives required to change the behaviour of land users were considered the most important factors for enabling or hindering the adoption of water saving strategies in all three regions.

5.5 Performance assessment of water saving strategies

A multi-criteria analysis of the performance of water saving strategies in the Spanish and Ukrainian study regions, based on field experimental results and stakeholder consultation, revealed that water saving strategies differed only slightly in their performance with regard to the selected economic, environmental and socio-economic criteria in the Spanish site, but more clearly so in the Ukrainian site. The strategy using fresh water and mulch obtained the highest overall performance score in Spain. In Ukraine, the strategy using fresh water also obtained the highest score. The strategies using waste water performed slightly less than strategies using fresh water. The use of mulch was also tested in the Ukrainian site, but insufficient data were available to include these strategies in the analysis.

For the Spanish region, the higher performance of irrigation using fresh water may be explained by the overall higher scores of strategies using fresh water on several indicators, which also received high assignments of importance from stakeholders. The use of mulch improved the performance of strategies for fresh water and waste water from a tertiary treatment, but not when waste water from a secondary treatment was used. This was attributed to the high salt content of this type of wastewater, and points to the necessity for due monitoring and control of wastewater used in irrigation.

For the region in Ukraine, fresh water irrigation performed better because, although using wastewater for irrigation slightly improved crop yield and irrigation use efficiency, this was insufficient to off-set the higher maintenance costs and larger number of legal restrictions associated with wastewater irrigation.

The performance of strategies on socio-cultural indicators in the Spanish region was equal for all strategies, except for legal restrictions, where strategies using fresh water performed better because no legal restrictions were reported. This indicates that the socio-cultural setting of the Alicante province offers a potentially receptive environment for the tested water saving strategies. However, the level of incentives required to change current land users' behavior and practice in water management was observed to be high (low score of performance) for all water saving strategies. This indicates that although the socio-economic context may be suitable for the strategies, the process of governance in the region to enable adoption of the strategies would require due attention.

5.6 Some remarks on the use of decision support systems for sustainable water management

Decision support systems have been widely used in sustainable water management (e.g. Catani et al., 2003; Mota et al., 2008). Key features of such systems are the integration of information on water resources and the related biophysical and human environments with views of stakeholders. In this study, a simple stated, non-hierarchical preference valuation technique was chosen to obtain stakeholder assignments of importance to performance indicators of water saving strategies. This approach was chosen because stakeholders were consulted in writing, and because no information on the possible trade-offs between the indicators in the study regions was available post-hoc. Also, the focus of the Watereuse project was on the experimental assessment of biophysical effects and performance of water saving strategies. Despite the relatively simple setup of the analysis shown in this report, it already shows its value in the ability to effectively evaluate the complex multi-criteria nature of the subject.

However, the stated preference valuation technique is often criticized for providing only narrow mono-criterion information to the decision-making process, not allowing for trade-offs between the indicators in the assignments of weights by stakeholders (e.g. Xenarios and Bithas, 2009). More balanced results on the stakeholder assignments could be achieved using the Analytical Hierarchy Process, a technique to support multi-criteria decision-making developed by Saaty (1980), and recently applied in work on multi-criteria analyses to explore stakeholder driven options for sustainable water management in combination with stated preference tools (e.g. Martin-Ortega and Berbel,2010; Lee and Wen, 1996). As a follow-up to the Water Reuse project, it is recommended to provide a more profound and in depth stakeholder consultation and participation as part of decision support systems for the implementation of water saving strategies. Participation of stakeholders in the process of environmental decision making on water saving strategies also has the advantage that local knowledge from stakeholders is integrated in environmental management (e.g. Raymond et al., 2010).

6 Conclusions

The Water Reuse project aimed to develop new, and advance existing, sustainable water saving strategies in the NIS and Mediterranean States by focusing on largely unexploited opportunities for (a) water saving and (b) use of organic-rich waste water as a non-conventional water resource on irrigated land. Several water saving strategies in irrigated agriculture were tested in experimental sites in Alicante province, Spain, Saratov Region, Russia, Kharkiv region, Ukraine, and Maggana region, Greece. This deliverable discussed the general human-environmental conditions of the study sites, and prospects for water saving strategies given these conditions.

Individuals and groups (communities or cooperatives) are the most likely types of land owners or land users to be targeted in initiatives to introduce water saving strategies in the studied regions. Land users likely to apply water saving strategies belong mostly to the average wealth category, and manage a large part of the agricultural land area. This offers good perspectives for initiatives to introduce water saving strategies in regions similar to the ones tested. Land ownership (or the type of land possession) varies widely between the study regions, indicating that the introduction of water saving strategies must be fine-tuned to address many different land owners.

The project identified the need for better communication and dissemination of experimental evidence of increased water use efficiency and production from using water saving strategies to land users, in order to increase the likelihood of adoption of these strategies. This applies specifically to the use of wastewater for irrigated agriculture, since the legislative mechanisms of recycling and using wastewater on private land are not settled, and there is a general mistrust of the populations to the use of wastewater due to ignorance of the effects on crops, environment and human health. The experimental results from the Water Reuse project may be used in a communication effort to create awareness on the strengths and weaknesses of water saving strategies.

In countries where water rights are (partly) unorganized, the project recommends regional authorities to consider the organization of water rights in water management programs. This could be done through subsidies or pricing mechanisms. In addition, for those strategies requiring infrastructure to cover large-scale production units, the initiative, investment and involvement of the state or decentralized governments is indispensable for the implementation of water saving strategies.

Of the stakeholder groups identified in the study areas as possibly relevant for the adoption of water saving strategies in the study areas, agricultural advisors and consultants, land users, farmers organizations, owners of agricultural land and water authorities were identified as very influential. The impact of policy makers is very different between the regions, and should be taken into account in the development of policy frameworks addressing water scarcity in the regions. A restricted stakeholder consultation provided information on stakeholder assignments of importance to economic, environmental and socio-cultural indicators of water saving strategies. This information could be used to identify suitable areas in the NIS and Mediterranean in action and learning initiatives for sustainable water management in these regions. Examples of the use of this information were demonstrated in multi-criteria analyses of the performance of the tested water saving strategies in the Spanish and Ukrainian study regions, based on field experimental results and the stakeholder consultations.

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8 Appendix I Configuration of key performance indicators for Alicante province, Spain

8.1 Economic indicators

Crop yield in treated area

- Expressed in mass of grapes in t/ha. 5.04 is taken as the maximum, based on the FAOSTAT number for yield of grapes in Spain over the year 2008. Linear value function chosen.
- For strategies with mulching no crop yield data were available. Therefore plant height was taken as a criterion (cm). Depending on the species, height can be till 20 feet, but this is 6 m, and unrealistic for cultivated species. Instead, the value of 8-10 feet is used found on internet sites[5]. A non-linear value function was chosen, based on the supposition that growth in height does not translate directly into yield.

Irrigation use efficiency

- Defined ín this study as the crop yield per ha and per mm of irrigation per growing season.
- Maximum is defined based on the FAOSTAT crop yield for grapes obtained under average annual rainfall of 486 mm for the region (i.e. no added irrigation) (database file 2.0): 10.4 kg/(ha*mm)
- Linear value function chosen to express that an increase in irrigation use efficiency immediately translates in a benefit.

Water use efficiency

- Defined according to Ouédraogo et al (2006) as the (aboveground biomass in treatments aboveground biomass in control situation)/total rainfall per growing season.
- Maximum value set based on FAOSTAT crop yield for grapes and the rainfall in the period Feb-Sep 2009, derived from the Database file 2.0 for Spain: 24.18 kg/(ha*mm)
- Linear value function chosen to express that an increase in water use efficiency immediately translates in a benefit.

8.2 Environmental indicators

Soil structural stability

- Expressed as the % of water stable aggregates, undergoing the following treatment: soil (4-0.25 mm) is placed into a 0.25-mm sieve and exposed to rainfall with the energy of 270 J m-2 for 1 minute.
- Also expressed as the stability of the soil colloid (mass % of silt and clay)
- More is better: a stabler soil means less soil sealing, and less hampering of infiltration into the soil

Bulk density

[5] http://davesgarden.com/guides/pf/go/129415/

- More is worse: less aeration for crops, biological activity and rainfall infiltration is assumed to be possible in a compacter soil
- A non-linear value function is chosen, because soil compaction are expected to translate non-linearly into pore structure changes that diminish aeration, biological activity and infiltration rate
- Minimum value is taken as 1000 kg/m3, as the general minimum value for mineral soils (Birkeland, 1984)[6]
- Maximum value is taken as the maximum value measured on the experimental plots up to depths of 35 cm (1910 kg/m3)

Soil alkalinity

Croes (2009): "The main cause of alkaline soils lies is their high content of sodium carbonates and bicarbonates, especially when found in clayey soils (Vorobeva et al. 2006). These types of alkaline soils are associated with a bad soil structure and a low infiltration capacity, making them difficult to use for agriculture purposes."

Wikipedia (http://en.wikipedia.org/wiki/Alkali_soils, consulted 30-3-2010): "Alkali, or alkaline, soils are clay soils with high pH (> 9), a poor soil structure and a low infiltration capacity. Often they have a hard calcareous layer at 0.5 to 1 meter. depth (in India this layer is called 'kankar'). Alkali soils owe their unfavorable physico-chemical properties mainly to the dominating presence of sodium carbonate which causes the soil to swell."

"Soil alkalinity is associated with the presence of sodium carbonates or (soda) (Na_2CO_3) in the soil,[2] either as a result of natural weathering of the soil particles or brought in by irrigation and/or flood water."

- Expressed by the pH of the soil solution
- Maximum is taken as the maximum value measured on the plots between 2007 and 2009 (9.03)
- Non-linear value function is chosen, based on results from the literature do not unambiguously point to negative effects of soil alkalinity on the environment

Soil salinity

- Irrigated land salinity is the case in this study (as opposed to dryland salinity)
- Excessive accumulation of soluble salts in the soil (Blaylock, 1994)[7]. The cations and anions of these salts include Ca, Mg, Na, K, carbonate and bicarbonate, chloride, nitrate and sulphate (IUSS Working Group WRB, 2006).
- Expressed by the electrical conductivity of the saturation extract (in µS/cm)
- As the maximum is taken the maximum EC value measured in the soil solution of the 0-5 cm depth layer (492.11 µS/cm).
- Non-linear value function is chosen, based on results from the literature do not unambiguously point to negative effects of soil salinity on the environment

Soil organic matter content

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[6]Birkeland, P.W., 1984, Soils and Geomorphology: Oxford University Press, New York, p. 14-15.

[7] Blaylock, A.D. 1994. Soil salinity, salt tolerance and growth potential of horticultural and landscape plants. In: Cooperative Extension Service Bulletin B-988, Department of Plant, Soil and Insect Sciences, University of Wyoming, February 1994.

FAO (2005): “Soil organic matter is any material produced originally by living organisms(plant or animal) that is returned to the soil and goes through the decomposition process (Plate 1). At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (Figure 1).”

- Expressed as the mass fraction of organic matter in the soil
- Maximum is taken as the maximum measured in the soils of the study site at 0-5 cm depth between 2007 and 2009 (2.43)
- Linear value function is chosen to indicate that increases in soil organic matter translate directly in beneficial soil and ecosystem functions (e.g. FAO, 2005)

8.3 Socio-cultural indicators

Legal restrictions

- Defined as the degree to which laws or regulations hamper the implementation and/or use of water saving strategies
- Expressed as the nr of laws or regulations hampering the implementation and/or use of water saving strategies.
- Linear value function chosen to express a direct influence of the nr of restrictions on the benefit of a water saving strategy

Acceptability of using waste water for irrigation

- Expresses inversely the degree of concern about use of waste water for irrigation
- Measured as low (1), medium (2) or high (3)
- Linear value function chosen in absence of any information on the value function of acceptability

Historical adoption of new technologies

- Is degree to which new technologies have been adopted historically, expressed as the % of the technologies adopted still in use at the moment
- Non-linear value function chosen to express the general finding that innovations do not follow linear increases in numbers of adopters (famous curve of ….)

Likelihood of adoption of new technologies from Water Reuse

- likelihood that a farmer will adopt a strategy from the Water Reuse project, expressed as the probability that a land user will implement the technique within 5 years
- based on interviews with land users
- non-linear value function chosen to reflect the non-linear trend of the adoption of innovative techniques by the famous curve of ….

Level of incentive required to change behavior

- defined as the level of positive or negative incentive that motivates change
- could be financial or policy type (guidelines, law)
  financial could be:
  none - none
  medium - some level of reward, subsidy or fine;
  high - reward/subsidy or fine amount = or > than cost of implementation

  Policy could be:

low (provide recommendation and guideline),
medium - in between high and low
high (needs to be a law/formal regulation)

- based on interviews with land users
- expressed as low(1), medium (2) or high (3)
- Linear value function chosen to reflect that an increase in the level of incentives will directly influence the uptake of water saving strategies

Farmer health and safety

- Expresses farmer health and safety, related to the use of waste water for irrigation, as judged by stakeholders
- Expressed as low (1), medium (2) or high (3)

9 Appendix II Configuration of key performance indicators for Kharkiv region, Ukraine

9.1 Economic indicators

Crop yield in treated area

- Data for winter wheat were taken from the growing season 2007 were taken (Sep 2006-July 2007) (dry grain).
- As the minimum was taken as 2.34 t/ha, based on the minimum crop yield for winter wheat in FAOSTAT for Ukraine for 2007, and considering that the crop yields recorded in the field experiments were higher than this average value for Ukraine. The maximum value was based on the data from the field experiments, since these yields were much higher than the average yields of wheat reported for Ukraine in FAOSTAT for the period 2000-2008 (between 1.47 and 3.67 t/ha), and by the Ukraine Agriculture Ministry, State Committee for Statistics (3.1 t/ha for 2009). In the field experiments, a maximum of 6.07 t/ha was observed; the maximum is set to 7.0 t/ha.

Irrigation use efficiency

- Defined ín this study as the crop yield per ha and per mm of irrigation per growing season.
- Minimum value based on minimum crop yield from FAOSTAT database (1.47 t/ha) and average irrigation for the growing season from September till July, taken from the field experimental database for the Ukrainian site for the periods 2006-2007: 120 mm: 12.25 kg/(ha*mm).

9.2 Environmental indicators

Bulk density

- More is worse: less aeration for crops, biological activity and rainfall infiltration is assumed to be possible in a compacter soil
- A non-linear value function is chosen, because soil compaction are expected to translate non-linearly into pore structure changes that diminish aeration, biological activity and infiltration rate
- Minimum value is taken as 1000 kg/m3, as the general minimum value for mineral soils (Birkeland, 1984)[8]
- Maximum value taken as the maximum observed during the whole field campaign at the site: 1430 kg/m3.

Soil alkalinity

Croes (2009): "The main cause of alkaline soils lies is their high content of sodium carbonates and bicarbonates, especially when found in clayey soils (Vorobeva et al. 2006). These types of alkaline soils are associated with a bad soil structure and a low infiltration capacity, making them difficult to use for agriculture purposes."

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[8]Birkeland, P.W., 1984, Soils and Geomorphology: Oxford University Press, New York, p. 14-15.

Wikipedia (http://en.wikipedia.org/wiki/Alkali_soils, consulted 30-3-2010): "Alkali, or alkaline, soils are clay soils with high pH (> 9), a poor soil structure and a low infiltration capacity. Often they have a hard calcareous layer at 0.5 to 1 meter. depth (in India this layer is called 'kankar'). Alkali soils owe their unfavorable physico-chemical properties mainly to the dominating presence of sodium carbonate which causes the soil to swell."

"Soil alkalinity is associated with the presence of sodium carbonates or (soda) (Na2CO3) in the soil,[2] either as a result of natural weathering of the soil particles or brought in by irrigation and/or flood water."

- Expressed by the pH of the soil solution
- Minimum and maximum taken from the field exp database. Minimum as average of all pH measurements of the soil solution minus one standard deviation (7.31); maximum as average of all measurements + one standard deviation (8.12).

Soil salinity

- Irrigated land salinity is the case in this study (as opposed to dryland salinity)
- Excessive accumulation of soluble salts in the soil (Blaylock, 1994)[9]. The cat ions and anions of these salts include Ca, Mg, Na, K, carbonate and bicarbonate, chloride, nitrate and sulphate (IUSS Working Group WRB, 2006).
- Expressed by the electrical conductivity of the saturation extract (in µS/cm)
- Minimum value taken as the minimum average value recorded in the soil between 0-5 cm under irrigation with fresh water minus one standard deviation: 158 microS/cm.
- Maximum value taken as the maximum average value recorded in the soil between 0-5 cm under irrigation with wastewater from tertiary treatment plus one standard deviation: 564 microS/cm.

Soil organic matter content

FAO (2005): "Soil organic matter is any material produced originally by living organisms(plant or animal) that is returned to the soil and goes through the decomposition process (Plate 1). At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (Figure 1)."

- Expressed as the mass fraction of organic matter in the soil
- Minimum taken as the minimum average value recorded in the soil between 0-5 cm in the field experimental database minus one standard deviation: 3.1 %
- Maximum value taken as the maximum average value recorded in the soil between 0-5 cm in the field experimental database plus one standard deviation: 4.4%.
- Linear value function is chosen to indicate that increases in soil organic matter translate directly in beneficial soil and ecosystem functions (e.g. FAO, 2005)

Legal restrictions

- Defined as the degree to which laws or regulations hamper the implementation and/or use of water saving strategies

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[9] Blaylock, A.D. 1994. Soil salinity, salt tolerance and growth potential of horticultural and landscape plants. In: Cooperative Extension Service Bulletin B-988, Department of Plant, Soil and Insect Sciences, University of Wyoming, February 1994.

- Expressed as the nr of laws or regulations hampering the implementation and/or use of water saving strategies.
- Linear value function chosen to express a direct influence of the nr of restrictions on the benefit of a water saving strategy