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

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Deliverable 2.2

Baseline eco-efficiency assessment for the analysed agricultural water systems

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Abstract

This document delivers the results of baseline meso-level eco-efficiency assessment of Sinistra Ofanto irrigation scheme (CS1) and the Monte Novo Irrigation Scheme (CS2). The methodological approach followed is the same in both case studies. Inventory analysis is used for data collection to estimate all the inputs (resources) and outputs (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) and the releases to air, soil and water associated with the processes. Two types of data are gathered for each unit process: environmental flows and economic flows.

For the Sinistra Ofanto irrigation scheme, the assessment was performed for two different cases; normal and dry year, corresponding to annual precipitation of 514 and 420 mm, respectively. The on-field agronomic and water management practices, water delivery and economic data refer to year 2007. Hence, the baseline scenario adopts the application of deficit irrigation strategy for artichoke, olives, orchards and sugarbeet, and full irrigation for other crops except wheat which was grown under rainfed conditions.

The eco-efficiency was estimated as a ratio between the economic performances of the system and produced environmental impacts. Economic performance was expressed in terms of the Total Value Added from the water use and adopted management practices, whereas the environmental performance referred to 11 midpoint environmental impact categories which were selected as the more representative for the environmental assessment of the system. The analysis was performed by using the Environmental Analysis Tool (SEAT) and Economic Value chain Analysis Tool (EVAT), both developed in EcoWater project. The environmental impacts analysis on a cluster (crop) level is performed on the basis of the irrigation (water) supply to crops and corresponding agronomic practices.

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List of acronyms and abbreviations

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
EEI	Eco-Efficiency Indicators
ET_c	Crop Evapotransipiration
ET_o	Reference Evapotransipiration
EVAT	Economic Value Chain Analysis Tool
FADN	Farm Accountancy Data Network
FEA	Fundação Eugénio de Almeida
GHG	Greenhouse gas emission
GIR	Gross Irrigation Requirement
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
LCA	Life Cycle Assessment
LCA	Life-cycle analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
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
ODS	Olivais do Sul
P_{eff}	Effective Rainfall

PO_4	Phosphates
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

1 Baseline eco-efficiency assessment of the Sinistra Ofanto Irrigation Scheme, Italy

1.1 Goal and scope definition

1.1.1 Objectives

The main goal of this study is the assessment of the environmental impacts and the eco-efficiency performance associated with the water value chain in the case of the Sinistra Ofanto (SO) Irrigation Scheme in Italy. 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 compromising the conditions of ecosystems, affecting agricultural production, long-term sustainability and economic growth in the area. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors. Assessment is performed in the baseline scenario which represents the reference point for benchmarking enhancements resulting from the upgrade of the value chain through the introduction of innovative technologies, which will be examined in a later stage.

1.1.2 System Boundaries

The agricultural water system of the SO irrigation scheme considers the entire life cycle of water from its origin (source) as a natural resource to the final use in agricultural fields. The main stages in the system include the water supply system (conveyance canal and reservoirs), the distribution systems (pumping plants, reservoirs and farm network infrastructures) and the final stage (fields) where water is used for agricultural production. As already presented and described in Deliverable 2.1, the entire command area of the Sinistra Ofanto irrigation system consists of three different chains of agricultural water supply which are identified and schematically represented in Figure 1.

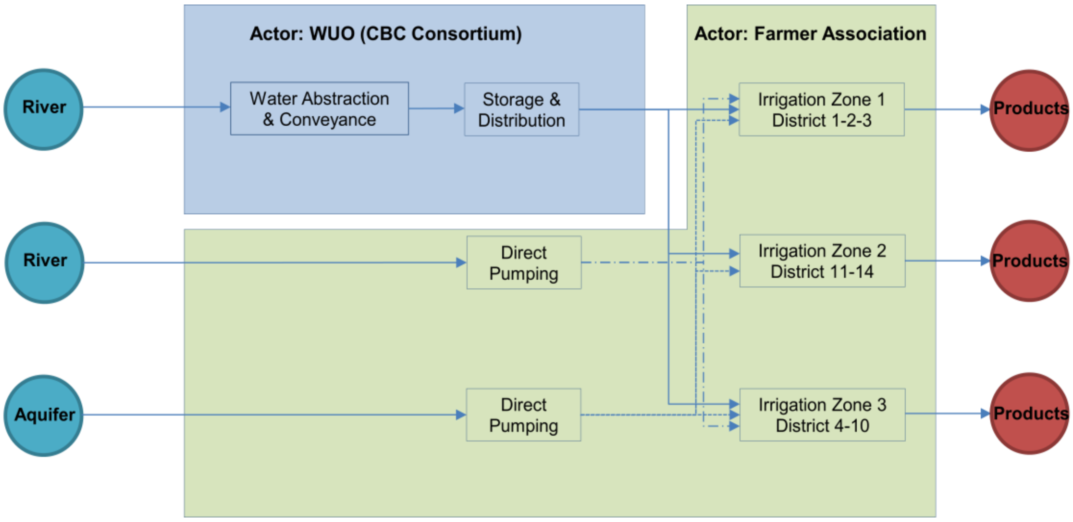


Figure 1. Stages and involved actors in the water value chain of the Sinistra Ofanto Irrigation Scheme

The Supply Chain 1 corresponds to the sub-scheme of Districts 1, 2 and 3 where conveyance occurs by gravity and distribution through water pumping/lifting. The Supply Chain 2, represented by the Upper Zone (Districts 11-14) where water is conveyed by lifting to the reservoirs at higher elevations and then distributed by gravity to the fields. The Supply Chain 3 is represented by the sub-scheme of Lower Zone (Districts 4-10) and it is characterized by gravity-fed conveyance and distribution of water to the final users.

Each stage has been defined in such way that encloses the relevant actors involved in the system and the interactions among them. Two main actors (Figure 1) are involved in the system:

- Consortium of “Bonifica della Capitanata” (CBC) which is the primary water supplier and it is in charge of the water abstraction from Ofanto River, conveyance and storage in Capacciotti Dam and district reservoirs and delivery to the agricultural farms (farm delivery points, hydrants);
- Farmer’s Associations operating downstream of the farm delivery points of the distribution networks and having full control on the management and use of irrigation water on their fields. Farmers use water mainly from the CBC water delivery network. However, in the case of water shortage, they also withdraw water directly from river Ofanto (irrigation zones 1 and 3) and from aquifers (all zones).

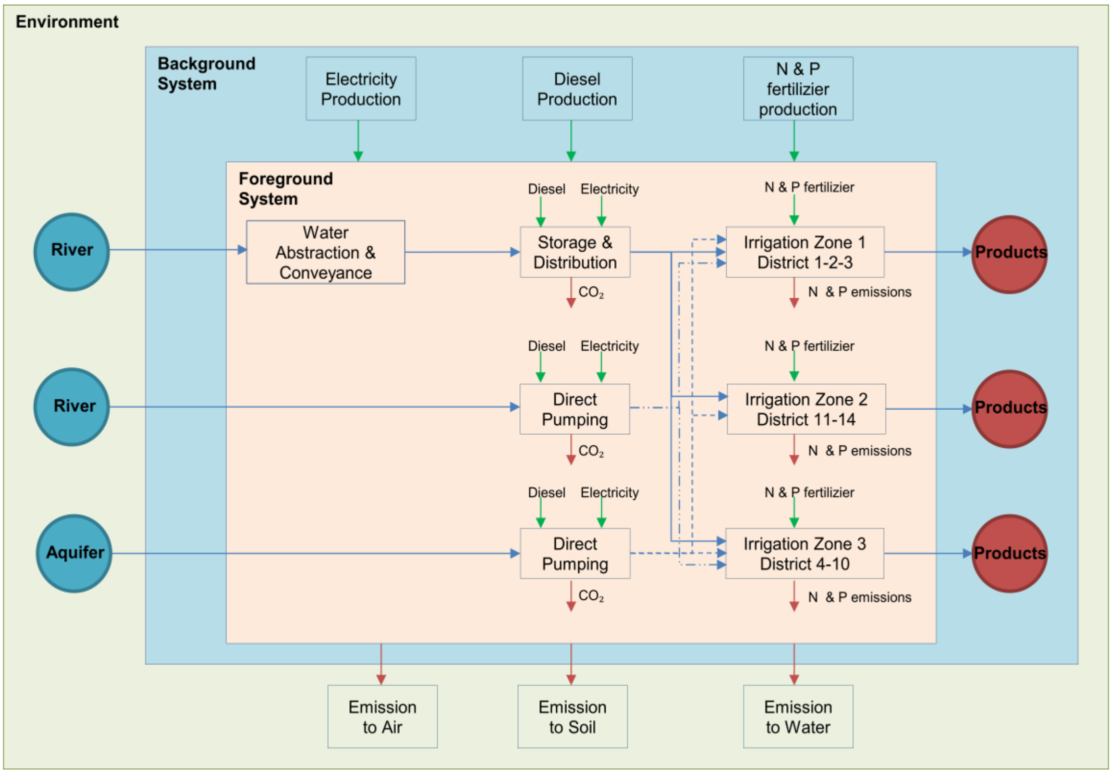


Figure 2. Foreground and background systems

The system is divided into “foreground” and “background” subsystems (Figure 2). The former is the system of direct interest and includes all the stages along the water value chain (the water abstraction and supply stage, the water distribution systems and the irrigation zones/final water use stages) where resources are used. The latter includes the resource production processes (nitrogen and phosphorus based fertilizer, electricity and diesel).

The summary of system processes and their characterization as Foreground or Background are shown in Table 1.

Table 1. Foreground and Background processes of the Sinistra Ofanto Irrigation Scheme

Type of Process	Name
Foreground	1. Water Abstraction and Conveyance
	2. Water Losses
	3. Water distribution in Zone 1
	4. Water distribution in Zone 2
	5. Water distribution in Zone 3
	6. Irrigation in Zone 1
	7. Irrigation in Zone 2
	8. Irrigation in Zone 3
Background	1. Electricity Production (electricity mix for Italy)
	2. Diesel Fuel Production
	3. Nitrogen Fertilizer Manufacturing Process
	4. Phosphorous Fertilizer Manufacturing Process

Final users with the same consumptive patterns (e.g. technology, socio-economic characteristics, management practices) can be grouped in clusters. A cluster can represent a crop cultivated in an agricultural area with common cultivation practices, climatic conditions, soil features and farmer habits. In this particular case, the clusters are: vegetables, olives, orchards, artichoke, asparagus, sugarbeet, tablegrapes, tomatoes and wheat, as main crops cultivated in the CS area. The environmental impacts analysis on a cluster level is performed on the basis of the irrigation (water) supply to crops and corresponding agronomic practices.

1.1.3 Functional unit

The purpose of a functional unit is to provide a reference to which the inputs and outputs can be related. This functional unit defines what is being studied. It can be used as a basis for selecting one or more alternative (product) systems that might provide these function(s). The functional unit of a system may be defined in a number of different ways. In this study two alternative options are examined:

1. Type I – when the unit of product delivered is the flow of interest, the functional unit is defined as 1 kg of product for each crop;
2. Type II – when the quantity of interest is the water used for the production purposes then the functional unit is 1 m^3 of water used in the production of each crop.

1.2 Inventory Analysis

Inventory analysis is used for data collection to estimate all the inputs (resources) and outputs (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) and the releases to air, soil and water associated with the processes. Two types of data are gathered for each unit process: environmental flows and economic flows.

1.2.1 Elementary Flows

The resources of the modeled system are presented in Table 2.

Table 2. Resources of Sinistra Ofanto agricultural water system

Category	Symbol	Resource
Water service related materials	w_1	Surface Water (Ofanto River)
	w_2	Groundwater (Aquifer)
Supplementary Resources	r_1	Electricity
	r_2	Diesel Fuel
	r_3	Nitrogen Based Fertilizers
	r_4	Phosphorus Based Fertilizers
	r_5	Land
Emissions to air	e_1	Carbon Dioxide (CO_2)
	e_2	Carbon Monoxide (CO)
	e_3	Methane (CH_4)
	e_4	Nitrogen Oxides (NO_x)
	e_5	Sulphur Oxides (SO_x)
	e_6	Nitrous dioxide (N_2O)
	e_7	Ammonia (NH_3)
	e_8	Water to Evaporation
Emissions to water	e_9	Nitrogen to Water (NO_3^-)
	e_{10}	Phosphorus to Water (PO_4^{3-})
	e_{11}	Water to Aquifer Recharge
	e_{12}	Water to Surface Water Bodies
Products	p_1	Artichoke
	p_2	Asparagus
	p_3	Olives
	p_4	Orchards
	p_5	Sugarbeet
	p_6	Tablegrapes
	p_7	Tomatoes
	p_8	Vegetables
	p_9	Wheat
	p_{10}	Winegrapes

1.3 Resource modeling and data input

Upon on-farm data collection and elaboration, the water supply chain and water value chain model were designed and calibrated using the tools developed within EcoWater project: SEAT – Systemic Environmental Analysis Tool and EVAT – Economic Value chain Analysis Tool. 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 primary information supplied by CBC has been complemented with secondary additional information, coming from scientific literature and official statistics.

1.3.1 Water service related materials

Water abstracted from Ofanto River was estimated on the basis of total gross water requirements (GIR) of each zone deducting water losses which were defined based on literature review conducted for each type of distribution system. Water losses in different stages and processes of Sinistra Ofanto irrigation scheme were modelled as a percentage of total water flowing to stage or processes (Table 3) and are considered as part of evaporation component of water balance.

Table 3. Water losses in different delivery stages of SO scheme

Stages – Processes	Water losses (as % of total flow/volume)
Canestrello Reservoir	3%
Capaciotti Dam	7%
Canals	4%
Reservoirs	3%
Pumping station	1%
Delivery Network	2%
District Network	2%

At farm level, a simple seasonal soil water-balance model (Figure 3) was developed to estimate aquifer recharge (as a part of non-effective precipitation) and aquifer depletion (as a part of water withdrawn by farmers when water delivered by the CBC Consortium was not sufficient to satisfy irrigation requirements) from commonly available soil, climate and crop data. Simplified water balance calculation is used because of the large study area, diversity of soil types and difficulties to collect and to assemble more detailed data.

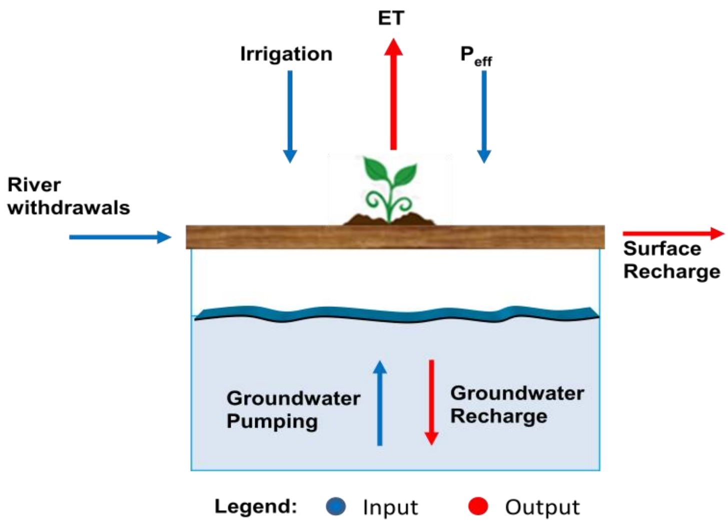


Figure 3. Simplified soil-water-balance

The components of agricultural water balance (crop water requirements – CWR, effective precipitation – P_{eff}, net irrigation requirements – NIR) and crop yield response to water were estimated for each crop on a monthly basis by using ISAREG irrigation water management decision support tool (Pereira et al., 2003).

The Penman-Monteith reference evapotranspiration (ET_o), crop evapotranpiration (ET_c) and NIR were estimated following the FAO standard method for crop evapotranspiration estimate (Allen et al., 1998). The effective rainfall was calculated with ISAREG over the whole growing season using the method of fixed percentage; in this work it was fixed to 80% of total monthly precipitation. The irrigation requirements for the baseline conditions, calculated with ISAREG model, are presented in Table 4. These data were used to estimate the total water demand for the three irrigation zones and the groundwater withdrawal.

Table 4. Seasonal ET_c, P_{eff}, and NIR for average and dry year conditions

Crops	CWR (mm)	P_{eff} (mm)	P_{eff}_Dry (mm)	NIR (mm)	NIR_Dry (mm)
Artichoke	645.0	257.28	245.0	387.7	400.0
Asparagus	896.0	411.36	328.3	484.6	567.7
Olive	552.0	309.44	227.4	242.6	324.6
Orchards	714.0	227.52	133.0	486.5	581.0
Sugarbeet	677.0	314.4	269.4	362.6	407.6
Table Grape	620.0	168.96	126.6	451.0	493.4
Tomato	511.0	86.88	58.9	424.1	452.1
Vegetables	457.4	177.44	97.4	280.0	360.0
Wheat	450.8	294.88	245.8	155.9	205.0
Winegrape	524.0	168.96	126.6	355.0	397.4

The crop water demand (WD_{Crop}) expressed as gross irrigation requirement (GIR) was estimated for each area covered by specific crop (A_{crop}) according to Equation 1 from the NIR computed by ISAREG model and considering the beneficial water use ratio (BWUR) for the network ($EFF_{network}$), the application efficiency of the irrigation method (EFF_{method}), and the irrigation factor W (0 for rainfed and 1 for full irrigation) which represents the product of the percentage of area irrigated and the water supply regime (a percentage of water supply by irrigation in respect to that necessary to cover completely evapotranspiration demand).

$$WD_{Crop} = \frac{(ET_c - P_{eff}) \cdot W_{crop}}{EFF_{method} \cdot EFF_{network}} \cdot A_{crop} \qquad \text{(Eq. 1)}$$

For each zone, total water demand at the level of hydrant was expressed as a sum of water requirements of individual crops served from that hydrant. The analysis was conducted for different irrigation zones and for each crop in the study area (cluster). Irrigation methods and their application efficiency are presented in Table 5. For each method on-farm distribution efficiency of 95% was assigned to calculate overall irrigation efficiency which is a product of irrigation method efficiency and on-farm distribution efficiency.

Table 5. Irrigation methods in Sinistra Ofanto scheme

Method	Method Efficiency, EFF_{method} (%)	Farm distribution efficiency, $EFF_{network}$ (%)	Irrigation Efficiency, $EFF_{irrigation}$ (%)
Drip[a]	0.9	0.95	0.855
Sprinkler	0.75	0.95	0.7125
Sprinkler	0.8	0.95	0.76
MicroSprinkler[b]	0.85	0.95	0.8075
Sub-Drip	0.95	0.95	0.9025

The estimation of aquifer water depletion ($W_{Aquifer}$) was done iteratively (from Equations 2 and 3) based on the sum of water requirement (WD, i.e. GIR) of each crop i (of a total of N crops) excluding water coming from the district network ($W_{Network}$) and water pumped from river Ofanto (W_{River}) which were defined as fixed input flows based on available data. The efficiency of water transfer from the source to the farm was estimated as a product of efficiencies of each specific stage j (of a total number of m stages).

$$WW = \frac{WD}{\prod_{j=1}^{m} EFF_j} = \frac{\sum_{i=1}^{n} \left(\frac{(ET_c - P_{eff}) \cdot W_{crop}}{EFF_{app}} \cdot A_{crop} \right)_i}{\prod_{j=1}^{m} EFF_j} \quad \text{(Eq. 2)}$$

$$WW_{aquifer} = WW - W_{network} - W_{river} \quad \text{(Eq. 3)}$$

Table 6 reports the water deliveries by the CBC recorded for 2007 which were assumed to resemble the baseline conditions. In irrigation zones 1 and 3, farmers abstracted from the river by booster pumps an estimated volume of 0.5 Mm^3 and 1 Mm^3, respectively. If necessary, the rest of water demand for all irrigation zones is covered from the aquifer.

Table 6. Water deliveries by the CBC network for three irrigation zones in 2007 and estimated river pumping

Water Delivered	Zone 1	Zone 2	Zone 3	Total
Estimated River Pumping (m^3/season)	500,000,00	0	1,000,000	1,500,000
Measured Deliveries 2007 (m^3/season)	2,012,772	8,786,265	25,826,376	36,625,413

1.3.2 Supplementary Resources

1.3.2.1 Electricity and Diesel Fuel

Energy consumption is measured in kilowatt hours (kWh) based on total of volume of water pumped throughout the irrigation season from water supply, groundwater and river pumping. Energy requirements of all technologies (i.e. pumps, borehole drills, hydrants, etc.) involved in the water supply chain of Sinistra Ofanto irrigation scheme are reported in Table 7 for different irrigation zones.

Table 7. Energy requirements in the water supply chain (CBC, and pumping from river and from aquifer)

Process/Stage	Zone 1	Zone 2	Zone3
CBC Energy Requirement (kWh/m³)	0.42	0.42	0
Pumping from River Energy Requirement (kWh/m³)	0.25	0	0.25
Groundwater pumping Energy Requirement(kWh/m³)	0.35	0.35	0.35

1.3.2.2 Agrochemical requirements

Total agrochemical used for each crop was estimated per unit area of land cultivation. Agrochemical requirement presented in Table 8 were obtained from CNR-ISPA (Dr. Vito Cantore, pers. comm.). They represent the recommended quantity used for plant growth and refer to pure nitrogen (N) and phosphorus (P) requirements. Potassium (K) application is not relevant because the land in Apulia is very reach with K and it should not be applied.

Table 8. Recommended Nitrogen and Phosphorus requirements for the crops in the CS

Crops	N_Req (kg/ha/yr)	P_Req (kg/ha/yr)
Artichoke	200	100
Asparagus	160	60
Olive	90	45
Orchards	110	60
Sugarbeet	110	85
Table Grape	170	95
Tomato	150	110
Vegetables	180	80
Wheat	110	33
Winegrape	170	90

1.3.2.3 Land Allocation

The crop land allocation for each irrigation zone is reported in Table 9 and refers to the period 2007-2012.

Table 9. Crop distribution [ha] in the sub-schemes of the CS area for the baseline

Crops	Zone 1	Zone 2	Zone 3
Artichoke	43	20	506
Asparagus	102	0	5
Olive	60	3656	3619
Orchards	67	13	3147
Sugarbeet	3	0	25
Table Grape	0	41	3233
Tomato	218	63	90
Vegetables	47	215	483
Wheat	2218	2604.6	1943
Winegrape	98	3793	7338
TOTAL	**2856**	**10405**	**20389**

1.3.3 Emissions to Air and Water

Emissions were estimated by multiplying activity data with emission factors for each resource.

1.3.3.1 Emissions from irrigation

Pumping water for irrigation requires use of energy (electricity and/or diesel) that could have a significant impact on the greenhouse gas (GHG) emission. The energy requirement and emission factors from pumping water were defined for each related resource for diesel pumps used in the on-farm water withdrawal from wells and water pumping from the river. The resource emission factors for diesel pumps are reported in Table 10. As a result, energy consumption and resource emissions due to water pumping were calculated for each irrigation zone and integrated over the whole SO irrigation scheme.

Table 10. Resource emission factor for diesel pumps used to pump water from river and from aquifer

Resource	Emission factor (kg/kWh)
CH_4	0.000025
CO_2	0.25
CO	0.00007
NO_X	0.000007
SO_X	0.0000005

The impacts from the electricity are included in the background system because power production processes do not take place inside systems' boundaries. Energy requirements to pump necessary volumes of water were taken from Table 7. Conversion from calculated diesel quantities in kWh to kg of diesel was based on conversion factor of 11.972 (1kg of Diesel = 11.972 kWh) assuming that the Calorific Value is 35,8 MJ/L. This conversion is required because the characterization factors for Diesel Production were defined per kg of diesel, while in SEAT model diesel quantities were calculated in kWh.

1.3.3.2 Emissions from the use and manufacture of farm machinery

Although a range of machines is used in cropping every year, the duration of each operation is relatively short. On average, approximately 83.7 MJ of energy are required to produce one kg of farm machine (Maraseni et al., 2007). Since 1 kWh = 3.6 MJ, 23.25 (83.7/3.6) kWh are required for each of those machinery kilos. About 0.70787 kg CO_2eq are emitted for each kWh of electricity production. Hence, for producing each kg of machinery 16.45 kg (0.70787 x 23.25) of CO_2eq GHGs are emitted into the atmosphere. Based on the work of Maraseni et al. (2007), the following equation was used to estimate tractor-generated GHG emissions:

Machinery GHGs emission (kgCO_2eq/ha) = Weight of machine (kg) x 16.45 kgCO_2eq kg^{-1} x Fraction of lifespan of that machine used for a ha of that land use (Eq. 4)

Average operation hour for farm operations and machine power used are reported in Table 11. Those data, provided by CNR-ISPA, are verified and adjusted by the relevant landholders in the CS area. Farm Operations include Plowing, Fertilization, Weed control, Chemical Treatments, Trans-plantation and Harvesting. Harvesting is given separately as for this operation for certain crop is used a different machine. Average weight of machines and average working life were assumed to be 8,000kg and 10,000 hour, respectively.

Table 11. Average Operation hours and machine power for different farm operations (CBC, CNR-ISPA)

Crops	Working hours	Working hours (Only for Harvesting)	Total Working hours	Machine Power (kW)	Machine Power for Harvesting (kW)
Artichoke	10.5	16	26.5	80	45
Asparagus	9.5	16	25.5	80	30
Olive	12	2	14	80	-
Orchards	15	2	17	60	-
Sugarbeet	8	3	11	80	130
Table Grape	19.5	8	27.5	45	-
Tomato	13	3	16	80	-
Vegetables	10.5	3	13.5	80	-
Wheat	5	1	6	80	130
Winegrape	17.5	8	25.5	45	-

1.3.3.3 Emissions from fuel use in farm operations

The total fuel consumption and GHG emissions for each liter (L) of fuel was used to calculate the total amount of GHG emissions from fossil fuel usage. GHG emissions from fuel use in farm machinery were calculated as follows:

Fuel GHGs ($kgCO_2eq/ha$) = Fuel (L/ha) • Emission Factor ($kgCO_2eq/L$) (Eq. 5)

Fuel consumption 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). Each litre of diesel produces 2.66 kg CO_2eq during its combustion. Combustion of fossil fuel also emits methane (CH_4) and nitrous oxide (N_2O). Each litre of diesel combustion gives of 2.66 kg CO_2, 0.000383 kg methane (0.009575 kg CO_2eq) and 0.0007645 kg nitrous oxide (0.2278 kg CO_2eq) (Nussey, 2005). Therefore, the total greenhouse gases emissions during combustion of one litre of diesel is 2.837 $kgCO_{2eq}$ L^{-1} (2.66 + 0.009575 + 0.2278 = 2.8974 $kgCO_2$ L^{-1}).

1.3.3.4 Emissions from fertilizer use

In addition to the GHG emissions associated with the manufacturing and acquirement of N and P fertilizers, the application of N and P results in emission into air, soil and water. With respect to agricultural soils, the emissions can be classified as direct or indirect. Direct emissions are linked to direct nitrogen additions to the agricultural soils like nitrogen fertilizer and animal manure, nitrogen fixation, crop residues and cultivation of histosols. Indirect emissions are the result of the subsequent leaching of nitrate from agricultural soils to ground water and surface waters and ammonia (NH_3) volatilization. Scientific background of direct and indirect

N_2O emissions from agricultural soils is explained elsewhere (Eggleston, 2006; van Schijndel 2007). In order to provide a useful approximation of GHG emissions from direct (nitrification and denitrification) and indirect (leaching, runoff, and ammonia (NH_3) volatilization) soil emission from N application and P emissions we used a simplified concept as presented in Figure 4.

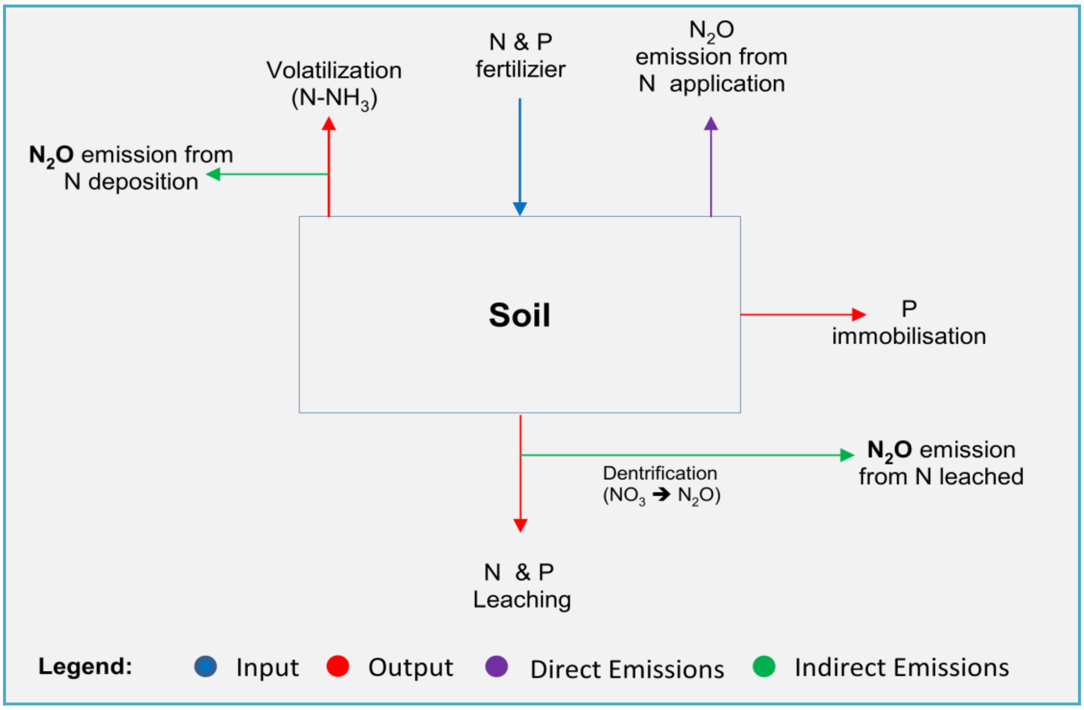


Figure 4. Simplified concept of N and P balances

The IPCC default values for emission factors were used in this study in combination with the CS activity data on fertilizer application for each crop as presented previously in Table 8. Low, average, and high emission factors for estimating N_2O emissions from N fertilizer and lime are proposed by the IPCC guidelines (Eggleston et al., 2006) as presented in Table 12.

Table 12. Low, average, and high emission factors used for estimating N_2O emissions from N fertilizer and lime using IPCC (Eggleston et al., 2006) guidelines.

	Low	Average	High
Emission factor for direct N_2O emission	0.003	0.01	0.03
Fraction of N fertilizier that volatilizes	0.05	0.2	0.5
Emission factor for volatilized N	0.002	0.01	0.05
Fraction of N fertilizier that leach	0.1	0.3	0.8
Emission factor for leached N	0.0005	0.0075	0.025
Emission factor for applied lime	0.12	0.125	0.13

Direct emissions are computed as the product of the direct N_2O emissions factor and the amount of N applied. The global mean fertilizer-induced emissions for N_2O and NO amount to 0.9% and 0.7%, respectively, of the N applied (Bouwman, 2002). However, due to the uncertainties associated with N_2O and the inclusion in the inventory calculation of other contributions to the nitrogen additions (e.g., from crop residues and the mineralisation of soil organic matter), the round value of 1% is appropriate (Eggleston, 2006). This method estimates the total direct N_2O emissions, irrespective of type of soils, of land use (e.g. grassland and cropland soils) and of vegetation, irrespective of the nitrogen compounds (e.g. organic, inorganic nitrogen), and irrespective of climatic factors.

Indirect N_2O emissions were broken down into those due to volatilization and those due to leaching or runoff. Each indirect emission path is 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. Leaching in groundwater and surface runoff fractions are expressed in percentage of N and P applied via fertilizer and calculated from the amount of applied fertilizers. The IPCC default value for fraction of N lost in leaching and runoff is 30%. For humid regions or in dryland regions where irrigation (other than drip irrigation) is used, the default FracLEACH-(H) is 0.30. For dry land regions, where precipitation is lower than evapotranspiration throughout most of the year and leaching is unlikely to occur, the default FracLEACH is zero. In Sinistra Ofanto, the command area is a flat plain and soil is mainly loamy clay with low percolation potential. Taking into account the slope of the area, precipitation surplus, irrigation, evaporation, soil type and diversity of crops grown, N leached for Sinistra Ofanto area was assumed 20% of N fertilizer applied and partitioned as 10% into groundwater and 10% into surface water. It is assumed that all N that leaches from the rooting zone is present as NO_3^-. Beyond the original site of N additions, the indirect N_2O emissions occur from N leached/lost in runoff with an emission factor of 0.75% of N leached (Eggleston, 2006).

The losses through NH_3-N volatilization were based on IPCC methodology which assumes that 10% of the fertilizer applied is lost through NH_3-N volatilization. The IPCC Guidelines explain that the calculations should be based on the emissions of NO_x and NH_3 originating from nitrogen fertilizers and animal manure in the country and not on the deposition of NO_x and NH_3 on the country territory. Atmospheric deposition of nitrogen was calculated using the IPCC default emission factor 0.01 kg N_2O-N per kg emitted NH_3.

Conversion of emission for each pollutant (N_2O, NH_3, NO_3) was performed by dividing the molecular/ionic mass of the species with the atomic mass of N. Conversion between emission gases was made according to the standard suggested by the IPCC (Eggleston et al., 2006).

The partitioning of P was assumed as 3% to surface water, 2% to groundwater and 4% for immobilization into calcium phosphate which cannot be used by plants (pers. comm. Judgment, Dr. Vito Cantore, CNR-ISPA). It is assumed that all P that leaches is present as PO_4^{3-}. Conversion factor 3.06 is used to convert from PO_4^{3-}- P to PO_4^{3-}.

1.3.4 Water to Aquifer Recharge, Surface Recharge and Evaporation

The difference between total annual precipitation and effective rainfall for each crop was assumed to be partitioned into the recharge of surface and groundwater and evaporation losses by 30, 30, and 40 %, respectively.

1.3.5 Products

After model validation on the data from the farms, the crop yield vs water input polynomial relationship was generated running the ISAREG model for different irrigation scheduling options (from full to rainfed). The model validation was performed on the statistical data collected in the CS area for 2007. The polynomial relationship was used in SEAT to estimate total agricultural production expressed as crop yield per area of land cultivation. These data are obtained from the simulations of crop yield under different irrigation input in ISAREG model and the results for each crop are shown in Table 13 for normal and dry hydrological year.

Table 13. Crop yield (CY) vs irrigation water factor (W) input as a polynomial relationship $CY=A \cdot W^2+B \cdot W+C$

Condition	NORMAL YEAR			DRY YEAR			
Crops	A	B	C	A	B	C	R^2
Artichoke	-0.37	0.9093	0.4813	-0.11	0.667	0.4515	0.98
Asparagus	-0.0387	0.4145	0.6379	0.0002	0.466	0.5302	0.98
Olive	0.0046	0.2254	0.7558	-0.1	0.469	0.6257	0.99
Orchards	-0.0081	0.5787	0.4309	-0.14	0.8787	0.2802	0.99
Sugarbeet	-0.2086	0.596	0.6264	0.0036	0.496	0.5025	0.98
Table Grape	-0.0954	0.5614	0.5266	-0.03	0.572	0.4738	0.99
Tomato	0.2529	0.3792	0.3843	-0.02	0.8076	0.2228	0.99
Vegetables	-0.1517	0.667	0.5064	-0.47	1.18	0.31	0.98
Wheat	-0.1257	0.2938	0.8368	0.0519	0.267	0.6919	0.98
Winegrape	-0.096	0.5485	0.5602	-0.19	0.673	0.5297	0.99

Eventual relative crop yield reduction was linked to the irrigation factor W assigned to each crop referring full or deficit irrigation supply. Irrigation factor is 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 comparing the data and discussing with local stakeholders we concluded that artichoke, orchards and sugarbeet were irrigated at 50% of water requirements and olives at 50% of water requirements over 50% of cultivated area while the rest was kept under rainfed. All other crops were under full irrigation regime while wheat was cultivated completely in rainfed. Relative yield is calculated proportionally to the maximum obtainable yield and irrigation factor, both estimated for the CS area and reported in Table 14.

Crop yield values were estimated by ISAREG model and the results of simulations were compared with the data available in the literature and in the practice (on-farm investigation in the case study area). The results of comparison for the most important crops grown in the Sinistra Ofanto are reported in Table 15. A good agreement was observed between the simulated data and those coming from the literature/case study area.

Table 14. Crop yield declared for FADN 2007, maximum obtainable yield under local condition and irrigation factor (W) defined for each crop.

Crops	Yield FADN 200 (ton/ha)	Yield_Optimal (ton/ha)	Irrigation factor (W)
Artichoke	11	14	0.5
Asparagus	7	8	1
Olive	4	5	0.125
Orchards	23	35	0.5
Sugarbeet	41	50	0.5
Table Grape	35	35	1
Tomato	90	90	1
VegeTables	27	27	1
Wheat	3	5	0
Winegrape	21	23	1

Table 15. Simulated and observed crop yield values (t/ha)

Crop	Yield ISAREG (t/ha)	Yield_FADN 2007 (t/ha)
Artichoke	11.81	11
Asparagus	8.00	7
Olive	3.95	4
Orchard	25.14	23
Sugarbeet	43.61	41
Tablegrapes	34.74	35
Tomato	90.00	90
VegeTables	27.00	27
Wheat	4.18	3
Winegrapes	23.00	21

1.4 Economic Data

1.4.1 Total Value Added and Financial Costs

The determination of the economic performance of single actor was based on the net economic output (NEO) while Total Value Added (TVA) of the system was calculated according to the EcoWater approach for eco-efficiency assessment. Gross income received by producers is determined at local (domestic) market prices per unit of production per hectare of crops at farm level. The Total Financial Cost related to water supply (TFCws) include the production costs, the cost of water for irrigation, the cost of groundwater withdrawal and the cost of surface water withdrawal, i.e. river water abstraction. Production costs correspond to the summation of specific crop expenses with costs for labour and mechanization. Specific crop expenses included the costs for seeds, fertilizers and pesticides; hire charges, fuel, insurance, and electricity. Costs of irrigation water were not included in the variable costs but considered separately according to the water tariff scheme used in the area. Annual price and production cost including variable and fixed costs (Table 16) were obtained from regional economic data Farm Accountancy Data Network (FADN, 2007).

Table 16. Gross Market Price and production cost (FADN, 2007)

Crops	Price (€/t)	Production Cost (€/ha)
Artichoke	736	5795
Asparagus	1142	5052
Olive	1297	2932
Orchards	516	5074
Sugarbeet	53	1950
Tablegrapes	423	6556
Tomato	95	4702
VegeTables	408	3513
Wheat	341	548
Winegrapes	258	4424

1.4.2 Water tariffs

In the case of the "Sinistra Ofanto" irrigation scheme farmers usually pay for irrigation service a tariff that is composed of two parts, a fixed rate with a fixed annual tariff per hectare (15.5 €/ha), which must be paid whether irrigated or not to cover running costs, and a variable rate which depends on volume of water used with an average water duty 2050 m^3/ha and with three levels as indicated hereafter:

- 0.09 €/m^3 for seasonal water withdrawal between 0 - 2050 m^3/ha;
- 0.18 €/m^3 for seasonal water withdrawal between 2050 - 3000 m^3/ha;
- 0.24 €/m^3 for seasonal water withdrawals higher than 3000 m^3/ha.

The water fees include all the costs of personnel, maintenance of structures, and consumables, but they do not include any profit mark-up, because the CBC is a non-profit organization and operates under the regime of full cost-sharing among the water users. In reality, the CBC bears the cost of 0.2 €/m^3 for supplying water in zone 1, 0.19 €/m^3 for supplying water in zone 2 and 0.16 €/m^3 for supplying water in zone 3. Although the cost for supplying irrigation water is significantly different between the areas supplied by gravity and those served by pumping and/or lifting, the CBC applies the same irrigation tariffs regardless the location of farms. In such a way, the CBC has enforced the principle of solidarity among the farmers and different served areas (irrigation zones 1, 2 and 3). Referring to other sources of water, farmers bear the cost of 0.40 €/m^3 (which includes equipment costs and energy costs) for groundwater abstraction and 0.20 €/m^3 for pumping water directly from Ofanto River.

1.5 Baseline eco-efficiency assessment

1.5.1 Calculated life cycle inventory flows (Normal Hydrological Year)

Calculation of life cycle inventory flow for baseline conditions was performed for normal and dry year, 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, when 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 started since that period. Accordingly, the water supply and value chain mapping were performed for the baseline conditions in SEAT and EVAT. Table 17 presents the calculated life cycle inventory flows for each irrigation zone for normal conditions. This information for the use of resources was extracted from SEAT model and all flows are referred to annual average values.

Total water withdrawal from Ofanto river was estimated by SEAT to be approximately 44,7 Mm^3 taking into account the on-farm water availability of 36.6 Mm^3 and water conveyance, delivery and storage losses as described in section 1.3.1. Water delivery simulated by SEAT fits well the volumes effectively delivered by the CBC in 2007. Overall losses in conveyance, storage and distribution account are about 8.1 Mm^3 or 18 % of total volume withdrawn. This is also in accordance with the values provided by the CBC where losses ranged from 15-20%. According to our model the highest losses occurred in canal due to the highest volume conveyed and relatively high conveyance distance. The assessment of global water losses shows that system performs good. Total water use on farm level, including the groundwater withdrawal and surface water originated from Ofanto River was estimated as 82.6 Mm^3 showing that the groundwater accounts in on-farm water input for 54%. 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 total water requirements were fulfilled from aquifer. The highest groundwater withdrawals were found in zone 3 with a rate of 1889 m^3/ha due to 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 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 as 56.8 Mm^3 which represents about 63% of total water withdrawal and corresponds to overall water deficit of 34 Mm^3. The annual recharge of the aquifer was estimated as 28.45 Mm^3 which, in the case of average year, represents about 64% of water withdrawal from the aquifer and indicates an annual trend of water depletion in the aquifer of 16.11 Mm^3.

Table 17. Life cycle inventory flows of the Sinistra Ofanto Irrigation Scheme (2007, a normal hydrological year)

Category	Material	Quantity Zone 1	Zone 2	Zone 3	Total	Unit
Water Resources	Surface Water (Ofanto River)[a]			46,263,955		m^3
	Surface Water (CBC delivered)	2,012,772	8,786,265	25,826,376	36,625,413	m^3
	Surface Water (river pumping)	500,000	0	1,000,000	1,500,000	m^3
	Groundwater (Aquifer)	41,805	9,655,386	34,861,267	44,558,458	m^3
Supplementary Resources	Electricity	862,271	3,876,957	-	4,739,228	kWh
	Diesel Fuel	139,631	3,379,385	12,451,443	15,970,459	kWh
	Nitrogen Based Fertilizers	339,820	1,320,950	2,887,870	4,548,640	kg
	Phosphorus Based Fertilizers	127,149	622,455	1,468,749	2,218,353	kg
	Land	2856	10405	20389	33,650	ha
Emissions to air	Carbon Dioxide (CO_2)[b]	1,673,768	11,220,419	23,981,837	36,876,024	kg
	Methane (CH_4)	3.5	84.5	311.3	399	kg
	Carbon Monoxide (CO)	9.8	236.6	871.6	1,118	kg
	Sulphur Dioxide (SO_2)	0.1	1.7	6.2	8	kg
	Nitrogen Oxides (NO_x)	1	23.7	87.2	112	kg
	Nitrous Oxide (N_2O)[c]	6,669	25,924	56,674	89,267	kg
	Ammonia (NH_3)	37,128	144,326	315,528	496,982	kg
	Evaporation	2,728,208	10,997,484	24,203,907	37,929,599	m^3
Emissions to water	N to Water	65,415	254,283	555,915	875,613	kg
	P to Water	19,453	95,235	224,718	339,406	kg
	Aquifer Recharge	2,046,156	8,248,113	18,152,930	28,447,199	m^3
	Surface Water Bodies	2,046,156	8,248,113	18,152,930	28,447,199	m^3
Products	Artichoke	507.7	236.1	5973.9	6,718	ton
	Asparagus	816.0	-	40.0	856	ton
	Olive	235.2	14329.8	14184.7	28,750	ton
	Orchards	1684.2	326.8	79108.9	81,120	ton
	Sugarbeet	107.3	-	894.1	1,001	ton
	Tablegrapes	-	1424.4	112317.7	113,742	ton
	Tomatoes	19620.0	5670.0	8100.0	33,390	ton
	Vegetables	1269.0	5805.0	13041.0	20,115	ton
	Wheat	9280.1	10899.3	8129.5	28,309	ton
	Winegrapes	87239.0	2254.0	168774.0	258,267	ton

[a] Surface water includes also direct pumping from river of 1,500,000 m^3 (See Table 6)

[b] CO_2 include emission from pumps, farm machinery and fuel consumption in farm operations.

[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. Total GHG emissions from the use of pumps for irrigation were estimated at 119 kg CO_2eq ha^{-1}. Insignificant emissions resulted for CH_4, CO, NO_x and SO_x which accounted for only 0.041% of total CO_2eq emission.

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$N_2O \cdot ha^{-1}$ or 795 kg CO_2eq$\cdot ha^{-1}$ agricultural soil. The largest source of N_2O was emitted through nitrification and denitrification which accounted for 80% of total N_2O emissions. Indirect emissions accounted for 12% in leaching and runoff and 8% from volatilization. The distribution of these emissions through different pathways is shown in Figure 5. The total GHG emissions from operation of machinery and fuel consumption ranged from 207 kg CO_2-eq ha^{-1} to 770 kg CO_2-eq ha^{-1}. In consistence with Table 11, the highest source for this emission was artichoke cultivation due to high working hours and high power of machine needed for farm operations.

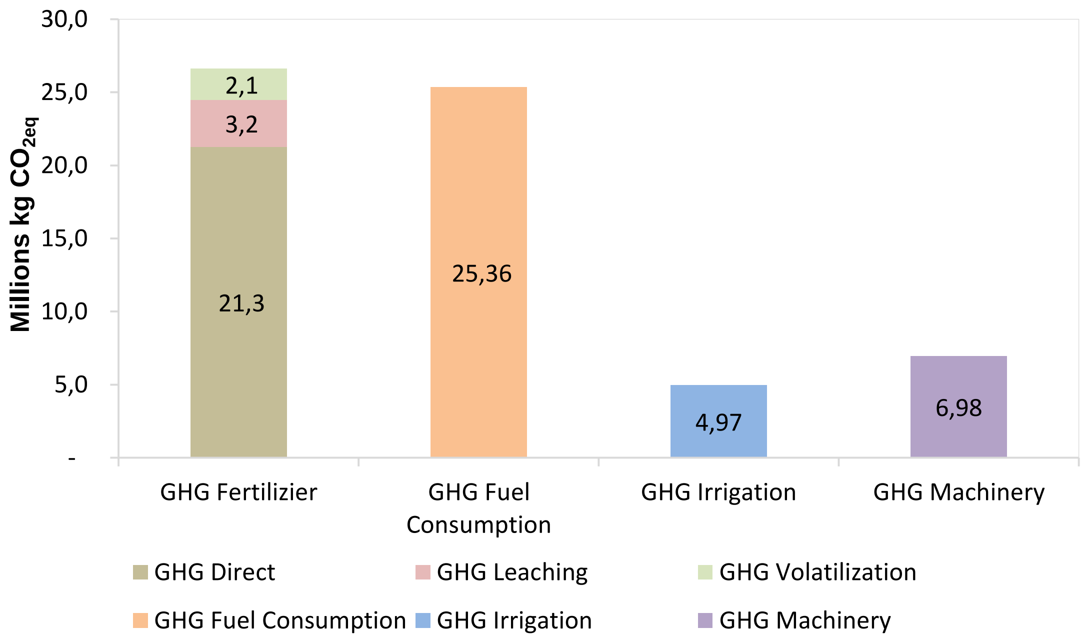


Figure 5. Greenhouse gas emissions from farm supplementary resources in Sinistra Ofanto irrigation scheme

Total agricultural production amounts to $572 \cdot 10^3$ ton with the highest production of winegrapes of about 45% of total production due to highest land allocation and relatively high production yield.

1.5.2 Calculated life cycle inventory flows (Dry Year)

Table 18 presents the calculated life cycle inventory flows for each irrigation zone for dry year conditions with a precipitation of about 420 mm/year and effective precipitation and crop irrigation water requirements presented in Table 4. Total water requirements were increased by approximately 11 Mm^3 or 12% comparing to a normal hydrological year. This increase in water requirements was compensated by the groundwater withdrawals which reached 55.5 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. Due to increase of groundwater withdrawals energy 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. Overall total agricultural production decreased by 2.1% mostly affected from wheat with total decrease of 17% for three irrigation zones.

Table 18. Life cycle inventory flows of the Sinistra Ofanto Irrigation Scheme (Dry Year)

Category	Material	Quantity Zone 1	Zone2	Zone 3	Total	Unit
Water Resources	Surface Water (Ofanto River)[a]				46,263,955	m^3
	Surface Water (CBC delivered)	2,012,772	8,786,265	25,826,376	36,625,413	m^3
	Surface Water (river pumping)	500,000	0	1,000,000	1,500,000	m^3
	Groundwater (Aquifer)	355,864	12,252,337	42,936,711	55,544,912	m^3
Supplementary Resources	Electricity	862,271	3,876,957	-	4,739,228	kWh
	Diesel Fuel	249,552	4,288,318	15,277,849	19,815,719	kWh
	Nitrogen Based Fertilizers	339,820	1,320,950	2,887,870	4,548,640	kg
	Phosphorus Based Fertilizers	127,149	622,455	1,468,749	2,218,353	kg
	Land	2,856	10,405	20,389	33,650	ha
Emissions to air	Carbon Dioxide (CO_2)[b]	1,701,272	11,448,207	24,690,186	37,839,665	kg
	Methane (CH_4)	6	107	382	495	kg
	Carbon Monoxide (CO)	17	300	1,069	1,386	kg
	Sulphur Dioxide	0	2	8	10	kg
	Nitrogen Oxides (NO_x)	2	30	107	139	kg
	Nitrous Oxide (N_2O)[c]	6,669	25,924	56,674	89,267	kg
	Ammonia (NH_3)	37,128	144,326	315,528	496,982	kg
	Evaporation	2,229,414	9,531,190	21,287,410	33,048,014	m^3
Emissions to water	N to Water	65,415	254,283	555,915	875,613	kg
	P to Water	19,453	95,235	224,718	339,406	kg
	Aquifer Recharge	1,672,061	7,148,393	15,965,557	24,786,011	m^3
	Surface Water Bodies	1,672,061	7,148,393	15,965,557	24,786,011	m^3
Products	Artichoke	456	212	5,365	6,033	ton
	Asparagus	813	-	39.86	853	ton
	Olive	205	12,481	12,355	25,041	ton
	Orchards	1,607	312	75,488	77,407	ton
	Sugarbeet	92	-	770	862	ton
	Tablegrapes	-	1,435	113,155	114,590	ton
	Tomatoes	19,620	5,670	8,100	33,390	ton
	Vegetables	1,269	5,805	13,041	20,115	ton
	Wheat	7,673	9,012	6,722	23,407	ton
	Winegrapes	87,239	2,254	168,774	258,267	ton

[a] Surface water includes also direct pumping from river of 1,500,000 m^3 (See Table 6)

[b] CO_2 include emission from pumps, farm machinery and fuel consumption in farm operations.

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

1.5.3 Environmental Impact Assessment of the Entire System

Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project (EcoWater, 2013), 11 impact categories were selected as the more representative for the environmental assessment of the system. Indicators considered, related units and the characterization factors which were used for the estimation of the impact of the foreground systems and the environmental impact factors for the background process are presented in Tables 19 and 20, respectively. The environmental impact factors are obtained from open access databases.

Table 19.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)	CO_2 (per kg)	CH_4 (per kg)	N_2O (per kg)	CO (per kg)	SO_2 (per kg)	NO_X (per kg)	NH_3 (per kg)
Climate Change	kg $CO_{2,eq}$	-	-	1	25	298	-	-	-	
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.1	1	-	-	-	-	-	0.13	
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-	-	-	1.2	0.5	1.88
Human Toxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	-	-	0.096	1.2	
Respiratory Inorganics	kg $PM_{2.5,eq}$	-	-	-	-	-	-	-	-	
Aquatic Ecotoxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	-	-	-	-	
Terrestrial Ecotoxicity	kg 1,4-$DCB_{,eq}$	-	-	-	-	-	-	-	-	
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	-	0.01	-	0.027	0.048	0.03	
Minerals Depletion	kg $Fe_{,eq}$	-	-	-	-	-	-	-	-	-
Fossil Fuels Depletion	kg $oil_{,eq}$	-	-	-	-	-	-	-	-	-

Table 20. Environmental Impact Factors for Background Processes

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	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	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)

1.5.3.1 Environmental Impact Assessment of the Entire System (Normal Hydrological Year)

The results of the environmental impacts of the entire system including also the results of the environmental impacts Type I (environmental impacts per unit of product – kg of yield) and Type II Impact Indicators (environmental impacts per m^3 of water used) for average climatic conditions are presented in Table 21. Disaggregation on the clusters level for a normal hydrological year is shown in Annex A. The contribution of background and foreground system in the environmental impact assessment is given in Figure 6 while the environmental impact breakdown for each indicator is presented in Figures 7 and 8. The studied system is characterized by significant contribution of the foreground processes in climate change impact category due to direct emissions from fertilizer 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 depletion due to irrigation (Figure 6).

Comparing the performance of the different clusters (i.e. crops), it is observed that, in type I of indicator (based on crop production) olives, asparagus and wheat had the highest impact indicators in most cases. The highest impacts refer to olives which represent higher unitary emission in respect to wheat and lower emission in respect to asparagus. However, when the environmental impacts are divided by the yield production, then the highest environmental impacts indicator corresponds to olives which has the lowest yield value (3.92 ton/ha). For olives, the most relevant impact categories in foreground processes are climate change and eutrophication potential whereas in background processes it is eutrophication potential. Wheat crop has the highest contribution in foreground processes related to acidification and in background processes to the freshwater aquatic eco-toxicity. On one side, this is due to greater induced related unitary emission of wheat in respect to olives and the lower in respect to asparagus. On the other hand, this is due to the fact that wheat has lower yield than asparagus but higher than olives. Asparagus presents the highest impact indicators in the case of foreground processes for impact categories of freshwater depletion, human toxicity and in the case of background processes for impact categories of human toxicity, respiratory inorganics, terrestrial eco-toxicity, photochemical ozone formation, mineral depletion, fossil depletion. This is because asparagus has the unitary highest related emission due to the highest water requirements, leading to a higher impact on the environment, directly associated with the water depletion, and also with the energy consumption (used in the water distribution process) and the corresponding impacts, among other factors.

From graphs of Type II indicators (given in Annex A and based on water use) the olives, characterized by the lowest unitary related emission and unitary water use, lead to highest impact indicator. This is explained by the fact that Type II indicators represent the ratio between the environmental impacts and crop water use. Hence, the crops with the high irrigation requirements are those with the lowest impact indicators. The exception is for the mineral depletion and terrestrial eco-toxicity impact categories where the highest impact refers to asparagus which for this category has the highest unitary related emission. The same is true for impact indicator of human toxicity for foreground processes where the highest impact is caused by tablegrapes.

Table 21. Environmental Impacts of the Study System (Normal Hydrological Year)

Indicator	Value (Unit)	Foreground Value (Unit)	Background Value(Unit)	Type I Indicator (per kg product)	Type II Indicator (per m^3 water used)
Climate Change (tCO2eq)	76,988,401	63,477,607	13,510,794	0.1345	0.9311
Fossil Fuels Depletion (kg $oil_{,eq}$)	6,657,080	0	6,657,080	0.0116	0.0805
Freshwater Resource Depletion (m^3)	13,623,492	13,623,492	0	0.0238	0.1648
Eutrophication ($kgPO_4eq$)	878,982	727,182	151,800	0.0015	0.0106
Human Toxicity (kg1,4-DBeq)	3,800,986	134	3,800,852	0.0066	0.0460
Acidification ($kgSO_2eq$)	1,112,264	934,417	177,847	0.0019	0.0135
Aquatic Ecotoxicity (kg1,4-DBeq)	1,250,516	0	1,250,516	0.0022	0.0151
Terrestrial Ecotoxicity (kg1,4-DBeq)	8,011	0	8,011	0.0000	0.0001
Respiratory Inorganics	24,201	0	24,201	0.0000	0.0003
Photochemical Ozone Formation	7,808	36	7,772	0.0000	0.0001
Mineral Depletion (kgFe-eq)	2,021	0	2,021	0.0000	0.0000

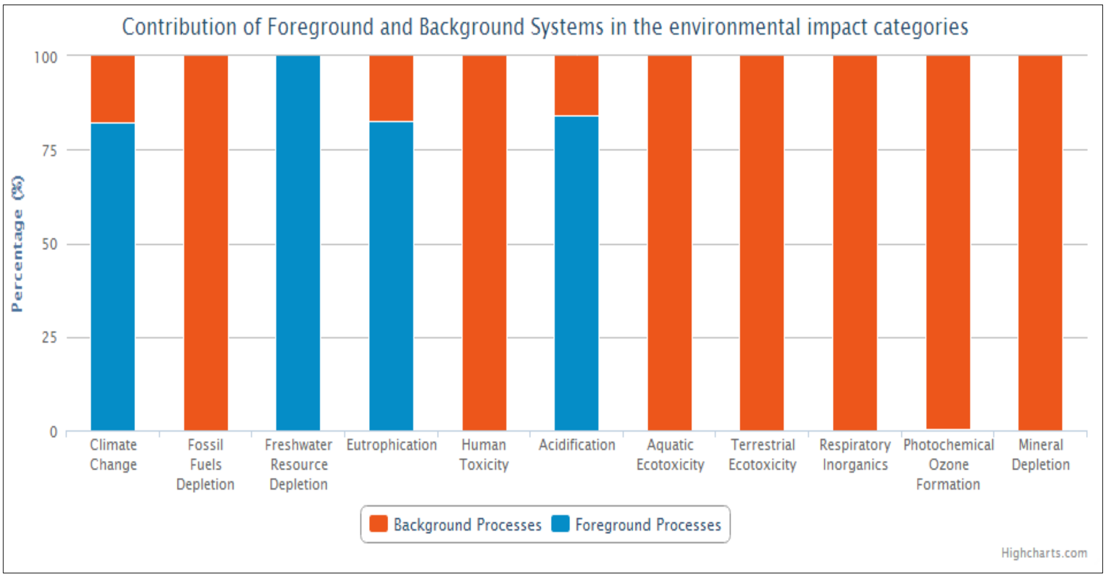


Figure 6. Contribution of Foreground and Background Systems in the environmental impact categories for normal year conditions

The GHG emissions (related to climate change) due to the foreground processes necessary for crop production accounted for 82% of total GHG emission of the study area (Figure 6). Nitrogen (N) fertilizer and fuel consumption were the largest contributors to GHG emissions (i.e. climate change impact), with N fertilizer accounting for 35% and fuel consumption for 34%. Irrigation accounted for only 9% of total GHG emissions. A share of 18% refers to background system processes where the main source, by 65%, was nitrogen production due to relative high impact factor (Table 20). 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 was assumed to be 0.15. Since the freshwater depletion indicator refers to the foreground river only foreground impact were calculated. From the results, the decreased availability of freshwater resources amounts for 13,623,362 m^3/year. Although P has a higher eutrophication potential than N (1 vs 0.1), the main source of eutrophication by 44% contribution was N fertilizer due to relatively high loads in water bodies. The contrary was 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 17% (Figure 6 and Table 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 ecotoxicity, 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 ecotoxicity and minerals depletion (Figure 8 and Table 20).

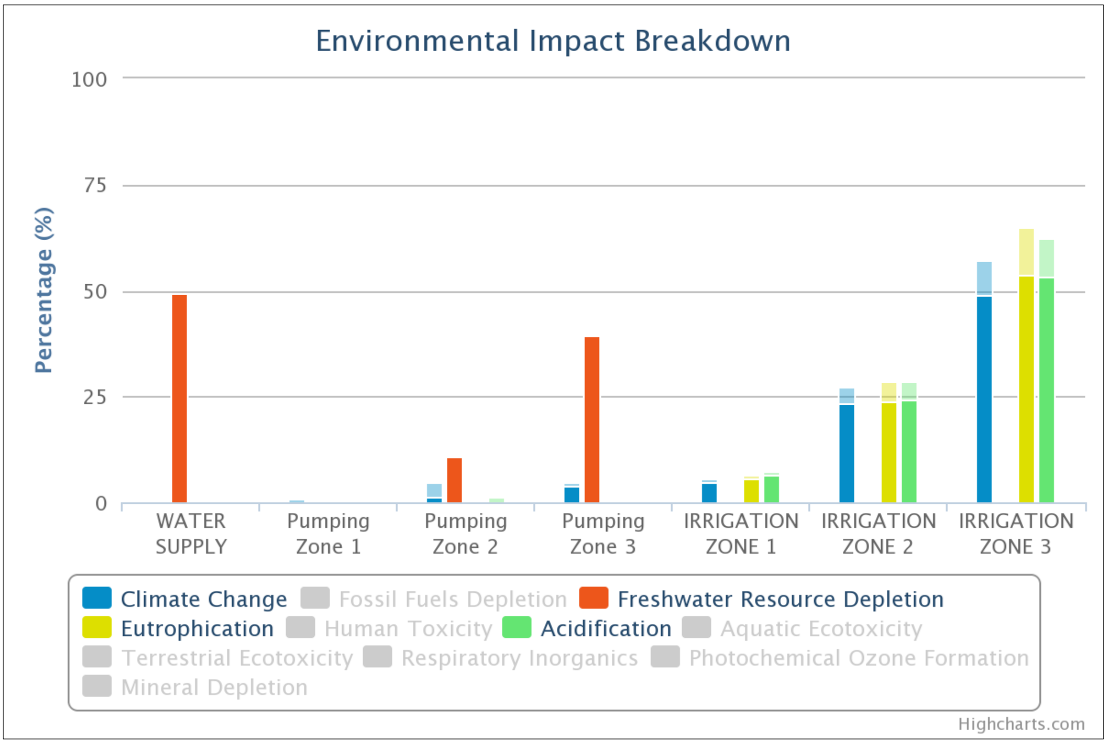


Figure 7. Environmental Impact Breakdown, percentage per stage (1/2)

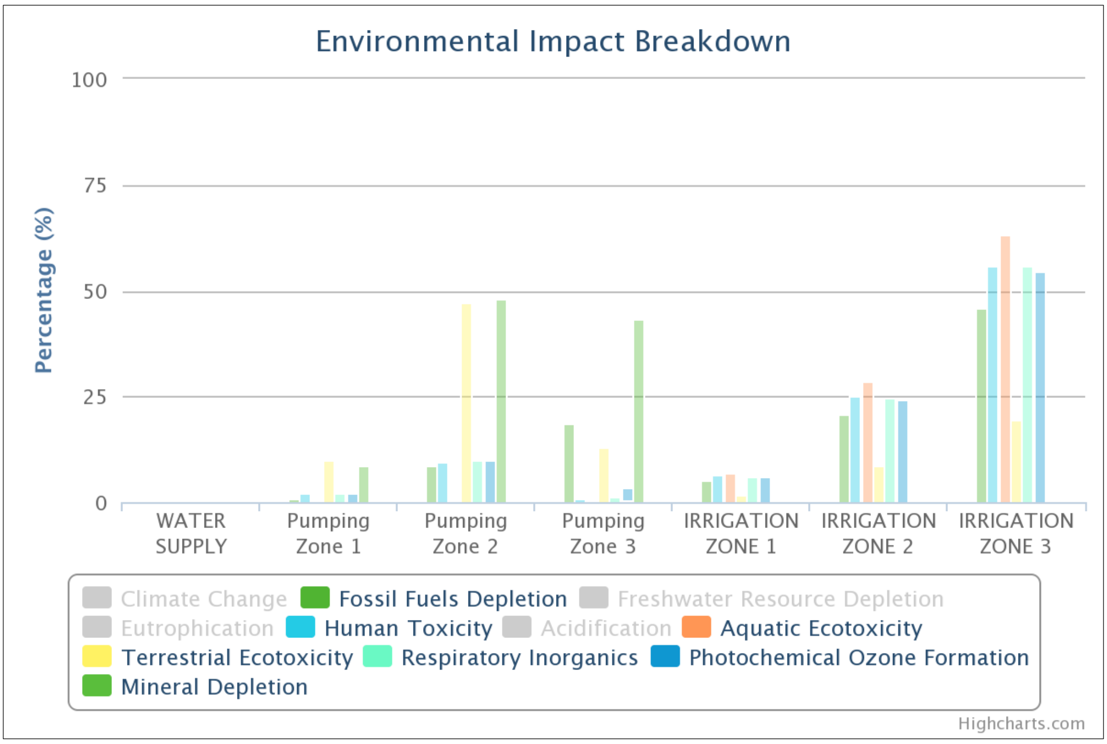


Figure 8. Environmental Impact Breakdown, percentage per stage (2/2)

Considering different irrigation zones, the highest environmental impacts indicators are observed in irrigation zone 3 due to highest consumption of water service related materials and supplementary resources (Figures 7 and 8). Differently, considering water withdrawal and delivery stages, the highest impact comes from irrigation zone 2 where the main impact categories are human toxicity, terrestrial ecotoxicity, respiratory inorganics, minerals depletion and photochemical ozone formation. This was due to higher relative impact factor from electricity production (Table 20) 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.

1.5.3.2 Environmental Impact Assessment of the Entire System (Dry year)

The results of the environmental impacts of the entire system for dry year conditions are presented in Table 22 and the contribution of the background and foreground processes into the system are presented in Figure 9. The environmental impact breakdown for each indicator are presented in Figure 10 and 11. Disaggregation on the clusters level is not shown in this case because from analysis was found that performance of clusters was similar with normal hydrological year due to the same allocation of resources.

Comparing with normal hydrological year, the environmental indicators change under dry year conditions because more irrigation and related energy input were required. This imposed for foreground subsystem an increase of GHG emission by 1.5%, freshwater resource depletion by 12.1%, human toxicity by 24.2 % and photochemical ozone formation by 24.4%. High environmental impacts from background processes was 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 found for eutrophication due to low impact factor for resource production processes and no changes in fertilizer application.

Table 22. Environmental Impacts of the Study System (Dry Year)

Indicator	Value (Unit)	Foreground Value (Unit)	Background Value(Unit)	Type I Indicator (per kg product)	Type II Indicator (per m^3 water used)
Climate Change (tCO2eq)	78,072,936	64,439,461	13,633,474	0.1364	0.9442
Fossil Fuels Depletion (MJ)	7,040,670	0	7,040,670	0.0123	0.0852
Freshwater Resource Depletion (m^3)	15,271,330	15,271,330	0	0.0267	0.1847
Eutrophication ($kgPO_4eq$)	879,040	727,182	151,858	0.0015	0.0106
Human Toxicity (kg1,4-DBeq)	3,813,165	166	3,812,998	0.0067	0.0461
Acidification ($kgSO_2eq$)	1,113,110	934,438	178,672	0.0019	0.0135
Aquatic Ecotoxicity (kg1,4-DBeq)	1,251,467	0	1,251,467	0.0022	0.0151
Terrestrial Ecotoxicity (kg1,4-DBeq)	8,335	0	8,335	0.0000	0.0001
Respiratory Inorganics	24,313	0	24,313	0.0000	0.0003
Photochemical Ozone Formation	7,890	45	7,845	0.0000	0.0001
Mineral Depletion (kgFe-eq)	2,291	0	2,291	0.0000	0.0000

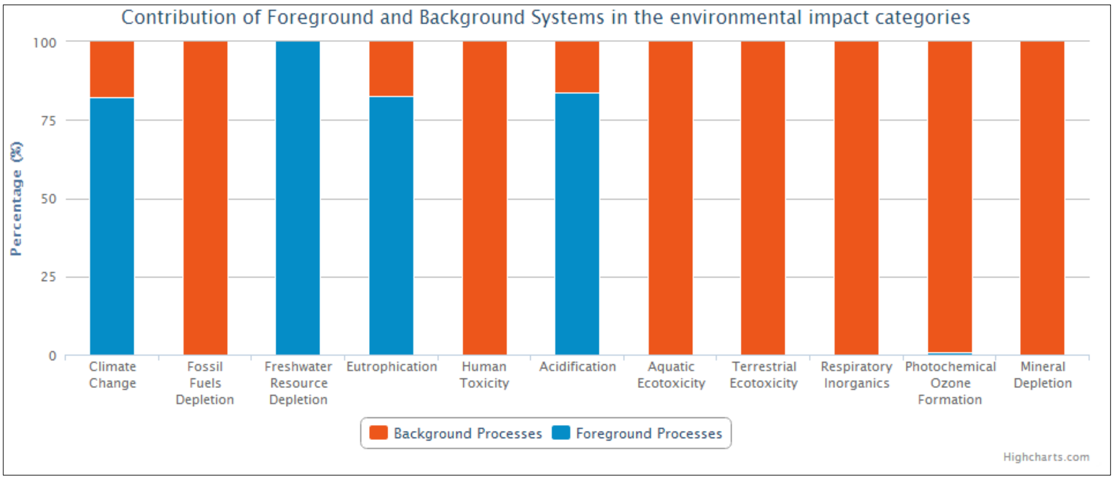


Figure 9. Contribution of Foreground and Background Systems in the environmental impact categories for dry year conditions

On the farm level (considering the irrigation zones), the most significant environmental impacts were observed in irrigation zone 3 due to highest consumption of water service related materials and supplementary resources. Similarly to the normal hydrological year, when considering the water distribution stages and withdrawals (pumping zones), the highest impact was observed in irrigation zone 2 for impact categories of human toxicity, terrestrial eco-toxicity, respiratory inorganics, and photochemical ozone formation. Differences were observed for the impact category of mineral depletion where the main source was irrigation zone 3 due to highest impact from diesel production for this category.

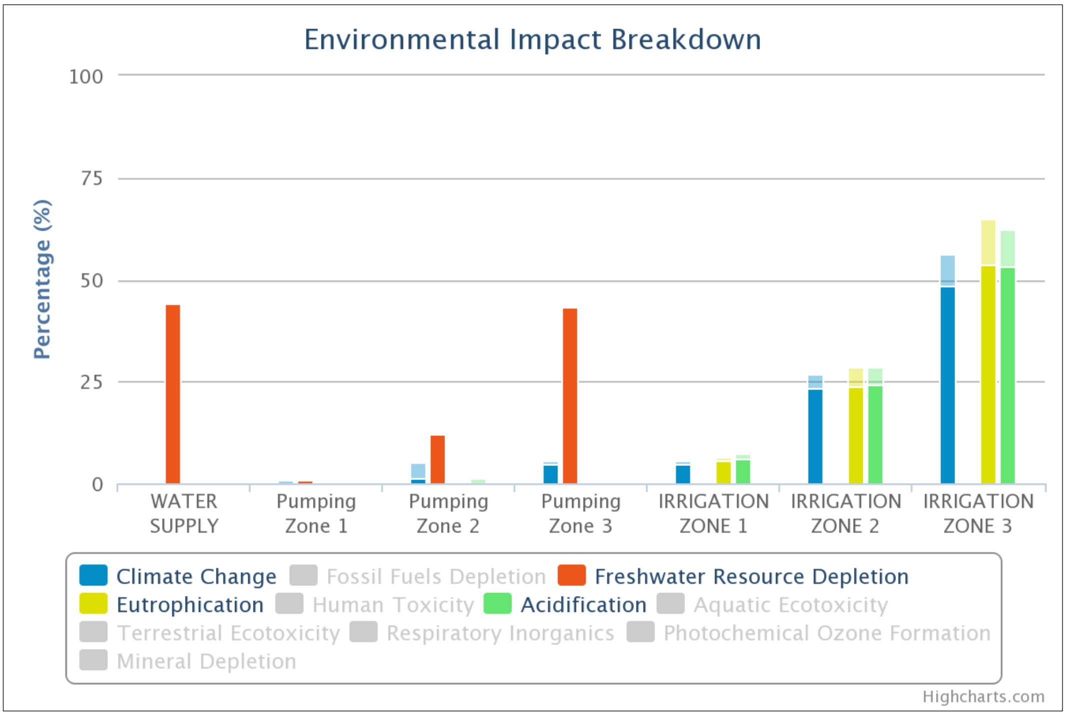


Figure 10. Environmental Impact Breakdown, percentage per stage (1/2) - Dry Year

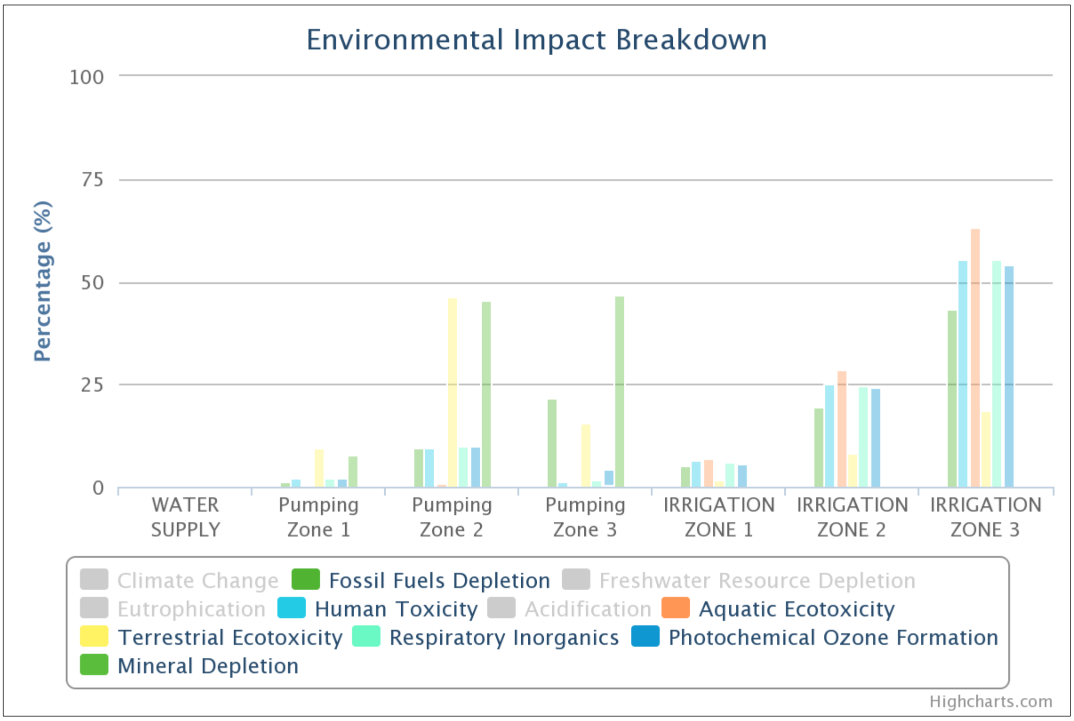


Figure 11. Environmental Impact Breakdown, percentage per stage (2/2) - Dry Year

1.5.4 Economic performance assessment

1.5.4.1 Economic performance assessment (Normal hydrological year)

The economic performance assessment for the baseline scenario and for a normal hydrological year at the level of individual actors is presented in Table 23 while Figure 12 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 is worth to mention that the costs of externalities (taxes for pollution/emission, either positive for governments or negative for farmers) of irrigation were not taken into account.

Table 23. Economic performance results (Normal Hydrological Year)

Actor	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
FA1	4,239,450	7,873,451	-294,779	3,339,221
FA2	34,288,601	48,090,264	-952,044	12,849,618
FA3	100,567,643	163,056,724	-2,640,400	59,848,680
Consortium CBC	6,204,164	0.00	3,887,224	-2,316,939
Total Value Added				73,720,580

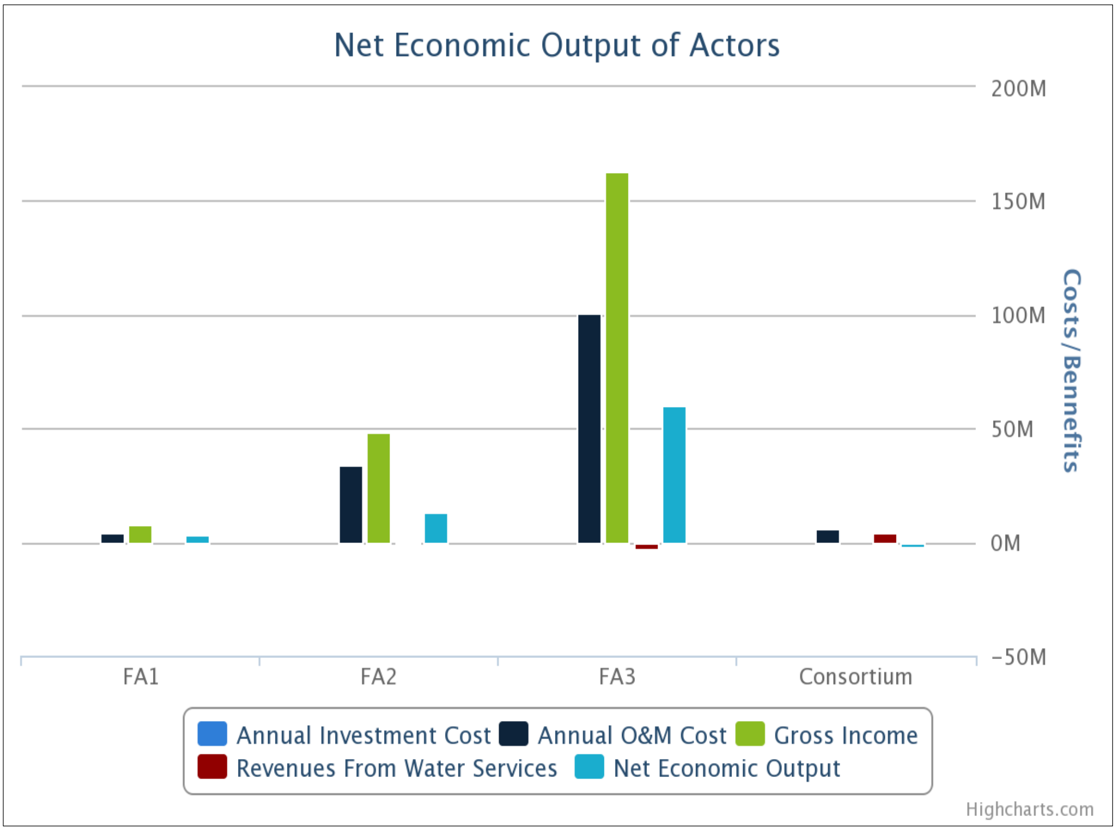


Figure 12. Environmental Performance per Actor (Normal Hydrological Year)

The Total Value Added (TVA) to the product from the water use of the Sinistra Ofanto irrigation system was estimated about 73.7 M€ or 2190 €/ha. Overall, the results indicate that the total value added of the system greatly depends upon the yields achieved, i.e. upon the level of water use. From Figure 12, it can be observed that the highest benefits are gained in FA3 with 2935 €/ha due to largest gross income which is the consequence of more profitable cropping pattern and greater irrigation water supply (3023 m^3/ha) in respect to zones 1 and 2 (895 and 1751 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 cropping pattern. In fact, in zone 2, the large areas are cultivated with table grape which has high production cost (6556 €/ha). On the contrary, in zone 1, the large areas are cultivated with wheat under rainfed and with low production cost (548 €/ha). The costs for groundwater pumping represents about 13% of total expenditures, varying proportionally between zones according to water demand. 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).

1.5.4.2 Economic performance assessment (Dry year)

The economic performance assessment for baseline scenario for dry year conditions at the level of individual actors is presented in Table 24 while Figure 13 summarizes the economic results for actors involved.

Table 24. Economic performance results (Dry Year)

Actor	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
FA1	4,365,073.70	7,234,120.60	-294,779.28	2,574,267.61
FA2	35,327,381.66	45,101,881.88	-952,044.85	8,822,455.37
FA3	103,797,820.34	158,306,858.08	-2,640,400.84	51,868,636.90
Consortium CBC	6,204,164.16	0.00	3,887,224.97	-2,316,939.19
	Total Value Added			60,948,420

The Total Value Added (TVA) of the Sinistra Ofanto irrigation system for dry year was estimated about 60.9 M€ or 1811 €/ha. Differences between both average and high water demand conditions were very significant. With regard to average year, in dry year TVA decreased by 12.7 M€ or 21 %. Life cycle (production) costs were increased by 3.1% due to greater water withdrawals to compensate the reduction of precipitation. The highest increase of costs was found in zone 3 due to high water demanding cropping patters and greatest water supply. The decline of unitary net economic output 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 by wheat under rainfed which caused a yield reduction, in respect to a normal hydrological year, in average from 4.18 to 3.45 t/ha.

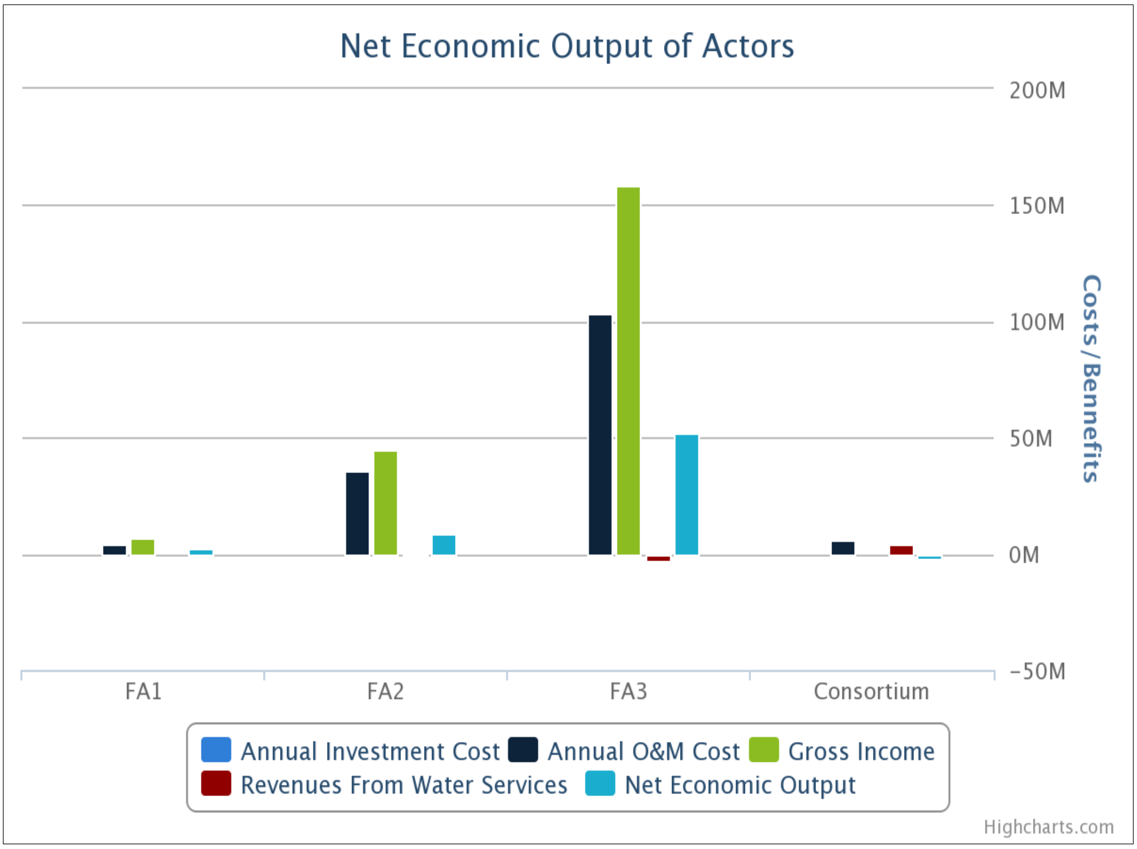


Figure 13. Environmental Performance per Actor (Dry Year)

1.6 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 25. A higher value of the indicator means a higher eco-efficiency.

The results indicate that the eco-efficiency tends to increase as pressure on resources decreases, i.e. when irrigation requirements are lower and the management practices are based on more efficient irrigation methods and/or non-optimal water supply. In absolute terms, the highest eco-efficiency corresponds to zone 1 due to 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, from the analysis is 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 negatively the eco-efficiency ratio.

Table 25. Eco-efficiency indicators for the baseline scenario of Sinistra Ofanto agricultural water system

Indicator	Unit	Value (Normal Year)	Value (Dry Year)
Climate Change	€/kgCO_2,eq	0.96	0.78
Fossil fuels depletion	€/tn oil eq	11.07	8.66
Freshwater resource depletion	€/m^3	11.03	3.99
Eutrophication	€/kgPO_4^{-3},eq	83.87	69.34
Human toxicity	€/kgDB	19.4	15.99
Acidification	€/kgSO_{2-},eq	66.28	54.7
Aquatic Ecotoxicity	€/kg DB	58.95	48.7
Terrestrial Ecotoxicity	€/kg DB	9,202	7312
Respiratory inorganics	€/kg$PM_{2.5}$,eq/	3,046	2506
Photochemical ozone formation	€/kgC_2H_4,eq	9,442	7724
Minerals depletion	€/kg Fe eq	36,477	26605

1.7 Conclusions

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 satisfy fully 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. 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. This could be applied at different scales, from farm to water distribution and delivery networks 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.

A baseline meso-level eco-efficiency assessment of Sinistra Ofanto irrigation scheme was performed for normal and dry hydrological year, corresponding to annual precipitation of 514 and 420 mm, respectively. 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 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.

In the case of 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 moving to the more commercial cropping pattern (as in the case of irrigation zone 3). However, it is increasing the environmental burden 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 the recharge for about 16.1 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 upgrading of the value chain through innovative technologies should aim at improving the key indicators which are related to the use of non-renewable energy sources, fresh water abstraction and chemicals use (Human Toxicity, Fresh water and Terrestrial Eco-toxicity, Freshwater depletion, Fossil fuels depletion, Acidification). 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 result to:
  - Decrease of the “climate change” eco-efficiency indicator and of the indicators related to the electricity production (human toxicity, terrestrial and aquatic ecotoxicity); and
  - Reduction of fresh water depletion indicator.
- Reduction of the discharge of pollutants due to the use of less toxic chemicals (fertilizers) which will affect the “eutrophication” and “acidification” eco-efficiency indicators.

2 Baseline eco-efficiency assessment of the Monte Novo Case Study

2.1 Introduction

The baseline eco-efficiency assessment of the Case Study # 2: Monte Novo Irrigation Area – Portugal was performed taking into account the five phases of an eco-efficiency assessment (ISO, 2012): (i) Goal and Scope Definition, (ii) Environment Assessment, (iii) Value Assessment, (iv) Quantification of Eco-efficiency and (v) Interpretation. The eco-efficiency assessment is a quantitative tool which enables the study of the environmental impacts in this specific case, of an agricultural product along with its value.

The environmental impacts were evaluated using a Life Cycle Assessment (LCA) oriented approach, based on the creation of an inventory of elementary flows (relevant energy, resource inputs and environmental releases) that allows the Life Cycle Impact Assessment (LCIA); identification and evaluation of the potential environmental impacts associated with identified inputs and releases.

The value assessment was performed considering the full life cycle of the product system. The values were calculated in monetary terms (€) and are expressed through costs, price, willingness to pay, added value, profit, etc.). The Total Value Added (TVA) was the economic performance indicator used.

Finally, the quantification of eco-efficiency was determined by relating the results of the environmental assessment to the results of the value assessment, based on the "eco-efficiency equation" (Figure 14). By the end of the study, 11 Eco-Efficiency Indicators (EEI) were obtained, one for each environmental impact category, as it will be hereafter presented.

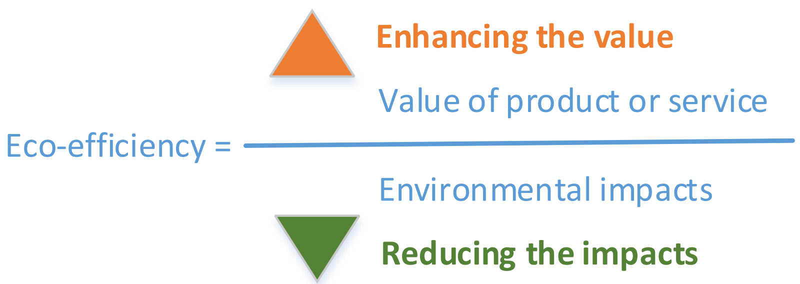


Figure 14. The eco-ifficiency equation.

2.2 Goal and Scope Definition

2.2.1 Objectives

The main goal of this study is the assessment of the environmental and economic impacts and the eco-efficiency performance associated with the water value chain in the Monte Novo case study. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors.

The assessment is performed in the baseline scenario which represents the reference point for benchmarking enhancements resulting from the upgrade of the value chain through the introduction of innovative technologies, which will be examined in a later stage.

2.2.2 System boundaries

The main stages of the Monte Novo case study are the water abstraction, water distribution, water use and disposal. Table 26 presents the stages, processes and technologies corresponding to the water supply chain presented in Figure 15.

Table 26. Stages, processes and technologies in the Monte Novo case study.

Stage 1: Water abstraction
Process 1: primary network
Technology 1: pumping station
Technology 2: conveyance canals and ducts
Stage 2: Water distribution
Process 2: secondary network – low pressure
Technology 3: regulating reservoirs
Process 3: secondary network – high pressure
Technology 1: pumping station
Technology 3: regulating reservoirs
Stage 3: Water use
Process 4: farmers – low pressure (olives, maize, pastures)
Technology 4: drip irrigation (olives – intensive and super intensive)
Technology 5: sprinkler irrigation (maize, pastures)
Process 5: farmers – high pressure (olives, maize, pastures)
Technology 4: drip irrigation (olives – intensive and super intensive)
Technology 5: sprinkler irrigation (maize, pastures)
Stage 4: Disposal
Residual water discharged to the environment (SW and GW)

More specifically, one can indicate that:

- the primary network corresponds to water abstraction in the Alqueva reservoir (main storage reservoir of the system), elevation and water transport to the secondary networks;
- the secondary network includes the regulating storage made through several reservoirs (R1, R2, R3, R4, R4.1), the elevation stage and the water distribution to the different irrigated farms considered;
- the farmers (users) in the Monte Novo case study are represented by means of the most representative crops in the area.

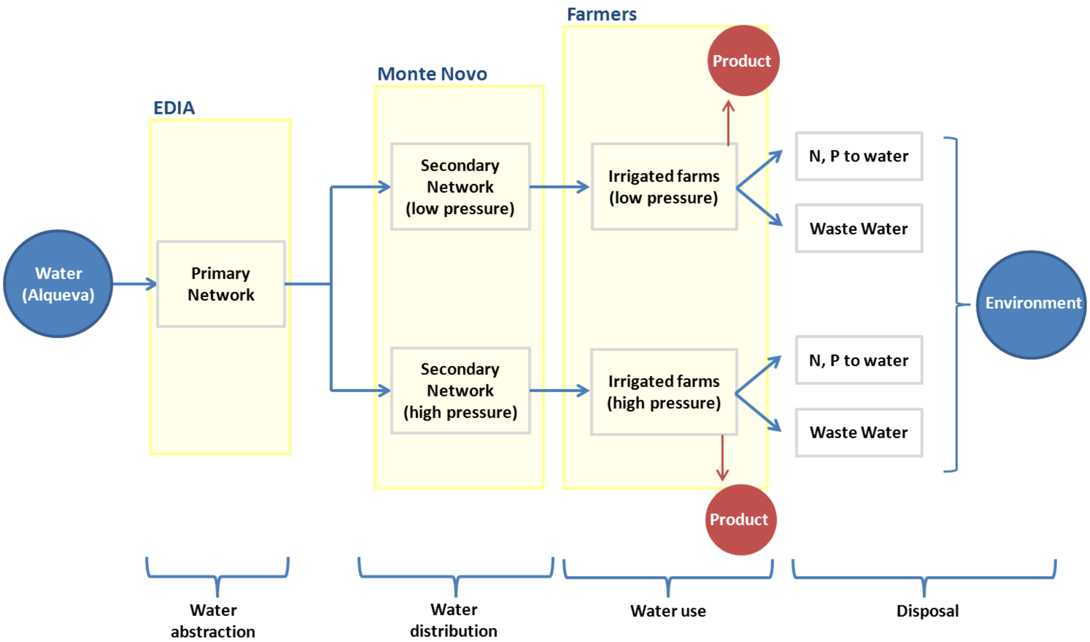


Figure 15. Stages, processes and involved actors in the water supply chain of the Monte Novo Case Study.

Three actors are directly involved in the system:

- EDIA ("Empresa para o Desenvolvimento das Infraestruturas de Alqueva). EDIA is the entity 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"), which represents all the farmers which are connected to the Alqueva water distribution system from EDIA, and
- Farmers that will benefit from the irrigation networks, more specifically, FEA ("Fundação *Eugénio* de Almeida") and ODS ("Olivais do Sul"). The main crops of *Fundação Eugénio de Almeida* are vineyards and olives. *Olivais do Sul* are specialized in olive growing and olive oil production. The olive production is made using both intensive and super-intensive methods.

As referred above, the environmental and eco-efficiency assessment incorporating a life cycle oriented approach along the water supply chain considers the environmental impacts of: the input resources and materials, the energy use and the agricultural facilities. Regarding the system boundary used for the LCA, the "cradle-to-gate" analysis was considered, which is an assessment of a partial product life cycle, i.e. starting from the extraction of primary resources (cradle) to the point that products leave the agricultural system boundaries (before the transportation to the consumer). However, no use or end life is taking into account.

With this approach, the system's boundaries of the Monte Novo Case Study were identified, emphasizing that the foreground and background systems have to be distinguished:

- the **foreground system** corresponds to the set of processes whose selection or mode of operation is affected directly by decisions based on the study;
- the **background system** includes all other activities which delivers energy and raw materials to the foreground system, usually via a homogeneous market so that individual plants and operations cannot be identified.

Figure 16 presents these concepts applied to the Monte Novo case study, according to the stages presented in Table 26.

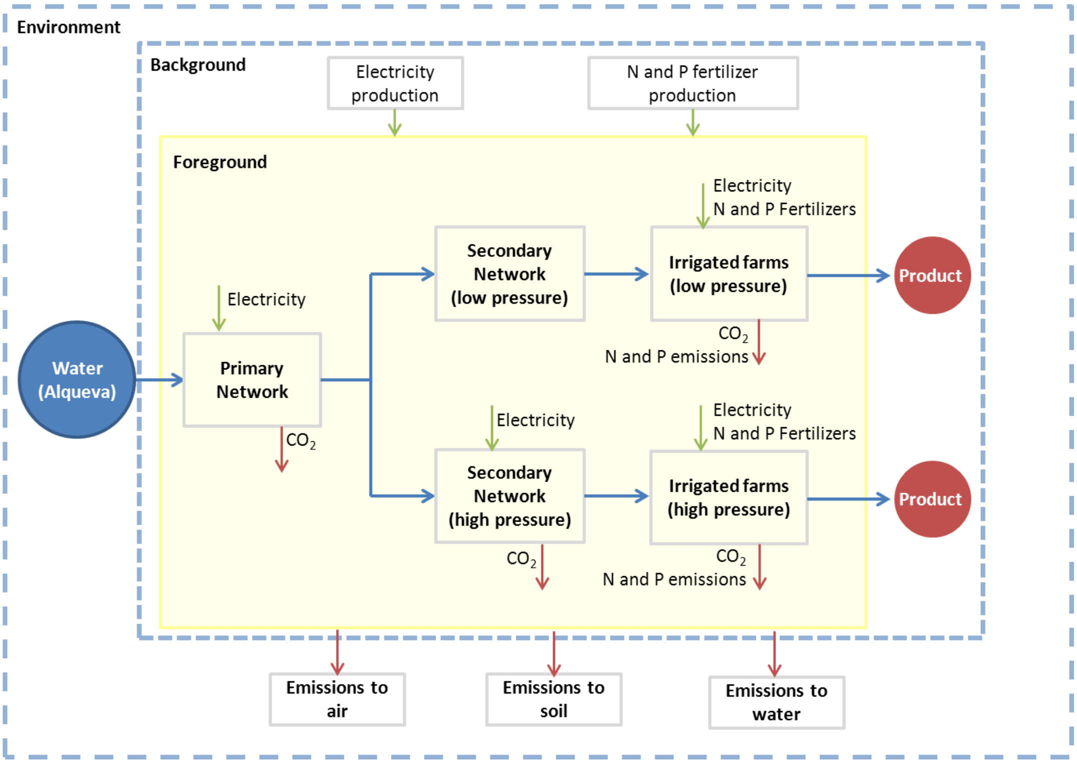


Figure 16. Life Cycle Diagram of the Study System including Foreground and Background Systems.

Table 27. Foreground and Background processes of the Monte Novo Irrigation Scheme.

Type of Process	Name
Foreground	1. Water abstraction – primary network
	2. Water distribution – secondary network (low pressure)
	3. Water distribution – secondary network (high pressure)
	4. Water use – farmers (low pressure)
	5. Water use – farmers (high pressure)
	6. Disposal
Background	1. Electricity production
	2. Nitrogen fertilizer manufacturing process
	3. Phosphorus fertilizer manufacturing process

The Life Cycle Assessment approach considers the impacts from elementary flows entering the system and also the direct emission to the environment from the operations of the study system itself. The foreground system was focused on all the stages along the water value chain where supplementary resources (agro-chemicals and energy) are used; while the background system includes the raw materials and energy production processes (fertilizers production and electricity production). The summary of the system processes and their characterization as Foreground and Background are shown in Table 27.

The simulation of the baseline scenario was performed considering data from 2012 in what concerns cultivated areas. The crops considered are the most representative of the Monte Novo irrigation perimeter, namely: maize, olive (intensive and super intensive) and pastures and represent a total area of 3673 ha (Table 27). These areas are irrigated by drip irrigation – for olives, intensive and super intensive - with an average efficiency of 90%, or sprinkler – for maize and pastures - with an average efficiency of 80%.

2.2.3 Function unit definition

The functional unit depends on the reference flow selected each time. In this study, two approaches were investigated, one unit of product and one unit of water used, as presented in Table 28. In both cases, the unit of specific product or water consumed for a specific product is only meaningful when examining a specific cluster (i.e. geographical area which has the same water use profile) and not an entire water use system. The main purpose for the functional unit definition is to provide a reference to which results are normalized and compared.

Table 28. Function unit definition according to two different approaches.

	Approach 1 (Product Oriented Approach)	Approach 2 (Water Service Oriented Approach)
Function	Agricultural Production, as water consumer	Water used in Agriculture
Functional unit	Production of each type of crop (1 ton)	Water used for the production of one type of crop (1m^3)
Reference flow	Crop production, 1ton	Water used for crop production, 1m^3

2.3 Environmental Assessment

The environmental assessment concerns the evaluation of the environmental impacts and follows the main stages of the typical LCA as described in ISO 14044:2006 (ISO, 2006). Thus, the presented methodology will be focusing on:

- Inventory analysis
  - Elementary flows
  - Economic data
- Impact assessment
  - Environmental impact categories
  - Classification and characterization
  - Calculation of environmental impacts for Foreground and Background processes
  - Environmental impact indicators

- Cluster and area indicators

2.3.1 Inventory analysis

2.3.1.1 Elementary flows

The LCI analysis involves the creation of an inventory of flows entering and leaving every process in the foreground system. In the Monte Novo case study, the data requirement is focused on:

i) Foreground data (direct emissions and water abstraction) extracted from SEAT model:
   - Nitrogen to Water
   - Phosphorus to Water
   - Water consumption

ii) Characterization factors for background processes:
   - Electricity production
   - Nitrogen fertilizer manufacturing process
   - Phosphorus fertilizer manufacturing process

For the next stage of the environmental assessment – the impact assessment –the main inputs and outputs coming from SEAT model were collected, for the baseline scenario. Table 29 presents the different resources involved in the Monte Novo case study.

Table 29. Resources of the Monte Novo case study.

Category	Symbol	Resource
Water service related materials	w	Water
Supplementary resources	r_1	Energy
	r_2	Fertilizer (Phosphorus)
	r_3	Fertilizer (Nitrogen)
	r_4	Irrigated area
Emissions	e_1	CO_2
	e_2	Wastewater
	e_3	Nitrogen to water
	e_4	Phosphorus to water
Products	p_1	Maize (grain)
	p_2	Olives
	p_3	Pastures

The corresponding elementary flows and associated quantities are depicted in Table 30. The information presented was extracted from SEAT model and all flows are referred to annual average values.

Table 30. Life cycle inventory flows of the Monte Novo Irrigation Scheme (from SEAT).

Category	Material	Quantity
Water service related materials	Water	24,904,792 m^3
Supplementary resources	Energy	13,370,830 kWh
	Fertilizer (Phosphorus)	587,680 kg
	Fertilizer (Nitrogen)	330,570 kg
	Irrigated area	3,673 m^2
Emissions	CO_2	6,779,011 kg
	Wastewater	6,546,100 m^3
	Nitrogen to water	110,190 kg
	Phosphorus to water	7,346 kg
Products	Maize (grain)	20,055 ton
	Olives	18,360 ton
	Pastures	5,090 ton

2.3.1.2 Economic data

Table 31 summarizes the economic data considered in the study.

Table 31. Unit costs of raw materials and supplementary resources.

Cost category	Item	Amount
Cost	Water – LP	0.0258 €/m^3
	Water – HP	0.042 €/m^3
	Electricity	0.118 €/kWh
	Fertilizer (N)	2.34 €/kg
	Fertilizer (P)	2.34 €/kg
Benefit	Maize (grain)	220 €/ton
	Olive	234 €/ton
	Pastures	135 €/ton

2.3.2 Impact Assessment

2.3.3 Environmental impact categories

The assessment of the environmental performance of the EcoWater meso-level water use system, and specifically, of the Monte Novo Case Study, follows a life-cycle oriented approach using the midpoint impact categories presented in Table 32, and according to each selected Impact Assessment Method.

Table 32. Midpoint impact categories and impact assessment methods.

Impact Category	Unit	Impact Assessment Method
Climate change	$kgCO_2$, eq	CML 2001
Eutrophication	$kgPO_4^{3-}$, eq	CML 2001
Acidification	$kgSO_2^{-}$,eq	CML 2001
Human toxicity	kg DB	CML 2001
Respiratory inorganics	$kgPM_{10}$, eq	Trace
Fresh water aquatic ecotoxicity	kg DB	CML 2001
Ecotoxicity Terrestrial	kg DB	CML 2001
Photochemical ozone formation	kgC_2H_4, eq	CML 2001
Minerals depletion	kg Fe, eq	Recipe
Fossil fuels depletion	kg oil, eq	Recipe
Freshwater depletion	m^3	(Milà i Canals et al., 2009)

2.3.3.1 Classification and characterization

During the classification phase, the results of the inventory, expressed as elementary flows, are assigned to impact categories according to the ability of resource/emission to contribute to different environmental problems.

The characterization factors for each Impact Assessment Method, according to the Impact Categories that they cover (Table 32), were collected. Tables 33 and 35 present the characterization factors which are used for the estimation of the impact of the foreground systems and the environmental impact factors for the background processes, respectively.

Table 33. Characterization factors of foreground elementary flows.

Impact category	Unit	N to water (per kg)	P to water (per kg)	Water (per m^3)
Climate change	kg CO_2, eq			
Eutrophication	kg PO_4^{-3}, eq	0.42	3.06	
Acidification	kg SO_2^{-}, eq			
Human toxicity	kg 1,4-DB, eq			
Respiratory inorganics	$kgPM_{10}$, eq			
Aquatic ecotoxicity	kg DB			
Terrestrial ecotoxicity	kg DB			
Photochemical ozone formation	kgC_2H_4, eq			
Minerals depletion	kg Fe, eq			
Fossil fuels depletionn	kg oil, eq			
Freshwater depletion	m^3			0.15

Table 34. Background processes and relevant data sources.

Process	Data Sources
Electricity Production	ELCD database (Process Name: Electricity Mix, AC, consumption mix, at consumer, 230V PT)
Nitrogen fertilizer production	USLCI database (Process name: Nitrogen fertilizer, production mix, at plant/kg/US)
Phosphorus fertilizer production	USLCI database (Process Name: Phosphorous fertilizer, production mix, at plant/kg/US)

Table 35. Environmental impact factors for background processes.

Impact category	Unit	Electricity Production (per kWh)	Nitrogen Fertilizer Productio n (per kg)	Phosphorus Fertilizer Production (per kg)
Climate change	kg CO_2, eq	0.80139	1.93006	0.39097
Eutrophication	kg PO_4^{-3}, eq	0.00030	0.00035	0.06724
Acidification	kg SO_2^{-}, eq	0.00606	0.02339	0.02197
Human toxicity	kg 1,4-DB, eq	0.06648	0.64951	0.16316
Respiratory inorganics	kgPM_{10}, eq	0.00095	0.00314	0.00300
Aquatic ecotoxicity	kg DB	0.00311	0.22896	0.08853
Terrestrial ecotoxicity	kg DB	0.00154	0.00022	0.00063
Photochemical ozone formation	kgC_2H_4, eq	0.00025	0.00100	0.00093
Minerals depletion	kg Fe, eq	0.00018	0.00000	0.00000
Fossil fuels depletionn	kg oil, eq	0.20155	0.97804	0.14833

2.3.3.2 Calculation of environmental impacts for foreground and background processes

The environmental impact was calculated by multiplying the elementary flows from the inventory analysis with the characterization factors. This method was applied for each impact category and the environmental impact assessment for an impact category can be estimated as the sum of the foreground and background processes.

The results of the environmental impacts, for the foreground and background systems, are presented in Table 36. For the foreground, two environmental indicators are relevant: eutrophication and freshwater depletion. On the other hand, for the background system, all the impact categories were considered.

Regarding the foreground system, it is possible to verify that eutrophication and water depletion impact categories are the only ones affected. The eutrophication value is a result of the nitrogen and phosphorus flows to surface water bodies and groundwater, due to the use of N and P fertilizers in agricultural use stages, whereas the freshwater depletion expresses the water abstraction to satisfy the irrigation requirements at the farmer's level.

Table 36. Environmental impacts from foreground and background systems.

Environmental Indicators	Unit	Value			
		Background from electricity	Background from other processes	Foreground	Total
Climate change	ton CO_2, eq	10,715	1,264	0	11,979
Eutrophication	kg PO_4^{3-}, eq	3,952	22,435	68,759	95,145
Acidification	kg SO_2^{-},eq	81,054	21,007	0	102,061
Human toxicity	ton DB	889	436	0	1,324
Respiratory inorganics	kg PM_{10}, eq	12,767	2,839	0	15,606
Aquatic ecotoxicity	ton DB	42	164	0	205
Terrestrial ecotoxicity	kg DB	20,542	338	0	20,880
Photochemical ozone formation	kg C_2H_4, eq	3,396	897	0	4,292
Minerals depletion	kg Fe, eq	2,443	0	0	2,443
Fossil fuels depletion	ton oil, eq	2,695	624	0	3,319
Freshwater depletion	m^3	0	0	3,735,719	3,735,719

Figure 17 summarizes the values presented in Table 36, and enables their better interpretation. In fact, it is possible to highlight the high environmental effect from the electricity production for most of the impact categories, namely, climate change, acidification, human toxicity, respiratory inorganics, terrestrial ecotoxicity, photochemical ozone formation, mineral depletion and fossil fuels depletion. Moreover, it is possible to verify the considerable contribution of the fertilizer manufacturing processes ("background from other processes") in the freshwater aquatic ecotoxicity due to the presence of toxic substances.

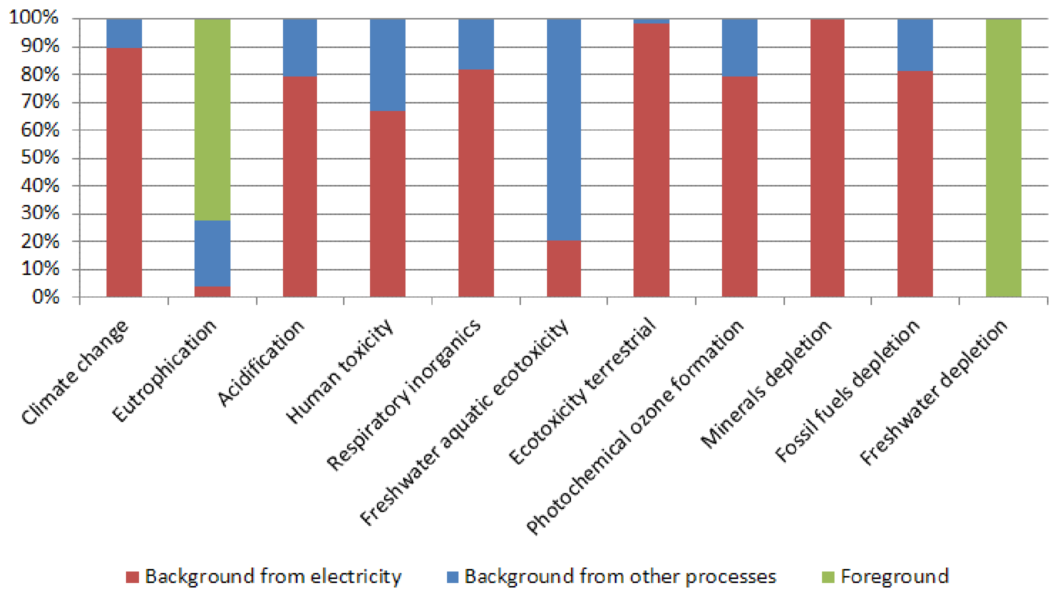


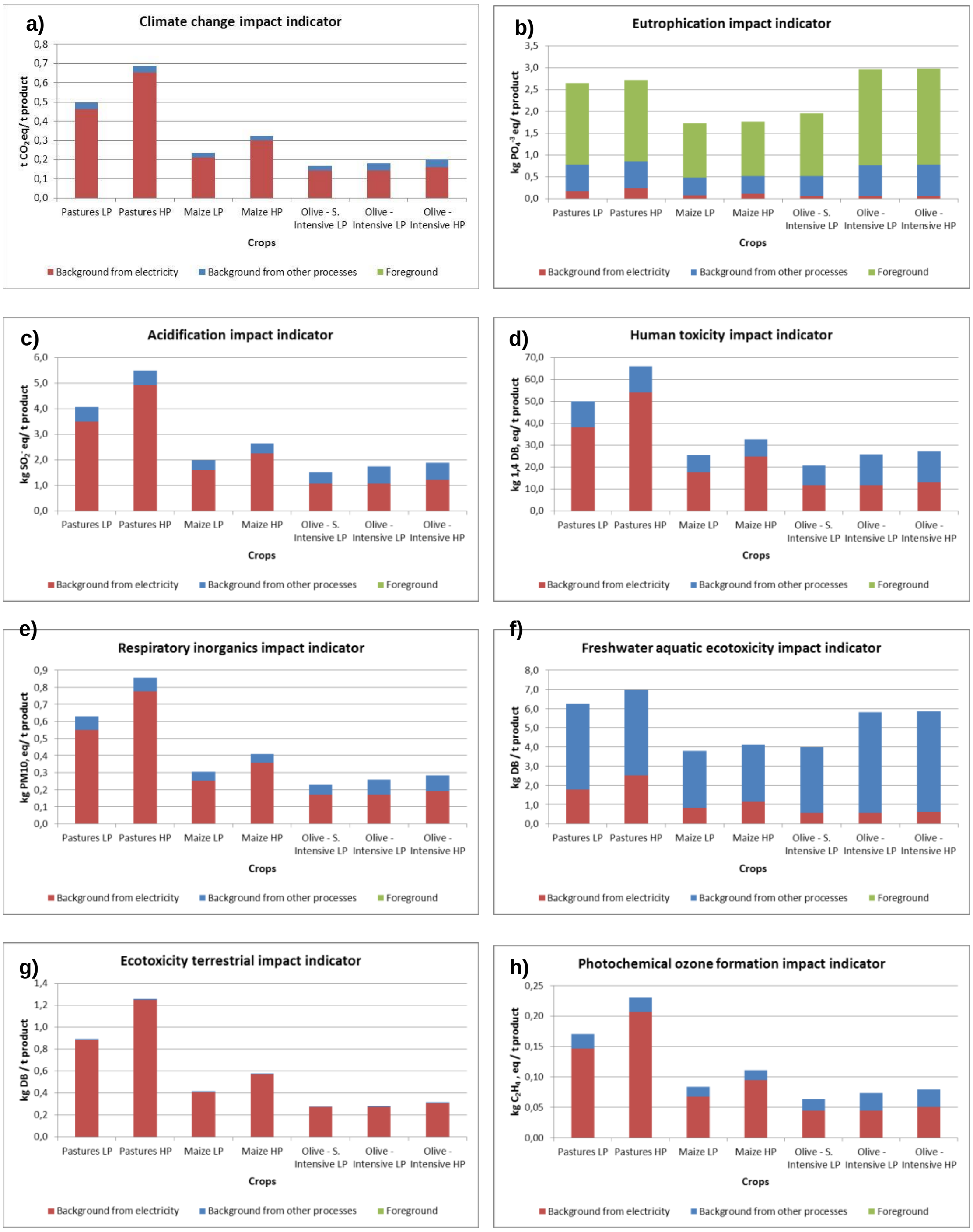
Figure 17. Environmental impact assessment for foreground and background systems.

2.3.3.3 Environmental impacts indicators

The environmental impact indicators were calculated by expressing the environmental impacts per unit of a product or per unit of water used (depending on the choice of functional unit). In this case study, both indicators are presented, following the two approaches:

- Type I (per ton of drop production)
- Type II (per m^3 of water used for crop production).

The Type I impact indicators are presented in the graphs presented in Figure 18.



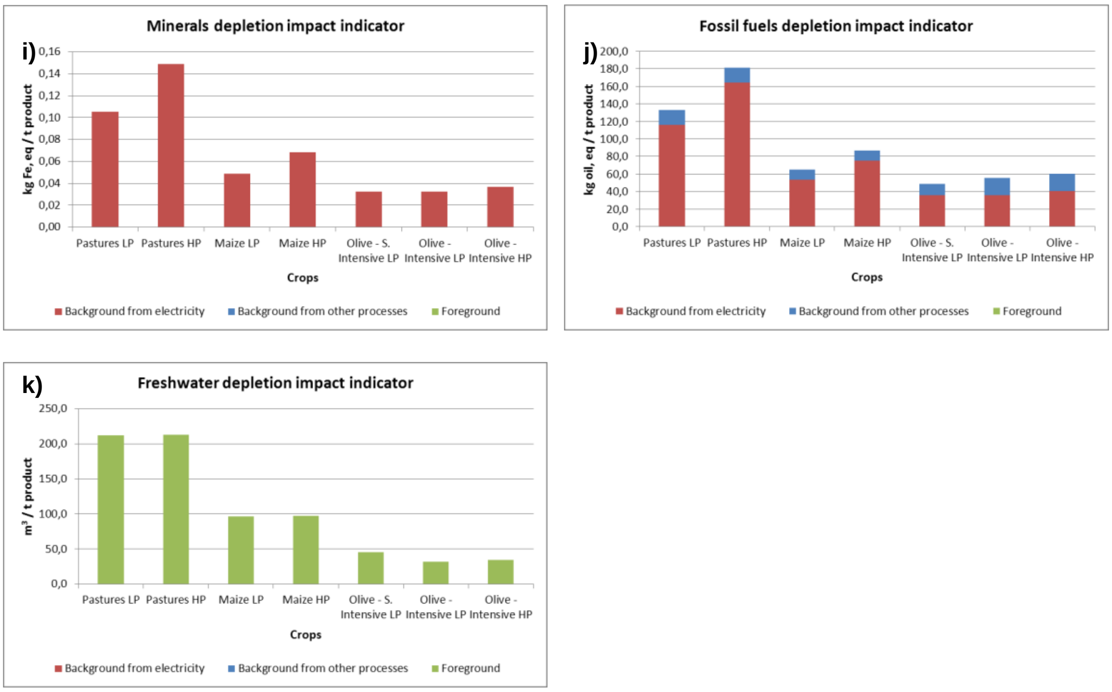
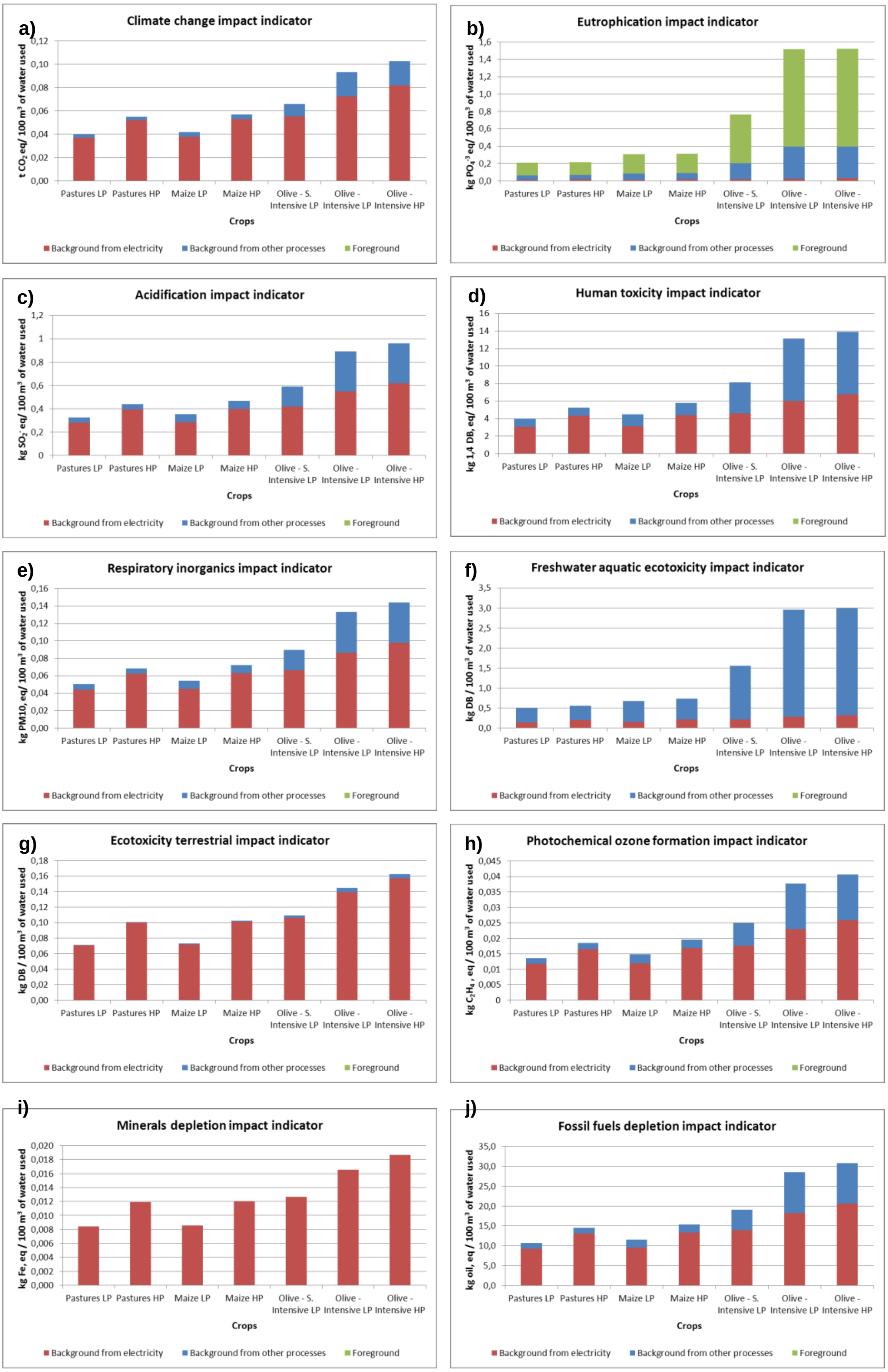


Figure 18. Environmental impact assessment on cluster scale – Type I indicators.

Each graph (a – k) corresponds to a specific impact indicator. Once again, the contribution of the foreground system for the high values of eutrophication and fresh water depletion impact indicators is noticeable, as shown in graphs (b) and (k). For almost all the remaining indicators - climate change, acidification, human toxicity, respiratory inorganics, terrestrial ecotoxicity, photochemical ozone formation, mineral depletion and fossil fuels depletion - the major contributor is the background electricity production, for all the clusters. Finally, for the aquatic ecotoxicity indicator, the relevant contribution is due to the fertilizers production.

Comparing the performance of the different clusters, it is possible to verify that, in most cases, pastures present the highest impact indicators. This could be justified taking into account that this type of indicators are expressed per ton of crop production, and pastures present one of the lowest values of crop yield (10 ton/ha) and the smallest area of production (509 ha). Thus, the environmental impacts are divided by the lowest values of production, which corresponds to the highest impact indicators. One the other hand, these crops have the highest water requirements, leading to a higher impact on the environment, directly associated with the water depletion, and also with the energy consumption (used in the water distribution process) and the corresponding impacts, among other factors.

The Type II impact indicators are presented in the following graphs (Figure 19).


a)
Climate change impact indicator
t CO2 eq/ 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
b)
Eutrophication impact indicator
kg PO4-3 eq/ 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
c)
Acidification impact indicator
kg SO2 eq/ 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
d)
Human toxicity impact indicator
kg 1,4 DB, eq/ 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
e)
Respiratory inorganics impact indicator
kg PM10, eq/ 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
f)
Freshwater aquatic ecotoxicity impact indicator
kg DB / 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
g)
Ecotoxicity terrestrial impact indicator
kg DB / 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
h)
Photochemical ozone formation impact indicator
kg C2H4, eq / 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
i)
Minerals depletion impact indicator
kg Fe, eq / 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground
j)
Fossil fuels depletion impact indicator
kg oil, eq / 100 m3 of water used
Pastures LP
Pastures HP
Maize LP
Maize HP
Olive - S. Intensive LP
Olive - Intensive LP
Olive - Intensive HP
Crops
Background from electricity
Background from other processes
Foreground

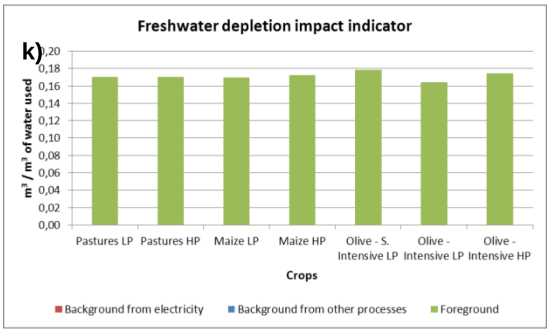
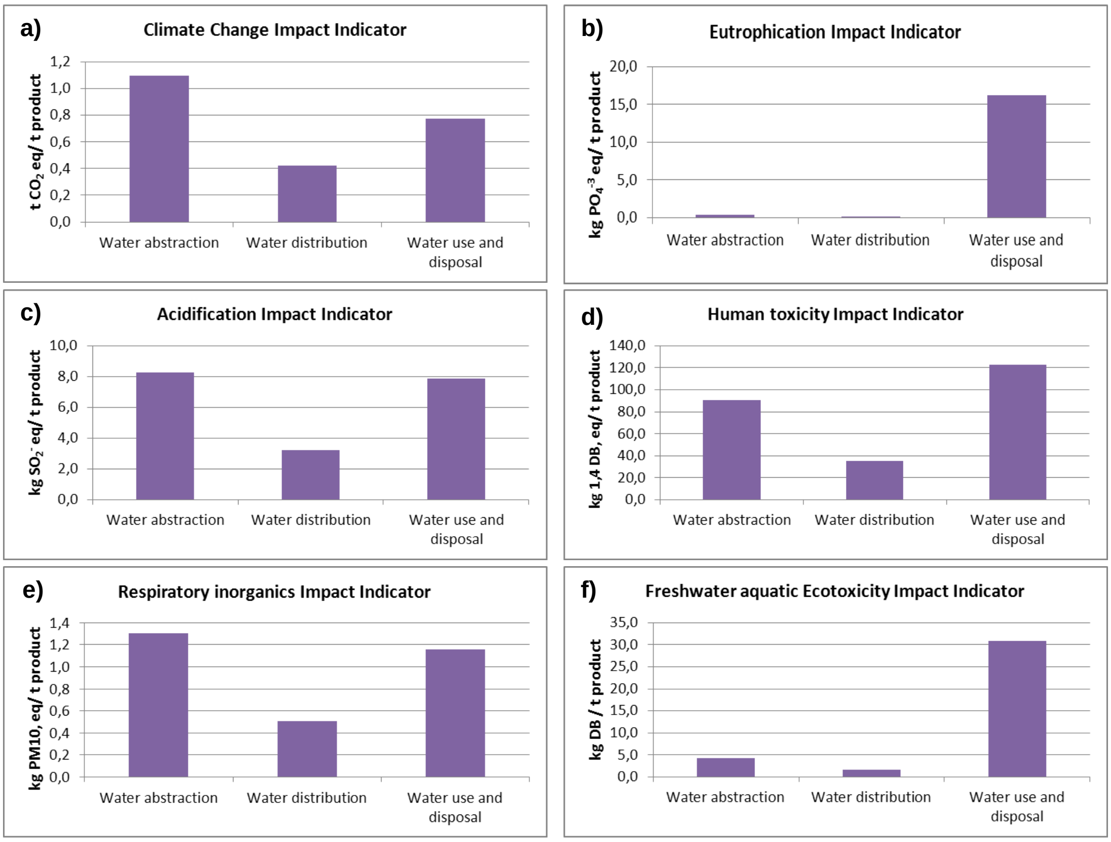


Figure 19. Environmental impact assessment on cluster scale – Type II indicators.

These graphs show that when the indicators are expressed by amount of water used for crop production, the pastures are the ones with the lowest values. This could be explained by the fact that the pastures are the crops with the highest water requirements and when calculating the type II indicators, the environmental impacts are divided by those water requirements. In the opposite side, the olives production (intensive) corresponds to the lowest water requirements, leading to the highest type II indicators. Once again, the major contribution of the foreground system is associated with eutrophication and fresh water depletion impact indicators.

Additionally, the type I indicators are presented for each stage of the Monte Novo case study: water abstraction, water distribution and water use and disposal. The two last stages are presented together since the environmental impacts are directly associated with the both these two later stages as it is difficult to separate the moment when the fertilizer is supplied and the actual water/soil pollution effect.



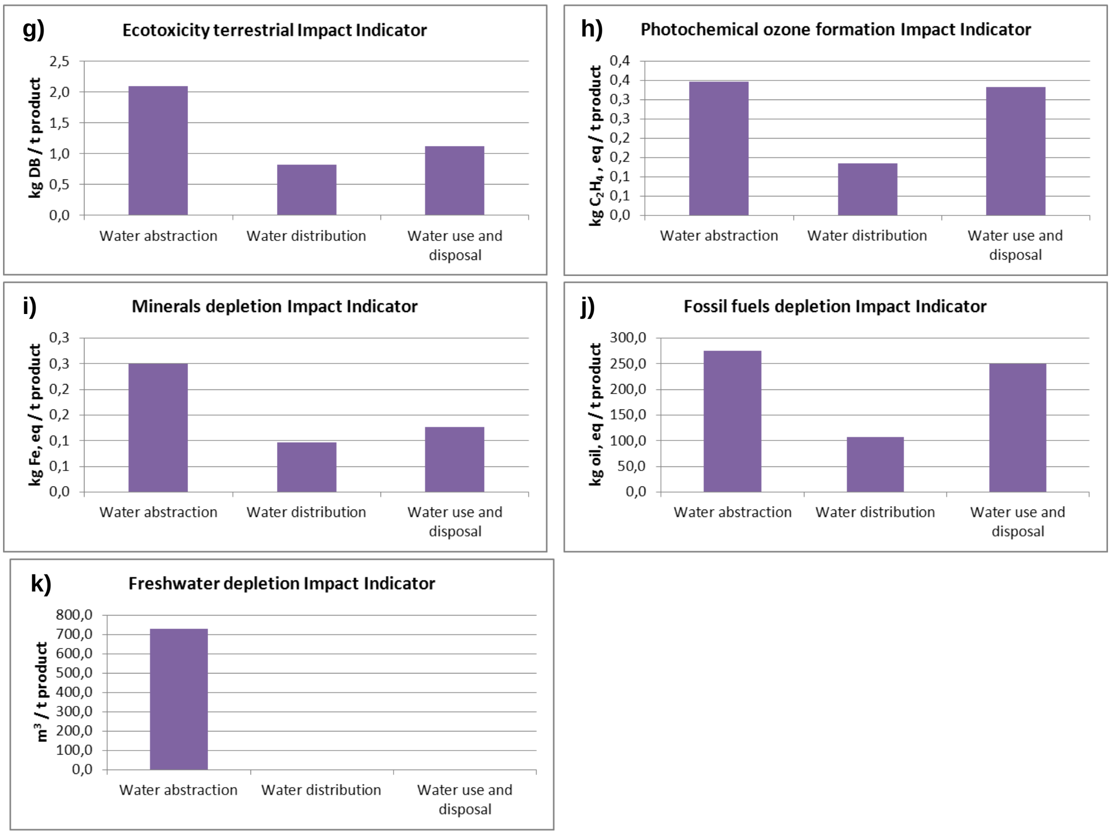


Figure 20. Environmental impact indicators per stage.

Through Figure 20 it is possible to verify that the most critical stages are the water abstraction and water use and disposal, which is justified mainly due to the high energy consumption and N and P fertilizers use.

In the graphs b) and f), the major contributor is the water use and disposal stage: in graph b) – eutrophication impact indicator – it is directly related with the high contribution of the N and P fertilizers (foreground systems) and in graph f) – freshwater aquatic ecotoxicity impact indicator – the background processes are the main responsible, more specifically the nitrogen and phosphorus fertilizer production.

2.4 Value Assessment

Applying the Economic Value Chain Analysis Tool to the Monte Novo case study value chain, the financial data per actor presented in Table 37 and Figure 21 was obtained.

Table 37. Financial summary per actor.

Actor	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
EDIA	801,934	0	330,611	-471,323
AB Monte Novo	302,161	0	242,805	-59,356
Farmers	2,582,255	9,395,490	-573,416	6,239,819
Total Value Added				5,709,140

The Total Value Added (TVA), to the product from the water use, is the sum of the net economic output of the actors, which is equal to 5,709,140 €.

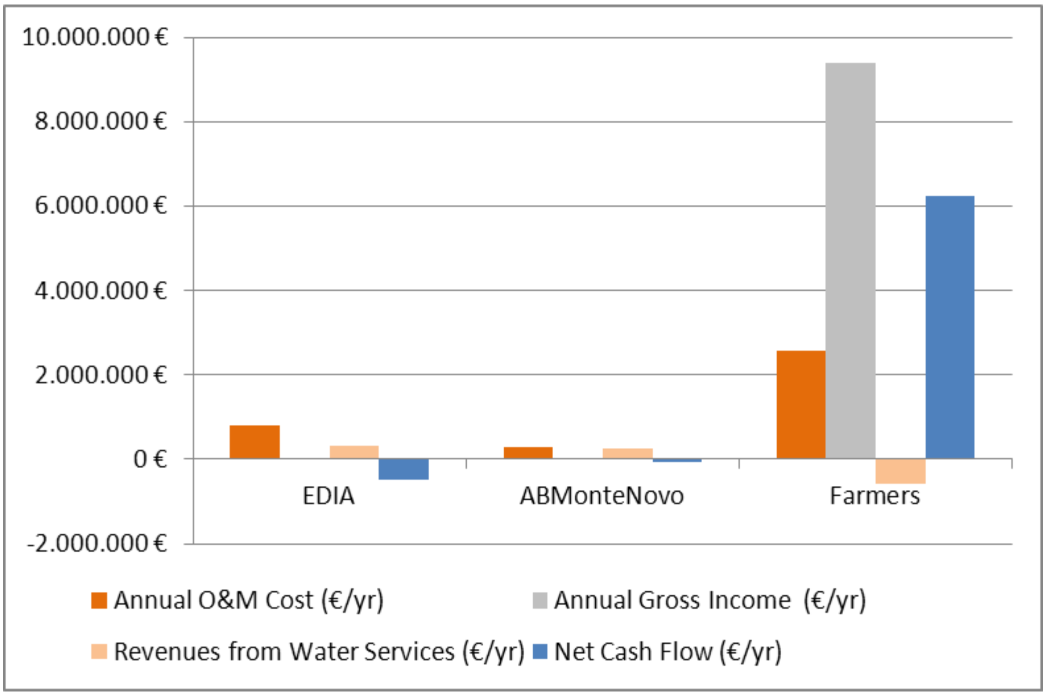


Figure 21. Economic performance per actor.

2.5 Eco-Efficiency Quantification

The Eco-Efficiency Indicators are defined as the ratio of the economic performance to the environmental performance of the system. Table 38 presents the eco-efficiency indicators, corresponding to the 11 relevant environmental impact categories.

Table 38. Eco-efficiency indicators.

Category impact	Unit	Eco-eficiency assessment
Climate change	€/tnCO_2, eq	476.6
Eutrophication	€/kgPO_4^{3-}, eq	60.0
Acidification	€/kgSO_2^{-}, eq	56.0
Human toxicity	€/tnDB	4,310.5
Resp inorganics	€/kgPM_{10}, eq	365.8
Freshwater aquatic ecotoxicity	€/kg DB	27,802.9
Terrestrial ecotoxicity	€/ kg DB	273.4
Photochemical ozone formation	€/kgC_2H_4, eq	1,330.1
Minerals depletion	€/kg Fe, eq	2,337.2
Fossil fuels depletion	€/tn oil, eq	1,720.3
Freshwater depletion	€/m^3	1.5

2.6 Conclusions

An upgrading of the water value chain should focus on the improvement of these eco-efficiency indicators, directly related with the non-renewable sources consumption: e.g. freshwater; and the chemicals use (such as the fertilizers components). These contributors increase the environmental impacts associated with agriculture (e.g. freshwater depletion, eutrophication, acidification, etc). The improvement of the Monte Novo environmental performance should focus on:

- Water supply chain technologies
- Production chain technologies
    - The adaptation of irrigation technologies that will reduce energy consumption on the agricultural use level and subsequently decreasing the “climate change” eco-efficiency indicator and the indicators related with the electricity production (human toxicity, terrestrial and freshwater ecotoxicity).
    - Cultivation of crop types/production methods with lower agrochemical needs, resulting to:
        - Reduction of the discharge of pollutants due to the use of fertilizers
        - Decrease of the “eutrophication” eco-efficiency indicator

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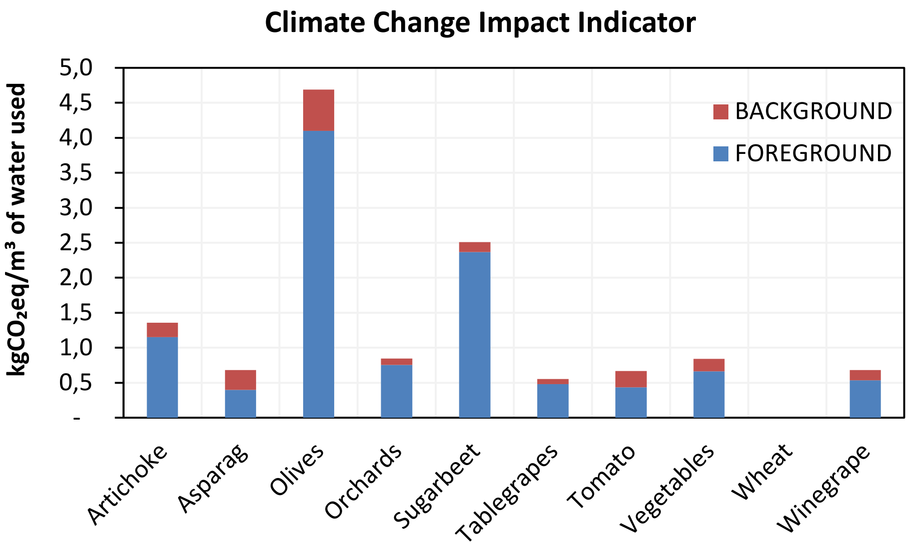
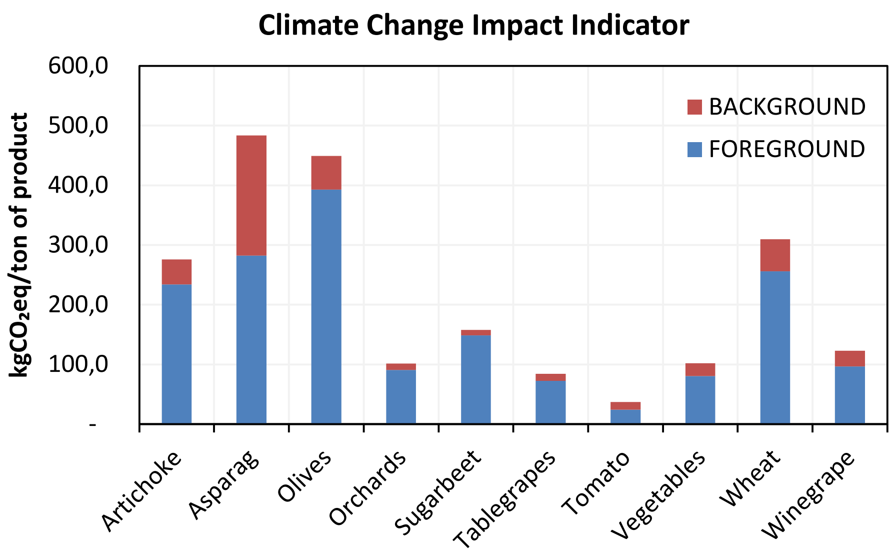
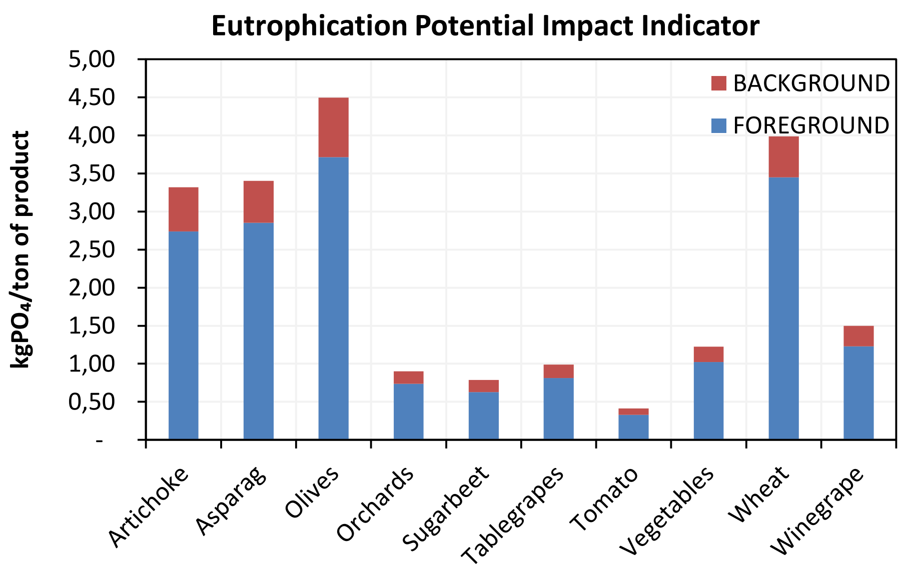
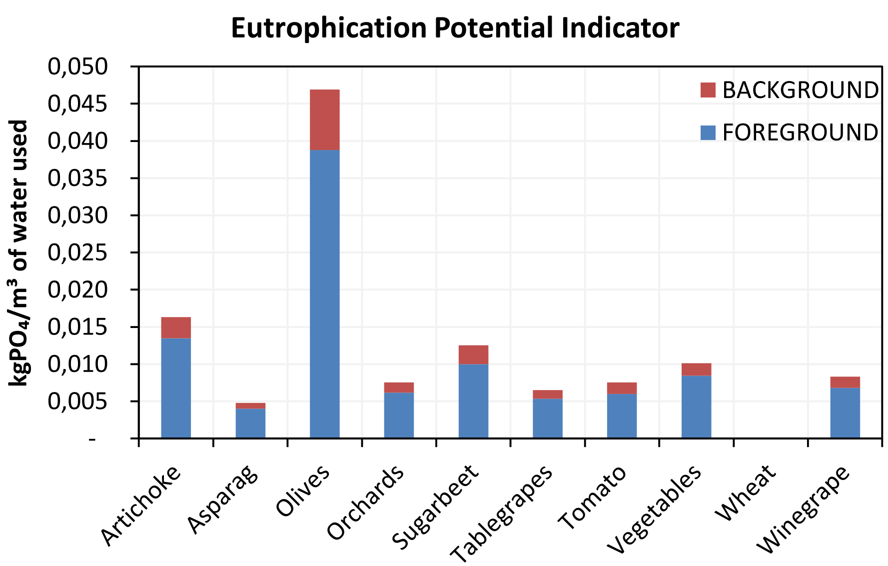
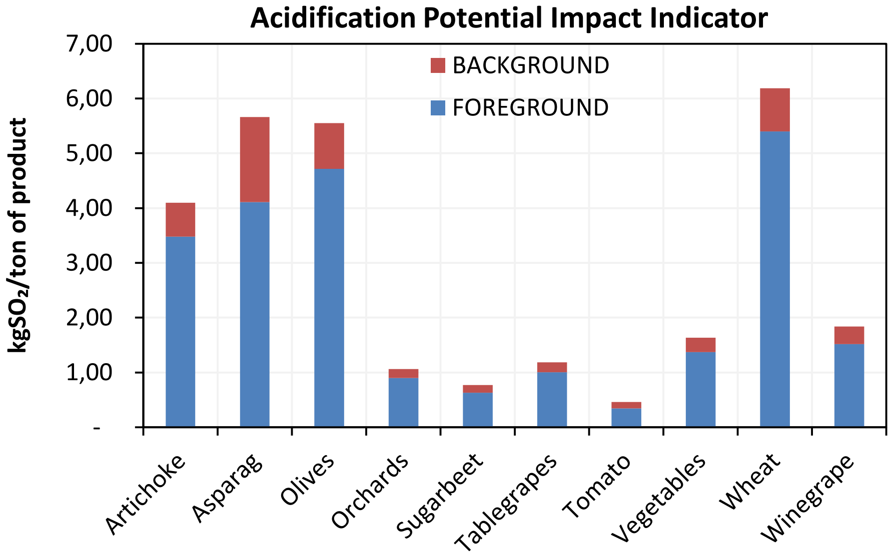
Annex A – The results of environmental impact indicators at cluster level for a normal hydrological year (Case Study #1)

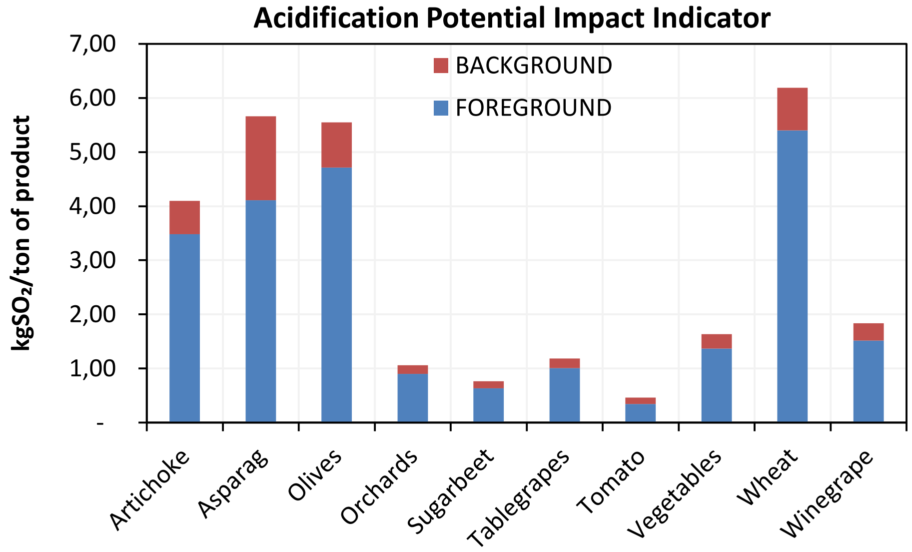


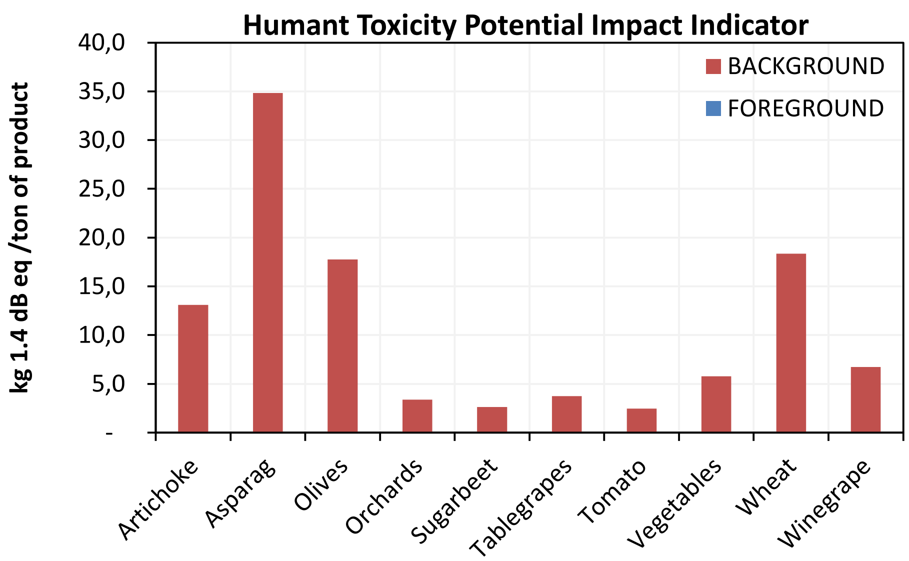


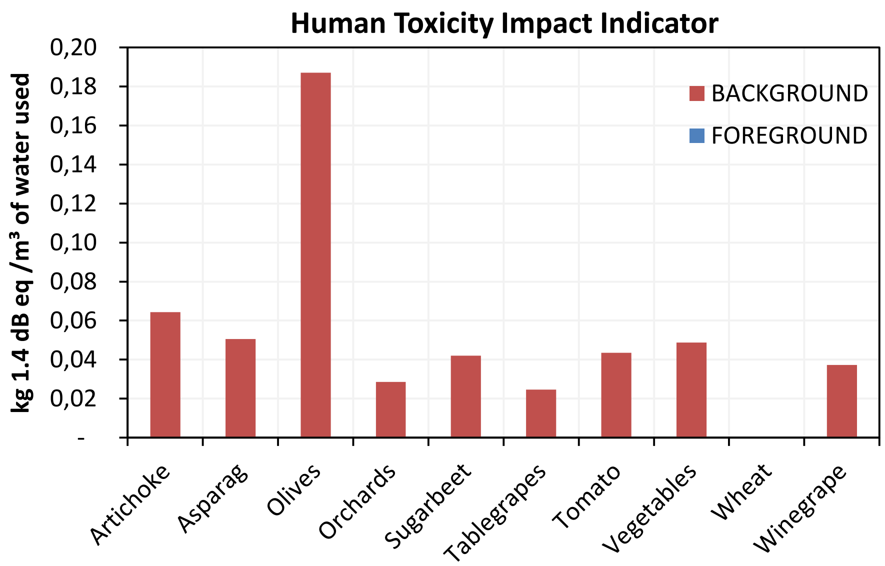


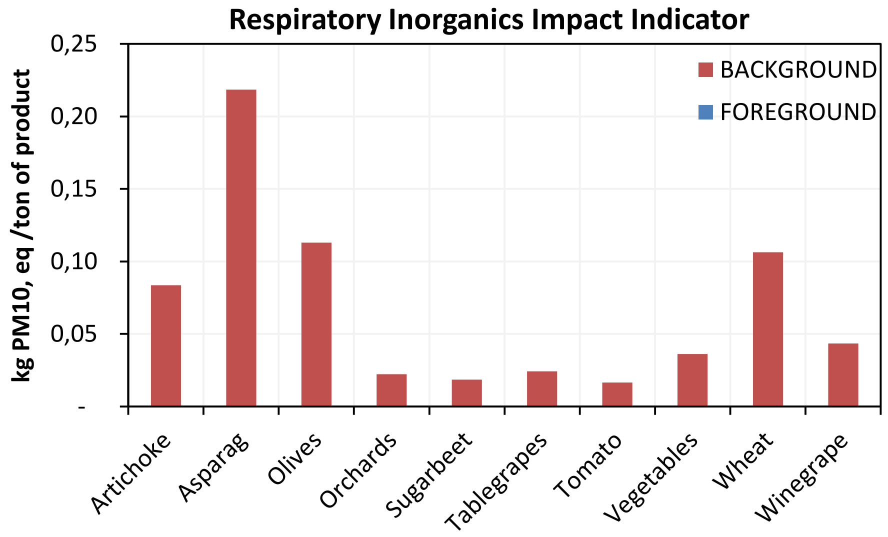


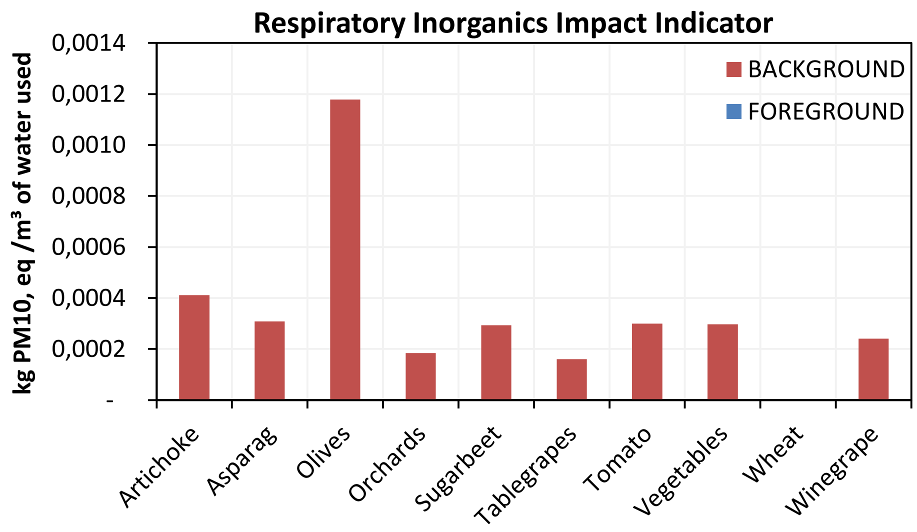

Acidification Potential Impact Indicator
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
kgSO₂/ton of product
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

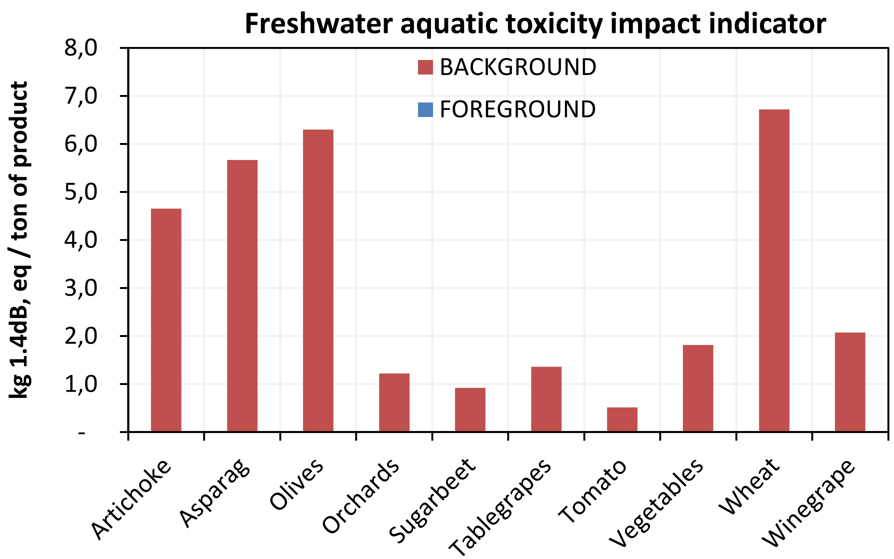

Acidification Potential Impact Indicator
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
kgSO₂/ton of product
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

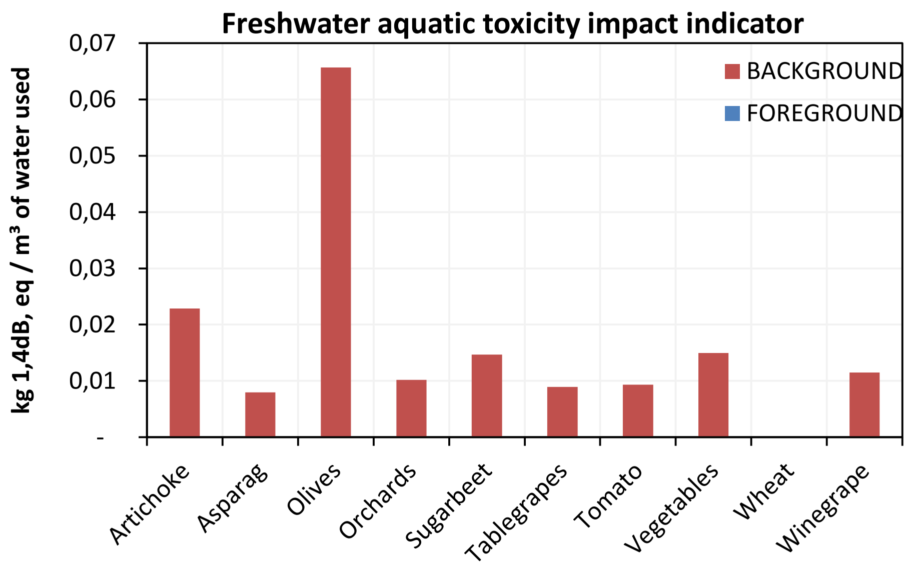

Humant Toxicity Potential Impact Indicator
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
-
kg 1.4 dB eq /ton of product
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

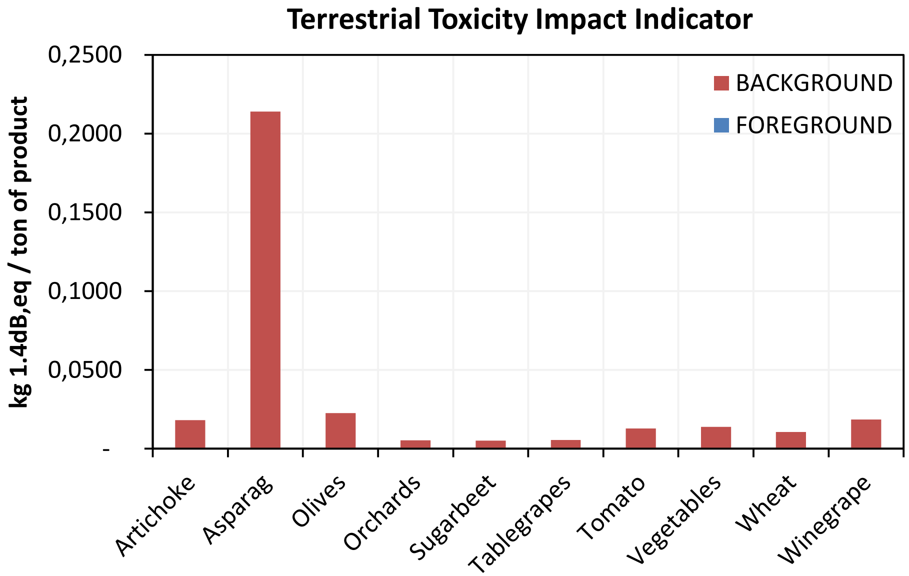

Human Toxicity Impact Indicator
0,20
0,18
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02
-
kg 1.4 dB eq /m³ of water used
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape


Respiratory Inorganics Impact Indicator
kg PM10, eq /ton of product
0,25
0,20
0,15
0,10
0,05
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

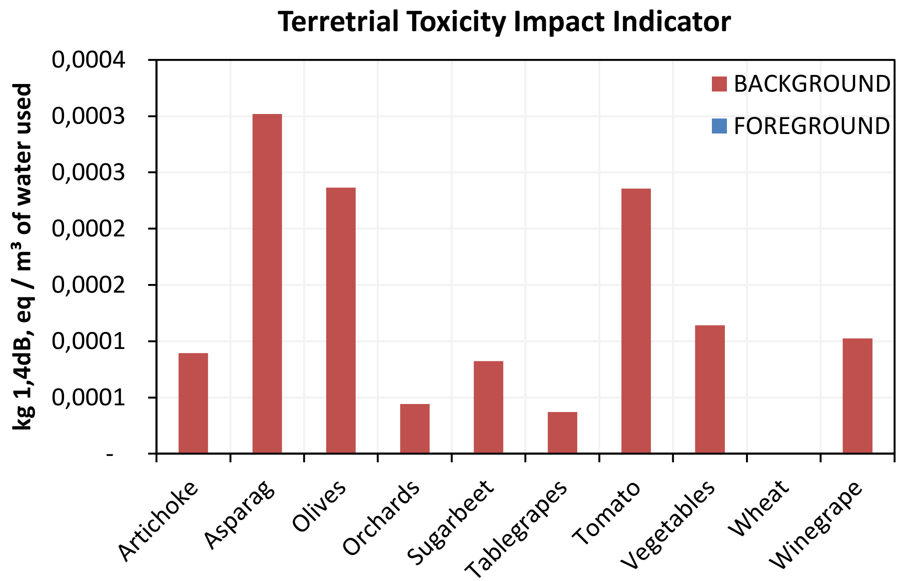

Respiratory Inorganics Impact Indicator
kg PM10, eq /m³ of water used
0,0014
0,0012
0,0010
0,0008
0,0006
0,0004
0,0002
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape


Freshwater aquatic toxicity impact indicator
kg 1.4dB, eq / ton of product
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

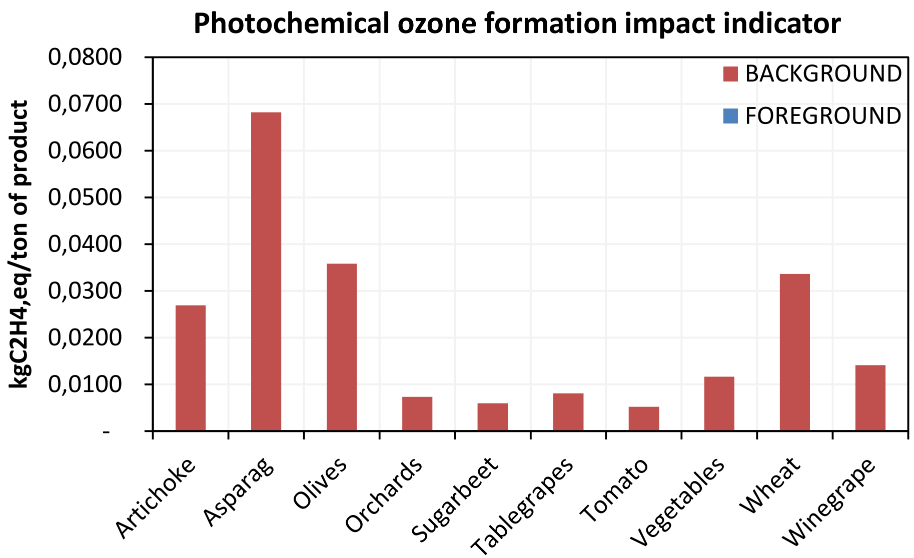

Freshwater aquatic toxicity impact indicator
kg 1,4dB, eq / m³ of water used
0,07
0,06
0,05
0,04
0,03
0,02
0,01
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape



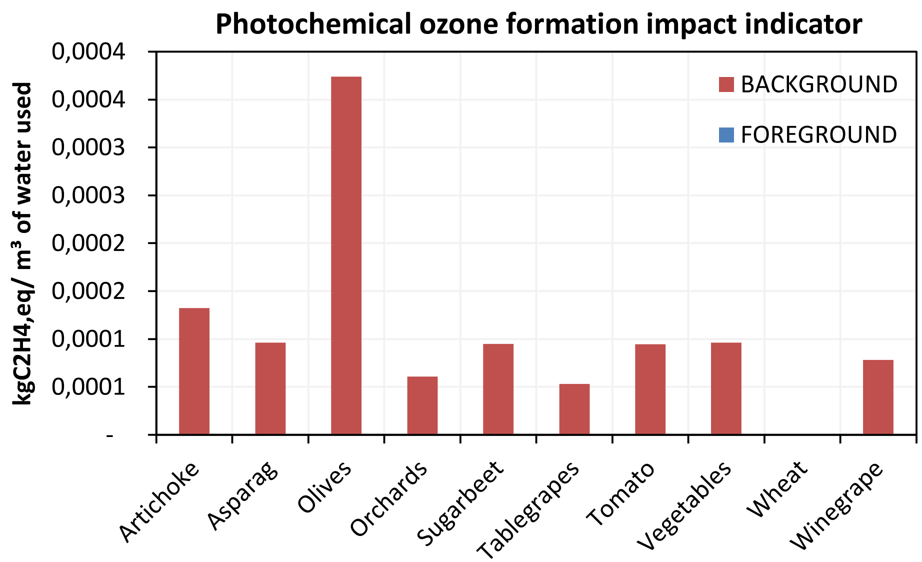
Terrestrial Toxicity Impact Indicator
kg 1.4dB,eq / ton of product
0,2500
0,2000
0,1500
0,1000
0,0500
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape



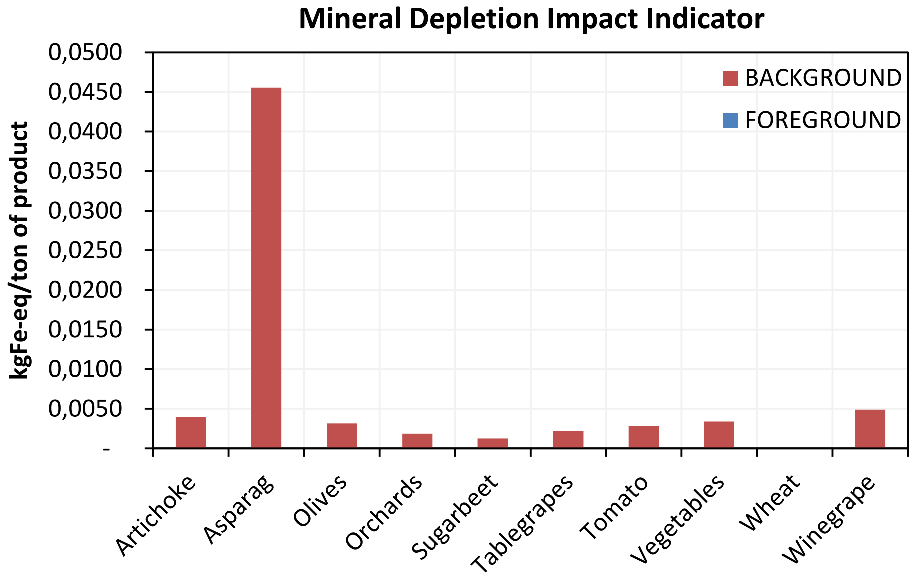
Terretrial Toxicity Impact Indicator
kg 1,4dB, eq / m³ of water used
0,0004
0,0003
0,0003
0,0002
0,0002
0,0001
0,0001
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

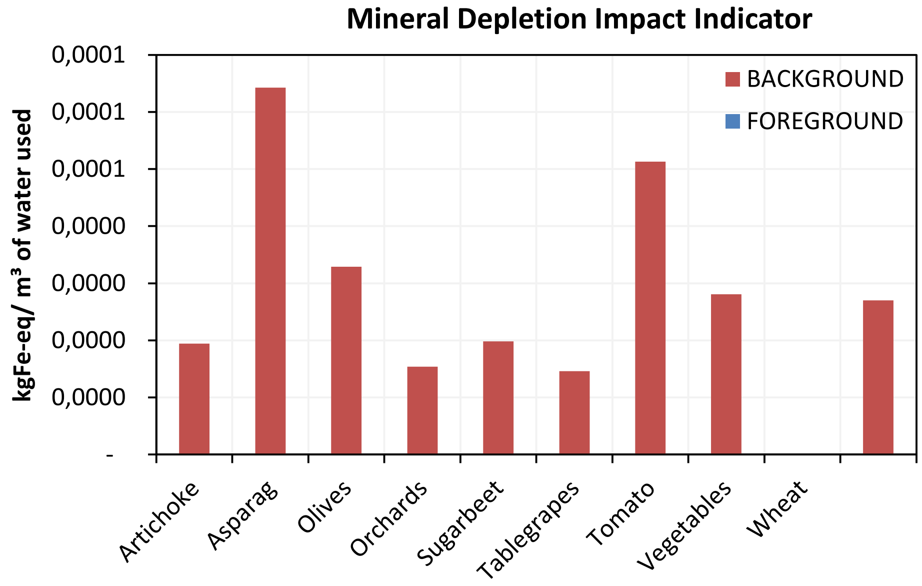


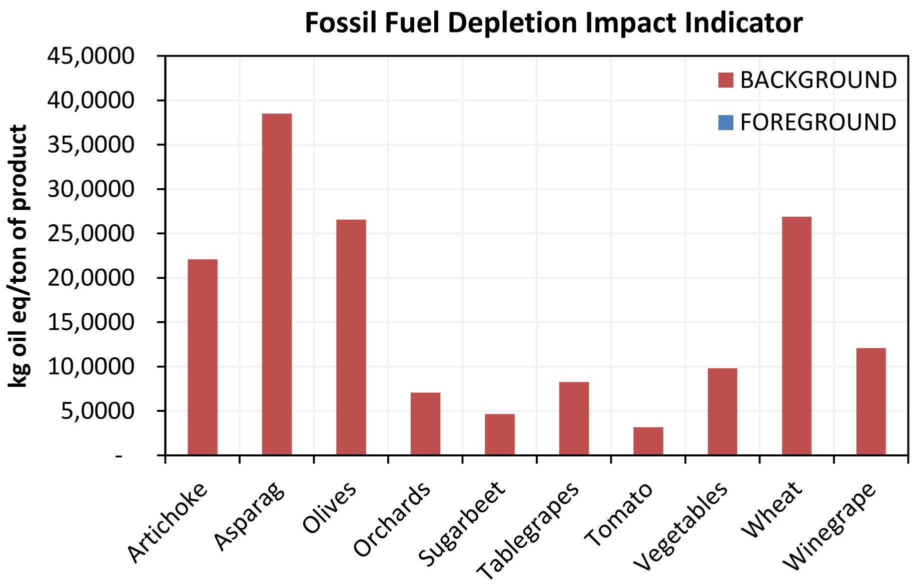
Photochemical ozone formation impact indicator
kgC2H4,eq/ton of product
0,0800
0,0700
0,0600
0,0500
0,0400
0,0300
0,0200
0,0100
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape

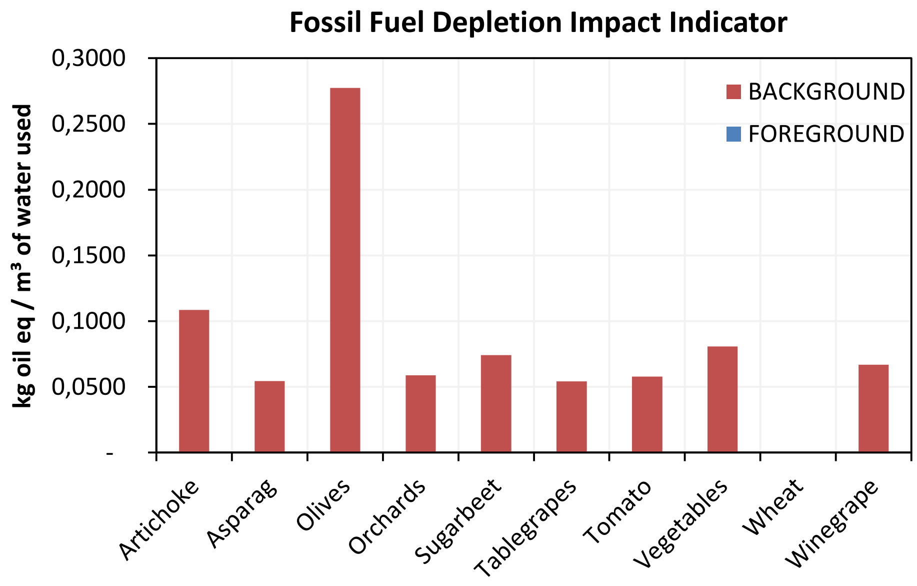


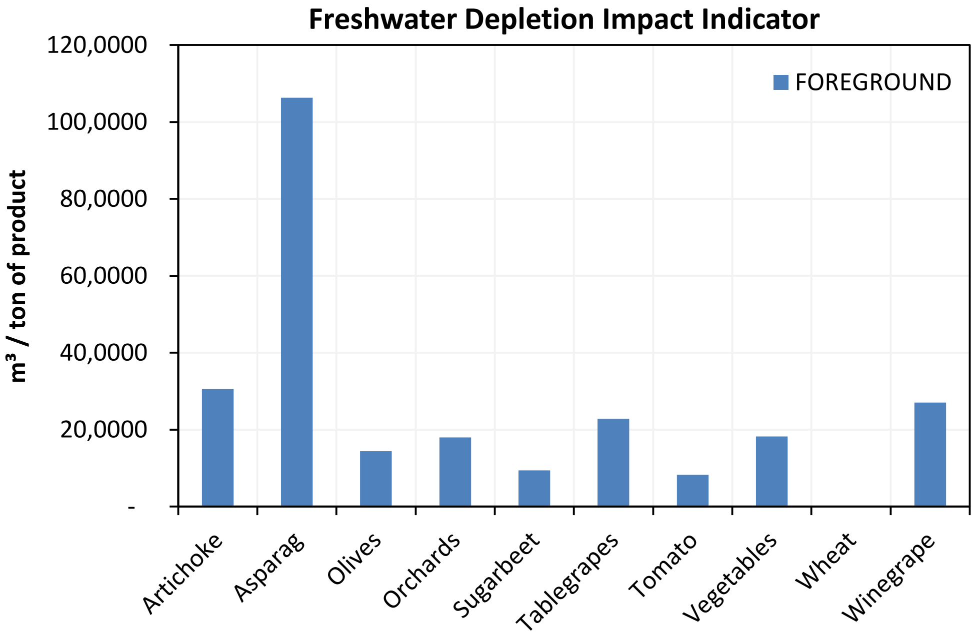
Photochemical ozone formation impact indicator
kgC2H4,eq/ m³ of water used
0,0004
0,0004
0,0003
0,0003
0,0002
0,0002
0,0001
0,0001
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape


Mineral Depletion Impact Indicator
kgFe-eq/ton of product
0,0500
0,0450
0,0400
0,0350
0,0300
0,0250
0,0200
0,0150
0,0100
0,0050
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape


Mineral Depletion Impact Indicator
kgFe-eq/ m³ of water used
0,0001
0,0001
0,0001
0,0000
0,0000
0,0000
0,0000
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat


Fossil Fuel Depletion Impact Indicator
kg oil eq/ton of product
45,0000
40,0000
35,0000
30,0000
25,0000
20,0000
15,0000
10,0000
5,0000
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape


Fossil Fuel Depletion Impact Indicator
kg oil eq / m³ of water used
0,3000
0,2500
0,2000
0,1500
0,1000
0,0500
-
BACKGROUND
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape



Freshwater Depletion Impact Indicator
120,0000
100,0000
80,0000
60,0000
40,0000
20,0000
-
m³ / ton of product
FOREGROUND
Artichoke
Asparag
Olives
Orchards
Sugarbeet
Tablegrapes
Tomato
Vegetables
Wheat
Winegrape