Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

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List of acronyms and abbreviations

AB Monte Novo	Associação de Beneficiários de Monte Novo,
CBC	Consortium of “Bonifica della Capitanata”
CH_4	Methane
CNR	National Research Council
CO	Carbon monoxide
CO_2	Carbon dioxide
CS	Case study
CWR	Crop Water Requirement
EDIA	Empresa para o Desenvolvimento das Infraestruturas de Alqueva
ET_c	Crop Evapotransipiration
ET_o	Reference Evapotransipiration
EVAT	Economic Value Chain Analysis Tool
FADN	Farm Accountancy Data Network
GHG	Greenhouse gas emission
GIR	Gross Irrigation Requirement
HP	High pressure
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ISPA	Institute of Sciences of Food Production
$kgCO_{2eq}$	Kilogram CO_2 equivalent
kWh	Kilowatt hours
L	Liter
LP	Low pressure
m^3/s	Cubic meter per second
mm/d	Millimeter per day
Mm^3	Million cubic meter
N_2O	Nitrous oxide
NH_3	Ammonia
NIR	Net Irrigation Requirement
NO_3	Nitrates
NO_x	Nitrogen oxides
P_{eff}	Effective Rainfall
PO_4	Phosphates
SDI	Subsurface drip irrigation
RDI	Regulated deficit irrigation
SEAT	Systemic Environmental Analysis Tool
SO	Sinistra Ofanto
SO_2	Sulphur dioxide
TFC_{WS}	Total Financial Cost related to Water Supply provision for the specific use
TVA	Total Value Added
W	Irrigation factor
WWT	Waste water treatment
WBCSD	World Bussiness Council for Sustainable Development

1 Case Study 1. Sinistra Ofanto Irrigation Scheme

Evaluation and monitoring environmental performance of agriculture, ideally viewed in a life cycle perspective, is crucial for achieving better management of natural resources approaching sustainability, economic and technological development. Eco-efficiency assessment is a methodology that stakeholders may use to evaluate their products, technology or services from an environmental and financial perspective. The concept of eco-efficiency was introduced in 1991 by the World Business Council of Sustainable Development (WBCSD) and is commonly referred to as a business link to sustainable development. Recently, the concept of eco-efficiency was introduced in agricultural water management and encompasses both the ecological and economic dimensions of sustainable agriculture. In the simplest terms, eco-efficiency is about achieving more with less — more agricultural outputs, in terms of quantity and quality, with less inputs of land, water, nutrients, energy, labor, or capital (Keating et al., 2010). In the Mediterranean region natural resources are scarce; therefore, it is important to study how to improve efficient use of these resources through the uptake of new technologies and adoption of the best management practices. This idea is fully embraced by water and land managers and applied at different scales, from farm to irrigation scheme, district and consortium. This work focusses on the assessment of eco-efficiency at a meso-level scale, which could be equated with a large irrigation scheme.

The "Sinistra Ofanto" irrigation scheme, located in the Apulia region (Southern Italy), is chosen for the analysis. The main problem of the area is that water supply through the network has already reached its maximum and farmers resort to abstracting water from the aquifer, which creates environmental concerns by compromising the conditions of ecosystems, affecting agricultural production, long-term sustainability and economic growth in the area. Therefore, the goal of this study is to support optimizing agricultural production under limited water supply while minimizing groundwater depletion through the adoption of the eco-efficiency philosophy, i.e., assuming a sound approach for pursuing sustainable development, increasing productivity and economic benefits and reducing negative environmental impacts.

Feasible options for eco-efficiency improvement and technology uptake were evaluated at a meso-scale level considering the Sinistra Ofanto irrigation scheme expanding over 39000 ha. The assessed scenarios, discussed with local stakeholders, refer to the introduction of innovative technologies for resource efficiency and pollution prevention. The irrigation scheme was analyzed applying a new approach, developed within the frame of EcoWater project, and using the new modeling tools SEAT (Systemic Environmental Analysis Tool) and EVAT (Economic Value chain Analysis Tool). Both tools were tested in the case of the Sinistra Ofanto irrigation scheme using the agronomic, engineering, economic and environmental data collected for several years. The system was mapped in terms of both water supply and value chain and the validation of SEAT and EVAT was done for the data referring to the baseline scenario, assumed to be similar to the conditions observed in year 2007. The eco-efficiency was estimated as a ratio of the economic performance of the system and produced environmental impacts. Economic performance was expressed in terms of Total Value Added to the product from water use, whereas the environmental performance followed a life-cycle oriented approach (ISO 2006, ISO 2011) using 11 midpoint environmental impact categories selected as the most representative for the environmental assessment of the system. Baseline results indicated that the system performance is strongly affected by uncontrolled water withdrawal from the aquifers, which is particularly relevant under dry year conditions. This increases the environmental burdens and requires the uptake of new technological solutions which may enhance the eco-efficiency of Sinistra Ofanto irrigation scheme. The overall results show that uptake of innovative technologies has relevant potential to optimize water, fuel and fertilizer use and thereby improve environmental performance of the system while maintaining a healthy agricultural economy. In turn, this contributed to the reduction of associated costs and enhanced yield due to operation flexibility. The decrease of associated emissions (foreground and background) with diesel and fertilizers showed relevant impact in the climate fossil fuel depletion, mineral depletion, freshwater depletion and eutrophication potential indicators. The adoption of both water and energy saving technologies is fundamental for the system performance although water saving could be considered as a priority. Still, the best solution could be a joint intervention including the uptake of both water and energy saving technologies as in the case of super-intensive scenario.

2 Methodological framework

The methodological framework applied in this study is adapted from the EcoWater Project (FP7-ENV, http://environ.chemeng.ntua.gr/EcoWater/) that attempts to explore the use of meso-level eco-efficiency indicators for the assessment of eco-innovation in the water sector. The study area is one of eight case studies of the project; the methodology adopted for assessing eco-efficiency is illustrated in Figure 1 and contains the following steps: a) analysis of the physical system and value chain mapping; b) eco-efficiency assessment for the baseline scenario; c) formulation of scenarios introducing water saving technologies/innovations and d) assessment of the system eco-efficiency for new technologies/innovations.

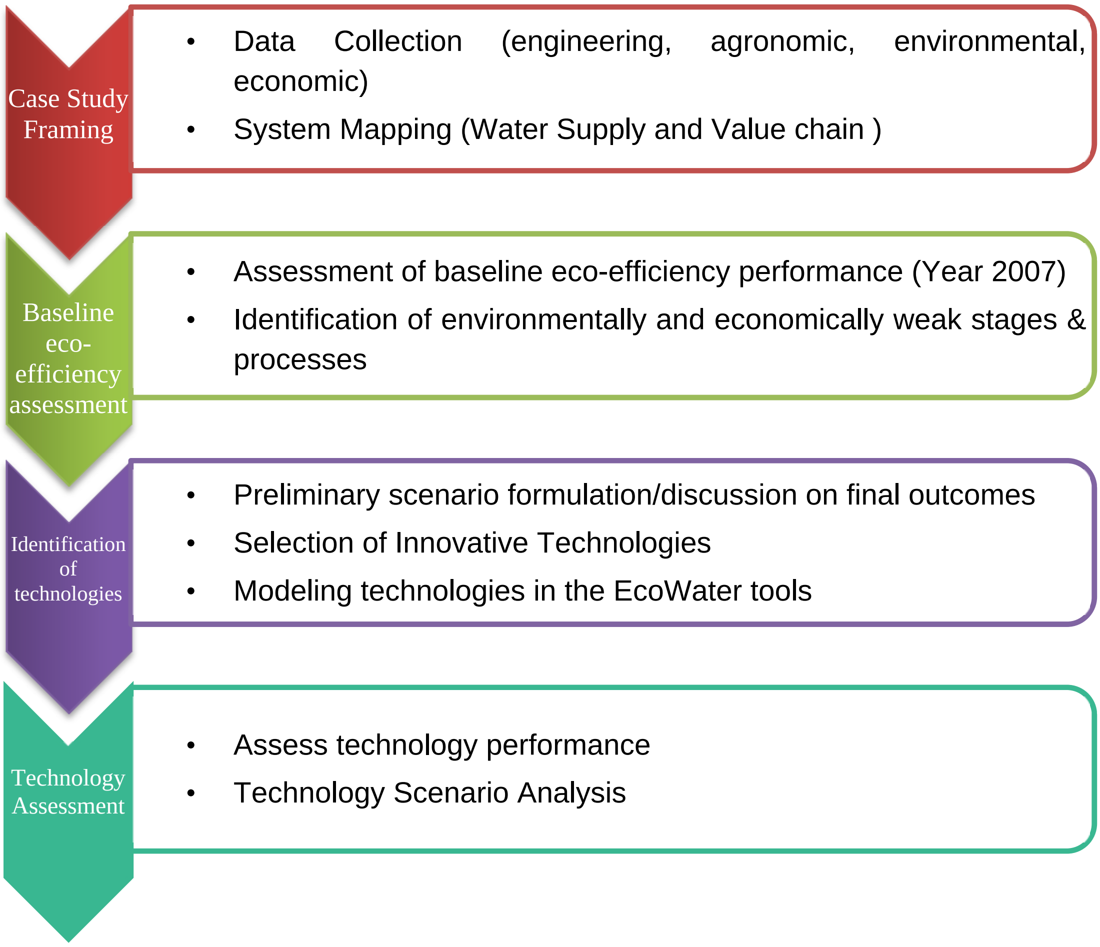


Figure 1. Methodology flowchart framework (Source: modified from EcoWater 2012)

Upon on-farm data collection and elaboration, the water supply chain and water value chain model were designed and calibrated for baseline conditions, corresponding to the year 2007, using the tools developed within EcoWater: SEAT – Systemic Environmental Analysis Tool, and EVAT – Economic Value chain Analysis Tool. The functional units of the system were defined as m^3 of water used and kg of yield, and inventory analysis was applied for data collection to estimate all the inputs (resources) and outputs (yield and emissions) in relation to the functional unit. The input and output data include the use of resources (water, energy, fuel and N and P fertilizers), the releases to air, soil and water associated with the processes, financial cost related to water supply production cost, fertilizers unitary cost, labour cost, energy cost, and gross market prices. The primary data, supplied by the main actor and water delivery consortium (Consortium Bonifica della Capitanata, CBC), were complemented with additional data from the scientific literature and official statistics.

In order to assess the impact of innovative technologies and management practices on the eco-efficiency indicators and the system performance, a reference or baseline scenario was first modeled and assessed. The eco-efficiency assessment of the baseline scenario represents the basis for the benchmarking enhancements resulting from the uptake of innovative practices and technologies at different stages of irrigation conveyance and distribution systems and at farm level. The year 2007 was chosen as a reference year for simulations since it resembles well the average climatic conditions over a 22 year period (1990-2011) and corresponds to the management conditions prior to the important changes aiming to improve the system performance. Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project, 11 impact categories were selected as the most representative for the environmental assessment of the system. The system economic performance was expressed in terms of Total Value Added to the product from water use, whereas the environmental performance assessment followed a life-cycle oriented approach (ISO 2006, ISO 2011).

The definition of relations between input and output flows were specified along with the resource flows to and from each process of the model of the system. The system was divided into “foreground” and “background” subsystems (Figure 2).

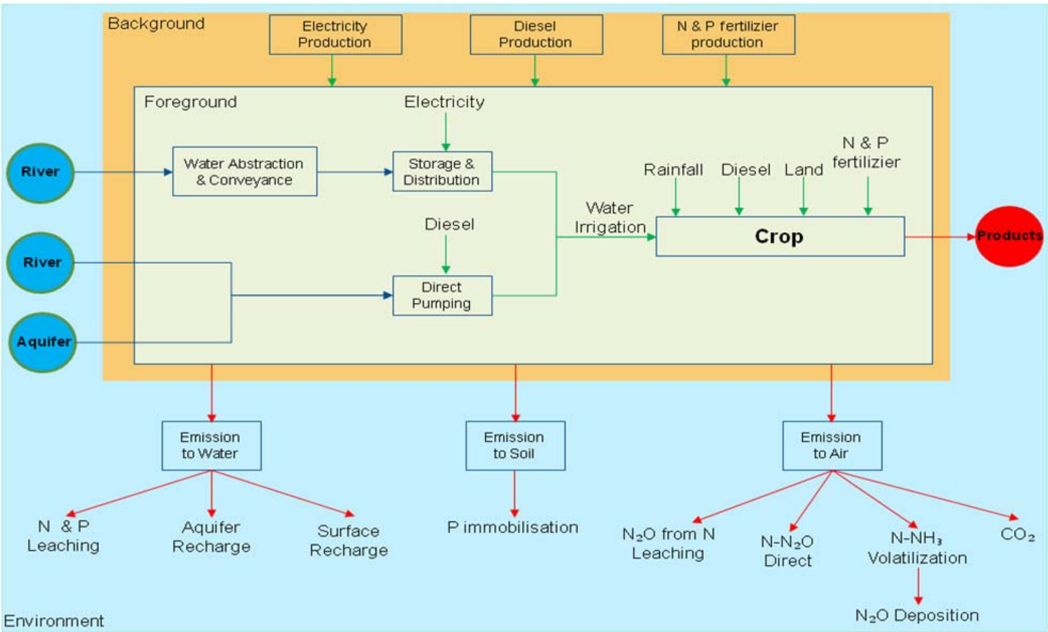


Figure 2. Foreground and background systems of Sinistra Ofanto irrigation scheme

The former was the system of direct interest and includes all direct emissions from on farm activities leading to carbon dioxide or other GHG, such as burning of diesel fuel in tractors, irrigation equipment and fertilizer application. The latter includes indirect emissions due to the resource production processes (nitrogen and phosphorus based fertilizer, electricity and diesel) prior to being used in the water system. These emissions were estimated by multiplying activity data with emission factors for each resource.

In full compliance with environmental concerns at farm level, a simple soil-water-balance model was introduced to estimate aquifer recharge from precipitation and aquifer depletion (as a part of water pumped for irrigation). The components of agricultural water balance - crop water requirements (CWR), effective precipitation (P_{eff}), and net irrigation requirements (NIR) - and crop yield response to water were estimated for a characteristic cropping pattern using the ISAREG irrigation management decision support tool (Pereira et al. 2003), which bases upon FAO standard methods for estimation of crop evapotranspiration (Allen et al., 1998) using commonly available crop, soil and climate data. The difference between total annual precipitation and effective rainfall was portioned in surface recharge, groundwater recharge and evaporation. The estimate of the aquifer water depletion was done iteratively based on the total water demand (GIR) of all crops excluding water coming from the district network (CBC) and water pumped from the river, which were defined as fixed input flow based on available data. The simulated gross irrigation requirements (GIR) were estimated from the computed net irrigation requirements considering a beneficial water use ratio (BWUR) for the network, an application efficiency for the irrigation method, and an irrigation factor (0-Rainfed, 1-Full irrigation) which represents the product of the percentage of area irrigated and the water supply regime (a percentage of water supply in respect to that necessary to cover completely evapotranspiration). The analysis was conducted for each crop in the study area and for different irrigation zones. Three irrigation methods were considered: micro-sprinkler, drip and subsurface drip with target irrigation efficiencies of 80%, 90% and 95%, respectively. The on-farm distribution efficiency was assumed at 95% considering that the network is a well maintained pipe system. From the comparison between estimated water demand and water deliveries, the amount of water withdrawals by farmers from the aquifers was assessed. The overall fuel consumption on pumps used for irrigation was based on the energy imparted to the water by a pump (water horsepower) and a specific consumption which was defined as a ratio of calorific value of the diesel (35.8 MJ/L or 9.94 kWh/L) and combustion efficiency of the diesel pumps.

Fuel consumption for farm operation (e.g. tillage practices) was derived from working hours and power of machine (Fuel consumption = Power of machine in kW • 0.25 L $hour^{-1}$ kW^{-1} • hour used) (Smith, 2004). Indirect GHG emissions from agricultural machinery were estimated on the basis of energy consumption in manufacturing (Maraseni, 2007). For all types of tractors, used in study area, the same weight and working life were assumed. Diesel combustion emission factor came from Nussey 2005, while the upstream or indirect emissions, for diesel and electricity production use were obtained from ELCD database (ELCD, 2013).

The fertilizer emission was estimated using the IPCC Guidelines and expert judgment in combination with the CS activity data on fertilizer application for each crop. Fertilizer emissions occurred both directly (on site) through nitrification and denitrification, and indirectly (off site) following leaching, runoff, and ammonia (NH_3) volatilization. Direct emissions were computed as the product of the direct N_2O

emissions factor and the amount of N applied. Indirect N_2O emissions were broken down into those due to volatilization and those due to leaching or runoff. Each indirect emission path was calculated as the product of the amount of N applied, the fraction of N lost through that emission path, and the emission factor for that path. Indirect emissions from the fertilizer production (N&P) came from USLCI database (USLCI, 2013).

To account for agricultural production, the crop yield vs water input relationship was generated after simulating various irrigation scheduling options in ISAREG. This relationship was used to estimate total agricultural production, expressed as crop yield per area of land cultivation. Eventual relative crop yield reduction, based on irrigation factor assigned to each crop, was calculated proportionally to the maximum yield defined for each crop. Irrigation factor was defined for each crop after comparing the data declared by farmers and obtained from FADN (Farm Accountancy Data Network) database and crop maximum yield under local conditions.

After performing the baseline eco-efficiency assessment, a list (screening) of technologies and innovations for enhancing eco-efficiency of SO scheme was compiled, based on preliminary inception, consultation with key actors and the pertinent literature. Proposed technologies were modelled and analyzed with identification of the parameters of the water supply and value chains that are affected by their implementation. Then, the estimation of the eco-efficiency indicators was made for each different technology or combination of technologies. Results were evaluated based on the respective values of the eco-efficiency indicators. Elaboration and comparison of results from different scenarios (prior and after the application of technologies and management practices) provided the data on the relative eco-efficiency improvement of the analysed system, thus arriving to a condition where the best alternative configurations were identified.

2.1 Finalized baseline scenario assessment

Calculation of life cycle inventory flow for baseline conditions (Table 1) was performed for normal and dry years, corresponding to annual precipitation of 514 (similar to year 2007) and 420 mm (similar to year 1990), respectively. The baseline scenario refers to the management practices in 2007, i.e. the application of deficit irrigation strategy for artichoke, olives, orchards and sugarbeet, other crops were cultivated under full irrigation while wheat was under rainfed conditions as described previously. The year 2007 was assumed to be the most appropriate for the baseline eco-efficiency assessment because of data availability related to water distribution, crops cultivation and market prices etc. Moreover, the precipitation in that year was very close to the 22-years average precipitation (1990-2011). Finally, the local stakeholders (CBC) indicated that year as the most appropriate one because some changes in the water management and the introduction of new technologies and management practices were made since that period. Accordingly, the water supply and value chain mapping were performed for the baseline conditions in SEAT and EVAT (Figure 3).

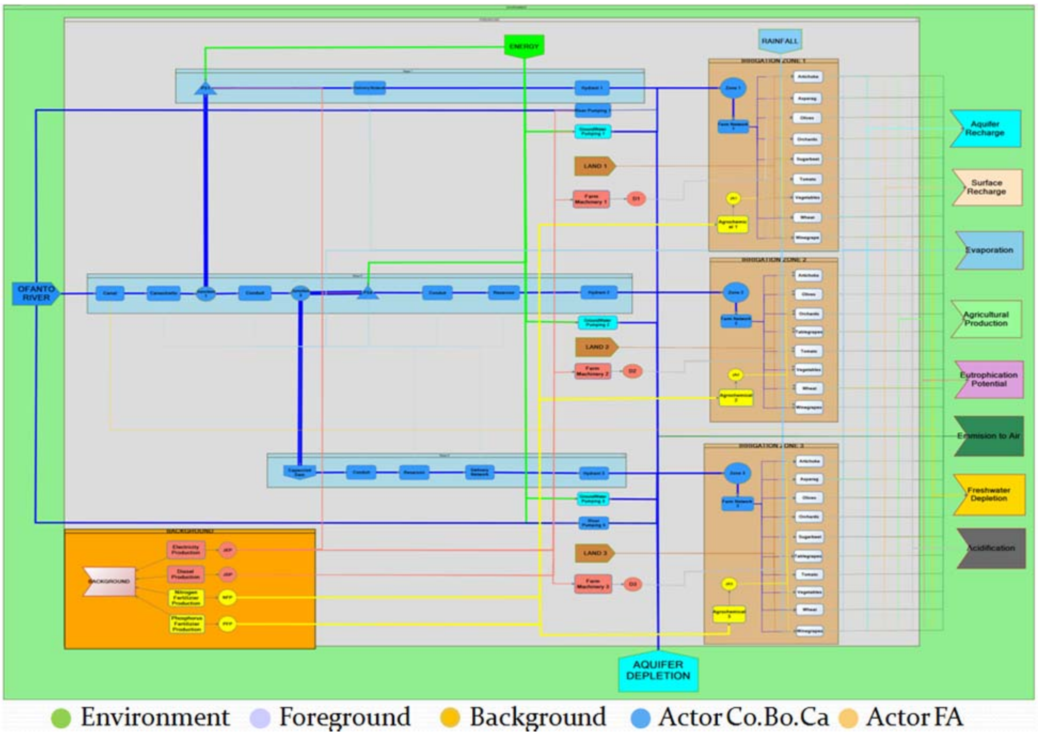


Figure 3. Water supply and value chain mapping of Sinistra Ofanto irrigation scheme

Total water use on farm level, including the groundwater withdrawal and surface water originated from Ofanto River was estimated at 83.5 Mm³ showing that the groundwater accounts 54% of on-farm water input for. There was significant difference among groundwater use between irrigation zones, indicating that groundwater pumping was mostly affected by different cropping patterns and water management practices. Zone 1 presents the lowest groundwater withdrawals due to high presence of wheat (78%) which is not irrigated. In zone 2, with a diversified cropping pattern, more than 50% of the total water requirements were fulfilled from the aquifer. The highest groundwater withdrawals were found in zone 3 with a rate of 1931 m^3/ha due to its largest surface area and high allocation of water demanding crops. Similar results for groundwater exploitation varying between 1000 and 4000 m^3/ha were simulated by Oueslati (2007) in the Sinistra Bradano scheme located close to the Sinistra Ofanto irrigation scheme. The water recharge mostly occurs during the autumn and winter months. The total annual recharge of groundwater and surface water from average precipitation of 514 mm/year is estimated at 56.8 Mm^3 which represents about 68% of total water withdrawal and corresponds to overall water deficit of 34 Mm^3. The annual recharge of the aquifer was estimated at 28.45 Mm^3 which, in the case of average year, represents about 63% of water withdrawal from the aquifer and indicates an annual trend of water depletion in the aquifer of 16.98 Mm^3. In the case of a dry year, total water requirement were increased by approximately 11.1 Mm^3 or 12% compared to a normal hydrological year. This increase in water requirements was compensated by the groundwater withdrawals which reached 56.6 Mm^3. The overall water deficit has increased from 34 Mm^3 (for a normal hydrological year) to 52.2 Mm^3. The highest water requirements and groundwater withdrawal are observed in irrigation zone 3 mainly due to intensive cultivation of vineyards which in zone 3 constitute 52% of total cultivated area.

Table 1. Life cycle inventory flows of the Sinistra Ofanto Irrigation Scheme (Baseline)

Category	Material	BASELINE AVG	BASELINE DRY
Water Resources	Surface Water (Ofanto River)[a]	46,263,956	46,263,956
	Water Losses	8,138,543	8,138,543
	Surface Water (CBC delivered)	36,625,413	36,625,413
	Surface Water (river pumping)	1,500,000	1,500,000
	Groundwater (Aquifer)	45,428,351	56,592,202
Supplementary Resources	Electricity	11,845,094	11,845,094
	Diesel Fuel	13,859,606	15,137,820
	Nitrogen Based Fertilizers	4,548,640	4,548,640
	Phosphorus Based Fertilizers	2,234,723	2,234,723
	Land	33,651	33,651
Emissions To Air	Carbon Dioxide (CO_2)	40,156,822	43,860,320
	Nitrous Oxide (N_2O)	89,267	89,267
	Ammonia (NH_3)	496,984	496,984
	Evaporation	37,557,379	32,727,494
Emissions to Water	N to Water	875,613	875,613
	P to Water	341,913	341,913
	Aquifer Recharge	28,447,423	24,781,780
	Surface Water Bodies	28,447,423	24,781,780
Products	Artichoke	7,105	6,433
	Asparagus	856	856
	Olive	40,804	35,059
	Orchards	80,990	76,633
	Sugarbeet	1,085	946
	Tablegrapes	114,590	114,590
	Tomatoes	33,390	33,390
	Vegetables	20,115	20,115
	Wheat	27,402	23,407
	Winegrapes	258,267	258,267

[a] Surface water includes also direct river pumping of 1,500,000 m^3

[b] CO_2 include emission from fuel consumption in pumps and farm operations. It refers only to foreground processes

[c] Nitrous oxides is presented as total N_2O produced from direct (Nitrification and dentrification) and indirect emission (Leaching & Volatilization) without conversion.

Energy use varies considerably between three irrigation zones depending largely on water supply. Although water is delivered and distributed to the farmers by gravity, zone 3 is the major contributor to the energy consumption and related resource emissions due to the greatest groundwater pumping to the fields.

The main source of field losses for N was ammonia (NH_3) volatilization. Ammonia is not a GHG, but some of this N in the atmosphere can return to the soil through atmospheric deposition, of which a certain amount will be nitrified, denitrified, or lost as N_2O. Nitrous oxide (N_2O) was the main source for field emissions. The total direct nitrous oxide emissions (N_2O) from agricultural soils for Sinistra Ofanto were estimated at $89.2 \cdot 10^3$ kg or $26.6 \cdot 10^6$ kgCO_2eq. This corresponds with 2.62 kg N_2O ha^{-1} or 791 kg CO_2eq ha^{-1} agricultural soil. The largest source of N_2O was nitrification and denitrification which accounted for 80% of total N_2O emissions. Indirect emissions accounted for 12% in leaching and runoff and 8% was produced from volatilization. The distribution of these emissions through different pathways is shown in Figure 4.

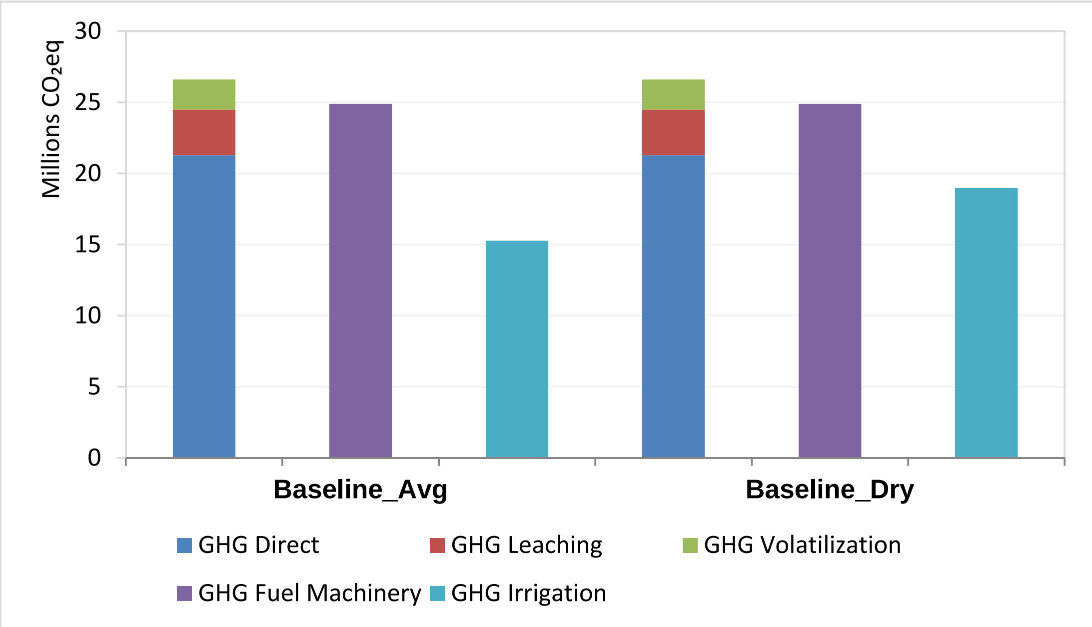


Figure 4. Greenhouse gas emissions from farm supplementary resources in Sinistra Ofanto irrigation scheme

The total GHG emissions from fuel combustion in the machinery used on farm operations was estimated at 740 kg CO_2-eq ha^{-1}. The highest unitary source for this emission was artichoke cultivation due to high working hours and high power of machine needed for farm operations. However, the highest emissions are produced from winegrapes due to the highest land allocation. Total GHG emissions from the use of pumps for irrigation were estimated at 454 kg CO_2eq ha^{-1}. Thus, the total GHG emissions from fossil fuel usage were estimated at 1193 kg CO_2eq ha^{-1}. It should be noted that calculation of emission from irrigation was based to the application deficit irrigation strategy as described previously. Due to increase of groundwater withdrawals in dry year, diesel consumption was increased in respect to normal hydrological year by 24% which means 24% higher related resource emissions in the atmosphere. No changes in emission from fertilizer, farm operation and machinery occurred due to no change in fertilizer application and on farm management practices.

Total agricultural production amounts to $584 \cdot 10^3$ ton with the highest production of winegrapes of about 45% of total production due to highest land allocation and relatively high production yield. During dry year overall total agricultural production decreased by 2.55% mostly affected from wheat with total decrease of 14.5% for three irrigation zones.

2.1.1 Environmental performance assessment

Characterization factors which used for the estimation of the impact of the foreground systems and the environmental impact factors for the background process are presented in Annex 1. The environmental impact factors were obtained from open access databases. The results of the environmental impacts of the entire system for average and dry year condition are presented in Table 2. The contribution of background and foreground system in the environmental impact assessment is given in Figure 5 while the environmental impact breakdown for each indicator is presented in Figure 6. The studied system was characterized by significant contribution of the foreground processes in climate change impact category due to direct emissions from fertilizer and fuel consumption, eutrophication of groundwater and surface water due to NO_3 and PO_4^{3-} leaching, acidification on non-agricultural soils through deposition of NH_3 and freshwater ecosystem impact due to irrigation (Figure 5). On background processes significant contribution of farm inputs (mainly N fertilizer production) was observed in the categories of climate change, human toxicity, fossil fuel depletion and freshwater aquatic eco-toxicity.

Table 2. Environmental Impacts of the Study System (Baseline). The change refers to the whole system and the difference between dry and average year.

	AVG YEAR		DRY YEAR		Change
Indicator	**FORE**	**BACK**	**FORE**	**BACK**	**%**
Climate Change (kgCO2eq)	66,758,406	22,537,727	70,461,903	22,952,751	4.6%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	20,863,178	6.63%
Freshwater Resource Depletion (m^3)	13,753,846	0	15,428,424	0	12.18%
Eutrophication (kgPO_4eq)	729,687	155,989	729,687	156,185	0.02%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,890,531	0.85%
Acidification (kgSO_2eq)	934,331	233,975	934,331	236,768	0.24%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,299,178	0.25%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	26,065	4.40%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	32,479	1.18%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	11,718	2.18%
Mineral Depletion (kgFe-eq)	0	12,146	0	13,059	7.51%

The GHG emissions (related to climate change) due to the foreground processes necessary for crop production accounted for 75% of total GHG emission of the study area, with fuel consumption accounting for 60% and N fertilizer 40%. A share of 18% refers to background system processes where the main source, by 58%, was N fertilizer production due to relative high impact factor.

For measuring the impacts on freshwater ecosystems due to freshwater abstraction the withdrawal of freshwater for each case (surface and groundwater) was quantified in the inventory analysis. The water availability (WTA) ratio represents the sensitivity of freshwater ecosystems towards freshwater withdrawal on a local level and, for the Ofanto River Basin, it was assumed to be 0.15. Since the WTA ratio refers to the foreground river basin only foreground impact was calculated. From the results of simulation it was estimated that the availability of freshwater resources decreases to 13,753,845 m^3/year.

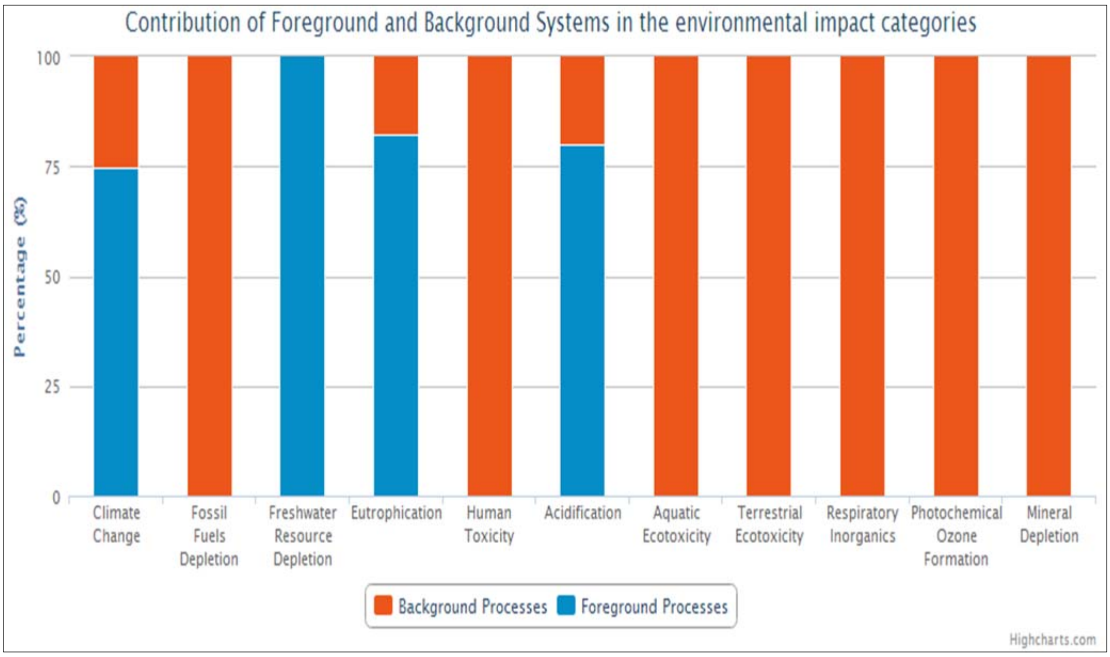


Figure 5. Contribution of Foreground and Background Systems in the environmental impact categories for normal year conditions

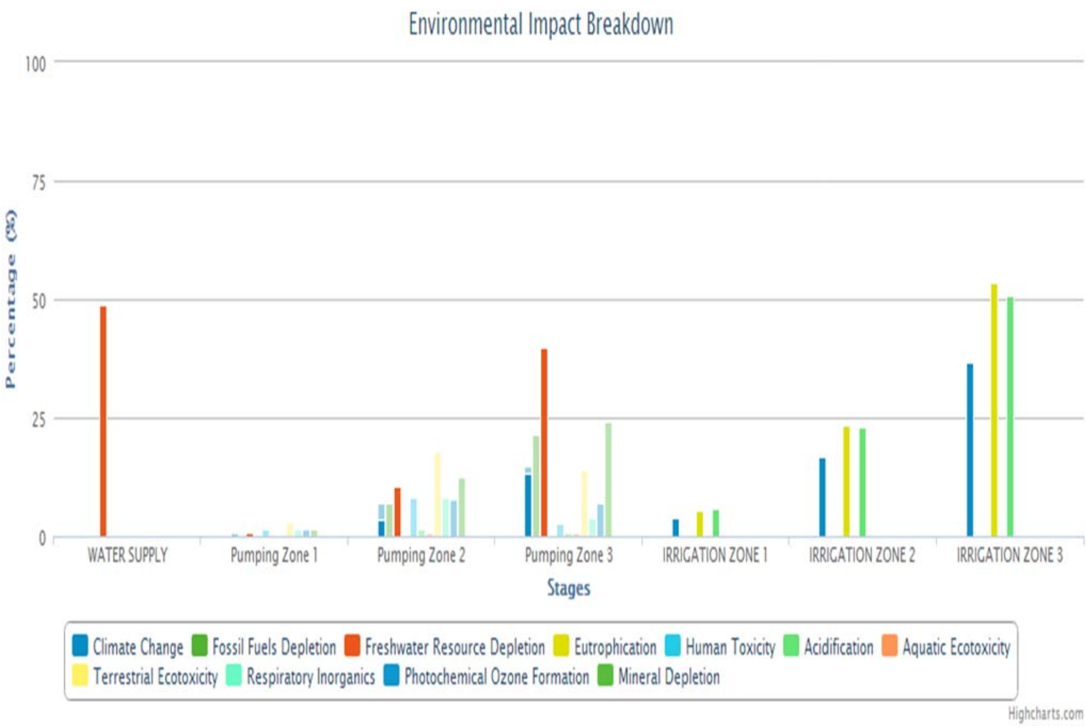


Figure 6. Environmental Impact Breakdown, percentage per stage

Although P has higher eutrophication potential than N (1 vs 0.1), the main source of eutrophication (44% contribution) was N fertilizer due to relatively high loads in water bodies. The opposite was true for background system processes where the main source of eutrophication by 98% was P fertilizer. Total contribution of background system processes to total eutrophication potential was 20%. The main source of acidification in foreground system was ammonia (NH_3) volatilization, whereas in background system it was nitrogen production. For background system processes of indicators human toxicity, respiratory inorganics, freshwater aquatic eco-toxicity, photochemical ozone formation and fossil fuel depletion the highest impacts refer to nitrogen production. High environmental effects from electricity and diesel production processes are mainly represented by the impact categories of terrestrial eco-toxicity and minerals depletion.

Considering different irrigation zones, the highest environmental impact indicators were observed in irrigation zone 3 due to highest consumption of water service related materials and supplementary resources. If water withdrawal and delivery stages are considered, the highest impact for impact categories of terrestrial eco-toxicity, respiratory inorganics and photo chemical ozone formation comes from irrigation zone 2. This was due to higher relative impact factor from electricity production for those impact categories and contribution of energy delivered and consumed in pumping stations of zone 2 which accounted for 54% of total energy used in that zone.

In comparison with normal hydrological years, the environmental indicators change under dry year conditions because more irrigation and related energy input were required. This caused an increase of GHG emissions by 4.6%, freshwater resource depletion by 12.2%, mineral depletion by 7.5%, fossil fuel depletion by 6.6% and terrestrial eco-toxicity by 4.4%. High environmental impacts from background processes were mainly caused for the impact categories of fossil fuel depletion, terrestrial eco-toxicity, and mineral depletion due to relatively high impact factors for diesel production. Minor change was seen in eutrophication, acidification, human toxicity and aquatic ecotoxicity due to low impact factor for resource production processes and no changes in fertilizer application.

2.1.2 Economic performance assessment

The economic performance assessment for the baseline scenario for a normal and dry hydrological year at the level of individual actors is presented in Table 3, while Figure 7 summarizes the economic results for the actors involved in the system. The results are calculated using the above data and the life cycle inventory flows. It should be noted that the costs of externalities (taxes for pollution/emission, either positive for governments or negative for farmers) of irrigation were not taken into account.

The Total Value Added (TVA) to the product from the water use of the Sinistra Ofanto irrigation system was estimated at about 96.5 M€ or 2,869 €/ha. This corresponds to 1.15 €/m^3 water used.

Overall, the results indicate that total value added of the system greatly depends upon the yields achieved, i.e. upon the level of water use. From Table 3 and Figure 7 it can be observed that the highest benefits are gained in FA3 with 3949 €/ha due to the largest gross income which is the consequence of more profitable cropping pattern and greater irrigation water supply (3,385 m^3/ha) with respect to zones 1 and 2 (901 and 2,375 m^3/ha). Despite having a smaller surface in comparison with zone 2 and high land occupation of wheat, zone 1 shows a better economic performance due to lower unitary life cycle cost (i.e. production cost) which depends on the cropping pattern. In fact, in zone 2, the large areas are cultivated with table grape which has high production cost (881 €/ha). On the contrary, in zone 1, the large areas are cultivated with rainfed wheat, with low production cost (125.7 €/ha). The total costs for CBC estimated for the reference year 2007 were about 6.2 million € where fixed cost was about 4.34 million € (70% of total) while the variable cost of water distribution was 1.86 million € (30% of total). The analysis of the CBC economic balance shows a large difference between the cost of water and revenues with a negative balance of more than 2 million €. The lowest cost of the CBC for supplying water is relative to the irrigation zone 1, although this zone has the biggest unitary cost. The low total cost in this zone is due to the lower volume of water supplied (2 Mm^3) in respect to zones 2 and 3 (8.7 and 25.8 Mm^3, respectively).

Table 3. Economic performance results (Baseline)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	**Baseline (Normal Year)**				
FA1	**0**	**4,047,730**	**8,420,521**	**-294,779**	**4,078,012**
FA2	**0**	**26,535,155**	**41,747,290**	**-952,045**	**14,260,090**
FA3	**0**	**74,179,575**	**157,340,808**	**-2,640,401**	**80,520,832**
CBC	**0**	**6,204,164**	**0**	**3,887,225**	**-2,316,939**
Total Value Added					**96,541,994**
Actor	**Baseline (Dry Year)**				
FA1	**0**	**4,087,619**	**7,861,843**	**-294,779**	**3,479,444**
FA2	**0**	**26,865,864**	**39,538,332**	**-952,045**	**11,720,423**
FA3	**0**	**75,215,012**	**152,669,470**	**-2,640,401**	**74,814,058**
CBC	**0**	**6,204,164**	**0**	**3,887,225**	**-2,316,939**
Total Value Added					**87,696,986**

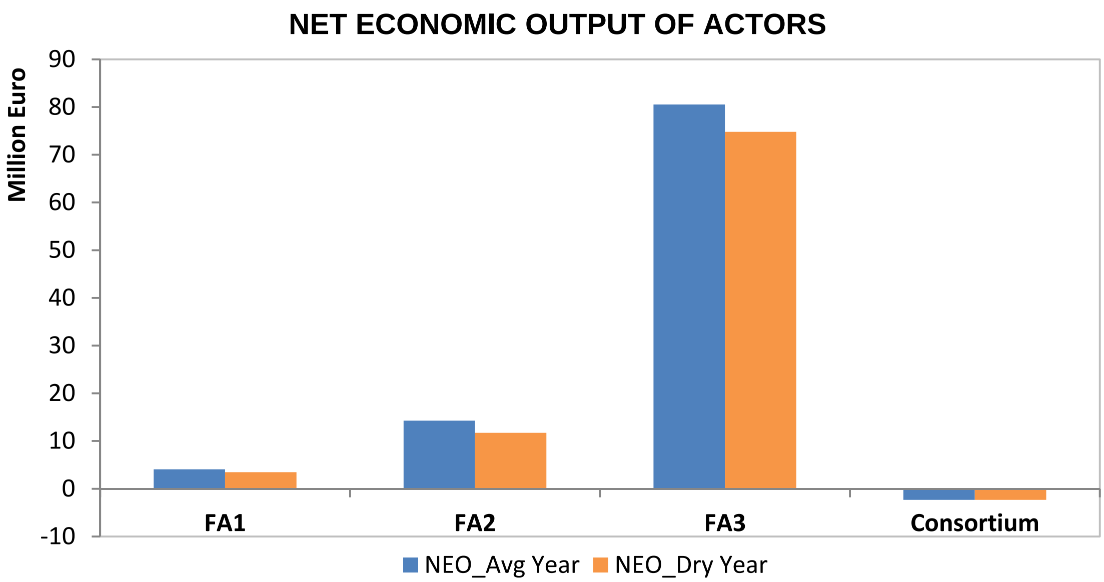


Figure 7. Economic Performance per Actor (Baseline)

For dry year conditions, the Total Value Added (TVA) of the Sinistra Ofanto irrigation system was estimated at about 87.6 M€ or 2606 €/ha. This corresponds to 0.926 €/m³ water used. The differences between average and high water demand conditions were very significant. With regard to average year, in a dry year TVA decreased by 8.8 M€ or 9.2 %. The decline of unitary net economic output (NEO) was larger in zones 1 and 2 than in zone 3. This is due to the fact that in these two zones large areas were cultivated with wheat rainfed which caused a yield reduction in comparison to normal hydrological years, in average from 4.05 to 3.45 t/ha.

2.1.3 Eco-efficiency indicators

The results of eco-efficiency indicators for baseline scenario and considering the whole agricultural water system of Sinistra Ofanto are reported in Table 4. The results are presented by the ratio of the economic indicator to the 11 relevant environmental impact categories considered for this study area. A higher value of indicator means a higher eco-efficiency.

The eco-efficiency tends to decrease as pressure on resources increase (Figure 8), i.e., when irrigation requirements are higher and efficiency of the system is declining. From Figure 8 it seems that change of weather conditions (i.e., annual precipitation) from 514 to 420 mm is worsening the eco-efficiency of the system mainly for indicators depending on life cycle production, diesel combustion and water withdrawals. The highest decrease, in the case of dry year conditions, was observed for freshwater resource depletion up to 19%. This was due to the highest decrease of environmental performance as a result of increase of groundwater withdrawals by 12% compared to a normal hydrological year.

In absolute terms, the highest eco-efficiency corresponds to zone 1 due to a less water demanding cropping pattern. However, as mentioned previously, the total value added of the system greatly depends upon the yields achieved, i.e. economic benefits. Thus, the analysis found that the highest eco-efficiency corresponds to irrigation zone 3 which has the highest net economic output although it causes the highest environmental burdens. Zone 2 has the lowest eco-efficiency due to relative high land occupation of low income crops which affected the eco-efficiency ratio negatively.

Table 4. Eco-efficiency indicators for the baseline scenario of Sinistra Ofanto agricultural water system

Indicator	Unit	Baseline (Normal Year)	Baseline (Dry Year)	Change %
Climate Change	€/tCO_2eq	1,081.1	938.79	-13.2%
Fossil fuels depletion	€/MJ	4.9	4.20	-14.8%
Freshwater resource depletion	€/m^3	7.0	5.68	-19.02%
Eutrophication	€/kgPO_4^{-3},eq	109.0	99.00	-9.18%
Human toxicity	€/kg1,4-DBeq	19.9	17.93	-9.93%
Acidification	€/kgSO_{2-},eq	82.6	74.88	-9.38%
Aquatic Ecotoxicity	€/kg1,4-DBeq	74.5	67.50	-9.39%
Terrestrial Ecotoxicity	€/kg1,4-DBeq	3,866.7	3364.56	-12.99%
Respiratory inorganics	€/kgPM_{10},eq	3,007.7	2700.11	-10.23%
Photochemical ozone formation	€/kgC_2H_4,eq	8,417.9	7483.65	-11.10%
Minerals depletion	€/kg Fe-eq	7,948.3	6715.48	-15.51%

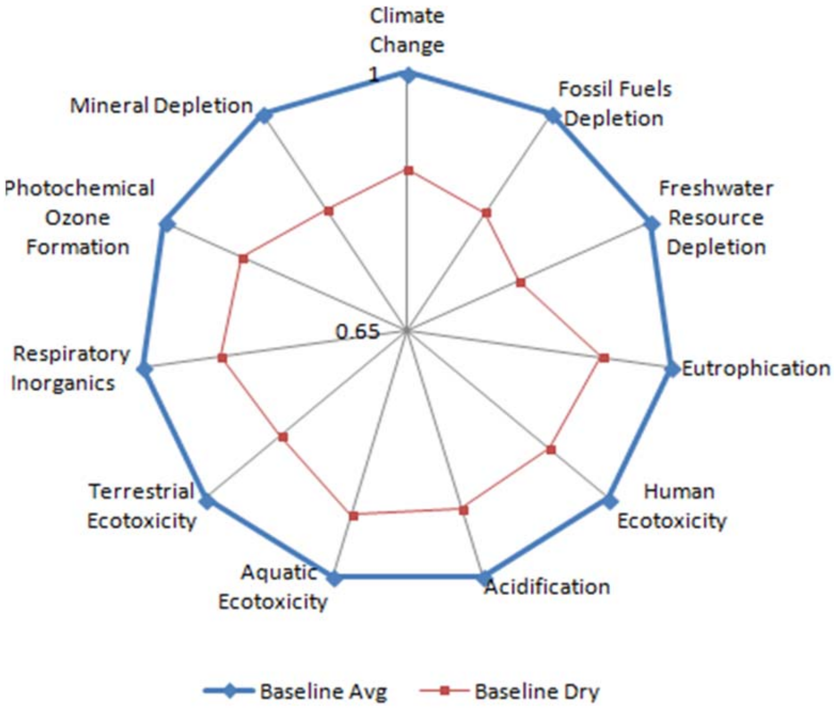


Figure 8. Comparison of eco-efficiency indicators in baseline scenario (Average and dry year conditions)

2.2 Value chain upgrade

In the case of the Sinistra Ofanto irrigation scheme, the environmental impacts are clearly dependent on cropping pattern and water availability and management, i.e. yield production. In general, the economic benefits increase with increasing irrigation water supply and its efficiency, and moving towards more commercial cropping pattern (as in the case of irrigation zone 3). However, if the efficiency of water delivery and supply does not improve, the environmental burden is increasing because greater water service related materials and supplementary resources are used. In general, the hydrological conditions play a relevant role in the eco-efficiency assessment because more precipitation usually means (at least for winter crops) lower irrigation requirements and therefore less consumption of resources. However, in the case of a dry year, with annual precipitation of around 400mm or less, several problems could occur in terms of both economic and environmental sustainability (including an excessive depletion of the aquifers). As a whole and in the case of a normal hydrological year, the results of this study confirm that the system is performing below the expected sustainability limits because the groundwater withdrawal is greater than recharge for about 16.8 Mm^3 per year which indicates a clear trend of reduction of water availability in the region and worsening of environmental conditions. Therefore, the introduction of new technologies and their uptake are urgently needed to contribute in the improvement of actual situation and the eco-efficiency of the system. These improvements are even more relevant for the system running under dry conditions.

The studied system was characterized by significant contribution of the foreground processes in climate change impact category due to direct emissions from fertilizer and fuel consumption, eutrophication of groundwater and surface water due to NO_3

and PO_4^{3-} leaching, acidification on non-agricultural soils through deposition of NH_3 and freshwater ecosystem impact due to irrigation. On the background processes, significant contribution of farm inputs (mainly nitrogen production) was observed in the categories of climate change, human toxicity, fossil fuel depletion and freshwater aquatic ecotoxicity. Thus, the upgrading of the value chain through innovative technologies should aim at improving the key indicators related to the use of non-renewable energy sources, fresh water abstraction and fertilizer use. Indicative options towards that are the following:

- The adaptation of more efficient irrigation technologies that will reduce energy and fresh water consumption on the agricultural use level. This will have an impact on:
    - the climate change, fossil fuel depletion, human toxicity eco-efficiency indicator from reduction of diesel use in direct pumping,
    - the climate change, acidification, human toxicity and fossil fuel eco-efficiency indicator from reduction of electricity used in water supply network, and
    - the reduction of freshwater resource depletion.
- Reduction of the discharge of pollutants due to the use of less toxic chemicals (fertilizers) with an impact on
    - the “eutrophication” and “acidification” eco-efficiency indicators.

2.3 Individual assessment of innovative technologies

After performing the baseline eco-efficiency assessment the next phase includes the assessment and comparison of alternative technologies that can best improve the eco-efficiency of the system. The baseline eco-efficiency assessment was performed and possible options for the improvement of the system performances were discussed and selected together with local stakeholders during workshops and meetings. Accordingly, the following technological scenarios were assessed to determine their impact on the eco-efficiency of the system:

- Scenario 1 (S1): Improvement of the on-farm irrigation efficiency and water saving through a larger adoption of drip irrigation instead of micro-sprinklers for artichoke, olives and orchards while keeping wheat rainfed.
- Scenario 2 (S2): Improvement of the on-farm irrigation efficiency and water saving through a larger adoption of subsurface drip irrigation (SDI) for artichoke, olives, table grapes and orchards while keeping wheat rainfed. This technology is implemented in FA1 and FA3.
- Scenario 3 (S3): Substitution of the on-farm diesel engine pumps with the electricity engine pumps – the pumps are used for the water abstraction from the aquifer and from the river and then for water delivery and on-farm irrigation.
- Scenario 4 (S4): Substitution of the on-farm diesel engine pumps with solar powered pumps – the pumps are used for the water abstraction from the aquifer and from the river and then for water delivery and on-farm irrigation.

- Scenario 5 (S5): Application of smart (remote) technologies for monitoring of soil-plant-atmosphere continuum and precise on-farm irrigation management.
- Scenario 6 (S6): Evaluating effectiveness of new water pricing policy and increasing annual water supply by CBC from 36 Mm^3 to 45 Mm^3. This is a strategy adopted at the water distribution stage.

All scenarios have been developed in SEAT and EVAT and results were evaluated on the respective values of the eco-efficiency indicators. For scenario 1 and 2 the groundwater withdrawal was assumed to remain the same as under the baseline, because in this study we cannot evaluate properly the groundwater balance and this evaluation should be integrated all over the watershed. This means that a farmer can irrigate more crop per unit area of water used due to increase of efficiency and therefore, there are increases of the agricultural production per unit of land. For each technology an "Eco-efficiency plot" was created which provides eco-efficiency performance comparison of the new technology compared to baseline and describes what are the impacts of each alternative evaluated. A value of 1 represents the baseline scenario and other alternatives are normalized in relation to 1. Farther to the origin (0) an alternative lies, the more favorable it is. To have a better understanding of how the indicators are affected from technology uptake, the eco-efficiency comparison was shown in two different scales. Based on that analysis the best scenario was chosen and recommendations to improve the performance of irrigation system were identified.

2.3.1 Scenario 1: Drip Irrigation Technology

The scenario examined consists in the improvement of the on-farm irrigation efficiency and water saving through a larger adoption of drip irrigation (instead of micro-sprinklers) for artichoke, olives and orchards while keeping wheat rainfed. By changing the irrigation method from mini-sprinkler to drip-irrigation, water and energy savings can be achieved through reducing the water input and pressure requirements.

Drip irrigation is nowadays one of the highly efficient irrigation method which allows precise application of water through the use of pressurized pipes and drippers directly to root zone. Since water is applied directly to the root zone, evaporation and runoff are minimized. This system also allows precise application of water-soluble fertilizers and other agricultural chemicals. Drip irrigation, especially in horticultural systems, offers a high potential to limit water inputs, to improve water use efficiency, and to better match the crop water demand in time and space. Yields often (but not always) exceed those obtained by other irrigation methods. This is because, inside the bulb, light, frequent irrigations and fertilizer applications (fertigation) can maintain optimum growth conditions. Irrigation frequency varies from daily to every three or four days. Drip irrigation systems that are operated by solar-driven pumps are a particularly promising alternative for the Mediterranean region. Despite such advantages, this technology faces some possible barriers to implementation including lack of access to financing for the purchase of equipment, higher initial investment cost and annual operation cost. Moreover, some problems may occur on these systems such as salt accumulation at edges of wetted areas and mechanical blocking of emitters (Phocaides, 2000).

The adoption of drip irrigation instead of micro-sprinkler irrigation will increase the overall on-farm irrigation efficiency from 76% to 85.5%. In addition, the adoption of drip systems means a reduction of operating pressure requirements by about 0.5 bars (Phocaides, 2000). Drip irrigation systems have an investment cost of 2000 €/ha, operation and maintenance cost of 100 €/ha/year and a lifetime of 15 years (Source: ECOWATER technology inventory).

2.3.1.1 Environmental performance assessment

The environmental performance of scenario 1 compared to the baseline scenario is presented in Table 5. The uptake of the drip irrigation technology will mainly affect the climate change environmental impacts because direct emissions (foreground) from fuel used for irrigation were reduced by 778 tonCO_2eq (i.e 1.16%) due to reduction of pressure requirements. In addition, all environmental impacts categories on background processes related to the life cycle of diesel production were positively affected according to the impact factor. In absolute terms, the environmental impact categories with the highest decrease of related emissions were climate change, fossil fuel depletion and human toxicity due to the highest impact factor for diesel production. Related emissions for these categories were reduced by 87 tnCO_2eq, 272 MJ and 8.6 tn1,4-DBeq. Thus, in the background system, the implementation of this technology is more suitable for reduction of fossil fuel depletion emission. For the climate change indicator, the results were mostly affected by the foreground system emissions, which have about 8 times more powerful impact than the background system (2.89 kgCO_2/Liter vs 0.38 kgCO_2/Liter). Overall, the uptake of drip irrigation technology tends to improve slightly the environmental performance in comparison with baseline condition, up to 1.58% in the case of mineral depletion.

Table 5. Environmental Impacts of the Study System (Baseline vs Drip Irrigation Technology)

	BASELINE		DRIP		Change
Indicator	**FORE**	**BACK**	**FORE**	**BACK**	**%**
Climate Change (kgCO_2eq)	66,758,406	22,537,727	65,980,005	22,450,498	-0.97%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	19,292,766	-1.39%
Freshwater Resource Depletion (m^3)	13,753,846	0	13,753,846	0	0.00%
Eutrophication (kgPO_4eq)	729,687	155,989	729,687	155,948	0.00%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,840,804	-0.18%
Acidification (kgSO_2eq)	934,331	233,975	934,331	233,388	-0.05%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,295,286	-0.05%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	24,737	-0.92%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	32,019	-0.25%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	11,416	-0.46%
Mineral Depletion (kgFe-eq)	0	12,146	0	11,954	-1.58%

2.3.1.2 Economic performance assessment

The assessment of the economic performance for scenario 1 at the level of individual actors is presented in Table 6. Following the increase of overall irrigation efficiency, total water use in the case of adoption of drip irrigation system was reduced by 2%

due to reduction of groundwater withdrawals from 45.4 Mm^3 to 43.7 Mm^3 (i.e. 3.6%). This means that a farmer can irrigate more crops per unit area of water used and, therefore, increases the agricultural production per unit of land. Using the same water withdrawals as in the baseline case (S0), the yield was increased in order of priority (Orchard, Artichoke, Olives), defined in agreement with farmers, with an average of 5, 10.2 and 4.67%, respectively for zone 1, 2 and 3. Thus, total potential additional yield was estimated to 4363 ton which gives an additional income of 2.32 MEuro/Year. Despite the yield increase, from the analysis, only zone 1 and 3 can cover annual investment cost due to more diversified cropping pattern in term of land allocation of each crop. In zone 2, the olive trees prevail (i.e., 35%) which for the same increase of unit of yield needs higher total water requirements than artichoke and orchards. The best economic performance was for zone 1 which has 7 % higher income that investment cost for the implementation of new technology. Life cycle cost due to diesel consumption were reduced by 0.29 M€/year. However, TVA decreased by 0.6% due to higher investment cost for the new technology. The Total Value Added (TVA) in the case of scenario 1 was estimated at 95.9 M€ or 2,850 €/ha. This correspond to 1.147 €/m^3 water used.

Table 6. Economic performance results (Drip Irrigation Technology)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Drip Irrigation Technology				
FA1	32,766	4,061,188	8,473,763	-294,779	4,085,029
FA2	710,736	26,842,637	41,830,605	-952,045	13,325,188
FA3	1,401,202	74,676,180	159,526,988	-2,640,401	80,809,205
CBC	0	6,204,164	0	3,887,225	-2,316,939
Total Value Added					95,902,483

2.3.1.3 Eco-efficiency assessment

In Table 7 the results of the eco-efficiency indicators are reported while Figure 9 presents the eco-efficiency comparison for baseline and scenario 1. The one on the left is the default chart and is necessary to compare all scenarios together while the one on the right highlights the differences between the baseline and the examined scenario.

Uptake of drip irrigation technology increased eco-efficiency for climate change, fossil fuel depletion, terrestrial ecotoxicity and mineral depletion environmental impact indicators due the highest decrease of related emissions. In relative terms, the highest increase of eco-efficiency in case of scenario 1 was for mineral depletion indicator by 0.9%. This was due to higher relative increase of environmental performance. Seven eco-efficiency indicators were negatively affected because Total Value Added reduction was higher than the reduction of emissions for those categories. Hence, the change in relative terms of environmental performance in comparison with value added is smaller, and eco-efficiency tends to decrease. The highest decrease was observed for freshwater resource depletion impact category.

Table 7. Eco-efficiency indicators (Baseline vs Drip Irrigation Technology)

Indicator	Baseline Scenario	Drip Irrigation	Change %
Climate Change (€/tCO_2eq)	1,081.1	1,084.50	0.31%
Fossil fuels depletion (€/MJ)	4.9	4.97	0.74%
Freshwater resource depletion (€/m^{3})	7.0	6.97	-0.662%
Eutrophication (€/kgPO_4^{-3},eq)	109.0	108.29	-0.658%
Human toxicity (€/kg1,4-Dbeq)	19.9	19.81	-0.485%
Acidification (€/kgSO_{2-},eq)	82.6	82.13	-0.612%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	74.04	-0.611%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	3,876.89	0.26%
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	2,995.19	-0.41%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	8,400.65	-0.21%
Minerals depletion (€/kg Fe-eq)	7,948.3	8,022.31	0.93%

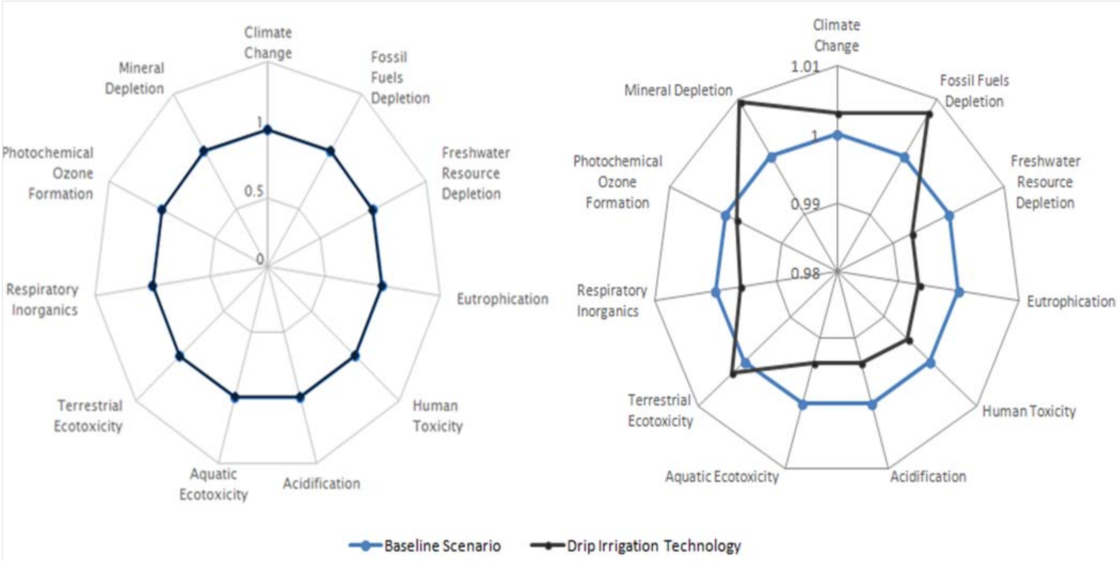


Figure 9. Comparison of eco-efficiency indicators in baseline scenario and scenario 1 (Drip irrigation technology)

2.3.2 Scenario 2: Subsurface Drip Irrigation Technology

The technology examined consists of the improvement of the on-farm irrigation efficiency and water saving for FA1 and FA3 through a larger adoption of drip irrigation (instead of micro-sprinklers) for artichoke, olives and orchards and sub-drip irrigation system (instead of drip) for table grapes while keeping wheat rainfed.

Subsurface drip (SDI) is a low-pressure, high efficiency irrigation system with typical application efficiencies in the order of 95% that uses buried drip tubes or drip tape to meet crop water needs. A SDI system is flexible and can provide frequent light irrigation which is especially suitable for arid, semi-arid, hot, and windy areas with limited water supply. With a well-maintained SDI system water and fertilizer application efficiencies are enhanced and labor needs are reduced (Reich, 2009). Subsurface irrigation saves water and improves yields by eliminating surface water evaporation and reducing the incidence of disease and weeds. Phene et al. (1987) demonstrated significant yield increases in tomatoes with the use of high frequency SDI and precise fertility management. Results reviewed by Ayars et al. (1999) on research conducted by scientists at the Water Management Research Laboratory over a period of 15 years demonstrated significant yield and water use efficiency increases in all crops. There are several barriers to SDI adoption which include farmer aversion to adopting new technology, high investment cost and periodic large water applications required to leach out salts. In addition, there are also some technical barriers that can restrict the adoption of SDI (i.e clogging of emitters, animal damage, leaks). However, all of them can be resolved by proper management strategies.

The adoption of subsurface drip irrigation instead of micro-sprinkler and drip irrigation will increase the overall on-farm irrigation efficiency from 76% and 85.5% to 90.25% for crop selected. In addition, the adoption of subsurface drip system means a reduction of operating pressure requirements by about 0.5 bars (Phocaides, 2000). Subsurface drip irrigation systems have an investment cost of 3000 €/ha, operation and maintenance cost of 100 €/ha/year and a lifetime of 15 years.

2.3.2.1 Environmental performance assessment

The environmental performance of scenario 2 compared to the baseline scenario is presented in Table 8. The uptake of subsurface drip technology shows the same environmental performance with scenario 1 due to the same operating pressure of the system. Thus, the environmental impact categories mainly affected from uptake of this technology were climate change, fossil fuel depletion and human toxicity due to the highest impact factor for diesel production. Net CO_2 savings were estimated as 865 tonCO_2eq or 1% due to high impact reduction from foreground processes. Related emission for fossil fuel depletion and human toxicity were reduced by 272 MJ and 8.6 ton1.4-DBeq, respectively. Overall, the uptake of subsurface drip irrigation technology tends to improve slightly the environmental performance in comparison with baseline condition, up to 1.58% in the case of mineral depletion.

Table 8. Environmental Impacts of the Study System (Baseline vs Subsurface Drip Irrigation Technology)

Indicator	AVG YEAR		SUB-DRIP		Change
	FORE	BACK	FORE	BACK	%
Climate Change (kgCO_2eq)	66,758,406	22,537,727	65,980,005	22,450,498	-0.97%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	19,292,766	-1.39%
Freshwater Resource Depletion (m^3)	13,753,846	0	13,753,846	0	0.00%
Eutrophication (kgPO_4eq)	729,687	155,989	729,687	155,948	0.00%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,840,804	-0.18%
Acidification (kgSO_2eq)	934,331	233,975	934,331	233,388	-0.05%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,295,286	-0.05%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	24,737	-0.92%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	32,019	-0.25%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	11,416	-0.46%
Mineral Depletion (kgFe-eq)	0	12,146	0	11,954	-1.58%

2.3.2.2 Economic performance assessment

The assessment of the economic performance for scenario 2 at the level of individual actors is presented in Table 9. In the case of SDI a larger reduction in irrigation water use can be achieved in comparison with a drip irrigation system, following the increase in irrigation efficiency and related crops. Efficiency of water use tends to increase by 3.6% for total water use and 6.6% for groundwater withdrawals in SDI comparing with baseline S0. This means that a farmer can irrigate more crop per unit area of water used and, therefore, increases of the agricultural production per unit of land. Using the same water withdrawals as in the baseline case (S0), the yield was increased in order of priority (Orchard, Artichoke, Olives) with an average of 7.5 and 10%, respectively for zones 1 and 3. Therefore, total potential additional yield was estimated as 8591 tons which gives an additional income of 4.55 M€/year. Moreover, life cycle cost due to diesel consumption were reduced by 0.29 M€/year. Hence, TVA in comparison with baseline was slightly increased by 0.8%. The Total Value Added (TVA) in the case of scenario 2 was estimated at 97.2 M€ or 2,889 €/ha. This corresponds to 1.163 €/m³ water used.

Table 9. Economic performance results (Baseline vs Subsurface drip irrigation technology)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Subsurface Drip Irrigation Technology				
FA1	49,149	4,061,188	8,500,299	-294,779	4,095,183
FA2	0	26,473,777	41,747,290	-952,045	14,321,468
FA3	3,036,227	74,999,480	161,817,878	-2,640,401	81,141,771
CBC	0	6,204,164	0	3,887,225	-2,316,939
Total Value Added					97,241,483

2.3.2.3 Eco-efficiency assessment

Table 10 shows the results of the eco-efficiency indicators while Figure 10 presents the eco-efficiency comparison for baseline and scenario 2. The one on the left is the default chart and is necessary to compare all scenarios together while the one on the right highlights the differences between the baseline and the examined scenario.

Table 10. Eco-efficiency indicators (Baseline vs Subsurface drip irrigation technology)

Indicator	Baseline Scenario	Subsurface drip	Change %
Climate Change (€/tCO_2eq)	1,081.1	1,100	1.7%
Fossil fuels depletion (€/MJ)	4.9	5	2.15%
Freshwater resource depletion (€/$m^{3)}$	7.0	7	1.01%
Eutrophication (€/kgPO_4^{-3},eq)	109.0	110	0.73%
Human toxicity (€/kg1,4-Dbeq)	19.9	20	0.90%
Acidification (€/kgSO_{2-},eq)	82.6	83	0.78%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	75	0.78%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	3,931	1.66%
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	3,037	0.98%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	8,518	1.19%
Minerals depletion (€/kg Fe-eq)	7,948.3	8,134	2.34%

The uptake of subsurface drip irrigation technology improves eco-efficiency for all environmental impact indicators considered in this study, as TVA was increased and environmental performance was slightly improved in comparison with baseline. The highest improvement of eco-efficiency was observed for climate change, fossil fuel depletion, mineral depletion and terrestrial ecotoxicity indicators due to higher relative increase of environmental performance. The highest increase of eco-efficiency in case of scenario 2 was for the mineral depletion indicator, up to 2.34%.

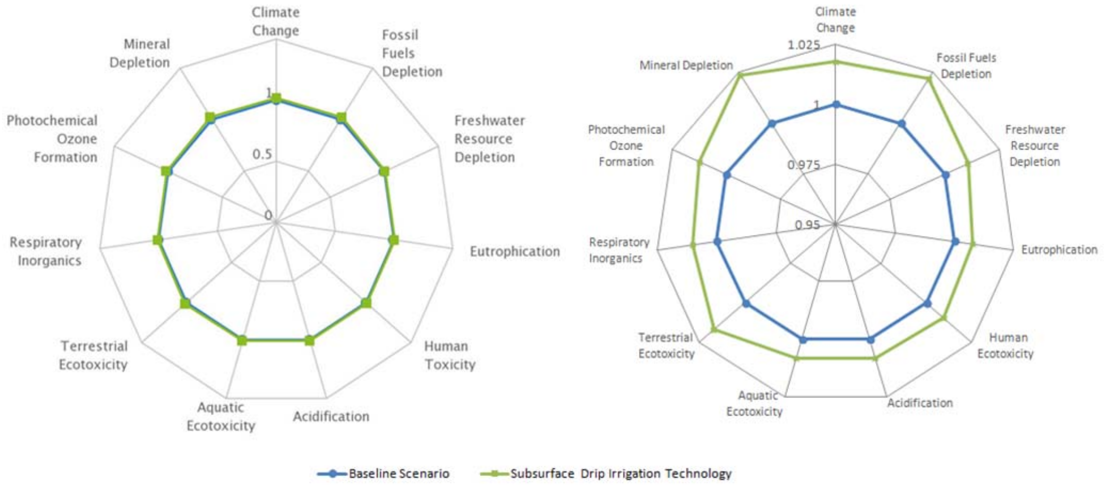


Figure 10. Comparison of eco-efficiency indicators in baseline scenario and scenario 2 (Subsurface drip irrigation technology)

2.3.3 Scenario 3: Electric Variable Speed Pumps

In the case of scenario 3, the improvement of the energy efficiency through the replacement of traditional pumps (diesel engine) with more efficient electric variable speed pumps was evaluated.

As the pump is a major energy consumer in an irrigation system, any improvement in its efficiency reduces the cost of operating the system. Recent studies have considered variable speed pumps (VSPs) as an attractive alternative to reach this target instead of fixed pumps (Marchi, 2011). Variable-frequency drives of electric motors have the potential to adjust pump performance to match operating conditions by reducing motor and pump rpm. The use of variable speed devices allows control of the pump's speed electrically while using only the energy needed to produce a given flow. A 20% reduction in pump rpm reduces the pump capacity by 20% and reduces the total head by about 38% (Hanson, 1996). Ait Kadi et al. (1998) demonstrated that around 25% of energy can be saved in an irrigation district in Morocco by using variable-speed pump technology. Barutcu (2007) showed that using variable speed pumping station, an average of 0.116 kilowatt-hours of energy were saved per unit cubic meter of water pumped. Previous studies on Sinistra Ofanto irrigation districts showed that by using variable-speed pumps 20-35 % of energy savings could be achieved (Lamaddalena and Piccinni, 1993, Lamaddalena and Khila, 2011). Apart from these savings, many farmers are finding that variable speed pumps provide the flexibility required for their range of irrigation demands. However, the field operating conditions can vary throughout the irrigation season, causing the pump to operate under conditions other than the design conditions. Nowadays, there are still many barriers to the full implementation of this technology such as of knowledge about the performance of variable speed pump control, perception that a VSD is more expensive than the classical pump control and concerns about the reliability of the electronic devices (Pemberton, 2005). A further barrier is that electricity prices do not reflect full social costs given externalities from electricity generation and distribution (Waide, 2011).

Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size). Higher and lower ratings are possible. In this study, the efficiency of the complete unit (pump + motor) was 68 %, assuming pump efficiency 80% and motor efficiency 85% (Waide, 2011). In addition, a 15% reduction in total head was assumed since the pump is able to adjust the performance based on the water demand and pressure variation over time. It is estimated that around 3395 pumps with an average discharge of 10-15 m^3/hour are needed to fulfill the demand as in case of baseline condition in study area. Electric variable speed pumps of the performance (Q-H) curve adaptable to the CS conditions have an investment cost of 2000 €/pump and a lifetime of 8 years. The listed cost of the pump and controller is a conservative price based on the suggested retail price and the price taken from various online distributors of pumps[1]. The price for electricity consumption was calculated as 0.2 €/kWh.

2.3.3.1 Environmental performance assessment

The environmental performance of scenario 3, compared to the baseline scenario, is presented in Table 11. The application of new electric variable speed pumps instead of diesel engine pumps will substantially affect the climate change environmental impacts because direct emissions from fuel combustion used for irrigation were reduced by 15,269 $tnCO_2eq$ or 22.8%. In addition, all the other environmental impacts related to the life cycle of diesel production, processing and distribution to the final customers were reduced by 38%, where the main environmental impact categories affected were climate change, fossil fuel depletion and human toxicity due to the highest impact factor.

Table 11. Environmental Impacts of the Study System (Baseline vs Electric VSP)

Indicator	AVG YEAR		ELECTRIC VSP		Change
	FORE	BACK	FORE	BACK	%
Climate Change ($kgCO_2eq$)	66,758,406	22,537,727	51,488,955	31,924,865	-6.6%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	15,161,282	-22.51%
Freshwater Resource Depletion (m^3)	13,753,846	0	13,753,846	0	0.00%
Eutrophication ($kgPO_4eq$)	729,687	155,989	729,687	157,848	0.21%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	6,116,010	26.12%
Acidification ($kgSO_2eq$)	934,331	233,975	934,331	286,274	4.48%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,311,551	1.20%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	34,554	38.39%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	39,781	23.93%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	13,260	15.62%
Mineral Depletion (kgFe-eq)	0	12,146	0	11,362	-6.45%

[1] www.deanbenett.com

However, when switching from diesel to electricity driven pumps, environmental impacts related to the life cycle of electricity production were increased by 132%. Overall, in background system climate change emission were increased by 42% or 9387 tonCO_2eq since electricity production has higher impact factor than diesel production (0.73 kgCO_{2eq}/Liter vs 0.38 kgCO_{2eq}/Liter). Hence, net CO_2 savings were estimated as 5882 tonCO_2eq or 6.6% due to high reduction of emission from foreground which has about 4-8 times more powerful impact than background processes. The indicator with the best environmental performance was fossil fuel depletion with net saving estimated as 4404 MJ (i.e 22.5%) since diesel production has higher impact factor than electricity production (1.19 vs 0.06). The highest decrease of environmental performance or highest increase of emission was observed for terrestrial ecotoxicity up to 38.4%.

Overall, uptake of new variable speed pumps shows good performance in foreground processes where climate change impact emissions were reduced by 22.8%. However, in background processes the environmental performance for 7 categories was worsening because electricity production has higher impact than diesel production. The new technology proposed is more suitable for climate change, fossil fuel depletion and mineral depletion environmental impact categories which are mainly affected from diesel combustion on foreground and life cycle production on background.

2.3.3.2 Economic performance assessment

The assessment of the economic performance for scenario 3 at the level of individual actors is presented in Table 12. Table 12 shows that the highest increase of costs was found for FA3 due to the need of greatest number of pumps which is a consequence of a high water demanding cropping pattern. Switching from diesel to electricity driven pumps the life cycle cost was reduced by 2.66 M€/yr due to reduction of diesel consumption which has higher cost than electricity (1.1 vs 0.2). Taking into account annual investment and operation and maintenance cost for each irrigation zone, net cost savings were estimated at 2.32 M€/yr. Hence, TVA in comparison with baseline was slightly increased by 1.3%. The Total Value Added (TVA) in the case of scenario 3 was estimated at 97.8 M€ or 2,906 €/ha. This corresponds to 1.17 €/m³ water used.

Table 12. Economic performance results (Baseline vs Electric VSP Pumps)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Electric Variable Speed Pumps				
FA1	12,607	4,036,585	8,420,521	-294,779	4,076,550
FA2	218,175	26,042,097	41,747,290	-952,045	14,534,974
FA3	819,684	72,361,870	157,340,808	-2,640,401	81,518,852
CBC	0	6,204,164	0	3,887,225	-2,316,939
Total Value Added					97,813,436

2.3.3.3 Eco-efficiency assessment

Table 13 shows the results of the eco-efficiency indicators while Figure 11 presents the eco-efficiency comparison for baseline and scenario 3. The one on the left is the default chart and is necessary to compare all scenarios together while the one on the right highlights the differences between the baseline and the examined scenario.

Implementation of new electric variable speed pumps was positively affecting the eco-efficiency of climate change, fossil fuel and mineral depletion due to reduction of foreground emission and lessening the impacts from life cycle of diesel production to electricity production. Comparing the eco-efficiency of different environmental impact categories was found that eco-efficiency of 5 environmental impact categories was negatively affected where the highest decrease was observed for terrestrial ecotoxicity indicator. Uptake of this technology can increase the eco-efficiency up to 30.75% in the case of fossil fuel depletion indicator.

Table 13. Eco-efficiency indicators (Baseline vs Electric VSP)

Indicator	Baseline Scenario	Electric VSP	Change %
Climate Change (€/tCO_2eq)	1,081.1	1,172.6	8.5%
Fossil fuels depletion (€/MJ)	4.9	6.5	30.75%
Freshwater resource depletion (€/$m^{3)}$	7.0	7.1	1.32%
Eutrophication (€/kgPO_4^{-3},eq)	109.0	110.2	1.10%
Human toxicity (€/kg1,4-Dbeq)	19.9	16.0	-19.66%
Acidification (€/kgSO_{2-},eq)	82.6	80.1	-3.02%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	74.6	0.11%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	2,830.8	-26.79%
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	2,458.8	-18.25%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	7,376.3	-12.37%
Minerals depletion (€/kg Fe-eq)	7,948.3	8,608.5	8.31%

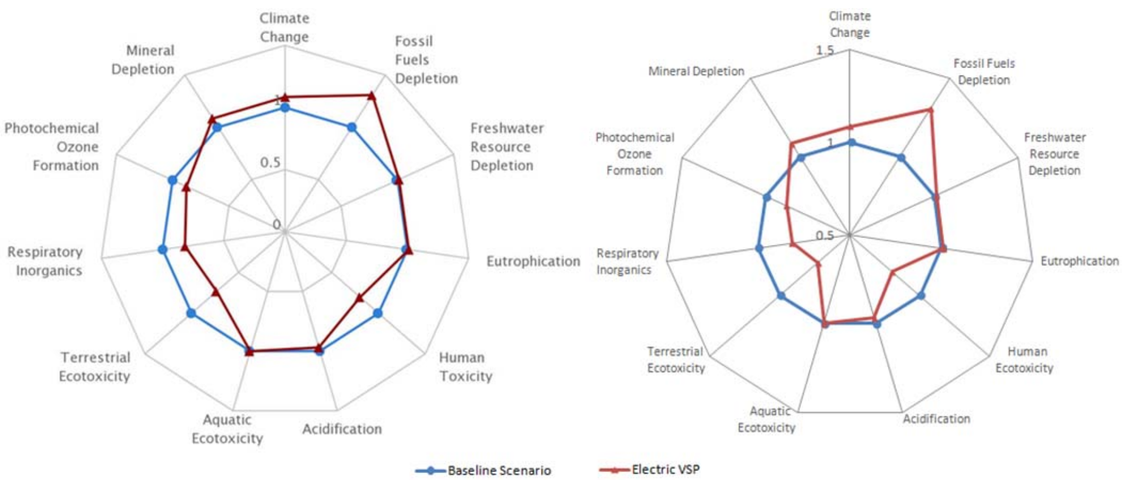


Figure 11. Comparison of eco-efficiency indicators in baseline scenario and scenario 3 (Electric VSP)

2.3.4 Scenario 4: Solar Powered Pumps

In the case of scenario 4, the improvement of the energy efficiency through the replacement of traditional pumps (diesel engine) with solar powered pumps was evaluated.

Solar water pumps are becoming attractive solutions towards sustainable agriculture. Solar pumps draw their energy from the sun, thus eliminating the need for diesel fuel or AC power and therefore produce no emissions. The pumping systems can be configured to meet a wide variety of demands. These pumps are reliable, cost effective, high-performance and low maintenance. The main disadvantages of these systems are high capital cost and requirement of water storage for cloudy days. Solar powered pumps are not adequate for large-scale irrigation, but can work for small-scale drip irrigation systems. Each solar water pumping system consists of a pump, pump motor, controller and matched solar panels. The cost of a solar-powered pumping system will vary according to its working characteristics, but the cost of most systems for stock-watering applications ranges between 1,500 and 5,000 €[2].

To fulfill the demand as in the case of baseline conditions, around 3925 pumps would need to be installed with an average discharge of 10-15 m^3/h and operation time of 6.5 hour/day (peak sunlight hours) for an irrigation season of 125 days. In general, taking into consideration the historical weather data, province of Foggia has an average of 210 sunny morning and 196 clear evenings. Regular irrigation season in the case of Sinistra Ofanto lasts from May to September (190 days). For this study it was assumed that the solar pumps have an investment cost of 6000€/pump and a lifetime of 10 years. The listed cost of the pump and controller is a conservative price based on the suggested retail price and the price taken from various online distributors of pumps[3].

2.3.4.1 Environmental performance assessment

The environmental performance of scenario 4 compared to the baseline scenario, is presented in Table 14. The uptake of new solar powered pumps improves moderately the environmental performance of environmental impact indicators which are mainly affected from diesel combustion and life cycle diesel production. Hence, related emission for climate change, fossil fuel depletion, mineral depletion and terrestrial ecotoxicitiy were decreased by 19, 27.3, 30.9 and 18.1%, respectively. For climate change indicator, the highest contribution (90%) was given by the foreground processes where direct emissions from fuel combustion used for irrigation were reduced by 15,269 tonCO_2eq or 22.8%. On background processes, climate change emission were reduced by 1711 tonCO_2eq i.e., 7.6%. Hence, net CO_2 savings by implementation of solar powered pumps were estimated as 16,980 tonCO_2eq or 19%. Related emission for fossil fuel depletion, mineral depletion and terrestrial ecotoxicitiy were decreased by 5350 MJ, 3.76 ton Fe-eq and 4.52 ton1,4-Dbeq, respectively. The indicator less affected was eutrophication potential due to the

[2] www.kellnsolar.com/+pub/document/tech-info/solar.pdf

[3] http://www.solaronline.com.au / www.grundfos.com / http://www.nasolarsolutions.com / www.sawtechnology.com

lowest impact factor from life cycle of diesel production. Overall, the indicator with the best environmental performance was mineral depletion.

Table 14. Environmental Impacts of the Study System (Baseline vs Solar Pumps)

Indicator	AVG YEAR		SOLAR PUMPS		Change
	FORE	BACK	FORE	BACK	%
Climate Change (kgCO_2eq)	66,758,406	22,537,727	51,488,955	20,826,591	-19.0%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	14,215,247	-27.35%
Freshwater Resource Depletion (m^3)	13,753,846	0	13,753,846	0	0.00%
Eutrophication (kgPO_4eq)	729,687	155,989	729,687	155,183	-0.09%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,680,024	-3.49%
Acidification (kgSO_2eq)	934,331	233,975	934,331	222,463	-0.99%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,282,703	-1.02%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	20,443	-18.12%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	30,531	-4.88%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	10,438	-8.98%
Mineral Depletion (kgFe-eq)	0	12,146	0	8,383	-30.98%

2.3.4.2 Economic performance assessment

The assessment of the economic performance for scenario 4 at the level of individual actors is presented in Table 15. From Table 14 it can be observed that the highest increase of costs was found in for FA3 due to the need of greatest number of pumps which is consequence of high water demanding cropping pattern. In the case of scenario 4 life cycle cost due to reduction of diesel consumption were reduced by 5.79 M€/year (i.e., 5.25%). Taking into account annual investment and operation and maintenance cost for each irrigation zone net cost saving were estimated 2.74 M€/year or 2.48%. Hence, TVA in comparison with baseline increases by 2.85%. The Total Value Added (TVA) in the case of scenario 4 was estimated at 99,2 M€ or 2,950 €/ha. This correspond to 1.188 €/m³ water used.

Table 15. Economic performance results (Baseline vs Solar Pumps)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	**Solar Powered Pumps**				
FA1	**36,597**	**4,014,579**	**8,420,521**	**-294,779**	**4,074,565**
FA2	**633,338**	**25,307,591**	**41,747,290**	**-952,045**	**14,854,315**
FA3	**2,379,460**	**69,643,231**	**157,340,808**	**-2,640,401**	**82,677,716**
CBC	**0**	**6,204,164**	**0**	**3,887,225**	**-2,316,939**
Total Value Added					**99,289,657**

2.3.4.3 Eco-efficiency assessment

In Table 16 are reported the results of the eco-efficiency indicators while Figure 12 presents the eco-efficiency comparison for baseline and scenario 4. The one on the left is the default chart and is necessary to compare all scenarios together while the one in the right highlights the differences between the baseline and the examined scenario.

As it can be noticed from Table 16 and Figure 9 implementation of new solar powered pumps was improving moderately the eco-efficiency for all environmental impact indicators considered in this study. Comparing the eco-efficiency of different environmental impact categories showed that highest eco-efficiency improvement was observed for mineral depletion indicator up to 49%.

Table 16. Eco-efficiency indicators (Baseline vs Solar Pumps)

Indicator	Baseline Scenario	Solar Pumps	Change %
Climate Change (€/tCO_2eq)	1,081.1	1,373.0	27%
Fossil fuels depletion (€/MJ)	4.9	7.0	41.6%
Freshwater resource depletion (€/m^{3})	7.0	7.2	2.85%
Eutrophication (€/kgPO_4^{-3},eq)	109.0	112.2	2.94%
Human toxicity (€/kg1,4-Dbeq)	19.9	21.2	6.57%
Acidification (€/kgSO_{2-},eq)	82.6	85.8	3.87%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	77.4	3.91%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	4,856.8	25.61%
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	3,252.1	8.13%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	9,512.1	13.00%
Minerals depletion (€/kg Fe-eq)	7,948.3	11,843.5	49.01%

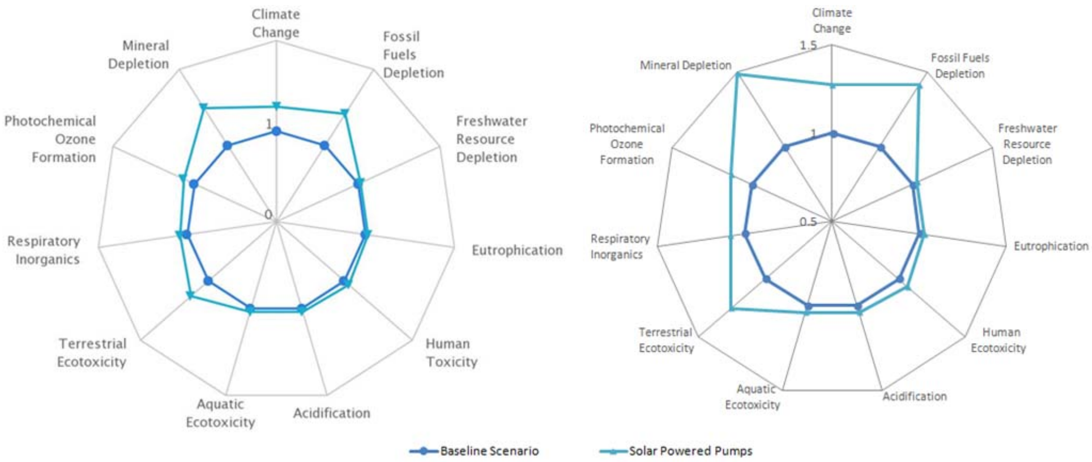


Figure 12. Comparison of eco-efficiency indicators in baseline scenario and scenario 3 (Solar Powered Pumps)

2.3.5 Scenario 5: Smart Technologies

In the case of scenario 5 the technology examined is application of smart (remote) technologies for monitoring of soil-plant-atmosphere continuum and more accurate irrigation management.

Smart technologies consist in a suite of software products and climatic and soil-water status monitoring devices which can be integrated within an irrigation system in order to support farmers with information on practices of irrigation and fertigation. This technology has a significant potential to optimize the water and fertilizer use efficiency, reduce associated costs and minimize the energy input requirement, while enhancing the crop yield. These benefits are achieved thanks to the interaction of soil-plant-atmosphere systems. Average water savings vary in the range from 8 to 20% according to case studies. For example, for a crop of peach water savings of

20% could be achieved while in the case of grapevine the efficiency of water use can be improved by 15% (examples taken from real experiments in the field of Bluleaf[4]).

In our study the new technology is implemented for vineyards and orchards to achieve a 5% reduction in water application and 5% in fertilizer application. Crops were selected from analysis based on area coverage, yield and market prices: 66% of irrigated area, the highest yield and good market prices. Thus, any improvement in water and fertilizers application results in the highest savings and thereby highest decrease of operational costs. Smart technologies have an investment cost of 1500 €/ha, and a lifetime of 15 years. Operation and maintenance cost were assumed as 5% of investment cost.

2.3.5.1 Environmental performance assessment

The environmental performance of scenario 5, compared to the baseline scenario, is presented in Table 17. The uptake of the smart technologies will mainly affect the climate change and eutrophication potential impacts because direct emissions (foreground) from fuel combustion and fertilizer use were slightly reduced. Direct emissions from fuel combustion used for irrigation were reduced by 2141 tonCO_2eq i.e. 3.2%. In addition, all environmental impacts categories related to the life cycle of diesel production were positively reduced by 3.28%. In background processes climate change emissions were reduced by 2% or 4.5 tonCO_2eq. Hence, net CO_2 savings were estimated as 2591 tonCO_2eq i.e. 2.9% due to high reduction of foreground emissions which has 4-8 times more powerful impact than background emissions. The emissions from fertilizer use were reduced by 3.1% in the foreground and background system affecting eutrophication and acidification environmental impact categories with net reduction of 28 tonPO_4eq/year and 35 tonSO_2eq/year, respectively. Freshwater resource depletion was reduced by 0.595 Mm^3 or 4.3 % due to reduction of groundwater withdrawals from 45.3 to 41.4 Mm^3.

Table 17. Environmental Impacts of the Study System (Baseline vs Smart Technologies)

Indicator	AVG YEAR		SMART TECH		Change
	FORE	BACK	FORE	BACK	%
Climate Change (kgCO2eq)	66,758,406	22,537,727	64,616,535	22,088,321	-2.9%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	18,954,837	-3.12%
Freshwater Resource Depletion (m^3)	13,753,846	0	13,158,292	0	-4.33%
Eutrophication (kgPO4eq)	729,687	155,989	706,073	150,776	-3.25%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,730,869	-2.45%
Acidification (kgSO_2eq)	934,331	233,975	905,363	228,019	-2.99%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,255,822	-3.10%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	24,499	-1.88%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	31,293	-2.51%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	11,168	-2.62%
Mineral Depletion (kgFe-eq)	0	12,146	0	11,822	-2.67%

[4] Blueleaf- http://www.blueleaf.it/

2.3.5.2 Economic performance assessment

The assessment of the economic performance for scenario 5 at the level of individual actors is presented in Table 18. Life cycle cost due to reduction of diesel and fertilizer consumption was reduced by 5.79 M€/year and 0.31 M€/year, respectively. However, TVA decreased by 3.26% due to the cost of investment and large scale implementation of the new technology. The Total Value Added (TVA) in the case of scenario 5 was estimated at 93.4 M€ or 2,777 €/ha. This corresponds to 1.174 €/m^3 water used. It should be noted that crops selected for the uptake of new technology constitutes about 53% of the cropping pattern for three irrigation zones.

Table 18. Economic performance results (Baseline vs Smart Technologies)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Smart Technologies				
FA1	23,744	4,052,707	8,420,521	-294,779	4,049,291
FA2	555,885	26,662,068	41,747,290	-952,045	13,577,292
FA3	1,982,435	74,566,370	157,340,808	-2,640,401	78,151,601
CBC	0	6,204,164	0	3,887,225	-2,316,939
Total Value Added					93,461,245

2.3.5.3 Eco-efficiency assessment

Table 18 reports the results of the eco-efficiency indicators while Figure 13 presents the eco-efficiency comparison for baseline and scenario 5. The one on the left is the default chart and is necessary to compare all scenarios together while the one on the right highlights the differences between the baseline and the examined scenario.

In the case of uptake of smart technologies, eco-efficiency was improved for eutrophication and freshwater resource depletion environmental indicators as increase of environmental performance was higher than the reduction of Total Value Added. For other environmental indicators eco-efficiency was slightly decreasing up to -1.3% in the case of terrestrial ecotoxicity. This was due to higher reduction of Value Added than the reduction of the related emissions for those environmental impact categories.

Table 19. Eco-efficiency indicators (Baseline vs Smart Technologies)

Indicator	Baseline Scenario	Smart TECH	Change%
Climate Change (€/tCO_2eq)	1,081.1	1,077.9	-0.3%
Fossil fuels depletion (€/MJ)	4.9	4.9	-0.1%
Freshwater resource depletion (€/m^3)	7.0	7.1	1.2%
Eutrophication (€/kgPO_4^{-3},eq)	109.0	109.1	0.1%
Human toxicity (€/kg1,4-Dbeq)	19.9	19.8	-0.8%
Acidification (€/kgSO_{2-},eq)	82.6	82.5	-0.2%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	74.4	-0.1%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	3,815.0	-1.3%
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	2,986.6	-0.7%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	8,368.5	-0.6%
Minerals depletion (€/kg Fe-eq)	7,948.3	7,883.0	-0.5%

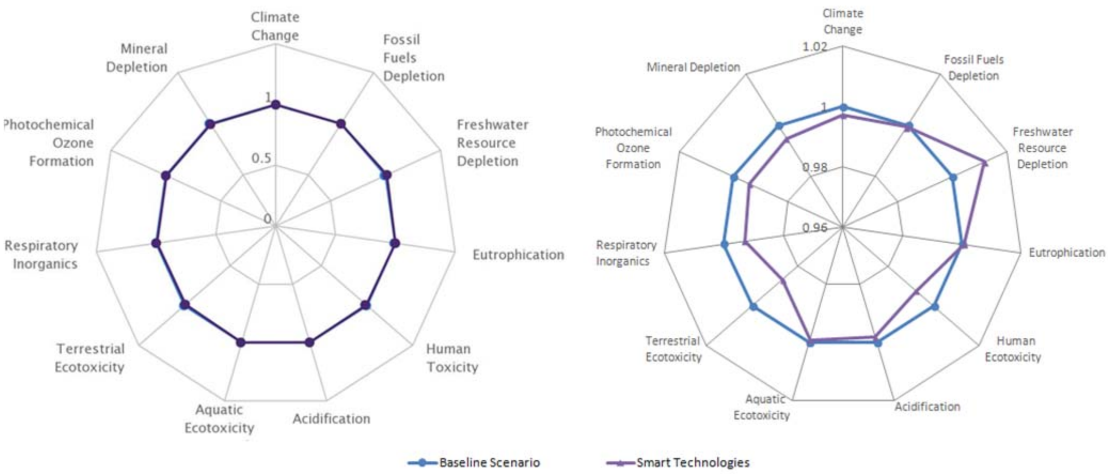


Figure 13. Comparison of eco-efficiency indicators in baseline scenario and scenario 5 (Smart Technologies)

2.3.6 Scenario 6: Increase of water supply and new water pricing policy

The scenario 6 concerns evaluating effectiveness of new water pricing policy and increasing water supply through the water delivery network from 36 Mm^3 to 45 Mm^3. The changes with respect to the reference year consist in the increase of water tariff from 0.09 €/m^3 to 0.12 €/m^3 for the first block and in the change of the upper limit of water allocation of block 2 from 3000 m^3 to 4000 m^3. The cropping pattern was assumed to be fixed and only the effects on groundwater withdrawals and related parameters were considered. Usually, increasing water price led to decrease of the amount of water used by favoring rainfed crop which may, or may not, be desirable. Further, this change can also decrease farmers' incomes but at the same time induces a reduction in fertilizer use as a result of reduced water consumption reflecting positive impact through the reduction of non-point chemical pollution by agriculture (Berbel, 2000). However, in this study, the water delivery by the CBC was increased because the farmers appreciate the increase of the upper limit of 2^{nd} water pricing block and start to consume more water from the network which reduces the water withdrawal from the aquifers.

2.3.6.1 Environmental performance assessment

The environmental performance of scenario 6 compared to the baseline scenario is presented in Table 20. Given the increasing water supply by the Consortium, the groundwater pumping was reduced by 18.6% showing positive effects in groundwater balance, energy consumption and related emissions from diesel combustion on foreground and life cycle of diesel production on background processes. The analysis found that in zone 1 no groundwater withdrawals were carried out because the water requirement were fully satisfied from distribution system and river pumping. Direct emissions for climate change from fuel combustion used for irrigation were reduced by 2805 tonCO_2eq or 4.2%. In addition all the other environmental impacts related to the life cycle of diesel production, processing and distribution to the final customers were reduced by 7%. However, increasing supply was associated with more pumping through the water delivery network, affecting the energy consumption and related emission from electricity production in zones 1 and 2. Accordingly, the energy consumption and emissions associated with life cycle electricity production used in water delivery from distribution system increased by 40% and 16%, respectively.

Table 20. Environmental Impacts of the Study System (Baseline vs Water Policy)

Indicator	AVG YEAR		WATER POLICY		Change
	FORE	BACK	FORE	BACK	%
Climate Change (kgCO2eq)	66,758,406	22,537,727	63,952,552	23,567,344	-2.0%
Fossil Fuels Depletion (MJ)	0	19,565,510	0	18,696,936	-4.44%
Freshwater Resource Depletion (m^3)	13,753,846	0	14,103,617	0	2.54%
Eutrophication (kgPO4eq)	729,687	155,989	729,687	156,164	0.02%
Human Toxicity (kg1,4-DBeq)	0	4,849,440	0	4,992,213	2.94%
Acidification (kgSO_2eq)	934,331	233,975	934,331	239,588	0.48%
Aquatic Ecotoxicity (kg1,4-DBeq)	0	1,295,962	0	1,297,019	0.08%
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	24,968	0	25,845	3.51%
Respiratory Inorganics (kgPM10,eq)	0	32,099	0	32,931	2.59%
Ozone Formation (kgC_2H_4,eq)	0	11,469	0	11,621	1.33%
Mineral Depletion (kgFe-eq)	0	12,146	0	11,816	-2.72%

In the background system climate change emissions were increased by 4.5% or 1029 tonCO_2eq since electricity production has a higher impact factor than diesel production (0.73 kgCO_2eq/Liter vs 0.38 kgCO_2eq/Liter). Hence, net CO_2 savings were estimated as 1776 tonCO_2eq or 2% due to high reduction of foreground emissions, which have 4-8 times more powerful impact than background emissions. Other important environmental impact categories positively affected were fossil fuel depletion and mineral depletion with net savings estimated at 868 MJ (i.e 4.44%) and 0.33 tonFe-eq (i.e 2.72%), since diesel production has a higher impact factor than electricity production. Freshwater resource depletion was increased by 0.29 Mm^3 or 2.1%. This indicator change was affected from water losses occurring into distribution network. Overall, increasing water supply shows positive effects on groundwater balance and fuel combustion in the foreground system but is increasing the freshwater resource depletion and impacts from life cycle of electricity production.

2.3.6.2 Economic performance assessment

The assessment of the economic performance for scenario 6 at the level of individual actors is presented in Table 21. The Total Value Added (TVA) in the case of scenario 6 was estimated at 97.3 M€ or 2,892 €/ha. This corresponds to 1.159 €/m^3 water used. Increasing water supply and new pricing policy led to greater income by 2.19 M€ for the water agency but still the balance is negative and the water agency cannot cover O&M cost. The unitary costs of water supply were 0.17, 0.15, 0.14 €/m^3 for zones 1, 2 and 3, respectively. For FA1 it was possible to supply extra water for irrigation resulting in the increase of production by 807 tons. Hence, an increase of 8.2% of NEO was estimated for FA1. Life cycle costs due to diesel consumption were reduced by 0.3 M€/year. The analysis shows that any increase of water supply from the distribution system is accompanied by an increase of Total Value Added as the increase of water supply and new pricing policy are associated with more environmental and economic benefits for WUO and FA1. For FA2 and FA3 a slight reduction of NEO was observed due to higher cost for irrigation water use.

Table 21. Economic performance results (Baseline vs Water Policy)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Water Policy&Water Supply				
FA1	0	4,039,768	8,862,890	-410,339	4,412,783
FA2	0	26,049,081	41,747,290	-1,678,761	14,019,448
FA3	0	73,608,366	157,340,808	-3,959,437	79,773,005
CBC	0	6,929,824	0	6,048,537	-881,287
Total Value Added					97,323,948

2.3.6.3 Eco-efficiency assessment

Table 22 reports the results of the eco-efficiency indicators while Figure 14 presents the eco-efficiency comparison for baseline and scenario 6. The one on the left is the default chart and is necessary to compare all scenarios together while the one on the right highlights the differences between the baseline and the examined scenario.

The new pricing policy and increase of water supply have positively affected the eco-efficiency of climate change indicator due to reduction of foreground emissions and fossil fuel depletion and mineral depletion indicators due to reduction of the impact factor from life cycle of diesel production. Eco-efficiency was improved also for environmental impact indicators of eutrophication, acidification and aquatic eco-toxicity due to the increase of Total Value Added. Comparing the eco-efficiency of different environmental impact categories, it was found that eco-efficiency of other remain categories was negatively affected from higher impacts of life cycle of electricity production which was not compensated from the TVA increase.

Table 22. Eco-efficiency indicators (Baseline vs Water Policy)

Indicator	Baseline Scenario	Water Policy	Change %
Climate Change (€/tCO_2eq)	1,078.8	1,112.0	2.9%
Fossil fuels depletion (€/MJ)	4.9	5.2	5.5%
Freshwater resource depletion (€/m^3)	7.0	6.9	-1.69%
Eutrophication (€/kgPO_4^{-3},eq)	108.8	109.9	0.79%
Human toxicity (€/kg1,4-Dbeq)	19.9	19.5	-2.07%
Acidification (€/kgSO_{2-},eq)	82.5	82.9	0.33%
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.3	75.0	0.73%
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,858.2	3,765.7	-2.61%
Respiratory inorganics (€/kgPM_{10},eq)	3,001.1	2,955.4	-1.74%
Photochemical ozone formation (€/kgC_2H_4,eq)	8,399.5	8,374.8	-0.51%
Minerals depletion (€/kg Fe-eq)	7,930.9	8,236.9	3.63%

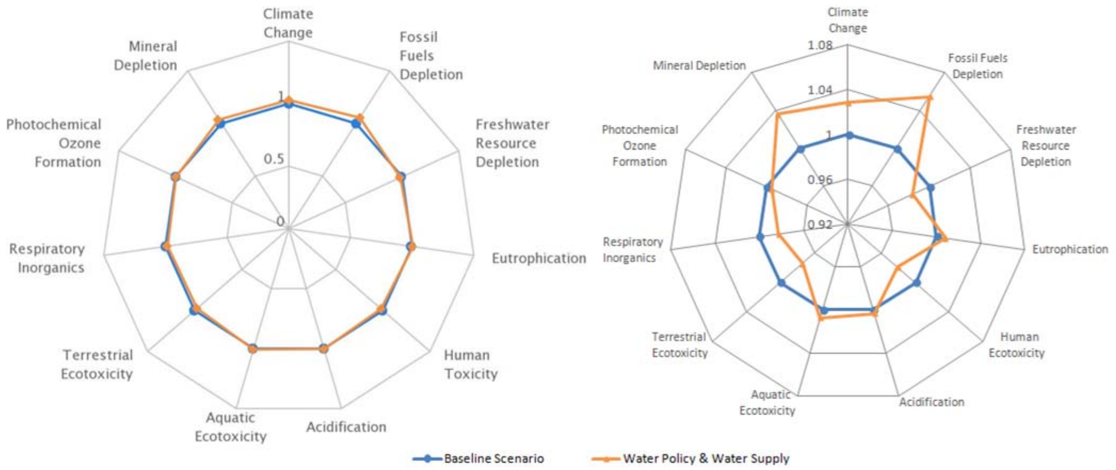


Figure 14. Comparison of eco-efficiency indicators in baseline scenario and scenario 6 (Water Policy)

2.4 Technology scenario focusing on resource efficiency

Table 23 shows the technology scenarios that have potential for water, energy and material saving. Resource efficient technologies are more suitable for climate change, fossil fuel depletion, mineral depletion, freshwater depletion and eutrophication potential indicators due to the reduction of associated emissions (foreground and background) with diesel and fertilizers. The use of a more efficient irrigation technology could reduce fuel consumption for irrigation in foreground processes by 0.268 MLiter/yr (i.e., 1.95%) due to a reduction of the operating pressure of the system. This means 1.95% less impact from combustion and life cycle production of diesel. Climate change emissions due to reduction of operating pressure of new irrigation technologies were reduced by 865 tonCO_2eq/year or 1%. In addition, related emission of fossil fuel depletion and mineral depletion were reduced by 272 MJ/yr and 8.6 ton1,4-DBeq/yr. Taking into account a life cycle perspective, net fuel savings were estimated to 4.03 MLiter and therefore a 29% higher environmental performance in comparison with baseline conditions for the given lifetime of the technology.

Water saved by the application of smart technologies was estimated at 8.7% per season and, thus a 3.3% saving on diesel fuel used for irrigation can be achieved. Therefore, a better performance was shown in this case with net CO_2 saving 2591 tonCO_2eq/yr or 2.9%. Fertilizer use efficiency was increased up to 3.1%, giving a high contribution on reduction of direct N_2O and NH_3 emissions. Hence. eutrophication and acidification emission were reduced by 28 tonPO_4eq/year and 35 tonSO_2eq/year, respectively. This was due to large scale implementation of the technology and related crops. Orchards and Vineyards constitute about 53% of cropping pattern or 66% of irrigated area. Moreover, application of smart technologies showed potential to increase water availability in the study area due to reduction of groundwater withdrawals from 45.3 to 41.4 Mm^3. This was affecting Freshwater resource depletion which was reduced by 0.595 Mm^3 or 4.3%. Other categories were slightly positively affected as, mainly, their performance depends on background processes, where fertilizer production and electricity production have higher impact than diesel production.

Table 23. Environmental Performance for resource use efficiency technologies on actor level (All results are in ton)

Actor	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Miineral Depletion	Fossil Fuels Depletion
FA1	5,183	57	86.404	364.5	2.288	92.50	1.645	0.77	0.590	946.9
FA2	26,503	252	347.76	1,613.9	10.563	377.59	9.106	3.67	3.736	5,468.4
FA3	57,610	577	734.13	2,871.0	19.248	825.87	14.216	7.03	7.820	13,150
Irrigation Technologies										
FA1	5,173	57	86.397	364.44	2.287	92.49	1.64	0.7678	0.5881	943.6
FA2	26,323	252	347.64	1,612.0	10.546	377.45	9.06	3.6613	3.6963	5,411.8
FA3	56,934	577	733.67	2,864.3	19.185	825.35	14.04	6.9870	7.6701	12,937
Smart Technologies										
FA1	5,161.2	57.12	86.11	363.53	2.2813	92.16	1.64	0.7659	0.588	941.6
FA2	25,931	245.14	339.70	1,586.7	10.379	368.33	9.01	3.6046	3.667	5,335.9
FA3	55,612	554.58	707.57	2,780.6	18.632	795.33	13.85	6.7978	7.567	12,677

Table 24. Economic Performance for resource use efficiency technologies

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added (€/yr)	Total Value Added (€/m³)
Actor	Baseline						
FA1	0	4,047,730	8,420,521	-294,779	4,078,012		
FA2	0	26,535,155	41,747,290	-952,045	14,260,090		
FA3	0	74,179,575	157,340,808	-2,640,401	80,520,832	96,541,994	1.155
	Drip Irrigation						
FA1	32,766	4,061,188	8,473,763	-294,779	4,085,029		
FA2	710,736	26,842,637	41,830,605	-952,045	13,325,188		
FA3	1,401,202	74,676,180	159,526,988	-2,640,401	80,809,205	95,902,483	1.147
	Subsurface Drip Irrigation						
FA1	49,149	4,061,188	8,500,299	-294,779	4,095,183		
FA2	0	26,473,777	41,747,290	-952,045	14,321,468		
FA3	3,036,227	74,999,480	161,817,878	-2,640,401	81,141,771	97,241,483	1.163
	Smart Technologies						
FA1	23,744	4,052,707	8,420,521	-294,779	4,049,291		
FA2	555,885	26,662,068	41,747,290	-952,045	13,577,292		
FA3	1,982,435	74,566,370	157,340,808	-2,640,401	78,151,601	93,461,245	1.174

The economic performance of resource efficiency technology compared to the baseline scenario is presented in Table 24. The introduction of water saving technologies (i.e., drip and subsurface drip) could contribute to the reduction of groundwater withdrawal from 3.6 up to 6.6% comparing with baseline S0. Otherwise, farmers can employ this water to increase irrigation input and agricultural production per unit of land. This was positively affecting the income of farmers as potential yield with the same water used as in baseline was increased from 0.7 up to 1.5%. Additional income was estimated from 2.32 (for drip) to 4.55 M€/year (for subsurface drip). Life cycle costs due to diesel consumption were reduced by 0.29 M€/year. The analysis showed that these technologies are not feasible in irrigation zone 2 as this zone is composed mainly by rainfed and low income crops. Application of smart technologies in the case of Sinistra Ofanto shows relevant potential to optimize water and fertilizer use efficiency and thereby to reduce associated cost and increase the income of the farmers. Life cycle costs due to reduction of diesel and fertilizer consumption were reduced by 5.79 M€/year and 0.31 M€/year, respectively. However, large scale implementation negatively affected Total Value Added of the system which decreased by 3.2%.

Table 25 shows the results of the eco-efficiency indicators while in Figure 15 the eco-efficiency comparison for baseline and resource use efficiency technologies is presented.

Table 25. Eco-efficiency indicators for resource use efficiency technologies

Indicators	Baseline	Drip	Subsurface Drip	Smart Tech
Climate Change (€/tCO_2eq)	1,081.1	1,084.5	1,099.6	1172.6
Fossil fuels depletion (€/MJ)	4.9	5.0	5.0	6.5
Freshwater resource depletion (€/m^3)	7.0	7.0	7.1	7.1
Eutrophication (€/kgPO_4^{-3},eq)	109.0	108.3	109.8	110.2
Human toxicity (€/kg1,4-Dbeq)	19.9	19.8	20.1	16.0
Acidification (€/kgSO_{2-},eq)	82.6	82.1	83.3	80.1
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	74.0	75.1	74.6
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	3,876.9	3,931.0	2830.8
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	2,995.2	3,037.0	2458.8
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	8,400.7	8,517.9	7376.3
Minerals depletion (€/kg Fe-eq)	7,948.3	8,022.3	8,134.3	8608.5

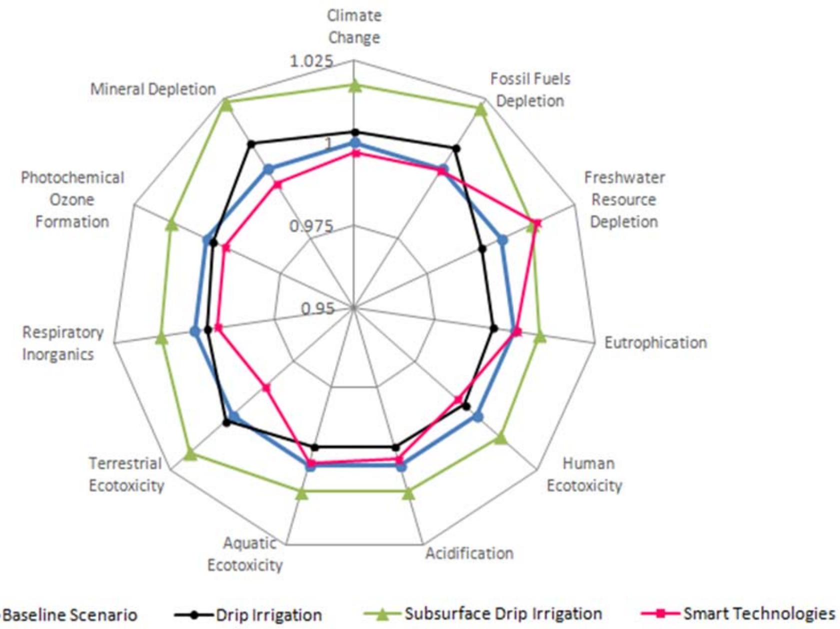


Figure 15. Comparison of eco-efficiency indicators in baseline scenario and resource efficiency technologies.

2.5 Technology scenario focusing on pollution prevention

Table 26 reports on the technology scenarios that have capabilities for pollution prevention. The analysis of all technology scenarios shows that solar powered pumps are most indicated as the technology that could contribute to pollution prevention of environment in the case of Sinistra Ofanto irrigation scheme. As already described, solar water pumps are becoming attractive solutions towards sustainable agriculture as they draw their energy from the sun and therefore produce no emissions.

Table 26. Pollution prevention technology comparison (All results are in ton)

	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Mineral Depletion	Fossil Fuels Depletion
FA1	5,183	57	86.404	364.5	2.288	92.50	1.645	0.77	0.590	946.9
FA2	26,503	252	347.76	1,613.9	10.563	377.59	9.106	3.67	3.736	5,468.4
FA3	57,610	577	734.13	2,871.0	19.248	825.87	14.216	7.03	7.820	13,150.
ELECTRIC VSP										
FA1	5149.7	57.38	86.70	371.78	2.33	92.59	1.70	0.78	0.59	921.67
FA2	25257.	252.16	358.84	1882.0	12.19	380.89	11.14	4.05	3.57	4535.7
FA3	53006.	578.00	775.06	3862.1	25.26	838.07	21.72	8.43	7.21	9703.8
SOLAR PUMPS										
FA1	5086.3	57.36	86.34	363.57	2.28	92.43	1.62	0.76	0.57	916.26
FA2	22907	251.60	345.33	1577.9	10.23	374.78	8.15	3.45	2.94	4335.4
FA3	44322	575.91	725.13	2738.4	18.02	815.50	10.68	6.22	4.88	8963.5

Table 27. Pollution prevention technology comparison

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added (€/yr)	Total Value Added (€/m³)
Actor	Baseline						
FA1	0	4,047,730	8,420,521	-294,779	4,078,012		
FA2	0	26,535,155	41,747,290	-952,045	14,260,090		
FA3	0	74,179,575	157,340,808	-2,640,401	80,520,832	96,541,994	1.155
	ELECTRIC VSP						
FA1	12,607	4,036,585	8,420,521	-294,779	4,076,550		
FA2	218,175	26,042,097	41,747,290	-952,045	14,534,974		
FA3	819,684	72,361,870	157,340,808	-2,640,401	81,518,852	97,813,416	1.17
	SOLAR PUMPS						
FA1	36,597	4,014,579	8,420,521	-294,779	4,074,565		
FA2	633,338	25,307,591	41,747,290	-952,045	14,854,315		
FA3	2,379,460	69,643,231	157,340,808	-2,640,401	82,677,716	99,289,657	1.188

The uptake of new solar powered pumps moderately improves the environmental performance of environmental indicators which are mainly affected from diesel combustion and life cycle diesel production. Reduction of diesel consumption by 5 MLiter/year (i.e., 38%) will contribute to net CO_2 savings 16,980 tonCO_2eq/year or 19%. Related emissions for fossil fuel depletion, mineral depletion and terrestrial eco-toxicity were decreased by 5350 MJ, 3.76 ton Fe-eq and 4.52 ton1.4-Dbeq, respectively. In the case of uptake of new variable speed pumps performance was improved in foreground processes for climate change and background fossil fuel depletion and mineral depletion indicators due to diesel consumption. However, in background processes the environmental performance for 7 categories was worsening because electricity has higher impact than diesel production.

Table 28. Eco-efficiency indicators for pollution prevention technologies

Indicators	Baseline	Electric VSP	Solar Pumps
Climate Change (€/tCO_2eq)	1,081.1	1,084.5	1,100
Fossil fuels depletion (€/MJ)	4.9	5.0	5
Freshwater resource depletion (€/m^3)	7.0	7.0	7
Eutrophication (€/kgPO_4^{-3},eq)	109.0	108.3	110
Human toxicity (€/kg1,4-Dbeq)	19.9	19.8	20
Acidification (€/kgSO_{2-},eq)	82.6	82.1	83
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	74.0	75
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	3,876.9	3,933
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	2,995.2	3,038
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	8,400.7	8,522
Minerals depletion (€/kg Fe-eq)	7,948.3	8,022.3	8,138

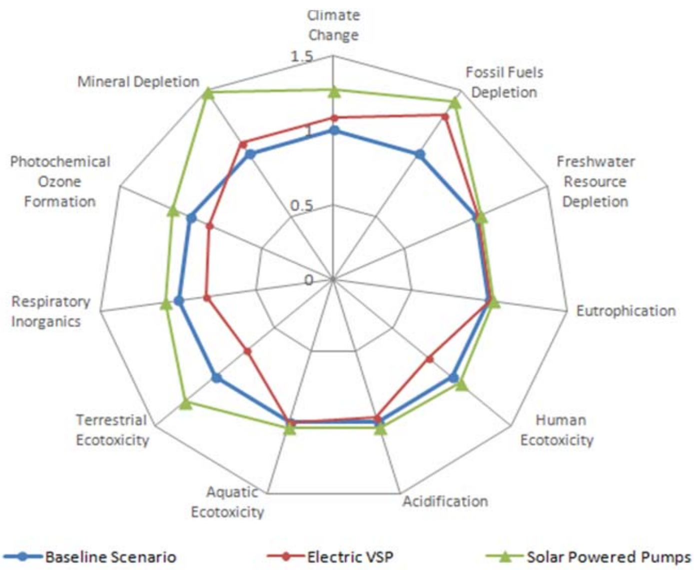


Figure 16. Comparison of eco-efficiency indicators in baseline scenario and pollution prevention technologies.

Economic performance for pollution prevention technologies at the level of individual actors is presented in Table 27. In the case of solar powered pumps a higher TVA was estimated in comparison to both S0 and electric variable speed pumps as, after the initial system cost, there was no ongoing operating costs. However, also in the case of electric variable speed pumps net cost saving was estimated as 2.32

M€/year due to reduction of diesel consumption which has higher cost than electricity (1.1 vs 0.2). Application of energy saving technologies appears to be good especially for FA2 (>50% withdrawals) where NEO was increased up to 1.9% in comparison with baseline.

Table 28 reports the results of the eco-efficiency indicators while Figure 16 presents the eco-efficiency comparison for baseline and pollution prevention technologies.

2.6 Technology scenario promoting circular economy

In the case of Sinistra Ofanto, a technology scenario for circular economy was not elaborated.

2.7 Eco-efficiency comparison for all technology scenarios

The Eco-Efficiency plot consists in 2x2 matrix and it is used to summarize the calculation of environmental and economic impacts of alternative/configuration on a single plot. Each circle represents one alternative, with environmental impact shown on the horizontal axis and TVA on the vertical axis. The alternative with the best eco-efficiency is found in the upper right corner of the graph, while the alternative with lower TVA and large impact on the environment is found in the lower left corner of the graph. Alternatives whose summed economy and environmental ratings are identical are considered to be equally eco-efficient. On the assumption that ecology and economics have the same importance, in a sustainability assessment an economically less advantageous system can compensate for this disadvantage with a better ecological assessment, and vice versa.

Figures 17, 18 and 19 present the eco-efficiency portfolios for 11 environmental indicators considered in this study. It appears evident that the uptake of the new technology proposed (mainly solar pumps) tends to increase the eco-efficiency for climate change, fossil fuel depletion and mineral depletion environmental indicators which are mainly affected from diesel combustion on foreground and life cycle production on background. As indicated in the graphs, uptake of energy efficient technologies shows the best performance in the case of fossil fuel and mineral depletion indicators due to highest impact from reduction of diesel consumption on background processes. Water saving technologies (i.e., irrigation technologies) tend to perform or maintain the same performance as the baseline due to slight increase of environmental performance. Subsurface drip irrigation technology performs better than drip and baseline due to higher economic performance. Scenario 3, with the application of electric variable speed pumps gives negative impact on human toxicity, acidification, terrestrial ecotoxicity, respiratory inorganics and photochemical ozone formation impact indicators due to high impact from electricity production.

LEGEND:

● Baseline ● Drip irrigation ● Subsurface drip irrigation ● Electric variable speed pumps

● Solar powered pumps ● Smart technologies ● Water Pricing policy & Water supply

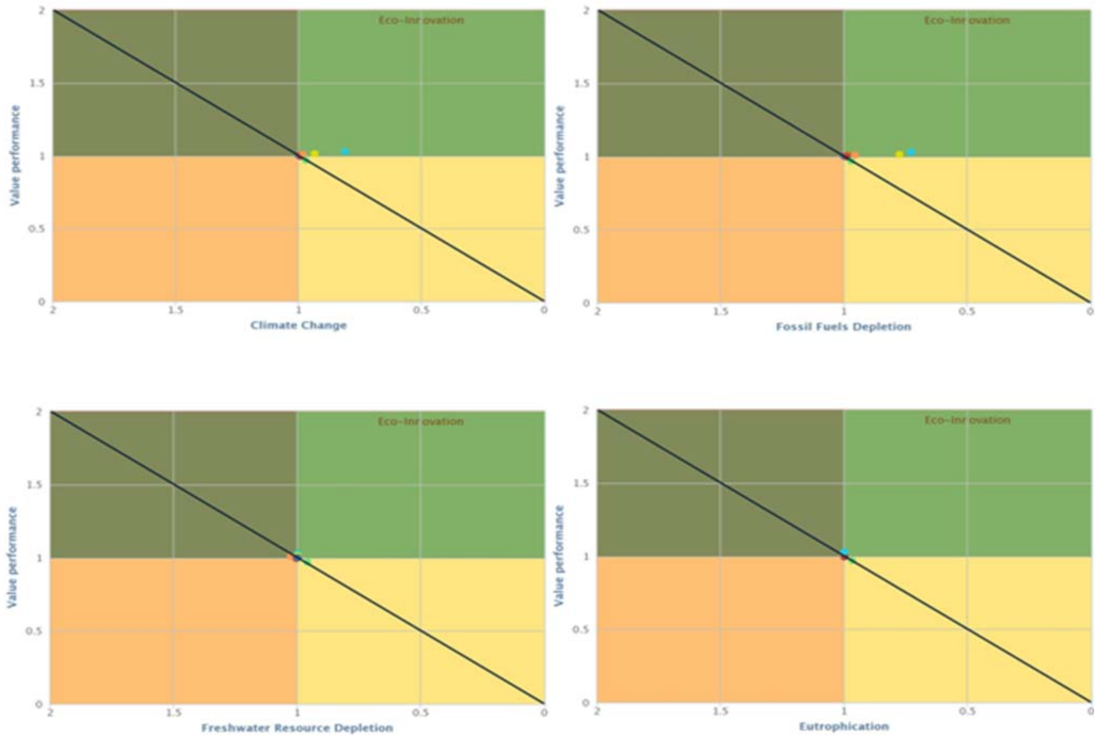


Figure 17. Eco-efficiency comparison for all technology scenarios – (1/3)

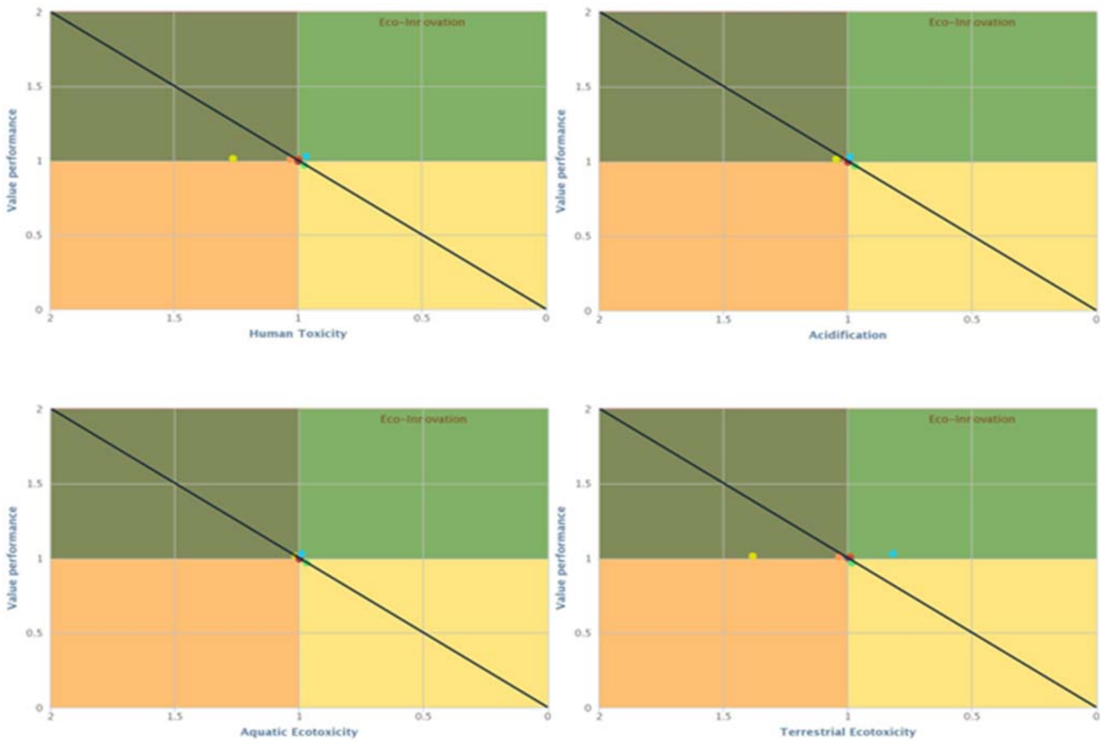


Figure 18. Eco-efficiency comparison for all technology scenarios – (2/3)

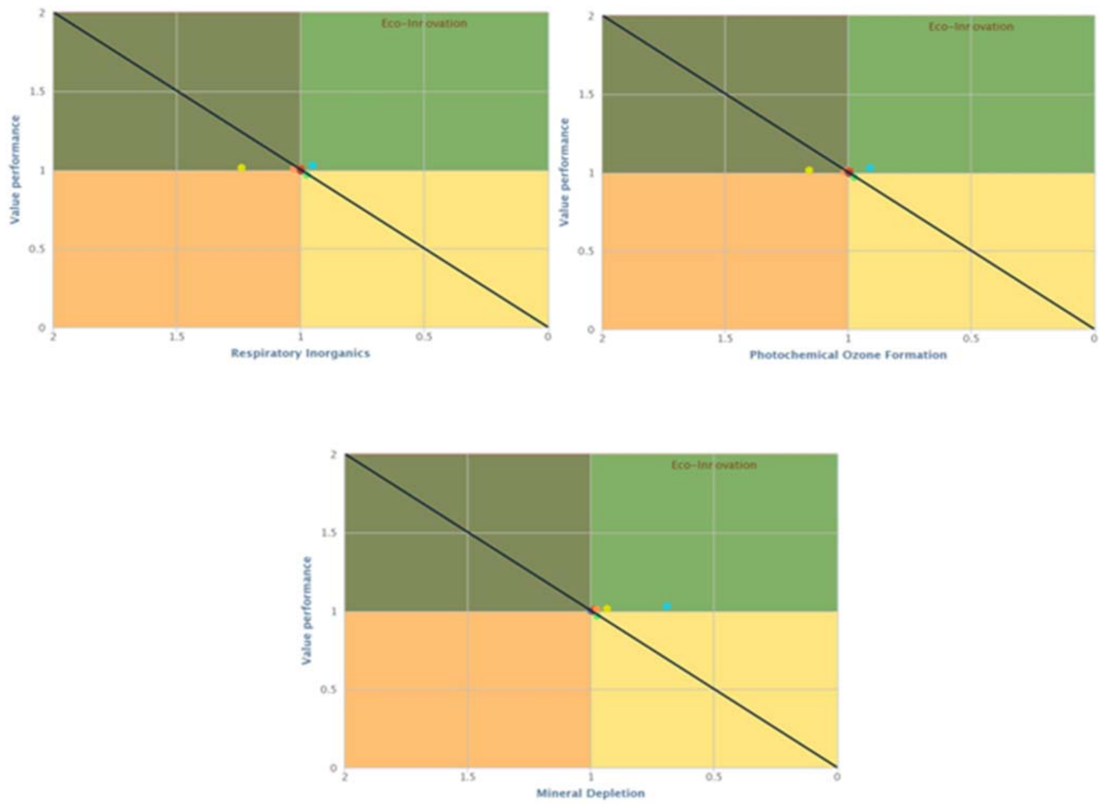


Figure 19. Eco-efficiency comparison for all technology scenarios – (3/3)

3 Technological interventions in the water use stage

After assessing each technology separately, a super-intensive and a low intensive scenario were elaborated combining innovative technologies implementation in different processes. The Super-intensive scenario consists of the uptake of solar powered in pumps, sub-surface drip irrigation and smart irrigation technologies. Solar pumps are fully implemented in three irrigation zones while subsurface drip irrigation and smart technologies are implemented for orchards in FA1 and FA3 and for olives in FA2. For the low-intensive scenario, drip irrigation, solar pumps and smart technologies are implemented only for orchard irrigation zone 1. The environmental performance of these scenarios compared to the baseline scenario, is presented in Table 29.

Table 29. Environmental Impacts of the Study System (Baseline vs Super-intensive & Low Intensive)

Actor	Climate Change	Eutroph-ication	Acidficatio	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Miineral Depletion	Fossil Fuels Depletion
Baseline										
FA1	5,183	57	86.404	364.5	2.288	92.50	1.645	0.77	0.590	946.9
FA2	26,503	252	347.76	1,613.9	10.563	377.59	9.106	3.67	3.736	5,468.4
FA3	57,610	577	734.13	2,871.0	19.248	825.87	14.216	7.03	7.820	13,150
Super-Intensive										
FA1	5083.3	57.29	86.25	363.30	2.28	92.32	1.62	0.76	0.57	915.87
FA2	22776	248.38	341.38	1565.9	10.15	370.28	8.14	3.43	2.94	4318.1
FA3	44183	572.35	720.96	2725.6	17.94	810.70	10.67	6.20	4.88	8945.2
Low-Intensive										
FA1	5083.3	57.29	86.25	363.30	2.28	92.32	1.62	0.76	0.57	915.87
FA2	26,503	252	347.76	1,613.9	10.563	377.59	9.106	3.67	3.736	5,468.4
FA3	57,610	577	734.13	2,871.0	19.248	825.87	14.216	7.03	7.820	13,150

In the case of Sinistra Ofanto, the combination of different eco-efficient technologies improves more the environmental performance of the system than the individual technology uptake. Net CO_2 savings by super-intensive implementation of these technologies were estimated as 17,253 tonCO_2eq or 19.4% mainly due to high contribution of solar pumps. Related emission for fossil fuel depletion, mineral depletion and terrestrial eco-toxicity were decreased by 5386 MJ, 3.76 ton Fe-eq and 4.54 ton1.4-Dbeq, respectively. Overall, super-intensive combination of new technologies tends to improve environmental performance in comparison with baseline condition, up to 31% in the case of mineral depletion.

The assessment of the economic performance at the level of individual actors is presented in Table 30. From the uptake of sub-surface drip irrigation system the yield was increased by 9.37% for FA1 and FA3 and 2.35% for FA2. Therefore, total potential additional yield was estimated 6140 ton which gives an additional income of 3.17 M€/year. Comparing the NEO for three actors, it has decreased by 10.7% for FA2 due to high cost of technology which cannot be compensated by the increase of yield for Olives. In general, this zone is composed by low income and rainfed crops (i.e Olives 35%, Wheat 25%). For FA1 and FA3, a slight increase of NEO was observed from 0.5% for FA1 up to 4.1% for FA3. Life cycle costs due to reduction of diesel and fertilizer consumption were reduced by 5.79 (i.e., 5.25%) and 0.104 M€/year. Hence, TVA in comparison with baseline was slightly increased by 1.9%.

The adoption of low-intensive combination of eco-efficient technologies in irrigation zone 1 has enhanced the yield, reduced the fuel and fertilizer consumption and thereby increased the NEO. For this zone any increase of efficiency of the system means more water available for additional irrigation and, therefore, more income.

Table 30. Economic performance results (Baseline vs Super-intensive&Low-Intensive)

	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added (€/yr)	Total Value Added (€/m³)
Actor	Baseline						
FA1	0	4,047,730	8,420,521	-294,779	4,078,012		
FA2	0	26,535,155	41,747,290	-952,045	14,260,090		
FA3	0	74,179,575	157,340,808	-2,640,401	80,520,832	96,541,994	1.155
	Super-Intensive						
FA1	65,613	4,024,632	8,485,083	-294,779	4,100,059		
FA2	2,218,361	25,925,650	41,827,294	-952,045	12,731,238		
FA3	3,743,811	70,163,315	160,373,339	-2,640,401	83,825,813	98,340,171	1.176
	Low-intensive						
FA1	65,357	4,012,922	8,463,581	-294,779	4,090,523		
FA2	0	26,535,154	41,747,289	-952,045	14,260,090		
FA3	0	74,179,575	157,340,807	-2,640,401	80,520,832	96,554,506	1.155

Table 31. Eco-efficiency indicators (Baseline vs Super-Intensive)

Indicator	Baseline Scenario	Super Intensive	Low Intensive
Climate Change (€/tCO_2eq)	1,081.1	1,365.0	1,082.50
Fossil fuels depletion (€/MJ)	4.9	6.9	4.94
Freshwater resource depletion (€/$m^{3)}$	7.0	7.2	7.02
Eutrophication (€/kgPO_4^{-3},eq)	109.0	112.0	109.03
Human toxicity (€/kg1,4-Dbeq)	19.9	21.1	19.92
Acidification (€/kgSO_{2-},eq)	82.6	85.6	82.66
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	74.5	77.2	74.51
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	3,866.7	4,814.8	3,871.24
Respiratory inorganics (€/kgPM_{10},eq)	3,007.7	3,238.1	3,009.05
Photochemical ozone formation (€/kgC_2H_4,eq)	8,417.9	9,467.1	8,423.77
Minerals depletion (€/kg Fe-eq)	7,948.3	11,730.2	7,963.40

Table 31 and Figure 20 showcase the eco-efficiency increase for all environmental impact indicators considered in this study due to greater TVA and better environmental performance in comparison with baseline. In the case of low-intensive scenario, a slight increase was observed as zone 1, where innovative technologies are implemented, is composed mainly by rainfed crops (i.e wheat 78%).

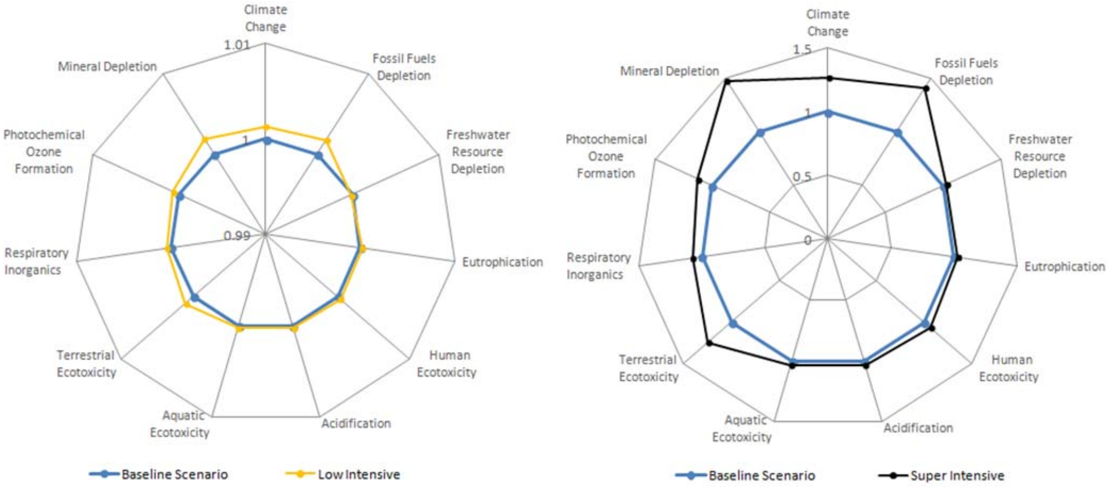


Figure 20. Eco-efficiency comparison for super-intensive and low-intensive scenarios

3.1 Policy Recommendations

3.1.1 Common for all scenarios towards eco-efficiency improvement

Eco-efficiency analysis was undertaken to identify alternatives and opportunities to reduce environmental burdens while increasing economic productivity by assessing technology scenarios over the entire life-cycle of a large scale irrigation system. The results indicated that the innovation process is driven mainly by cropping pattern, water, fertilizer and energy consumption, corresponding greenhouse gas emissions, market price of agricultural products, and production costs including the use of resources and application of new technologies. On the basis of the conclusions derived from our analysis and stakeholders meeting, a set of recommendations is proposed for eco-efficiency enhancement of Sinistra Ofanto irrigation water system. Hence, the research strategy and technology transfer activities should be directed towards:

a) Use of PESTLE method analysis to identify factors which influence technology uptake and penetration.
b) Coordinated decision-making process based on stakeholder driven approach including all relevant actors (farmers and citizens, water user organizations, water authorities, policy and decision makers, investors, technology providers, etc.).
c) Adoption of new policy instruments for a more equitable distribution of costs and benefits.
d) Use of new measuring tools and models (like SEAT and EVAT with embedded life cycle approach) to generate, collect, and analyze data from agricultural water systems.
e) Benchmarking of “current situation” to identify weak stages and processes of the system and possible options for its enhancement including the

quantification of the resource and cost saving options and the existence of eventual barriers for their implementation.

f) Adoption of combinations of different technologies (i.e., super-intensive, when combination of different technologies is applied). Technical assistance is needed to meet large scale water delivery issues and farm-specific situations.

g) Increase the flexibility for participants in commodity programs to respond to market signals and adopt environmentally sound production practices and systems, thereby increasing profitability and enhancing environmental quality in compliance with EU regulation.

h) Create incentives for the farmers to adopt the best (environmentally friendly) management practices at farm level. Solutions should be sought in water-energy saving technologies combined with organic types of fertilizers and adoption of zero-tillage where possible.

i) Developing financial programs to improve access to capital for those willing to invest in eco-efficient practices. Securing sufficient access to capital is crucial for eco-innovations to grow in scope, especially for innovations with long development times.

j) Design an effective information and education program on adoption of eco-efficient technological solutions at various scales. Sponsor targeted workshops and roundtables are needed to promote technology demonstrations.

k) The use the knowledge systems and web platforms (as that developed within ECOWATER project) to underpin the policy making process at the various levels of stakeholders and actors including regional environmental and water agencies, authorities and consultancy firms.

3.1.2 Specific for each of the key objectives

3.1.2.1 Resource efficiency

A variety of techniques can be employed to increase resource efficiency such as:

- Real-time monitoring of water delivery network and use of remote control device for managing hydrants operation.
- Real-time monitoring of the soil-plant-atmosphere continuum and use of soil water balance models to provide adequate irrigation advice and improve on-field irrigation management practices through the application of smart technological solutions.
- Implementation of low-impact irrigation methods (such as drip and subsurface drip) which reduce water, energy and fertilizer use.
- Use of variable speed pumps for more efficient energy consumption.
- Use of green-energy solutions for water pumping systems (e.g. solar and electricity driven pumps).
- Adoption of technologies that directly minimise dependence on non-renewable resources, such as minimum tillage and biological pest and weed control.

- Use of biodegradable organic mulches to reduce soil evaporation, minimize weed growth, and improve crop growth and productivity value.
- Improving soil health through the use of legumes, green manures and cover crops.

3.1.2.2 Pollution prevention

The techniques already described to improve the resource use efficiency contribute also in pollution prevention. Additionally:

- Adoption of “correction” crop rotation (with legumes and cover crops) will minimise the need for nutrient additions, and also reduce the need for pesticides to control soil-borne-diseases.
- Measures to improve vehicle fuel efficiency using alternatively fuelled vehicles which reduces the reliance on fossil fuels.
- Design of local participatory strategies to co-interest agricultural producers in reducing agricultural NPS pollution.

3.2 Conclusion

Water shortage is among the main problems to be faced in Mediterranean region over the coming decades. In many cases under water scarcity, there is not enough water to fully satisfy irrigation requirements and farmers are constrained to move into deficit irrigation and innovative management practices (including technology enhancement) for reducing water demand and other environmental burdens. This could be applied at different scales, from farm to the water distribution and delivery network in order to amplify the positive management strategies on a large scale and produce a relevant impact from environmental and socio-economic point of view.

The eco-efficiency assessment of potential technology uptake in the Sinistra Ofanto irrigation scheme was conducted. The assessed scenarios, discussed with local stakeholders, referred to the introduction of innovative technologies for resource efficiency and pollution prevention. The eco-efficiency improvements related to technological innovations of the Sinistra Ofanto agricultural water system may result from: a) the higher economic value being generated by irrigated agriculture in the area, b) the lower financial costs at different stages of the irrigation system improvement to sustain the agricultural production levels, c) the reduced environmental impacts being generated as a result of intensive farming under proper irrigation strategies.

The eco-efficiency of the system greatly depends upon the yields achieved (irrigation input), market prices, the location and sources of water (surface or ground), the hydraulic characteristics of water delivery and distribution network, landscape, cropping pattern and adopted irrigation method. Eco-efficiency might increase when the economic benefits grow or remain constant while the pressure on resources decreases, i.e. when the cropping pattern and resources use are optimized in terms of economic outputs, irrigation requirements are lower and the management practices are based on non-optimal water supply and more efficient irrigation methods. The main physical production risk, which is always an important factor in agricultural production, concerns the uncertainties associated with weather conditions (i.e. irrigation input). In general, the hydrological conditions play a relevant role in the eco-efficiency assessment because more precipitation usually means (at least for winter crops) lower irrigation requirements and therefore less consumption of resources. In this line, increase of water supply from the Consortium and prioritizing the agriculture sector in the region showed positive effects on groundwater balance. Likewise, the market price fluctuation and market volatility means different performance of the system. High price variability can cause a failure of the supply chain; therefore, a relatively stable income level for farmers is important in order to ensure sustainable agricultural production and maintain competitiveness. However, this should be associated with more water supply from the Consortium in order to ensure the minimum performance of the system. In this context, the adoption of the most adequate water pricing policies may have relevant impact on the system performance. However, definitive conclusions cannot be derived because they depend on the eventual changes of cropping patterns in the study area and other market and environmental drivers, often external to the system.

The overall results showed that the uptake of innovative technologies has potential to optimize water, fuel and fertilizer use and thereby improve environmental performance of the system while maintaining a healthy agricultural economy. Through the adoption of a more efficient irrigation technology, water and energy savings can be achieved reducing water input and pressure requirements. In turn, this is reducing associated costs and enhancing yield due to operation flexibility. The decrease of associated emissions (foreground and background) with diesel and fertilizers showed relevant impact in the climate fossil fuel depletion, mineral depletion, freshwater depletion and eutrophication potential indicators. The adoption of both water and energy saving technologies is fundamental for the system performance although water saving could be considered a priority. Still, the best solution could be a joint intervention including the uptake of both water and energy saving technologies as in the case of the super-intensive scenario.

4 Case Study 2. Monte Novo Irrigation Scheme

4.1 Finalized baseline scenario assessment

The Portuguese case study underwent some improvements concerning the costs estimation since Deliverable 2.2. In fact, until now, only costs for water, energy and fertilizers were considered. The baseline scenario was, in the meanwhile, re-evaluated, considering costs for seeds, labour and equipment and other costs, which mostly include an estimation of investment cost amortization (Table 32).

Table 32. Costs considered in the Monte Novo case study (baseline scenario)

Cost (€/ha)	Maize LP	Maize HP	Olives Intensive LP	Olives Intensive HP	Olives Super Intensive LP	Olives Super Intensive HP	Pastures LP	Pastures HP
Fertilizers and pesticides	522	522	69	69	150	150	62.75	87
Seeds	220	220	0	0	0	0	0	0
Labour and equipment	93	93	780	780	1169	1169	65	65
Other relevant costs	989	989	804	804	1005	1005	121	121

Concerning the life cycle diagram, no modifications were introduced. The main stages are (as depicted in Figure 21): (i) the primary network, which corresponds to water abstraction in the Alqueva reservoir (main storage reservoir of the system), elevation and water transport to the secondary networks; (ii) the secondary network, which includes the regulating storage made through several reservoirs, the elevation stage and the water distribution to the different irrigated farms considered; and, (iii) the farmers (users) in the Monte Novo case study, which are represented by means of the most representative crops in the area (maize, olives – intensive and super intensive – and pastures).

Figure 21 also indicates the main actors directly involved in the three stages:

- EDIA ("Empresa para o Desenvolvimento das Infraestruturas de Alqueva), responsible for the management and development of the Alqueva multipurpose project, including the operation of primary and secondary irrigation network where the Monte Novo irrigation perimeter is included.
- AB Monte Novo ("Associação de Beneficiários de Monte Novo"), representing all the farmers which are connected to the Alqueva water distribution system from EDIA, and
- Farmers that will benefit from the irrigation networks.

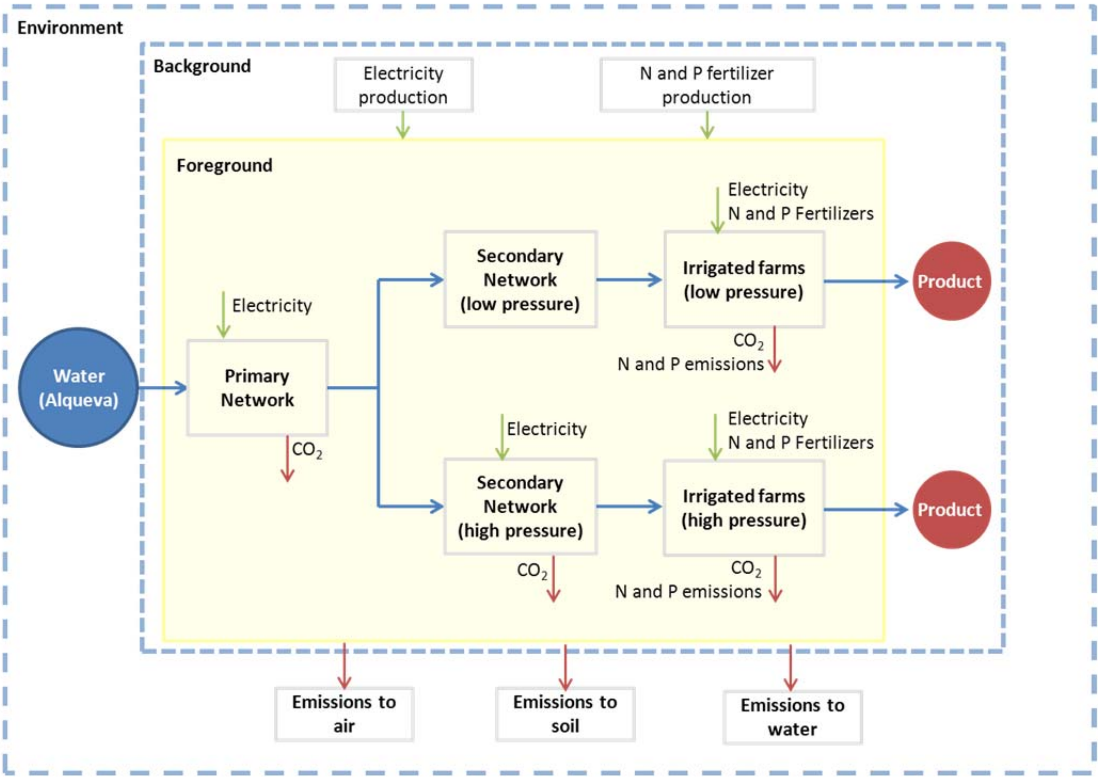


Figure 21. Life cycle Diagram of the Monte Novo case study including foreground and background systems

4.1.1 Environmental performance assessment

As detailed in Deliverable 2.2, the environmental impact is calculated by multiplying the elementary flows from the inventory analysis by the characterization factors. Table 33 presents the results for the environmental impacts.

Concerning the foreground system, only two the indicators are affected:

- The “freshwater resource depletion” indicator, which expresses the water extraction to satisfy the agricultural requirements at the farmers’ level and,
- The “eutrophication” indicator which translates the use of Phosphorous and Nitrogen fertilizers in agriculture.

Table 33. Environmental impacts from background and foreground systems (baseline scenario)

	Value (Unit)	Foreground Value(Unit)	Background Value(Unit)
Climate Change (tCO_2eq)	10,761.65	0	10,761.65
Fossil Fuels Depletion (MJ)	124,668,758	0	124,668,758
Freshwater Resource Depletion (m^3)	3,189,641.23	3,189,641.23	0
Eutrophication (kgPO_4eq)	129,621.29	105,703.29	23,918.00
Human Toxicity (kg1,4-DBeq)	1,186,343.42	0	1,186,343.42
Acidification (kgSO_2eq)	91,680.89	0	91,680.89
Aquatic Ecotoxicity (kg1,4-DBeq)	182,956.92	0	182,956.92
Terrestrial Ecotoxicity (kg1,4-DBeq)	18,786.18	0	18,786.18
Respiratory Inorganics (kgPM10,eq)	13,961.50	0	13,961.50
Photochemical Ozone Formation (kgC_2H_4,eq)	3,854.12	0	3,854.12
Mineral Depletion (kgFe-eq)	2,165.45	0	2,165.45

In this context, Figure 22 summarizes the percentages of background and foreground processes for the different indicators considered. In this figure, the background contribution is divided in “background contribution from electricity” and “background contribution from fertilizers”, allowing to highlight the high environmental impact from electricity for most of the indicators: for the climate change, acidification, respiratory inorganics, terrestrial ecotoxicity, photochemical ozone formation, minerals depletion and fossil fuels depletion indicators, it represents more than 75%.

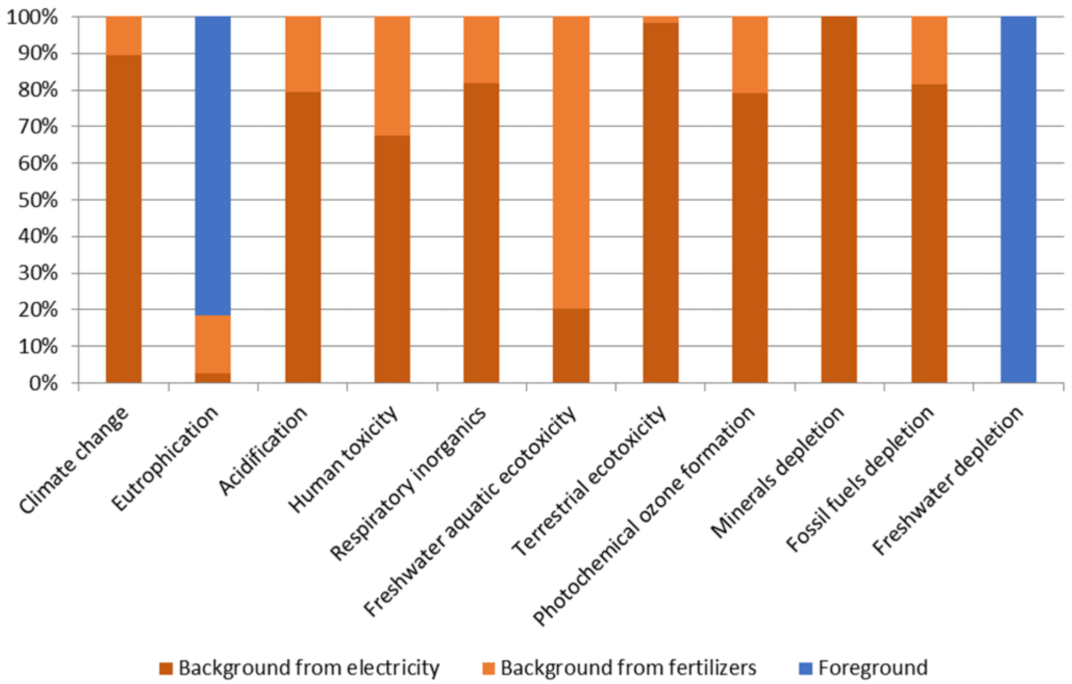


Figure 22. Contribution of foreground and background systems in the environmental impact categories (baseline scenario)

Figure 23 presents the environmental breakdown per stage. The more critical stages are the “primary network” (water abstraction stage) and the “farmers” stage. In the first case, the indicator “freshwater resource depletion” is the most representative as expected. For the “farmers” stage, the most relevant indicators are “eutrophication”, directly related with the use of fertilizers (foreground system) and “aquatic ecotoxicity”, mostly due to the high characterization factor of nitrogen production in the background processes.

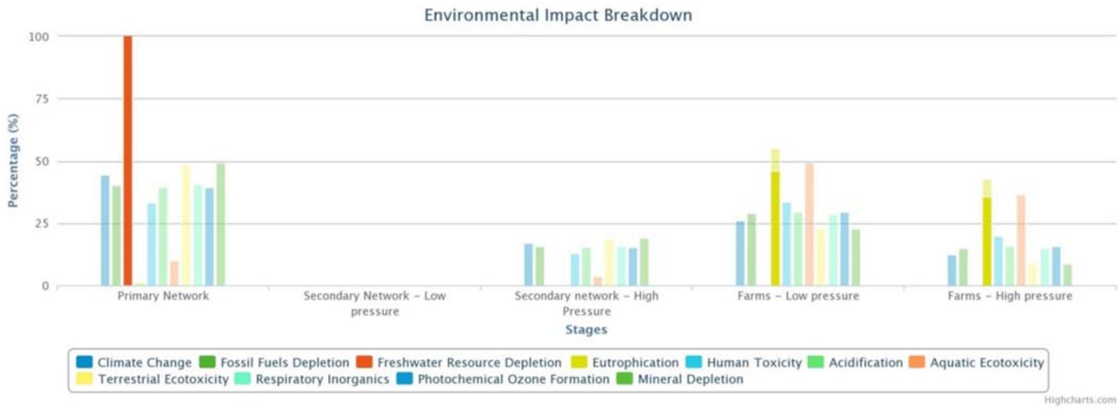


Figure 23. Environmental impact breakdown per stage (baseline scenario)

4.1.2 Economic performance assessment

Table 34 and Figure 24 present the economic performance assessment for the baseline scenario in the Monte Novo case study obtained applying the Economic Value Chain Analysis Chain. The results are presented per actor and it should be noted that, as referred in section 5.1, the amortization of investment costs are, in this case study, included in the annual OM costs, translated in annual amortizations. The Total Value Added (TVA) obtained from the water used, corresponding to the sum of the net economic output of the actors, is around 2 M.

Table 34. Financial summary per actor (baseline scenario)

Stage	Annual O&M Cost (€/yr)	Annual Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Cash Flow (€/yr)
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08
Total	7,396,817.73	9,395,490.00	0.00	1,998,672.27

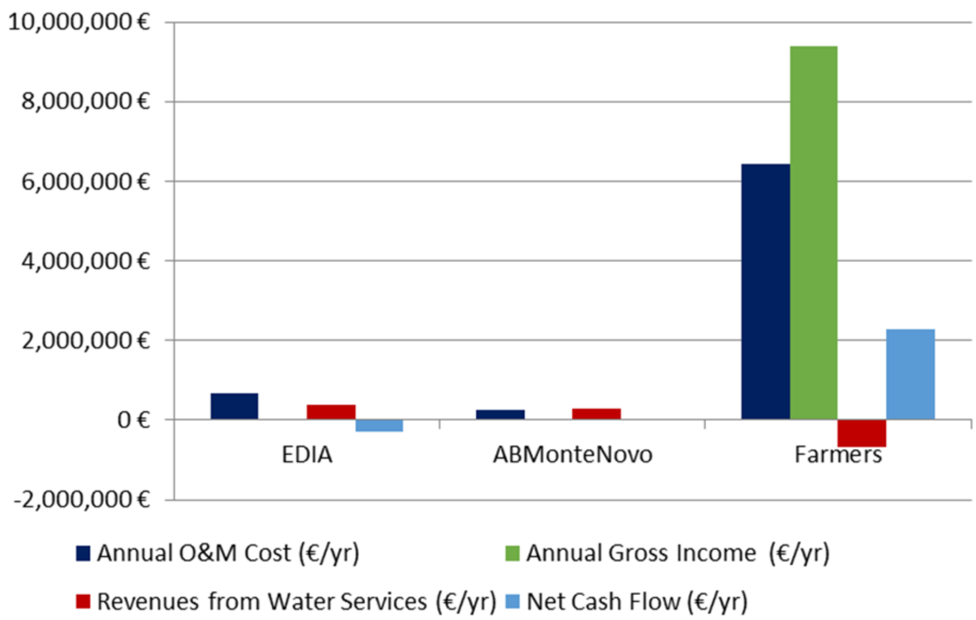


Figure 24. Economic performance per actor (baseline scenario)

4.1.2.1 Eco-efficiency indicators

The eco-efficiency indicators are defined as the ratio of the economic performance to the environmental performance of the system and are presented in Table 35. The assessment of innovative technologies for the Monte Novo case study will intend to improve the eco-efficiency results obtained for the baseline scenario.

Table 35. Eco-efficiency indicators (baseline scenario)

Indicator	Value (€/Unit)
Climate Change (tCO_2eq)	185.72
Fossil Fuels Depletion (MJ)	0.02
Freshwater Resource Depletion (m3)	0.63
Eutrophication ($kgPO_4eq$)	15.42
Human Toxicity (kg1,4-DBeq)	1.68
Acidification ($kgSO_2eq$)	21.80
Aquatic Ecotoxicity (kg1,4-DBeq)	10.92
Terrestrial Ecotoxicity (kg1,4-DBeq)	106.39
Respiratory Inorganics (kgPM10,eq)	143.16
Photochemical Ozone Formation (kgC_2H_4,eq)	518.58
Mineral Depletion (kgFe-eq)	922.98

4.2 Individual assessment of innovative technologies

After the assessment of the baseline scenario, and according to the know-how, interest and feedback from stakeholders of the region, a set of scenarios were defined considering, in this phase, the application of individual technologies for the improvement of the eco-efficiency of the Monte Novo case study.

1. Scenario 1: Improvement of water saving using Regulated Deficit Irrigation (RDI) for olives, maize and pastures. This technology is implemented for both “Low Pressure” and “High Pressure” areas.
2. Scenario 2: Decrease of fertilizer use through the introduction of sludge from waste water treatment plants of the area. This technology is implemented for both “Low Pressure” and “High Pressure” areas.
3. Scenario 3: Decrease of fertilizer use through the introduction of organic compounds appropriate for biological agriculture. This technology is implemented for both “Low Pressure” and “High Pressure” areas.
4. Scenario 4: Improvement of the irrigation efficiency through the adoption of subsurface drip irrigation instead of drip irrigation for maize and olives. This technology is implemented for both “Low Pressure” and “High Pressure” areas.
5. Scenario 5: Reduction in water costs by re-scheduling irrigation to periods during which the energy price is lower.

The assessment of the implementation of the technologies will be presented separately for each crop, intending to facilitate the next phase of combining different technologies.

4.2.1 Scenario 1: Regulated Deficit Irrigation Technology

In the case of scenario 1, the application of Regulated Deficit Irrigation (RDI) in the Monte Novo perimeter was evaluated. RDI consists in applying lower amounts of water comparatively to the defined water needs of the plant. These cuts in water supply are defined taking into account the seasonal sensitivity of plant to water stress. The aim of this technology is to reduce vegetative growth and improve qualitative aspects of crop production without decreasing the yield production.

RDI has had significantly more success in tree crops and vines but can be applied to maize or pastures. However, it is necessary to adjust the scheduling of irrigation with the crop type, in other words, the water deficits will be induced according the phenological stages of the culture. For each crop, the water savings will be different. The water needs for each crop depend on precipitation, evapotranspiration (ETc) and efficiency of the irrigation method. For calculation purposes, the scheduling of irrigation agro-meteorological data is needed.

In the case of maize, the deficit irrigation is applied in the eight weeks after sowing, providing only 70% - 80% of the water required for the culture. In the ninth and tenth weeks, the phenological stage of maize requires water needs to be fully satisfied (100%). After this period, 70%-80% of the water required by the crop is applied until the last phenological stage. (Toureiro *et al.,* 2007)

For olives, the scheduling of deficit irrigation is different. Figure 25 summarizes the deficit irrigation percentage for the different development stages.

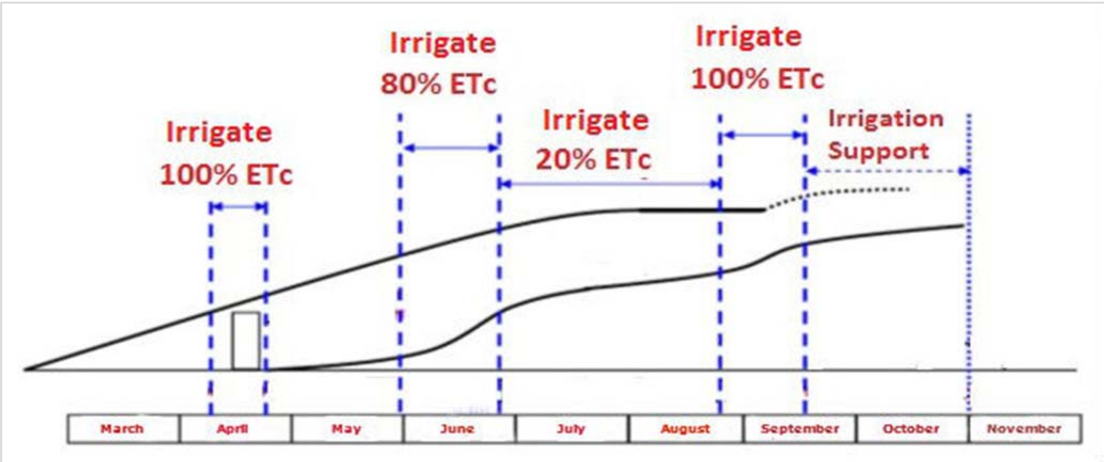


Figure 25. Deficit irrigation per each phenological stage. (Adapted from Jose Enrique Fernández, CSIC, Spain)

Between July and August the water applied is very low because these phenological stages are associated to a vegetative growth (biomass production). In April and September, no reduction can be introduced.

Finally, for pastures, the RDI was also tested. Pastures can tolerate 35% of deficit irrigation without a noticeable lowering in production (Gomes, 1997). In this case, no critical phenological stages are considered, using the same reduction rate for all the life cycle of pastures.

In absolute terms, it was possible to determine the water saving obtained for each culture, based on the water requirements before and after the application of the RDI technology. For maize, two reductions were considered, according to different studies: 21% and 35%. For the olive – intensive and olive - super intensive the reductions considered in water supplied were of 44% and 64%, respectively. Finally, for pastures, a 35% reduction of water requirements was assumed.

4.2.1.1 Environmental performance assessment

The environmental performance of the RDI technology was compared to the baseline scenario, and the main results are presented in Tables 36, 37, 38, 39, and 40. The application of this technology mainly affects the "freshwater resource depletion" indicator as the RDI technology application corresponds to a water consumption decrease in each crop type (foreground system). The largest reduction for this environmental impact was obtained for maize (II) with a total reduction of water supplied in the system of around 17%. This fact can be explained as maize, in this case study, requires an important amount of water in a very large area. As a consequence, small changes on the water needs of this crop have great repercussions throughout the system.

The reduction of water consumption directly influences the energy consumption of the system. As a consequence, there is a decrease in the "climate change" and "fossil fuels depletion" indicators. In addition, all environmental impact categories on background processes related to the life cycle of energy production were positively affected.

a) **Maize** – Reduction of Water Requirements: 21%

Table 36. Environmental Impacts of the Study System (baseline scenario vs RDI technology)

Indicator	BASELINE		RDI	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,007.88
Fossil Fuels Depletion (MJ)	0	124,668,758.19	0	116,731,667.67
Freshwater Resource Depletion (m^3)	3,189,641.23	0	2,827,694.43	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	105,703.29	23,640.01
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,123,817.48
Acidification (kgSO_2eq)	0	91,680.89	0	85,979.08
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	180,035.89
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	17,341.11
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,067.95
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,615.26
Mineral Depletion (kgFe-eq)	0	2,165.45	0	1,996.15

b) **Maize** – Reduction of Water Requirements: 35%

Table 37. Environmental Impacts of the Study System (baseline scenario vs RDI technology)

Indicator	BASELINE		RDI	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	9,614.61
Fossil Fuels Depletion (MJ)	0	124,668,758.19	0	112,590,577.0
Freshwater Resource Depletion (m^3)	3,189,641.23	0	2,638,852.63	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	105,703.29	23,494.97
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,091,195.25
Acidification (kgSO_2eq)	0	91,680.89	0	83,004.22
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	178,511.87
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	16,587.17
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	12,601.74
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,490.63
Mineral Depletion (kgFe-eq)	0	2,165.45	0	1,907.82

c) **Pastures** – Reduction of Water Requirements: 35%

Table 38. Environmental Impacts of the Study System (baseline scenario vs RDI Technology)

Indicator	BASELINE		RDI	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	9,959.17
Fossil Fuels Depletion (MJ)	0	124,668,758.19	0	116,218,782.42
Freshwater Resource Depletion (m^3)	3,189,641.23	0	2,827,454.75	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	105,703.29	23,622.04
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,119,777.13
Acidification (kgSO_2eq)	0	91,680.89	0	85,610.63
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	179,847.13
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	17,247.74
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,010.21
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,599.82
Mineral Depletion (kgFe-eq)	0	2,165.45	0	1,985.21

d) **Olive intensive** – Reduction of Water Requirements: 64%

Table 39. Environmental Impacts of the Study System (baseline scenario vs RDI technology)

Indicator	BASELINE		RDI	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,318.99
Fossil Fuels Depletion (MJ)	0	124,668,758	0	120,007,587
Freshwater Resource Depletion (m^3)	3,189,641.23	0	2,970,865.91	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	105,703.29	23,754.75
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,149,624.17
Acidification (kgSO_2eq)	0	91,680.89	0	88,332.42
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	181,241.50
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	17,937.54
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,436.75
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,713.85
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,066.03

e) **Olive super intensive** – Reduction of Water Requirements: 44%

Table 40. Environmental Impacts of the Study System (baseline scenario vs RDI technology)

Indicator	BASELINE		RDI	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,561.18
Fossil Fuels Depletion (MJ)	0	124,668,758	0	122,557,843
Freshwater Resource Depletion (m^3)	3,189,641	0	3,055,630	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	105,703.29	23,844.07
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,169,714.29
Acidification (kgSO_2eq)	0	91,680.89	0	90,164.46
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	182,180.06
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,401.85
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,723.85
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,790.60
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,120.43

4.2.1.2 Economic performance assessment

The assessments of the economic performance for the Regulated Deficit Irrigation technology at the individual stages' level are presented in Tables 41, 42, 43, 44 and 45.

The water savings achieved by the RDI technology do not reduce the productive capacity of the different cultures. Thus, the Net Economic Output obtained for each culture is always higher than the baseline scenario. Theoretically, it is possible to obtain the same yield in production with the smallest amount of water (lowest cost). Taking into account the economic performance assessment, it is possible to establish priorities in the application of the RDI technology to different crops. The best results are obtained for maize (II) followed by pastures, maize (I), olive intensive and finally olive super-intensive.

a) **Maize** – Reduction of Water Requirements: 21%

Table 41. Economic performance results (RDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Regulated Deficit Irrigation			
EDIA	607,011.74	0.00	350,351.34	-256,660.40
ABMonteNovo	234,755.14	0.00	252,263.29	17,508.15
Farmers	6,446,884.00	9,395,490.00	-602,614.63	2,345,991.37
Total	7,288,650.88	9,395,490.00	0.00	2,106,839.12

b) **Maize** – Reduction of Water Requirements: 35%

Table 42. Economic performance results (RDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Regulated Deficit Irrigation			
EDIA	566,473.70	0.00	326,953.84	-239,519.86
ABMonteNovo	218,858.31	0.00	238,618.21	19,759.90
Farmers	6,446,884.00	9,395,490.00	-565,572.05	2,383,033.95
Total	7,232,216.01	9,395,490.00	0.00	2,163,273.99

c) **Pastures** – Reduction of Water Requirements: 35%

Table 43. Economic performance results (RDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Regulated Deficit Irrigation			
EDIA	606,960.29	0.00	350,321.64	-256,638.64
ABMonteNovo	227,816.98	0.00	248,558.16	20,741.17
Farmers	6,446,884.00	9,395,490.00	-598,879.80	2,349,726.20
Total	7,281,661.27	9,395,490.00	0.00	2,113,828.73

d) **Olive intensive** – Reduction of Water Requirements: 64%

Table 44. Economic performance results (RDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Regulated Deficit Irrigation			
EDIA	637,745.88	0.00	368,090.29	-269,655.60
ABMonteNovo	248,665.31	0.00	263,598.79	14.933.48
Farmers	6,446,884.00	9,395,490.00	-631,689.08	2,316,916.92
Total	7,333,295.20	9,395,490.00	0.00	2,062,194.80

e) **Olive super intensive** – Reduction of Water Requirements: 44%

Table 45. Economic performance results (RDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Actor	Regulated Deficit Irrigation			
EDIA	655,942.06	0.00	378,592.64	-277,349.41
ABMonteNovo	265,224.07	0.00	274,746.91	9,522.83
Farmers	6,446,884.00	9,395,490.00	-653,339.55	2,295,266.45
Total	7,368,050.13	9,395,490.00	0.00	2,027,439.87

4.2.1.3 Eco-efficiency assessment

The results of the eco-efficiency indicators are reported in Tables 46, 47, 48, 49 and 50, while Figure 26 presents the eco-efficiency comparison for the baseline scenario and the Regulated Deficit Irrigation Technology application. The RDI technology increases the eco-efficiency for all the environmental impacts including "fossil fuels depletion", even if very small, not noticeable in the tables.

a) **Maize** – Reduction of Water Requirements: 21%

Table 46. Eco-efficiency indicators (baseline scenario vs RDI technology)

Indicator	Baseline Scenario	RDI
Climate Change (€/tCO_2eq)	185.72	210.52
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/m^{3})	0.63	0.75
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.29
Human toxicity (€/kg1,4-Dbeq)	1.68	1.87
Acidification (€/kgSO_{2-},eq)	21.8	24.5
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.70
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	121.49
Respiratory inorganics (€/kgPM_{10},eq)	143.16	161.22
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	582.76
Minerals depletion (€/kg Fe-eq)	922.98	1,055.45

b) **Maize** – Reduction of Water Requirements: 35%

Table 47. Eco-efficiency indicators (baseline scenario vs RDI technology)

Indicator	Baseline Scenario	RDI
Climate Change (€/tCO_2eq)	185.72	225.00
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.82
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.74
Human toxicity (€/kg1,4-Dbeq)	1.68	1.98
Acidification (€/kgSO_{2-},eq)	21.8	26.06
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	12.12
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	130.42
Respiratory inorganics (€/kgPM_{10},eq)	143.16	171.66
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	619.74
Minerals depletion (€/kg Fe-eq)	922.98	1,133.90

c) **Pastures** – Reduction of Water Requirements: 35%

Table 48. Eco-efficiency indicators (baseline scenario vs RDI technology)

Indicator	Baseline Scenario	RDI
Climate Change (€/tCO_2eq)	185.72	212.25
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.75
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.35
Human toxicity (€/kg1,4-Dbeq)	1.68	1.89
Acidification (€/kgSO_{2-},eq)	21.8	24.69
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.75
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	122.56
Respiratory inorganics (€/kgPM_{10},eq)	143.16	162.47
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	587.20
Minerals depletion (€/kg Fe-eq)	922.98	1,064.79

d) **Olive intensive** – Reduction of Water Requirements: 64%

Table 49. Eco-efficiency indicators (baseline scenario vs RDI technology)

Indicator	Baseline Scenario	RDI
Climate Change (€/tCO_2eq)	185.72	199.84
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.69
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.93
Human toxicity (€/kg1,4-Dbeq)	1.68	1.79
Acidification (€/kgSO_{2-},eq)	21.8	23.35
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.38
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	114.97
Respiratory inorganics (€/kgPM_{10},eq)	143.16	153.47
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	555.27
Minerals depletion (€/kg Fe-eq)	922.98	998.15

The application of the RDI technology is beneficial to the system: the highest increase in eco-efficiency, in this case, was observed for the "mineral depletion" indicator. As expected, among all the crops tested, the maize (II) is the one which presents the highest increases for each indicator.

e) **Olive super intensive** – Reduction of Water Requirements: 44%

Table 50. Eco-efficiency indicators (baseline scenario vs RDI technology)

Indicator	Baseline Scenario	RDI
Climate Change (€/tCO_2eq)	185.72	191.97
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.66
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.65
Human toxicity (€/kg1,4-Dbeq)	1.68	1.73
Acidification (€/kgSO_{2-},eq)	21.8	22.49
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.13
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	110.18
Respiratory inorganics (€/kgPM_{10},eq)	143.16	147.73
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	534.86
Minerals depletion (€/kg Fe-eq)	922.98	956.15

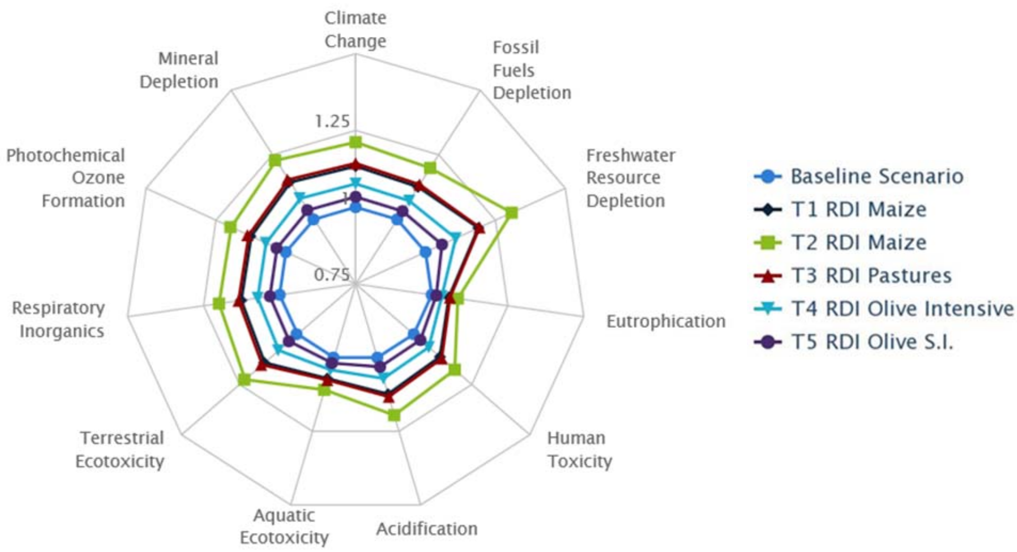


Figure 26. Comparison of eco-efficiency indicators in baseline scenario and scenario 1 (RDI technology for each crop)

4.2.2 Scenario 2: Biological Production (Sludge of WWT)

The scenario examined consists in the application of sludge from the wastewater treatment process. This sludge will be applied for olives, maize and pastures.

In Portugal, the soils are generally poor in organic compounds and nutrients (nitrogen and phosphorus). The application of sludge allows correcting these deficiencies making soils fertile and productive. The introduction of sludge in agriculture has two direct associated benefits: (i) it will allow a decrease in the amount of fertilizers used in Monte-Novo case study and (ii) prevent the deposition of sludge in landfill, decreasing the environmental impacts and waste of resources.

The distribution of sludge in soil, due to its simplicity and reduced costs, is an economically and technologically interesting alternative, used in several countries, particularly in vineyards. (Pirra, 2009)

With the aim of ensuring human and animal safety, as well as to prevent possible pollution of the soil and water courses, it is advisable to submit the sludge to specific treatments before being applied (Costa & Ferreira, 2002):

- Thickening for reduction of volume;
- Stabilization for elimination of pathogens;
- Dehydration for ease of transport and preventing release of odours.

After that, it is still necessary to analyse the sludge in order to verify that the concentrations in heavy metals are within the legal limits. Even with the former conditions verified, the amount of sludge to be applied should not exceed 6 ton/ha.year.

The application of sludge is associated with the production of various crops, as for example maize and pastures. In several studies, the application of sludge showed an increase in dry matter production on pastures. (Serrão *et al.,* 2007 and 2010)

In the study developed by Melo (2011), the use of sludge has increased the yield production of maize. This increase depends directly on the amount of sludge used. It was noted that the use of sludge can be advantageous when compared with chemical fertilization as, even after the harvesting of maize, the soil still presents high rates of fertility. The application of sludge usually increases all soil nutrients.

In the case of olives, it is possible to use sludge, with no legal constraints, however it is still currently little applied. For this crop, the sludge should be applied in depth and access should be sealed to the public during the following 10 months (Godinho, 2009).

The sludge produced in waste water treatment plants is normally sent to landfill with costs for the waste water treatment plant. The use of sludge in agriculture allows lower costs with their deposition and, on the other hand, provides the farmer with a low-cost product with excellent agronomic quality.

Around the Monte Novo irrigation perimeter, there are many waste water treatment plants, however most of them are of small dimensions. So the only one who presents a production of sludge that justifies its recovery is the Évora wastewater treatment plant, with a sludge production was estimated at around 2644 kg/day (dry matter). The sludge produced is already suitable for agricultural use.

The amount of sludge to be used in each crop was calculated taking into account the nutritional needs of nitrogen and phosphorus and the levels of nitrogen and phosphorus existing, on average, in sludge produced in Portugal.

4.2.2.1 Environmental performance assessment

In the case of scenario 2, the use of sludge in agriculture is evaluated for all the different crops considered in the case study, for both low pressure (LP) and high pressure (HP) blocks. The environmental performances for each crop compared to the baseline scenario are presented in Tables 51, 52, 53, 54, 55, 56 and 57.

The application of sludge instead of chemical fertilizers will affect positively the foreground system at the level of the "eutrophication" indicator. The reduction verified in this indicator is similar in all crops except for pastures. These results are due to the decrease in chemical fertilizers quantities used in the Monte Novo case study.

For the background system, a marked reduction for all indicators is verified compared with the baseline scenario. An exception is verified for the "mineral depletion" environmental impact because this indicator depends only on energy consumption. For maize and olive, the "fossil fuels depletion" and "aquatic ecotoxicity" are the indicators which suffer greatest decrease in absolute terms.

For pastures the chemical fertilizer used is formed by phosphorus. This type of fertilization in comparison with nitrogen fertilizer cause less environmental impacts. Thus the decline in consumption of phosphorus fertilizer does not bring so many benefits to the system (table 21 and 22).

a) **Olive Intensive (HP)** – Fertilizer reduction: Phosphorus - 89% reduction; Nitrogen - 100% reduction;

Table 51. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

Indicator	BASELINE		Biolog. Prod. Sludge	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,690.88
Fossil Fuels Depletion (MJ)	0	124,668,758	0	123,200,753
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	99,105.81	22,824.54
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,162,018.34
Acidification (kgSO_2eq)	0	91,680.89	0	90,545.97
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	173,883.08
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,768.69
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,808.33
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,805.75
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

b) **Olive Super Intensive (LP)** – Fertilizer reduction: Phosphorus - 78% reduction; Nitrogen - 87% reduction;

Table 52. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

Indicator	BASELINE		Biolog. Prod. Sludge	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,685.84
Fossil Fuels Depletion (MJ)	0	124,668,758	0	123,096,250
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	98,636.57	22,747.47
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,160,287.45
Acidification (kgSO_2eq)	0	91,680.89	0	90,465.39
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	173,237.76
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,767.45
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,797.45
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,802.32
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

c) **Olive Intensive (LP)** – Fertilizer reduction: Phosphorus - 72% reduction; Nitrogen - 80.5% reduction;

Table 53. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

Indicator	BASELINE		Biolog. Prod. Sludge	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,685.83
Fossil Fuels Depletion (MJ)	0	124,668,758	0	123,096,095
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	98,635.89	22,747.39
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,160,284.92
Acidification (kgSO_2eq)	0	91,680.89	0	90,465.28
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	173,236.83
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,767.45
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,797.44
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,802.31
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

d) **Maize (HP)** – Fertilizer reduction: Phosphorus - 18% reduction; Nitrogen - 18.6% reduction;

Table 54. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

Indicator	BASELINE		Biolog. Prod. Sludge	
	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,684.54
Fossil Fuels Depletion (MJ)	0	124,668,758	0	123,076,224
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	98,424.59	22,503.13
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,159,734.83
Acidification (kgSO_2eq)	0	91,680.89	0	90,387.00
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	172,930.24
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,765.18
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,786.74
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,799.00
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

e) **Maize (LP)** – Fertilizer reduction: Phosphorus - 16.4% reduction; Nitrogen - 17% reduction;

Table 55. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

	BASELINE		Biolog. Prod. Sludge	
Indicator	FORE	BACK	FORE	BACK
Climate Change (kgCO_2eq)	0	10,761.65	0	10,684.46
Fossil Fuels Depletion (MJ)	0	124,668,758	0	123,074,304
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	98,421.63	22,512.37
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,159,713.29
Acidification (kgSO_2eq)	0	91,680.89	0	90,388.44
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	172,926.92
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,765.25
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,786.94
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,799.06
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

f) **Pastures (HP)** – Fertilizer reduction: Phosphorus - 82% reduction;

Table 56. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

	BASELINE		Biolog. Prod. Sludge	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change (kgCO_2eq)	0	10,761.65	0	10,754.92
Fossil Fuels Depletion (MJ)	0	124,668,758	0	124,561,789
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	104,649.16	22,759.84
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,183,533.09
Acidification (kgSO_2eq)	0	91,680.89	0	91,302.47
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	181,432.05
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,775.32
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,909.83
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,838.11
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

g) **Pastures (LP)** – Fertilizer reduction: Phosphorus - 100% reduction;

Table 57. Environmental Impacts of the Study System (baseline scenario vs Biological Production - sludge)

	BASELINE		Biolog. Prod. Sludge	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change (kgCO_2eq)	0	10,761.65	0	10,755.88
Fossil Fuels Depletion (MJ)	0	124,668,758	0	124,577,032
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	104,799.37	22,924.87
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,183,933.55
Acidification (kgSO_2eq)	0	91,680.89	0	91,356.39
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	181,649.34
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,776.87
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,917.19
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,840.39
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

4.2.2.2 Economic performance assessment

The assessment of the economic performance for scenario 2 at the individual stages' level is presented in Tables 58, 59, 60, 61, 62, 63 and 64.

The use of sludge from waste water treatment plants reduces the cost with chemical fertilizers. Assuming that the use of sludge does not decrease the crop production, a higher net economic output can be obtained. The greatest net economic output is obtained for olive - super intensive (low pressure).

This scenario only influences the economic performance at the farmers' stage. The amount of water used in the Monte Novo irrigation perimeter remains the same leading to identical values as for the baseline scenario for the EDIA and ABMonteNovo stages.

With the introduction of sludge in agriculture cost savings can be obtained, with percentages of decrease going from 5% to 26%, depending on the crop area/type of crop considered.

a) **Olive Intensive (HP)** – Fertilizer reduction: Phosphorus - 89% reduction; Nitrogen - 100% reduction;

Table 58. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,412,446.00	9,395,490.00	-673,612.92	2,309,431.08
Total	7,362,379.73	9,395,490.00	0.00	2,033,110.27

b) **Olive Super Intensive (LP)** – Fertilizer reduction: Phosphorus - 78% reduction; Nitrogen - 87% reduction;

Table 59. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,367,630.00	9,395,490.00	-673,612.92	2,354,247.08
Total	7,317,563.73	9,395,490.00	0.00	2,077,926.27

c) **Olive Intensive (LP)** – Fertilizer reduction: Phosphorus - 72% reduction; Nitrogen - 80.5% reduction;

Table 60. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,409,948.00	9,395,490.00	-673,612.92	2,311,929.08
Total	7,359,881.73	9,395,490.00	0.00	2,035,608.27

d) **Maize (HP)** – Fertilizer reduction: Phosphorus - 18% reduction; Nitrogen - 18.6% reduction;

Table 61. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,381,808.00	9,395,490.00	-673,612.92	2,340,069.08
Total	7,331,741.73	9,395,490.00	0.00	2,063,748.27

e) **Maize (LP)** – Fertilizer reduction: Phosphorus - 16.4% reduction; Nitrogen - 17% reduction;

Table 62. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,381,877.00	9,395,490.00	-673,612.92	2,340,000.08
Total	7,331,810.73	9,395,490.00	0.00	2,063,679.27

f) **Pastures (HP)** – Fertilizer reduction: Phosphorus - 82% reduction;

Table 63. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,425,428.00	9,395,490.00	-673,612.92	2,296,449.08
Total	7,375,361.73	9,395,490.00	0.00	2,020,128.27

g) **Pastures (LP)** – Fertilizer reduction: Phosphorus - 100% reduction;

Table 64. Economic performance results (Biological Production - sludge)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production - sludge			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,433,591.00	9,395,490.00	-673,612.92	2,288,286.08
Total	7,383,524.73	9,395,490.00	0.00	2,011,965.27

4.2.2.3 Eco-efficiency assessment

The results of the eco-efficiency indicators assessment are presented in Tables 65, 66, 67, 68, 69, 70 and 71 while Figure 26 presents the eco-efficiency comparison for the baseline scenario and scenario 2.

The application of sludge in agriculture improves eco-efficiency for all the environmental impact indicators considered in this case study. The highest increase of eco-efficiency is observed for “climate change”, “photochemical ozone formation” and “minerals depletion” indicators. The increase of the eco-efficiency for some indicators (“climate change” and “photochemical ozone formation”) is due to the increase of the environmental performance. For the “minerals depletion” indicator, the increase of eco-efficiency is due to the increase in economic performance.

Figure 27 also highlights that the area associated with olive - super intensive (LP) is the one which achieves the best eco-efficiency values for the different indicators.

a) **Olive Intensive (HP)** – Fertilizer reduction: Phosphorus - 89% reduction; Nitrogen - 100% reduction;

Table 65. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	190.17
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.64
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.67
Human toxicity (€/kg1,4-Dbeq)	1.68	1.75
Acidification (€/kgSO_{2-},eq)	21.80	22.45
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.69
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	108.32
Respiratory inorganics (€/kgPM_{10},eq)	143.16	147.24
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	534.22
Minerals depletion (€/kg Fe-eq)	922.98	938.88

b) **Olive Super Intensive (LP)** – Fertilizer reduction: Phosphorus - 78% reduction; Nitrogen - 87% reduction;

Table 66. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	194.46
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.65
Eutrophication (€/kgPO_4^{-3},eq)	15.42	17.12
Human toxicity (€/kg1,4-Dbeq)	1.68	1.79
Acidification (€/kgSO_{2-},eq)	21.80	22.97
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.99
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	110.72
Respiratory inorganics (€/kgPM_{10},eq)	143.16	150.60
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	546.49
Minerals depletion (€/kg Fe-eq)	922.98	959.58

c) **Olive Intensive (LP)** – Fertilizer reduction: Phosphorus - 72% reduction; Nitrogen - 80.5% reduction;

Table 67. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	190.5
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.64
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.77
Human toxicity (€/kg1,4-Dbeq)	1.68	1.75
Acidification (€/kgSO_{2-},eq)	21.80	22.50
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.75
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	108.46
Respiratory inorganics (€/kgPM_{10},eq)	143.16	147.54
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	535.36
Minerals depletion (€/kg Fe-eq)	922.98	940.04

d) **Maize (HP)** – Fertilizer reduction: Phosphorus - 18% reduction; Nitrogen - 18.6% reduction;

Table 68. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	193.15
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.65
Eutrophication (€/kgPO_4^{-3},eq)	15.42	17.07
Human toxicity (€/kg1,4-Dbeq)	1.68	1.78
Acidification (€/kgSO_{2-},eq)	21.80	22.83
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.93
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	109.98
Respiratory inorganics (€/kgPM_{10},eq)	143.16	149.69
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	543.23
Minerals depletion (€/kg Fe-eq)	922.98	953.03

e) **Maize (LP)** – Fertilizer reduction: Phosphorus - 16.4% reduction; Nitrogen - 17% reduction;

Table 69.Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog. Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	193.15
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.65
Eutrophication (€/kgPO_4^{-3},eq)	15.42	17.06
Human toxicity (€/kg1,4-Dbeq)	1.68	1.78
Acidification (€/kgSO_{2-},eq)	21.80	22.83
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.93
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	109.97
Respiratory inorganics (€/kgPM_{10},eq)	143.16	149.68
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	543.21
Minerals depletion (€/kg Fe-eq)	922.98	953.00

f) **Pastures (HP)** – Fertilizer reduction: Phosphorus - 82% reduction;

Table 70. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	187.83
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.63
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.86
Human toxicity (€/kg1,4-Dbeq)	1.68	1.71
Acidification (€/kgSO_{2-},eq)	21.80	22.13
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.13
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	107.59
Respiratory inorganics (€/kgPM_{10},eq)	143.16	145.23
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	526.33
Minerals depletion (€/kg Fe-eq)	922.98	932.89

g) **Pastures (LP)** – Fertilizer reduction: Phosphorus - 100% reduction;

Table 71. Eco-efficiency indicators (baseline scenario vs Biological Production - sludge)

Indicator	Baseline Scenario	Biolog.Prod. Sludge
Climate Change (€/tCO_2eq)	185.72	187.06
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.63
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.75
Human toxicity (€/kg1,4-Dbeq)	1.68	1.70
Acidification (€/kgSO_{2-},eq)	21.80	22.02
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.08
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	107.15
Respiratory inorganics (€/kgPM_{10},eq)	143.16	144.57
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	523.90
Minerals depletion (€/kg Fe-eq)	922.98	929.12

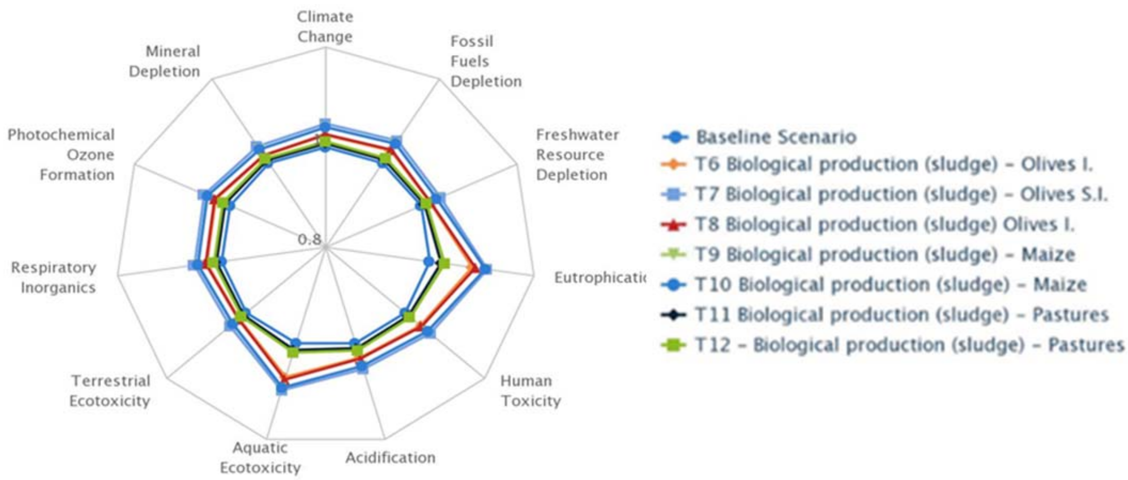


Figure 27. Comparison of eco-efficiency indicators in baseline scenario and scenario 2 (Biological Production using sludge for each crop)

4.2.3 Scenario 3: Biological Production (Organic fertilizers)

The purpose of scenario 3 is to apply organic compounds in olive, maize and pastures instead of chemical fertilizers. Organic fertilizers consist of a mixture produced from natural organic waste trough natural processes such as composting or vermicomposting. This kind of fertilization allows re-allocating nutrients to crops, for example, from green waste, manure or municipal solid waste. The use of this type of fertilization can simultaneously provide nutrients and improves soil quality (structure, water retention capacity, microbiological activity) (Alcobia *et al.,* 2001).

There are already several organic fertilizers with the most diverse origins (coffee husks, green waste, and chicken manure) in the Portuguese market. However only those who have certification in accordance with the Regulation CEE Nº2092/91 can be used in biological production. The replacement of chemical fertilizers by organic fertilizers decreases the quantities of leachate preserving the quality of surface water and groundwater. Chemical fertilizers are associated to the greatest impacts on the environment both at the production (background) and at the use (foreground) levels.

The main disadvantage of using organic fertilizer is usually related with the increase in cost. These products are usually very expensive and require high dosages per hectare. For maize, according to supplier information, it is advisable to use 700 kg/ha corresponding to a cost of 420€/ha, only for fertilizer. In the case of olives, the amount recommended is around 600 kg/ha corresponding to a cost of 360€/ha. For pastures, no values were provided. Based on the content of phosphorus that may be present in organic fertilizer and the phosphorus requirements of pastures, it was possible to estimate the amount of organic fertilizer to be used: 467 kg/ha corresponding to a cost of 280€/ha.

The use of organic fertilizers with other environmentally favourable farming techniques allows the production of, for example, organic olive oil. The change from traditional agriculture to organic agriculture allows a 20% increase in the olives price to be paid to the farmer (Ferreira, 2010). For maize, the organic production has a selling price around 300/330 €/ton, while the conventional corn sells for 260 €/ton, on average (Slow Europe, 2013). This means an increase in the price paid to the farmer between 15% and 27%. A 20% average increase in the price paid to the farmer for organic corn was also considered. It should be pointed out that some higher increases in prices should have been considered. However, as no increase in labour and equipment costs was introduced due to lack of data for the studied area, which shall occur with biological production, lower increases in selling prices were defined.

Finally, no variation in the crop production was considered.

4.2.3.1 Environmental performance assessment

The environmental performance of scenario 3 compared to the baseline scenario is presented in Tables 72, 73 and 74.

The application of organic fertilizers instead of chemical fertilizers will affect positively the foreground system, more specifically the “eutrophication” indicator. The largest decrease for this indicator can be observed for the maize, followed by olives and pastures. The main contribution to “eutrophication” comes from the use of chemical fertilizers. Their replacement by organic fertilizers allows large decreases for this indicator.

For the background system, a notorious value reduction for all indicators can be observed when compared with the baseline scenario. The exception is the "mineral depletion" environmental impact as this indicator only depends on the energy consumption.

a) **Olive Intensive and Olive Super Intensive (LP/HP)** – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 72. Environmental Impacts of the Study System (baseline scenario vs biological production – organic fertilizer)

	BASELINE		Biolog. Prod. Org. Fertil.	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change (kgCO_2eq)	0	10,761.65	0	10,507.45
Fossil Fuels Depletion (MJ)	0	124,668,758	0	119,408,793
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	81,839.02	19,576.78
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,098,777.60
Acidification (kgSO_2eq)	0	91,680.89	0	87,498.34
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	150,105.73
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,719.76
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,396.77
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,675.90
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

b) **Pastures (LP/HP)** – Fertilizer reduction: Phosphorus 100% reduction;

Table 73. Environmental Impacts of the Study System (baseline scenario vs biological production – organic fertilizer)

	BASELINE		Biolog. Prod. Org. Fertil.	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change (kgCO_2eq)	0	10,761.65	0	10,747.72
Fossil Fuels Depletion (MJ)	0	124,668,758	0	124,447,485
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication (kgPO_4eq)	105,703.29	23,918.00	103,522.73	21,522.24
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,180,530.03
Acidification (kgSO_2eq)	0	91,680.89	0	90,898.10
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	179,802.60
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,763.73
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	13,854.61
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,820.99
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

For maize and olives, the "fossil fuels depletion", "eutrophication", "aquatic ecotoxicity" and "acidification" indicators are the ones with greatest decreases, in absolute terms. These indicators are directly related to the use of chemical fertilizers in the form of nitrogen and phosphorus. For pastures the chemical fertilizer used is considered to only contain phosphorus. This type of fertilization causes less environmental impacts when compared with nitrogen fertilization impacts. Thus the decrease in the phosphorus fertilizer use does not bring so important benefits to the system (Table 73).

c) **Maize (LP/HP)** – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 74. Environmental Impacts of the Study System (baseline scenario vs biological production – organic fertilizer)

	BASELINE		Biolog. Prod. Org. Fertil.	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change ($kgCO_2eq$)	0	10,761.65	0	9,909.10
Fossil Fuels Depletion (MJ)	0	124,668,758	0	106,998,811
Freshwater Resource Depletion (m^3)	3,189,641.23	0	3,189,641.23	0
Eutrophication ($kgPO_4eq$)	105,703.29	23,918.00	26,044.83	10,292.64
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	893,103.22
Acidification ($kgSO_2eq$)	0	91,680.89	0	77,893.08
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	73,366.38
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	18,571.59
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	12,100.39
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,266.51
Mineral Depletion (kgFe-eq)	0	2,165.45	0	2,165.45

4.2.3.2 Economic performance assessment

The assessment of the economic performance for scenario 3 is presented in Tables 75, 76 and 77, at the different stage level/actor level. The use of organic fertilizers reduces the cost with fertilizers for maize, leading to a higher net economic output. With the introduction of organic fertilizers in the maize area, cost savings associated with fertilizers of around 20% can be achieved. For olive and pastures the application of organic fertilizers instead of chemical fertilizers increase the costs associated with these cultures.

This scenario only influences the economy at the farmers´ stage. The amount of water used in the Monte Novo case study remains the same: the values associated with the EDIA and ABMonteNovo stages do not change.

The net economic output for pastures is smaller than the net economic output of the baseline scenario as the introduction of organic fertilizers represents a production cost increase. For the maize and olive intensive/olive super-intensive, the net economic output is 50% and 18% higher than the net economic output obtained for the baseline scenario, respectively. Although the olive fertilizer costs increase, the TVA increases due to the increase of the price paid to the farmer.

a) Olive Intensive and Olive Super Intensive (LP/HP) – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 75. Economic performance results (Biological Production - organic fertilizer)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production – Organic Fertilizer			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,927,592.00	10,254,738.00	-673,612.92	2,653,533.08
Total	7,877,525.73	10,254,738.00	0.00	2,377,212.27

b) Pastures (LP/HP) – Fertilizer reduction: Phosphorus 100% reduction;

Table 76. Economic performance results (Biological Production - organic fertilizer)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production – Organic Fertilizer			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,550,185.00	9,395,490.00	-673,612.92	2,171,692.08
Total	7,500,118.73	9,395,490.00	0.00	1,895,371.27

c) Maize (LP/HP) – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 77. Economic performance results (Biological Production - organic fertilizer)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Biological Production – Organic Fertilizer			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,311,847.00	10,277,910.00	-673,612.92	3,292,450.08
Total	7,261,780.73	10,277,910.00	0.00	3,016,129.27

4.2.3.3 Eco-efficiency assessment

The results of the eco-efficiency indicators are presented in Tables 78, 79 and 80 and Figure 28 presents the eco-efficiency comparison between the baseline scenario and scenario 3.

The application of organic fertilizers in agriculture improves eco-efficiency for maize and olive. The highest increase of eco-efficiency for these crops were observed for “climate change”, “eutrophication”, “photochemical ozone formation” and “minerals depletion” indicators.

For pastures, the eco-efficiency decreases for all the environmental indicators. The benefits achieved with the introduction of organic compounds aren´t sufficient to justify the economic impact associated with the application of this technology. There is consequently a decrease in eco-efficiency (Figure 28).

a) Olive Intensive and Olive Super Intensive (LP/HP) – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 78. Eco-efficiency indicators (baseline scenario vs Biological Production – organic fertilizer)

Indicator	Baseline Scenario	Biolog.Prod. Org. Fertil.
Climate Change (€/tCO_2eq)	185.72	226.24
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.75
Eutrophication (€/kgPO_4^{-3},eq)	15.42	23.44
Human toxicity (€/kg1,4-Dbeq)	1.68	2.16
Acidification (€/kgSO_{2-},eq)	21.80	27.17
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	15.84
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	126.99
Respiratory inorganics (€/kgPM_{10},eq)	143.16	177.45
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	646.70
Minerals depletion (€/kg Fe-eq)	922.98	1097.79

b) **Pastures (LP/HP)** – Fertilizer reduction: Phosphorus 100% reduction;

Table 79. Eco-efficiency indicators (baseline scenario vs Biological Production – organic fertilizer)

Indicator	Baseline Scenario	Biolog.Prod. Org. Fertil.
Climate Change (€/tCO_2eq)	185.72	176.35
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.59
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.16
Human toxicity (€/kg1,4-Dbeq)	1.68	1.61
Acidification (€/kgSO_{2-},eq)	21.80	20.85
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	10.54
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	101.01
Respiratory inorganics (€/kgPM_{10},eq)	143.16	136.80
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	496.04
Minerals depletion (€/kg Fe-eq)	922.98	875.28

c) **Maize (LP/HP)** – Fertilizer reduction: Phosphorus 100% reduction; Nitrogen 100% reduction;

Table 80. Eco-efficiency indicators (baseline scenario vs Biological Production – organic fertilizer)

Indicator	Baseline Scenario	Biolog. Prod. Org. Fertil.
Climate Change (€/tCO_2eq)	185.72	304.38
Fossil fuels depletion (€/MJ)	0.02	0.03
Freshwater resource depletion (€/$m^{3)}$	0.63	0.95
Eutrophication (€/kgPO_4^{-3},eq)	15.42	83.00
Human toxicity (€/kg1,4-Dbeq)	1.68	3.38
Acidification (€/kgSO_{2-},eq)	21.80	38.72
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	41.11
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	162.41
Respiratory inorganics (€/kgPM_{10},eq)	143.16	249.26
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	923.35
Minerals depletion (€/kg Fe-eq)	922.98	1,392.84

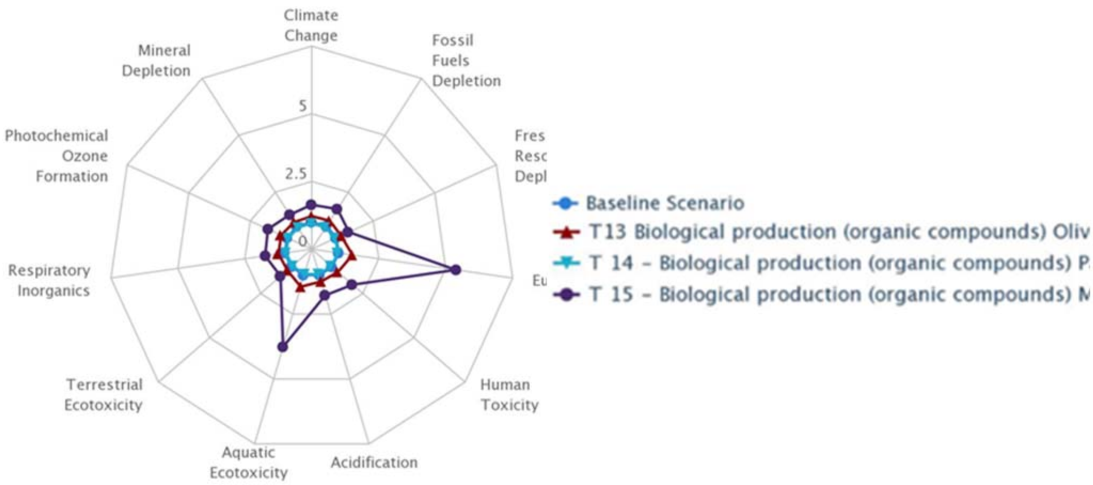


Figure 28. Comparison of eco-efficiency indicators in baseline scenario and scenario 3 (Biological Production using organic fertilizers for each crop)

4.2.4 Scenario 4: Subsurface Irrigation Technology

This scenario consists in applying subsurface irrigation for maize and olives (for high pressure and low pressure blocks). For maize, the change in the irrigation method from sprinkler to subsurface drip irrigation allows water and energy savings that can be achieved through reducing the water supplied and pressure requirements. In the case of olives, changing from drip-irrigation to subsurface drip irrigation allows to substantially reduce the volume of water supplied.

Subsurface drip irrigation (SDI) is the application of water below the soil surface though emitters (ASAE, 2005). The discharge rates are similar to drip-irrigation. This method of irrigation has been used all over the world in a wide variety of crops, woody crops and others such maize, tomato, etc. The efficiency of subsurface drip irrigation could be similar to drip irrigation but it uses less water because the soil evaporation, surface runoff and deep percolation are reduced or eliminated. Simultaneously, the risk of water contamination is decreased since the movement of fertilizers by deep percolation is reduced (Sinobas *et al.*, 2012). In widely spaced crops, a smaller fraction of the soil volume can be wetted reducing the weed germination and weed growth. Studies conducted in Kansas have concluded that it is possible to reduce the net irrigation needs by 25% with SDI, maintaining productivity (Lamm et al., 2000).

It should be noted that a reduction in water needs leads to an energy saving of the same order of magnitude. Additionally, the operating pressures used in SDI are often less than in drip irrigation which corresponds to a reduction in energy costs (Sinobas et al., 2012). This system allows precise application of water-soluble fertilizers and other agricultural chemicals.

The adoption of subsurface drip irrigation instead of drip irrigation will increase the overall on-farm irrigation efficiency from 90% to 95%. In the case of changing from sprinkler to SDI, the irrigation efficiency increases from 80% to 95%. Subsurface Drip irrigation systems were considered to have an investment cost of 5000 €/ha, operation and maintenance cost of 600 €/ha/year (12% investment cost) and a lifetime of 15 years (Source: ECOWATER technology inventory).

4.2.4.1 Environmental performance assessment

The environmental performance obtained by the implementation of the Subsurface Drip Irrigation technology for maize and olive crops is presented in Tables 81 and 82, comparing it directly with the baseline scenario.

a) **Olive Intensive and Olive Super Intensive (LP/HP)** – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 81. Environmental Impacts of the Study System (baseline scenario vs SDI technology)

	BASELINE		SDI	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change (kgCO_2eq)	**0**	**10,761.65**	**0**	**10,097.46**
Fossil Fuels Depletion (MJ)	**0**	**124,668,758**	**0**	**117,674,960**
Freshwater Resource Depletion (m^3)	**3,189,641.23**	**0**	**3,021,416.21**	**0**
Eutrophication (kgPO_4eq)	**105,703.29**	**23,918.00**	**105,703.29**	**23,673.05**
Human Toxicity (kg1,4-DBeq)	**0**	**1,186,343.42**	**0**	**1,131,248.45**
Acidification (kgSO_2eq)	**0**	**91,680.89**	**0**	**86,656.72**
Aquatic Ecotoxicity (kg1,4-DBeq)	**0**	**182,956.92**	**0**	**180,383.04**
Terrestrial Ecotoxicity (kg1,4-DBeq)	**0**	**18,786.18**	**0**	**17,512.85**
Respiratory Inorganics (kgPM10,eq)	**0**	**13,961.50**	**0**	**13,174.14**
Ozone Formation (kgC_2H_4,eq)	**0**	**3,854.12**	**0**	**3,643.65**
Mineral Depletion (kgFe-eq)	**0**	**2,165.45**	**0**	**2,016.27**

The main effect of the increased irrigation efficiency is the reduction of water consumption, confirmed by the decrease of “freshwater resource depletion”. At the same time, there is also a reduction of energy consumption. Thus, the environmental impact categories mainly affected due to the application of this technology are "acidification", "fossil fuels depletion" and "human toxicity" indicators.

When comparing the performance for each crop, it can be noted that the application of subsurface drip irrigation in the maize area brings more environmental benefits than in the olives area, as water requirements for maize are higher than for olives.

b) **Maize (LP/HP)** – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 82. Environmental Impacts of the Study System (baseline scenario vs SDI technology)

	BASELINE		SDI	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change ($kgCO_2eq$)	0	10,761.65	0	9,289.10
Fossil Fuels Depletion (MJ)	0	124,668,758	0	109,163,007
Freshwater Resource Depletion (m^3)	3,189,641.23	0	2,609,863.75	0
Eutrophication ($kgPO_4eq$)	105,703.29	23,918.00	105,703.29	23,374.92
Human Toxicity (kg1,4-DBeq)	0	1,186,343.42	0	1,064,193.92
Acidification ($kgSO_2eq$)	0	91,680.89	0	80,541.94
Aquatic Ecotoxicity (kg1,4-DBeq)	0	182,956.92	0	177,250.44
Terrestrial Ecotoxicity (kg1,4-DBeq)	0	18,786.18	0	15,963.13
Respiratory Inorganics (kgPM10,eq)	0	13,961.50	0	12,215.87
Ozone Formation (kgC_2H_4,eq)	0	3,854.12	0	3,387.48
Mineral Depletion (kgFe-eq)	0	2,165.45	0	1,834.70

4.2.4.2 Economic performance assessment

The assessment of the economic performance obtained by the implementation of the Subsurface Drip Irrigation technology, at the actors/stage level is presented in Tables 83 and 84. The SDI technology allows a larger reduction in irrigation water use for maize (18% of reduction) in comparison with olives (5% of reduction).

a) **Olive Intensive and Olive Super Intensive (LP/HP)** – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 83. Economic performance results (SDI Technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Subsurface Irrigation			
EDIA	648,597.35	0.00	374,353.47	-274,243.88
ABMonteNovo	257,734.50	0.00	269,817.53	12,083.03
Farmers	6,944,654.25	9,395,490.00	-644,171.00	1,806,664.75
Total	7,850,986.10	9,395,490.00	0.00	1,544,503.90

For both cultures, the net economic output is lower than the value obtained for the baseline scenario. Despite the water saving introduced, the investment associated with the SDI technology is very high. The net economic output associated to olive is higher than the one obtained for maize as the costs (€/ha) for olive (without water and energy) are smaller than for maize.

b) Maize (LP/HP) – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 84. Economic performance results (SDI technology)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Subsurface Irrigation			
EDIA	560,250.75	0.00	323,362.12	-236,888.63
ABMonteNovo	216,418.01	0.00	236,523.57	20,105.56
Farmers	7,589,407.25	9,395,490.00	-559,885.69	1,246,197.06
Total	8,366,076.01	9,395,490.00	0.00	1,029,413.99

4.2.4.3 Eco-efficiency assessment

The results of the eco-efficiency indicators obtained for each crop are presented in Tables 85 and 86. Figure 29 summarizes the eco-efficiency comparison for the baseline scenario and each of the two crops considered (olive and maize). The implementation of the SDI technology originates a decrease in the eco-efficiency for all the environmental impact indicators. Despite a water saving for both crops, the simultaneous increase in costs associated with irrigation is higher and offsets the environmental benefits. It should be noted that the eco-efficiency associated to the different environmental impact indicators is higher for olives than for maize.

a) **Olive Intensive and Olive Super Intensive (LP/HP)** – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 85. Eco-efficiency indicators (baseline scenario vs SDI technology)

Indicator	Baseline Scenario	SDI
Climate Change (€/tCO_2eq)	185.72	152.96
Fossil fuels depletion (€/MJ)	0.02	0.01
Freshwater resource depletion (€/$m^{3)}$	0.63	0.51
Eutrophication (€/kgPO_4^{-3},eq)	15.42	11.94
Human toxicity (€/kg1,4-Dbeq)	1.68	1.37
Acidification (€/kgSO_{2-},eq)	21.80	17.82
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	8.56
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	88.19
Respiratory inorganics (€/kgPM_{10},eq)	143.16	117.24
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	423.89
Minerals depletion (€/kg Fe-eq)	922.98	766.02

b) **Maize (LP/HP)** – Increased irrigation efficiency: 95%; Decreased in water consumption: 25%; Decreased in energy consumption: 25%;

Table 86. Eco-efficiency indicators (baseline scenario e vs SDI technology)

Indicator	Baseline Scenario	SDI
Climate Change (€/tCO_2eq)	185.72	110.82
Fossil fuels depletion (€/MJ)	0.02	0.01
Freshwater resource depletion (€/m^3)	0.63	0.39
Eutrophication (€/kgPO_4^{-3},eq)	15.42	7.98
Human toxicity (€/kg1,4-Dbeq)	1.68	0.97
Acidification (€/kgSO_{2-},eq)	21.80	12.78
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	5.81
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	64.49
Respiratory inorganics (€/kgPM_{10},eq)	143.16	84.27
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	303.89
Minerals depletion (€/kg Fe-eq)	922.98	561.08

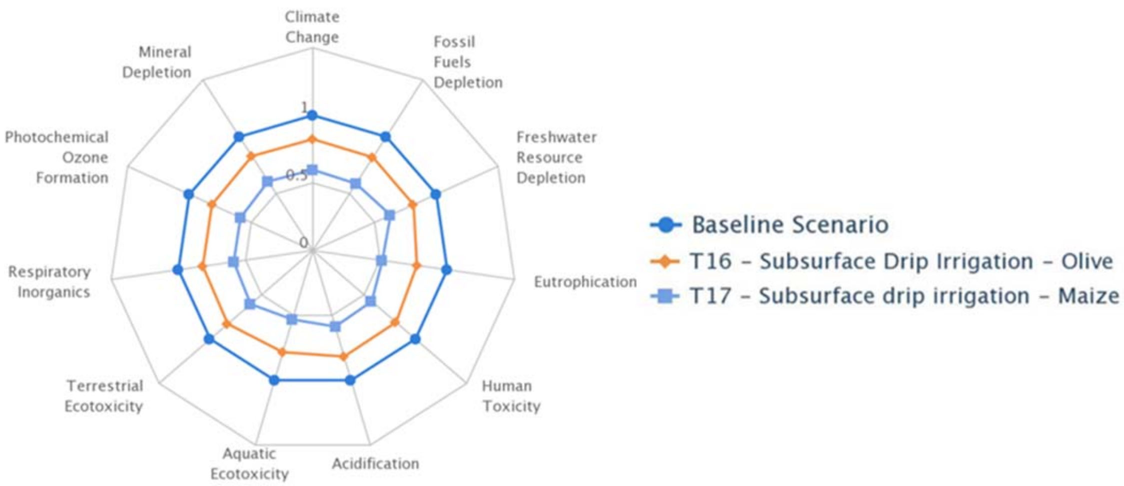


Figure 29. Comparison of eco-efficiency indicators in baseline scenario and scenario 2 (Biological Production using sludge for each crop)

4.2.5 Scenario 5: New energy pricing policy

Scenario 5 consists of the adoption of a new contract for the purchase of electricity. In Portugal, the energy consumer has the possibility to choose between 3 different types of contract. The price per KWh depends directly on the schedule during which they consume energy.

For the contract “Tarifa Simples” the price of KWh is the same throughout the day. For the “Tarifa bi-horária” contract, the price of the KWh varies according to two scheduled periods. Finally the third type of contract, “Tarifa tri-horária” sets the price of energy according to three different time periods.

Of the three different contracts, the lowest price of the KWh is, as expected, available for one of the time periods of the “Tarifa tri-horária” contract, but the energy has to be used between 10:00 PM and 08:00 AM. Energy costs associated with agriculture are mostly due to the use of water pumps to irrigate the different cops, with special emphasis on the “low-pressure” blocks.

The different producers’ associations of olive and maize emphasized that there are no disadvantages in irrigating these cultures during the lowest energy price period. Bearing the in mind, this scenario considers a decrease in the energy price from 0.115€/KWh to 0.0831€/KWh, which corresponds to a 28% reduction. This decrease in energy costs will only be taken into account for olives and maize. For pastures, it has not yet been confirmed whether irrigation water could be applied in the lowest price time period.

4.2.5.1 Environmental performance assessment

The environmental performance obtained by the implementation of the new energy price for maize and olive crops is presented in Table 87, comparing it directly with the baseline scenario. The environmental performance for all three crops (maize, olive and pastures) will be the same as the decrease in the price of energy does not affect the environmental performance.

a) **Olive Intensive and Olive Super Intensive, Maize and Pastures (LP/HP)** – Decreased in energy price: 28%;

Table 87. Environmental Impacts of the Study System (baseline scenario vs new energy price)

	BASELINE		Energy Price	
Indicator	**FORE**	**BACK**	**FORE**	**BACK**
Climate Change ($kgCO_2eq$)	**0**	**10,761.65**	**0**	**10,761.65**
Fossil Fuels Depletion (MJ)	**0**	**124,668,758**	**0**	**124,668,758**
Freshwater Resource Depletion (m^3)	**3,189,641.23**	**0**	**3,189,641.23**	**0**
Eutrophication ($kgPO_4eq$)	**105,703.29**	**23,918.00**	**105,703.29**	**23,918.00**
Human Toxicity (kg1,4-DBeq)	**0**	**1,186,343.42**	**0**	**1,186,343.42**
Acidification ($kgSO_2eq$)	**0**	**91,680.89**	**0**	**91,680.89**
Aquatic Ecotoxicity (kg1,4-DBeq)	**0**	**182,956.92**	**0**	**182,956.92**
Terrestrial Ecotoxicity (kg1,4-DBeq)	**0**	**18,786.18**	**0**	**18,786.18**
Respiratory Inorganics (kgPM10,eq)	**0**	**13,961.50**	**0**	**13,961.50**
Ozone Formation (kgC_2H_4,eq)	**0**	**3,854.12**	**0**	**3,854.12**
Mineral Depletion (kgFe-eq)	**0**	**2,165.45**	**0**	**2,165.45**

4.2.5.2 Economic performance assessment

The assessment of the economic performance obtained by the implementation of the new energy price, at the actors/stage level is presented in Tables 88, 89 and 90. This technology allows a further reduction in annual O&M costs for maize in comparison with olives. Yet the net economic output for olives is higher than maize as the price paid to the farmer (€/ton) is higher than the one for olives, counterbalancing the smaller decrease in costs.

For both cultures, the net economic output is higher than the value obtained for the baseline scenario.

a) Olive Intensive and Olive Super Intensive (LP/HP) – Decreased in energy price: 28%;

Table 88. Economic performance results (New Energy Price)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Subsurface Irrigation			
EDIA	648,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,389,508.66	9,395,490.00	-673,612.92	2,332,368.42
Total	7,339,442.39	9,395,490.00	0.00	2,056,047.61

b) **Maize (LP/HP)** – Decreased in energy price: 28%;

Table 89. Economic performance results (New Energy Price)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Subsurface Irrigation			
EDIA	684,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,404,667.54	9,395,490.00	-673,612.92	2,317,209.54
Total	7,354,601.27	9,395,490.00	0.00	2,040,888.73

c) **Pastures (LP/HP)** – Decreased in energy price: 28%;

Table 90. Economic performance results (New Energy Price)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Stage	Subsurface Irrigation			
EDIA	648,709.65	0.00	395,196.55	-289,513.10
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,426,212.80	9,395,490.00	-673,612.92	2,295,664.28
Total	7,376,146.53	9,395,490.00	0.00	2,019,343.47

4.2.5.3 Eco-efficiency assessment

The results of the eco-efficiency indicators obtained for each crop are presented in Tables 91, 92 and 93. Figure 30 summarizes the eco-efficiency comparison for the baseline scenario and each of the two crops considered (olive and maize).

The implementation of the new energy price technology increases eco-efficiency for all the environmental impact indicators. The increase of eco-efficiency is due solely to a reduction in energy costs. It should be noted that the eco-efficiency associated to the different environmental impact indicators is higher for olives than for maize.

a) **Olive Intensive and Olive Super Intensive (LP/HP)** – Decreased in energy price: 28%;

Table 91. Eco-efficiency indicators (baseline scenario vs new energy price)

Indicator	Baseline Scenario	Energy Price
Climate Change (€/tCO_2eq)	185.72	191.05
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.64
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.86
Human toxicity (€/kg1,4-Dbeq)	1.68	1.73
Acidification (€/kgSO_{2-},eq)	21.80	22.43
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.24
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	109.44
Respiratory inorganics (€/kgPM_{10},eq)	143.16	147.27
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	533.47
Minerals depletion (€/kg Fe-eq)	922.98	949.48

b) **Maize (LP/HP)** – Decreased in energy price: 28%;

Table 92. Eco-efficiency indicators (baseline scenario e vs new energy price)

Indicator	Baseline Scenario	Energy Price
Climate Change (€/tCO_2eq)	185.72	189.64
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.64
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.75
Human toxicity (€/kg1,4-Dbeq)	1.68	1.72
Acidification (€/kgSO_{2-},eq)	21.80	22.26
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.16
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	108.64
Respiratory inorganics (€/kgPM_{10},eq)	143.16	146.18
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	529.53
Minerals depletion (€/kg Fe-eq)	922.98	942.48

c) **Pastures (LP/HP)** – Decreased in energy price: 28%;

Table 93. Eco-efficiency indicators (baseline scenario e vs new energy price)

Indicator	Baseline Scenario	Energy Price
Climate Change (€/tCO_2eq)	185.72	187.64
Fossil fuels depletion (€/MJ)	0.02	0.02
Freshwater resource depletion (€/$m^{3)}$	0.63	0.63
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.58
Human toxicity (€/kg1,4-Dbeq)	1.68	1.70
Acidification (€/kgSO_{2-},eq)	21.80	22.03
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.04
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	107.49
Respiratory inorganics (€/kgPM_{10},eq)	143.16	144.64
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	523.94
Minerals depletion (€/kg Fe-eq)	922.98	932.53

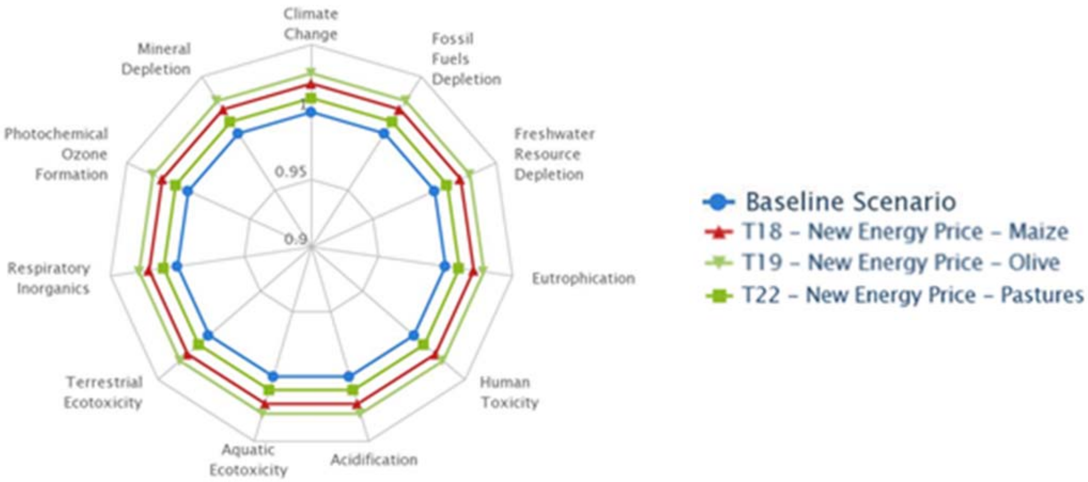


Figure 30. Comparison of eco-efficiency indicators in baseline scenario and scenario 2 (New energy price for maize and olive).

4.2.6 Scenario 5: New water pricing policy

This scenario presents an alternative value for the water price in the Monte-Novo irrigation site. In Portugal, and more specifically in the Alentejo region, future prospects of water use are depending on the implementation of the new CAP (Common Agricultural Policy) and the Water Framework Directive (2000/60/CE - WFD) (Fragoso et al.,2006).

Agriculture in Europe is heavily subsidized; this leads to the production of crops with low economic income and the low efficiency in the use of water. The application of New CAP intends to “motivate” farmers to adopt measures which are more efficient in the use of water in order to decrease the costs and increase the economic return. Generally speaking, in Portugal, the price of water is also subsidized, i.e, the price of water is lower than the actual cost of obtaining water. This policy of subsidized prices has allowed maintaining the competitiveness of irrigated crops but has created budget difficulties in the management agencies/institutions. One of the main goals of the implementation of the WFD is the sustainable use of the resource by allocating the costs to the user (Fragoso *et al.,*2006).

According to the study of Noéme (2004),in the Vigia irrigation perimeter, near the Monte Novo area, the price of water is expected to be maintained around 0,04 €/m^3 in the scenario of the new CAP, however with an utilization rate below 50%. The full compliance with the WFD (user pays) in the scenario of the new CAP will lead to a decrease in ecological variability as crop production with higher economic return will be favoured.

In the other irrigation perimeters belonging to the same river basin as the Monte-Novo, the water prices are between 0.0189€/m^3 and 0.034 €/m^3 (PGRH, 2012).

4.3 Assessment of Technology Scenarios

4.3.1 Technology scenario promoting resource efficiency

Two of the technologies tested in the Monte Novo case study mostly promote resource efficiency: the Regulated Deficit Irrigation (RDI) and the Subsurface Drip Irrigation (SDI) technology.

The application of the Regulated Deficit Irrigation technology allows increasing the efficiency of water use, maintaining a similar productive yield and spending smaller amounts of water, which result in lower energy costs. For this technology, four sub-scenarios were developed, based on the water requirement reduction considered: 21% and 35% for maize, 64% for olive intensive and 44% for olive super intensive. The results presented below refer to these four scenarios.

On the other hand, the Subsurface Drip Irrigation technology increases the efficiency of the irrigation process, which means lower water losses (water saving) and energy consumption.

Tables 94 and 97 present the environmental performance for these technology scenarios that have potential for water and energy saving. Water saving will affect, directly, the environmental indicator “freshwater depletion” (foreground). The energy saving is mainly related with the “climate change”, “fossil fuel depletion”, “mineral depletion”, “respiratory inorganics” and “human toxicity potential” indicators due to the reduction of associated emissions due to electricity.

RDI applied to maize in the Monte Novo case study results in a reduction in water consumption used for irrigation between 11% and 17% (for 21% and 35% scenarios respectively). For olives, the verified reduction is between 4% (olive super intensive) and 7% (olive intensive). With regard to energy saving, with the application of the RDI technology, for maize, savings between 8% and 12% are verified. For olives, the reduction achieved is between 2% and 5% (olive intensive).

For maize, due to the reduction of energy consumption, the environmental indicator “fossil fuels depletion” is reduced between 11% and 17% for the EDIA stage. For olives, the reduction verified is between 4% and 7% for the same stage.

The SDI allows decreasing water and energy consumption. For maize, water and energy savings are around 18% and 15%, respectively. For olives, water saving is about 5% and energy saving approximately 6%. Climate change emissions due to increased efficiency irrigation are reduced by 18% for maize (EDIA stage) and 5% for olives (EDIA stage).

a) Maize

* Reduction of Water Requirements: 21%

**Reduction of Water Requirements: 35%

Table 94. Environmental Performance for resource use efficiency technologies at the stage level (All results are in kg except climate change - ton)

Stage	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Mineral Depletion	Fossil Fuels Depletion
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Regulated Deficit Irrigation (*)										
EDIA	0.83	0.31	6.26	68.70	0.99	3.21	1.59	0.26	0.19	208.28
ABMonteNovo	0.33	0.12	2.49	27.30	0.39	1.28	0.63	0.10	0.08	82.77
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Regulated Deficit Irrigation (**)										
EDIA	0.77	0.29	5.85	64.11	0.92	2.99	1.48	0.24	0.18	194.37
ABMonteNovo	0.31	0.11	2.32	25.45	0.37	1.19	0.59	0.10	0.07	77.17
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Subsurface Drip Irrigation										
EDIA	0.76	0.28	5.78	63.40	0.91	2.96	1.47	0.24	0.17	192.23
ABMonteNovo	0.30	0.11	2.30	25.17	0.36	1.18	0.58	0.10	0.07	76.31
Farmers	0.66	16.12	6.40	90.35	0.95	19.83	1.06	0.27	0.12	198.62

The economic performance of the two resource efficiency technologies is compared to the baseline scenario in Tables 95 and 98.

The application of the Regulated Deficit Irrigation technology contributed to reduced water consumption for maize and olives. This positively affected the Total Value Added for farmers. The increase for maize, with the application of RDI, is between 5% and 8%. For olives this increase is only between 1% and 3%.

The Total Value Added for maize and olives, obtained by the application of the Subsurface Drip Irrigation technology, is lower than the one obtained for the baseline scenario as the improvement of the environmental performance is not enough to justify the costs associated with the implementation of this technology.

Table 95. Economic Performance for resource use efficiency technologies

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	1,998,672.3
	Regulated Deficit Irrigation (*)				
EDIA	607,011.74	0.00	350,351.34	-256,660.40	
ABMonteNovo	234,755.14	0.00	252,263.29	17,508.15	
Farmers	6,446,884.00	9,395,490.00	-602,614.63	2,345,991.37	2,106,839.1
	Regulated Deficit Irrigation (**)				
EDIA	566,473.70	0.00	326,953.84	-239,519.86	
ABMonteNovo	218,858.31	0.00	238,618.21	19,759.90	
Farmers	6,446,884.00	9,395,490.00	-565,572.05	2,383,033.95	2,163,274.0
	Subsurface Drip Irrigation				
EDIA	560,250.75	0.00	323,362.12	-236,888.63	
ABMonteNovo	216,418.01	0.00	236,523.57	20,105.56	
Farmers	7,589,407.25	9,395,490.00	-559,885.69	1,246,197.06	1,029,414.0

Tables 96 and 99 show the results of eco-efficiency indicators, while Figures 31 and 32 summarize the eco-efficiency comparison for baseline and resource efficiency technologies.

The increase of eco-efficiency is evident when using the Regulated Deficit Irrigation technology. For the Subsurface Drip Irrigation technology, the eco-efficiency decreases for all the environmental indicators, for both cultures.

Table 96. Eco-efficiency indicators for resource use efficiency technologies

Indicators	Baseline	RDI (*)	RDI (**)	Subsurface Drip
Climate Change (€/tCO_2eq)	185.72	210.52	225.00	110.82
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.01
Freshwater resource depletion (€/m^3)	0.63	0.75	0.82	0.39
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.29	16.74	7.98
Human toxicity (€/kg1,4-Dbeq)	1.68	1.87	1.98	0.97
Acidification (€/kgSO_{2-},eq)	21.80	24.50	26.06	12.78
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.70	12.12	5.81
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	121.49	130.42	64.49
Respiratory inorganics (€/kgPM_{10},eq)	143.16	161.22	171.66	84.27
Ozone formation (€/kgC_2H_4,eq)	518.58	582.76	619.74	303.89
Minerals depletion (€/kg Fe-eq)	922.98	1,055.45	1,133.90	561.08

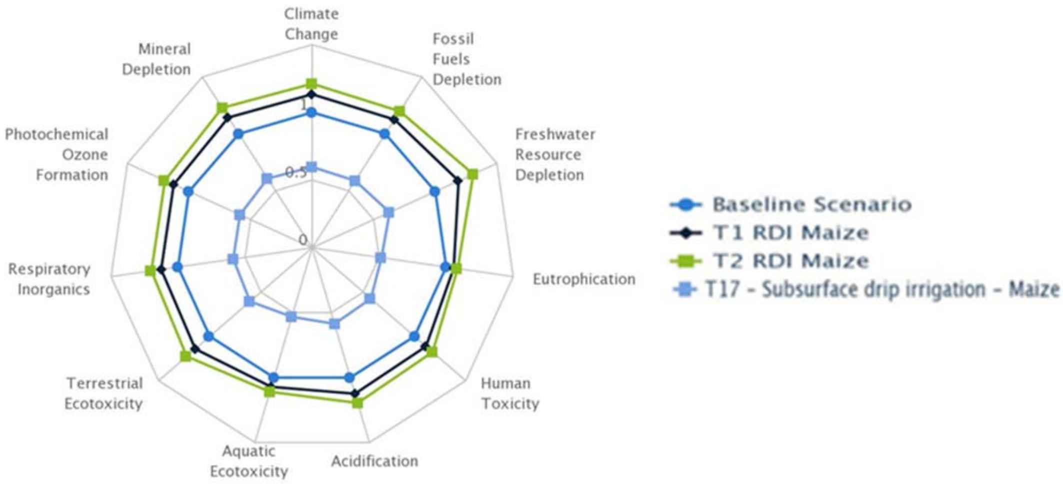


Figure 31. Comparison of eco-efficiency indicators in baseline scenario and resource efficiency technologies.

b) Olives

*Olive Intensive (LP and HP)

**Olive Super Intensive (LP and HP)

***Olive Int. and S.Int. (LP and HP)

Table 97. Environmental Performance for resource use efficiency technologies at the stage level (All results are in kg except climate change - ton)

Stage	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Miineral Depletion	Fossil Fuels Depletion
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Regulated Deficit Irrigation (*)										
EDIA	0.87	0.32	6.58	72.17	1.04	3.37	1.67	0.28	0.20	218.82
ABMonteNovo	0.35	0.13	2.64	28.92	0.42	1.35	0.67	0.11	0.08	87.68
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Regulated Deficit Irrigation (**)										
EDIA	0.89	0.33	6.77	74.23	1.07	3.47	1.72	0.28	0.20	225.07
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Subsurface Drip Irrigation (***)										
EDIA	0.88	0.33	6.69	73.4	1.05	3.43	1.70	0.28	0.20	222.55
ABMonteNovo	0.36	0.13	2.73	29.97	0.43	1.40	0.69	0.11	0.08	90.88
Farmers	0.63	16.1	6.15	87.66	0.92	19.71	0.99	0.26	0.11	190.44

Table 98. Economic Performance for resource use efficiency technologies

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	1,998,672.3
	Regulated Deficit Irrigation (*)				
EDIA	637,745.88	0.00	368,090.29	-269,655.60	
ABMonteNovo	248,665.31	0.00	263,598.79	14,933.48	
Farmers	6,446,884.00	9,395,490.00	-631,689.08	2,316,916.92	2,062,194.8
	Regulated Deficit Irrigation (**)				
EDIA	655,942.06	0.00	378,592.64	-277,349.41	
ABMonteNovo	265,224.07	0.00	274,746.91	9,522.83	
Farmers	6,446,884.00	9,395,490.00	-653,339.55	2,295,266.45	2,027,439.9
	Subsurface Drip Irrigation (***)				
EDIA	648,597.35	0.00	374,353.47	-274,243.88	
ABMonteNovo	257,734.50	0.00	269,817.53	12,083.03	
Farmers	6,944,654.25	9,395,490.00	-644,171.00	1,806,664.75	1,544,503.9

Table 99. Eco-efficiency indicators for resource use efficiency technologies

Indicators	Baseline	RDI (*)	RDI (**)	Subsurface Drip (***)
Climate Change (€/tCO_2eq)	185.72	199.84	191.97	152.96
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.01
Freshwater resource depletion (€/m^3)	0.63	0.69	0.66	0.51
Eutrophication (€/kgPO_4^{-3},eq)	15.42	15.93	15.65	11.94
Human toxicity (€/kg1,4-Dbeq)	1.68	1.79	1.73	1.37
Acidification (€/kgSO_{2-},eq)	21.80	23.35	22.49	17.82
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.38	11.13	8.56
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	114.97	110.18	88.19
Respiratory inorganics (€/kgPM_{10},eq)	143.16	153.47	147.73	117.24
Ozone formation (€/kgC_2H_4,eq)	518.58	555.27	534.86	423.89
Minerals depletion (€/kg Fe-eq)	922.98	998.15	956.15	766.02

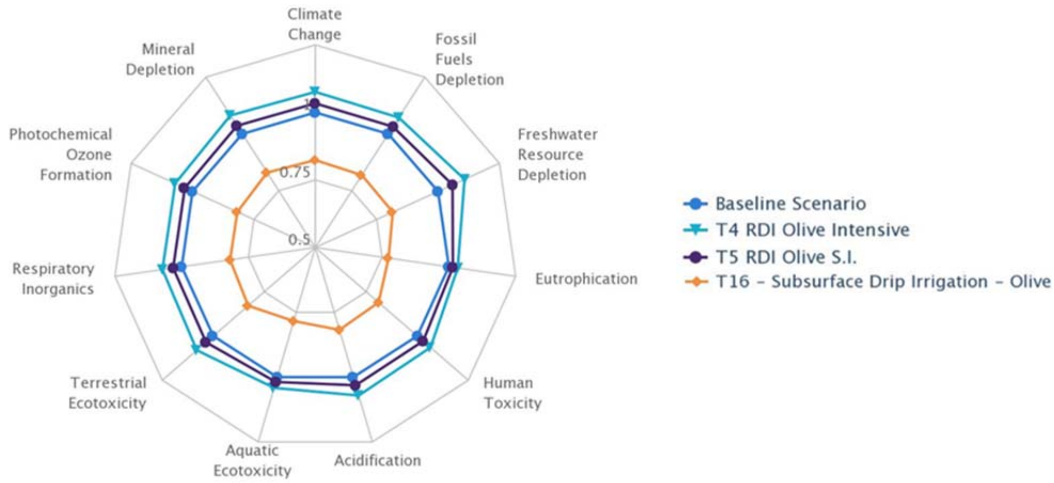


Figure 32. Comparison of eco-efficiency indicators in baseline scenario and resource efficiency technologies.

4.3.2 Technology scenario focusing on pollution prevention

From the analysis of all scenarios considered for the Monte Novo case study, the use of sludge from waste water treatment plants and organic fertilizers are the most suitable to prevent pollution of the environmental the study area.

The introduction of sludge in agriculture prevents pollution caused by the use of chemical fertilizers (nitrogen and phosphorus). This change moderately improves the environmental performance of the environmental indicators which are mainly affected by the life cycle of nitrogen and phosphorus production (background) and by the use of chemical fertilizers.

Pollution prevention can also be achieved through the use of organic fertilizers. This enables a high increase of the environmental performance of environmental indicators which are mainly affected by the use of chemical fertilizers (“eutrophication” indicator - foreground). There are also changes in the indicators associated with the life cycle of nitrogen and phosphorus production (“acidification”, “human toxicity”, “fresh aquatic ecotoxicity” and “fossil fuel depletion” indicators).

In Tables 100, 103 and 106 the different environmental performances (by crops) of the technology scenarios that have potential for pollution prevention are reported. It should be noted that different scenarios were considered, according to the crop considered:

- Maize high pressure and maize low pressure,
- Olives intensive low pressure, olives intensive high pressure and olives super intensive low pressure, and
- Pastures low pressure and pastures high pressure.

Regardless of the crop considered, the emissions avoided thanks to the use of sludge are minor as, in the Monte Novo case study, only a small amount of sludge is available that could only satisfy a small portion of the global nutritional needs of the Monte-Novo case study. For example, the environmental indicator “fresh aquatic toxicity” suffers a decrease between 3% (pastures) and 5% (maize) for farmers’ stage.

Sludge applied to maize results in a reduction in chemical fertilizers of approximately 7% for nitrogen and 7% for phosphorus. For olives, the reduction verified is between 6% for nitrogen and 5% for phosphorus. Finally, for pastures, the chemical fertilizer savings range between 5% and 6% for phosphorus.

The application of organic fertilizers results in a reduction of chemical fertilizers for maize of 77% (for nitrogen) and 66.8% (for phosphorus). When applied to olives, organic fertilizers can reduce the consumption of chemical fertilizers in 23% (for nitrogen) and 21% for phosphorus. For pastures, there is a reduction of 12% for phosphorus.

Related emissions for “fossil fuel depletion” decrease between 1% (for pastures) and 21% (for maize). The emissions for “fresh aquatic toxicity” decrease between 6% (for pastures) and 55% (for maize). These values are associated with the farmers’ stage.

a) Maize

*Maize (HP)

**Maize (LP)

Table 100. Pollution prevention technology comparison (All results are in kg except climate change - ton)

Stage	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Miineral Depletion	Fossil Fuels Depletion
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Biological Production – Sludge of WWT (*)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.68	15.22	6.46	89.73	0.97	18.88	1.10	0.27	0.13	201.19
Biological Production – Sludge of WWT (**)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.68	15.30	6.47	89.97	0.97	18.98	1.10	0.27	0.13	201.53
Biological Production – Organic Fertilizers										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.60	6.82	5.22	63.27	0.80	9.00	1.08	0.22	0.13	163.08

The economic performance for the pollution prevention technologies considered at the individual stages level is presented in Tables 101, 104 and 107.

The application of sludge contributed to the reduction of chemical fertilizers consumption for maize, olive and pastures. This has a positive effect on the Total

Value Added (TVA) of farmers. The increase in TVA for maize, with the application of sludge, is between 3% and 4% (for the two scenarios considered for the crop). For olives, the increase is between 2% and 4%. Finally, in the case of pastures, the increase in TVA is smaller, between 0.7% and 1%.

The TVA for pastures, obtained with the application of organic fertilizers, is less than that verified for the baseline scenario as the improvement of the environmental performance is not enough to justify the costs associated with the use of organic fertilizers. For maize and olives, the TVA obtained by the application of organic fertilizers is higher than the TVA obtained for the baseline scenario. In the case of maize, the increase of TVA is mainly due to the reduction of costs with fertilization and the increase in the price paid to the farmer which. In this case, the increase in TVA is larger than when using chemical fertilizers. For olives, the increased profitability of the crop due to organic agriculture allows the increase in TVA.

Table 101. Pollution prevention technology comparison

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	1,998,672.3
	Biological Production – Sludge of WWT (*)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,063,748.3
Farmers	6,381,808.00	9,395,490.00	-673,612.92	2,340,069.08	
	Biological Production – Sludge of WWT (**)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,063,679.3
Farmers	6,381,877.00	9,395,490.00	-673,612.92	2,340,000.08	
	Biological Production – Organic Fertilizers				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	3,016,129.3
Farmers	6,311,847.00	10,277,910.00	-673,612.92	3,292,450.08	

Tables 102, 105 and 108 present the results of the eco-efficiency indicators while Figures 33, 34 and 35 summarize the eco-efficiency comparison between the baseline scenario and the pollution prevention technologies evaluated.

For maize and olives, there is an obvious increase of eco-efficiency when using sludge or organic fertilizers. For pastures, only the introduction of sludge in the case study increases the eco-efficiency for all the environmental indicators considered.

Table 102. Eco-efficiency indicators for pollution prevention technologies

Indicators	Baseline	Sludge (*)	Sludge (**)	Organic F. (***)

Climate Change (€/tCO_2eq)	185.72	193.15	193.15	304.38
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.03
Freshwater resource depletion (€/m^3)	0.63	0.65	0.65	0.95
Eutrophication (€/kgPO_4^{-3},eq)	15.42	17.07	17.06	83.00
Human toxicity (€/kg1,4-Dbeq)	1.68	1.78	1.78	3.38
Acidification (€/kgSO_{2-},eq)	21.80	22.83	22.83	38.72
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.93	11.93	41.11
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	109.98	109.97	162.41
Respiratory inorganics (€/kgPM_{10},eq)	143.16	149.69	149.68	249.26
Ozone formation (€/kgC_2H_4,eq)	518.58	543.23	543.21	923.35
Minerals depletion (€/kg Fe-eq)	922.98	953.03	953.00	1,032.84

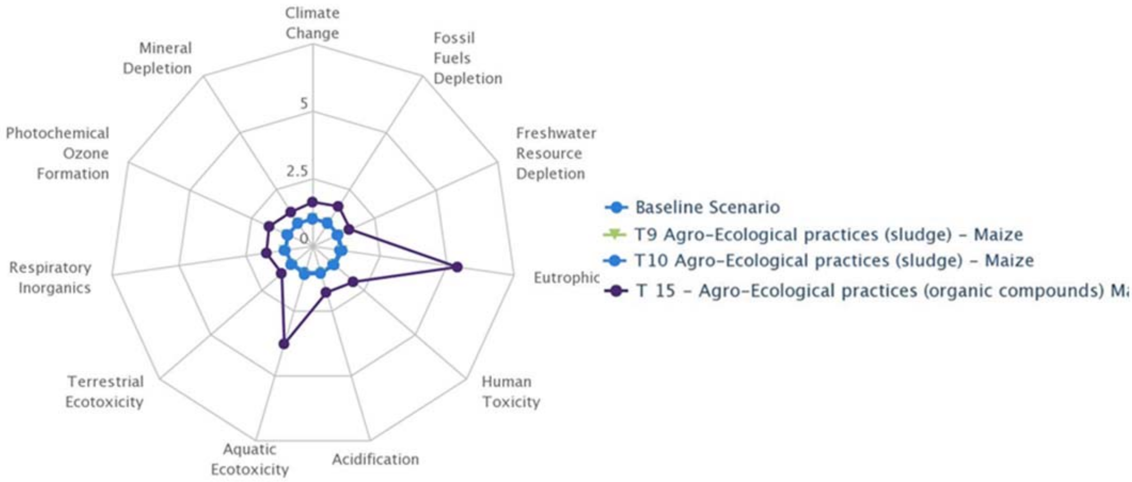


Figure 33. Comparison of eco-efficiency indicators in baseline scenario and pollution prevention technologies.

b) Olive

*Olive Intensive (HP)

**Olive Super Intensive (LP)

***Olive Intensive (LP)

Table 103. Pollution prevention technology comparison (All results are in kg except climate change - ton)

Stage	Climate Change	Europh-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Miineral Depletion	Fossil Fuels Depletion
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52

Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Biological Production – Sludge of WWT (*)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.67	15.37	6.33	89.95	0.95	17.86	1.10	0.27	0.13	197.14
Biological Production – Sludge of WWT (**)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.68	15.12	6.45	89.33	0.97	18.74	1.10	0.27	0.13	200.57
Biological Production – Sludge of WWT (***)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.68	14.71	6.38	88.03	0.96	18.26	1.10	0.27	0.13	198.71
Biological Production – Organic Fertilizers										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.65	11.31	5.88	77.55	0.89	14.32	1.09	0.25	0.13	183.70

Table 104. Pollution prevention technology comparison

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	1,998,672.3
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	
	Biological Production – Sludge of WWT (*)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,033,110.3
Farmers	6,412,446.00	9,395,490.00	-673,612.92	2,309,431.08	
	Biological Production – Sludge of WWT (**)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,077,926.3
Farmers	6,367,630.00	9,395,490.00	-673,612.92	2,354,247.08	
	Biological Production – Sludge of WWT (***)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,035,608.3
Farmers	6,409,948.00	9,395,490.00	-673,612.92	2,311,929.08	
	Biological Production – Organic Fertilizers				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,377,212.3
Farmers	6,311,592.00	10,254,738.00	-673,612.92	2,653,533.08	

Table 105. Eco-efficiency indicators for pollution prevention technologies

Indicators	Baseline	Sludge (*)	Sludge (*)	Sludge (***)	Organic F.
Climate Change (€/tCO_2eq)	185.72	190.17	194.46	190.5	226.24
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.02	0.02
Freshwater resource depletion (€/m^3)	0.63	0.64	0.65	0.64	0.75
Eutrophication (€/kgPO_4^{-3},eq)	15.42	16.67	17.12	16.77	23.44
Human toxicity (€/kg1,4-Dbeq)	1.68	1.75	1.79	1.75	2.16
Acidification (€/kgSO_{2-},eq)	21.80	22.45	22.97	22.50	27.17
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.69	11.99	11.75	15.84
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	108.32	110.72	108.46	126.99
Respiratory inorganics (€/kgPM_{10},eq)	143.16	147.24	150.60	147.54	177.45
Ozone formation (€/kgC_2H_4,eq)	518.58	534.22	546.49	535.36	646.70
Minerals depletion (€/kg Fe-eq)	922.98	938.88	959.58	940.04	1,097.79

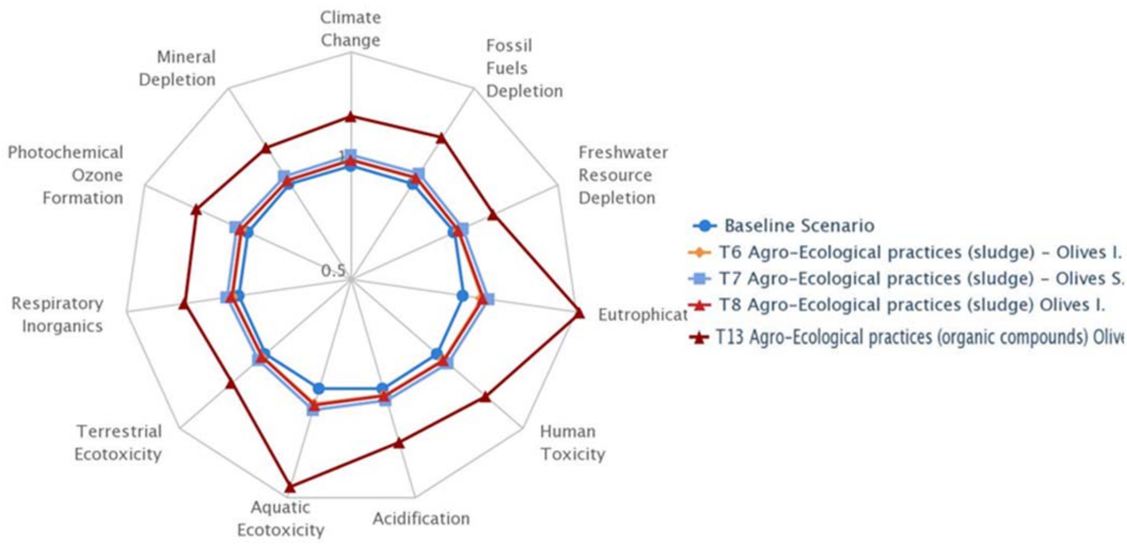


Figure 34. Comparison of eco-efficiency indicators in baseline scenario and pollution prevention technologies.

c) Pastures

*Pastures (LP)

**Pastures (HP)

Table 106. Pollution prevention technology comparison (All results are in kg except climate change - ton)

Stage	Climate Change	Eutroph-ication	Acidification	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Mineral Depletion	Fossil Fuels Depletion
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94

ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Biological Production – Sludge of WWT (*)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	15.23	6.44	91.37	0.96	19.31	1.10	0.27	0.13	204.13
Biological Production – Sludge of WWT (**)										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	15.38	6.47	91.57	0.97	19.42	1.10	0.27	0.13	204.31
Biological Production – Organic Fertilizers										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.68	14.33	6.29	90.23	0.94	18.69	1.10	0.27	0.13	203.09

Table 107. Pollution prevention technology comparison

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	1,998,672.3
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	
	Biological Production – Sludge of WWT (*)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,011,965.3
Farmers	6,433,591.00	9,395,490.00	-673,612.92	2,288,286.08	
	Biological Production – Sludge of WWT (**)				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	2,020,128.3
Farmers	6,425,428.00	9,395,490.00	-673,612.92	2,296,449.08	
	Biological Production – Organic Fertilizers				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	1,895,371.27
Farmers	6,550,185.00	9,395,490.00	-673,612.92	2,171,692.08	

Table 108. Eco-efficiency indicators for pollution prevention technologies

Indicators	Baseline	Sludge (*)	Sludge (**)	Organic F.
Climate Change (€/tCO$_2$eq)	**185.72**	**187.06**	**187.83**	**176.35**
Fossil fuels depletion (€/MJ)	**0.02**	**0.02**	**0.02**	**0.02**
Freshwater resource depletion (€/m^3)	**0.63**	**0.63**	**0.63**	**0.59**
Eutrophication (€/kgPO$_4^{-3}$,eq)	**15.42**	**15.75**	**15.86**	**15.16**
Human toxicity (€/kg1,4-Dbeq)	**1.68**	**1.70**	**1.71**	**1.61**
Acidification (€/kgSO$_{2-}$,eq)	**21.80**	**22.02**	**22.13**	**20.85**

Aquatic Ecotoxicity (€/kg1,4-Dbeq)	**10.92**	**11.08**	**11.13**	**10.54**
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	**106.39**	**107.15**	**107.59**	**101.01**
Respiratory inorganics (€/kgPM$_{10}$,eq)	**143.16**	**144.57**	**145.23**	**136.80**
Photochemical ozone formation (€/kgC$_2$H$_4$,eq)	**518.58**	**523.90**	**526.33**	**496.04**
Minerals depletion (€/kg Fe-eq)	**922.98**	**929.12**	**932.89**	**875.28**

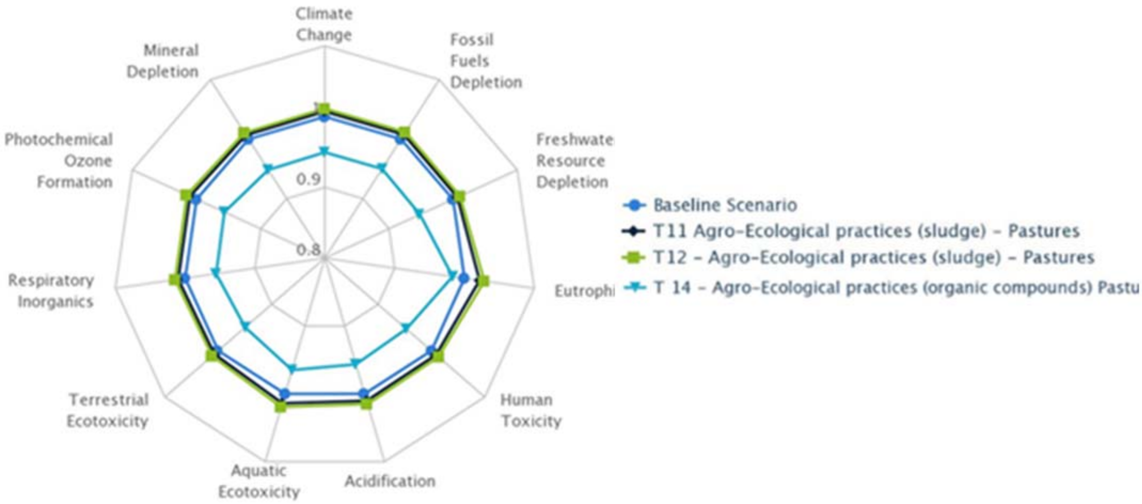


Figure 35. Comparison of eco-efficiency indicators in baseline scenario and pollution prevention technologies.

4.3.3 Technology scenario promoting circular economy

In the case of Monte-Novo no technology scenarios promoting circular economy were considered.

4.4 Eco-efficiency comparison for all technology scenarios

The eco-efficiency plots allow a quick preview of the eco-efficiency achieved by a technology for each indicator of environmental impact considered. The plot adds, at the same time, the calculation of environmental and economic impacts for the different technologies. Each coloured dot represents one alternative. The environmental impact is represented on the horizontal axis and the Total Value Added on the vertical axis. Therefore, as the eco-efficiency increases, the coloured dot will be rising towards the upper right corner of the graph. In the case of a technology that shows high emissions (impact) and low TVA, i.e. low eco-efficiency, the coloured dot is in the lower left corner of the graph.

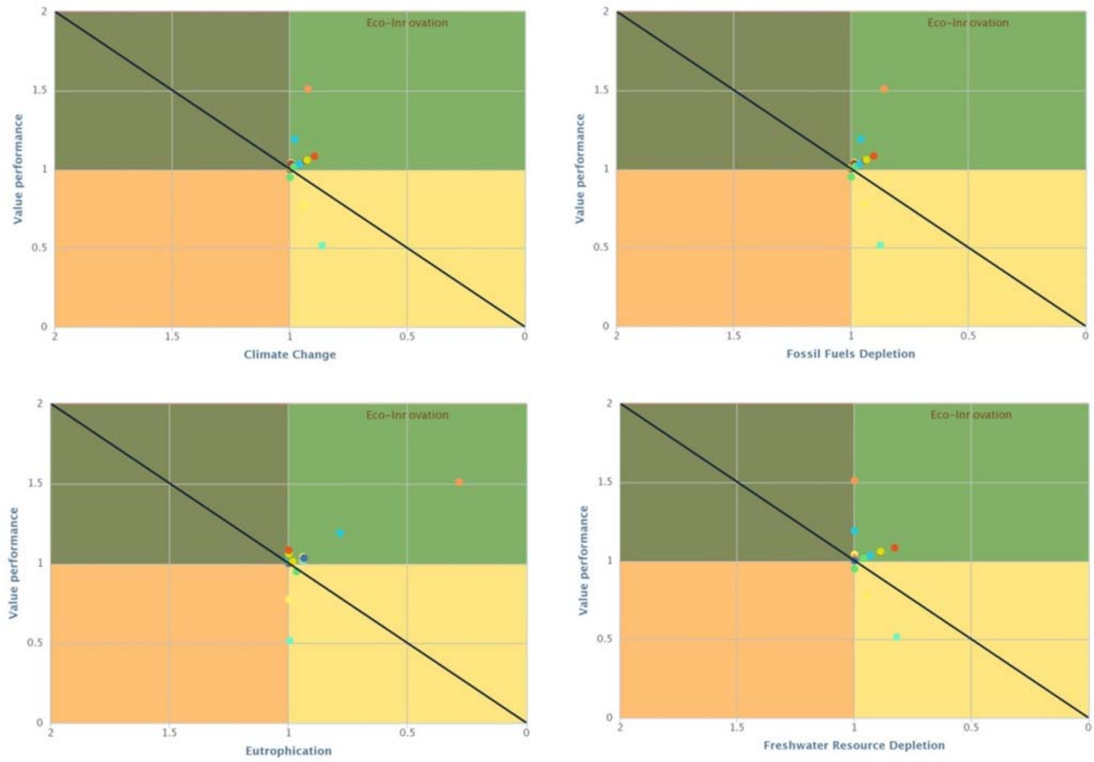
The diagonal line (the eco-efficiency line) divides the plot in two areas: in the upper area are the technologies that enable eco-efficiency gains and in the lower area technologies that, when implemented, result in a decrease of eco-efficiency. This kind of analysis considers that ecology and economics contribute equally to eco-efficiency.

Figures 36 and 37 present the eco-efficiency for the eleven environmental indicators considered in the Monte Novo case study. Among the technologies evaluated, the application of the organic fertilizers to maize stands out from the selection of technologies tests. The indicators “eutrophication” and “aquatic ecotoxicity” suffer a high increment when compared with the baseline scenario due to a reduction in consumption of chemical fertilizers.

The application of sludge of waste water treatment plants presents, for all the crops evaluated and for all the indicators of environmental impact considered, a slight improvement in eco-efficiency. The coloured dots corresponding to the sludge application are near the eco-efficiency line.

The Regulated Deficit Irrigation technology offers a high improvement of environmental performance for all the crops due to the reduction in water and energy consumption. The dots corresponding to the application of the RDI technology are far from the eco-efficiency line, in the upper right corner of the graph, indicating an increased eco-efficiency.

The Subsurface Drip Irrigation technology does not allow the increase of the eco-efficiency due to the increased costs, in the case of olive. Hence, the corresponding coloured dots are found in the lower left corner of the graph (under the eco-efficiency line).



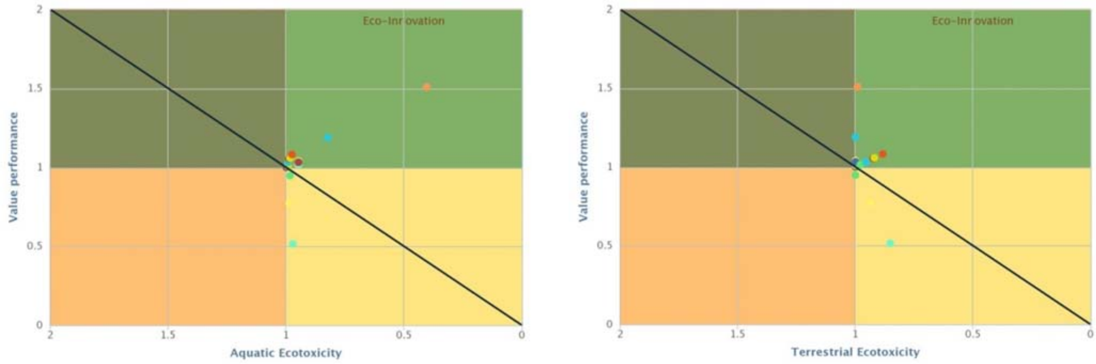


Figure 36. Eco-efficiency comparison for all technology scenarios – (1/2)

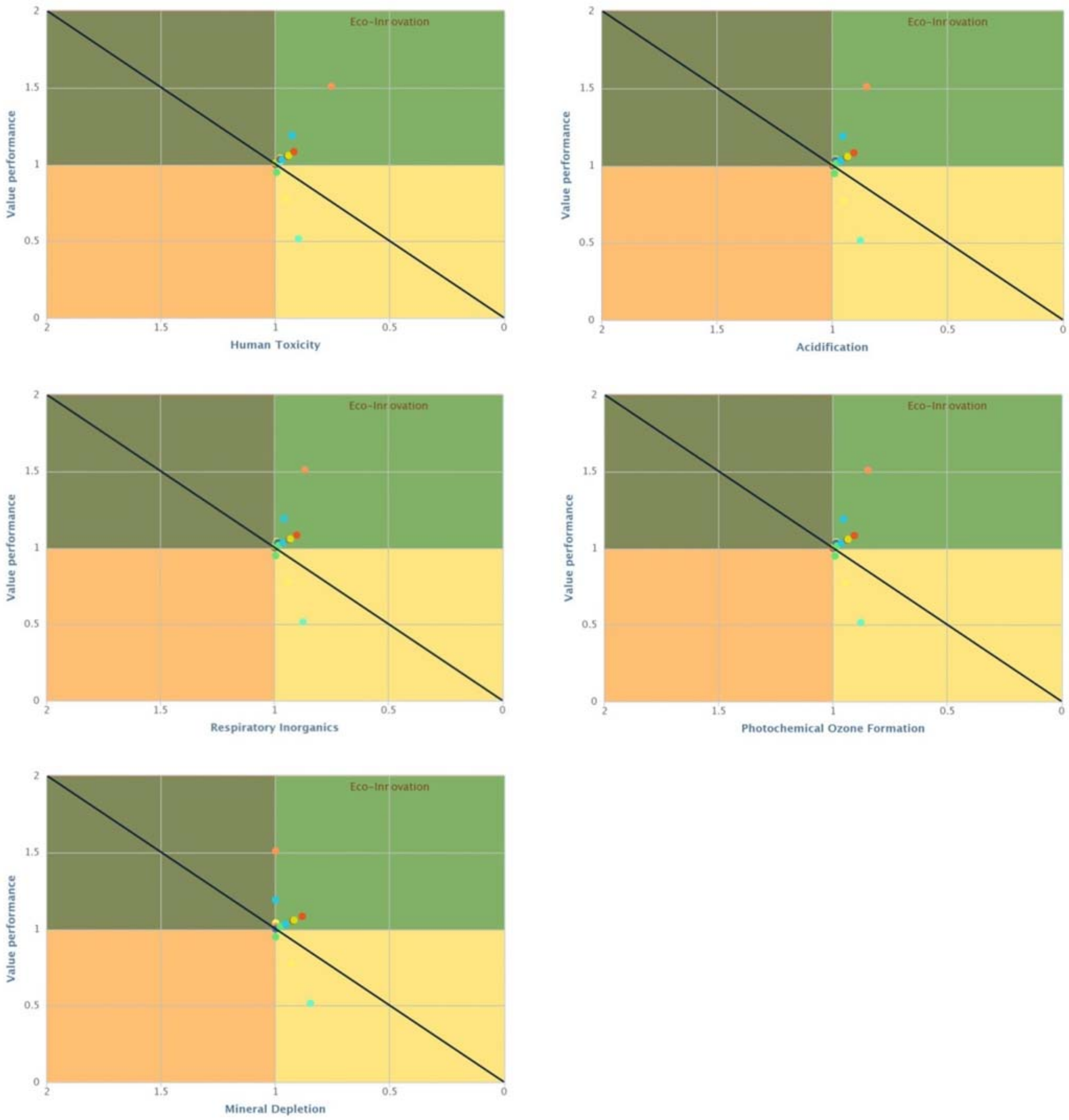


Figure 37. Eco-efficiency comparison for all technology scenarios – (2/2)

5 Technological interventions in the water use stage

With the aim of increasing the eco-efficiency in the Monte-Novo case study, several technologies were evaluated separately. In this chapter, the aim is to combine these technologies in order to achieve higher levels of eco-efficiency.

The first scenario of combination of technologies, the "super-intensive" scenario, includes the application of organic fertilizers, sludge from waste water treatment plants and regulated deficit irrigation.

The organic fertilizers are only applied to maize (HP and LP), as, according to the individual assessment of technologies, it is the crop with a higher increase in eco-efficiency. The regulated deficit irrigation technology was considered for maize, olives and pastures for both low pressure and high pressure areas. The use of sludge was only considered for pastures (high pressure) due to restrictions with the availability of sludge.

The second scenario, the "low-intensive" scenario, includes organic fertilizers, sludge and regulated deficit irrigation technologies only for high pressure areas, i.e. organic fertilizers applied to maize (high pressure), sludge applied to pastures (high pressure) and regulated deficit irrigation applied to maize (high pressure), olives (high pressure) and pastures (high pressure).

The environmental performance of these scenarios compared to the baseline scenario, is presented in Table 109.

Table 109. Environmental Impacts of the Study System (baseline scenario vs "super-intensive" and "low intensive" scenarios)

Stage	Climate Change	Eutroph-ication	Acidfication	Human Toxicity	Respiratory Inorgan	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Mineral Depletion	Fossil Fuels Depletion
Baseline										
EDIA	0.93	0.34	7.07	77.49	1.11	3.62	1.79	0.30	0.21	234.94
ABMonteNovo	0.37	0.14	2.81	30.84	0.44	1.44	0.71	0.12	0.08	93.52
Farmers	0.69	16.13	6.59	92.51	0.99	19.93	1.11	0.28	0.13	205.17
Super-Intensive										
EDIA	0.56	0.21	4.26	46.74	0.67	2.18	1.08	0.18	0.13	141.71
ABMonteNovo	0.23	0.09	1.75	19.18	0.28	0.90	0.44	0.07	0.05	58.14
Farmers	0.60	6.08	5.09	62.33	0.78	8.49	1.08	0.21	0.13	162.22
Low-Intensive										
EDIA	0.77	0.28	5.81	63.67	0.91	2.97	1.47	0.24	0.17	193.04
ABMonteNovo	0.23	0.09	1.75	19.18	0.28	0.90	0.44	0.07	0.05	58.14
Farmers	0.64	10.73	5.78	76.95	0.88	13.96	1.09	0.24	0.13	183.27

The combination of different technologies results in a noticeable increase in eco-efficiency for all the environmental indicators. The implementation of the "super-intensive" scenario decreases, for example, the indicator "fossil fuels depletion" in 21% and the indicator "eutrophication" in 62% (farmers´ stage).

For the “low-intensive” scenario reductions of 11% and 33% for “fossil fuels depletion” and “eutrophication”, respectively are obtained for the farmers’ stage. The combination of different eco-efficient technologies provides a higher environmental performance of the system than the individual technologies.

The assessment of the economic performance at the individual stages level is presented in Table 110. The implementation of organic fertilizers and sludge allows decreasing the costs with fertilization. The regulated deficit irrigation technology decreases the costs associated with consumption and transport of water.

The “super-intensive” scenario reduces the Annual O&M costs in 40%, 38% and 2% for the EDIA, ABMonteNovo and Farmers stages, respectively. In comparison, the “low-intensive” scenario reduces the Annual O&M cost in 18%, 38% and 1%. Simultaneously, in both scenarios, there is a decrease of water service costs for the farmer. In this way, TVA, when compared with the baseline scenario is increased by 70% for the “super-intensive” scenario and by 36% for the “low-intensive” scenario.

Table 110. Economic performance results (baseline scenario vs “super-intensive” and “low-intensive” scenarios)

	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)	Total Value Added
Stage	Baseline				
EDIA	684,709.65	0.00	395,196.55	-289,513.10	
ABMonteNovo	265,224.07	0.00	278,416.37	13,192.29	1,998,672.3
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08	
	Super-Intensive				
EDIA	412,992.97	0.00	238,368.77	-174,624.20	
ABMonteNovo	164,892.46	0.00	190,272.96	25,380.50	
Farmers	6,290,391.00	10,277,910.00	-428,641.73	3,558,877.27	3,409,633.57
	Low-intensive				
EDIA	562,619.90	0.00	324,729.53	-237,890.37	
ABMonteNovo	164,892.46	0.00	209,358.69	44,466.23	
Farmers	6,360,990.00	9,816,570.00	-534,088.22	2,921,491.78	2,728,067.64

Table 111 summarizes the results of the eco-efficiency indicators while Figure 38 presents the eco-efficiency comparison for the baseline scenario vs. “super-intensive” and “low-intensive” scenarios. The eco-efficiency increases for all the environmental impact indicators due to the reduction of environmental impacts and increase of TVA.

In the “super-intensive” scenario, the high increase in eco-efficiency of the environmental impact indicator “eutrophication” is mainly due to the change in the type of fertilization used.

Table 111. Eco-efficiency indicators (baseline scenario vs “super-intensive” and “low-intensive” scenarios)

Indicator	Baseline Scenario	Super-intensive	Low-intensive
Climate Change (€/tCO_2eq)	185.72	466.45	310.07
Fossil fuels depletion (€/MJ)	0.02	0.04	0.03
Freshwater resource depletion (€/$m^{3)}$	0.63	1.77	1.04
Eutrophication (€/kgPO_4^{-3},eq)	15.42	102.80	33.14
Human toxicity (€/kg1,4-Dbeq)	1.68	5.05	2.98
Acidification (€/kgSO_{2-},eq)	21.80	58.89	37.37
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	55.18	22.16
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39	250.89	173.75
Respiratory inorganics (€/kgPM_{10},eq)	143.16	379.89	243.92
Photochemical ozone formation (€/kgC_2H_4,eq)	518.58	1,403.78	889.63
Minerals depletion (€/kg Fe-eq)	922.98	2,153.75	1,501.15

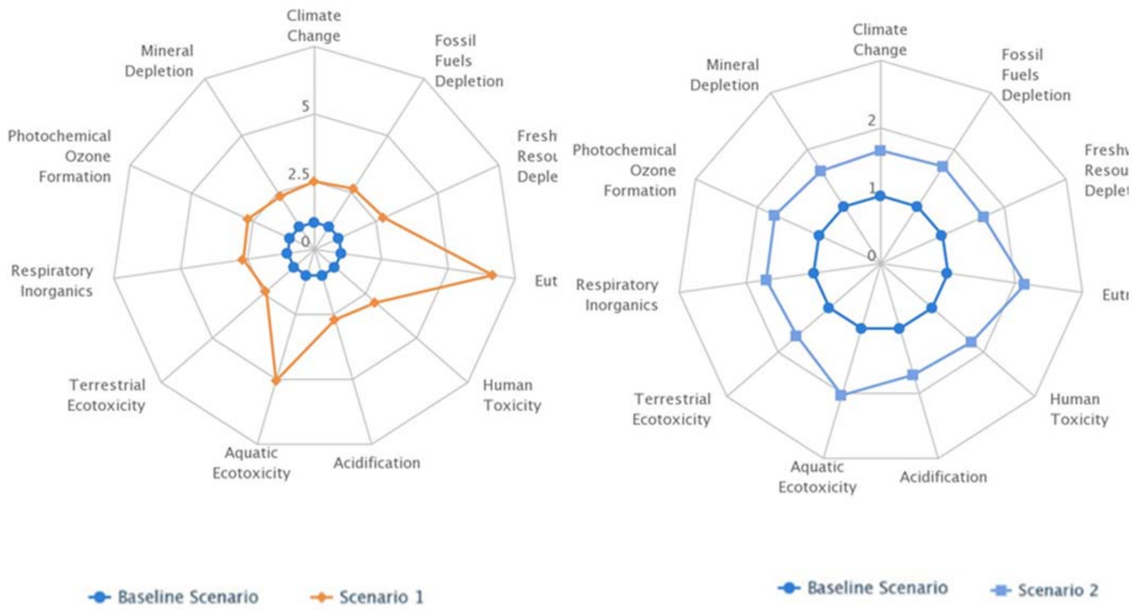


Figure 38. Eco-efficiency comparison for “super-intensive” and “low-intensive” scenarios

5.1 Policy Recommendations

5.1.1 Common for all scenarios towards eco-efficiency improvement

The sustainability evaluation of the Monte Novo irrigation perimeter through the determination of eco-efficiency allows the identification of the best technologies that maximize economic productivity and reduce the environmental impact. The various simulations carried out show that the new procedures implemented have particular influence on water, fertilizer and energy consumption. Water and energy savings are directly related to greenhouse emissions and to production costs. The type of fertilizer used influences the composition of the soil and the water quality in the surrounding areas of the irrigation perimeter. The market price of agricultural products is also influenced by the type of fertilization.

Based on the work developed, it is possible to make some recommendations to increase the eco-efficiency in the Monte Novo irrigation perimeter. The research strategy should be based on the following assumptions:

a) Proper evaluation of the technologies taking into account the following factors: political, economic, social and technological.

b) Adoption of measures taking into consideration all stakeholders (farmers, water user organizations, policy and decision makers, etc.).

c) Study of the feasibility of production of new crops economically more profitable in the current economic context in accordance with the new European agricultural policies. Developing the competitiveness of the products.

d) Consideration of crop production with hydric deficiency tolerance.

e) Use of new measuring tools and models (like SEAT and EVAT taking into consideration life cycle approach) to generate, collect, and analyse data from agricultural water systems.

f) Identification of possible barriers/weaknesses to the implementation of new technologies moving beyond quantification, saving cost and resources.

g) Adoption of combinations of different technologies, creating/providing technical support to farmers in the implementation of new technologies.

h) Creation of incentives for the farmers to adopt the best (environmentally friendly) management practices at the farm level. Simplification of the licensing for the use of sludge (WWT) in agriculture.

i) Creation of financing mechanisms to ensure access to capital for investing in more eco-efficient crops. Increase of loan duration with lower rates.

j) Promotion of more eco-efficient agricultural practices providing adequate information to farmers. Training of farmers on new technologies available (workshops). Increase of technical capacity.

k) Use of new information platforms as developed during the EcoWater Project. Support in decision-making for the different actors.

l) Combine the sustainability of the irrigation system (water price) to the economic value generated by crops.

m) Adoption of drip irrigation (superficial or subsurface) facing the high cost of water.
n) Promotion of the link between the production sector (difficulty in disposing of the product) and the marketing sector (difficulty in obtaining the product).
o) Promotion of the trade of organic products in the region/country (benchmark). Increase the demand for products.
p) Creating communication platforms among farmers (need of sludge) and the producer (availability of sludge).
q) Assistance to farmers´ associations in order to have easier access to organic fertilizers at a lower cost.
r) Consideration of crops' production with lower nutritional requirements.
s) Maximization of the operation of pumping stations during periods with lower energy costs.
t) Provision of information to farmers about agro-meteorological data for better water management on a day-to-day basis. Proper training of farmers on the ground-water-atmosphere system.

5.1.2 Specific for each of the key objectives

5.1.2.1 Resource efficiency

A variety of techniques can be employed to increase the resource efficiency such as:

- Use of subsurface drip irrigation for more efficient energy consumption.
- Implementation of low-impact irrigation methods (subsurface drip irrigation) which reduce water and energy use.
- Use of regulated deficit irrigation for more efficient water consumption.
- Irrigation schedule depending on the weather (software).
- Real-time monitoring of soil and climate conditions (temperature and humidity) to provide adequate irrigation (depending on the cultural evapotranspiration).
- Adjustment of the sowing period to weather conditions.

5.1.2.2 Pollution prevention

Some other techniques can be employed to increase the resource efficiency such as:

- Adoption of organic fertilizers to reduce the environmental impact associated to the crop.
- Adoption of sludge from waste water treatment to reduce the costs with fertilization and improve environmental performance, with a simultaneous potential reduction in sludge disposal in landfill.
- Establishment of contacts between farmers and producing entity in order to allow rapid assimilation of sludge in soils (low storage period).

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7 Annex

Characterization Factors of foreground elementary flows (CML, 2001, Milà i Canals, et al., 2009)

Impact Category	Unit	N to Water (per kg)	P to Water (per kg)	CO2 (per kg)	N_2O (per kg)	NH_3 (per kg)
Climate Change	kg $CO_{2,eq}$	-	-	1	298	
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.1	1	-	-	
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-	1.88
Human Toxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	
Respiratory Inorganics	kg $PM_{2.5,eq}$	-	-	-	-	
Freshwater Aquatic Ecotoxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	
Terrestrial Ecotoxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	-	-	
Minerals Depletion	kg $Fe_{,eq}$	-	-	-	-	-
Fossil Fuels Depletion	kg $oil_{,eq}$	-	-	-	-	-

Environmental Impact Factors for Background Processes (Sinistra Ofanto)

Impact Category	Unit	Electricity Production (per kWh)	Diesel Production (per kg)	Nitrogen Fertilizer Production (per kg)	Phosphorus Fertilizer Production (per kg)
Climate Change	kg $CO_{2,eq}$	0.70787	0.38199	1.93006	0.39097
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.00017	0.00018	0.00035	0.06724
Acidification	kg $SO_2^{-}{}_{,eq}$	0.00407	0.00257	0.02339	0.02197
Human Toxicity	kg 1,4-$DCB_{,eq}$	0.09159	0.03782	0.64951	0.16316
Respiratory Inorganics	kg $PM_{2.5,eq}$	0.00059	0.00035	0.00314	0.00300
Freshwater Aquatic Ecotoxicity	kg 1,4-$DCB_{,eq}$	0.00184	0.00296	0.22896	0.08853
Terrestrial Ecotoxicity	kg 1,4-$DCB_{,eq}$	0.00090	0.00101	0.00022	0.00063
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	0.00018	0.00023	0.00100	0.00093
Minerals Depletion	kg $Fe_{,eq}$	0.00019	0.00084	0.00000	0.00000
Fossil Fuels Depletion	kg $oil_{,eq}$	0.06034	1.19438	0.97804	0.14833

•Data for electricity production and diesel production are obtained from ELCD database (ELCD, 2013) and for fertilizer production from USLCI database (USLCI, 2013)