HYDROUSA

H2020-CIRC-2-2017

Water in the context of circular economy

Full project title:

Demonstration of water loops with innovative regenerative business models for the Mediterranean region

Deliverable: D36

Relative Number in WP D6.1

Functional and Economic indicators

Due date of deliverable: 30th June 2023

Actual submission date: 30th June 2023

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

DOCUMENT INFORMATION

Deliverable	**Number**	D6.1	**Title:**	Functional & Economic indicators
Work Package	**Number**	WP6	**Title:**	Evaluation of HYDROUSA demonstration systems and services

Due date of deliverable	**Contractual**	M60	**Actual**	M60	
Version number	1.3				
Format	MS Office Word document				
Creation date	10th of June 2023				
Version date	30th of June 2023				
Type	☐ R	☐ DEM	☐ DEC	☒ OTHER	☐ ETHICS
Dissemination Level	☒ PU Public		☐ CO Confidential		
Rights	Copyright "HYDROUSA Consortium". During the drafting process, access is generally limited to the HYDROUSA Partners.				

Responsible authors	**Name:**	Evina KATSOU Eliza NIKA George TSALIDIS Matia GHAFOURIAN Josh KASSONGO Emmanuel AMOAH	**E-mail:**	evina.katsou@brunel.ac.uk elisa.nika2@brunel.ac.uk george.tsalidis@brunel.ac.uk matia.ghafourian@brunel.ac.uk josh.kassongo@brunel.ac.uk emmanuelyawadjepong.amoah@brunel.ac.uk
	Partner:	UBRUN	**Phone:**	

Brief Description	This deliverable presents the Economic and Environmental Assessment of the HYDROUSA case studies (HYDRO1&2, HYDRO3, HYDRO4, HYDRO5 and HYDRO6) with specific emphasis on the functional, environmental and economic indicators used to assess the systems. It presents the vision of the project, the proposed solutions (HYDROsystems), the developed economic and environmental models and indicators, and the analysis of the assessment results. The analysis of the assessment focuses on the production yields and efficiency of the processes, the costs, revenues and savings of the systems, and the potential environmental impacts of the whole lifecycle of the systems. The results of this deliverable are used in D6.3 to complement the circularity evaluation of the systems. This deliverable acts as a suitable guide for the partners to understand the economic and environmental impacts of their solutions, as well as to provide input to the European debate on the economic and environmental sustainability of circular water systems.
Keywords	Environmental life cycle assessment; Life cycle cost-benefit; Global warming; Eutrophication; wastewater; agriculture

Version log			
Rev. No.	**Issue Date**	**Modified by**	**Comments**
1.0	30th May 2023	George Tsalidis, Matia Ghafourian, Josh Kassongo	First draft
1.1	17th June 2023	Eliza Nika, George Tsalidis	Editing and revision
1.2	24th June 2023	Eric Mino (SEMIDE)	Internal review
1.3	30th June 2023	Eliza Nika, George Tsalidis, Matia Ghafourian	Editing and revision

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

HYDROUSA aims to provide innovative solutions for decentralized water scarce areas in terms of water/wastewater treatment and management, which will close the water loops and will boost agricultural and energy profile in Mediterranean and other water-scarce regions in Europe and worldwide. HYDROUSA consists of six case study projects (namely HYDROs), consisting of different configurations of technology units to treat water and harvest water of different sources:

- Urban wastewater treatment, energy recovery and fruits cultivation in Lesvos Island. (Case studies HYDRO1&2).
- Essential oil production in Mykonos Island (Case studies HYDRO3&4).
- Salt and water production for exotic fruits cultivation in Tinos Island (Case study HYDRO5).
- Urban wastewater treatment and food production in Tinos Island (Case study HYDRO6).

The multi-faceted objective of the case studies was to operate a nature-based system to treat urban wastewater and produce food (CS 1&2 and CS6); together with a nature-inspired system to reduce the consumption of freshwater resources, produce high-value products (CS 3&4), and food (CS5).

The deliverable is structured into six chapters:

1. Chapter 1 (HYDROUSA project) introduces the vision of the project.
2. Chapter 2 (the HYDROs) briefly describes each HYDRO.
3. Chapter 3 (methodology) introduces and describes the applied methods to assess the economic and environmental performance.
4. Chapter 4 (application of methods) describes how the Life cycle assessment and Life cycle cost- benefit are applied to the HYDROUSA project.
5. Chapter 5 (the results) presents and analyses the economic and environmental impact assessment results of each HYDRO under the current conditions.
6. Chapter 6 (the conclusions) summarises the main points of the previous chapters as a take-home message.

The developed water/wastewater treatment and recovery systems (HYDRO case studies) involve combining existing water treatment technologies and innovative units developed within the project. The current document summarises the key aspects related to environmental and economic assessments of all the HYDRO case studies with environmental life cycle assessment (LCA) and life cycle costing (LCC), respectively. In LCC, three indicators of Net present value (NPV), Internal rate of return (IRR), and paybak period (PP) are calculated and analysed. A project can be considered feasible if it exhibits a positive NPV, an IRR exceeding the Market (government) rate of return, and a payback period within an acceptable timeframe (lifespan of project). These indicators collectively provide insights into the project's profitability, return on investment, and ability to recover the initial investment.

The assessment of HYDRO1&2 shows that wastewater treatment was successful, energy is recovered in the form of biogas for electricity generation or vehicle-grade biomethane, and fruits are cultivated with the recovered water from the wastewater treatment stage. In general, the HYDRO1&2 system performs better environmentally than the baseline system which provides the same functions. The economic evaluation shows that HYDRO1&2 is highly economically viable. All scenarios of HYDRO1&2 exhibited a positive net present value and acceptable payback period; thus, they were found feasible. One scenario that involved selling treated wastewater and utilizing irrigation water savings, projected to generate substantial revenues.

The assessment of HYDRO3&4 shows that cultivation in a water scarce island and production of residential water and essential oils was successful and provides environmental benefits when compared with baseline systems that produce non-potable water and the same high-value products but use groundwater, respectively. Rainwater was harvested to cater fully for the non-potable water needs of local residences; thus, alleviating further environmental pressures exerted on the centralized water plant for the supply of water for non-potable use. In terms of economic analysis, HYDRO3 is not currently more profitable than the baseline scenario due to the low farm yield. However, from 2023 the profitability of HYDRO3 will be greater than baseline due to the expected increase in oregano yield. The same is expected with HYDRO4, in 2023 HYDRO4 becomes more profitable than baseline. Since both HYDRO3&4 will continue increasing the farm yields, revenues are expected to increase in the coming years. Therefore, from 2023 both HYDRO3&4 are considered feasible due to positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

The assessment of HYDRO5 shows that the production of salt, freshwater and exotic fruits is possible on a water scarce island, but it does not provide environmental benefits due to industrial salt production. In contrast, the production of freshwater and exotic fruits does produce environmental benefits, thus, these functions should be included in future discussions on investing on the HYDRO5 experience. The economic assessment shows that HYDRO5 is considered feasible based on a positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

The assessment of HYDRO6 shows that wastewater treatment was successful, and water was harvested and recovered to be used for internal use at the Eco-Lodges (such as toilet flushing) or in food production that was consumed by the Eco-Lodge in HYDRO6, and compost production, respectively. The HYDRO6 system resulted in environmental benefits regarding the operation of the Eco-Lodge. The economic assessment shows that HYDRO6 is considered feasible based on a positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

A summary of the LCA analysis of the six case studies compared to the baseline cases, is shown in Figure ES1. Figure ES1 compares two of the most relevant impact categories: global warming (i.e., carbon footprint) and water consumption. It shows that the global warming and global warming impacts of the HYDROUSA systems (orange bars) are lower than the baseline system in all cases, except for HYDRO5. They are lower due to the harvesting and employment of rainwater, and cultivation of fruits and plants with organic practices, and in HYDRO1&2 and HYDRO3 result in negative values due to water replacement resulting in credits and CO_2 sequestration during the plant growth, respectively.

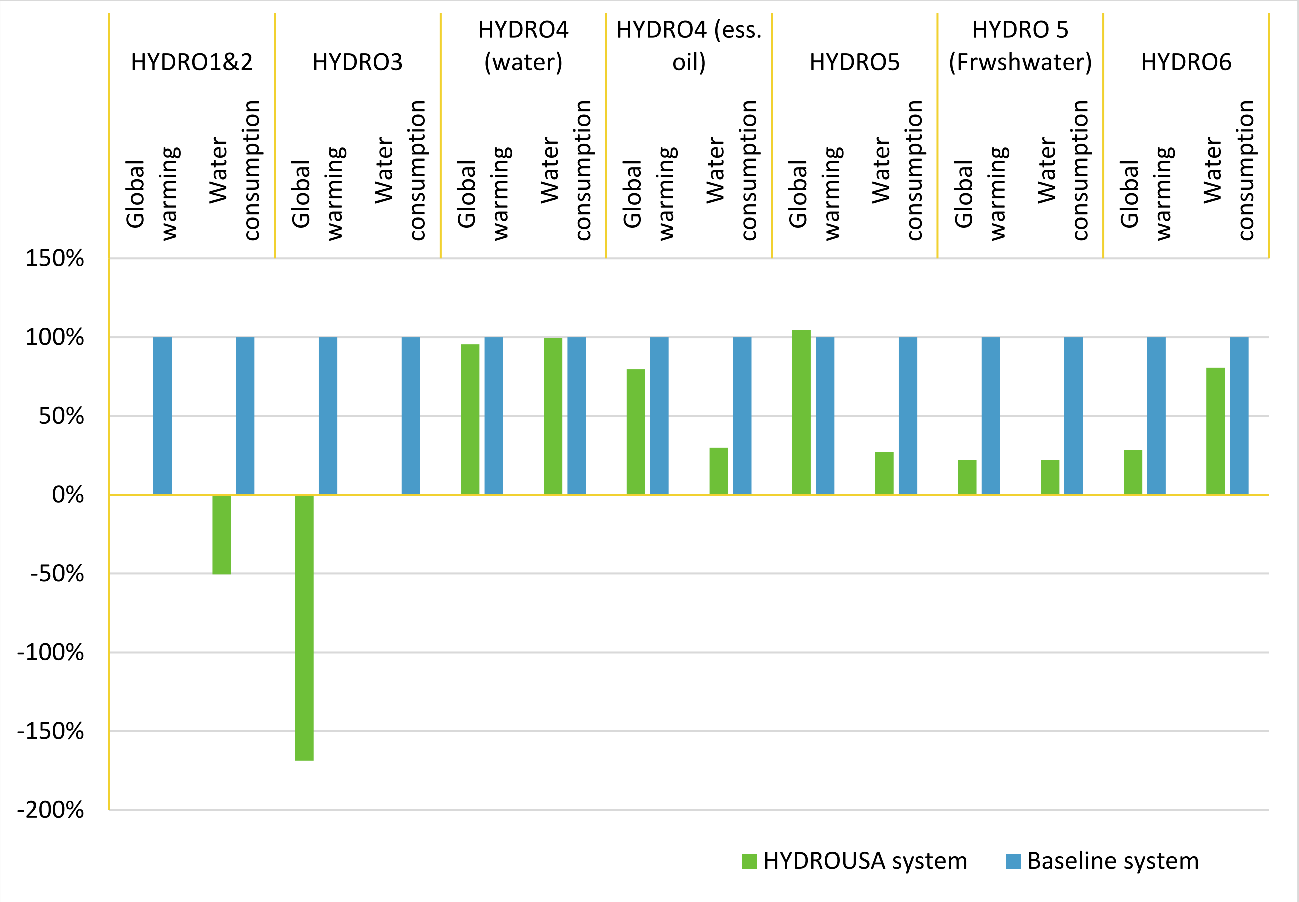


Figure ES1: Normalised percentage comparison of HYDROUSA systems with Baseline systems for the six case studies; only HYDRO4 is separated in two sub-systems

However, the benefits of lower global warming and water consumption need to be considered alongside the economic impacts. Table ES1 summaries the environmental and economic results for the six case studies. All six cases studies were considered feasible.

Table ES1: Relative expected change in environmental performance of HYDROUSA systems compared to baseline, and net present value based on the economic assessment of HYDROUSA systems. Green and red shading signify a reduction in impact or economic benefits, and increase in impact, respectively.

	Environmental (LCA)		**Economic (LCC)**
	Global warming	Water consumption	Net present value
HYDRO1&2	99.5%	-51%	654,095
HYDRO3	-169%	99.2	14,997
HYDRO4 (water)	95%	99%	-
HYDRO4 (essential oil)	80%	30%	-28,768
HYDRO5	105%	27%	25,635
HYDRO5 (only freshwater)	22%	22%	-
HYDRO6	28%	81%	576,156

It should be noted that D6.1 “Economic and Environmental Assessment – Functional, Environmental & Economic indicators” and D6.3 “Circularity Assessment using physical and virtual nexus models” are complementary deliverables for the assessment of the HYDROs and both act as a guide to assess the circularity and sustainability benefits and hotspots which remain and require further optimization. D6.1 presents in detail the environmental and economic impacts and benefits of each HYDRO. D6.3 uses some results of D6.1 (i.e., carbon footprint and a few economic indicators) but focuses more on circularity achievements and hotspots of the HYDROs.

In conclusion, the HYDROUSA systems provide environmental benefits, except for HYDRO5, and all are considered feasible. In particular, it is expected that the HYDRO3&4 cases where essential oils are produced will improve their environmental footprint and feasibility the coming years due to the increasing farm yield.

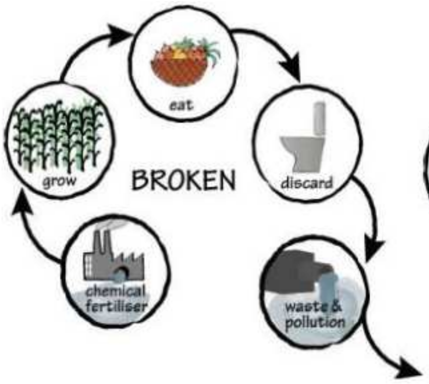
HYDROUSA has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 776643.

ABBREVIATIONS

AGF	**Agroforestry**
CBA	**Cost-Benefit Analysis**
CE	**Circular economy**
CS	**Case study**
CWS	**Circular water system**
CW	**Constructed wetland**
GWP	**Global warming potential**
HRWG	**Hybrid Rain-waste – grey water**
IRR	**Internal Rate of Return**
MWS	**Main water system**
NBWS	**Nature-based water system**
NPV	**Net Present Value**
LCA	**Life cycle assessment**
LCB	**Life cycle benefit**
LCC	**Life cycle costing**
LCCB	**Life cycle cost benefit**
LCIA	**Life cycle impact assessment**
LCI	**Life cycle inventory**
O&M	**Operation and maintenance**
PP	**Payback Period**
RWH	**Rainwater harvesting**
RM	**Ratio method**
SDRB	**Sludge drying reed beds**
SLCCB	**Shadow pricing- Life cycle cost-benefit**
UASB	**Upflow anaerobic sludge blanket**
UF	**Ultrafiltration (Membrane)**
UV	**Ultraviolet**
WWTP	**Wastewater treatment plant**

1. HYDROUSA: INNOVATIVE, REGENERATIVE AND CIRCULAR WATER SOLUTIONS

Globally, water resources have been facing considerable challenges due to water availability and management, climate change impacts and the deterioration of natural ecosystems. One way to manage water sustainably is to close water loops, especially in regions with scarce water resources such as the Mediterranean region. The approach of closing water loops is proposed by HYDROUSA project, an EU-funded project under Horizon 2020 program, which is developing new circular business models suitable for the Mediterranean region as well as other water-scarce regions in Europe and worldwide. Unlike the traditional way of managing water in broken loops, HYDROUSA's closed loops are managing water sustainably, while creating additional products and ecosystem services leading to a win-win-win situation for the economy, the environment, and the community (Figure 1.1).



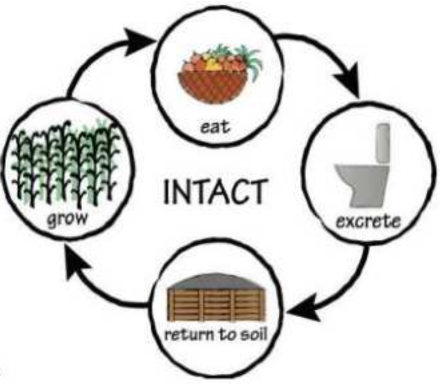


Figure 1.1 Differences between a broken and intact water loops

HYDROUSA goes beyond the current water and wastewater management practices by adopting innovative, nature-based and nature-inspired water management solutions for different types of non-conventional water characterized by low energy footprint via closing the water loops and boosting their agricultural and energy profiles (Figure 1.2). By closing water loops, the whole water value chain is transformed from a disruptive approach to an integrated one; turning the challenges faced by the water sector into opportunities.

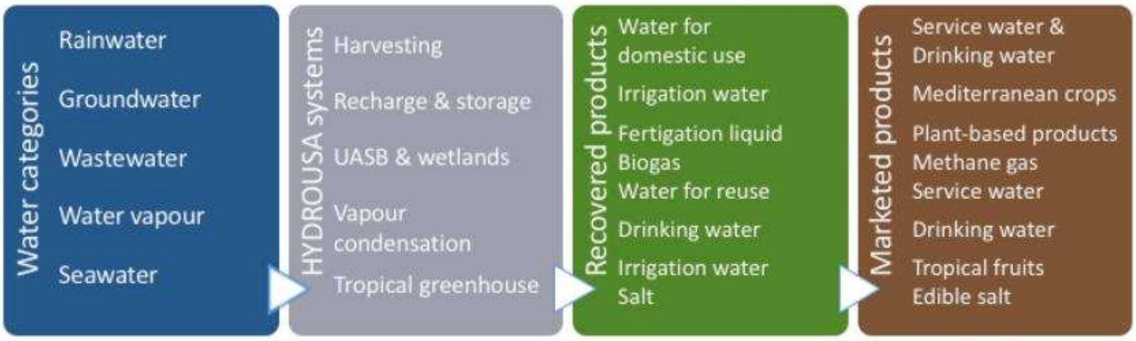


Figure 1.2 HYDROUSA: water categories and related systems and products

HYDROUSA aims to create a community of 'water allies' which believes and works on shifting the development paradigm of our world from an open market society based on economic profits to a world where local communities are empowered to develop tailor-made solutions to improve their well-being, while regenerating the local environmental ecosystems. This gives the opportunity to local operators to develop economic, social and environmental services based on closed water loops where decentralized, low-tech systems are favoured.

HYDROUSA solutions provide several services and integrated technologies which are based on traditional handcraft and ancient methods combined with modern nature-based solutions (NBS); information and communication technologies (ICT) connection; and automation systems. The proposed solutions show a perfect combination of building green infrastructures to make use of the plant-bearing benefits and generating green growth within an existing and demanding market, while restoring ecosystems.

2. DESCRIPTION OF THE HYDROUSA CASE STUDIES

2.1. Description of HYDRO1&2

The demo site is adjacent to the wastewater treatment plant (WWTP) of Antissa, village on the island of Lesvos, Greece. Lesvos is in the northeast Aegean Sea and has a population of 86,436 (2011). It recently gained media attention due to a holding station for hundreds of asylum seekers arriving there regularly. Tourism is not developed as much as in other HYDROUSA case studies, while agricultural production is significant with olive oil production being the main source of income. HYDRO1&2 regards the recovery of resources from wastewater treatment (HYDRO1) with fertigation of an agroforestry system using the nutrient-rich reclaimed water (HYDRO2). The wastewater treatment system is designed to be applied in decentralized areas with high seasonal loads where resources are recovered from wastewater treatment, such as nutrient-rich water for fertigation, compost, and biogas. Fertigation water is used in agroforestry to grow trees, crops, and aromatic plants.

HYDRO1&2 (Figure 2.1) is based on an integrated solution of anaerobic treatment and sludge composting, wetland water purification, water reuse and biogas production, and fertigation of agroforestry system. The concept of agroforestry is particularly suitable to further enrich agricultural production with high added value superfoods and herbs. The implementation of an upflow anaerobic sludge blanket (UASB) coupled with a constructed wetlands (CW) and fertigation of crops can result in a self-sustaining wastewater management system with significant economic benefits due to the coupled agroforestry system.

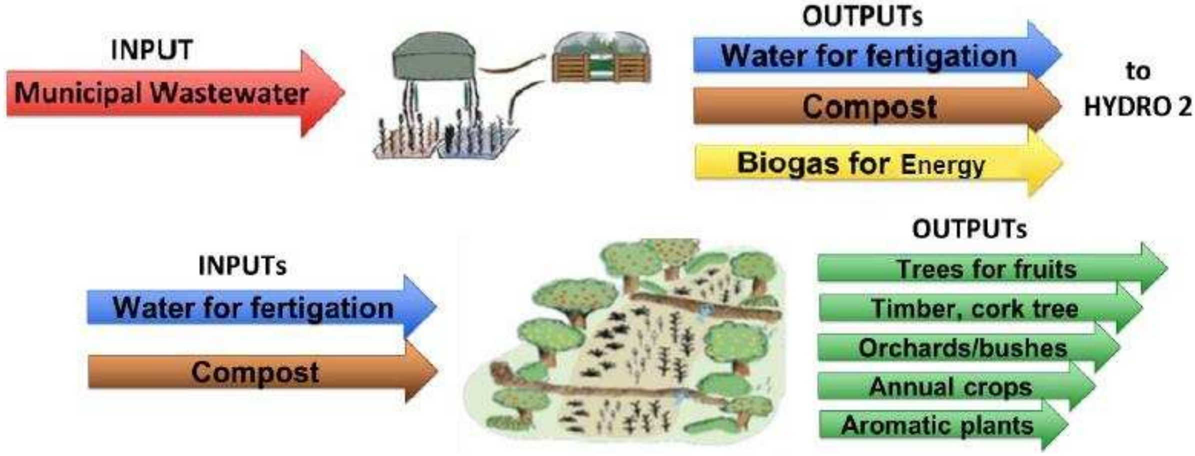


Figure 2.1 Simplified illustration of the HYDRO1&2 system

2.2. Description of HYDRO3

The HYDRO3 case study is in Mykonos Island, Greece, which is home to approx. 10,134 (2011) inhabitants. The island has a very dry climate with high summer temperatures (Travel Guide, 2014). Mykonos is a popular touristic destination, with approx. 2 million tourists during summer, which results in high water demands. Therefore, agricultural activities are under severe pressure. There are parts of the island where it is not allowed to build to preserve its natural beauty, but agricultural development is allowed. However, the price of water and even the unavailability of water are significant barriers to agricultural development. Therefore, HYDRO3 regards rainwater harvesting with the construction of a sub-surface rainwater collection and to build a precision irrigation system to optimize water consumption. The harvested water in HYDRO3 demo site is used to irrigate oregano plants and produce oregano essential oil on site (Figure 2.2). The cultivation of oregano was selected because it can grow on the island and requires low amounts of water. HYDRO3 is managed by a private, local, operator and aims to produce 150 kg/year of high value crops, i.e., fresh oregano, for essential oil production; irrigate a farm of 0.4 ha surface area; and collect 50 m^3/year (at least) of rainwater.

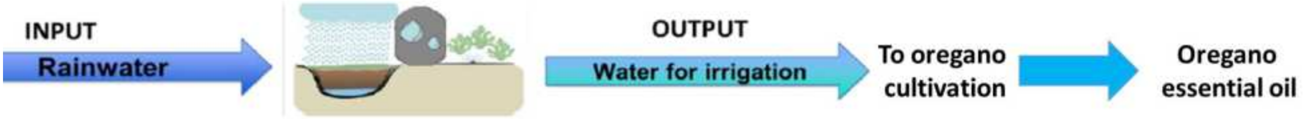


Figure 2.2 Simplified illustration of HYDRO3

2.3. Description of HYDRO4

The infrastructure of HYDRO4 is in the village of Ano Mera in Mykonos, Greece. The services of the interrelated sub-systems of HYDRO4 integrate similar functionalities to those of the HYDRO3 systems which are further expanded to artificial storage and recharge of the aquifer with harvested rainwater (Figure 2.3). It begins with rainwater which is collected from existing upgraded residential rooftops (438 m^2) that is fed back to the residences, through a network of pipes, to cater for the domestic non-potable water needs. This infrastructure includes a water storage tank (40 m^3) to store excess water during the winter months for reuse in the summer months, thus offering a decentralized solution to increase the water supply. Additionally, elsewhere on the site, stormwater is collected on built-up harvesting system and temporarily stored in tanks (70 m^3 and 20 m^3) for irrigation of a lavender field (0.2 ha) in the dry summer months. The excess rainwater collected is channeled to a subterranean reservoir for aquifer recharging and later retrieval. The lavender plant, renowned for its antimicrobial and antiseptic properties, is a perennial crop which is very suitable for dry Mediterranean climatic conditions. Following cultivation, the lavender flowering shoots will be pruned for subsequent extraction of valuable essential oils through a distillation process.

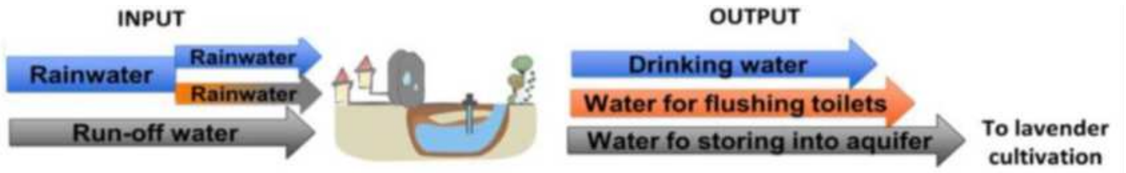


Figure 2.3 Simplified illustration of the HYDRO4 system

2.4. Description of HYDRO5

The HYDRO5 demo site is in Tinos Island, Greece and aims to produce table salt and tropical fruits. The island has a population of 8,636 (2011) and attracts tourists who mainly focus on pilgrimage. Furthermore, the municipality is making efforts to develop hiking and eco-tourism. Since Tinos Island is a point of attraction to tourists, the HYDROUSA project aims at providing added value to the island by introducing some exotic fruits which could each secure the status of geographical indication (viz. trademark); for instance, the "pineapple of Tinos". The agricultural demo site regards a conventional greenhouse which is located on the water desalination facilities (Figure 2.4). The greenhouse is adjacent to a mangrove-still desalination system which will provide irrigation water via desalination.

Figure 2.4 Simplified illustration of the HYDRO5 system

2.5 Description of HYDRO6

The HYDRO6 demo site (Figure 2.5) is in Tinos Island in Greece. It is within the facilities of the eco-tourist resort trading as “Tinos Ecolodge”. The demo site includes the treatment of the liquid part from wastewater after separation using reed beds and rainwater harvesting. Upon UV treatment of treated wastewater, reclaimed water is safely used to irrigate 0.15 ha of local crops that are consumed at the eco-agro-touristic facility and within the local economy (e.g., local restaurants). The eco-tourist resort “Tinos Ecolodge” along with the associated demo site are not connected to the national electricity grid; thus, all activities will be powered using renewable electricity generated by photovoltaics.

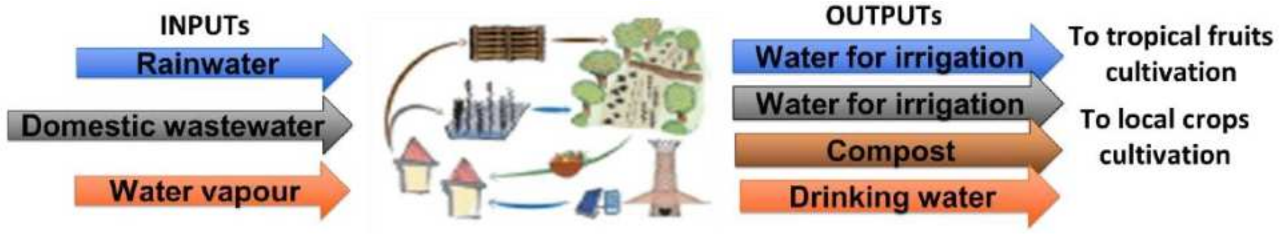


Figure 2.5 Simplified illustration of the HYDRO6 system

3. ECONOMIC & ENVIRONMENTAL IMPACT ASSESSMENT METHODS

3.1. Economic Impact Assessment Methods

To create a comprehensive economic assessment of the circular economy (CE) in a water system, *Internal* and *External* economic, social and environmental parameters are calculated. The challenge lies in translating external impacts including environmental, social and health to a monetary value, which requires a custom economic valuation method to be applied. The estimation of the "true" total cost and benefit needs to be considered to capture the overall performance of the transition to a circular water system (CWS) CWS. Therefore, in the proposed economic model, the shadow pricing method was employed to monetize the cost and benefit of environmental externalities to generate a holistic estimate of this transition.

A new and inclusive framework called Shadow pricing Life Cycle Cost-Benefit analysis (SLCCB) summarises the results of life cycle cost-benefit (LCCB) and cost-benefit analysis (CBA) as the sub-methodologies. The CBA has been used as the main evaluation method that financial agents use to assess the economic impacts throughout the whole life cycle of the project (Belli et al., 2001). Furthermore, to confirm the result from SLCCB, two indicators were estimated: 1) the payback period (PP) and 2) net present value (NPV). A project with a positive NPV and a PP less than the project's lifespan is feasible to be implemented. The flowchart in Figure 3.1 shows the integrated SLCCB framework.

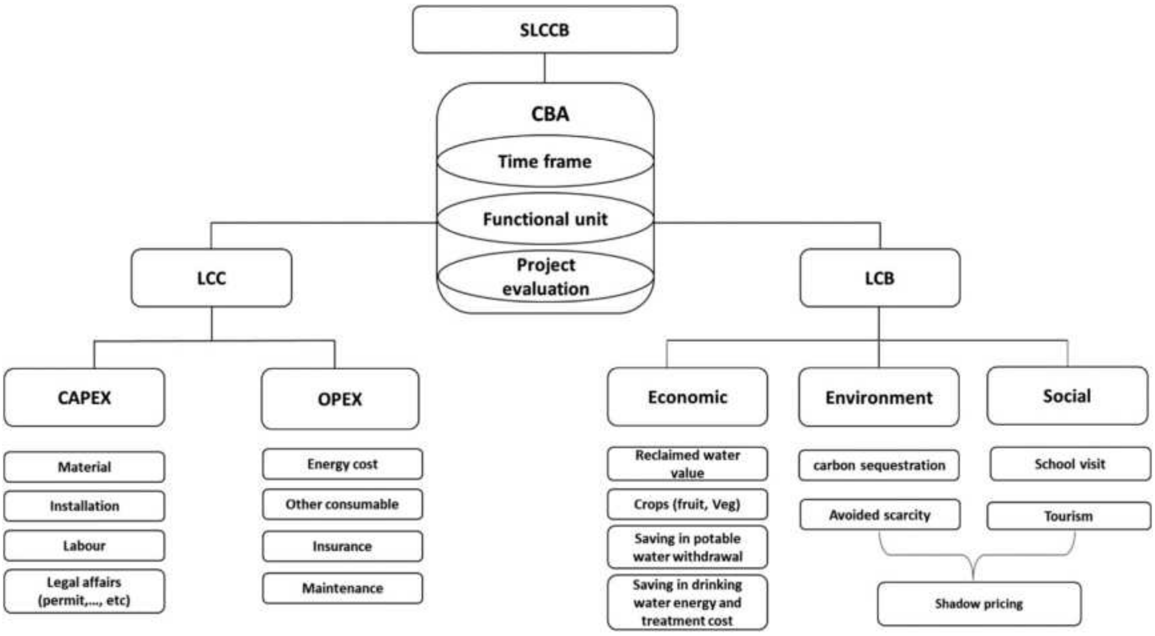


Figure 3.1 Integration of LCC, CBA and shadow pricing methods

According to Zhang et al. (2020) and Hoogmartens et al. (2014), the LCCB only includes real money flows in the life of the project; and the CBA considers a period (time frame) and functional unit of the project to evaluate it. Therefore, as shown in Figure 3.1, the integration of CBA, life cycle costing (LCC), life cycle benefit (LCB), and shadow pricing (S) methods is proposed to have a comprehensive economic assessment. The parameters and indicators in this model belong to two categories: i) the base-indicators, which are applicable for the analysis of majority of cases including NPV and PP; and ii) the case-indicators, which are case specific indicators.

3.2. Life cycle cost- benefit (LCCB)

Eq. (1) shows the SLCCB of Circular water system (CWS), excluding transportation and internal piping expenses. The currency is computed in Euro (€).

$$SLCCB_i = CX_i + \sum_{t=1}^{T} \frac{OMC_{i,t}}{(1+r)^t} - \sum_{t=1}^{T} \frac{(B_I + B_E)_{i,t}}{(1+r)^t} \tag{1}$$

Where $CX_i$is the initial capital cost (Euro); $OMC_{i,t}$ is the maintenance and operational costs (Euro) for t years after installing; T is the lifespan of the project, and r is the yearly discount rate (%);B_I is the internal benefit; B_E is the external benefit.

The internal/economic benefits included revenues from the market value of harvested or recycled water, agriculture products including organic products, vegetable and herbs, savings in energy of pumping drinking water, saving in chemical for water treatment, and fertiliser production out of waste. Eq. (2) shows the internal benefit calculation.

$$\begin{aligned} B_I = \sum_{t=0}^{T} & [(AVH_t * SPH_t) + (AVG_t * SPG_t) + (ACP_t * SPP_t) + (AVP_t * SPP_t) \\ & + (ACE_t * SPE_t) + (ACS_t * SPS_t) + (ACP_t * SPP_t) + (APF_t \\ & * SPF_t) \end{aligned} \tag{2}$$

where $\boldsymbol{B_I}$= internal benefit (€); $\boldsymbol{AVH_t}$= annual harvested rainwater volume (m^3); $\boldsymbol{SPH_t}$: market value of harvested rainwater (€/m^3); $\boldsymbol{AVG_t}$= annual reclaimed water volume (m^3); $\boldsymbol{SPG_t}$= market value of reclaimed greywater (€/m^3); $\boldsymbol{AVP_t}$= annual agriculture products amount or weight (kg); $\boldsymbol{SPP_t}$= market value of agriculture products (€/kg); $\boldsymbol{ACE_t}$= annual cost of pumping (energy-saved) (kWh); $\boldsymbol{SPE_t}$= market value of saved electricity (€/kWh); $\boldsymbol{ACS_t}$= annual chemical saving cost (m^3); $\boldsymbol{SPS_t}$= market value of saved chemical; $\boldsymbol{ACP_t}$= annual volume of saved potable water (m^3); $\boldsymbol{SPP_t}$= market value of potable water (€/m^3).

3.2.1. Shadow price

According to Färe et al. (1993), the shadow price valuation of the undesirable outputs is established on the theory of directional distance function. In the present study, the avoided cost linked with carbon sequestration), reduction of waste, and reduction of excess nutrient loads in water bodies (i.e., environmental benefits) was estimated by shadow pricing. It is determined by a combination of Hernández-Sancho et al. (2010) linear programming, subject to constraints formula, and the distance function, Färe et al. (1993), in Eq. (3):

$$\begin{aligned} & \mathrm{LnD_0}(\mathrm{Input^p}, \mathrm{Output^p}) \\ & \quad = \partial_0 + \sum_{\mathrm{i=I}}^{\mathrm{I}} \lambda_\mathrm{i} * \ln(\mathrm{Input_i^p}) \\ & \quad + \sum_{\mathrm{O=1}}^{\mathrm{O}} \nu_\mathrm{o} * \ln(\mathrm{Output_o^p}) \sum_{\mathrm{i=1}}^{\mathrm{I}} \sum_{\mathrm{i'=1}}^{\mathrm{I}} \lambda_{\mathrm{ii'}} * \ln(\mathrm{Input_i^p}) * \ln(\mathrm{Input_{i'}^p}) \\ & \quad + \frac{1}{2} \sum_{\mathrm{o=1}}^{\mathrm{O}} \sum_{\mathrm{o'}}^{\mathrm{O}} \nu_{\mathrm{oo'}} * \ln(\mathrm{Output_o^p}) \\ & \quad * \ln(\mathrm{Output_{o'}^p}) \\ & \quad + \frac{1}{2} \sum_{\mathrm{i=1}}^{\mathrm{I}} \sum_{\mathrm{o'}}^{\mathrm{O}} \omega_{\mathrm{io}} * \ln(\mathrm{Input_i^p}) * \ln(\mathrm{Output_o^p}), \end{aligned} \tag{3}$$

Where $\mathrm{Input}^{\mathrm{p}}$ is the operational cost *i* (energy, staff, electricity, and other operation costs), $\mathrm{Output}^{\mathrm{p}}$ is the external impact (environmental) of transition to CWS. According to Hernández-Sancho et al. (2010), the co-efficients of the trans-log distance function (Eq. (4)) are explained by enhancing the objective function in Eq. (5) and using linear programming subject to system constrains:

$$Max \sum_{p=1}^{p} [(lnD_0(Input^p, Output^p) - ln(4)], \qquad (4)$$

S.t.:
(5.1) $LnD_0(Input^p, Output^p) \leq 0$
(5.2) $\frac{\Delta LnD_0(Input^p, Output^p)}{\Delta ln\ (Input_i^p)} \geq 0, p;$ Desired output
(5.3) $\frac{\Delta LnD_0(Input^p, Output^p)}{\Delta ln\ (Input_o^p)} \leq 0, p;$ Undesired output
(5.4) $\sum_{o=1}^{O} \nu_O = 1, \sum_{o'=1}^{O} \nu_{OO'} = \sum_{o=1}^{O} \omega_{io} = 0$
(5.5) $\nu_{oo'} = \nu_{o'o}, \lambda_{ii'} = \lambda_{i'i}$

For instance, in this report, the quantitative value of environmental impact of carbon sequestration, reduction of waste, and reduction of excess nutrient loads in water bodies, were calculated by Eq. (5) by M. Molinos-Senante et al, (2011).

$$PE = \sum_{j=1}^{J} q_j VP_j \qquad (5)$$

Where PE = positive externalities (€/year) q_j = shadow price of the external impact j (€/kg) and VP_j= The amount of external impact j (kg/year).

3.2.2. Economic Indicators

To test the proficiency of the proposed framework of SLCCB, two economic indicators of the PP and NPV were estimated. The project with a positive NPV and less PP than the project's life span is feasible to be fulfilled (Boardman, 2015). NPV can be calculated by the Eq. (6), and PP can be calculated by Eq. (7). If the NPV is negative, or the PP was not presented in the life span of a project, the project is deemed not economically viable.

$$NPV = \sum_{t=0}^{20} \left[\frac{(B_t - C_{t)}}{(1+i)^t} \right] \qquad (6)$$

Where B_t is the benefit; C_t= cost for t; t= years, i = discount rate. The analysis period is 20 years in this study. According to the European Commission (Competition Policy, 2023), the discount rate for investment evaluation in Greece is 3.5% which was used in this study.

$$PP = \frac{CAPEX}{yearly\ revenues - OPEX} \qquad (7)$$

$$CAPEX = \Delta PP\&E + current\ depreciation \qquad (8)$$

Where, CAPEX is Capital expenditures, ΔPP&E is Change in property, plant, and equipment.

$$IRR = \sum_{t-1}^{10} \frac{CF_t}{(1+r)^t} - C_0 \tag{9}$$

Where, CF is Cash flow, and r is discount rate, and C0 is initial investment.

3.3. Environmental Impact Assessment Methods

Life Cycle Assessment (LCA) is a widely used and accepted method for studies of environmental performance of various products and systems. For more details on how an LCA is performed, we refer the reader to the literature, such as Rebitzer et al. (2004) and the guidelines for Product Environmental Footprint (Manfredi et al., 2012). The LCA in this report is performed in accordance with ISO 14040:2006 (International Organization for Standardization, 2006a) and ISO 14044:2006 standards (International Organization for Standardization, 2006b). Furthermore, the Ecoinvent database (Wernet et al., 2016) and Simapro LCA software (Pre Consultants, 2018) were used to calculate the environmental performance of each case study.

LCA is an iterative method to optimize input parameters, assumptions, and refine environmental impact calculations with each round. For instance, the first round of analysis may tell the LCA practitioner that more data may be needed, the results of the assessment or an interpretation thereof may nudge the LCA practitioner to revise the goal and scope definition step. In this sense, every LCA one performs provides oneself with insights on how to best plan the next LCA to learn even more.

According to ISO 14040:2006 (International Organization for Standardization, 2006a), an LCA consists of four phases: i) goal and scope definition, ii) inventory analysis, iii) impact assessment and iv) interpretation. Each of these is explained for each case study in the relevant sections (Figure 3.2).

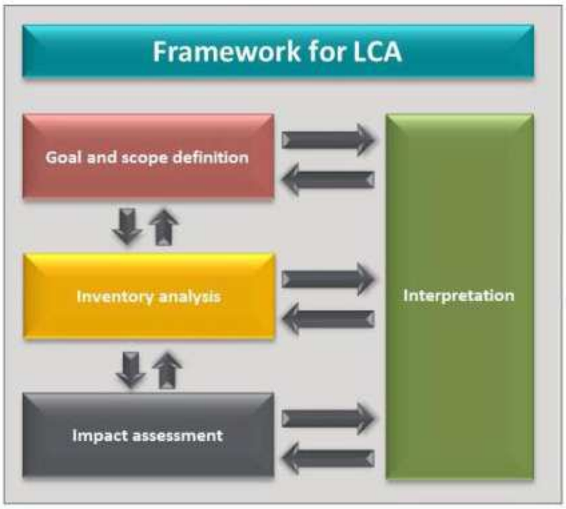


Figure 3.2 The life cycle assessment framework (International Organization for Standardization, 2006a)

3.3.1. Step 1. LCA goal and scope definition

The goal and scope definition phase ensures that the LCA is performed consistently. An LCA models a product, service, or system life cycle. A model is a simplification of a complex reality. As with all simplifications, this means that reality will be distorted in some way. The challenge for an LCA practitioner is to make sure the simplification and distortions do not influence the results too much. The best way to do this is to carefully define the goal and scope of the LCA study (Golsteijn and Pre Sustainability, 2020).

The goal and scope phase describes the most important choices, which are often subjective. For instance, the reason for executing the LCA, a precise definition of the product and its life cycle, and a description of the system boundaries. The system boundaries describe what is considered by the assessment and what is ignored. For instance, small amounts of ingredients that contribute little to the environmental footprint can be left out of the scope of the study and the system boundaries (Golsteijn and Pre Sustainability, 2020). Furthermore, other important choices which are made at this phase are the selection of functional unit, the selection of environmental impacts, the baseline system, and how allocation will be handled.

The functional unit describes a quantity of a product or product system based on the performance it delivers in its end-use application. Furthermore, the functional unit is used to compare the system or product under study with the baseline system. All environmental impacts are reported per functional unit, i.e., the functional unit acts as a normalization factor for environmental impact results and a comparison factor with other product systems.

The baseline system serves as the baseline for comparison with the product system under study. The selection of the baseline system needs to be justified in relation to the goal and scope of the study. Baseline systems are typically modelled with secondary data, i.e., data collected from LCA databases.

The selection of the environmental impacts depends on data availability, i.e., environmental releases to the environment, and the goal and scope phase. For instance, if the goal of a study is to calculate the environmental footprint of the product under study, then the environmental impact selection will be limited to the Global Warming Potential. Furthermore, scientific literature (Corominas et al., 2020; Mihelcic et al., 2017; Montemayor et al., 2022) shows that depending on the economic sector that the product under study belongs to, specific environmental impacts are expected to be affected.

Lastly, handling allocation refers to isolating one function out of many functions on a process or system level. For instance, a refinery produces gasoline, diesel fuel, and jet fuel. When one wants to assess the environmental impacts of gasoline production, part of the environmental impacts of the refinery operation needs to be allocated to gasoline product system and the rest environmental impacts to the other product systems. The ISO 14044:2006 (International Organization for Standardization, 2006b) provides a hierarchy for solving the allocation "problem":

1. Avoid allocation if possible;
2. Divide the process in sub-processes;
3. Expand the system with respect to its functions;
4. Perform mass allocation;
5. Perform energy allocation; or
6. Perform other kind of allocation.

3.3.2. Step 2. Inventory analysis of extractions and emissions

The inventory analysis regards the data collection (such as inputs, outputs, and environmental releases) occurs, and data is associated with the product system under study. An example of an input is the use of raw materials and energy consumption. Outputs regard the intermediate, final products, and environmental releases. The latter are emissions of pollutants and waste streams to soil, water, or air. Together, this gives the complete picture of the life cycle inventory (LCI). The LCI is all about collecting relevant data and modeling this data via inputs and outputs in a correct manner (Golsteijn and Pre Sustainability, 2020). Therefore, results exist at this phase. The LCI results regard the emissions of pollutants to the soil, water and air, and the consumption of materials and energy. All data of the LCI were acquired from D6.3, and materials for construction were excluded from the environmental assessment.

3.3.3. Step 3. Life cycle impact assessment (LCIA)

The LCI results are associated with environmental impact categories. This is done with life cycle impact assessment (LCIA) methods which firstly classify emissions into impact categories and secondly characterize them to common units according to the impact to allow comparison (European Commission and Joint Research Centre., 2018). For instance, Global Warming Potential greenhouse gases are considered and converted to CO_2 equivalent units.

3.3.4. Step 4. Interpretation

Finally, in the Life Cycle Interpretation phase, results from LCIA are interpreted in accordance with the stated goal and scope. This step includes completeness, sensitivity, and consistency checks. A contribution analysis may occur to identify most contributing emissions, processes or life cycle stage to environmental impacts. Furthermore, scenarios can be developed to predict the environmental performance in the near future or assess different configurations on the system level. The reporting and recommendations also take place in this step (European Commission, n.d.).

3.3.4.1. Contribution analysis

The contribution analysis decomposes environmental impact results into contributing elements (% of total). It can be performed at several levels, such as on the inventory analysis or characterisation. It can be performed for different elements, such as processes, interventions, or impact categories. The objective of a contribution analysis is to may provide opportunities for redesign, prevention strategies, etc., when it is applied early in the design process, or identify what data is more important for highest contributors, than those that hardly contribute. A contribution analysis was conducted to identify which processes contribute the highest to the environmental impact results.

3.3.4.2. Scenario Analysis

Scenario analysis was conducted to determine the impact of different energy mixes on the results. A country specific projection was developed for electricity production in 2030 in Greece based on goals of the Greek government.

Table **3.1** shows the composition of the current and future Greek electricity mix.

Table 3.1. Composition of the current and future Greek electricity mix (ref: Ministry of Environment and Energy, 2019, National Energy and Climate Plan, Athens)

Energy source	Current electricity mix (%)	2030 electricity mix (%)
Waste incineration	0.3	2.8
Photovoltaics	9.6	21.1
Wind energy	19.5	30.7
Hydropower	10.9	11.8
Natural gas	35.8	32.6
Hard coal	12.9	2.8
Oil	10.9	-
Geothermal	-	1.1

3.3. Eco-Efficiency Analysis

Ecological sustainability is acknowledged as the primary indicator of the interplay between social development, economic growth, and environmental protection, whereas ecological efficiency (eco-efficiency) is an index used to measure the ecological environment's sustainable development (Li et al., 2020). How can we maximise economic and social value while minimising environmental impact? This is a crucial topic in the context of the new normal of economic development and the promotion of carbon neutrality strategies. Eco-efficiency encompasses numerous facets of environmental, economic, and social development; thus, it necessitates the participation of numerous disciplines. The eco-efficiency metric proposed by Kristina et al. (2005) is commonly understood as doing more with less, frequently incorporating economic and environmental variables. In conjunction with life cycle theory, Laso et al. (2018) discovered that eco-efficiency could correlate the environmental performance of a product to its economic value. Eco-efficiency is a measure of a company's ability to address environmental issues during its operations; it is a comprehensive economic and environmental indicator. Well-known evaluation methods include the ratio method, the index system method, the material flow analysis method, and the ecological imprint method, among others. Due to its objectivity and comprehensiveness, the Ratio method (RM) proposed by Zhang B. et al., (2008) has been extensively adopted in numerous fields. The economic value of the product of each HYDRO according to the functional unit is then divided by the environmental impact of its production for each HYDRO in this report (see Eq. 10).

$$Eco - efficiency = \frac{product's\ economic\ value}{environmental\ impact\ caused\ by\ the\ product} \tag{10}$$

3.4. Sensitivity Analysis of Economic indicators

LCC and NPV is dependent on several variables (investment cost, project timelines, operational expenses, and other derivable economic applications, for example), the values of which vary greatly depending on the period of analysis. The analysis begins by giving the most likely value (designated as the "base case") to each of these variables. In our instance, considering the CWS and the places where this system is implemented. The LCC and NPV are performed on the "base case" using a deterministic technique and assuming complete knowledge of the predicted cash flows. The actual wide range of variability in the basis data should be considered. Each variable is replaced with extreme values (once the maximum and then once the minimum). This enables us to assess the influence of variation in each variable on the economic feasibility outcomes. Sensitivity analysis is divided into two types: local sensitivity analysis and global sensitivity analysis. Local sensitivity analysis is used to investigate the impact of small changes in input parameters around a reference value (i.e., nominal value) on analysis output (values of one parameter vary while other input parameters remain constant to investigate the sensitivity of one input parameter). The variable range of all input parameters is addressed simultaneously in global sensitivity analysis; the sensitivity is assessed for the complete range space of the input parameters. Systematic evaluations of the LCC input cost uncertainties were carried out using variance-based global sensitivity analysis to provide insight into the robustness of the outcome and the life-cycle cost reductions of the CWS integration into water system for the many scenarios evaluated. The Extended FAST (EFAST) method proposed by Saltelli et al. (1999) (see Eq. 11) was used in this study to estimate both first order and total sensitivity indices at a minimal computing cost. The EFAST technique computes the sensitivity indices of each parameter using an approximated one-dimensional integral and the scenario sequence described by:

$$z_{i,j} = G_j(\sin \omega_j s_i), s_i = \frac{2(\mathrm{i}-1) - (\mathrm{n}_0 - 1)}{(\mathrm{n}_0 - 1)} \tag{11}$$

Where z_(i,j) denotes the level of the uncertain factors Z_j in the scenario z_i, where i = 1,...,n_0 and _j are frequency parameters.

4. APPLICATION OF ECONOMIC & ENVIRONMENTAL IMPACT ASSESSMENT TO HYDROUSA CASE STUDIES

4.1. Economic & Environmental Impact Assessment to HYDRO1&2

4.1.1. Goal and scope of HYDRO1&2

The goal of the HYDRO1&2 system (called Scenario 1) was to treat urban wastewater, produce compost and fertigation water for agroforestry and other products, and generate electricity. The baseline system had the same goal/functions. Regarding the baseline system, primary data for wastewater treatment was collected from the Antissa WWTP, secondary data from Ecoinvent database was collected for the same amount of compost production and co-generation of heat from biogas combustion in Greece, and conventional agriculture was considered to produce fruits.

4.1.2. Functional unit of HYDRO1&2

The functional unit was one year of operation of the Scenario 1 (HYDRO1&2 system). In one year, the system treats 23,780 m^3 of urban wastewater and produces 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of crops. The same functionalities are covered by the baseline system. It should be mentioned that the capacities of the compost unit and AGF were increased upon discussions with experts to improve its efficiency and represent an AGF that reached maturity, respectively.

4.1.3. System boundaries of HYDRO1&2

Figure 4.1 illustrates the system boundaries of the Scenario 1. It comprised an upflow anaerobic sludge blanket (UASB), a constructed wetland (CW), an ultraviolet (UV) unit, a sludge drying reed beds (SRDB), a composting unit, a CHP unit and agroforestry land where fruits are produced. The baseline system regarded the provision of the same functions, such as urban wastewater treatment, fruits, etc. However, food production involved conventional farming, i.e., employing non-organic fertilizers.

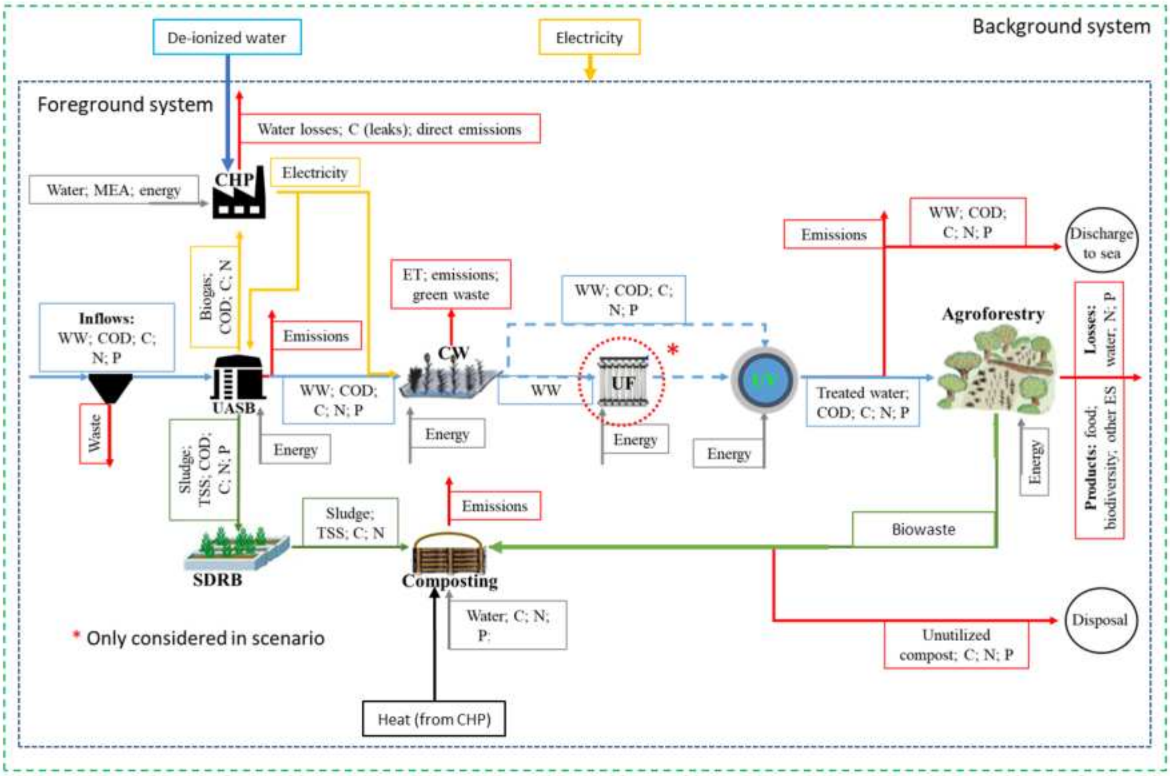


Figure 4.1 System boundaries of Scenario 1 (HYDRO1&2)

4.1.4. Allocation of HYDRO1&2

The system was expanded to include four functions, the provision of urban wastewater treatment, and production of compost, heat and fruits, vegetables, aromatic herbs, livestock feeding and biomass.

4.1.5. Assumptions of HYDRO1&2

Assumptions were made due to data uncertainty, especially for CO_2 sequestration by the plants and trees.

1. The wastewater inflow is constant at 35 m^3/d in winter, 60 m^3/d in middle season, 100 m^3/d in summer based on year 2020;
2. The productivity of the cultivation stage is the same for both original and baseline systems;
3. It was not possible to measure how much carbon is absorbed aboveground and underground during cultivation stage, therefore, atmospheric CO_2 sequestration was assessed according to the amount of carbon in the harvested plant.

4.1.6. Contribution Analysis of HYDRO1&2

According to a recent literature review of LCA studies about wastewater treatment systems, global warming, eutrophication, and ecotoxicity are recommended as key indicators. These indicators align with proposed metrics for a national wastewater testbed in the U.S. (Mihelcic et al., 2017) and can connect to current wastewater monitoring (e.g., nutrient effluent concentrations) and dynamic modeling (Corominas et al., 2013; Bisinella de Faria et al., 2015). Therefore, first a contribution analysis is performed on these impacts to identify the most influential parameters.

4.1.7. Scenario Analysis of HYDRO1&2 for Environmental assessment

Scenarios were developed to investigate how the HYDRO1&2 system performs when 1) an additional ultrafiltration unit is installed upstream of the UV unit which is called Scenario 1 (UF) , 2) reclaimed water is not discharged to the sea but it is collected and sold to farmers which regards Scenarios 1.1, 1.2 and 1.3, 3) if biogas is upgraded to biomethane (called Scenario 1 (Biomethane) for use in vehicles instead of combustion in the CHP unit. In the latter case, the baseline system was also modified to produce biomethane instead of CHP, 4) when Scenario 1 operates in 2030 with the Greek electricity system of 2030.

Regarding the scenarios where the wastewater is sold to farmers Scenarios 1.1, Scenario 1.2 and Scenario 1.3 correspond to HYDRO1&2 (50% drip 50% open channels and farmers), HYDRO1&2 (100% drip 0% open channels and farmers), and HYDRO1&2 (0% drip 100% open channels and farmers), respectively.

4.1.8. Life Cycle Inventory of HYDRO1&2

Table 4.1 presents consumables, in terms of input materials and electricity, and environmental emissions during one year of operating HYDRO1&2 (i.e., functional unit). The first process of the HYDRO1&2 system is the UASB where the wastewater is received and wastewater, sludge, and biogas are produced. Furthermore, methane (dissolved methane escapes with the treated anaerobic effluent) is emitted in this stage of treatment. All outputs will be further treated downstream. The constructed wetland (CW) receives the treated wastewater from the UASB and further treats it while absorbing atmospheric carbon dioxide to send it to the UV process. However, emissions also occur in this stage, such as methane and dinitrogen monoxide emissions. The UV stage eliminates pathogens to produce reclaimed water that will be used for fertigation at the AGF. However, the largest part of the reclaimed water is discharged to the sea (main scenario) and the same emissions with the CW occur in this stage, such as methane and dinitrogen monoxide emissions. The composting process receives mainly sludge from the UASB stage and converts it to compost with the addition of shredded and mixed greens. The composting process produces compost that is provided to local farmers. The CHP plant receives the biogas from the UASB process and produces heat and power with the provision of deionized water. The entire amount of electricity produced at this stage is consumed by the UASB process (it covers the UASB electricity requirements entirely) and the CW. Methane and carbon dioxide are emitted at this stage due to leakage and combustion of biogas. The final process is the AGF where fruits are produced with the employment of reclaimed water, compost, and electricity. Carbon dioxide is absorbed during the fruits' cultivation, and emissions to air and soil occur due to the employment of the reclaimed water which is rich in nitrogen and phosphorus.

The additional processes of Scenario 1 (Biomethane) with biomethane production or Scenario 1 (UF) with the UF unit installation can be found in Appendix (Tables 8.1 and 8.2).

Table 4.1. Life Cycle Inventory of HYDRO1&2 (for FU-1 year of operation)

Input	Amount	Unit	Output	Amount	Unit
UASB					
Wastewater	23,780.0	m^3	Treated wastewater (to UASB)	23,740.37	m^3
Electricity	5,570	kWh	Sludge	39.63	m^3
			Biogas	3,380.23	m^3
			Leaked methane	293.56	kg
Constructed wetland					
Treated wastewater	23,740.37	m^3	Treated wastewater (to UV)	22,829.00	m^3
Electricity	1,679	kWh	Water losses	911.37	m^3
Carbon dioxide	200	kg	CH_4	15.82	kg
			N_2O	9.58	kg
UV					
Wastewater (from CW)	22,829.0	m^3	Reclaimed water to AGF	6,535.2	m^3

Electricity	921.71	kWh	Reclaimed water (discharged to the sea)	16,293.8	m^3
			CH_4	3.9	kg
			N_2O	4.3	kg
Composting					
Sludge	39.63	m^3	Compost (external)	7,371.7	kg
Shredded and mixed greens	7,700	kg			
Electricity	395	kWh			
Combined Heat and Power (CHP)					
Biogas (from UASB)	3,380.23	m^3	Electricity	7,242	kWh
Deionized water	13.66	m^3	Heat	37,243	MJ
			CH_4 (leakage)	92.14	kg
			CO_2	2,777	kg
Agroforestry (AGF)					
Reclaimed water	6,535	m^3	Crops production	9,864	kg
Electricity	1,583	kWh	N_2O	7.2	kg
CO_2	6,408	kg	Phosphorus	15.46	kg
			Water losses	3,142	m^3
			Carbon	25	kg
			Nitrogen	122	kg

4.1.9. Life Cycle Costing of HYDRO1&2

Table 4.2 presents the investment cost for the construction of HYDRO1&2 that appeared in the year of the project. In addition, Scenarios were developed to investigate how the HYDRO1&2 system economically performs when 1) an additional ultrafiltration unit is installed upstream of the UV unit with 50% drip irrigation and 50% open channel (Scenario 1), 2) reclaimed water is not discharged to the sea but it is collected and sold to farmers (Scenario 1.1) 3) same scenario but 100% drip irrigation and 0% open channel and reclaimed water discharge to sea (scenario 1.2) 4) same as scenario ,but with 0% drip irrigation and 100% open channel. 5) if biogas is upgraded to biomethane for use in vehicles instead of combustion in the CHP unit with 50% drip irrigation and 50% open channel (Scenario 2). 6) CHP and Ultrafiltration with 50% drip irrigation and 50% open channel.

Table 4.2. Capital cost of HYDRO1&2

Initial Investment	UASB	Constructed Wetlands	UF	UV	Biogas Upgrade	CHP	SDRB & Compost Unit	AGF	TOTAL
CAPEX - €	270,000	135,757.0	50,000	6,500	0.00	25,000	25,000	15,000	487,257
CAPEX - €/year	6,515.5	3,276.05	1,206.6	156.86	0.00	603.29	603.29	361.98	12,723.57

Table 4.3 presents the annual operation cost of the project which is extension over the lifespan of the project. present annual operation cost of the project, including consumable, electricity, and human resources, etc., during the lifespan of operating HYDRO 1&2.

Table 4.3. Operational costs of HYDRO1&2

OPEX	UASB	Constructed Wetlands	UF	UV	Biogas Upgrade	CHP	SDRB & Compost Unit	AGF	TOTAL
Maintenance costs - €/year	2,000.00 €	2,000.00€	100.00 €	500.00€		1,500.00€	800.00€	1,000.0 €	7,900.00€
HR requirement (equal. distr. without UF) - €/year	1,566.67 €	1,566.67 €		1,566.67 €		1,566.67 €	1,566.67 €	1,566.67 €	9,400.00€
Costs for electricity - €/year	947.00€	282.51€	30.69€	153.44€			67.21€	255.68 €	1,736.53€
Costs for Chemicals - €/year			34.69€						34.69€
Lost revenues from energy losses - €/year						231,528.90€			231528.9€
Lost revenues from remaining treated WW discharge- €/year				3,990.90 €					3990.93€

The economic revenue, which is presented in Table 4.4, has the specific market value therefore it is calculated by multiplying their quantity to their unit market price. The environmental benefit of carbon sequestration is estimated as 1.47 (T/year) in line with Ex-ACT method from FAO - Cost of carbon (FAO, 2016). For estimating the carbon sequestration, the FAO's Ex-ACT (Ex-ante Carbon Balance Tool) gives an ex-ante assessment. Based on a World Bank report on the State and Trends of Carbon Pricing, 2020, the EX-ACT Tool estimates the monetary quantification for unit price in the range of 41.5 to 81 €/t, which is the target value for the Paris agreement (World Bank Group, 2020). In this study, 60 €/t was considered. The indirect benefit in this study is the pressure on the environment that is addressed by implementing NBWS as the water demand is fulfilled by harvested rainwater; also, transition to NBWS helps to eliminate the amount of water wasted comprised of leakage from pipes, joints and fittings. Hence, these are counted as indirect benefits.

Table 4.4. Revenue of HYDRO1&2

Revenue	TOTAL
Revenues for WW treatment - €/year	33,292.00
Revenues from visits (schools & tourists) - €/year	1,750.00
Savings from electricity production & use - €/year	918.4
Revenues from thermal energy - €/year	1,312.00
Revenues from selling compost - €/year	1,105.74
Revenues from produced food - €/year	49,248.7
Savings from irrigation water - €/year	1,307.04
Savings from nutrients in fertigation water - €/year	1,307.0

4.2. Economic & Environmental Impact Assessment to HYDRO3

4.2.1. Goal and scope of HYDRO3

The goal of the original system is the production of essential oil from oregano in Mykonos Island, Greece. This is called Scenario 1 in the rest of the document. The baseline system regarded the production of the same essential oil but with conventional farming and no water harvesting. However, due to conventional farming the oregano field output was higher by 25%, according to (Litskas et al., 2019).

4.2.2. Functional unit of HYDRO3

The purpose of the system is to produce oregano essential oil. Therefore, the functional unit of 1 bottle of oregano essential oil was selected.

4.2.3. System boundaries of HYDRO3

Figure 4.2 and Figure 4.3 show the system boundaries of the original and baseline systems, respectively. The system boundaries were cradle-to-packaging plant gate and comprised stages from oregano cultivation, to steam distillation and packaging. These stages employ materials and energy flows. The difference between the original system and baseline system was the use of fertilizers and water collection. The baseline system applied chemical fertilizers due to conventional farming. This resulted in higher oregano production by 25% than the original system which employed organic farming (Litskas et al., 2019). Furthermore, while the original system harvested rainwater, the baseline system employed groundwater in the farm. Both systems purchased industrial water for the steam distillation stage. A detailed inventory of materials can be found in Table 4.6.

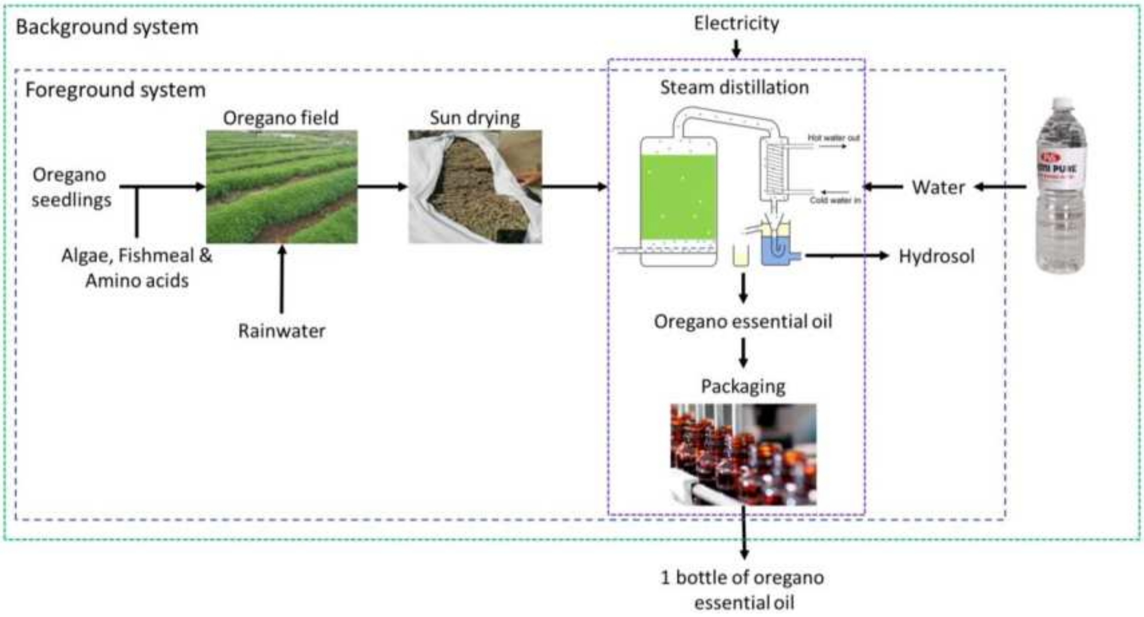


Figure 4.2 System boundaries of original system, functional unit = 1 bottle of oregano essential oil (= 1 bottle (5 ml) of essential oil)

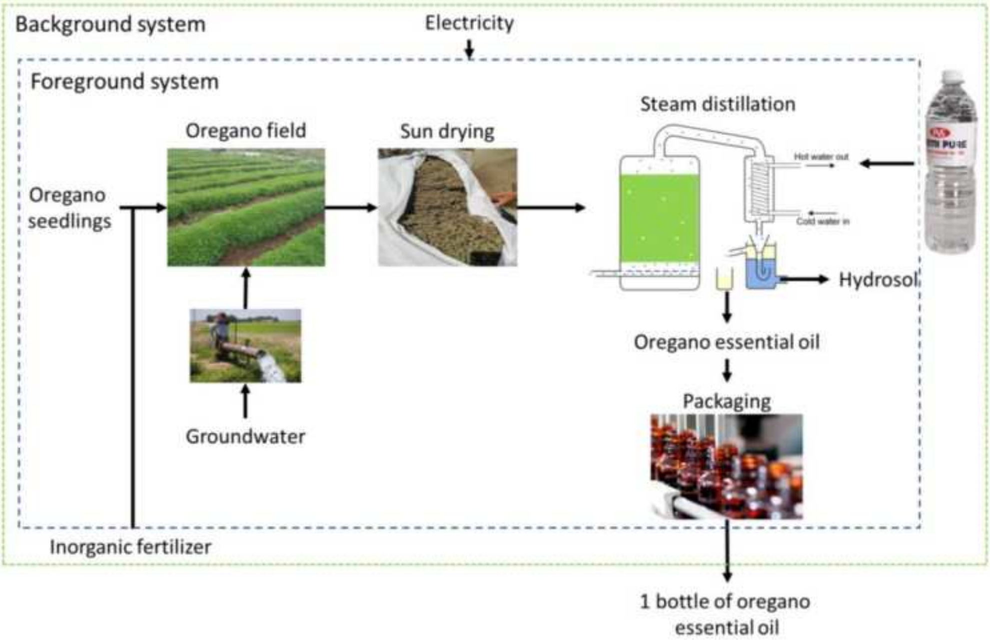


Figure 4.3 System boundaries of baseline system, functional unit = 1 bottle of oregano essential oil (= 1 bottle (5 ml) of essential oil)

4.2.4. Allocation of HYDRO3

Steam distillation is the only multifunctional process. Multifunctionality was handled according to ISO hierarchy with economic allocation. It was impossible to decouple processes that were used explicitly in oregano essential oil or hydrosol production lines. Furthermore, system expansion was not preferred because it would limit comparison with baseline systems of oregano essential oil production. Table 4.5 presents the economic allocation factors.

Table 4.5. Economic allocation factors at steam distillation stage of HYDRO3

Co-product	Amount (kg)	Price (€/kg)	Allocation factor (%)	Reference
Oregano oil	0.98	3,000	85	(Essential Oils Vessel, 2022)
Hydrosol	9.00	54	15	(Olympic senses, 2022)

4.2.5. Assumptions of HYDRO3

Assumptions were made due to lack of data and to reduce uncertainty. It was assumed that:

1. The productivity of the cultivation stage of the baseline system is 25% higher than the original system due to conventional agricultural practices (Litskas et al., 2019);
2. It was impossible to measure how much CO_2 is absorbed aboveground and underground during cultivation stage; therefore, atmospheric CO_2 sequestration was assessed according to the amount of carbon in the harvested plant;
3. No data existed to produce the waste-type soil enhancers that were used once in the original system. Thus, their supply chain was disregarded.

4.2.6. Life Cycle Inventory of HYDRO3

The inventory was normalised per bottle of oregano oil. Table 4.6 shows the inventory per life cycle stage of the original system. The cultivation stage regards the inputs and outputs at the agricultural field for the original system. Furthermore, materials for water irrigation were considered as well. The original system employed amino acids, fishmeal and algae as soil enhancers, and harvested rainwater. In contrast, chemical fertilizers and irrigation with pumped groundwater were considered as inputs for the baseline system which had 25% larger oregano yield and 67% more water used than the baseline system according to a recent study by Litskas et al. (Litskas et al., 2019). In both systems, atmospheric CO_2 absorption was considered during cultivation. Due to data limitations, CO_2 was calculated based on the carbon composition of harvested fresh oregano plant which was converted to CO_2 according to stoichiometry.

Drying took place naturally in a room without direct sunlight for both original and baseline systems. During drying, the weight was reduced by 45% for both systems. Furthermore, steam distillation occurred the same way for both original and baseline systems. Steam distillation used dried oregano, water (for steam generation and cooling), and electricity to produce hydrosol and oregano oil. Multifunctionality was handled with economic allocation as shown in Table 4.5. Deionized water for steam distillation of both systems was purchased from Athens, Greece; and transported by track and ship to the distillation plant. The deionized water was heated electrically by the distillation column to produce steam. In addition, cooling water was sourced from tap water; it was passed through the fridge and sent to the HYDROtank. For both systems the solid waste is landfilled locally.

Lastly, produced oregano essential oil was packaged in the distillation plant in the same way for both original and baseline systems. Packaging regarded use of brown glass containers and electricity consumption. It is important to use a glass type that will reduce deterioration of the oil due to sunlight exposure during its shelf-time.

Table 4.6. Life cycle inventory of Scenario 1 (HYDRO3 system) normalised per 1 bottle (=5 ml) of oregano oil

Inputs	Amount	Unit	Outputs	Amount	Unit
Cultivation					
Harvested rainwater	306	kg	Harvested oregano plants	0.689	kg
Amino acids (as soil enhancer)	0.006	kg	N_2O to air	0.0001	kg
Fishmeal (as soil enhancer)	0.006	kg	NH_3 to air	0.0003	kg
Algae (as soil enhancer)	0.006	kg	NO_3- to water	0.003	kg
Electricity	0.066	kWh	P to water	0.00002	kg
Polyethylene (irrigation)	0.002	kg	PO_4 to water	0.0001	kg
Occupation, permanent crop	20.41	m^2			
People in harvesting	1	number			
People in planting	4	number			
CO_2 capture by the plant	1.041	kg CO_2			
Oregano seedlings	0.006	g			
Steam distillation					
Occupation, industrial area	0.153	m^2	Hydrosol	0.05	kg
Deionized water	0.050	kg	Oregano solid waste	0.41	kg
Water (cooling)	0.015	kg	Oregano oil	0.005	kg
Electricity (for distillation)	0.365	kWh			
Oregano (dried)	0.378	kg			
Packaging					
Glass bottle	0.022	kg	Bottled oregano oil	1	bottle
Land use	0.000001	m^2			

Oregano oil	0.055	kg			
Electricity	0.0001	kWh			

4.2.7. Scenario Analysis of HYDRO3 for Environmental Assessment

In this study, scenario analysis was performed with input factors: electricity and oregano yield. The oregano yield is expected to increase significantly according to the local agronomist because the plants are still young. The yield in 2023 is expected to range between 275 and 300 kg of fresh oregano, instead of the 135 kg which were harvested in 2022. Therefore, two scenarios are made: 1) Scenario 2 where the yield is higher than in 2022 but on the low side and 2) Scenario 3 when the yield in 2023 is maximal. Furthermore, the Greek electricity grid is expected to become greener by year 2030 according to Greek government agenda. Therefore, Scenario 1 is assessed for year 2030.

4.2.8. Scenario Analysis of HYDRO3 for Economic Assessment

System boundaries are depicted in Figure 4.4 whilst

Table **4.7**. presents the system's processes. For the rainwater harvesting (RWH) employed in Mykonos, CAPEX, OPEX, economic revenues and environmental and social revenues of the shallow sub-surface rainwater collection, irrigation system, cultivation, and essential oil distillation and packaging of the oil were calculated. The proposed assessment only includes the value of extra materials and energy needed to modify the current water system to an RWH system.

RWH systems are built from raw materials, including extraction, processing, and manufacturing, as well as transportation of all components. A prior study found that the transportation of goods from one location to another, as well as the recycling, landfilling, and incineration of waste at the end of its useful life, had no impact on this analysis (Ghafourian et al., 2021 Hasik et al, 2017); therefore, these data are not included in this assessment.

The following seven evaluation parameters are included in the operational and maintenance phases: (i) total electricity usage, (ii) renewing annual organic certification, (iii) cost of packaging the essential oil, (iv) other consumable, (v) human resources for the system's operations, (vi) cleaning rainwater tank, (vii) replacing valve and pump.

The following revenue have also been considered during the operational phase: (i) essential oil sale, (ii) saving from main water consumption when it is replaced with rainwater, (iii) environmental benefit from carbon sequestration due to oregano cultivation, (iv) Contribution to economy, and (v) benefit from avoided fertilizer import.

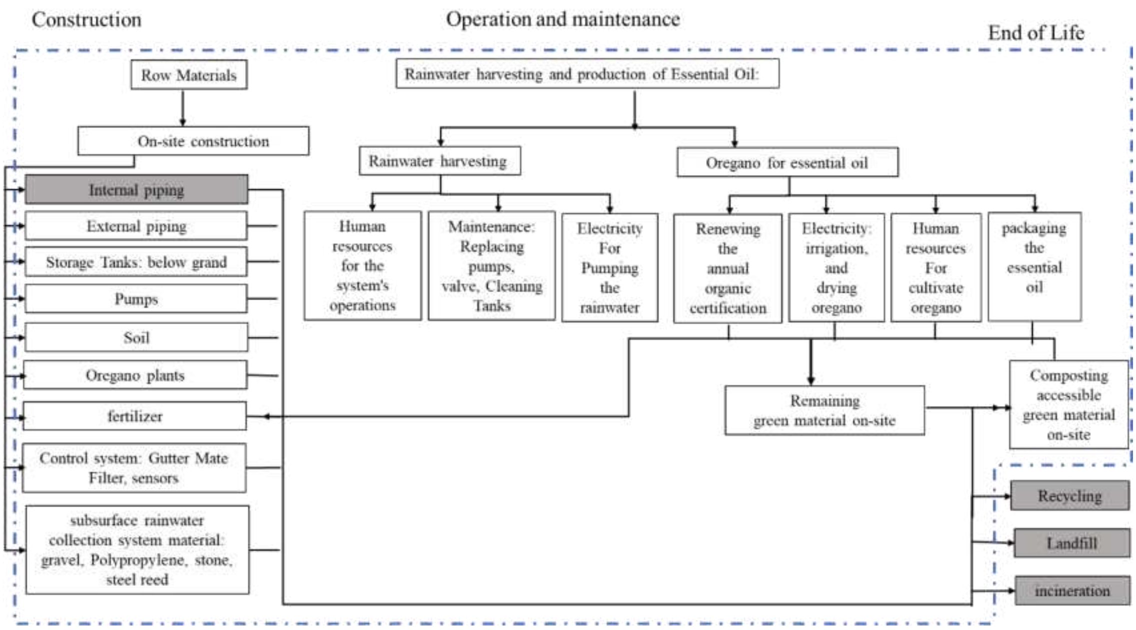


Figure 4.4 System Boundary of NBWS in Mykonos

Table 4.7. General added costs and benefits of the nature-based water system (Response indicators)

Added Cost		Added Benefit		Applied
Capital Cost	Material cost	**Economic**	Benefit from organic products (essential oil)	✓
	Installation		Benefit from Hydrosol	✓
	Legal affairs (e.g., permits)		Fertilizer production out of waste	✓
	Purchase and installation costs of additional technologies	**Environmental**	Environment benefit from carbon sequestration	✓
Operational Cost			Wastewater treatment	
	Total energy usage (kWh/year)		Reduction of negative impacts of extracting mineral (water, soil)	
	Other consumable & maintenance costs		Biodiversity	
	Organic certificate		Reduction of excess nutrient loads in water bodies	
		Human resources	School visits	
			Tourism	
			Contribution to economy	✓

4.2.9. Life Cycle Costing of HYDRO3

Table 4.8 summarises the capital and installation, for the nature-based water system (NBWS) implemented in Mykonos. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards. Since the amount of fertilizer that will be used is equivalent to the amount of fertilizer produced from green residual waste, it is omitted from the calculation.

Table 4.8. Capital and installation cost of HYDRO3

Initial Investment (installation)	Agriculture RW harvesting	Irrigation and Cultivation of Oregano Field	Drying	Distillation	Packaging	Energy system (PV panels)	Other (legal affairs, certifications, etc.)	TOTAL
CAPEX - €	17,500	5,330	0	2,800	0	0	1,000	15,215.0
CAPEX - €/year	509.65	155.22	0	163.09	0	0	58.245	886.21

Table 4.9 presents the annual operation cost of the project which is extension over the lifespan of the project. present annual operation cost of the project, including consumable, electricity, human resources, etc., during the lifespan of operating HYDRO3 (i.e., functional unit).

Table 4.9. Operational cost of HYDRO3

OPEX	RW harvesting	Agriculture	Irrigation system	Drying	Distillation	Packaging	Other (legal affairs, certifications, etc.)	TOTAL
Costs for water (irrigation) - €/year					4.60			4.60
Costs for energy - €/year			3.24	0.00	14.65	0.01		17.90
Costs for fertilizers - €/year		3.15						3.15
Consumables, Certification & Product Packaging - €/year							530.00	530.00

The economic revenue (Table 4.10) has a specific market value; therefore, it is calculated by multiplying their quantity to their unit market price. The environmental benefit of carbon sequestration is estimated as 1.47 (T/year) in line with Ex-ACT method from FAO - Cost of carbon (FAO, 2016). For estimating the carbon sequestration, the FAO's Ex-ACT (Ex-ante Carbon Balance Tool) gives an ex-ante assessment. The FAO's EX-ACT (Ex-ante Carbon Balance Tool) calculates the effects of land use and land use change on GHG emissions and carbon sequestration ex-ante. EX-ACT depicts the impact of agricultural and forestry activities by using the carbon footprint as a climate change mitigation measure. EX-ACT is used to calculate the amount of carbon that can be sequestered by various natural and inspired solutions. Based on a World Bank report on the State and Trends of Carbon Pricing, 2020, the EX-ACT Tool estimates the monetary quantification for unit price in the range of 41.5 to 81 €/t, which is the target value for the Paris agreement (World Bank Group, 2020). In this study, 60.00 €/t was considered. The indirect benefit in this study is the pressure on the environment that is addressed by implementing NBWS as the water demand is fulfilled by harvested rainwater; also, transition to NBWS helps to eliminate the amount of water wasted comprised of leakage from pipes, joints and fittings.

Hence, these are counted as indirect benefits. According to Ormond (2020), the use of oregano in different forms can reduce carbon footprint by 24 %.

Table 4.10. Economic revenue of HYDRO3

Revenue	TOTAL
Savings from water production & use (irrigation) - €/year	62
Revenues from selling hydrosol - €/year	486.27
Revenues from selling essential oil - €/year	2881.591
Savings from Carbon sequestration - €/year	88.2

4.3. Economic & Environmental Impact Assessment to HYDRO4

4.3.1. Goal and scope of HYDRO4

The demonstration site for HYDRO4 located on Mykonos Island aimed to enable the harvesting of low-cost rainwater for (a) non-potable domestic use and (b) the production of bottled lavender essential oil after irrigation of a lavender field. To simplify the study, the overall configuration of the HYDRO4 system was broken down into two practical sub-systems which were evaluated in relation to equivalent baselines, Scenario 1A and 1B. Scenario 1A regarded the production of water for residential use, and its baseline considered the activities involved in the conventional treatment of water in a centralized system to the dispensing of tap water to end-users. Scenario 1B regarded the production of essential oil from lavender, and its baseline considered all processes in the production of bottled lavender oil required conventional farming practices which use synthetic fertilizers and pumped underground water for field irrigation; following cultivation, the plants were sun dried and essential oils were extracted through a distillation process using distilled water sourced from Athens. The scope of this study included the annual operational phase only since there were significant differences in the infrastructure characteristics of the sub-systems in comparison to their respective baselines.

4.3.2. Functional unit of HYDRO4

The activities for functional unit of Scenario 1A start from the harvesting of rainwater on the residential rooftops to the supply of harvested water for non-potable domestic use; additionally, tap water from the centralized system is provided for all potable water needs. On the other hand, the activities for functional unit of Scenario 1B start from the harvesting of surface rainwater for irrigation of a field to the production of bottled lavender oil.

4.3.3. System boundaries of HYDRO4

A configuration was developed incorporating existing residential rooftops for rainwater harvesting during the winter months for current domestic purposes and a storage tank for future water use during summer months. Concurrently, a sprawling surface water collection system which included two buffer tanks and an artificial subsurface water reservoir for extended water availability for perennial crop cultivation. A combination of two organic fertilizers (Hundzsoil and Agrohumic) were manually applied onto the cultivation field. For essential oil extraction during distillation, on-site decarbonized water was produced through use of an atmospheric water generator (Stratus S200 model). Figure 4.5 presents the system boundaries of HYDRO4 Scenario A and B.

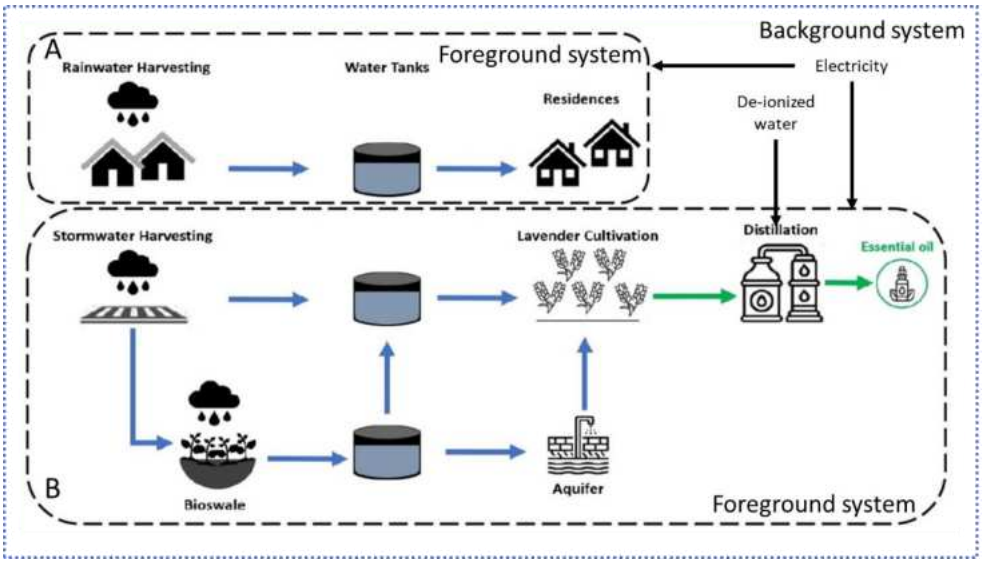


Figure 4.5 System boundaries of Scenarios 1A and 1B of HYDRO4; top is Scenario A and bottom is Scenario B

4.3.4. Allocation of HYDRO4

Multifunctionality was observed at points where tanks were used. Consequently, we applied volume-based allocation to the part of the system which dealt with the supply of water to the residence. Harvested rainwater from rooftops was concentrated in Tank 1 prior to supply to the residence for non-potable applications; any water surplus was stored in the same tank. Similarly, rainwater from the agricultural harvesting network transited through Tank 2 to the field for irrigation during the summer months. Also, Tank 2 was always kept full; hence any overflows were discharged to aquifer. In addition, in the stormwater harvesting network, rainwater was channeled to a buffer tank (i.e., Open Tank) and managed in the same way as Tank 2 (Table 4.11).

Table 4.11. Volume allocation factors for field irrigation of HYDRO4

Coproduct	Amount (m^3/yr)	Allocation factor (%)
Scenario 1A (Tank 1)		
Water from Tank 1 to residences	118.63	94.39
Water stored in Tank 1	7.05	5.61
Scenario 1B (Tank 2)		
Water from Tank 2 to field irrigation	102.72	48.99
Water from Tank 2 to aquifer	66.94	31.93
Water stored in Tank 2	40	19.08
Scenario 1B (Open Tank)		
Water from Open Tank to field irrigation	9	8.68
Water from Open Tank to aquifer	74.72	72.04
Water stored in Open Tank	20	19.28

In addition, to produce bottled lavender essential oil, economic allocation for the coproducts at the distillation phase was preferred (Table 4.12).

Table 4.12. Economic allocation for the steam distillation process of Scenario 1B

Co-product	Amount (kg)	Price (€/kg)	Allocation factor (%)	Reference
Lavender oil	0.2	2000	78.74	(Essential Oils Vessel, 2022)
Hydrosol	1.8	60	21.26	(Olympic senses, 2022)

4.3.5. Assumptions of HYDRO4

The proposed model involves the operation of fully functional HYDRO4 sub-systems over a calendar year. The model is an optimized framework under the following additional assumptions: i) five adults were daily occupants of the residence, ii) the two tanks (Tank 2 and Open Tank) for field cultivation were always kept full, (iii) the agricultural yields of the HYDROsolution was on par with the Baseline system, and (iv) all the required input materials were transported from Athens to Mykonos Island for on-site essential oil production.

4.3.6. Life Cycle Inventory of HYDRO4

The inventory to produce water for residential use was normalised per cubic meter of water supplied to the residence on an operational basis only, i.e., without considering infrastructure contribution (Table 4.14). The daily water needs for residence (e.g., washing, toilet flashing, etc.) were met by harvested rainwater; whereas for the potable water needs (e.g., cooking, laundry, etc.), tap water was used (Crouch et al., 2021). The only output of the HYDRO4 A system was used domestic water (i.e., wastewater) following utilization of both collected rainwater and centralized water, annually.

Furthermore, the inventory for HYDRO4 B was normalised per bottle (of 5 ml) of lavender essential oil along the stages of production within the system boundaries, namely cultivation, distillation, and packaging. Noteworthy, the agricultural rainwater and the stormwater harvesting systems collected an estimated 100.42 m^3/year and 100 m^3/year of rainwater, respectively, regardless of the final outputs at the lavender essential oil packaging stage. Consequently, considering the low harvest of lavender crops in the first year of cultivation with the resultant low number of bottled essential oil (40 units), the harvested rainwater was skewed toward an elevated value upon normalization (Table 4.13). The farm management strategy for aromatic plants required a one-off application of soil enhancers on the demonstration sites during the cultivation phase over the lifetime of the project (Table 4.13). The baseline system considered conventional farming practices with soil application of synthetic fertilizers, twice a year, and field irrigation with pumped groundwater (Moncada et al., 2016). The drip irrigation network installed on the original lavender cultivation field resulted in 69% reduced water utilization in comparison to the corresponding baseline. Also, the carbon sequestration from the atmosphere was calculated based on the ratio of CO_2 to carbon and the ratio of carbon in harvested plants. During sun-drying the fresh weight of harvested biomass was reduced by 36% for both the original and baseline systems. Subsequently, the dried plants underwent steam distillation for essential oil extraction along the same operational model as for HYDRO3 (Table 4.13). Also, a scenario was included to cater for utilization of an electricity-powered atmospheric water generator (i.e., dehumidifier) to produce water required for distillation.

Infrastructure for distillation and packaging was shared for essential oils extracted from aromatic plants harvested on the HYDROUSA project. Additionally, glass bottles of identical physical properties were used for the packaging of oregano and lavender essential oils (Table 4.13).

Table 4.13. Life cycle inventory of HYDRO4 of annual operation

PRODUCTION OF WATER FOR DOMESTIC USE (NORMALISED PER 1 M^3 OF WATER SUPPLIED)					
Inputs	**Amount**	**Unit**	**Outputs**	**Amount**	**Unit**
Harvested rainwater (non-potable uses)	270.84	kg	Wastewater	1.00	kg
Centralized water (potable uses)	729.16	kg			
People in residence	5	number			

Electricity (pump)	0.0001	kWh			
LAVENDER CULTIVATION (NORMALISED PER 1 BOTTLE OF LAVENDER OIL)					
Harvested rainwater	5,010.50	kg	Harvested lavender	0.44	kg
Hundz soil (soil enhancer)	0.28	kg	N_2O to air	0.03	kg
Agrohumic (soil enhancer)	0.63	kg	NH_3 to air	0.16	kg
Electricity	2.51	kWh	NO_3 to water	1.81	kg
CO_2 capture by the plant	0.51	kg CO_2	P to water	0.02	kg
Lavender seedlings	0.035	g	PO_4 to water	0.10	kg
STEAM DISTILLATION (NORMALISED PER 1 BOTTLE OF LAVENDER OIL)					
Water required (distillation)	0.05	kg	Hydrosol	0.045	kg
Water (cooling)	0.075	kg	Solid waste	0.28	kg
Electricity (for distillation)	0.38	kWh	Lavender oil	0.005	kg
Electricity (dehumidifier)	0.033	kWh			
Lavender (dried)	0.28	kg			
PACKAGING (NORMALISED PER 1 BOTTLE OF LAVENDER OIL)					
Glass bottles	0.022	kg	Lavender oil	1	bottle
Lavender oil	0.005	kg			
Electricity	0.0001	kWh			

4.3.7. Scenario Analysis of HYDRO4

Scenario analyses were mainly performed with either electricity or lavender yield as input parameters. Additionally, we simulated the impact of use of an atmospheric water generator for the distillation stage of lavender essential oil extraction. Due to the perennial nature of aromatic plants, a protracted adaptation phase of the seedlings to soil and climatic conditions may delay plant growth. However, a greater harvest of the flowering shoots is anticipated for the second year of cultivation. The yield for the second year of cultivation (2023) is expected to range between 150 (Scenario 2B) and 170 (Scenario 3B) kg of fresh lavender, instead of the 17.5 kg which were harvested in the first year. Furthermore, the effect of harvesting water vapor and employing it in distillation process was investigated. Therefore, Scenario 4B was developed which employed a dehumidifier for the water vapor harvesting. Lastly, the effect of operating HYDRO4, both Scenarios 1A and 1B in 2030 was investigated.

4.3.8. Life Cycle Costing of HYDRO4

Table 4.14 summarises the capital and installation, for the nature-based water system (NBWS) implemented in Mykonos. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards. Since the amount of fertilizer that will be used is equivalent to the amount of fertilizer produced from green residual waste, it is omitted from the calculation.

Table 4.14. Capital and installation costs of HYDRO4

Initial investment (Installation)	RW harvesting - residential	RW harvesting - open tank (ASR)	RW harvesting - Agricultural	Irrigation system	Drying	Distillation	Packaging	Residence of HYDRO4	Other (legal affairs, certifications, etc.)	TOTAL
CAPEX - €	5,500	9000	1,000	4,650	0	700	0	0	1000	16,275

CAPEX - €/year	160.18	524.21	29.12	135.42	0	40.77	0	0	58.24	947.95

Table **4.15** presents the annual operation cost of the project which is extension over the lifespan of the project. present annual operation cost of the project, including consumable, electricity, human resources, etc., during the lifespan of operating HYDRO4 (i.e., functional unit).

Table 4.15. Operational cost of HYDRO4

OPEX	RW harvesting - residential	RW harvesting - open tank (ASR)	RW harvesting - Agricultural	Irrigation system	Drying	Distillation	Packaging	Residence of HYDRO 4	Other (legal affairs, certifications, etc.)	TOTAL
Costs for water - €/year						1.02		141.06		142.08
Costs for energy - €/year			11.83	12.575		3.80		13.59		41.80
Costs for fertilizers - €/year				22.6						22.6
Consumables,Certification & Product Packaging - €/year							336		1700	2036

The economic revenue of Table 4.16 has the specific market value; therefore, it is calculated by multiplying their quantity to their unit market price. The environmental benefit of carbon sequestration is estimated as 1.47 (T/year) in line with Ex-ACT method from FAO - Cost of carbon (FAO, 2016). For estimating the carbon sequestration, the FAO's Ex-ACT (Ex-ante Carbon Balance Tool) gives an ex-ante assessment. The FAO's EX-ACT (Ex-ante Carbon Balance Tool) calculates the effects of land use and land use change on GHG emissions and carbon sequestration ex-ante. EX-ACT depicts the impact of agricultural and forestry activities by using the carbon footprint as a climate change mitigation measure. EX-ACT is used to calculate the amount of carbon that can be sequestered by various natural and inspired solutions. Based on a World Bank report on the State and Trends of Carbon Pricing, 2020, the EX-ACT Tool estimates the monetary quantification for unit price in the range of 41.5 to 81 €/t, which is the target value for the Paris agreement (World Bank Group, 2020). In this study, 41.5 €/t was considered. The indirect benefit in this study is the pressure on the environment that is addressed by implementing NBWS as the water demand is fulfilled by harvested rainwater; also, transition to NBWS helps to eliminate the amount of water wasted comprised of leakage from pipes, joints and fittings. Hence, these are counted as indirect benefits.

Table 4.16. Economic revenue of HYDRO4

Revenue	TOTAL
Savings from water production & use (irrigation) - €/year	306.2

Revenues from selling essential oil - €/year	400
Revenues from selling hydrosol - €/year	97.2
Savings from Carbon sequestration - €/year	43.8

4.4. Economic & Environmental Impact Assessment to HYDRO5

4.4.1. Goal and scope of HYDRO5

The goal of the HYDRO5 system was to treat seawater to produce salt and tropical fruits. The baseline system had the same functions as the HYDRO5 system but regarded conventional farming which employed irrigation water produced at the local reverse osmosis plant.

4.4.2. Functional unit of HYDRO5

The functional unit was one year of operation of the HYDRO5 system. In one year, the system produced 730 kg of salt and 608 kg of fruits.

4.4.3. System boundaries of HYDRO5*

Figure 4.6 illustrates the system boundaries of the HYDRO5 system. It comprised a filtration unit to feed with seawater, the mangrove still system, a PGH unit to collect rainwater and store it at a freshwater tank, a salt production unit, and the greenhouse with tropical fruits. The baseline system regarded the provision of the same products, such as table salt and tropical fruits. However, the latter were produced with conventional farming, i.e., employing non-organic fertilizers and irrigation water from seawater reverse osmosis desalination.

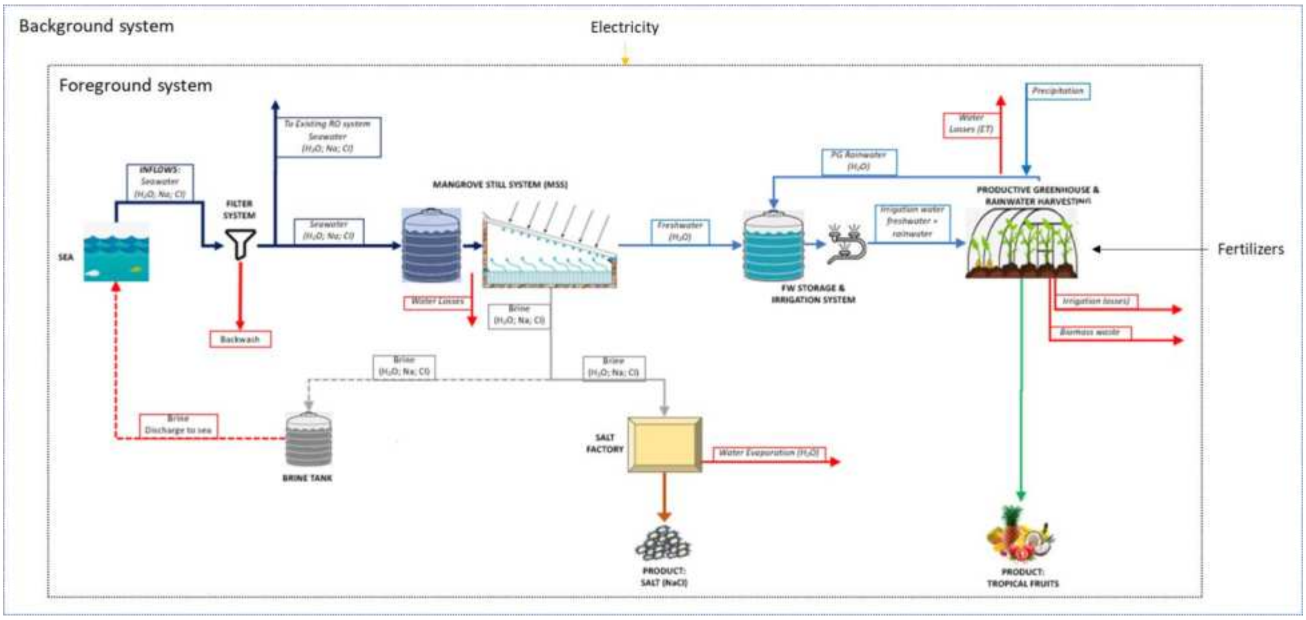


Figure 4.6 System boundaries of HYDRO5

4.4.4. Allocation of HYDRO5

The only multifunctional process was the filtration unit which produced water for the local reverse osmosis plant and the HYDRO5 system. Thus, allocation was handled based on volume because both water outputs are of the same quality and, consequently, price. Table 4.17 presents the allocation factors.

Table 4.17. Volume allocation factors of HYDRO5

Co-product	Amount (m^3)	Allocation factor (%)
Seawater SW to RO	2,815,714.29	90.901%
Seawater SW to MSS	259.01	0.008%
Seawater SW for backwash	281,597	9.091%

4.4.5. Assumptions of HYDRO5

Assumptions were made due to data uncertainty, especially for CO_2 sequestration by the plants and trees;

1. Electricity consumption for pumping water was not measured but taken from (Pinto, 2020);
2. The HYDRO5 system produced 0.203 m^3 per day;
3. It was impossible to measure how much CO_2 was absorbed during the growth period of plants; thus, it was calculated only based on the agriproducts annual yield, according to (Ma et al., 2018).

4.4.6. Life Cycle Inventory of HYDRO5

Table 4.18 presents the input materials and electricity during one year of operating HYDRO5 to produce fruits and table salt.

Table 4.18. Life cycle inventory of HYDRO5 (FU=1 year of operation)

PRETREATMENT					
Input	Value	Unit	Output	Value	Unit
Seawater SW	3,097,570	m^3	Seawater SW to RO	2,815,714	m^3
Electricity	1,393,906	kWh	Seawater SW to MSS	259	m^3
			Seawater SW for backwash	281,597	m^3
FRESHWATER PRODUCTION PROCESS (MANGROVE STILL SYSTEM - MSS)) and PGH RAINWATER HARVESTING SYSTEM					
Seawater SW to MSS	259.0	m^3	Freshwater FW	74.1	m^3
Precipitation (rainwater)	51.4	m^3	Brine	14.9	m^3
Electricity	302.9	kWh	Brine discharge	170.0	m^3
			Harvested Rainwater RW from PGH	46.3	m^3
			Water losses (rainfall losses)	5.1	m^3
FRESHWATER STORAGE TANK					
Freshwater FW	74.1	m^3	Water for irrigation	117.8	m^3
Harvested Rainwater RW from PGH	46.3	m^3	Surplus water	2.6	m^3
SALT PRODUCTION PROCESS (SALT FACTORY SYSTEM - SF)					
Brine	14.9	m^3	Salt produced	730.0	kg
Electricity	1,372	kWh	Water evaporated	14.5	m^3
TROPICAL FRUIT PRODUCTION PROCESS (PRODUCTIVE GREENHOUSE SYSTEM - PGH)					
Water for irrigation	117.8	m^3	PGH Plants Irrigation water demand (ETc)	116.6	m^3
Electricity	7.3	kWh	Water losses (irrigation losses)	1.2	m^3
Organic fertilizer Super Eco-Vas.	24.2	kg	Total produced yield of Tropical Fruits	608	kg
Chicken manure	44.4	kg			

Idai ENGORDE (liquid PK (0-5-3,6) fertilizer)	2.4	kg			
Pyrethrum (Insecticide)	0.034	kg			
Nitropol 97.6% (Insecticide)	0.0025	kg			
Copper oxychloride (Fungicide)	0.04	kg			

4.4.7. Scenario Analysis of HYDRO5

Scenario analysis was performed with input factors electricity. The Greek electricity grid is expected to become greener by 2030 according to Greek government agenda (Table 3.1).

4.4.8 Life Cycle Costing of HYDRO5

Table 4.19 summarises the capital and installation for the water system implemented in Tinos. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards.

Table 4.19. Capital and installation cost of HYDRO5

CAPEX	MSS	Salt Evaporation	RW harvesting	Greenhouse	Agriculture	Other (legal affairs, certifications, etc.)	TOTAL
CAPEX - €	30,400 *	18,453	1,150	-	-		**25,001.5**
CAPEX - €/year	885.34	537.40	33.49	-	-	-	**1,456.23**

*MSS CAPEX includes the Greenhouse and AGR

Table 4.20 presents the annual operation cost of the project which is extension over the lifespan of the project. present annual operation cost of the project, including consumable, electricity, human resources, etc., during the lifespan of operating HYDRO5.

Table 4.20. Operational cost of HYDRO5

OPEX	MSS	Salt Evaporation	RW harvesting	Greenhouse	Agriculture	TOTAL
HR requirement - €/year	375	375	375	375	375	1,875
Costs for water (irrigation) - €/year					294.43	294.43
Costs for energy - €/year	67	212.72		1.13	46.96	327.64
Consumable (chemical)		1,986				1,986
System operation	500	500	500	500	500	2,500

The economic revenue (Table 4.21) has the specific market value; therefore, it is calculated by multiplying their quantity to their unit market price. The environmental benefit of carbon sequestration is estimated as 1.47 (T/year) in line with Ex-ACT method from FAO - Cost of carbon (FAO, 2016). For estimating the carbon sequestration, the FAO's Ex-ACT (Ex-ante Carbon Balance Tool) gives an ex-ante assessment. The FAO's EX-ACT (Ex-ante Carbon Balance Tool) calculates the effects of land use and land use change on GHG emissions and carbon sequestration ex-ante. EX-ACT depicts the impact of agricultural and forestry activities by using the carbon footprint as a climate change mitigation measure. EX-ACT is used to calculate the amount of carbon that can be sequestered by various natural and inspired solutions. Based on a World Bank report on the State and Trends of Carbon Pricing, 2020, the EX-ACT Tool estimates the monetary quantification for unit price in the range of 41.5 to 81 €/t, which is the target value for the Paris agreement (World Bank Group, 2020). In this study, 60€/t was considered. The indirect benefit in this study is the pressure on the environment that is addressed by implementing NBWS as the water demand is fulfilled by harvested rainwater; also, transition to NBWS helps to eliminate the amount of water wasted comprised of leakage from pipes, joints and fittings. Hence, these are counted as indirect benefits.

Table 4.21. Economic revenue of HYDRO5

REVENUE	TOTAL
Savings from water production & use (saved water) - €/year	302.25
Revenues from selling salt - €/year	4,219.41
Revenues from selling crop products (Fruit) - €/year	7,008.57

4.5. Economic & Environmental Impact Assessment to HYDRO6

4.5.1. Goal and scope of HYDRO6

The operation of the “Tinos Ecolodge” resort results with the HYDRO6 system. The objective was to produce water for non-potable domestic use from rainwater collection food for guests and local market, and treat the wastewater of the “Tinos Ecolodge” resort to produce compost for agricultural production and minimize waste disposal in Tinos. The baseline system regards the operation of the “Tinos Ecolodge” results without the HYDRO6 system, i.e., with its current equipment.

4.5.2. Functional unit of HYDRO6

The functional unit was 183 days of operation of “Tinos Ecolodge” resort. The functional unit included several functions of the Resort, such as consumption of drinking water and water collection for various services in the Resort, fertigation water production for irrigating the cultivation of fruits and vegetables which are consumed by the Resort’s customers, and treatment of the Resort’s wastewater.

4.5.3. System boundaries of HYDRO6

Figure 4.7 illustrates the system boundaries of the HYDRO6 system. It comprised old and new lodges, a composting facility, a constructed wetland (CW), ultraviolet lamps, and agricultural land where fruits and vegetables are produced for consumption in the Resort. The baseline system regarded the provision of the same functions, however, several functions are provided from external systems to the Resort, such as urban wastewater treatment, food production, etc.

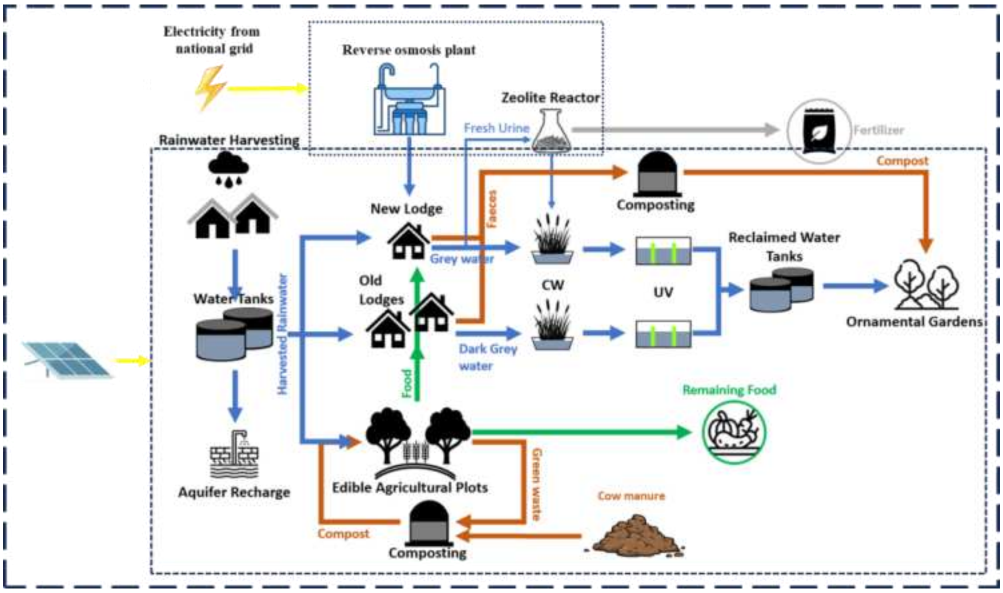


Figure 4.7 System boundaries of the HYDRO6 system

4.5.4. Allocation of HYDRO6

System expansion took place on a system level to include all the additional products that are produced by the HYDRO6 system, such as compost that is distributed to local farmers. if it is not used for food production locally.

4.5.5. Assumptions of HYDRO6

Due to lack of data a few assumptions were considered:

1. The inventory of green food (vegetables and fruits) consumption at the Resort included the class “Vegetables, other”. Such a food class does not exist in Ecoinvent database; thus, cauliflower was selected because it is a popular vegetable in Greece, and it can fairly represent vegetables in terms of carbon footprint (Applied Horticultural Research, 2023);

4.5.6. Life Cycle Inventory of HYDRO6

This section provides the inventory of the HYDRO6 system normalised per functional unit: 183 days of operation of “Tinos Ecolodge” resort. Table 4.22 presents all input materials and energy, and intermediate products of HYDRO6 according to the functional unit.

Table 4.22. Life Cycle Inventory of HYDRO6 (FU-183 days of operation)

Input	Amount	Unit	Output	Amount	Unit
Old cistern					
Harvested rainwater (1)	147.7	m^3	Water to old lodges for toilet flushing	31.6	m^3
River water	179.7	m^3	Water to all lodges for washing machine	18.4	m^3
			Harvested rainwater for irrigation	80.9	m^3
New cistern					
Harvested rainwater (2)	104.9	m^3/year	Harvested RW to garden (old lodges)	5.9	m^3

			Harvested RW to garden (new lodge)	2.0	m^3
			Harvested rainwater for irrigation	276.7	m^3
Old lodges					
Harvested Rainwater for toilet flushing (from old cistern)	31.6	m^3	Total dark grey water to CW vf 1	85.4	m^3
Harvested Rainwater for washing machine (from old cistern)	13.8	m^3	Toilet flushing water to faces	1.6	m^3
Harvested Rainwater for garden (from new cistern)	5.9	m^3	Faces production	138.3	kg
Electricity	1186.9	kWh	Carbon	1.15	kg
Externally sourced green food	355.0	kg	Nitrogen	0.26	kg
Green food	782.4	kg	Phosphorus	0.04	kg
New lodges					
Harvested Rainwater for washing machine (from old cistern)	4.6	m^3	Urine production	0.51	m^3
Harvested Rainwater for garden (from new cistern)	2.0	m^3	Feces production	46.12	kg
Electricity	350.2	kWh	Carbon	0.32	kg
Externally sourced green food	118.3	kg	Nitrogen	0.004	kg
Green food	260.8	kg	Phosphorus	0.004	kg
Zeolite production					
Zeolite input (external input)	408.9	kg	Zeolite production	408.9	kg
Urine inflow from new lodge	0.5	m^3	Liquid effluent to CW vf 2	0.5	m^3
CW-UV 1 Treatment					
Dark grey water inflow (from old lodges)	85.38	m^3	Effluent to UV 1	59.77	m^3
Electricity	42.54	kWh	CH_4	0.16	kg
			N_2O	0.001	kg
CW-UV 2 Treatment					
Grey water inflow (from new lodge plus liquid effluent from zeolite)	19.0	m^3	Effluent to UV 2	13.3	m^3
Electricity	59.3	kWh	CH_4	0.06	kg
			N_2O	0.00	kg
UV1					
Influent from CW vf 1	13.3	m^3	Fertigation water	13.3	m^3
Electricity	3.2	kWh			
Composting (1)					
Toilet flushing water to feces from old lodges	1.6	m^3	Compost (1)	72.0	kg
Feces input from old lodges	138.3	kg	Water losses	345.3	kg
Feces input from new lodge	46.1	kg	CO_2	90.5	kg
Electricity	263.6	kWh	NH_4-3	1.5	kg

			N_2O	0.1	kg
Composting (2)					
Cow manure	240	kg	Compost (2)	135.73	kg
Electricity	1717.5	kWh	Water losses	2253.16	kg
			CO_2	92.32	kg
			NH_4-3	1.92	kg
			N_2O	0.04	kg
Agricultural Plots with Harvested Rainwater (1)					
Harvested rainwater from old cistern	80.9	m^3	Produced green food to old lodges	736.5	kg
Harvested rainwater from new cistern	276.7	m^3	Produced green food to new lodge	363.8	kg
River water for irrigation	179.7	m^3	Remaining produced food	975.5	kg
Compost (2)	135.7	kg	N_2O	0.11	kg
Electricity	837.1	kWh	NO_3	0.66	kg
CO_2	323.0	kg	NH_3	0.12	kg
			Phosphorus	0.04	kg
Agricultural Plots with Reclaimed Water (2)					
Reclaimed water	45.0	m^3	Produced green food to old lodges	45.9	kg
Compost (1)	72.0	kg	Produced green food to new lodge	15.3	kg
Electricity	70.0	kWh	Remaining produced food	442.9	kg
CO_2	78.5	kg	N_2O	0.012	kg
			Nitrogen	0.108	kg
			Phosphorus	0.035	kg
Ornamental Plots with Reclaimed Water					
Reclaimed water	20	m^3	Flowers	n.d.	kg
Electricity	31.12	kWh	N_2O	0.003	kg
		kg	Nitrogen	0.048	kg
			Phosphorus	0.015	kg

4.5.7. Scenario Analysis of HYDRO6

Scenario analysis was performed regarding the 2030 electricity mix. Even though the Eco-Lodge is remote and powered by photovoltaics that belong to the Resort, the drinking water is produced at the local reverse osmosis plant which is employs electricity from the Greek national grid. The Greek electricity grid is expected to become greener by 2030 according to Greek government agenda (see Table 3.1).

4.5.8. Life Cycle Costing of HYDRO6

Table 4.23 presents the general added costs and benefits of the CWS with suitable economic indicators in its life cycle. In the added cost section, the economic cost of CAPEX and OPEX for the CWS system and OPEX for the conventional system were considered. However, in the added benefit section three types of benefits including economic, environmental and social benefit were measured. Social benefits including employment, tourist and school visit’s growth; and environmental benefits such as the waste reduction, evading of extra nutrient loads in water bodies, and carbon sequestration which is the result of an innovative farming to sequester (absorb) carbon dioxide out of the atmosphere on the agriculture plots in the selected area of Tinos were calculated. Three sets of cost and benefit data are collected in this study. Data related to the capital expenditures (CAPEX) of the systems were gathered from the project's relevant partners by providing them with a excel spreadsheet with the list of inventories to be filled by them with their on-site measured data during 2019-2021. and the benefits, operation, and maintenance (OPEX) data were collected from project's partners based on their estimation of annual cost and benefit using monitoring system.

To demonstrate the performance of the proposed economical assessment of CWS, live data from HYDROUSA project were used. The Greek discount rate (location of the demonstrator sites) of 3.5% percent and a life span of 20 years is considered. Table 4.23 lists data gathered from partners and information from local norms of HYDROUSA demonstrator sites. The data for CAPEX, OPEX, and revenue were expressed per functional unit (FU) (i.e., collection, storage, and distribution of 1 m^3 of non-potable water for toilet flushing and irrigation.

Table 4.23. Circular water systems (CWS) cash flow

HYDRO6	RW harvesting	Lodges	CW & UV treatment	Zeolite	Composting	Agricultural Plots	Other (legal affairs, certifications, etc.)	TOTAL
CAPEX - €	15,000		900	1,528		35,000	3,600	48,078.2
CAPEX - €/year	436.84		26.21	44.51		2038.6	104.84	2,695.5
Maintenance costs - €/year							550	550
HR requirement - €/year						12,320		12,320
Costs for water (domestic purposes) - €/year		73.363						73.36
Costs for water (irrigation) - €/year						175.9		175.9
Savings from water production & use (domestic purposes) - €/year		67.25			2.3			69.55
Savings from water saving measures (lodges & irrigation) - €/year		131.1				201.1		332.24
Savings from water production & use (irrigation) - €/year						422.5		422.52
Savings from energy production & use - €/year		273.4	77.778		0.377	114.3		465.91
Savings from food production & use - €/year		7,770						7,770
Revenues from lodges (touristic activity) - €/year		59,240						59,24
Revenues from compost selling - €/year					4.36			4.36
Revenues from zeolite selling (as fertilizer) - €/year				3,524				3,524
Revenues from selling remaining food - €/year						10,940		10,940
Savings from Carbon sequestration - €/year						45		45

The shadow price method was applied to monetize the environmental benefits obtained from CWSs. The shadow price can be calculated using the estimation of the directional distance function for three environmental impacts of carbon sequestration (CS) which is the result of increasing green area, reduction of waste (pollutants were removed during wastewater treatment), and reduction of excess nutrient loads in water bodies. According to World Bank press in 2017, the shadow price of carbon currently set from $ 40 to $ 80 per ton (Pricing Carbon - World Bank Group, 2017). In this study, 60 Euro per ton, which corresponds to the carbon sequestration price calculated by the FAO's EX-ACT (FAO, 2016) is considered. The carbon sequestration from soil is estimated as 0.11 tone/year in line with Ex-ACT method from FAO - Cost of carbon

(FAO, 2016). The social impacts of school visit growth, tourism growth, and employment growth were formed since the eco-lodge is upgraded to a unique agro-eco-touristic facility that is planned to attract organized visits from schools and local and international tourists. To monetize these impacts, a more complex pricing method was used. The pricing method is the calculation of the value added to local economy in effect of a social effect. If the money coming from tourism and school visits is being spent on schools, cultural improvements, temple maintenance, and improving the image of the community, this income is calculated as a social benefit (Marshal et al., 2015). On the other hand, the growth in tourism industry and agriculture prosperity increase employment which in turn influences the GDP and more specifically the local economy (CORE – Aggregating the world's open access research papers). The quantitative value of the external impacts is demonstrated in Table 4.24.

Table 4.24. Environmental and Social benefits of CWS

Specification	Cost/Benefit	Unit	HRWG	MWS
EXTERNAL REVENUES	Environment benefit from carbon sequestration	€/year	5.49	0.00
	Reduction of waste	€/year	6.8	0.00
	Reduction of excess nutrient loads in water bodies	€/year	4.3	0.00
	School visit growth	€/year	8.1	0.00
	Tourism growth	€/year	120	40.00
	Employment growth	€/year	19.7	0.00
	Total (Total saving)	**€/year**	**164.39**	**40.00**

5. ECONOMIC & ENVIRONMENTAL IMPACT ASSESSMENT RESULTS OF HYDROUSA CASE STUDIES

5.1. HYDRO1&2 results

5.1.1. Environmental impacts of HYDRO1&2 – Comparison with baseline

Figure 5.1 presents normalised environmental results of the Scenario 1 (HYDRO1&2 system) with the baseline system. Non-normalised environmental results can be found in Table 8.1 of the Appendix. All environmental impacts are reduced with the Scenario 1 (HYDRO1&2 system) between 49% and 99%. The largest environmental benefits occur for Marine eutrophication, Marine ecotoxicity, Freshwater ecotoxicity, Mineral resource depletion and Global warming potential because they are reduced by 99%. In addition, regarding Water consumption impact, Scenario 1 results in a negative value due to the recovered water that is used for fertigation and water losses to the environment at the CW.

Regarding the Global warming potential, the environmental benefits derive mainly from the electricity generation at the CHP unit which replaces local electricity generation, and to a smaller extent due to the avoidance of inorganic fertilizer consumption. However, direct greenhouse emissions of methane and CO_2 occur at the UASB and constructed wetland stages.

Marine eutrophication benefits occur due to avoiding the discharge of WWTP effluent to the sea, even though at the UV stage water is released to the sea, thus, this was further analyzed with scenarios (see below in this section). Marine ecotoxicity and Freshwater ecotoxicity benefits occur due to avoiding the employment of fertilizers at the AGF stage and treatment of the solid waste of the local WWTP. Mineral resource depletion occurs due to the replacement of the local electricity generation mainly based on diesel oil with electricity generation from biogas by HYDRO1&2.

Similarly, regarding the other environmental impacts the replacement of local electricity generation with greener electricity, and the avoidance of fertilizers use at the AGF stage and wastewater treatment due to the local WWTP are the main contributors to the environmental benefits.

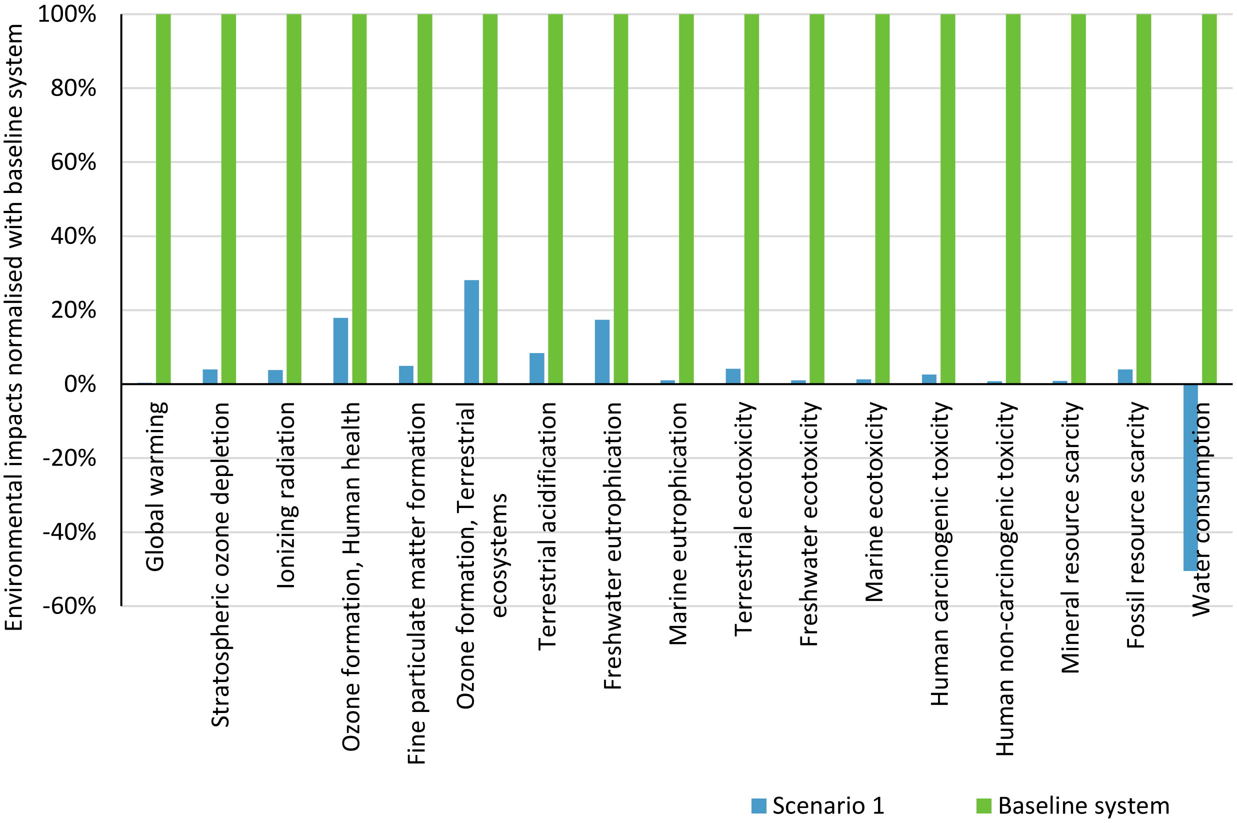


Figure 5.1 Environmental impact of Scenario 1 (HYDRO1&2 system) normalised with baseline system's results

5.1.1.1. Effect of ultrafiltration unit addition

The addition of an ultrafiltration unit affects the environmental impact results as shown in Figure 5.2. Non-normalised environmental results due to the addition of the ultrafiltration unit can be found in Table 8.2 of the Appendix. The effect ranges between 0% and 50% mainly due to the additional electricity consumption of the ultrafiltration stage. The most affected environmental impacts are Global warming, Freshwater ecotoxicity, Human non-carcinogenic toxicity and Mineral resource scarcity. Whereas, Marine eutrophication, Freshwater eutrophication and Water consumption remain unaffected by the added ultrafiltration stage. The main reason for the changes is the additional electricity that is consumed by the UF unit and produced locally. Furthermore, the hydrochloric acid, sodium hydroxide and sodium hypochlorite use at the UF affects the results, but to a much smaller extent than electricity.

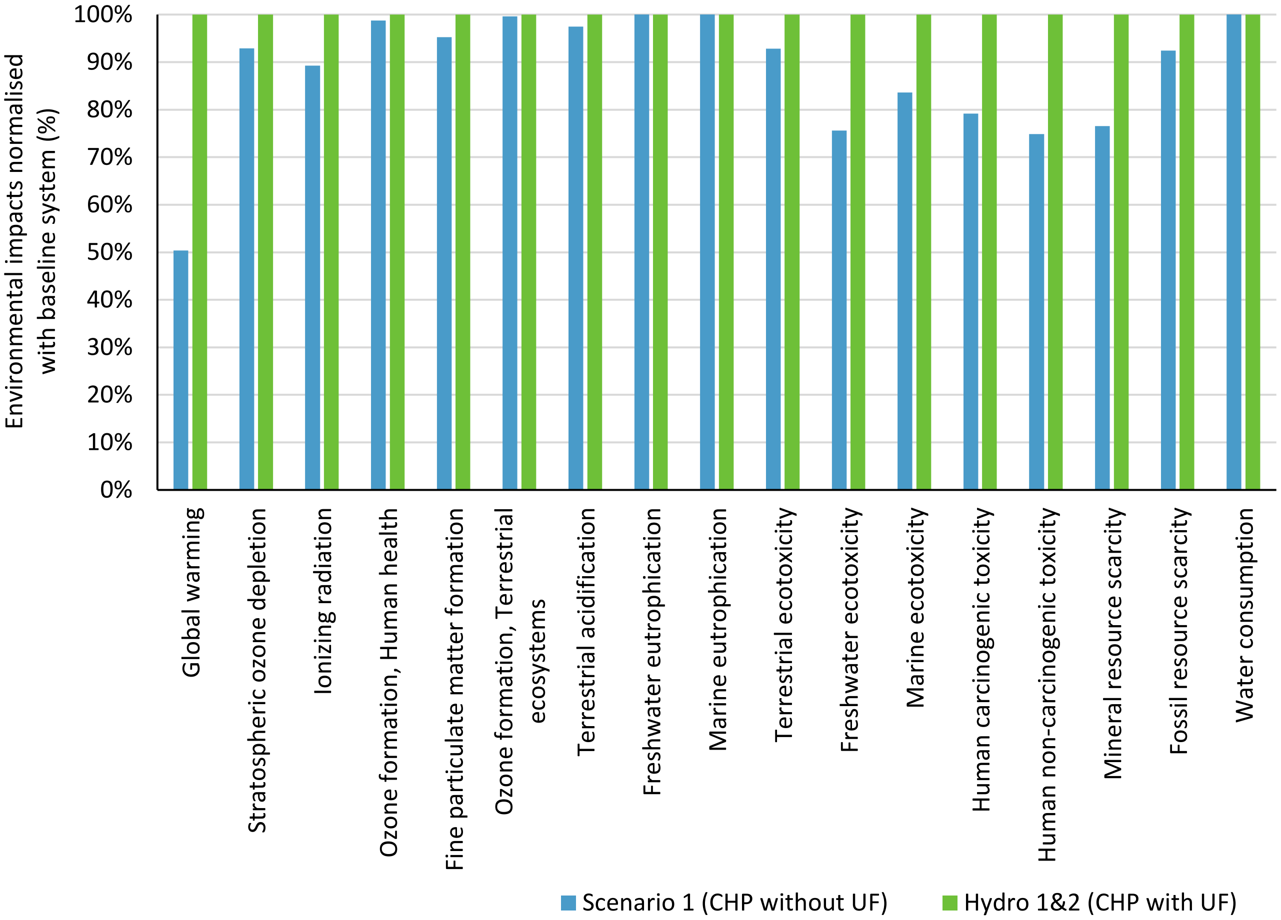


Figure 5.2 Comparison between operation of Scenario 1, with and without the ultrafiltration unit

5.1.1.2. Effect of biomethane production

Figure 5.3 shows that the upgrade and production of biomethane for vehicles results in environmental benefits when compared to the baseline system providing the same functions, including the production of biomethane for vehicles. Non-normalised environmental results due to biomethane production can be found in Table 8.3 of the Appendix. However, the relative environmental benefits (the relative reduction) are lower than the main scenario, which converts biogas to electricity and heat, due to the electricity consumption for the biogas upgrade; and more importantly, the local source of electricity that is consumed now at the UASB and CW stages because no electricity is generated anymore by the HYDRO1&2 system. The UASB and CW stages of HYDRO1&2 consume approx. 70% of the system electricity needs, and the local electricity mix in Lesvos is based primarily on diesel oil engines. Thus, the generation of electricity at the CHP unit by HYDRO1&2 (Figure 5.1) avoids the GHG emissions that are now generated in the biomethane scenario.

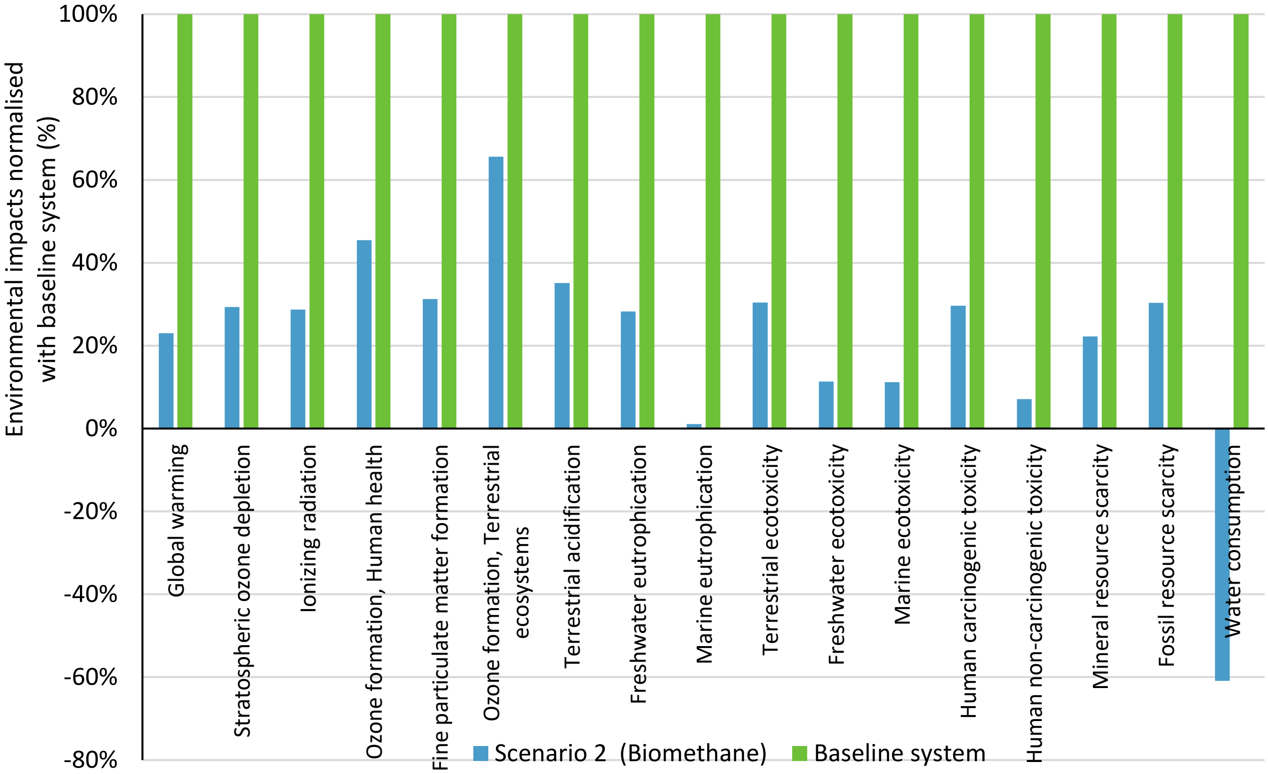


Figure 5.3 Comparison between operation of HYDRO1&2 and baseline systems with biomethane production

5.1.1.3. Effect of various fertigation methods

Various fertigation methods were assessed to investigate their effects on the environmental impacts. Figure 5.4 shows that various fertigation and irrigation methods resulted in minimal differences among the analyzed configurations, mainly due to the different electricity needs and amount of irrigation or fertigation water. Non-normalised environmental results due to various fertigation methods can be found in Table 8.4 of the Appendix. In general, the “HYDRO1&2 (0% drip 100% open channels and farmers)” results in the greater environmental benefits than “HYDRO1&2 (50% drip 50% open channels)”, “HYDRO1&2 (50% drip 50% open channels)”and Farmers” and “HYDRO1&2 (100% drip 0% open channels and farmers)” for all environmental impacts but Ozone formation, Freshwater eutrophication and Water consumption. Furthermore, the largest benefits are seen in Marine eutrophication and the largest burden is seen in Freshwater eutrophication due to the farmers employing the reclaimed water (that is not used by the AGF) instead of direct disposal to the sea. The relatively worse environmental performance of “HYDRO1&2 (100% drip 0% open channels and farmers)” when compared with the other configurations is mainly due to its larger needs of local electricity. Lastly, in the case of water consumption, the larger the difference means that less water is consumed because the original scenario had a negative water consumption value.

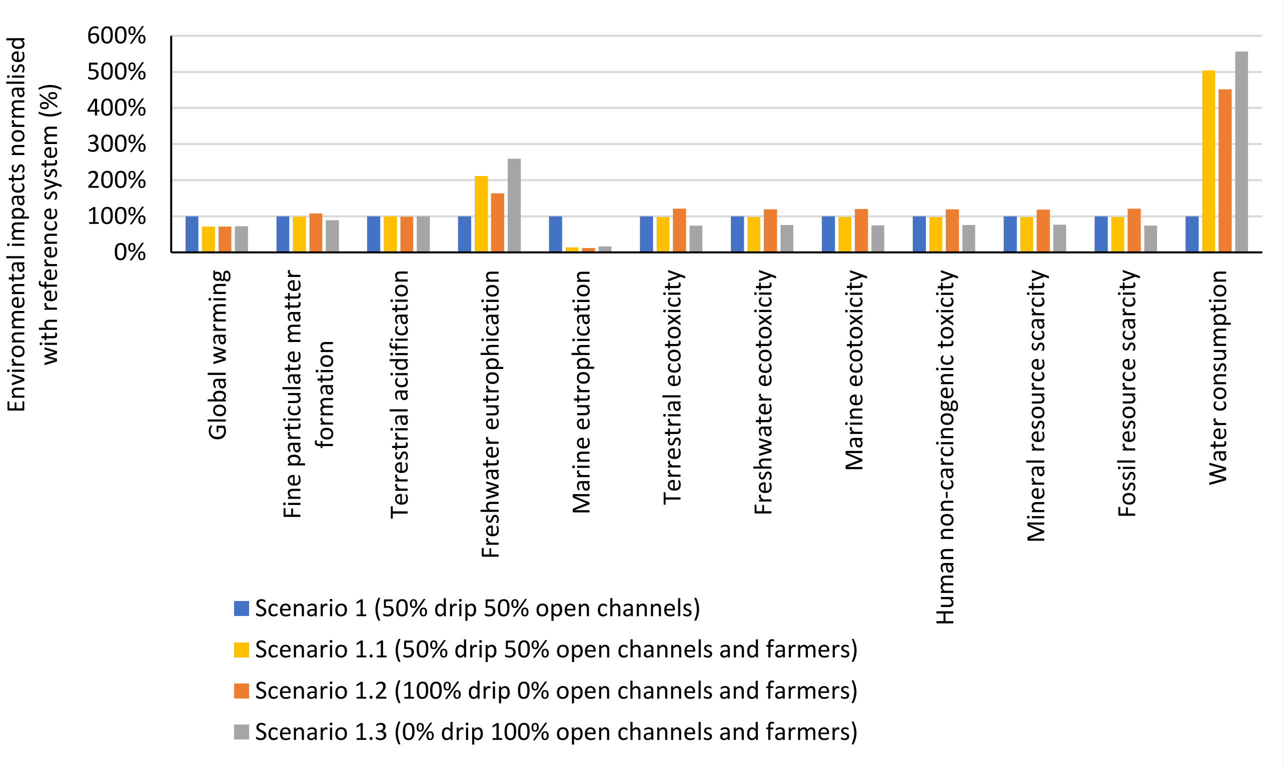


Figure 5.4 Comparison of operation of HYDRO1&2 scenarios with various fertigation options

5.1.1.4. Contribution analysis

Figure 5.5 shows the contribution of life cycle stages in most critical impacts of wastewater treatment systems according to a recent review (Corominas et al., 2020). The generation of local electricity in Lesvos Island contributes significantly to all selected environmental impacts, except for Freshwater eutrophication and Marine eutrophication due to the direct disposal of fertigation water to the sea, and Water consumption. Furthermore, in the case of Global warming, there is a significant contribution of the AGF due to the sequestration of atmospheric CO_2 by the plants and trees; and direct greenhouse gas emissions during electricity generation by the local power plant or the CHP plant; and UASB and constructed wetland stages.

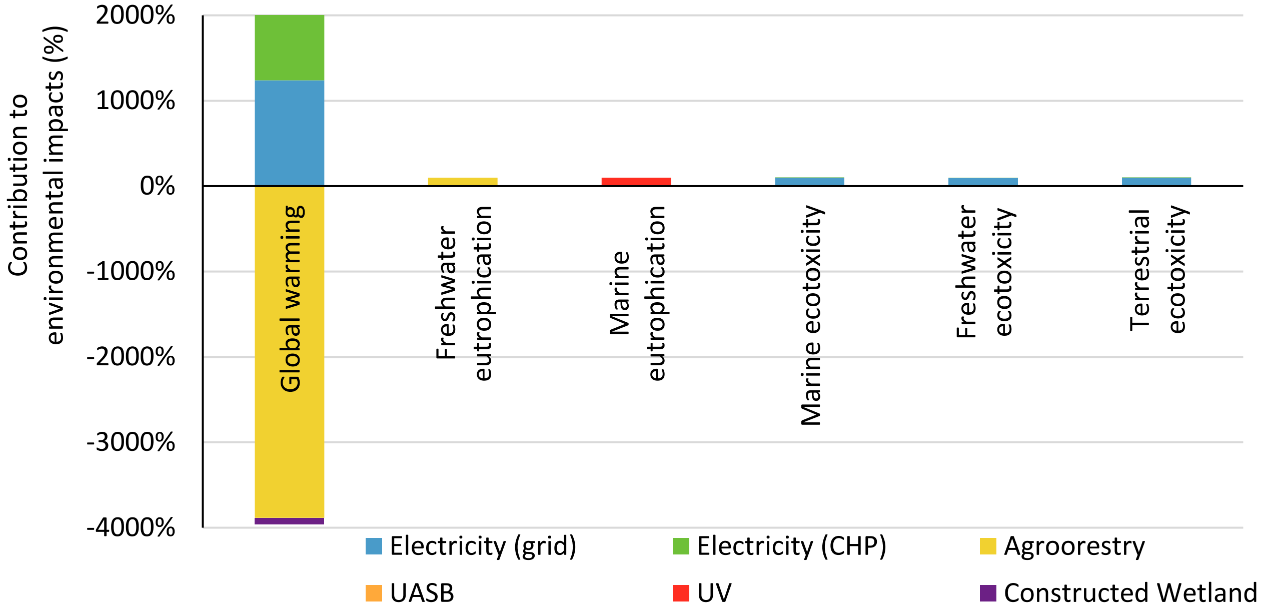


Figure 5.5 Contribution of operation of Scenario 1 (HYDRO1&2) to critical environmental impacts for wastewater treatment systems

5.1.1.5. 2030 Scenario

Figure 5.6 shows that the HYDRO1&2 system improves by 2030 because the Lesvos Island is planned to be interconnected with the mainland which improved the environmental footprint of electricity generation in Greece. Non-normalised environmental results due to the 2030 electricity scenario can be found in Table 8.5 of the Appendix. The improvement is expected to occur in environmental impacts which are mainly affected by electricity generation from diesel oil. Global warming becomes negative, i.e., more CO2 is sequestered due to agriproducts than emitted by the HYDRO1&2 processes, while Stratospheric ozone depletion, Ionizing radiation, Terrestrial ecotoxicity, and Marine ecotoxicity greatly reduce between 93% and 99%. The other environmental impacts also reduce to a great extent, e.g., Freshwater ecotoxicity and Human non-carcinogenic toxicity are reduced by approx. 87%. In contrast, Water consumption and Marine eutrophication remain unaffected by the 2030 electricity replacement due to both impacts being affected by the amount of water produced and release of reclaimed water to the sea, respectively.

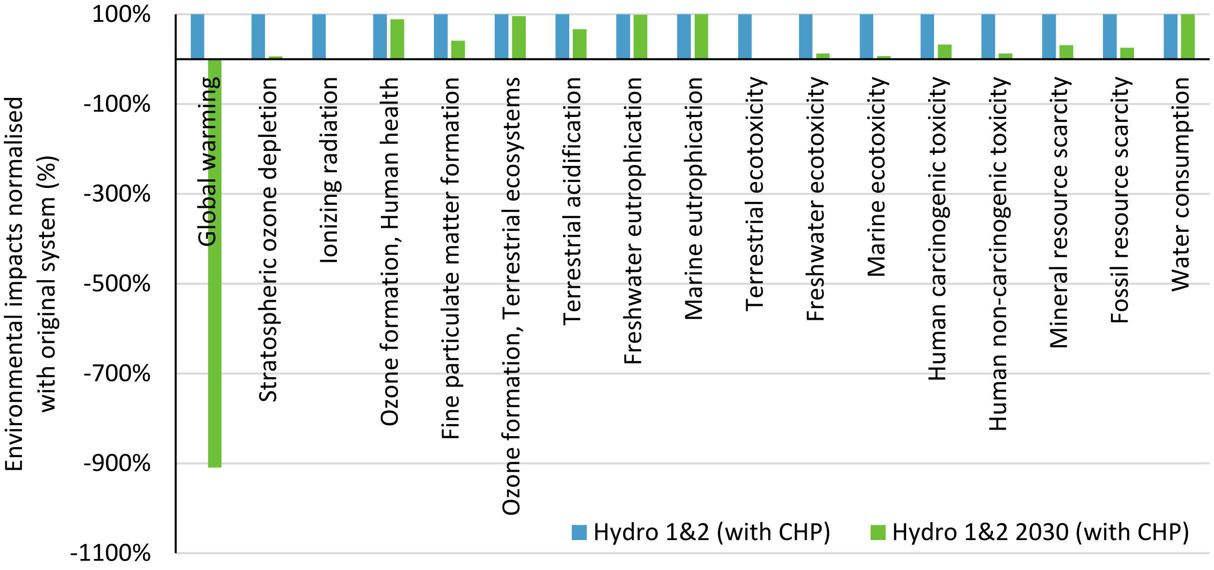


Figure 5.6 Effect of electricity generation in 2030 on Scenario 1

5.1.2. Economic impacts Assessment of HYDRO1&2

To demonstrate the functionality of the CWS, real data from the site was utilized. Table 4.2 and Table 4.4 summarize the capital, installation, and annual operation and maintenance costs for the system. Consideration is given to the 8% Greek discount rate (location of the demonstrator sites) and a 20-year lifespan. Table 5.1 and Figure 5.7 depict the outcomes of the LCC analysis for Scenario 1 based on the collected data. The CAPEX is the same for all scenarios, as are the OPEX costs of maintenance and human resources, but the cost of energy is 11% higher in Scenario 1.2 than in 1, 1.1, and 1.3. In the revenue analysis, the revenue from WW treatment, school visits, the sale of compost, and the sale of food produced is the same for all scenarios except scenario 1.1, where revenues from selling of remaining treated WW exist. In scenario 1.2, the savings from irrigation water are 36% greater than in scenarios 1.2 and 1.3, while in scenario 1, the savings are 11% greater than in scenarios 1.2 and 1.3. These variations in OPEX and revenue in the calculation of the economic indicators NPV, IRR, and PP led to the disparity in economic profitability between these scenarios. Therefore, based on the results of economic indicators, the economic profitability of scenario 1.1 is the best situation in comparison to others. The respective scenarios based on economic profitability is as follows:

Scenario 1.1> Scenario 1.3 > Scenario 1> Scenario 1.2

Table 5.1. LCC results of HYDRO1&2

Scenario 1				
	Scenario1	Scenario1.1	Scenario1.2	Scenario1.3
CAPEX - €	477,257.00	477,257.00	477,257.00	477,257.00
CAPEX - €/year	11,517.04	11,517.04	11,517.04	11,517.04
Maintenance costs - €/year	7,800.00	7,800.00	7,800.00	7,800.00
HR requirement (equal. distr. without UF) - €/year	9,400.00	9,400.00	9,400.00	9,400.00
Costs for energy - €/year	1,705.84	1,705.84	1,833.68	1,578.00
Costs for Chemicals - €/year	0.00	0.00	0.00	0.00
Revenues for WW treatment - €/year	33,292.00	33,292.00	33,292.00	33,292.00

Revenues from visits (schools & tourists) - €/year	1,750.00	1,750.00	1,750.00	1,750.00
Revenues from fuel production - €/year	0.00	0.00	0.00	0.00
Savings from electricity production & use - €/year	918.40	918.40	918.40	918.40
Revenues from thermal energy - €/year	1,312.00	1,312.00	1,312.00	1,312.00
Revenues from selling compost - €/year	1,105.74	1,105.74	1,105.74	1,105.74
Revenues from produced food - €/year	49,248.76	49,248.76	49,248.76	49,248.76
Revenues from remaining treated WW sold - €/year	0.00	3,205.90	0.00	0.00
Savings from irrigation water - €/year	1,307.04	1307.04	1,146.53	1,467.55
Savings from nutrients in fertigation water - €/year	13,897.39	13,894.39	12,188.06	15600.72
Saving from Carbon Sequestration	156	156	156	156
Scenario 1				
	Scenario1	Scenario1.1	Scenario1.2	Scenario1.3
CAPEX	477,257.00 €	477,257.00 €	477,257.00 €	477,257.00 €
OPEX	9,505.84 €	18,905.84 €	19,033.68 €	18,778.00 €
REVENUE	102,996.32 €	106,202.22 €	101,129.48 €	104,863.17 €
CASH FLOW	81,973.45 €	75,779.35 €	70,578.77 €	74,568.13 €
Scenario 1				
	Scenario1	Scenario1.1	Scenario1.2	Scenario1.3
NPV	654,095.90 €	587,975.26 €	532,460.21 €	575,045.79 €
IRR	13.08	11.63	10.50	11.36
PP	5.82	6.30	6.76	6.40

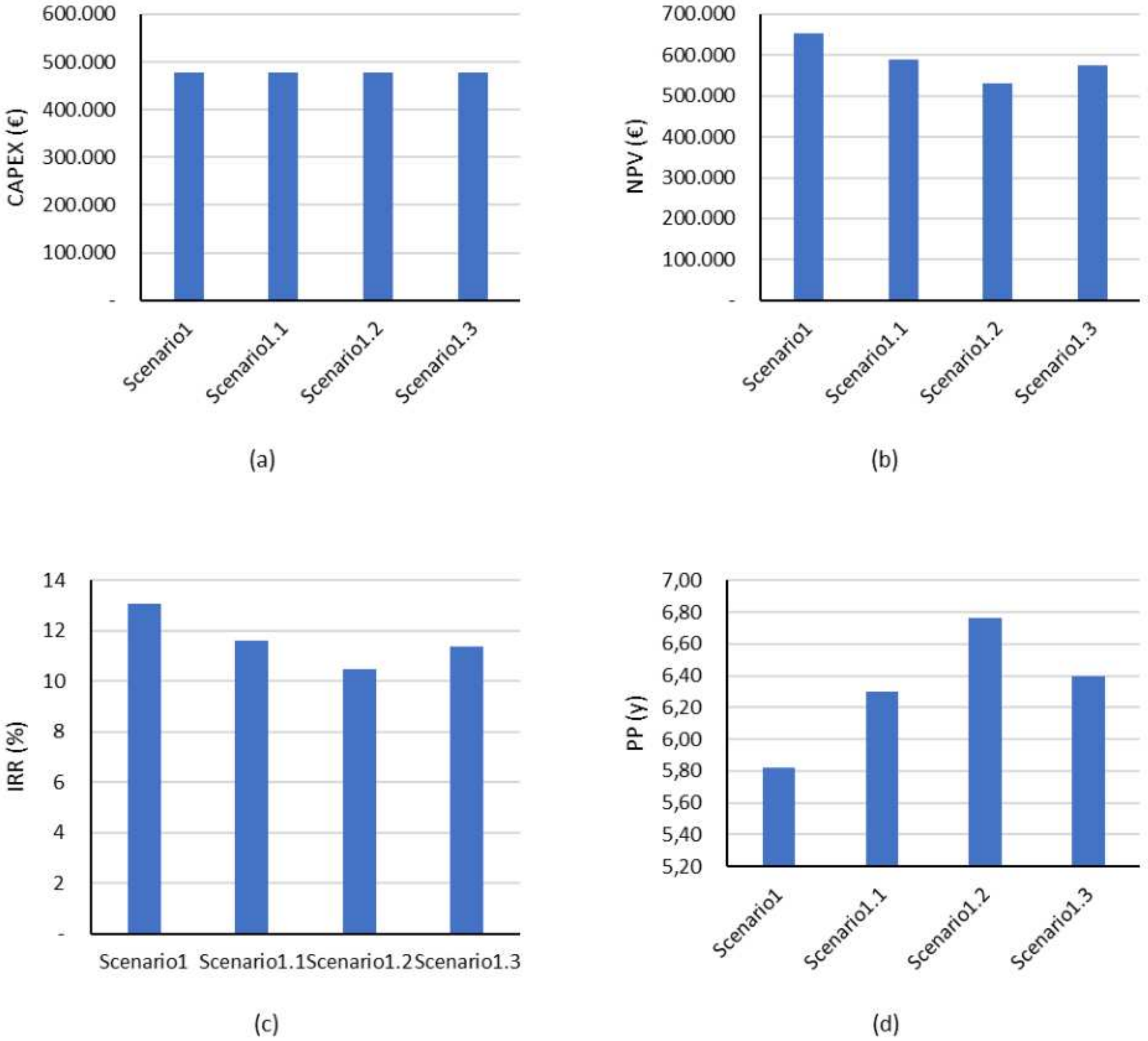


Figure 5.7. Economic result of various HYDRO1&2 scenarios: (a) CAPEX, (b) NPV, (c) IRR, and (d) PP

The economic assessment and calculated economic indicators of Scenarios 2 and 3 are presented in Table 5.2, Table 5.3 and Figure 5.8. The CAPEX in Scenario 3, is 11% more than Scenario2, in the OPEX, human resources cost is same, however cost of energy and cost of maintenance in Scenario 2 are respectively 9% and 11% more than Scenario 3. In the revenue analysis, revenue from fuel production exists in scenario 2 while the revenue from energy production and saving energy only exist in scenario 3 which is 0.06% of all Scenario3's revenue. These differences in OPEX and revenue in the calculation of economic indicators of NPV, IRR and PP caused the difference between economic profitability of these scenarios. Based on the results of economic indicators, the economic profitability of Scenario 2 is better than Scenario 3.

Scenario 2 > Scenario 3

Table 5.2. Economic assessment of scenarios 2 and 3 of HYDRO1&2

Scenario 2 & 3		
	Scenario 2	Scenario 3
CAPEX - €	467,257.00	527,257.00
CAPEX - €/year	11,275.72	12,723.62

Maintenance costs - €/year	7,800.00	7,900.00
HR requirement (equal. distr. without UF) - €/year	9,400.00	9,400.00
Costs for energy - €/year	2,854.12	1,736.53
Costs for Chemicals - €/year	219.77	34.69
Revenues for WW treatment - €/year	33,292.00	33,292.00
Revenues from visits (schools & tourists) - €/year	1,750.00	1,750.00
Revenues from fuel production - €/year	2,654.94	0.00
Savings from electricity production & use - €/year	0.00	1,016.99
Revenues from thermal energy - €/year	0.00	1,452.85
Revenues from selling compost - €/year	1,105.74	1,105.74
Revenues from produced food - €/year	49,248.76	49,248.76
Revenues from remaining treated WW sold - €/year	0.00	0.00
Savings from irrigation water - €/year	1,307.04	1,307.04
Savings from nutrients in fertigation water - €/year	11,930.86	11,930.86
Saving from Carbon Sequestration	156	156

Table 5.3. Economic indicators of scenarios 2 and 3 of HYDRO1&2

Scenario 2 & 3		
	Scenario 2	Scenario 3
CAPEX	467,257.00 €	527,257.00 €
Annual CAPEX	20,273.89 €	12,723.62 €
OPEX	101,457.34 €	19,071.22 €
REVENUE	69,907.74 €	101,272.24 €
CASH FLOW	20,273.89 €	69,477.40 €
NPV	529,926.79 €	497,555.22 €
IRR	10.67	8.94
PP	6.68	7.59

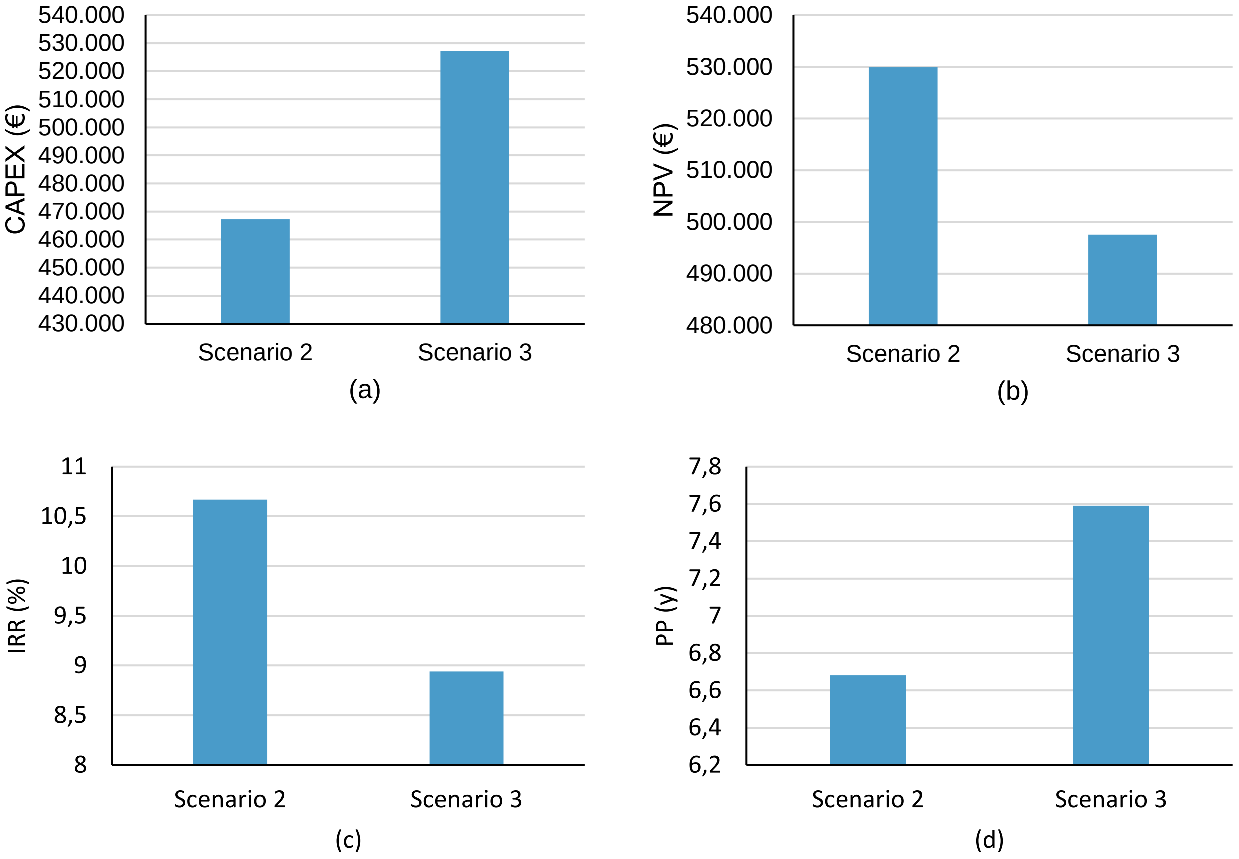


Figure 5.8. Economic results of scenarios 2 and 3 of HYDRO1&2: (a) CAPEX, (b) NPV, (c) IRR, and (d) PP

5.1.3. Eco-Efficiency Analysis

Saving in yearly OPEX is the economic impact indicator that is evaluated in eco-efficiency and it is calculated for each HYDRO1&2 scenarios. The metrics for environmental effect and economic impact are expressed per functional unit. Figure 5.9 shows the eco-efficiency results of each scenario. Figure 5.9 depicts the changing trajectory of eco-efficiency for all HYDRO1&2 scenarios. In general, the eco-efficiency of all HYDROs was positive. For some environmental impacts, the eco-efficiency is equal to 1, indicating that the system is eco-efficient when considering these impacts.

As can be seen in Figure 5.9, for Scenario2 all impacts are equal to 1, making it more eco-efficient than other scenarios. In terms of environmental impact, considering the mineral resource scarcity impact the system is less eco-efficient in all scenarios, with scenario 1 being the least eco-efficient. Regarding ozone formation, every scenario is entirely eco-efficient.

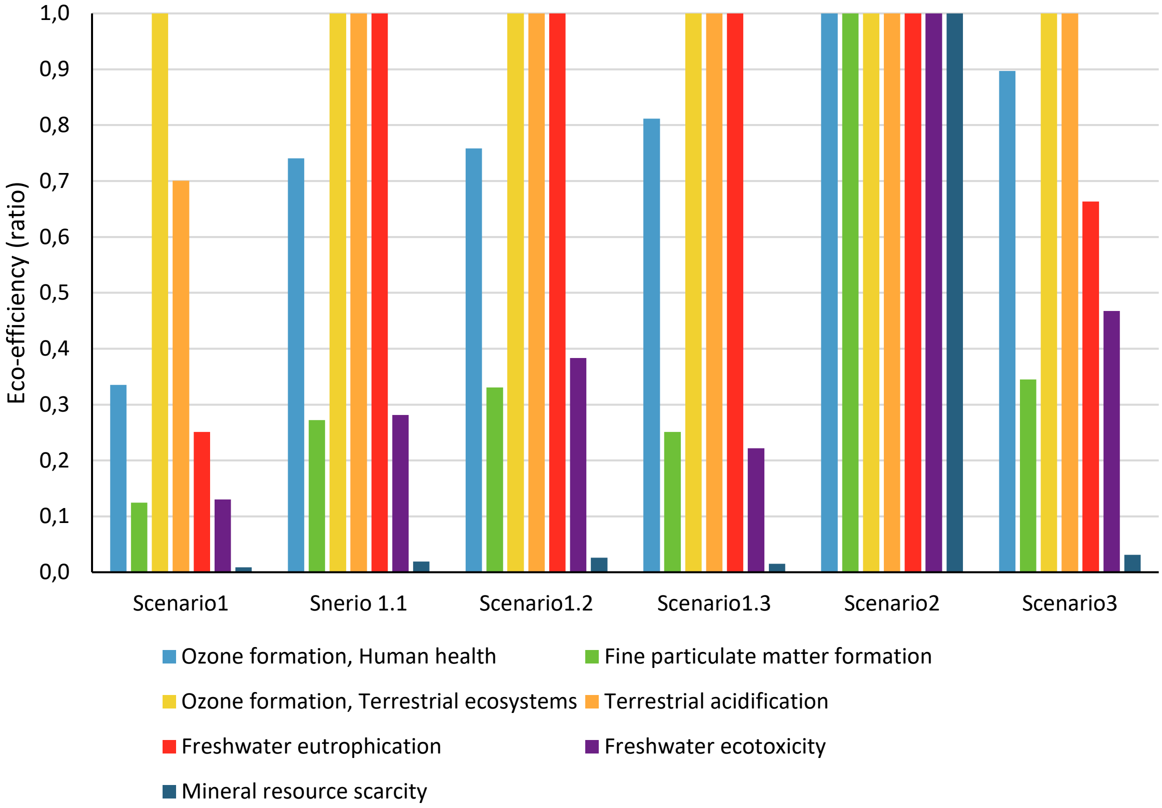


Figure 5.9. Normalised eco-efficiency results of HYDRO1&2 scenarios

5.1.3.1. Sensitivity analysis

A sensitivity analysis is performed to simultaneously assess the variation range of all input parameters in the proposed model. This aids in the detection of any variation from the expected target. A sensitivity analysis using graphical methods was performed on the economic indicators. Table 5.4 presents the sensitivity analysis that revealed that the market price of essential oil has the maximum effect on the project revenue; discount rate has the maximum effect on the project NPV; loan interest rate has the maximum effect on the project annual CAPEX and consumable has the maximum effect on the project OPEX.

The parameters exerting the most effect on the economic indicators is presented in Table 5.4 and Figure 8.1 in Appendix. The sensitivity analysis results in terms of total and main indices are presented in Table 5.4, which presents all the investigated parameters and the indicators each of these parameters affects the most, differentiating between main and total indices.

Table 5.4. Most influenced Economic indicator per parameter tested (main and total indices) – HYDRO1&2

Annual CAPEX	Main indices	OPEX	Main indices	REV	Main indices	CF	Main indices	NPV	Main indices
Loan interest rate - %	1.12	Consumables - €/year	0.641	Remaining water sold scenario	0.629	Wastewater treatment tax	0.529	Discount rate - %	1.1
Maintenance costs - €/year	0.080	HR requirement (HYDRO1&2) €/Year	0.309	Price of compost - €/year	0.541	Consumables -€/year	0.441	Wastewater treatment tax	0.0803
UASB CAPEX (€)	0.050	Maintenance costs - €/year	0.05	fuel production - €/year	0.0528	Energy use for irrigation - kWh/m2	0.062	Rubus Fruticose - kg/plant	0.0502
Water price for irrigation - €/m^3	0.002	Energy use for irrigation - kWh/m^2	0.0309	Water price for irrigation - €/m^3	0.00448	Price of compost - €/year	0.011	Loan duration (years)	0.00213
Energy use for irrigation - kWh/m^2	0.0001	Nitrogen fertilizer price - €/kg	0.0198	Unit Price of Carbon sequestration in €/tons	0.00153	HR requirement (HYDRO1&2) - €/Year	0.0041	HR requirement (HYDRO1&2) - €/Year	0.00018

5.1.4. Recommendations for HYDRO1&2

In general, the HYDRO1&2 system performs better than the baseline whether it produces electricity of biomethane for vehicles. Thus, according to the LCA the recommendations regard the further improvement of environmental performance. It is highly recommended that the HYDRO1&2 system employs electricity from renewable sources. Secondly, if the process efficiencies or electricity generation efficiency improve; these, in turn, will also improve the environmental performance due to lower electricity consumption or higher electricity generation, respectively. Lastly, if there is no future water scarcity issue in Lesvos, the use of reclaimed water (that is not needed by the AGF) by external farmers with 100% open channels provides generally better environmental results than discharge to the sea or other irrigation options.

The project under consideration demonstrates a higher level of economic feasibility; thus, appears more favorable to undertake when compared to alternative options. Through rigorous financial analysis, indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period have been evaluated, consistently pointing towards a positive outcome for the project. The calculated NPV reveals a positive value, indicating that the project's anticipated cash inflows are expected to exceed its initial investment and associated costs. This suggests the potential for substantial returns on investment and the creation of value over time. Additionally, the project's favorable IRR signifies an attractive rate of return, while the shorter payback period indicates a relatively rapid recovery of the initial investment. Considering these economic indicators collectively, the project's superior feasibility becomes apparent, providing strong support for its implementation and potential success when compared to alternative options.

After comparing the economic indicators of six scenarios in HYDRO1&2, it is evident that scenario 1.1 emerges as the best option to pursue (Figure 5.10). On the other hand, Scenario 3 shows the lowest feasibility. Analyzing the profitability of HYDRO1&2, the results shown in Figure 5.10 indicate the following rankings:

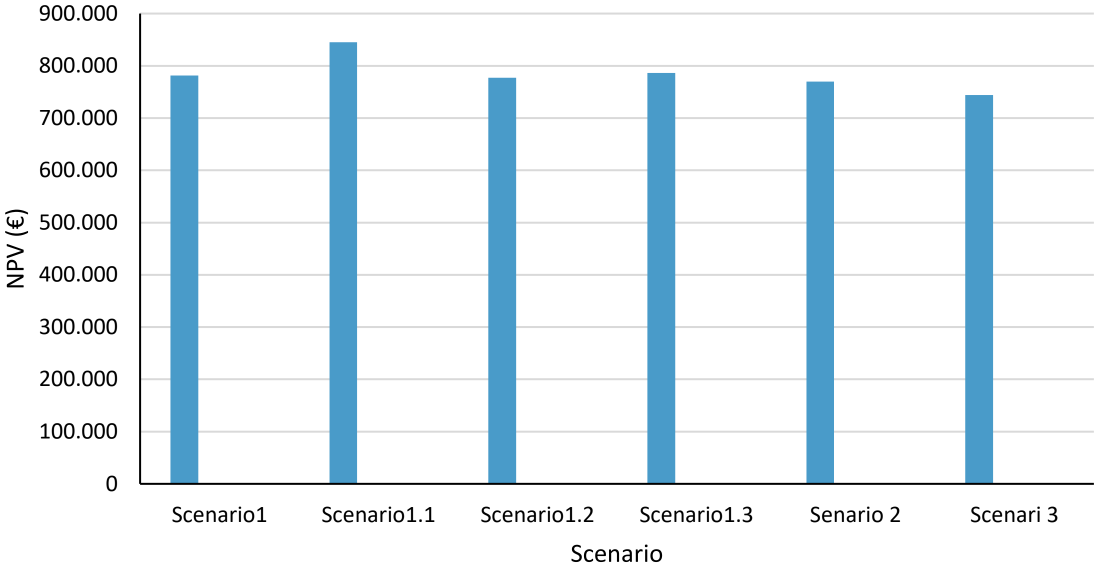


Figure 5.10. Feasibility of HYDRO1&2 scenarios

Scenario 1.1> Scenario 1.3 > Scenario 2> Scenario 1> Scenario 1.2> Scenario 3

5.2. HYDRO3 results

5.2.1. Environmental impacts of HYDRO3 – Comparison with baseline

Figure 5.11 shows the normalised results of the original and baseline systems. Non-normalised environmental results can be found in Table 8.8 of the Appendix. In most environmental impact categories, the original system performs better than the baseline system. Notably, environmental decrease is expected for Water consumption, Stratospheric ozone depletion, Mineral resource scarcity, Terrestrial acidification, and Ionizing radiation, approx. 100%, 99%, 97%, 91%, 91% and 99%, respectively. Furthermore, Freshwater eutrophication, Fine particulate matter formation, Ozone formation, Freshwater ecotoxicity, and Human non-carcinogenic toxicity result in environmental benefits which range between 21% and 81%. Only Marine ecotoxicity and Human carcinogenic toxicity result in a minor decrease of approx. 9% due to the increased oregano yield with conventional farming of the baseline system. Lastly, Global warming potential results in the largest increase because it is a positive value regarding the baseline system (net emitter of CO_2), while the value becomes negative in the case of the HYDRO3 system (net carbon sink).

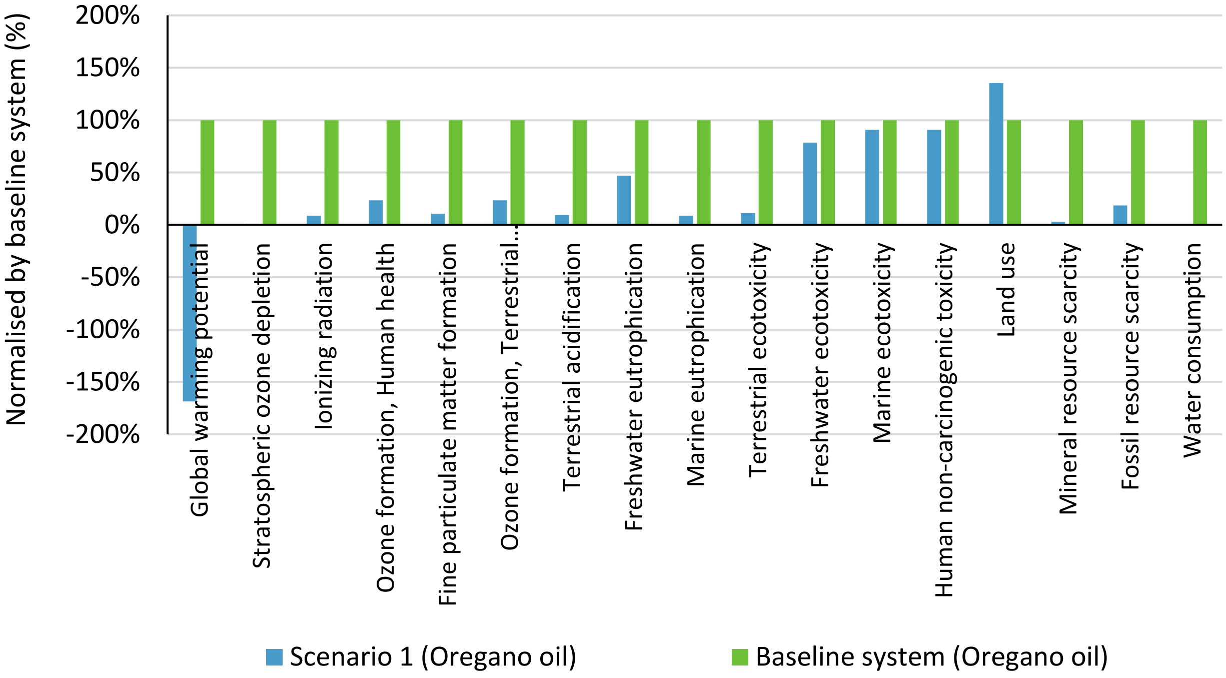


Figure 5.11 Environmental impact resultsof Senario 1 (HYDRO3) normalised by baseline system

5.2.1.1. Contribution Analysis of impacts of HYDRO3

Figure 5.12 shows how much each stage contributes to the Global warming potential. First, the packaging and distillation stages and atmospheric CO_2 capture contribute the same absolute amounts to both systems. Second, the difference between the original and baseline systems stems from energy consumption in the cultivation stage. Regarding the original system, electricity consumption contributes to a considerable extent for the original system (approx. 25%) and it is mainly consumed at the distillation stage (approx. 80.7% of the total electricity). On the other hand, regarding the baseline system the production and application of fertilizers in the cultivation stage is the main contributor, approx. 2.3 kg CO_2 eq. or 581% of total emissions. The contribution is higher than 100% due to the atmospheric CO_2 sequestration resulting in reducing the Global warming potential. The contribution of electricity consumption is also small (approx. 50%) due to the low amounts that are consumed, mainly in the cultivation stage for the provision of irrigation water (approx. 43.5% of the total electricity).

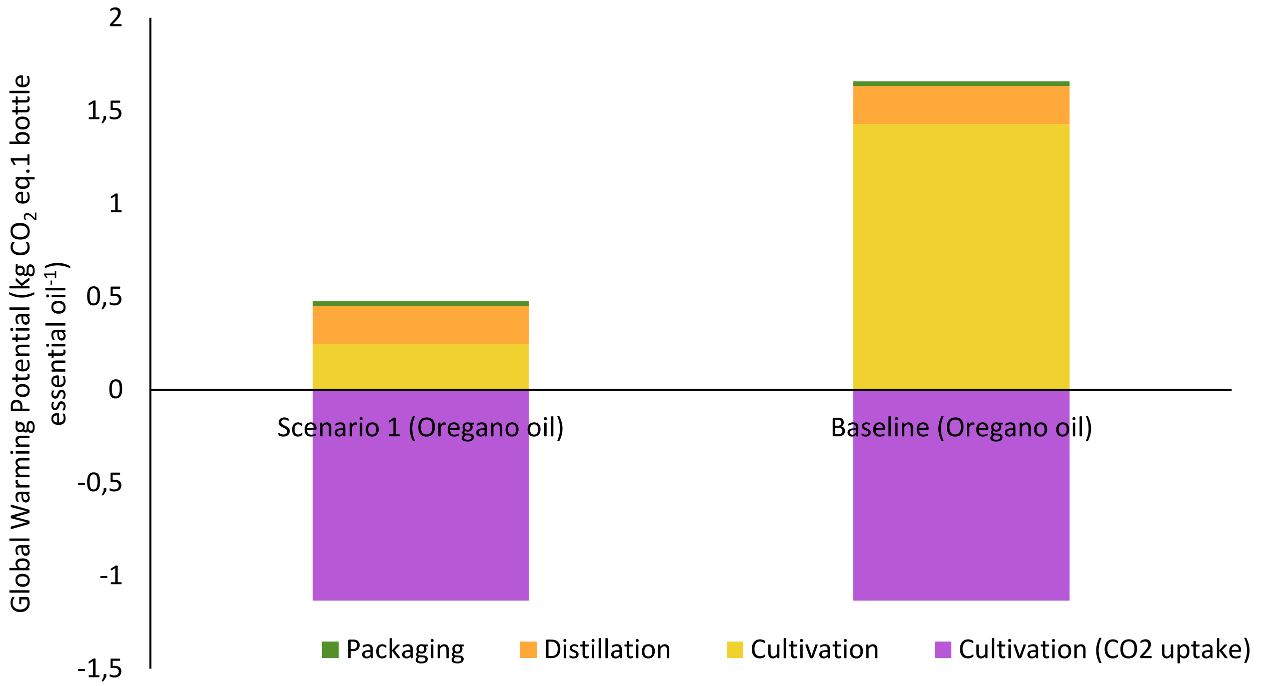


Figure 5.12 Contribution analysis of global warming potential by life cycle stage

5.2.1.2. Environmental impacts of HYDRO3 – Alternative scenarios

Figure 5.13 shows the environmental impact results of HYDRO3 in two years of cultivation (i.e., 2022 and 2023) in relation to the Baseline system. Non-normalized environmental results due to future production yields of oregano can be found in Table 8.7 of the Appendix. HYDRO3 performs better for all considered environmental impacts than the Baseline, even for 2022 when the oregano yield was low due to the young age of the oregano plants and bad weather conditions. This improvement ranges between 9% and 100% of the Baseline system results. Furthermore, due to the employment of rainwater and limited use of fertilizers, the GWP score of HYDRO3 is negative which means that the production and consumption of one oregano essential oil bottle sequesters more atmospheric CO_2 than it emits. In addition, the expected increase in oregano yield in 2023 results in a minor improvement of all environmental impacts. In contrast, the anticipated lower and higher oregano yields in 2023 do not significantly affect the environmental impact results.

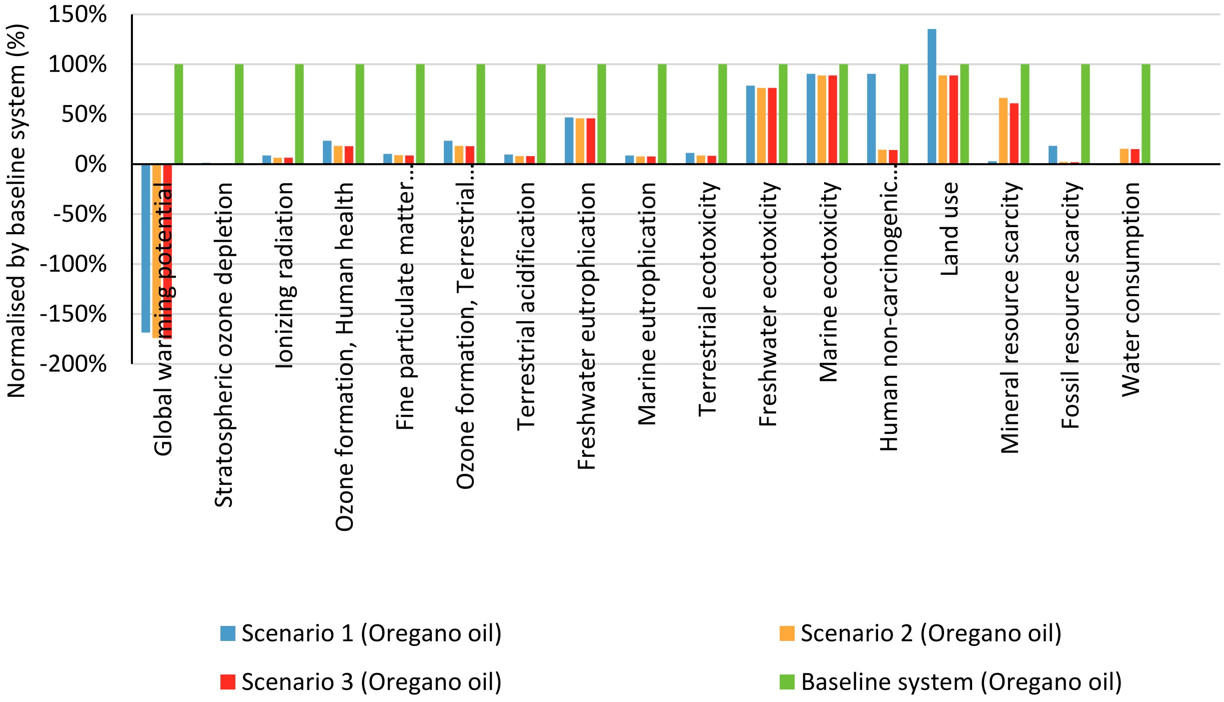


Figure 5.13 Environmental impact results of Scenario 1 in 2022, Scenarios 2 and 3 in 2023, and Baseline system, with functional unit 1 bottle of oregano essential oil

5.2.1.3. 2030 Scenario

Figure 5.14 shows the expected environmental performance in 2030 normalised with the performance of 2022. Non-normalised environmental results due to electricity generation in 2030 can be found in Table 8.10 of the Appendix. Figure 5.13 shows that all environmental impacts are improved in 2030. The Global warming value is larger in 2030 because the oregano oil acts as a carbon sink because its Global warming value is negative. Thus, an increase upon normalization in 2030 means that the environmental benefit regarding Global warming is greater. The rest environmental impacts improve between 39% and 61% due to the 2030 Greek electricity mix.

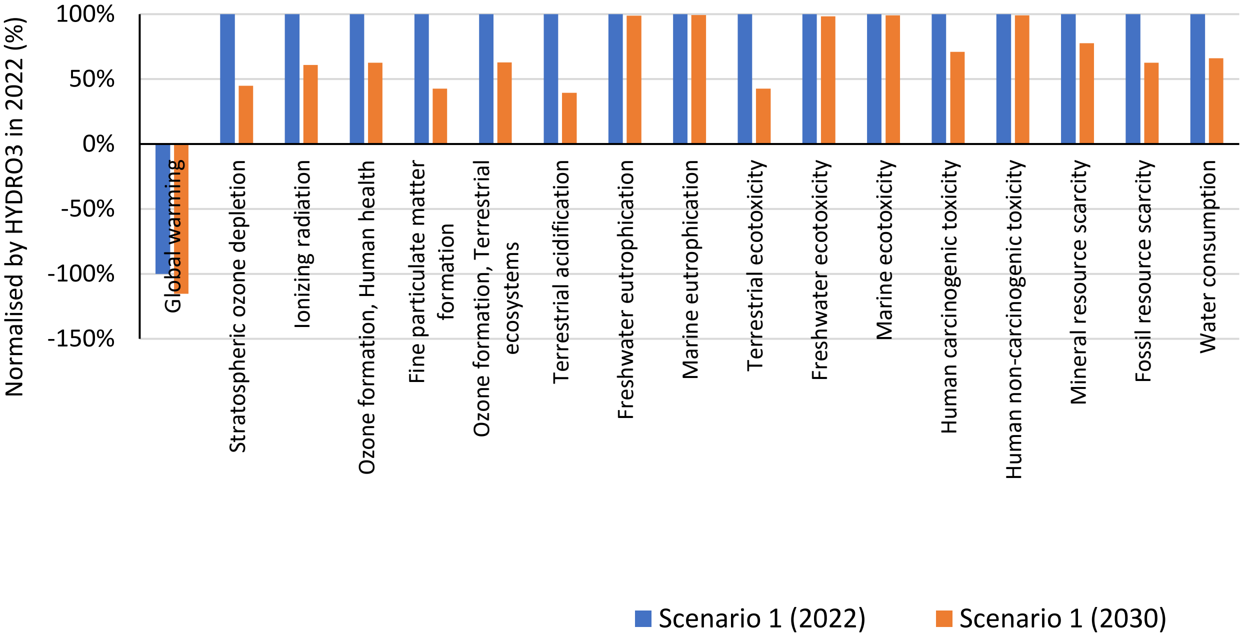


Figure 5.14 Environmental performance of oregano oil in 2030 normalised with performance in 2022

5.2.2. Economic impacts Assessment of HYDRO3

Based on data from the implemented nature-based water system (NBWS) in HYDRO3, the total harvested rainwater is approx. 66.79 m^3/year. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards (actual discount rate of Greece is 8% which is counted in this calculation over a life span of 20-years for the project). Since the amount of fertilizer that will be used is equivalent to the amount of fertilizer produced from green residual waste, it is omitted from the calculation. Table 5.5. presents all the internal and external benefits caused by implementing HYDRO3 in three different scenarios of yield 2022 (Scenario 1), and low yield (Scenario 2) and high yield of 2023 (Scenario 3). Figure 5.15 and Table 5.6 present the result of calculating economic indicators to compare the profibality of different scenarios and baseline scenario. The CAPEX is the same for all scenarios, but the CAPEX for the baseline scenario is only 23% of the CAPEX for all three HYDRO3 scenarios. In terms of OPEX, baseline and scenario 3 have the same cost of water for irrigation, while scenario 1 has the lowest cost. The revenue generated from the sale of essential oil in Scenario 3 is approximately double that of Scenario 1, which is approximately 34% less than Scenario 3. These differences in OPEX and revenue used to calculate the economic indicators NPV, IRR, and PP contributed to the disparity in economic profitability between these scenarios.

Based on the outcomes of economic indicators, the economic profitability of Scenario 3 is therefore superior to that of other scenarios. The respective economic profitability-based scenarios are as follows:

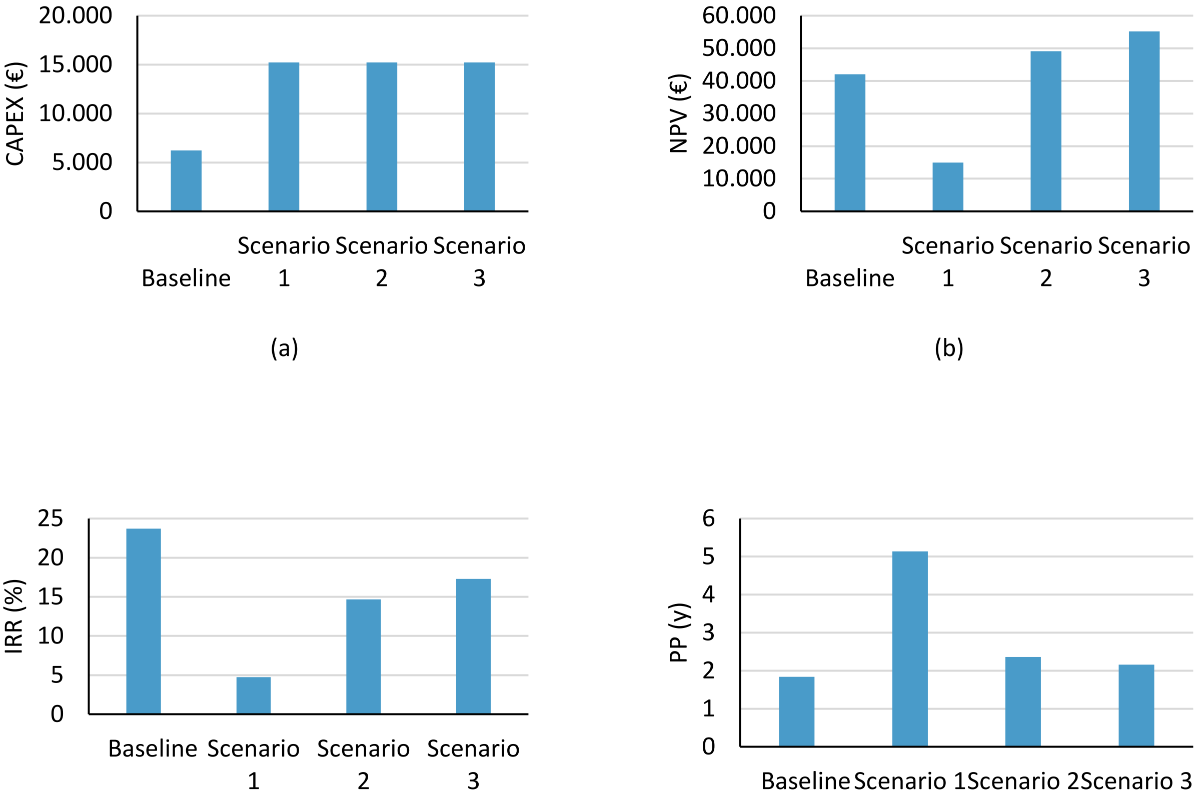
Scenario3 > Scenario 2 > Baseline> Scenario 1

Table 5.5. Internal and external cost and benefit caused by implementing HYDRO3 in baseline scenario and scenario 1, 2, and 3:

HYDRO3				
	Baseline	Scenario 1	Scenario 2	Scenario 3
CAPEX - €	6,230.00	15,215.00	15,215.00	15,215.00
CAPEX - €/year	242.6	886.21	886.21	886.21
Costs for water (irrigation) - €/year	10.21	4.6	9.36	10.21
Costs for energy - €/year	30.96	17.9	33.09	35.81
Costs for fertilizers - €/year	425.13	3.15	3.15	3.15
Consumables, Certification & Product Packaging - €/year	330	530	530	530
Savings from water production & use (irrigation) - €/year	63.49	62	63.49069	63.49
Revenues from selling essential oil - €/year	3,601.99	2,881.59	5,869.91	6,403.54
Revenues from selling hydrosol - €/year	607.84	486.27	990.55	1,080.6
Savings from Carbon sequestration - €/year	61.01	88.20	88.20	88.20

Table 5.6. Economic parameters and indicators

Economic parameters				
	Baseline	Scenario 1	Scenario 2	Scenario 3
CAPEX	6,230.00€	15,215.00 €	15,215.00 €	15,215.00 €
OPEX	242.59€	555.64 €	575.61 €	579.17 €
REVENUE	892.10€	3,518.06 €	7,010.66 €	7,634.34 €
CASH FLOW	4,270.83€	2,962.42 €	6,435.05 €	7,055.16 €
Economic Indicators				
	Baseline	Scenario 1	Scenario 2	Scenario 3
NPV	42,000.57€	14,997.50 €	49,092.32 €	55,180.68 €
IRR	23.70	4.75	14.66	17.29
PP	1.84	5.14	2.36	2.16



(a)

(b)

(c)

(d)

Figure 5.15. Economic result of various HYDRO3 scenarios: (a) CAPEX, (b) NPV, (c) IRR, and (d) PP

5.2.3. Eco-Efficiency Analysis

Saving in yearly OPEX, which is calculated for each of the HYDRO3 scenarios, is the economic impact indicator that is evaluated in eco-efficiency. The metrics for environmental effect and economic impact are expressed per functional unit. Figure 5.16 shows the eco-efficiency results of each scenario.

Figure 5.16 depicts the changing trajectory of eco-efficiency for all HYDRO3 scenarios. In general, the eco-efficiency of all HYDROs was positive. For some environmental impacts, the eco-efficiency is equal to 1, indicating that the system is eco-efficient when considering these impacts. As can be seen in Figure 5.16, for Scenario2 and 3 most of the eco-efficiency for different environmental impacts are around 1, making it more eco-efficient than other scenarios. In terms of environmental impact, considering the Ozone formation, Terrestrial ecosystems impact the system is less eco-efficient in scenario 1, with scenario 2 and 3 being the most eco-efficient. Regarding Human non-carcinogenic toxicity and Marine ecotoxicity, every scenario is entirely more eco-efficient than baseline scenario.

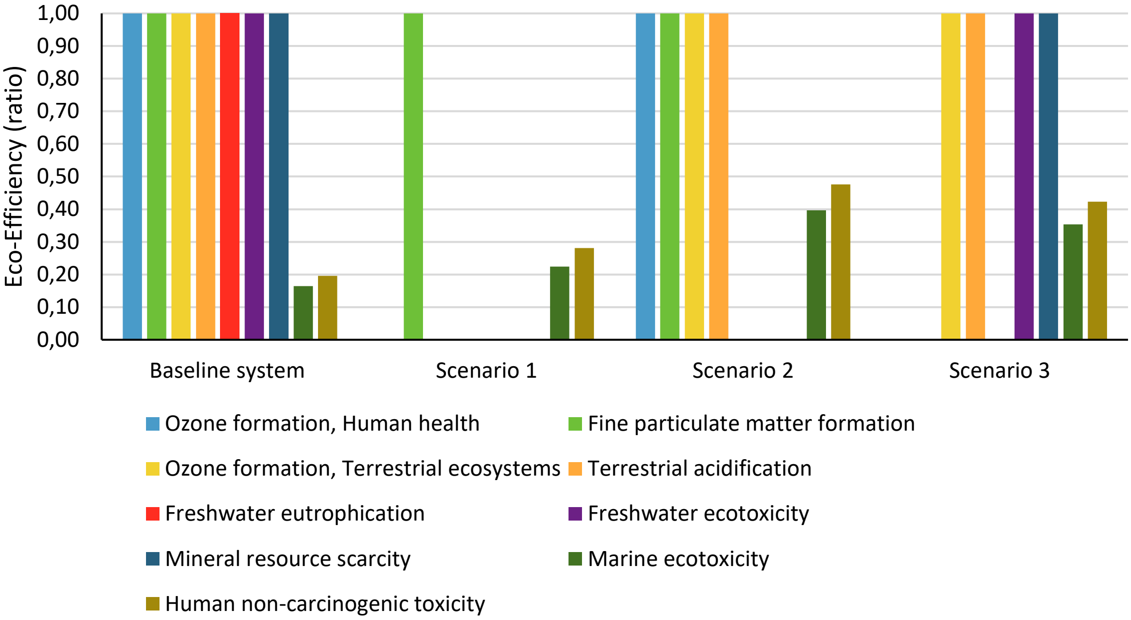


Figure 5.16. Normalised eco-efficiency of HYDRO3 scenarios and baseline systems with environmental impacts

5.2.3.1. Sensitivity Analysis

A sensitivity analysis is performed to simultaneously assess the variation range of all input parameters in the proposed model. This aids in the detection of any variation from the expected target. A sensitivity analysis using graphical methods was performed on the economic indicators. Table 5.7. and Figure 8.2 in Appendix presents the sensitivity analysis that revealed that the market price of essential oil has the maximum effect on the project revenue; discount rate has the maximum effect on the project NPV; loan interest rate has the maximum effect on the project annual CAPEX and; consumable has the maximum effect on the project OPEX. The parameters exerting the most effect on the economic indicators are presented in Table 5.7. The sensitivity analysis results in terms of total and main indices are presented in Table 5.7 and it presents all the investigated parameters and the indicators each of these parameters affects the most, differentiating between main and total indices.

Table 5.7. Most influenced Economic indicator per parameter tested (main and total indices) – HYDRO3

Annual CAPEX	Main indices	OPEX	Main indices	REV	Main indices	CF	Main indices	NPV	Main indices
Loan interest rate - %	1.02	Consumables - €/year	0.54	Market price for Essential oil - €/bottle	0.53	Market price for Essential oil - €/bottle	0.43	Discount rate - %	1.00
Consumables - €/year	0.00	Product packaging- €/year	0.23	Yield 2022	0.46	Consumables - €/year	0.36	Market price for Hydrosol - €/ml	0.00
Product packaging- €/year	0.00	Energy Price in Mykonos- €/kWh	0.17	Market price for Hydrosol - €/ml	0.01	Energy Price in Mykonos- €/kWh	0.01	Selling price for irrigation water - €/m^3	0.00
Energy Price in Mykonos- €/kWh	0.00	Planting coefficient K	0.03	Water price for irrigation in Mykonos - €/m^3	0.00	Yield 2022	0.01	Market price for Essential oil - €/bottle	0.00
Water price for irrigation in Mykonos - €/m^3	0.00	Cultivation area (10*ha)	0.02	Unit Price of Carbon sequestration in €/tons	0.00	Unit Price of Carbon sequestration in €/tons	0.00	Water price for irrigation in Mykonos - €/m^2	0.00

5.2.4. Recommendations for HYDRO3

The HYDRO3 system performs better than the baseline system for all environmental impacts. The recommendations regard further improvement of the HYDRO3 system. Because the oregano farm is young, its annual yield is expected to increase in the first five years. Therefore, it is recommended to model the system again with the oregano yield in 2024-2026. In addition, the electricity consumption in distillation and cultivation are the major contributors; thus, based on the environmental assessment, it is suggested to employ renewable electricity in both stages to further decrease environmental burdens. However, the employment of renewable electricity may result in increased costs. Therefore, an economic assessment needs to be performed beforehand. Lastly, the distillation organic wastes are currently landfilled. It is suggested to compost them and use them as soil enhancers to return nutrients to the soil; or process them to produce biochar and use the waste (in this case) as a carbon stock. However, in both cases, the current LCA model will need to be updated to quantify the prospective environmental benefits.

5.3. HYDRO4 results

5.3.1. Environmental impacts of HYDRO4 – Comparison with baseline

Figure 5.17 depicts the environmental impact results of the original system normalised with the baseline system to produce water for domestic use of Scenario 1A. Non-normalised environmental results can be found in Table 8.11 of the Appendix. A combination of harvested rainwater (27% of total volume) and tap water (73% of total volume) was used to meet the overall water needs of the residence. Noteworthy, tap water was modelled based on an assortment of current water transformation methods prevalent in Europe without Switzerland, namely conventional treatment, conventional with biological, direct filtration, microstrainer, ultrafiltration, underground water with chemical, underground water with disinfection, and underground without treatment. As a result, most of the environmental impact categories were significantly lower (Ionizing radiation, Human carcinogenic toxicity, and Mineral resource scarcity) or marginal (>95% of normalised baseline) in the original system when compared to the baseline, water treatment processes at the centralized plant. However, Freshwater ecotoxicity was slightly higher in the original system because of the emissions mainly resulting from copper mine operations necessary for the provision of low voltage electricity required to pump harvested rainwater to the residences.

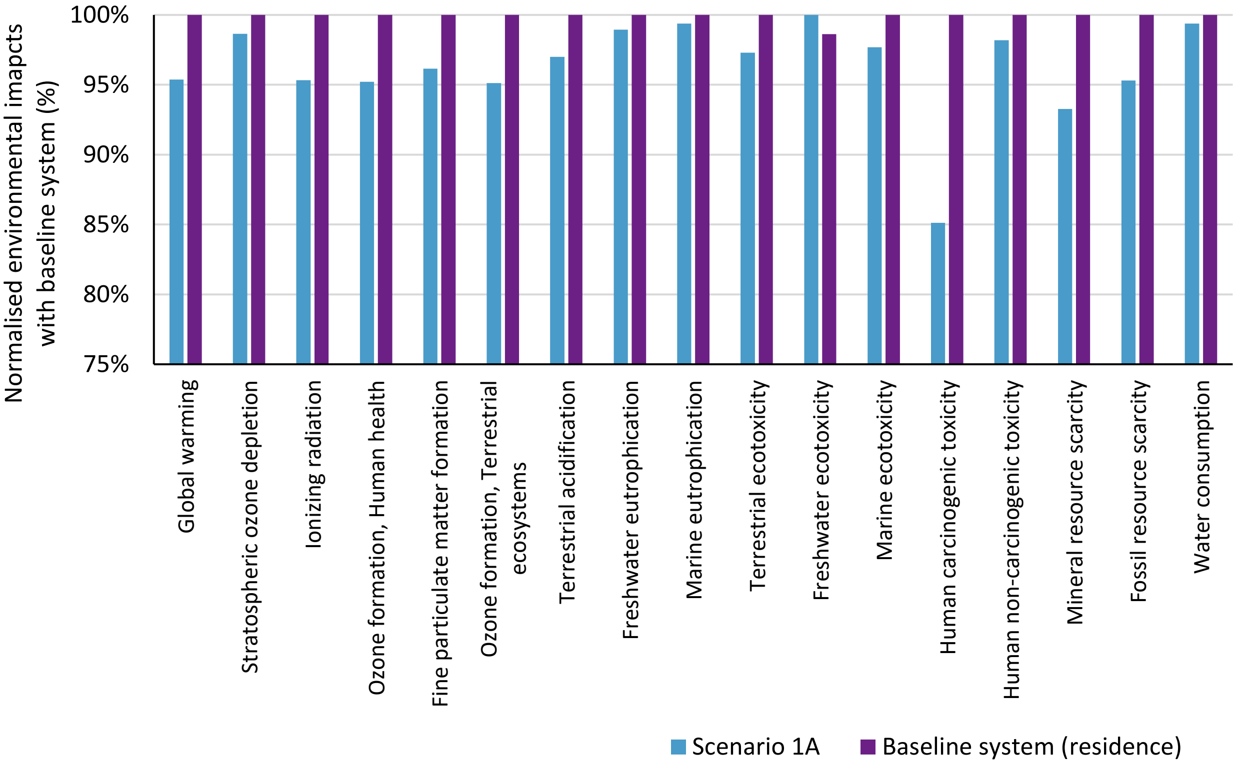


Figure 5.17 Normalised environmental impact results of original and baseline systems, with functional unit of 1 m^3 of water supplied for residential use (Scenario 1A)

Figure 5.18 shows the results of the original system normalised with the baseline system to produce bottled lavender essential oil of Scenario 1B. Non-normalised environmental results can be found in Table 8.12 of the Appendix. Many of the environmental benefits such as Global warming potential, Stratospheric ozone depletion, Ionizing radiation, Ozone formation (human health and terrestrial ecosystems), Terrestrial acidification, Freshwater ecotoxicity and Water consumption ranged between 20% and 73% reduction, when normalised with baseline. However, for Aquatic (freshwater and marine) eutrophication, Marine ecotoxicity, Human carcinogenic and non-carcinogenic toxicities, and Fossil resource scarcity, the original system had higher impacts. A comparative process contribution analysis of Scenario 1B with the corresponding Baseline revealed that for the Freshwater eutrophication impact category, irrigation stage alone was contributing approx. 42% (0.00104 kg P eq.) to the total emissions. Whereas for the baseline, the irrigation stage did not impact on the Freshwater eutrophication. Similarly, there was approx. 97% (0.00238 kg N eq.) contribution to the total emissions to the Marine eutrophication from irrigation stage on Scenario 1B; whilst irrigation stage did not affect the Marine eutrophication indicator for the Baseline system. When purchased deionized water was used for distillation, there was an overall 51.19% increase in electricity consumption (52.92% increase, when a dehumidifier was used) in the activities related to the production of bottled lavender essential oil in the first year of operation in comparison to the baseline system. Moreover, the cultivation stage alone consumed an estimated 86.85% of total electricity inputs in the original system.

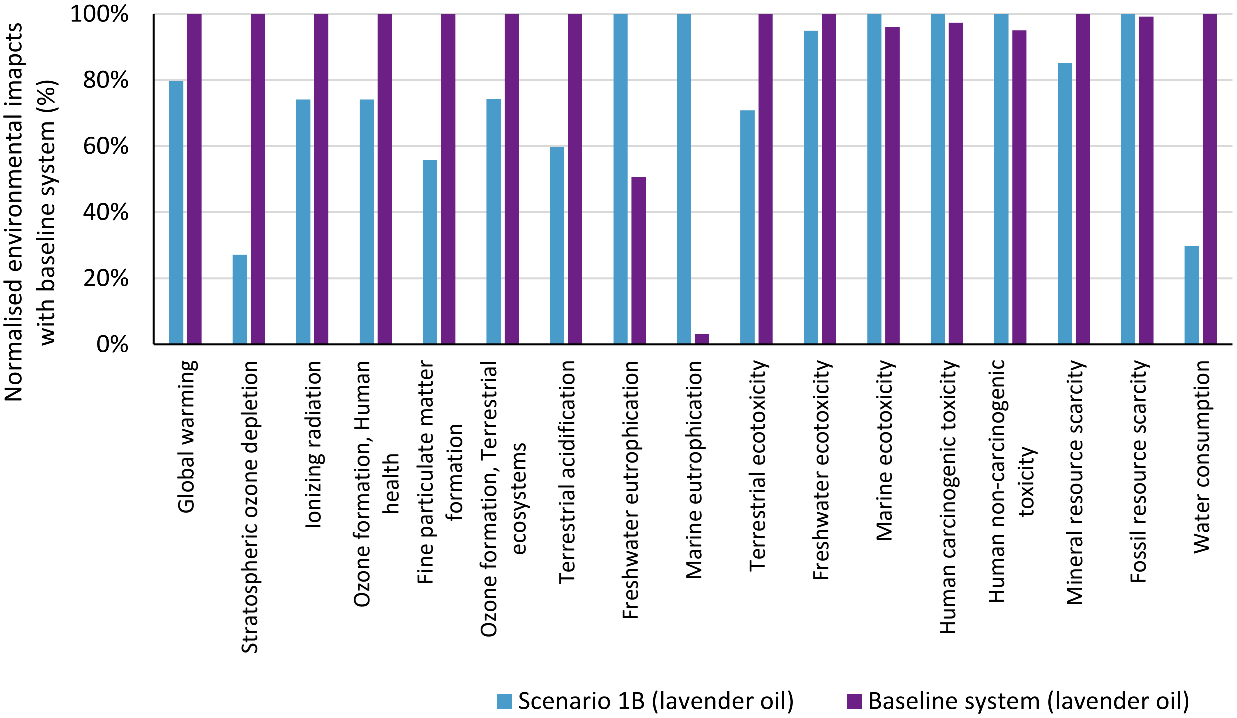


Figure 5.18 Normalised environmental impact results of the original system in year 1 (2022) and the corresponding baseline system, with functional unit 1 bottle of lavender essential oil (Scenario 1B)

5.3.1.1. Environmental impacts of HYDRO4 – Alternative scenarios

Figure 5.19Figure 5.19 represents the environmental impact results of Scenarios 1B, 2B and 3B in relation to the corresponding baseline system. Non-normalised environmental impact values are provided in Table 8.11 of the Appendix. There were substantial improvements in the environmental profile in the second year of operation over the previous year. Year 2 (Scenarios 2B and 3B) improvements were between 32% and 111% emissions reduction when compared to the baseline system. However, the variation in expected yields (viz. low and high) in year 2 did not result in any marked differences in the environmental impact categories. In addition, the improved biomass harvest with subsequently larger volumes of lavender essential oil extracted in the second year of cultivation resulted in a negative GWP value over the previous year, including the baseline system. Therefore, no greenhouse gases were emitted across the life cycle of bottled lavender essential oil through HYDRO4 as it removed more CO_2 equivalences from the atmosphere than produced. Also, there was substantial (89%) reduction of marine eutrophication in year 2 over the previous year; however, this impact category was 8% above the baseline system. The improvement in the marine eutrophication impact category can be attributed to a higher cultivation output followed by a higher product output in year 2.

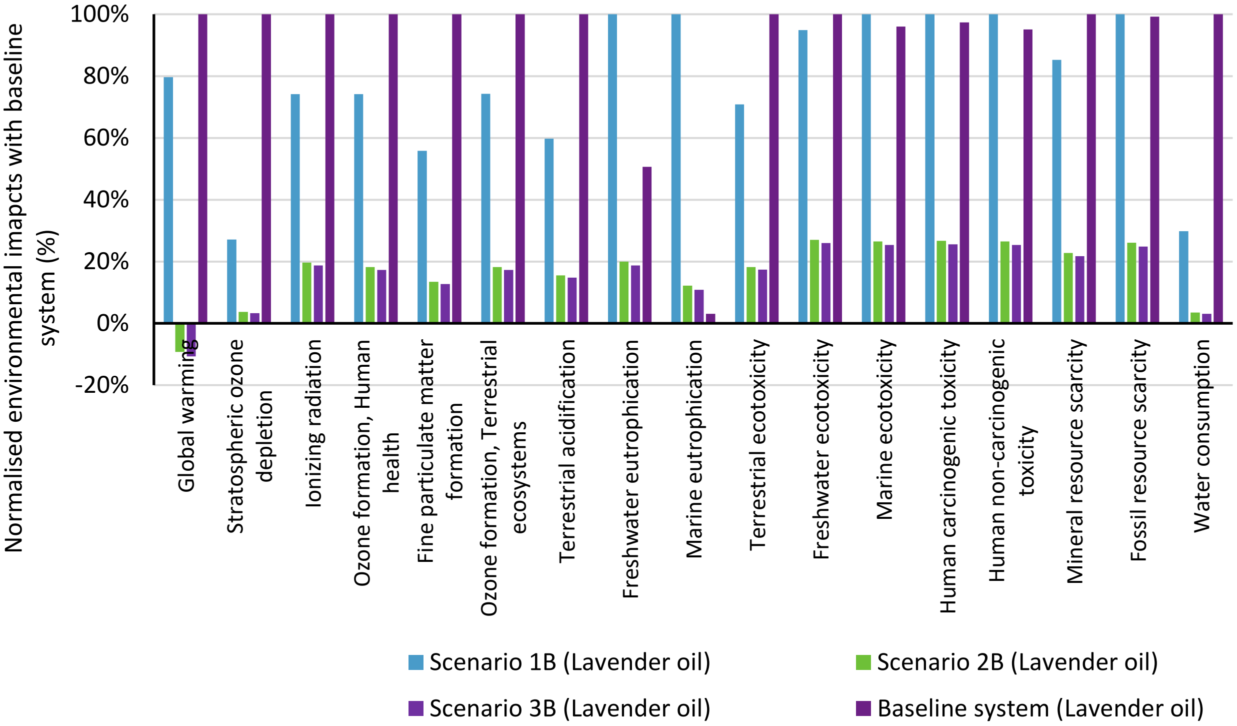


Figure 5.19 Normalised environmental impact results of Scenario 1B (2022), Scenario 2B and 3B (2023), and baseline system, with functional unit 1 bottle of lavender essential oil

5.3.1.2. 2030 Scenario

Figure 5.20 shows the anticipated performance of environmental impact categories in year 2030, when factoring in improvements in the current the electricity mix for Greece, to supply water for domestic applications in Scenario 1B. Non-normalised environmental results due to electricity consumption in 2030 can be found in Table 8.14 of the Appendix. The global warming potential score can be reduced to a further 4% and fossil resource scarcity category can be improved further to a 4.7% reduction for year 2030 as efforts to decarbonize the Greek economy come to fruition.

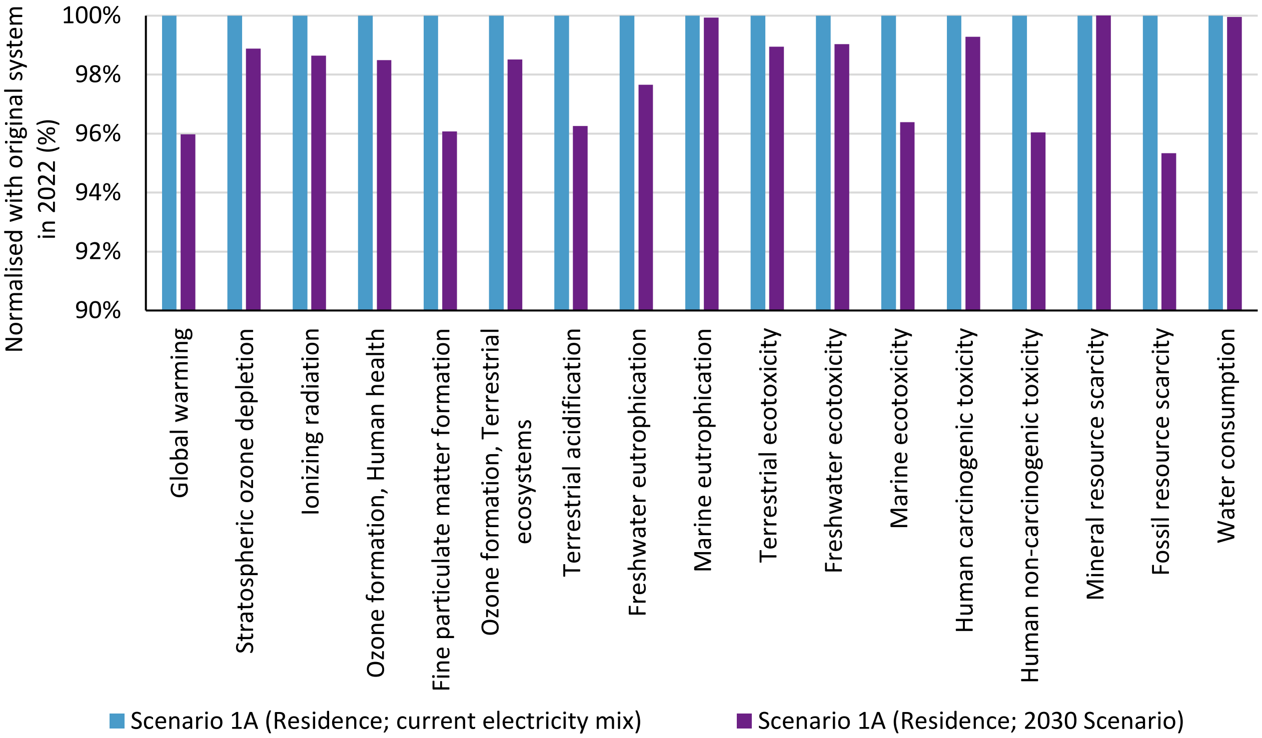


Figure 5.20 Environmental performance of the supply of water for domestic use (Scenario 1A) with the projected electricity mix for the year 2030 normalised with performance for the year 2022, using current electricity mix

Figure 5.21 depicts the expected environmental performance for the Scenario 1B system with regards to the production of bottled lavender oil when the projected Greek electricity mix for the calendar year 2030 is normalised with the performance of the first year for the current farm management practices and essential oil production (viz. 2022). Non-normalised environmental impact values are provided in Table 8.13 of the Appendix. The environmental impact results have improved for 2030, except for mineral resource scarcity which was found elevated. For example, the anticipated GWP score for 2030 was reduced to 47% of that of calendar year 2022. This suggests that the drive toward greater share for green energy sources for the Greek electricity mix favorably impacted on the overall environmental profile for bottled lavender essential oil production.

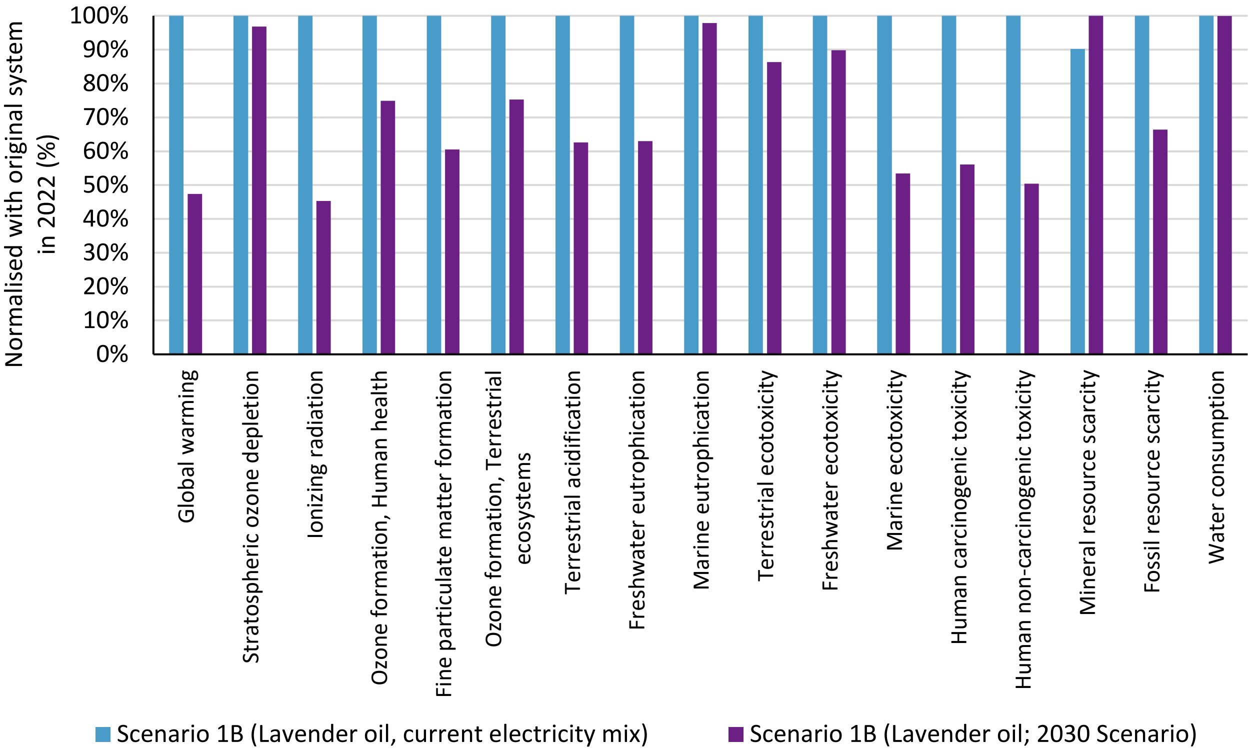


Figure 5.21 Environmental performance of bottled lavender essential oil production (Scenario 1B) with the projected electricity mix for the year 2030 normalised with performance for the year 2022, using current electricity mix

5.3.1.3. Dehumidifier Scenario

Figure 5.22 illustrates the impact of using a dehumidifier (Scenario 4B) instead of purchased deionized water at the distillation phase to produce bottled lavender essential oil. Despite the transportation requirements of supplying purchased deionized water from Athens to Mykonos Island, purchased deionized water had 1.59% lower global warming potential value when compared to water produced on-site using a dehumidifier at the distillation stage to produce lavender essential oil. Furthermore, when expected future lavender yields are considered, the purchased deionized water results also in greater global warming benefits than water vapor harvesting.

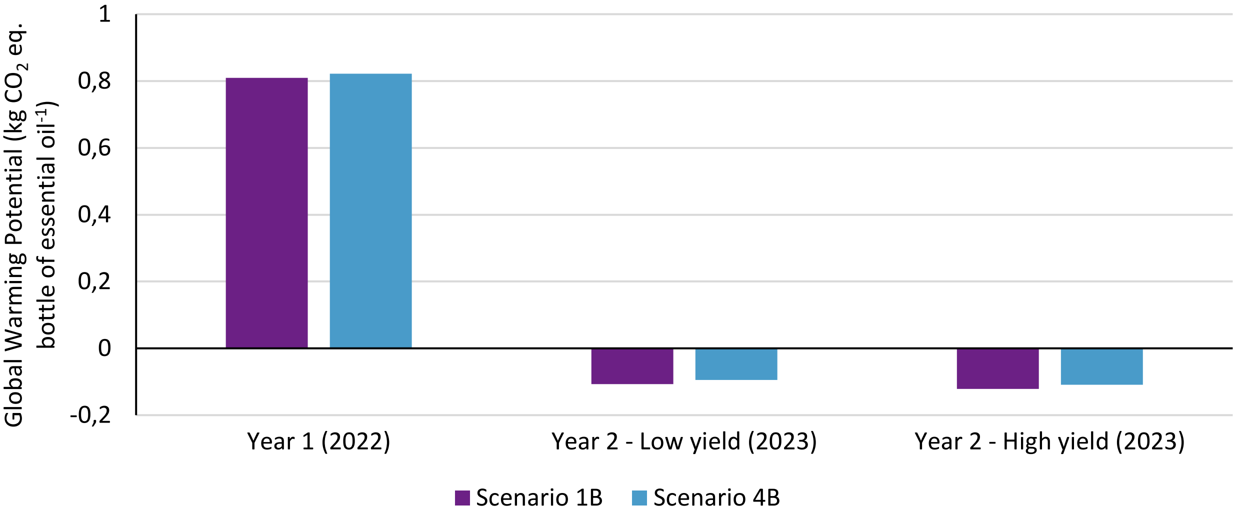


Figure 5.22 A comparison of the global warming potential when using either a dehumidifier (Scenario 4B) or purchased deionized water (Scenario 1B) at the distillation stage to produce bottled lavender oil

5.3.1.4. Contribution Analysis for impacts of HYDRO4

Figure 5.23 portrays the process contribution of supplying water to residences for domestic use (HYDRO4A). The share of the wastewater to the overall GWP score is identical (0.43 kg CO_2 eq/m^3) for both the original and Baseline systems because of the identical volumes of used water being discharged domestically. However, the original system uses less tap water than the baseline system because the non-potable water needs are fully met by harvested rainwater. This is equally reflected in the supplied water to the residence contributing 0.32 kg CO_2 eq/m^3 (42.83% of total emissions) to GWP for the original system whilst 0.36 kg CO_2 eq/m^3 (45.98% of total emissions) to GWP for the Baseline system. Moreover, the overall electricity (medium voltage) required for supplying water had a slightly lower GWP score (appr. 0.221 kg CO_2 eq/m^3; or 29.59% of total emissions) for the original system compared to 0.225 kg CO_2 eq/m^3 (28.74% of total emissions) for the Baseline system.

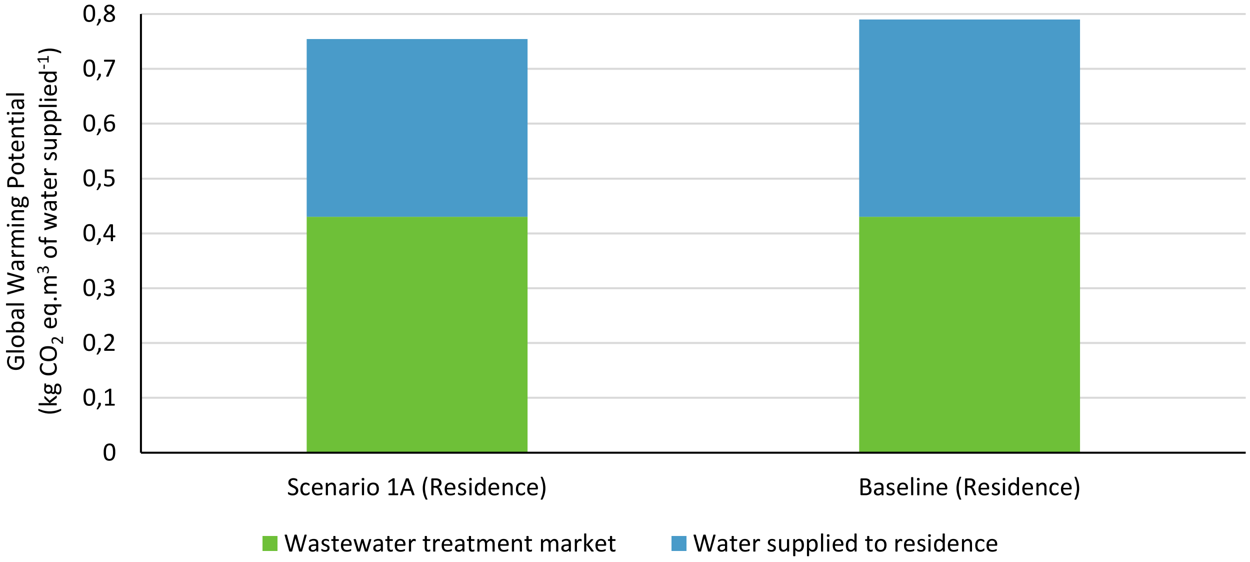


Figure 5.23 Contribution analysis of global warming potential by life cycle stage for Scenario 1A

Figure 5.24 depicts how much each stage contributes to the GWP score of HYDRO4B. The packaging, distillation and biomass-based atmospheric CO_2 capture stages were assumed of the same contributions to both original and baseline systems. However, the differences between the production systems were observed in the energy consumption at the cultivation stage. In the original system, the total electricity consumption contributed 0.956kg CO_2 eq/bottle (118% of total emissions, before factoring in negative emissions); this was mainly channeled to the cultivation stage (approx. 83.89% of the total electricity input per bottle of essential oil; and 99.12% of total emissions of system). Noteworthy, the activity of circulating irrigation water between aquifer and Tank 2 for the cultivation stage consumed 33.37% of total electricity per bottle of oil produced. Conversely, for the Baseline system, the total electricity consumption was 0.743 kg CO_2 eq/bottle (72.84% of total emissions). The contribution of electricity consumption was 0.588 kg CO_2 eq/bottle (approx. 79.14% of the total electricity) in the cultivation stage for the provision of irrigation water in the baseline system. In both the original and Baseline systems, electricity requirements were the main drivers of CO_2 gaseous emissions.

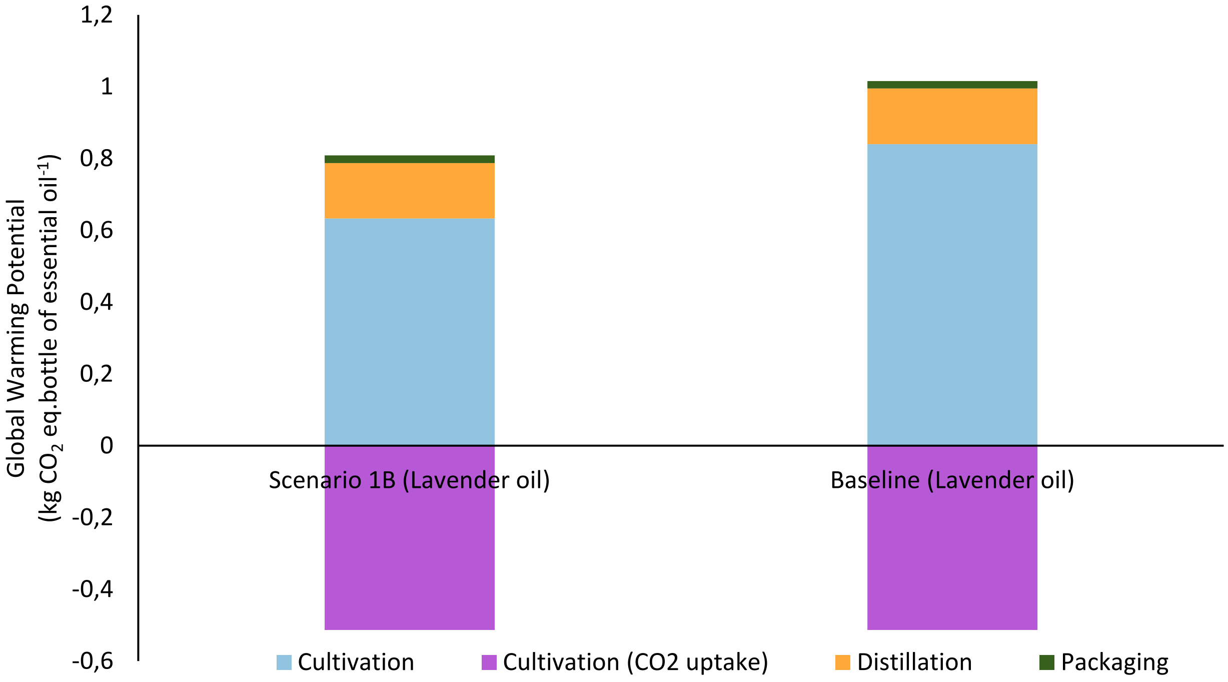


Figure 5.24 Contribution analysis of global warming potential by life cycle stage for Scenario 1B

5.3.2. Economic impacts Assessment of HYDRO4

Table 5.8 summarises the capital, installation, annual operating and maintenance expenditures for the HYDRO4 implemented in Mykonos. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards (actual discount rate of Greece is 6.1% which is counted in this calculation over a life span of 20-years for the project). Since the amount of fertilizer that will be used is equivalent to the amount of fertilizer produced from green residual waste, it is omitted from the calculation. Table 5.8 presents all the internal and external benefits caused by implementing HYDRO4 in three different scenarios of yield 2022 (Scenario 1B), and low (Scenario 2B) and high yield of 2023 (Scenario 3B).
Table 5.9 and Figure 5.25 show the results of calculating economic indicators to compare the profitability of various scenarios and the baseline scenario. The CAPEX is identical across all scenarios, but the CAPEX for the baseline scenario is 34% of the CAPEX for the three HYDRO4 scenarios. Three scenarios have the same cost of water for irrigation in terms of OPEX, while the baseline has approximately five times the cost. Scenario 3's revenue from the sale of essential oil is roughly double that of Scenario 2B, while Scenario 1B's revenue is approximately 0.05% of Scenario 3B. These differences in CAPEX, OPEX and revenue used to calculate the economic indicators NPV, IRR, and PP contributed to the disparity in economic profitability between these

scenarios. Since the NPV is negative and the IRR is below zero, Scenario 1B is not feasible to be implemented. It is evident that the low value of yield 2022 demonstrated in Scenario 1B makes this scenario unprofitable. In fact, the results of NPV and IRR analyses also substantiate this result.

Based on the outcomes of economic indicators, the economic profitability of Scenario 3B is therefore superior to that of other scenarios. The respective economic profitability-based scenarios are as follows:

Scenario 3B > Baseline > Scenario 2B> Scenario 1B

Table 5.8. Cost and benefit caused by implementing HYDRO4 in Baseline and Scenario 1, 2, and 3

HYDRO4				
	Baseline	Scenario 1B	Scenario 2B	Scenario 3B
CAPEX - €	4,900.00	16,275.00	16,275.00	16,275.00
CAPEX - €/year	285.4	947.95	947.95	947.95
Costs for water - €/year	507.501	142.08	159.71	150.97
Costs for energy - €/year	28.050	41.80	107.51	74.93
Costs for fertilizers - €/year	257.294	22.6	22.60	22.6
Consumables, Certification & Product Packaging - €/year	2,036	2,036	2,036	2,036
Savings from water production & use (irrigation) - €/year	0	306.20 €	306.20	306.21
Revenues from selling essential oil - €/year	4,285.71	400	3,428.57	3,885.71
Revenues from selling hydrosol - €/year	1041.42	97.2	833.14	944.23
Savings from Carbon sequestration - €/year	0	43.80	43.80	43.80

Table 5.9. Economic parameters and indicators

Economic parameter				
	Baseline	Scenario 1B	Scenario 2B	Scenario 3B
CAPEX	4,900.00	16,275.00 €	16,275.00 €	16,275.00 €
OPEX	285.4	2,242.48 €	2,325.82 €	2,284.49 €
REVENUE	2,865.85	847.20 €	4,611.72 €	5,179.95 €
CASH FLOW	5,327.14	-1,395.28 €	2,285.89 €	2,895.45 €
Economic Indicators				
NPV	29,730.30	-28,768.48 €	7,373.81 €	13,358.54 €
IRR	19.60	0	3.05	4.21
PP	2.02	-11.66	7.12	5.62

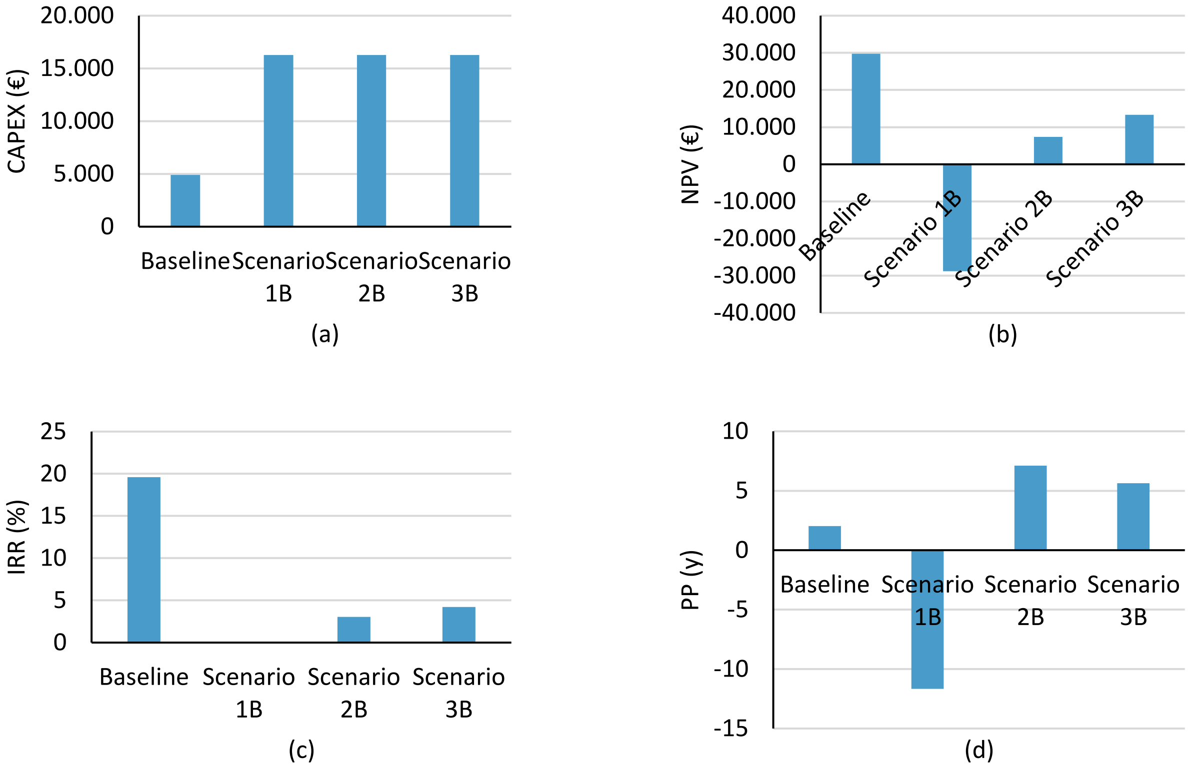


Figure 5.25. Economic result of various HYDRO4 scenarios: (a) CAPEX, (b) NPV, (c) IRR, and (d) PP

5.3.3. Eco-Efficiency Analysis

Saving in yearly OPEX, which is calculated for each of the **HYDRO4** scenarios, is the economic impact indicator that is evaluated in eco-efficiency. The metrics for environmental effect and economic impact are expressed per functional unit. Figure 5.26 shows the eco-efficiency results of each scenario.

Figure 5.26 depicts the changing trajectory of eco-efficiency for all HYDRO4 scenarios. In general, the eco-efficiency of all HYDROs was positive. For some environmental impacts, the eco-efficiency is equal to 1, indicating that the system is eco-efficient when considering these impacts. As can be seen in Figure 5.26, for Scenario 1B and 2B most of the impacts are around 1, making it more eco-efficient than other scenarios. In terms of environmental impact, considering the Marine ecotoxicity, the system is less eco-efficient in scenario 1B and 3B, with scenario 2B being the most eco-efficient. Regarding the Freshwater ecotoxicity and mineral resource scarcity, every scenario is entirely more eco-efficient than baseline scenario.

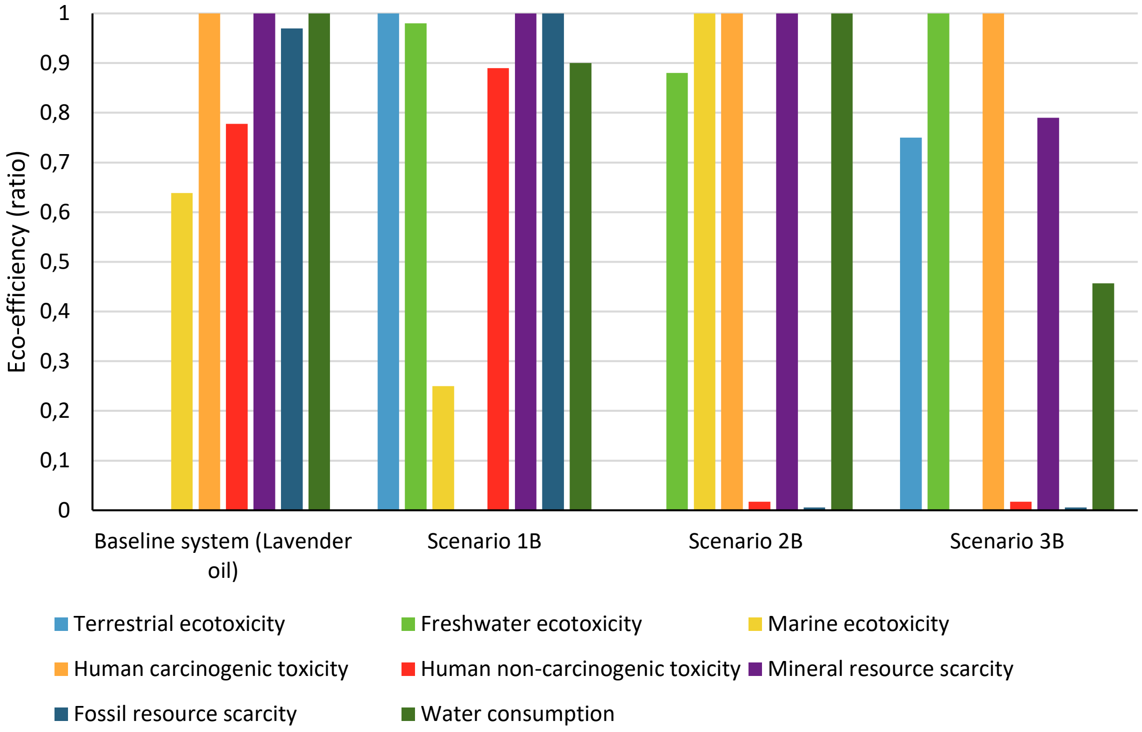


Figure 5.26. Eco-efficiency results of HYDRO4

5.3.3.1. Sensitivity Analysis

A sensitivity analysis is performed to simultaneously assess the variation range of all input parameters in the proposed model. This aids in the detection of any variation from the expected target. A sensitivity analysis using graphical methods was performed on the economic indicators. Table 5.10. presents the sensitivity analysis that revealed that the market price of essential oil has the maximum effect on the project revenue; the discount rate has the maximum effect on the project NPV; the loan interest rate has the maximum effect on the project annual CAPEX and consumable has the maximum effect on the project OPEX.
The parameters exerting the most effect on the economic indicators is presented in Table 5.10 and Figure 8.3 . in Appendix. The sensitivity analysis results in terms of total and main indices are presented in Table 5.10. which presents all the investigated parameters and indicators, differentiating between main and total indices.

Table 5.10. Most influenced Economic indicator per parameter tested (main and total indices) – HYDRO4

Annual CAPEX	Main indices	OPEX	Main indices	REV	Main indices	CF	Main indices	NPV	Main indices
Loan interest rate	1.12	Consumables - €/year	0.64	Market price for Essential oil - €/bottle	0.63	Market price for Essential oil -€/bottle	0.53	Discount rate - %	1.1
Consumables - €/year	0.1	Product packaging- €/year	0.33	Yield 2022	0.56	Consumables - €/year	0.46	Market price for Hydrosol - €/ml	0.01
Product packaging- €/year	0.1	Energy Price in Mykonos- €/KWH	0.27	Market price for Hydrosol - €/ml	0.11	Energy Price in Mykonos- €/KWH	0.11	Selling price for irrigation water - €/m3	0
Energy Price in Mykonos- €/KWH	0.1	Planting coefficient K	0.13	Water price for irrigation in Mykonos - €/m3	0.1	Yield 2022	0.11	Market price for Essential oil - €/bottle	0.01
Water price for irrigation in Mykonos - €/m3	0.1	Cultivation area (10*ha)	0.12	Unit Price of Carbon sequestration in €/tons	0.1	Unit Price of Carbon sequestration in €/tons	0.1	Water price for irrigation in Mykonos - €/m2	0.01

5.3.4. Recommendations for HYDRO4

From an operational LCA point of view, an increased volume of harvested rainwater to cater for the annual potable water needs of the residence may further reduce the currently observed environmental impacts associated with purification methods employed at the centralized plant. To that end, the utilization of a scalable sand filtration system for on-site treatment of harvested rainwater for domestic use can be envisaged for the residence. Also, forecasts of the future Greek electricity mix towards an eco-friendlier profile would results in lighter environmental impacts for both the activity of pumping harvested rainwater to the residence of HYDRO4, together with lavender essential oil production.

5.4. HYDRO5 results

5.4.1. Environmental impacts of HYDRO5 – Comparison with baseline

Figure 5.27 shows the results of HYDRO5 normalised by the baseline system. Non-normalised environmental results can be found in Table 8.16 of the Appendix. For most of the environmental impacts considered, HYDRO5 system performs much better than the baseline system. Expected environmental benefits range between 3% to 87% reduction. However, Global warming, Stratospheric ozone depletion, and Fossil resource scarcity result in environmental burdens when compared with the baseline system due to the excessive electricity consumption, that is sourced from the national grid, by HYDRO5.

Figure 5.28 shows that the main reason for the environmental impacts is the production of salt because consumes large amount of electricity (which is supplied from the Greek electricity grid, see Table 4.18) and it results in increasing the environmental impact scores between 6% and 692%. The lowest increase is found in Freshwater eutrophication, while the largest increase is found in Stratospheric ozone depletion and Fossil resource scarcity. In contrast, salt production by HYDRO5 results in the reduction of environmental burdens regarding Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Marine eutrophication, Mineral resource scarcity, and Ionizing radiation. In addition, the production of freshwater and fruits in the HYDRO5 system is beneficial regarding all environmental impacts, when compared with Baseline systems, due to the mangrove still system and collection of rainwater and its use as irrigation water instead of irrigation water production at the local reverse osmosis plant. Non-normalised environmental results of the different end-products (i.e., fruits, salt or freshwater) can be found in Table 8.17-8.19 of the Appendix.

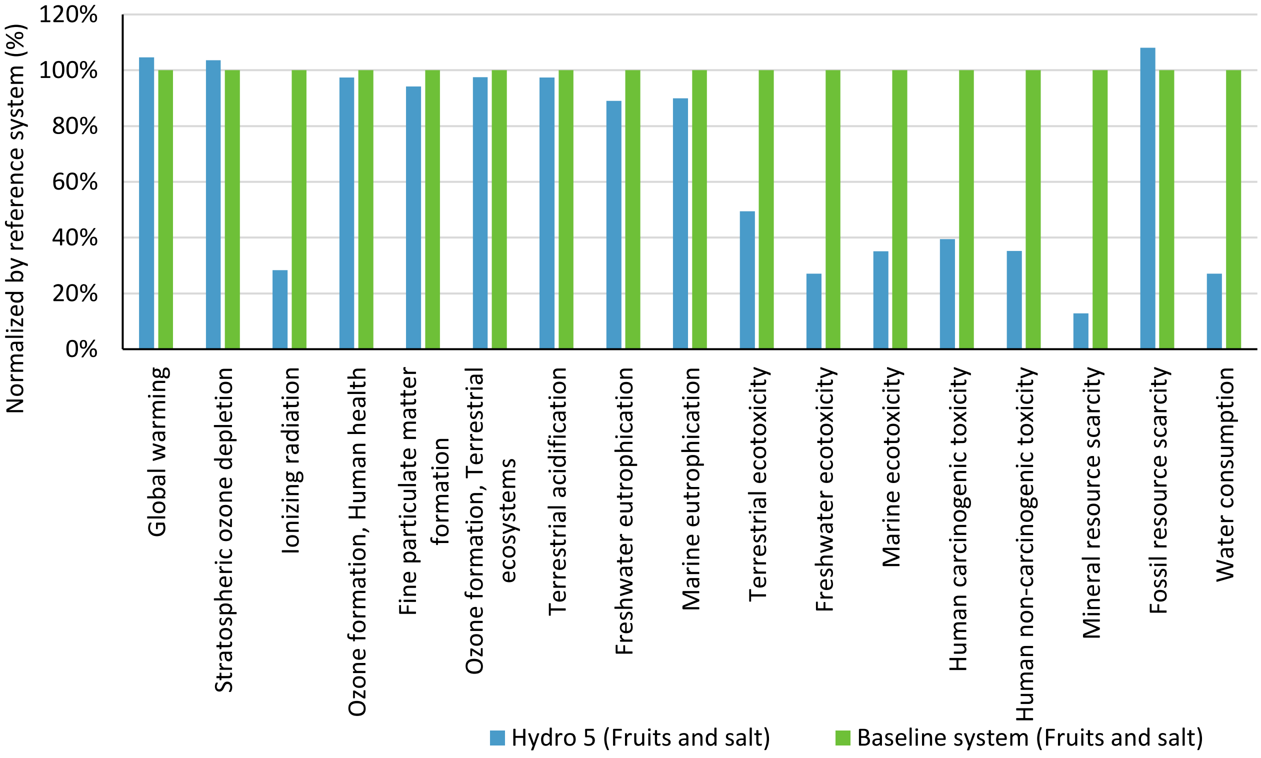


Figure 5.27 Environmental impact results of HYDRO5 and Baseline system, FU=1 year of operation

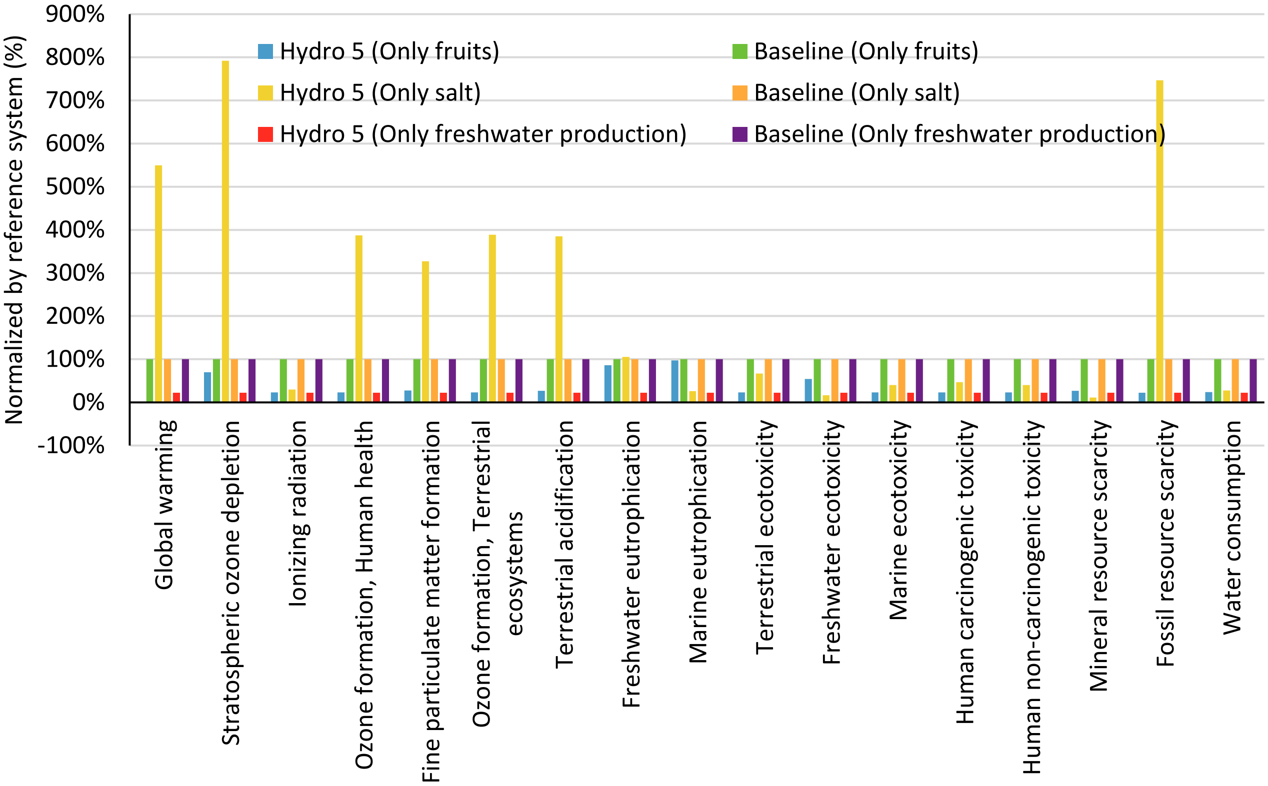


Figure 5.28 Normalised environmental performance between specific HYDRO5 products and respective Baseline systems.

5.4.1.1. Contribution Analysis of impacts of HYDRO5

Figure 5.29 shows the contribution analysis of selected environmental impacts according to a recent review paper (Lee and Jepson, 2021). Figure 5.29 shows that electricity generation is the main contributor to almost all environmental impacts. Its contribution ranges from 22% for Freshwater eutrophication to 99% for Marine ecotoxicity and Water consumption. The source of electricity is the Greek national grid which was fossil-based in 2021. Alternatively, the farm stage contributes positively to Global warming due to the CO_2 absorbance, and negatively to Freshwater eutrophication and Freshwater ecotoxicity due to air, soil and water emission upon application of fertilizers and manure.

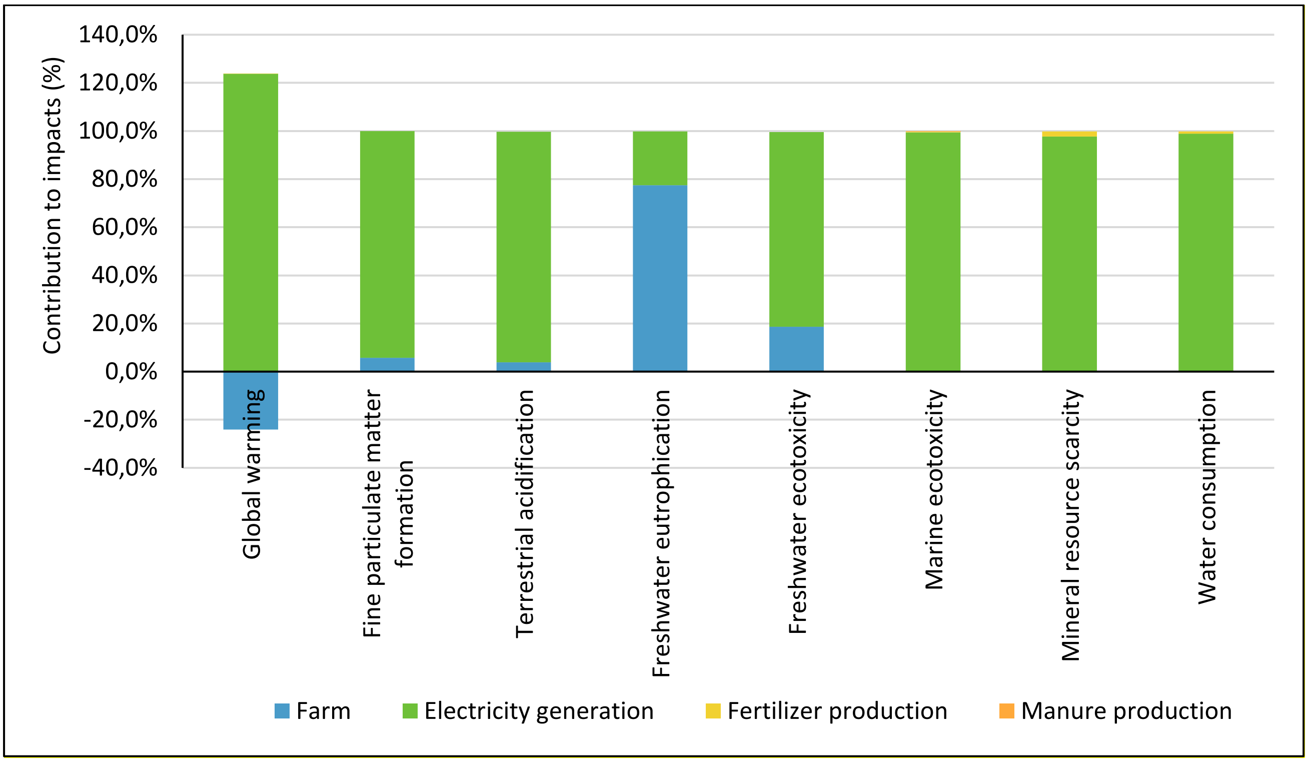


Figure 5.29 Contribution analysis of environmental impacts of HYDRO5, FU=1 year of operation

5.4.1.2. 2030 Scenario

Figure 5.30 shows how the HYDRO5 will perform with a greener electricity mix in 2030. Non-normalised environmental results due to electricity consumption in 2030 can be found in Table 8.20 of the Appendix. According to the contribution analysis, a greener electricity mix is expected to affect all environmental impacts greatly, except for (at least) Marine eutrophication which is decreased by 6%. Figure 5.30 shows that all environmental impacts were affected to a great extent, except for Freshwater eutrophication, Marine eutrophication, and Stratospheric ozone depletion. Freshwater eutrophication and Marine eutrophication are mainly affected by the farm stage and the application of fertilizers and manure, while the Stratospheric ozone depletion is additionally affected by the combustion of natural gas which is expected to continue being used for electricity generation in Greece in 2030.

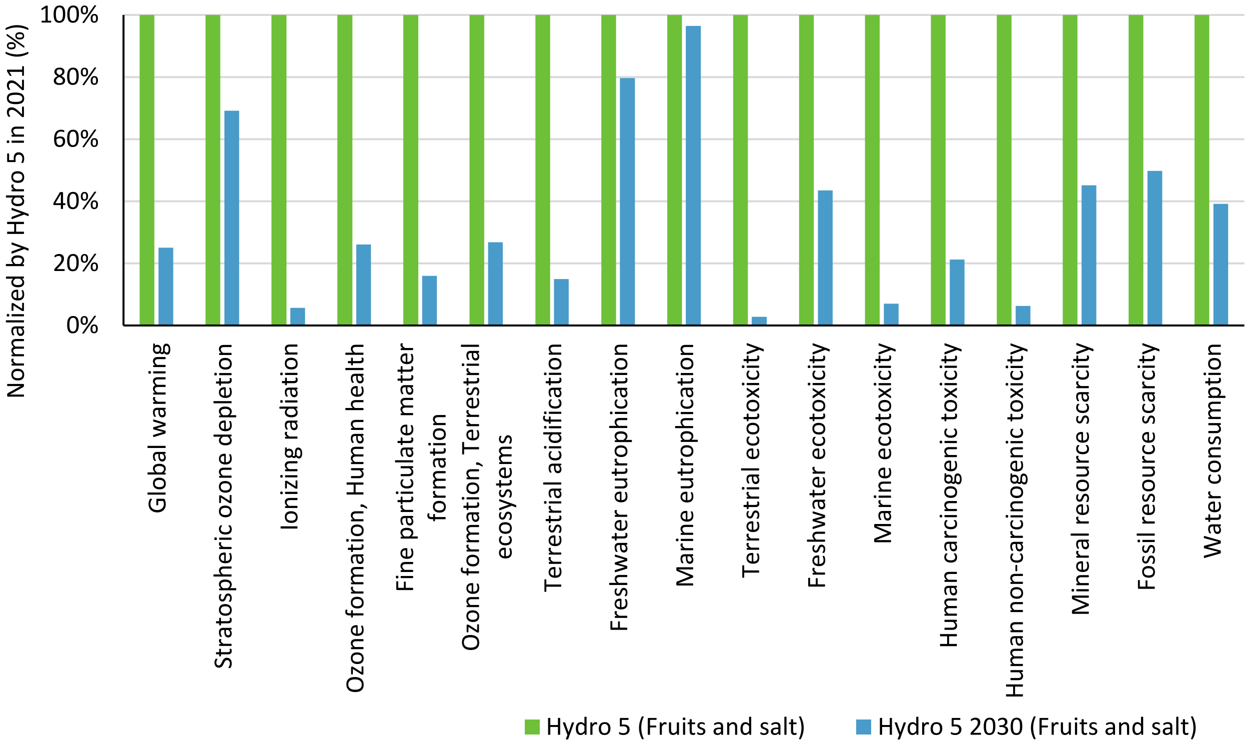


Figure 5.30 Environmental performance of HYDRO5 in 2030 in comparison with the environmental performance of 2021, FU=1 year of operation

5.4.2. Economic impacts Assessment of HYDRO5

The data are received from partners as well as information from HYDROUSA demonstrator site-local standards (actual discount rate of Greece is 3.5% which is counted in this calculation over a project life span of 20 years). Table 5.11 present all the internal and external benefits caused by implementing HYDRO5 and Theoretical scenario.

Table 5.12 and Figure 5.31 demonstrate the economic parameters and indicators to compare the profitability of HYDRO5 and the theoretical scenario. baseline scenario. CAPEX is the same for both scenarios. The main difference between the two scenarios is the revenue generated from the sale of salt, which is more in theoretical scenario. Therefore, the theoretical scenario is more profitable.

Theoretical> HYDRO5

Table 5.11. Internal and external costs of HYDRO5 and Theoretical Scenario

	HYDRO5	Theoretical
CAPEX - €	25,001.50	25,001.50
CAPEX - €/year	6,983.07	6,954.36
HR requirement - €/year	1875	1875
Costs for water (irrigation) - €/year	294.43	294.43
Costs for energy - €/year	280.68	280.68
Consumable (chemical)	1986	1986
System operation	2500	2500
Savings from water production & use (saved water) - €/year	300.96	300.96
Revenues from selling salt - €/year	4219.41	4873.75

Revenues from selling crop products (Fruit) - €/year	7927.31	7927.31

Table 5.12. Economic parameters and indicators

Economic parameters		
	HYDRO5	Theoretical
CAPEX	25,001.50€	25,001.50€
OPEX	6,936.11 €	6,936.11 €
REVENUE	12,447.67 €	13,102.01 €
CASH FLOW	5,511.56 €	6,165.90 €
Economic Indicators		
	HYDRO5	Theoretical
NPV	25,635.30 €	31,427.10 €
IRR	5.51	6.45
PP	4.54	4.05

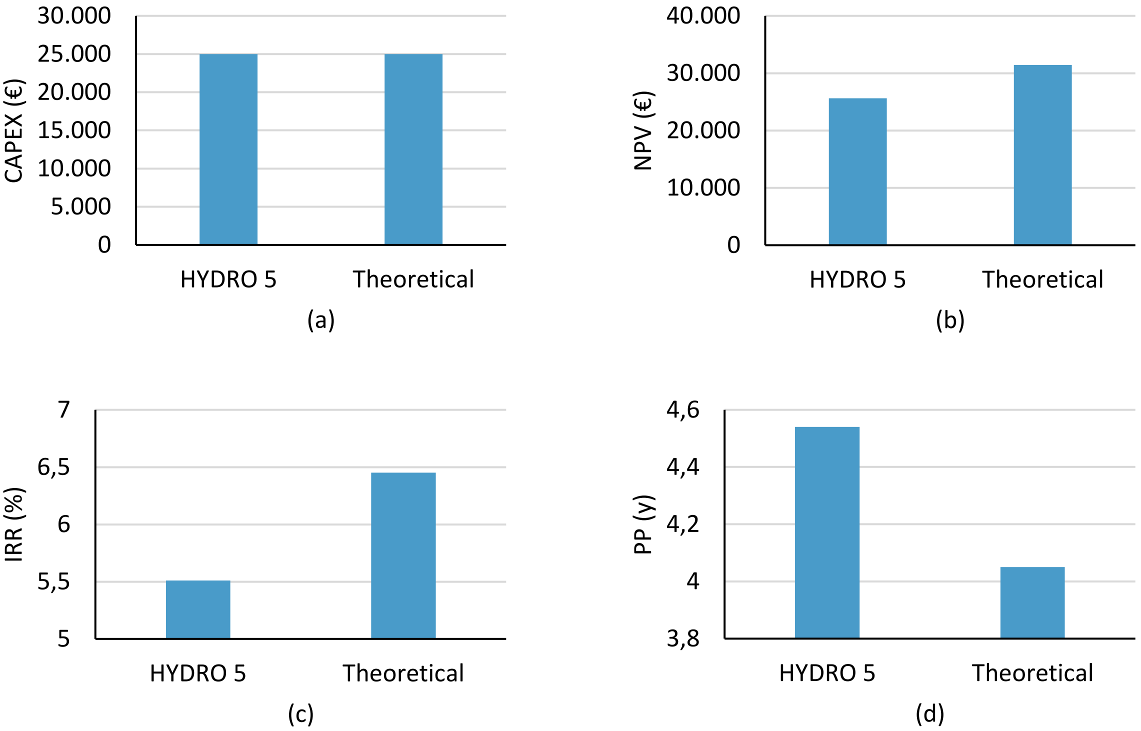


Figure 5.31 Economic result of various HYDRO5 scenarios: (a) CAPEX, (b) NPV, (c) IRR, and (d) PP

5.4.3. Eco-Efficiency Analysis

Saving in yearly OPEX, which is calculated for each of the HYDRO5 scenarios, is the economic impact indicator that is evaluated in eco-efficiency. The metrics for environmental effect and economic impact are expressed per functional unit. Figure 5.32 shows the eco-efficiency results of each scenario.

Figure 5.32 depicts the changing trajectory of eco-efficiency for HYDRO5. In general, the eco-efficiency of HYDRO5 is positive. For some environmental impacts, the eco-efficiency is equal to 1, indicating that the system is eco-efficient when considering these impacts. As can be seen in Figure 5.32, HYDRO5 is less eco-efficient considering the Marin ecotoxicity impact.

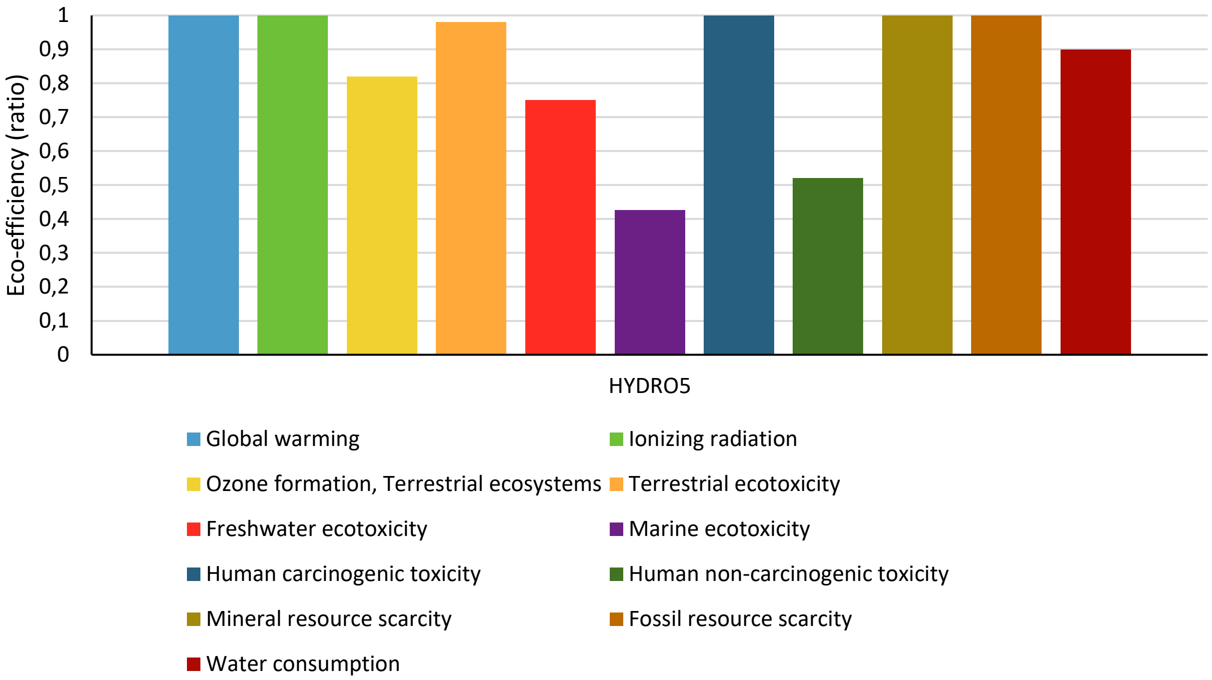


Figure 5.32. Eco-efficiency analysis of HYDRO5

5.4.3.1. Sensitivity Analysis

A sensitivity analysis is performed to simultaneously assess the variation range of all input parameters in the proposed model. This aids in the detection of any variation from the expected target. A sensitivity analysis using graphical methods was performed on the economic indicators. The sensitivity analysis revealed that the market price of salt has the maximum effect on the project revenue; the discount rate has the maximum effect on the project NPV; the loan interest rate has the maximum effect on the project annual CAPEX and Energy price in Tinos has the maximum effect on the project OPEX. The parameters exerting the most effect on the economic indicators is presented in Table 5.13 and Figure 8.4 in Appendix.

Table 5.13. Parameters that affect HYDRO5

Annual CAPEX	Main Indices	OPEX	Main Indices	REV	Main Indices	CF	Main Indices	NPV	Main Indices
loan interest rate	1.12	Energy Price in Tinos- €/ kWh	0.64	Market price for Salt- €/bottle	0.63	Market price for Salt- €/bottle	0.53	Discount rate	1.1
Consumables - €/year	0.1	Costs for water (irrigation) - €/year	0.33	Yield	0.56	Consumables - €/year	0.46	Market price for Salt- €/bottle	0.01
Energy Price in Tinos- €/kWh	0.1	System maintenance - €/year	0.27	Market price of greenhouse product- €/ml	0.11	Energy Price in Tinos- €/ kWh	0.11	Selling price for irrigation water - €/m^3	0
Water price for irrigation in Tinos - €/m^2	0.1	System maintenance - €/year	0.13	Water price for irrigation in Tinos - €/m^3	0.1	Market price of greenhouse product- €/ml	0.11	Market price of greenhouse product - €/ml	0.01
System maintenance - €/year	0.1	HR requirement - €/year	0.12			System maintenance - €/year	0.1	Energy Price in Tinos - €/ kWh	0.01

Annual CAPEX	Main Indices	OPEX	Main Indices	REV	Main Indices	CF	Main Indices	NPV	Main Indices
Loan interest rate - %	1.12	Energy Price in Tinos-€/KWH	0.64	Market price for Salt-€/bottle	0.63	Market price for Salt-€/bottle	0.53	Discount rate - %	1.10
Consumables - €/year	0.10	Costs for water (irrigation) - €/year	0.33	Yield	0.56	Consumables - €/year	0.46	Market price for Salt-€/bottle	0.01
Energy Price in Tinos-€/kWh	0.10	System maintenance-- €/year	0.27	Market price of greenhouse product-€/ml	0.11	Energy Price in Tinos-€/kWh	0.11	Selling price for irrigation water - €/m^3	0.00
Water price for irrigation in Tinos - €/m^2	0.10	System maintenance - €/year	0.13	Water price for irrigation in Tinos - €/m^3	0.10	Market price of greenhouse product-€/ml	0.11	Market price of greenhouse product-€/ml	0.01
System maintenance - €/year	0.10	HR requirement - €/year	0.12			System maintenance - €/year	0.10	Energy Price in Tinos-€/kWh	0.01

5.4.4. Recommendations for HYDRO5

The HYDRO5 system performs much worse than the baseline system when it is producing both salt and fruits. However, Figure 5.28 shows that it is salt production that results in environmental burdens due to the very high electricity consumption. In contrast, fruits or only freshwater consumption results in environmental benefits for all environmental impacts. Furthermore, even in 2030 when the Greek electricity mix will be greener, the environmental performance is worse than the baseline for Global warming and Fossil resource scarcity. Therefore, it is suggested that HYDRO5 omits salt production and focuses on freshwater production which is used for fruits cultivation.

5.5. HYDRO6 results

5.5.1. Environmental impacts of HYDRO6 – Comparison with baseline

Figure 5.33 shows the results of HYDRO6 normalised with the baseline system. Non-normalised environmental results can be found in Table 8.19 of the Appendix. For all the environmental impacts considered, the HYDRO6 system performs better than the baseline system with expected environmental benefits ranging between 19% to 77%. The improvement of 19% regards the water consumption. Even though rainwater is harvested by the HYDRO6 system to cultivate and consume crops (green food) locally, river water is also used and drinking water is produced with reverse osmosis. In contrast, the replacement of the conventional wastewater treatment with constructed wetlands and the production of vegetables and crops organically, results in greater environmental benefits which can be up to 77%.

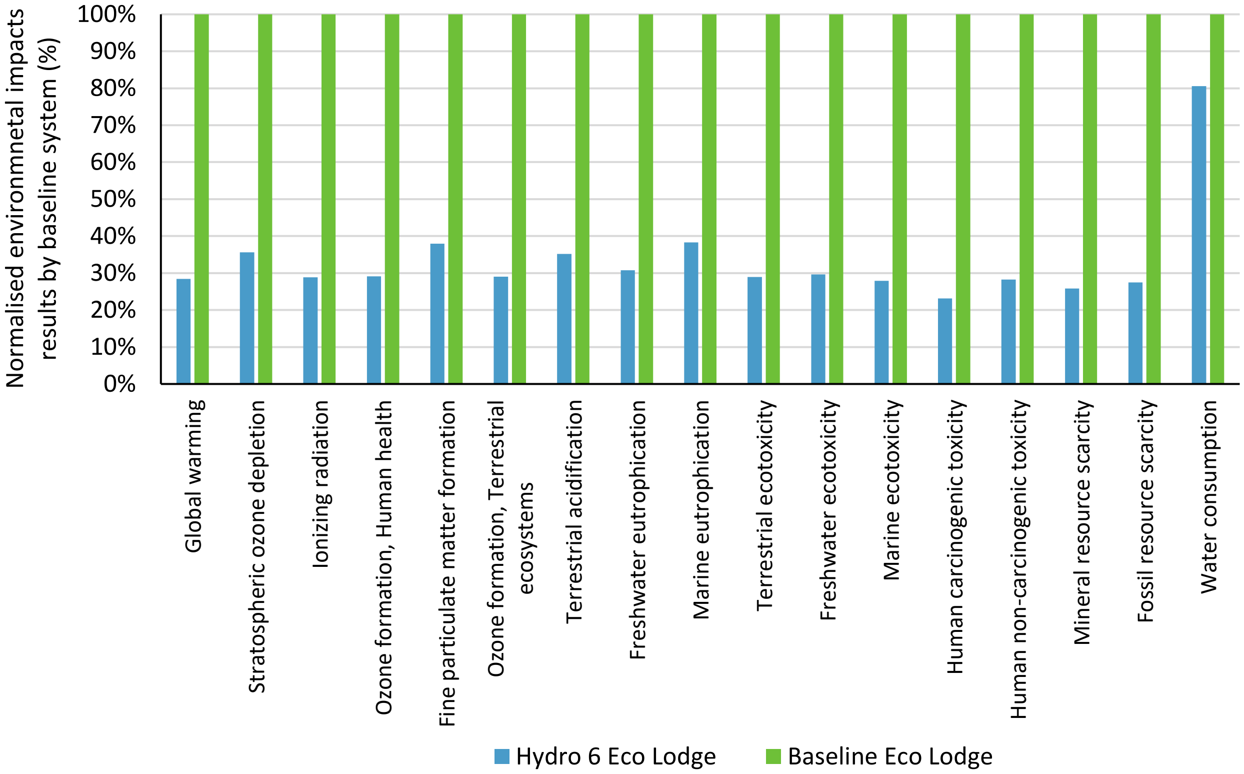


Figure 5.33 Normalised environmental impacts results of the Eco Lodge with and without the HYDRO6 system

5.5.1.1. Contribution Analysis of impacts of HYDRO6

Figure 5.34 shows the relative contribution of various inputs to selected environmental impacts for the HYDRO6 Eco Lodge. The selection of environmental impacts was based on two recent review papers (Corominas et al., 2020; Mihelcic et al., 2017) which showed what environmental impacts are most relevant to wastewater treatment and agricultural systems. Among all material and energy inputs, the provision of external food, the production of zeolite, and electricity consumption by the reverse osmosis to produce drinking water are environmental hotspots. In contrast, the green food production by the HYDRO6 Eco Lodge results in benefits for Global warming due to atmospheric CO_2 absorption during the plants' growth phase and no use of chemical fertilizers. Among the external green food, wheat flour, cauliflower and potato are the foods with the highest embodied environmental footprint.

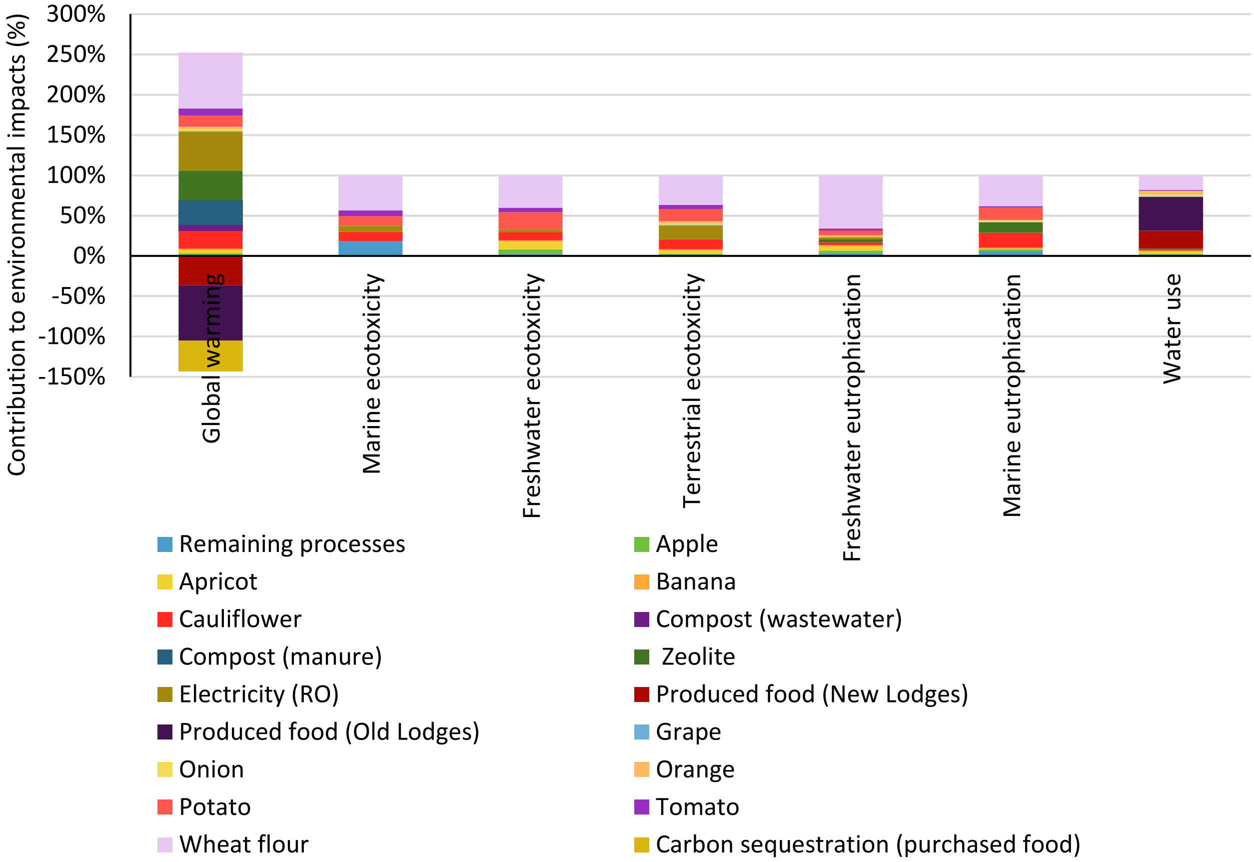


Figure 5.34 Relative contribution of various inputs to the environmental impacts

5.5.1.2. 2030 Scenario

The HYDRO6 system is powered by photovoltaics which belong to the Eco-Lodge resort, but the drinking water is produced by the local reverse osmosis plant. Figure 5.35 shows the effect of the electricity mix in 2030, i.e., the effect if the production of drinking water becomes greener. Non-normalised environmental results due to electricity consumption in 2030 can be found in Table 8.19 of the Appendix. Figure 5.35 shows that the environmental performance of HYDRO6 is expected to improve in 2030 to a small extent because water, for uses excluding drinking, is harvested from rainwater, or taken from the local river. Environmental performance in 2030 is expected to improve between 0% and 20%. The greater benefits are found in Global warming because the main objective of the electricity mix in 2030 is to decrease its carbon intensity. In contrast, Freshwater eutrophication and Marine eutrophication are affected minimally because their main contributors are emissions upon compost application and in 2030 natural gas will be combusted for electricity, thus contributing still to these environmental impacts.

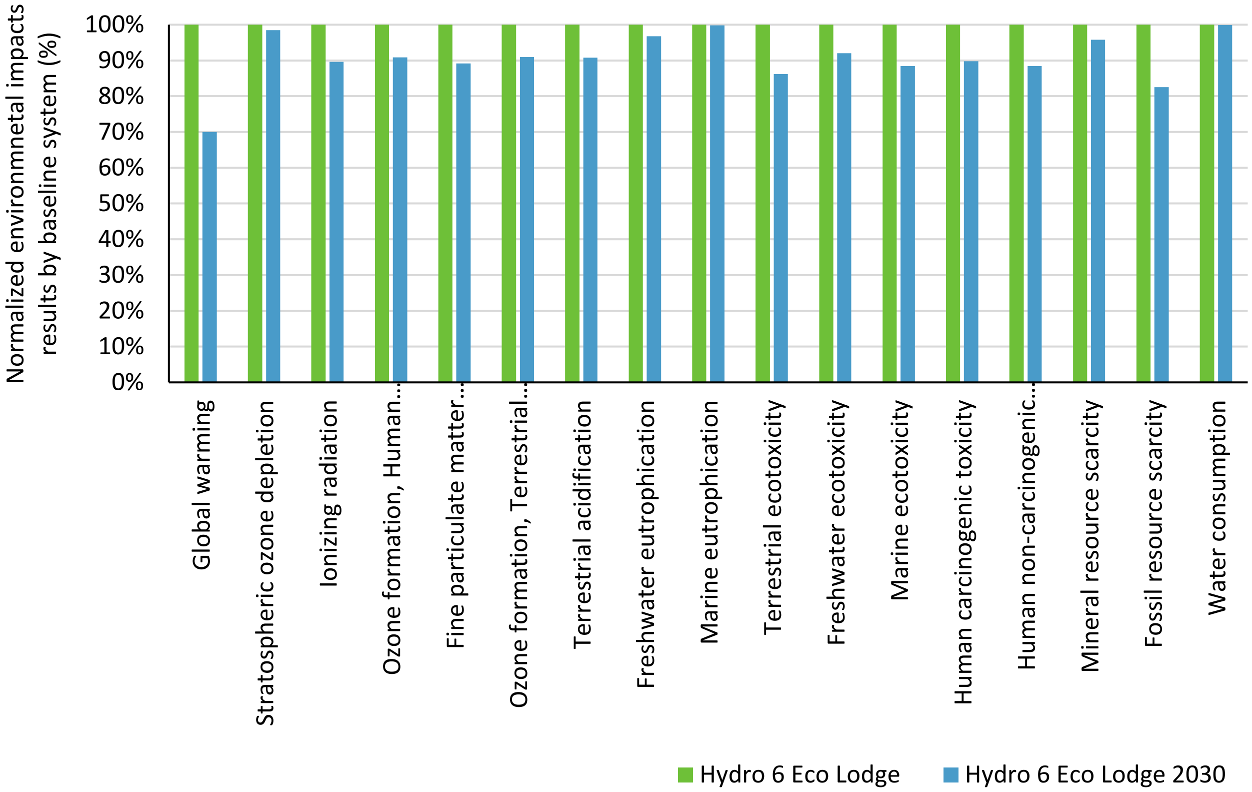


Figure 5.35 Environmental performance of HYDRO6 in 2030 in comparison with the environmental performance of 2021, FU=1 year of operation

5.5.2. Economic impacts Assessment of HYDRO6

Table 5.14 summarises the capital, installation, and annual operating and maintenance expenditures as well as the revenue for HYDRO6 implemented in Tinos. The data are received from partners as well as information from HYDROUSA demonstrator site-local standards (actual discount rate of Greece is 3.5% which is counted in this calculation over a project life span of 20 years).

Table 5.15 presents the economic parameters and indicators to analyse the feasibility of implementation of HYDRO6. Since the NPV is more than 1, PP is within the lifespan of the project and IRR is larger than the Greece discount rate, the implementation of HYDRO6 is feasible.

Table 5.14. Capital, installation, and annual operating and maintenance costs of HYDRO6

HYDRO6	
CAPEX - €	48,078.20
CAPEX - €/year	2,695.51
Maintenance costs - €/year	550
HR requirement - €/year	12,320
Costs for water (domestic purposes) - €/year	73.36
Costs for water (irrigation) - €/year	175.94
Savings from water production & use (domestic purposes) - €/year	69.55
Savings from water saving measures (lodges & irrigation) - €/year	332.25
Savings from water production & use (irrigation) - €/year	422.53
Savings from energy production & use - €/year	465.91
Savings from fertilizers production & use - €/year	46.77
Savings from food production & use - €/year	7,770.14
Revenues from lodges (touristic activity) - €/year	59,240
Revenues from compost selling - €/year	4.36
Revenues from zeolite selling (as fertilizer) - €/year	3,524.68
Revenues from selling remaining food - €/year	10,939.86
Savings from Carbon sequestration - €/year	45

Table 5.15. Economic parameters and indicators

Economic parameter	
CAPEX	48,078.20 €
OPEX	13,119.30 €
REVENUE	82,814.28 €
CASH FLOW	64,303.96 €
Economic Indicators	
NPV	576,155.89 €
IRR	100.16
PP	0.75

5.5.3. Eco-Efficiency Analysis

Saving in yearly OPEX, which is calculated for HYDRO6, is the economic impact indicator that is evaluated in eco-efficiency. The metrics for environmental effect and economic impact are expressed per functional unit. Figure 5.9 Figure 5.36 show the eco-efficiency results. Figure 5.36 depicts the changing trajectory of eco-efficiency for HYDRO6. In general, the eco-efficiency HYDRO6 is positive. For some environmental impacts, the eco-efficiency is equal to 1, indicating that the system is eco-efficient when considering these impacts.
As can be seen in Figure 5.36, the system is less eco-efficient when considering the environmental impacts of Marin ecotoxicity and human non-carcinogenic toxicity.

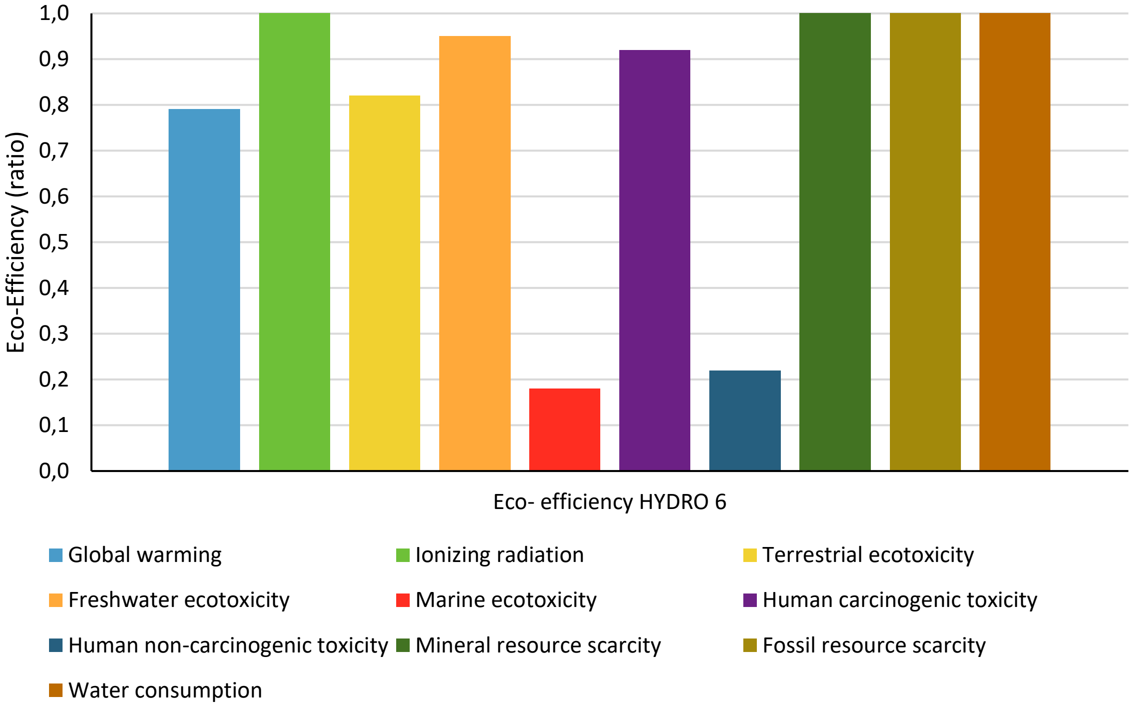


Figure 5.36. Eco-efficiency of HYDRO6

5.5.3.1. Sensitivity analysis

A sensitivity analysis is performed to simultaneously assess the variation range of all input parameters in the proposed model. This aids in the detection of any variation from the expected target. A sensitivity analysis using graphical methods was performed on the economic indicators. Figure 8.5**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** in Appendix presents the sensitivity analysis that revealed that the market price of crop Produced food (fruit and vegetable) has the maximum effect on the project revenue; discount rate has the maximum effect on the project NPV; loan interest rate has the maximum effect on the project annual CAPEX and consumable has the maximum effect on the project OPEX. The parameters exerting the most effect on the economic indicators are presented in **Table 5.16** and Figure 8.5 in Appendix.

Table 5.16. Parameters that affect HYDRO

Annual CAPEX	Main Indices	OPEX	Main Indices	REV	Main Indices	CF	Main Indices	NPV	Main Indices
loan interest rate - %	1.21	Consumables - €/year	0.54	Produced food price- €/Kg	0.53	Produced food price- €/Kg	0.43	Discount rate - %	0.91
Consumables - €/year	0.01	Water price for domestic purpose in Tinos - €/m^3	0.32	Lodges rent (touristic activity) -€ per day	0.36	Lodges rent (touristic activity) -€ per day	0.36	Lodges rent (touristic activity) -€ per day	0.1
Cost for purchasing zeolite (material) - €/kg	0	Energy Price in Tinos- €/ kWh	0.17	Market price for zeolite (selling as fertilizer) - €/kg	0.01	Energy Price in Tinos- €/ kWh	0.11	Produced food price- €/Kg	0.03
Energy Price in Tinos- €/ kWh	0.01	System operation (Human resources) - €/year	0.01	Water price for irrigation in Tinos - €/m3	0	System operation (Human resources) - €/year	0.01	Energy Price in Tinos- €/ kWh	0
Water price for irrigation in Tinos - €/m^3	0	Cultivation area-m^2	0.01	Unit Price of Carbon sequestration in €/tons	0	Unit Price of Carbon sequestration in €/tons	0	Water price for irrigation in Tinos - €/m^2	0

5.5.4. Recommendations for HYDRO6

HYDRO6 performs better than the Baseline system for all environmental impacts. It is recommended that a few food products that are purchased by the Eco-Lodge be replaced with others of lower environmental impacts, such as wheat flour. Furthermore, it is suggested that the employment of drinking water from the reverse osmosis plant is reduced due to the high consumption of electricity that is sourced from the mainland. Therefore, either HYDRO systems for rainwater collection can be considered or the electricity source should change. In both cases, a significant environmental performance improvement can be expected.

6. CONCLUSIONS

The objective of this report was the investigation of the environmental and economic benefits of the proposed HYDRO solutions. It is shown that all HYDRO systems result in environmental and economic benefits, except for HYDRO5 which resulted in minor environmental burdens due to salt production. However, if salt production is excluded from the environmental assessment, both fruits and freshwater production result in environmental benefits.

HYDRO1&2: The HYDRO1&2 demonstration site was successful in wastewater treatment, energy recovery, compost production and fruits cultivation. The demonstration resulted in environmental benefits which were maximized when HYDRO1&2 generated electricity instead of vehicle-grade biomethane. It is expected that in 2030 the environmental performance of HYDRO1&2 will further improve due to a greener Greek electricity system. The economic evaluation shows that HYDRO1&2 is highly economically viable. All scenarios of HYDRO1&2 exhibited a positive net present value and acceptable payback period; thus, they were found feasible. One scenario that involved selling treated wastewater and utilizing irrigation water savings, projected to generate substantial revenues.

HYDRO3: The HYDRO3 demonstration site was successful in rainwater harvesting and its employment in the production of high-value products, i.e., oregano essential oil. Furthermore, HYDRO3 demonstration resulted in environmental benefits which will increase as the oregano yield increases with time and in 2030 due to the greener Greek electricity system. The production of oregano essential oil will offer complimentary benefits to the local community, such as additional income and job employment. However, HYDRO3 is not currently more profitable than the baseline scenario due to the low farm yield. From 2023 the profitability of HYDRO3 will be greater than baseline due to the expected increase in oregano yield. The same is expected with HYDRO4, in 2023 HYDRO4 becomes more profitable than baseline. Therefore, from 2023 HYDRO3 is considered feasible due to positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

HYDRO4: The HYDRO4 demonstration site was successful in the harvesting of rainwater for non-potable domestic use, thus offering a decentralized solution to increase water supply. Also, harvested rainwater was stored in a series of tanks and in aquifer during the rainy winter months for field irrigation in dry summer months to boost lavender crop cultivation and to reduce saltwater intrusion into the local groundwater reserves. Furthermore, the nature-based water management solutions and organic farming practices of HYDRO4 offered an improved environmental impacts profile than their respective conventional counterparts. Furthermore, HYDRO4 demonstration that was responsible for lavender oil production resulted in environmental benefits which will increase as the lavender yield increases with time and in 2030 due to a greener Greek electricity system. However, HYDRO4 is not currently more profitable than the baseline scenario due to the low farm yield. From 2023 the profitability of HYDRO4 will be greater than baseline due to the expected increase in lavender yield. Therefore, from 2023 HYDRO4 is considered feasible due to positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

HYDRO5: The HYDRO5 demonstration site was successful in water harvesting. However, the very large electricity consumption in the salt factory stage resulted in environmental burdens when compared with the baseline system. In contrast, freshwater production and fruits cultivation performed better than the baseline system. The economic assessment shows that HYDRO5 is considered feasible based on a positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

HYDRO6: The HYDRO6 demonstration site was successful in water harvesting, wastewater treatment and food production. The demonstration resulted in environmental benefits. However, a large part of the environmental impacts derives from electricity consumption in the local reverse osmosis plant that produces drinking water for the Eco-Lodge residents. Therefore, improving the environmental footprint of Greek electricity in 2030 which is employed in drinking water production for the Eco-Lodge will further improve its environmental performance. The economic assessment shows that HYDRO6 is considered feasible based on a positive net present value, an internal rate of return exceeding the market rate of return, and a payback period within the project lifespan.

7. REFERENCES

Applied Horticultural Research, 2023. Greenhouse gas emissions by crop | Vegetable Climate. URL https://www.vegetableclimate.com/climate-credentials/greenhouse-gas-emissions-by-crop/ (accessed 26.02.2023).

Beccali, M., Cellura, M., Iudicello, M., Mistretta, M., 2010. Life cycle assessment of Italian citrus-based products. Sensitivity analysis and improvement scenarios. Journal of Environmental Management 91, 1415–1428. https://doi.org/10.1016/j.jenvman.2010.02.028

Belli, P., Anderson, J.R., Barnum, H.N., Dixon, J.A., Tan, J.-P., 2001. Economic Analysis of Investment Operations—Analytical Tools and Practical Applications. World Bank, Washington D.C. 978-0-82134850-5.

Boardman, A.E., 2015. Cost-benefit analysis. International Encyclopedia of the Social & Behavioral Sciences, Second edition Elsevier Inc., pp. 47–54 https://doi.org/10.1016/B978-0-08-097086-8.71068-3

Boxman, S.E., Zhang, Q., Bailey, D., Trotz, M.A., 2017. Life Cycle Assessment of a Commercial-Scale Freshwater Aquaponic System. Environmental Engineering Science 34, 299–311. https://doi.org/10.1089/ees.2015.0510

Corominas, L., Byrne, D.M., Guest, J.S., Hospido, A., Roux, P., Shaw, A., Short, M.D., 2020. The application of life cycle assessment (LCA) to wastewater treatment: A best practice guide and critical review. Water Research 184, 116058. https://doi.org/10.1016/j.watres.2020.116058

Crouch, M.L., Jacobs, H.E. and Speight, V.L. orcid.org/0000-0001-7780-7863 (2021) Defining domestic water consumption based on personal water use activities. Journal of Water Supply Research and Technology—AQUA, 70 (7). pp. 1002-1011. ISSN 1605-3974.

Essential Oils Vessel, 2022. Greek Oregano Organic Essential Oil - Carvacrol Content 82,1% [WWW Document]. Vessel Essential Oils. URL https://evessel.gr/products/oregano-organic-essential-oil (accessed 1.4.23).

European Commission, 2023. Competition Policy. Reference and discount rates [WWW Document]. Law Competition Policy. URL https://competition-policy.ec.europa.eu/state-aid/legislation/reference-discount-rates-and-recovery-interest-rates/reference-and-discount-rates_en (accessed 7.14.23).

European Commission. Joint Research Centre., 2018. Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods: new methods and differences with ILCD. Publications Office, LU.Fao, 2016.

Fao, 2016. EX-ANTE Carbon-Balance Tool (EX-ACT) EX-ANTE CARBON-BALANCE TOOL (EX-ACT) Technical Guidelines EASYPol MODULE. 101.

Fare, R., Grosskopf, S., Lovell, C.A.K., Yaisawarng, S., 1993. Derivation of shadow prices for undesirable outputs: a distance function approach. Rev. Econ. Stat. 75, 374. https://doi.org/10.2307/2109448.

Golsteijn, L., Pre Sustainability, 2020. Life Cycle Assessment (LCA) explained. PRé Sustainability. URL https://pre-sustainability.com/articles/life-cycle-assessment-lca-basics/ (accessed 3.2.23).

González-Aguirre, J.-A., Solarte-Toro, J.C., Cardona Alzate, C.A., 2020. Supply chain and environmental assessment of the essential oil production using Calendula (Calendula Officinalis) as raw material. Heliyon 6. https://doi.org/10.1016/j.heliyon.2020.e05606

Hernández-Sancho, F., Molinos-Senante, M., Sala-Garrido, R., 2010. Economic valuation of environmental benefits from wastewater treatment processes: an empirical approach for Spain. Sci. Total Environ. 408, 953–957. https://doi.org/10.1016/j.scitotenv.2009.10.028.

Hoogmartens, R., Van Passel, S., Van Acker, K., Dubois, M., 2014. Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environ. Impact Assess. Rev. https://doi.org/10.1016/j.eiar.2014.05.001.

Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A., van Zelm, R., 2017. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. International Journal of Life Cycle Assessment 22, 138–147. https://doi.org/10.1007/s11367-016-1246-y

International Organization for Standardization, 2006a. DIN EN ISO 14044:2006. Environmental management-Life cycle assessment-Requirements and guidelines, 1st ed. Geneva, Switzerland.

International Organization for Standardization, 2006b. DIN EN ISO 14040:2006. Environmental Management - Life Cycle Assessment - Principles and Framework. Geneva, Switzerland.

Kristina, K., 2005. Public and private attitudes towards “green” electricity: the case of Swedish wind power. Energy Policy 33, 1677–1689. https://doi.org/10.1016/J.ENPOL.2004.02.005

Lee, K., Jepson, W., 2021. Environmental impact of desalination: A systematic review of Life Cycle Assessment. Desalination 509. https://doi.org/10.1016/j.desal.2021.115066

Liu, Y., Zhu, J., Li, E.Y., Meng, Z., Song, Y., 2020. Environmental regulation, green technological innovation, and eco-efficiency: The case of Yangtze river economic belt in China. Technol. Forecast. Soc. Change 155, 119993. https://doi.org/10.1016/J.TECHFORE.2020.119993

Litskas, V., Chrysargyris, A., Stavrinides, M., Tzortzakis, N., 2019. Water-energy-food nexus: A case study on medicinal and aromatic plants. Journal of Cleaner Production 233, 1334–1343. https://doi.org/10.1016/j.jclepro.2019.06.065

Ma, S., He, F., Tian, D., Zou, D., Yan, Z., Yang, Y., Zhou, T., Huang, K., Shen, H., Fang, J., 2018. Variations and determinants of carbon content in plants: a global synthesis. Biogeosciences 15, 693–702. https://doi.org/10.5194/bg-15-693-2018

Maham, S.G., Rahimi, A., Smith, D.L., 2018. Environmental assessment of the essential oils produced from dragonhead (Dracocephalum moldavica L.) in conventional and organic farms with different irrigation rates. Journal of Cleaner Production 204, 1070–1086. https://doi.org/10.1016/j.jclepro.2018.08.348

Manfredi, S., Allacker, K., Chomkhamsri, K., Pelletier, N., de Souza, D.M., 2012. Product Environmental Footprint (PEF) Guide. ISPRA, Italy.

Marshall, K., S. Riche, R. Seeley and P. Westcott (2015), Effects of Recent Energy Price Reductions on U.S. Agriculture, ERS/USDA, Bio-04, Washington D.C., www.ers.usda.gov/webdocs/publications/bio04 /52998_bio-04.pdf

Mihelcic, J.R., Ren, Z.J., Cornejo, P.K., Fisher, A., Simon, A.J., Snyder, S.W., Zhang, Q., Rosso, D., Huggins, T.M., Cooper, W., Moeller, J., Rose, B., Schottel, B.L., Turgeon, J., 2017. Accelerating Innovation that Enhances Resource Recovery in the Wastewater Sector: Advancing a National Testbed Network. Environ. Sci. Technol. 51, 7749–7758. https://doi.org/10.1021/acs.est.6b05917

Ministry of Environment and Energy, 2019. National Energy and Climate Plan. Hellenic Republic, Athens, Greece.

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., 2011. Cost-benefit analysis of water-reuse projects for environmental purposes: a case study for spanish wastewater treatment plants. J. Environ. Manag. 92, 3091–3097. https://doi.org/10.1016/j.jenvman.2011.07.023.

Moncada, J., Tamayo, J.A., and Cardona, C.A (2016) Techno-economic and environmental assessment of essential oil extraction from Oregano (Origanum vulgare) and Rosemary (Rosmarinus officinalis) in Colombia. Journal of Cleaner Production 112: 172-181.

Montemayor, E., Andrade, E.P., Bonmatí, A., Antón, A., 2022. Critical analysis of life cycle inventory datasets for organic crop production systems. Int J Life Cycle Assess 27, 543–563. https://doi.org/10.1007/s11367-022-02044-x

Olympic senses, 2022. Oregano Hydrosol – Olympussenses | Βότανα | Ανθοϊάματα | Αιθέρια Έλαια. URL https://www.olympussenses.com/product/oregano-hydrosol/?lang=en (accessed 1.4.23).

Pinto, J.M., 2020. Energy Consumption and Desalination.

Pre Consultants, 2018. SimaPro Life Cycle Analysis version 7.2. available at: https://simapro.com/

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.-P., Suh, S., Weidema, B.P., Pennington, D.W., 2004. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment International 30, 701–720. https://doi.org/10.1016/j.envint.2003.11.005

Saltelli, A., S. Tarantola & K. P.-S. Chan (1999) A Quantitative Model-Independent Method for Global Sensitivity Analysis of Model Output, Technometrics, 41:1, 39 56, DOI: 10.1080/00401706.1999.10485594

Thompson, M., Ellis, R.J., Wildavsky, A., Mary "Wildavsky, T., 1990. Cultural Theory, 1st edition. ed. Routledge, Boulder, Colo.

Travel Guide, 2014. The climate of Mykonos: when to go to Mykonos. Travel Guide. URL https://www.travelguide-en.org/mykonos-climate/ (accessed 12.14.22).

World Bank. World Development Report 2020: Trading for Development in the Age of Global Value Chains. World Bank Publications, Washington, DC, p. 1457. https://doi.org/10. 1596/978-1-4648-.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. Int J Life Cycle Assess 21, 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Zhang, B., Menzin, J., Tran, M., Neumann, P., Friedman, M., Sussman, M., Hepner, D., 2008. PHC9 THE POTENTIAL SAVINGS IN OPERATING ROOM TIME ASSOCIATED WITH THE USE OF SUGAMMADEXTO REVERSE SELECTED NEUROMUSCULAR BLOCKING AGENTS: FINDINGS FROM A HOSPITAL EFFICIENCY MODEL. Value Heal. 11, A244. https://doi.org/10.1016/S1098-3015(10)70771-3

Zhang, X., Zhang, M., Zhang, H., Jiang, Z., Liu, C., Cai, W., 2020. A review on energy, environment and economic assessment in remanufacturing based on life cycle assessment method. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2020.120160

8. APPENDIX

The appendixes present the absolute environmental impact scores which are normalised in the present document.

8.1 HYDRO1&2

Table 8.1. Inventory of ultrafiltration unit of Scenario 1 (UF) in one year of operation

Input	Amount	Unit	Output	Amount	Unit
Wastewater (from CW)	22,829	m^3	Wastewater (to UF)	22,827.28	m^3
Electricity	184	kWh			

Table 8.2. Inventory of biogas upgrade of Scenario 1 (Biomethane) in one year of operation

Inputs			Outputs		
Total biogas	3,380	m^3	Biomethane	1,751	kg
Electricity	8,113	kWh	Methane (leaked)	92.14	kg
			Carbon dioxide (leaked)	51.30	kg

Table 8.3. Non-normalised environmental impact results of HYDRO1&2 system and baseline system, with functional unit 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of fruits

Impact category	Unit	HYDRO1&2 (with CHP)	Baseline system
Global warming	kg CO_2 eq	166	44,842
Stratospheric ozone depletion	kg CFC11 eq	0.00	0
Ionizing radiation	kBq Co-60 eq	150.72	3,912
Ozone formation, Human health	kg NO_x eq	23.05	129
Fine particulate matter formation	kg PM2.5 eq	8.58	173
Ozone formation, Terrestrial ecosystems	kg NO_x eq	72.03	256
Terrestrial acidification	kg SO2 eq	48.19	571
Freshwater eutrophication	kg P eq	17.26	99
Marine eutrophication	kg N eq	882.37	81,823
Terrestrial ecotoxicity	kg 1,4-DCB	19,770	479,677
Freshwater ecotoxicity	kg 1,4-DCB	9	863
Marine ecotoxicity	kg 1,4-DCB	92,625	6,885,088
Human carcinogenic toxicity	kg 1,4-DCB	908	35,399
Human non-carcinogenic toxicity	kg 1,4-DCB	37,814	4,849,051
Land use	m^2a crop eq	-3,679,974	-3,679,223
Mineral resource scarcity	kg Cu eq	1	66
Fossil resource scarcity	kg oil eq	600	15,179
Water consumption	m^3	-4,035	7,984

Table 8.4. Non-normalised environmental impact results of HYDRO1&2 system with and without the UF, with functional unit 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of fruits

Impact category	Unit	HYDRO1&2 (CHP without UF)	HYDRO1&2 (CHP with UF)
Global warming	kg CO_2 eq	167.2	331.7
Stratospheric ozone depletion	kg CFC11 eq	0.0	0.0
Ionizing radiation	kBq Co-60 eq	150.8	169.0
Ozone formation, Human health	kg NO_x eq	23.1	23.4
Fine particulate matter formation	kg PM2.5 eq	8.6	9.0
Ozone formation, Terrestrial ecosystems	kg NO_x eq	72.0	72.3
Terrestrial acidification	kg SO2 eq	48.2	49.5
Freshwater eutrophication	kg P eq	17.3	17.3
Marine eutrophication	kg N eq	882.4	882.4
Terrestrial ecotoxicity	kg 1,4-DCB	19786.6	21313.7
Freshwater ecotoxicity	kg 1,4-DCB	9.2	12.2
Marine ecotoxicity	kg 1,4-DCB	93081.5	111300.4
Human carcinogenic toxicity	kg 1,4-DCB	936.3	1182.8
Human non-carcinogenic toxicity	kg 1,4-DCB	38098.5	50877.4
Land use	m^2a crop eq	-3679974.02	-3679971.26
Mineral resource scarcity	kg Cu eq	0.621	0.812
Fossil resource scarcity	kg oil eq	600.929	650.313
Water consumption	m^3	-4035.302	-4034.107

Table 8.5. Non-normalised environmental impact results of HYDRO1&2 system and Baseline system of biomethane scenario, with functional unit 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of fruits

Impact category	Unit	HYDRO1&2 (Biomethane)	Baseline system
Global warming	kg CO_2 eq	9,931.80	43,129.38
Stratospheric ozone depletion	kg CFC11 eq	0.03	0.11
Ionizing radiation	kBq Co-60 eq	1,079.78	3,765.49
Ozone formation, Human health	kg NO_x eq	41.89	92.17
Fine particulate matter formation	kg PM2.5 eq	40.23	128.75
Ozone formation, Terrestrial ecosystems	kg NO_x eq	91.31	139.22
Terrestrial acidification	kg SO2 eq	148.64	423.07
Freshwater eutrophication	kg P eq	17.37	61.53
Marine eutrophication	kg N eq	867.28	81,663.79
Terrestrial ecotoxicity	kg 1,4-DCB	139,806.38	459,648.49
Freshwater ecotoxicity	kg 1,4-DCB	84.47	745.88
Marine ecotoxicity	kg 1,4-DCB	716,251.47	6,379,010.52
Human carcinogenic toxicity	kg 1,4-DCB	8,562.36	28,875.86
Human non-carcinogenic toxicity	kg 1,4-DCB	315,922.44	4,435,652.93

Land use	m^{2}a crop eq	-3679812.06	-3679249.972
Mineral resource scarcity	kg Cu eq	5.65	25.41
Fossil resource scarcity	kg oil eq	4,349.37	14,357.93
Water consumption	m^3	-4,031.08	6,616.07

Table 8.6. Non-normalised environmental impact results of HYDRO1&2 system with various irrigation methods, with functional unit 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of fruits

Impact category	Unit	HYDRO1&2 (50% drip 50% open channels)	HYDRO1&2 (50% drip 50% open channels and farmers)	HYDRO1&2 (100% drip 0% open channels and farmers)	HYDRO1&2 (0% drip 100% open channels and farmers)
Global warming	kg CO_2 eq	165.68	118.75	118.26	119.25
Stratospheric ozone depletion	kg CFC11 eq	0.00	0.00	0.01	0.00
Ionizing radiation	kBq Co-60 eq	150.72	147.27	182.10	112.44
Ozone formation, Human health	kg NO_x eq	23.05	23.03	21.21	24.85
Fine particulate matter formation	kg PM2.5 eq	8.58	8.47	9.25	7.68
Ozone formation, Terrestrial ecosystems	kg NO_x eq	72.03	72.12	64.16	80.09
Terrestrial acidification	kg SO2 eq	48.19	47.88	47.74	48.02
Freshwater eutrophication	kg P eq	17.26	36.49	28.18	44.80
Marine eutrophication	kg N eq	882.37	124.67	105.44	143.90
Terrestrial ecotoxicity	kg 1,4-DCB	19,769.52	19,314.77	23,908.16	14,721.39
Freshwater ecotoxicity	kg 1,4-DCB	8.96	8.76	10.72	6.80
Marine ecotoxicity	kg 1,4-DCB	92,624.97	90,536.82	111,441.58	69,632.07
Human carcinogenic toxicity	kg 1,4-DCB	908.44	888.68	1,083.29	694.07
Human non-carcinogenic toxicity	kg 1,4-DCB	37,814.09	36,981.09	45,232.59	28,729.59
Land use	m^{2}a crop eq	-3,679,974	-3,679,974.68	-3,679,968	-3,679,980
Mineral resource scarcity	kg Cu eq	0.60	0.59	0.72	0.47
Fossil resource scarcity	kg oil eq	600.48	586.68	726.07	447.29
Water consumption	m^3	-4,035.31	-20,328.36	-18,215.28	-22,441.44

Table 8.7. Non-normalised environmental impact results of HYDRO1&2 system in 2021 and 2030, with functional unit 7,373 kg of compost, 35,644 MJ of heat and 9,864 kg of fruits

Impact category	Unit	HYDRO1&2 (with CHP)	HYDRO1&2 2030 (with CHP)
Global warming	kg CO_2 eq	166.00	-1,510.14
Stratospheric ozone depletion	kg CFC11 eq	0.00	0.00
Ionizing radiation	kBq Co-60 eq	150.72	1.86
Ozone formation, Human health	kg NO_x eq	23.05	20.44
Fine particulate matter formation	kg PM2.5 eq	8.58	3.53
Ozone formation, Terrestrial ecosystems	kg NO_x eq	72.03	69.37
Terrestrial acidification	kg SO2 eq	48.19	32.08
Freshwater eutrophication	kg P eq	17.26	17.02
Marine eutrophication	kg N eq	882.37	882.37
Terrestrial ecotoxicity	kg 1,4-DCB	19,769.52	88.60
Freshwater ecotoxicity	kg 1,4-DCB	8.96	1.14
Marine ecotoxicity	kg 1,4-DCB	92,624.97	6,362.69
Human carcinogenic toxicity	kg 1,4-DCB	908.44	295.99
Human non-carcinogenic toxicity	kg 1,4-DCB	37,814.09	4,907.99
Land use	m^2a crop eq	-3,679,974.00	-3,679,998.53
Mineral resource scarcity	kg Cu eq	0.60	0.19
Fossil resource scarcity	kg oil eq	600.48	153.52
Water consumption	m^3	-4,035.31	-4,037.00

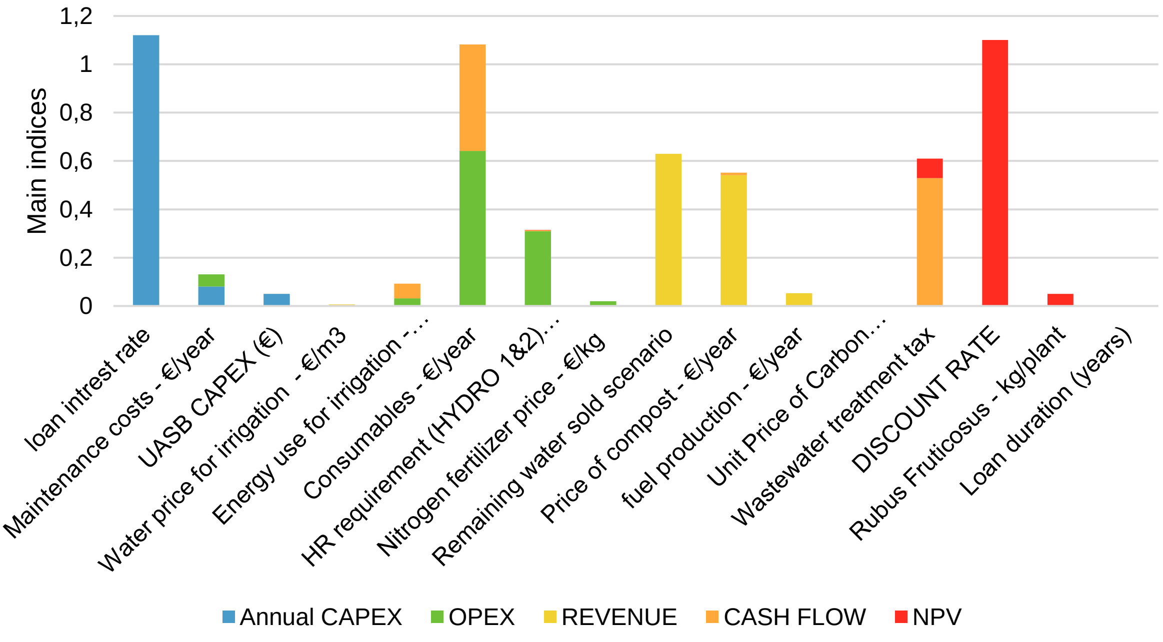


Figure 8.1. Most influential paramaters of HYDRO1&2

8.2. HYDRO3

Table 8.8. Non-normalised environmental impact results of HYDRO3, its scenarios and Baseline system, with functional unit one bottle of oregano essential oil

Impact category	Unit	HYDRO 3 2022 (Oregano oil)	HYDRO3 2023-Low (Oregano oil)	HYDRO3 2023-High (Oregano oil)	Baseline system (Oregano oil)
Global warming	kg CO_2 eq	-0.658	-0.680	-0.682	0.390
Stratospheric ozone depletion	kg CFC11 eq	0.000	0.000	0.000	0.000
Ionizing radiation	kBq Co-60 eq	0.010	0.008	0.007	0.116
Ozone formation, Human health	kg NO_x eq	0.001	0.000	0.000	0.002
Fine particulate matter formation	kg PM2.5 eq	0.000	0.000	0.000	0.003
Ozone formation, Terrestrial ecosystems	kg NO_x eq	0.001	0.000	0.000	0.003
Terrestrial acidification	kg SO2 eq	0.001	0.001	0.001	0.011
Freshwater eutrophication	kg P eq	0.003	0.003	0.003	0.006
Marine eutrophication	kg N eq	0.000	0.000	0.000	0.004
Terrestrial ecotoxicity	kg 1,4-DCB	0.902	0.704	0.688	8.100
Freshwater ecotoxicity	kg 1,4-DCB	0.176	0.171	0.171	0.224
Marine ecotoxicity	kg 1,4-DCB	1,482.119	#######	1,451.501	1,635.446
Human carcinogenic toxicity	kg 1,4-DCB	0.876	0.685	0.670	4.692
Human non-carcinogenic toxicity	kg 1,4-DCB	1,239.163	#######	1,214.279	1,368.111
Land use	m^2a crop eq	13.331	6.541	6.000	9.853
Mineral resource scarcity	kg Cu eq	0.001	0.000	0.000	0.017
Fossil resource scarcity	kg oil eq	0.078	0.065	0.064	0.423
Water consumption	m^3	0.001	0.001	0.001	0.368

Table 8.9. Non-normalised environmental impacts results of HYDRO3 in 2022 and 2030, with functional unit one bottle of oregano essential oil

Impact category	Unit	Essential oregano oil 2022	Essential oregano oil 2030
Global warming	kg CO_2 eq	-0.6581	-0.7594
Stratospheric ozone depletion	kg CFC11 eq	0.0000	0.0000
Ionizing radiation	kBq Co-60 eq	0.0101	0.0061
Ozone formation, Human health	kg NO_x eq	0.0006	0.0004
Fine particulate matter formation	kg PM2.5 eq	0.0004	0.0002
Ozone formation, Terrestrial ecosystems	kg NO_x eq	0.0006	0.0004

Terrestrial acidification	kg SO2 eq	0.0010	0.0004
Freshwater eutrophication	kg P eq	0.0030	0.0030
Marine eutrophication	kg N eq	0.0004	0.0003
Terrestrial ecotoxicity	kg 1,4-DCB	0.9022	0.3842
Freshwater ecotoxicity	kg 1,4-DCB	0.1758	0.1731
Marine ecotoxicity	kg 1,4-DCB	1,482.1190	1,467.1084
Human carcinogenic toxicity	kg 1,4-DCB	0.8759	0.6207
Human non-carcinogenic toxicity	kg 1,4-DCB	1,239.1634	1,226.8464
Land use	m^2a crop eq	13.3314	13.3302
Mineral resource scarcity	kg Cu eq	0.0005	0.0004
Fossil resource scarcity	kg oil eq	0.0780	0.0488
Water consumption	m^3	0.0007	0.0005

Table 8.10. Non-normalised environmental impacts of HYDRO3 in 2022 and 2030, with functional unit one bottle of oregano essential oil

Impact category	Unit	Essential oregano oil 2022	Essential oregano oil 2030
Global warming	kg CO_2 eq	-0.6581	-0.7594
Stratospheric ozone depletion	kg CFC11 eq	0.0000	0.0000
Ionizing radiation	kBq Co-60 eq	0.0101	0.0061
Ozone formation, Human health	kg NOx eq	0.0006	0.0004
Fine particulate matter formation	kg PM2.5 eq	0.0004	0.0002
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.0006	0.0004
Terrestrial acidification	kg SO2 eq	0.0010	0.0004
Freshwater eutrophication	kg P eq	0.0030	0.0030
Marine eutrophication	kg N eq	0.0004	0.0003
Terrestrial ecotoxicity	kg 1,4-DCB	0.9022	0.3842
Freshwater ecotoxicity	kg 1,4-DCB	0.1758	0.1731
Marine ecotoxicity	kg 1,4-DCB	1,482.1190	1,467.1084
Human carcinogenic toxicity	kg 1,4-DCB	0.8759	0.6207
Human non-carcinogenic toxicity	kg 1,4-DCB	1,239.1634	1,226.8464
Mineral resource scarcity	kg Cu eq	13.3314	13.3302
Fossil resource scarcity	kg oil eq	0.0005	0.0004
Water consumption	m3	0.0780	0.0488

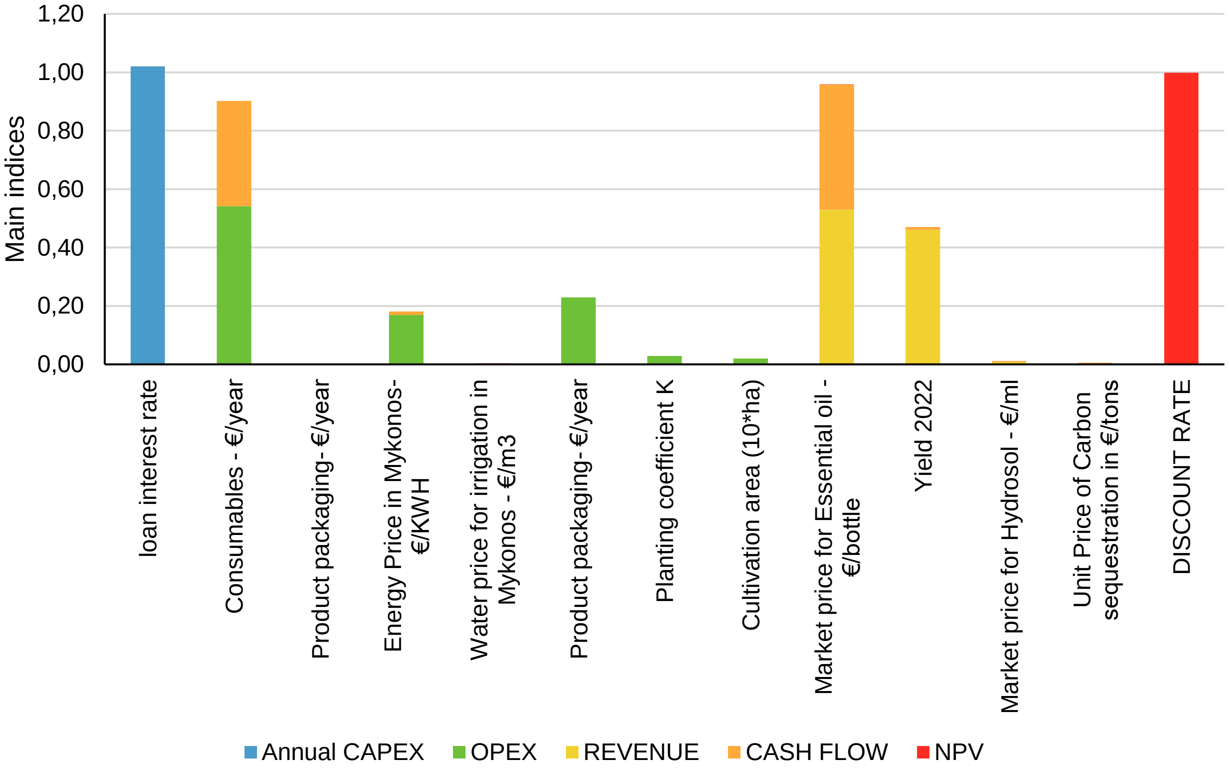


Figure 8.2. Most influential parameters of HYDRO3

8.3. HYDRO4

Table 8.11. Non-normalised environmental impact results of HYDRO4A and Baseline systems, with functional unit 1m^3 of water for residential use

Impact category	Unit	HYDRO4 (Residence)	Baseline system (Residence)
Global warming	kg CO_2 eq	0.747171017	0.783458697
Stratospheric ozone depletion	kg CFC11 eq	2.4749E-06	2.50883E-06
Ionizing radiation	kBq Co-60 eq	0.109965576	0.115350173
Ozone formation, Human health	kg NOx eq	0.002466635	0.002590638
Fine particulate matter formation	kg PM2.5 eq	0.00194942	0.002027416
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.002521356	0.002650666
Terrestrial acidification	kg SO2 eq	0.005095399	0.005252509
Freshwater eutrophication	kg P eq	0.002706751	0.00273532
Marine eutrophication	kg N eq	0.005984214	0.006020792
Terrestrial ecotoxicity	kg 1,4-DCB	4.693749775	4.824545231
Freshwater ecotoxicity	kg 1,4-DCB	0.069617785	0.068664672
Marine ecotoxicity	kg 1,4-DCB	422.3605796	432.3090187
Human carcinogenic toxicity	kg 1,4-DCB	28.23098324	33.16905753
Human non-carcinogenic toxicity	kg 1,4-DCB	340.3798705	346.6879914
Mineral resource scarcity	kg Cu eq	0.012369985	0.013261048

Fossil resource scarcity	kg oil eq	0.212919827	0.22338676
Water consumption	m3	0.108126491	0.108799717

Table 8.12. Non-normalised environmental impact results of the original system in year 1 (2022) and the corresponding Baseline system, with functional unit 1 bottle of lavender essential oil (HYDRO4B)

Impact category	Unit	HYDRO4, Year 1 (Lavender oil)	Baseline system (Lavender oil)
Global warming	kg CO_2 eq	0.808956858	1.01632437
Stratospheric ozone depletion	kg CFC11 eq	1.24262E-05	4.583E-05
Ionizing radiation	kBq Co-60 eq	0.062650978	0.084514266
Ozone formation, Human health	kg NOx eq	0.00218926	0.002953346
Fine particulate matter formation	kg PM2.5 eq	0.00276137	0.004945297
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.002236995	0.00301377
Terrestrial acidification	kg SO2 eq	0.007260766	0.012158427
Freshwater eutrophication	kg P eq	0.00245587	0.001242974
Marine eutrophication	kg N eq	0.00246263	7.67357E-05
Terrestrial ecotoxicity	kg 1,4-DCB	5.152086663	7.275979963
Freshwater ecotoxicity	kg 1,4-DCB	0.095404756	0.100515132
Marine ecotoxicity	kg 1,4-DCB	465.533518	447.0652423
Human carcinogenic toxicity	kg 1,4-DCB	6.710901592	6.534046362
Human non-carcinogenic toxicity	kg 1,4-DCB	385.6062525	366.5483646
Mineral resource scarcity	kg Cu eq	0.002256017	0.002648217
Fossil resource scarcity	kg oil eq	0.402779176	0.399572341
Water consumption	m3	2.123589472	7.12534332

Table 8.13. Non-normalised environmental impact results of HYDRO4B in year 1 (2022), year 2 (2023), and Baseline system, with functional unit 1 bottle of lavender essential oil

Impact category	Unit	HYDRO4 Year 1 (Lavender oil)	HYDRO4 Year 2-Low yield (Lavender oil)	HYDRO4 Year 2-High yield (Lavender oil)	Baseline system (Lavender oil)
Global warming	kg CO_2 eq	0.808956858	-0.094404579	-0.108703739	1.01632437
Stratospheric ozone depletion	kg CFC11 eq	1.24262E-05	1.68251E-06	1.51539E-06	4.583E-05
Ionizing radiation	kBq Co-60 eq	0.062650978	0.016567937	0.015842672	0.08451427
Ozone formation, Human health	kg NOx eq	0.00218926	0.000536809	0.000510876	0.00295335
Fine particulate matter formation	kg PM2.5 eq	0.00276137	0.00066395	0.000631015	0.0049453
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.002236995	0.000548525	0.000522026	0.00301377
Terrestrial acidification	kg SO2 eq	0.007260766	0.001883429	0.001799021	0.01215843
Freshwater eutrophication	kg P eq	0.00245587	0.0004899	0.000459082	0.00124297
Marine eutrophication	kg N eq	0.00246263	0.000299858	0.000266236	7.6736E-05

Terrestrial ecotoxicity	kg 1,4-DCB	5.152086663	1.322199444	1.261845591	7.27597996
Freshwater ecotoxicity	kg 1,4-DCB	0.095404756	0.027176155	0.026094944	0.10051513
Marine ecotoxicity	kg 1,4-DCB	465.533518	123.4428341	118.0381038	447.065242
Human carcinogenic toxicity	kg 1,4-DCB	6.710901592	1.789681562	1.711998975	6.53404636
Human non-carcinogenic toxicity	kg 1,4-DCB	385.6062525	102.0622257	97.58281345	366.548365
Mineral resource scarcity	kg Cu eq	0.002256017	0.000601561	0.000575525	0.00264822
Fossil resource scarcity	kg oil eq	0.402779176	0.104869254	0.100171402	0.39957234
Water consumption	m3	2.123589472	0.248308538	0.219170183	7.12534332

Table 8.14. Non-normalised environmental performance of the supply of water for domestic use (HYDRO4A) with the projected electricity mix for the year 2030 with performance for the year 2022, using current electricity mix

Impact category	Unit	HYDRO4 (Residence; 2030 Scenario)	HYDRO4 (Residence; current electricity mix)
Global warming	kg CO_2 eq	0.689226404	0.718092231
Stratospheric ozone depletion	kg CFC11 eq	2.37127E-06	2.39797E-06
Ionizing radiation	kBq Co-60 eq	0.169352964	0.171675063
Ozone formation, Human health	kg NOx eq	0.002432642	0.002469915
Fine particulate matter formation	kg PM2.5 eq	0.001808114	0.001882057
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.002485015	0.002522535
Terrestrial acidification	kg SO2 eq	0.004727337	0.004911318
Freshwater eutrophication	kg P eq	0.002559136	0.002620677
Marine eutrophication	kg N eq	0.005885984	0.005889632
Terrestrial ecotoxicity	kg 1,4-DCB	4.481029528	4.528873287
Freshwater ecotoxicity	kg 1,4-DCB	0.067250046	0.067905693
Marine ecotoxicity	kg 1,4-DCB	391.9784458	406.6668825
Human carcinogenic toxicity	kg 1,4-DCB	27.8124103	28.01218366
Human non-carcinogenic toxicity	kg 1,4-DCB	314.3674846	327.3384768
Mineral resource scarcity	kg Cu eq	0.012385543	0.012368939
Fossil resource scarcity	kg oil eq	0.187306695	0.196477828
Water consumption	m3	0.109399272	0.109441976

Table 8.15. Non-normalised environmental performance of bottled lavender essential oil production (HYDRO4B) with the projected electricity mix for the year 2030 with performance for the year 2022, using current electricity mix

Impact category	Unit	HYDRO4 (Lavender essential oil; 2030 Scenario)	HYDRO4 (Lavender essential oil year 1, 2022; current electricity mix)
Global warming	kg CO_2 eq	0.383026282	0.808956858

Stratospheric ozone depletion	kg CFC11 eq	1.20324E-05	1.24262E-05
Ionizing radiation	kBq Co-60 eq	0.028387201	0.062650978
Ozone formation, Human health	kg NOx eq	0.001639284	0.00218926
Fine particulate matter formation	kg PM2.5 eq	0.001670307	0.00276137
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.001683365	0.002236995
Terrestrial acidification	kg SO2 eq	0.004546024	0.007260766
Freshwater eutrophication	kg P eq	0.001547797	0.00245587
Marine eutrophication	kg N eq	0.002408797	0.00246263
Terrestrial ecotoxicity	kg 1,4-DCB	4.446126339	5.152086663
Freshwater ecotoxicity	kg 1,4-DCB	0.085730331	0.095404756
Marine ecotoxicity	kg 1,4-DCB	248.7978401	465.533518
Human carcinogenic toxicity	kg 1,4-DCB	3.76313753	6.710901592
Human non-carcinogenic toxicity	kg 1,4-DCB	194.21238	385.6062525
Mineral resource scarcity	kg Cu eq	0.002501013	0.002256017
Fossil resource scarcity	kg oil eq	0.267454242	0.402779176
Water consumption	m3	2.122959472	2.123589472

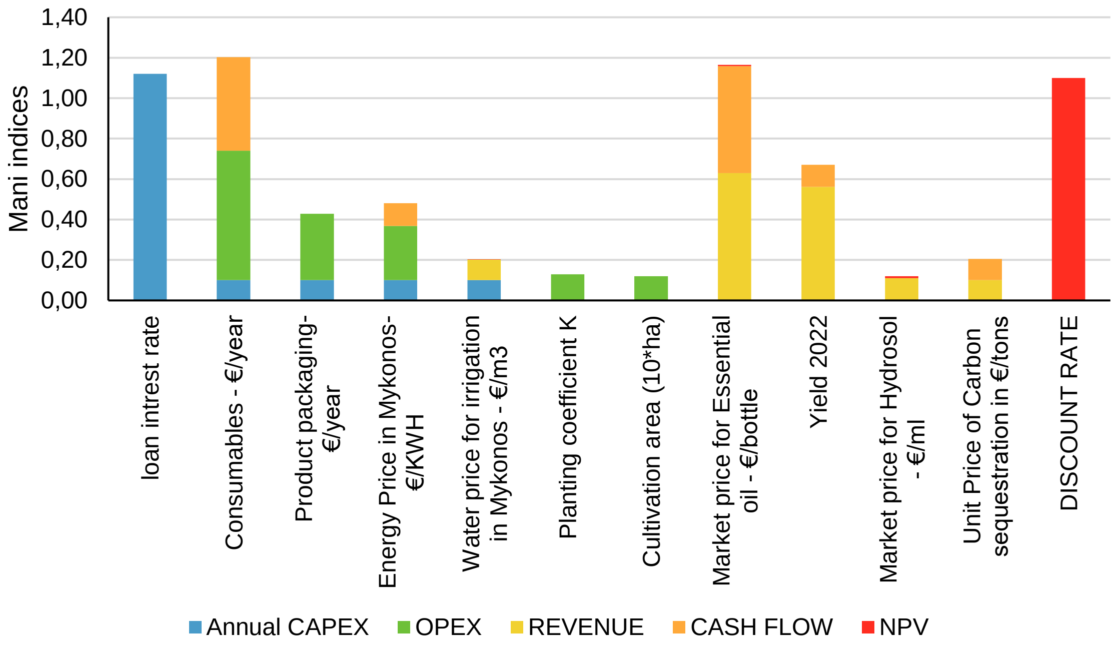


Figure 8.3. Most influential paramaters of HYDRO4

8.4. HYDRO5

Table 8.16. Absolute environmental impact results of HYDRO5 and Baseline systems producing fruits and salt

Impact category	Unit	HYDRO5 (Fruits and salt)	Baseline system (Fruits and salt)
Global warming	kg CO_2 eq	580.8903566	555.307994
Stratospheric ozone depletion	kg CFC11 eq	0.00168365	0.001624851

Ionizing radiation	kBq Co-60 eq	17.08155693	60.20252381
Ozone formation, Human health	kg NOx eq	1.26276088	1.296612077
Fine particulate matter formation	kg PM2.5 eq	1.062165828	1.127906434
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.290868259	1.324200286
Terrestrial acidification	kg SO2 eq	3.194245653	3.279683213
Freshwater eutrophication	kg P eq	0.726334951	0.8162932
Marine eutrophication	kg N eq	0.23497103	0.261194647
Terrestrial ecotoxicity	kg 1,4-DCB	1895.818646	3832.423134
Freshwater ecotoxicity	kg 1,4-DCB	8.481659219	31.36280949
Marine ecotoxicity	kg 1,4-DCB	54805.46933	155967.3788
Human carcinogenic toxicity	kg 1,4-DCB	955.720463	2421.509236
Human non-carcinogenic toxicity	kg 1,4-DCB	46139.31156	130829.9136
Mineral resource scarcity	kg Cu eq	0.290920657	2.272925766
Fossil resource scarcity	kg oil eq	246.6788753	228.3518959
Water consumption	m3	1.136065022	4.197593408

Table 8.17. Absolute environmental impact results of HYDRO5 and Baseline systems producing fruits

Impact category	Unit	HYDRO5 (Only fruits)	Baseline (Only fruits)
Global warming	kg CO_2 eq	-10.57587814	450.951972
Stratospheric ozone depletion	kg CFC11 eq	0.001089607	0.001553286
Ionizing radiation	kBq Co-60 eq	3.299449704	14.02327671
Ozone formation, Human health	kg NOx eq	0.237802182	1.036985316
Fine particulate matter formation	kg PM2.5 eq	0.245741396	0.882582207
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.243086961	1.060069167
Terrestrial acidification	kg SO2 eq	0.703467071	2.646807239
Freshwater eutrophication	kg P eq	0.601744955	0.6988508
Marine eutrophication	kg N eq	0.227806924	0.234058931
Terrestrial ecotoxicity	kg 1,4-DCB	362.7886328	1557.125178
Freshwater ecotoxicity	kg 1,4-DCB	4.081035659	7.504446376
Marine ecotoxicity	kg 1,4-DCB	10449.67096	45010.14557
Human carcinogenic toxicity	kg 1,4-DCB	181.7825138	784.8679949
Human non-carcinogenic toxicity	kg 1,4-DCB	8793.802656	37892.96467
Mineral resource scarcity	kg Cu eq	0.06512729	0.24085367
Fossil resource scarcity	kg oil eq	46.10136388	202.6344661
Water consumption	m3	0.222272306	0.934428744

Table 8.18. Absolute environmental impact results of HYDRO5 and Baseline systems producing salt

Impact category	Unit	HYDRO5 (Only salt)	Baseline (Only salt)
Global warming	kg CO_2 eq	0.810227719	0.14747431
Stratospheric ozone depletion	kg CFC11 eq	8.13758E-07	1.02767E-07

Ionizing radiation	kBq Co-60 eq	0.018879599	0.063322778
Ozone formation, Human health	kg NOx eq	0.001404053	0.000362659
Fine particulate matter formation	kg PM2.5 eq	0.00111839	0.000341993
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.001435317	0.000368991
Terrestrial acidification	kg SO2 eq	0.003412025	0.000885659
Freshwater eutrophication	kg P eq	0.000170671	0.000161677
Marine eutrophication	kg N eq	9.81384E-06	3.72143E-05
Terrestrial ecotoxicity	kg 1,4-DCB	2.100041114	3.126351283
Freshwater ecotoxicity	kg 1,4-DCB	0.006028251	0.036245848
Marine ecotoxicity	kg 1,4-DCB	60.76136763	152.2657386
Human carcinogenic toxicity	kg 1,4-DCB	1.060188972	2.246756166
Human non-carcinogenic toxicity	kg 1,4-DCB	51.15823137	127.5388305
Mineral resource scarcity	kg Cu eq	0.000309306	0.002784752
Fossil resource scarcity	kg oil eq	0.274763714	0.03679011
Water consumption	m3	0.001251771	0.004475859

Table 8.19. Absolute environmental impact results of HYDRO5 and Baseline systems producing freshwater

Impact category	Unit	HYDRO5 (Only freshwater production)	Baseline (Only freshwater production)
Global warming	kg CO2 eq	1.111301003	5.005943055
Stratospheric ozone depletion	kg CFC11 eq	1.11614E-06	5.02775E-06
Ionizing radiation	kBq Co-60 eq	0.025895087	0.116646462
Ozone formation, Human health	kg NOx eq	0.001925786	0.008674857
Fine particulate matter formation	kg PM2.5 eq	0.001533973	0.006909903
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.001968668	0.008868019
Terrestrial acidification	kg SO2 eq	0.004679903	0.021080993
Freshwater eutrophication	kg P eq	0.000234091	0.001054482
Marine eutrophication	kg N eq	1.34606E-05	6.06342E-05
Terrestrial ecotoxicity	kg 1,4-DCB	2.880397376	12.97497726
Freshwater ecotoxicity	kg 1,4-DCB	0.008268295	0.037245188
Marine ecotoxicity	kg 1,4-DCB	83.33974166	375.4104423
Human carcinogenic toxicity	kg 1,4-DCB	1.454145594	6.550313567
Human non-carcinogenic toxicity	kg 1,4-DCB	70.16816692	316.0780446
Mineral resource scarcity	kg Cu eq	0.000424241	0.001911028
Fossil resource scarcity	kg oil eq	0.376863423	1.697611024
Water consumption	m3	0.001716918	0.007733991

Table 8.20. Absolute environmental impact results of HYDRO5 system in 2021 and 2030

Impact category	Unit	HYDRO5 2021 (Fruits and salt)	HYDRO5 2030 (Fruits and salt)

Global warming	kg CO_2 eq	580.8903566	145.3372
Stratospheric ozone depletion	kg CFC11 eq	0.00168365	0.001165
Ionizing radiation	kBq Co-60 eq	17.08155693	0.96595
Ozone formation, Human health	kg NOx eq	1.26276088	0.32905
Fine particulate matter formation	kg PM2.5 eq	1.062165828	0.170009
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.290868259	0.346463
Terrestrial acidification	kg SO2 eq	3.194245653	0.476095
Freshwater eutrophication	kg P eq	0.726334951	0.578999
Marine eutrophication	kg N eq	0.23497103	0.226738
Terrestrial ecotoxicity	kg 1,4-DCB	1895.818646	53.12922
Freshwater ecotoxicity	kg 1,4-DCB	8.481659219	3.685516
Marine ecotoxicity	kg 1,4-DCB	54805.46933	3844.667
Human carcinogenic toxicity	kg 1,4-DCB	955.720463	202.8955
Human non-carcinogenic toxicity	kg 1,4-DCB	46139.31156	2898.912
Mineral resource scarcity	kg Cu eq	0.290920657	1.143095
Fossil resource scarcity	kg oil eq	246.6788753	0.131299
Water consumption	m3	1.136065022	122.7775

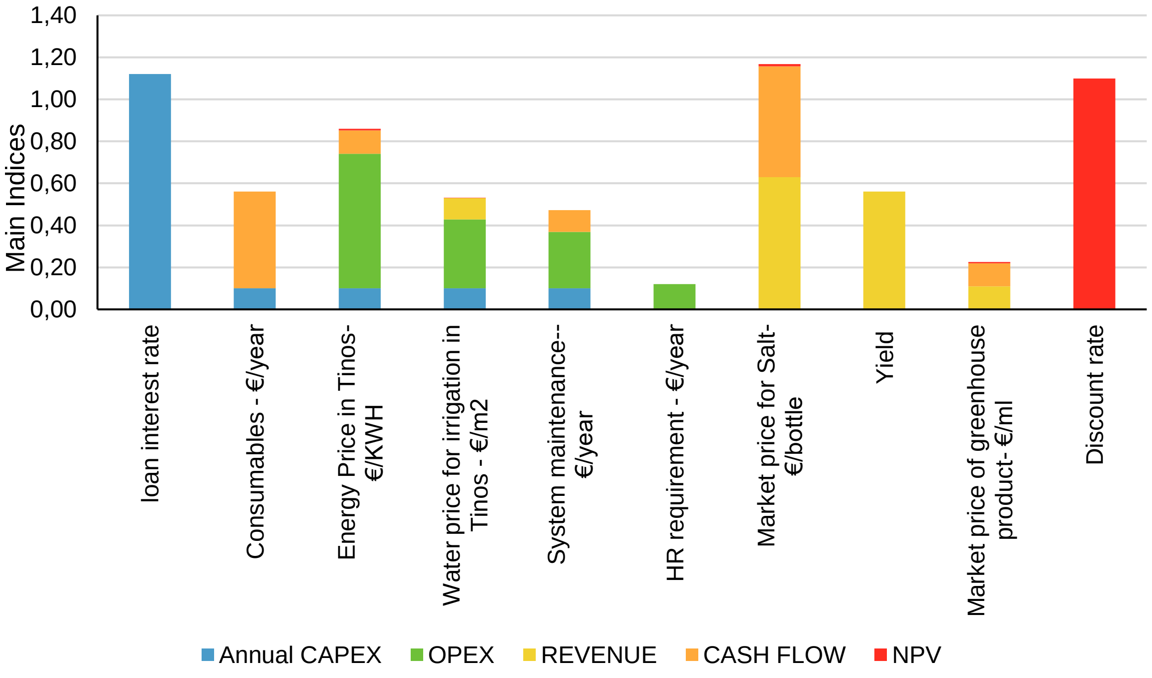


Figure 8.4 Most influential parameters of HYDRO5

8.5. HYDRO6

Table 8.21. Absolute environmental impact results of HYDRO6 and Baseline systems

Impact category	Unit	HYDRO6 Eco Lodge	Baseline Eco Lodge
Global warming	kg CO_2 eq	164.73	578.75

Stratospheric ozone depletion	kg CFC11 eq	0.00	0.01
Ionizing radiation	kBq Co-60 eq	18.41	63.81
Ozone formation, Human health	kg NOx eq	1.17	4.01
Fine particulate matter formation	kg PM2.5 eq	0.92	2.43
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.19	4.09
Terrestrial acidification	kg SO_2 eq	3.27	9.31
Freshwater eutrophication	kg P eq	0.53	1.73
Marine eutrophication	kg N eq	0.58	1.51
Terrestrial ecotoxicity	kg 1,4-DCB	1,831.37	6,330.33
Freshwater ecotoxicity	kg 1,4-DCB	16.82	56.75
Marine ecotoxicity	kg 1,4-DCB	63,360.41	227,283.40
Human carcinogenic toxicity	kg 1,4-DCB	1,219.45	5,278.28
Human non-carcinogenic toxicity	kg 1,4-DCB	52,068.89	184,437.44
Mineral resource scarcity	kg Cu eq	478.64	1,537.83
Fossil resource scarcity	kg oil eq	1.34	5.18
Water consumption	m3	81.18	295.54

Table 8.22. Absolute environmental impact results of HYDRO6 system in 2021 and 2030

Impact category	Unit	HYDRO6 Eco Lodge 2021	Baseline Eco Lodge 2030
Global warming	kg CO_2 eq	164.73	115.3636
Stratospheric ozone depletion	kg CFC11 eq	0.00	0.00371
Ionizing radiation	kBq Co-60 eq	18.41	16.49358
Ozone formation, Human health	kg NOx eq	1.17	1.058901
Fine particulate matter formation	kg PM2.5 eq	0.92	0.82412
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.19	1.080502
Terrestrial acidification	kg SO_2 eq	3.27	2.973744
Freshwater eutrophication	kg P eq	0.53	0.515982
Marine eutrophication	kg N eq	0.58	0.576546
Terrestrial ecotoxicity	kg 1,4-DCB	1,831.37	1578.972
Freshwater ecotoxicity	kg 1,4-DCB	16.82	15.48573
Marine ecotoxicity	kg 1,4-DCB	63,360.41	56047.24
Human carcinogenic toxicity	kg 1,4-DCB	1,219.45	1095.1
Human non-carcinogenic toxicity	kg 1,4-DCB	52,068.89	46068.05
Mineral resource scarcity	kg Cu eq	478.64	478.0653
Fossil resource scarcity	kg oil eq	1.34	1.282483
Water consumption	m3	81.18	66.97496

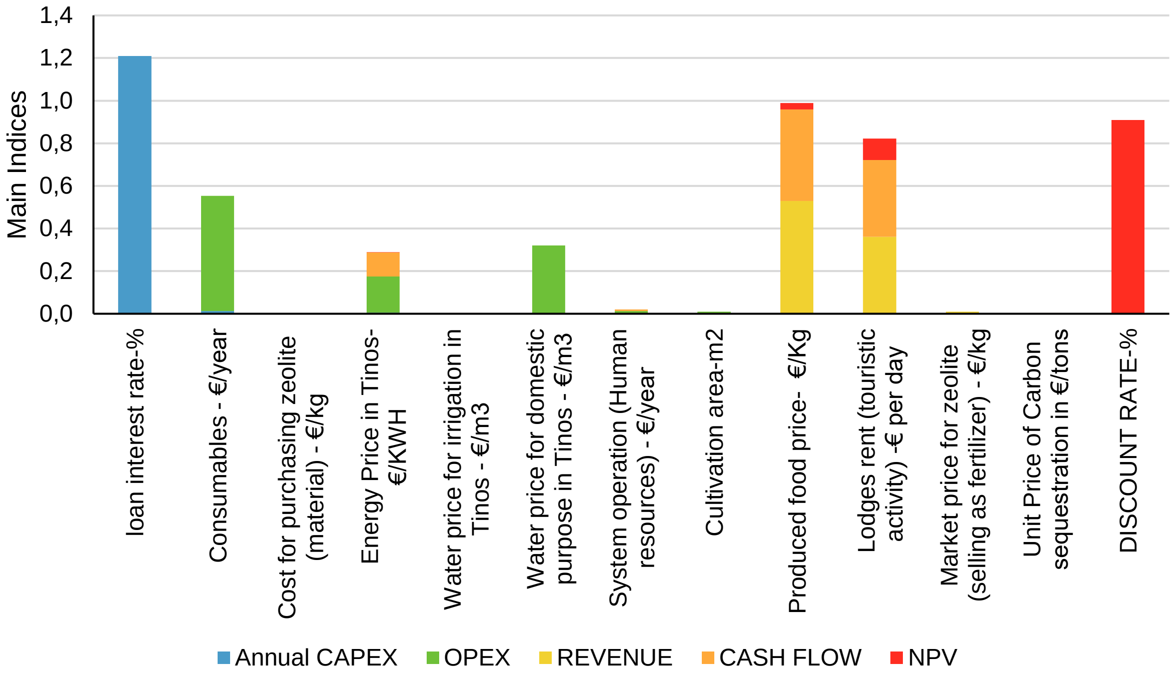


Figure 8.5. Most influential paramaters of HYDRO6