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LESS-WATER BEV.TECH Project

Contract ECO/13/630314

WP4 - START-UP, TUNING AND PERFORMANCE / SUSTAINABILITY ANALYSIS

D4.2 Performance & energy analysis, environmental and economic indicator assessment

Reporting Date

30/06/2017

Project coordinator: **A DUE DI SQUERI DONATO & C. S.p.A.**

Project website: **www.lesswaterbevtech.com**

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Introduction

The present document is part of the activities carried out in Work Package 4 (WP4) which foresees the start-up, tuning and performance/sustainability analysis of the water treatment system developed under LESS-WATER BEV.TECH project.

All the WP4 deliverables are hereafter reported:

Delive-rable N°	Deliverable name (self-explanatory)	Type of deliverable	Quantifi-cation	For Publica-tions: Language(s)	Accessibility of delive-rable	Month of comple-tion
D4.1	Plant start-up and operating parameters tuning	Report	1	EN	CO	30
D4.2	Performance & energy analysis, environmental and economic indicator assessment	Report	1	EN	PU	30
D4.3	Plant Life Cycle Assessment (LCA)	Report	1	EN	PU	30

In particular, deliverable D4.2 reports on the activities implemented to assess the performances of the proposed plant and technical solution for the wastewater recovery, presenting the evidences and the result analysis of the field-tests developed on the full-scale pilot prototype installed within a relevant industrial environment.

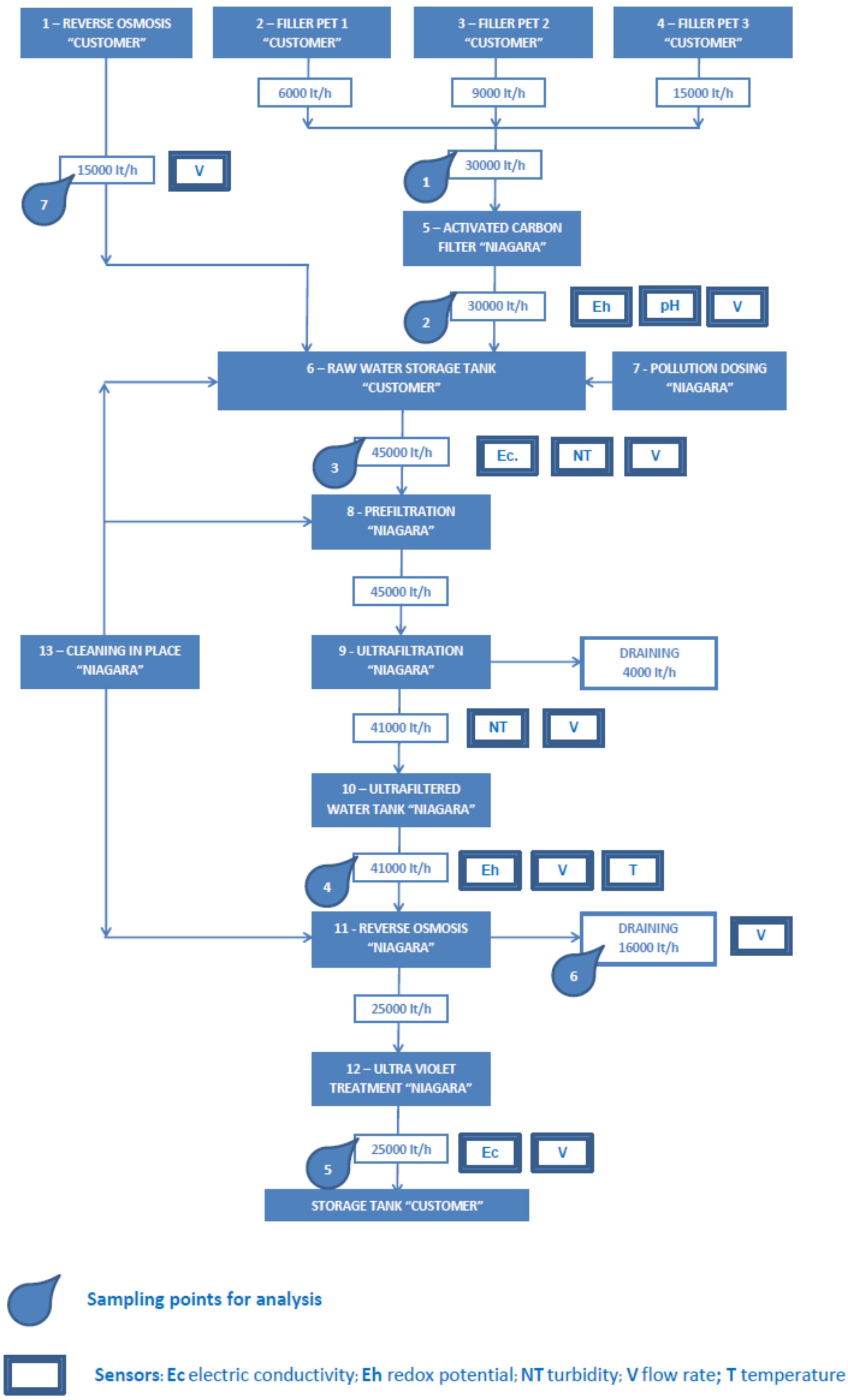
After the start-up phase, necessary to calibrate the pilot making it ready to treat the wastewater coming from the production lines and already reported on previous deliverable D4.1, the project team has been involved into a double test-set reproducing standard daily working conditions of the plant:

- stress-test with water streams heavily contaminated by organic pollutants, i.e. fruit & vegetable based. Such test enlarges and completes the previous ones already described in deliverable D4.1;
- long-duration test with line wastewater coming from the most water intensive sources of the production plant, i.e. PET filler lines and entry-water purification unit through RO.

The basic concept driving the performance analysis is to make the plant working automatically and continuously, collecting and processing the real-time data measured by the on-line sensors and equipments. Furthermore, to benchmark and validate the plant performances, allowing a reliable and comprehensive quality analysis of the purified water, quantifying the effect of the water post-treatment, an independent lab is involved - SAVI LAB Chemical and Microbiological Laboratory - through off-line sample analyses.

The reference block diagram of the pilot plant, already presented in deliverable D4.1, is in the following figure for any convenience.

The collected data, both on- and off-line, allow concluding about the quality of the purified water (and, consequently, about its reusability within local closed-loop chain) and about the efforts to get it in terms of energy requirements, chemicals and other auxiliaries. Such data are the basis for the forthcoming environmental and economic plant assessment. The former is roughly presented here because it is detailed in deliverable D4.3, fully dedicated to the environmental LCA of the plant, the latter is developed from a cost rising perspective including opportunity costs due to savings for raw water unuse.


1 – REVERSE OSMOSIS "CUSTOMER"
2 – FILLER PET 1 "CUSTOMER"
3 – FILLER PET 2 "CUSTOMER"
4 – FILLER PET 3 "CUSTOMER"
6000 lt/h
9000 lt/h
15000 lt/h
15000 lt/h
V
7
30000 lt/h
1
5 – ACTIVATED CARBON FILTER "NIAGARA"
30000 lt/h
2
Eh
pH
V
6 – RAW WATER STORAGE TANK "CUSTOMER"
7 - POLLUTION DOSING "NIAGARA"
45000 lt/h
3
Ec.
NT
V
8 - PREFILTRATION "NIAGARA"
45000 lt/h
13 – CLEANING IN PLACE "NIAGARA"
9 - ULTRAFILTRATION "NIAGARA"
DRAINING 4000 lt/h
41000 lt/h
NT
V
10 – ULTRAFILTERED WATER TANK "NIAGARA"
41000 lt/h
4
Eh
V
T
11 - REVERSE OSMOSIS "NIAGARA"
DRAINING 16000 lt/h
6
V
25000 lt/h
12 – ULTRA VIOLET TREATMENT "NIAGARA"
25000 lt/h
5
Ec
V
STORAGE TANK "CUSTOMER"
Sampling points for analysis
Sensors: Ec electric conductivity; Eh redox potential; NT turbidity; V flow rate; T temperature

Test with water streams contaminated by organic pollutants

This section summarises the evidences of a last set of field-tests on the pilot plant conducted by the project team to validate the capacity to purify water contaminated by organic matter, among the typical source of pollution within the F&B industry.

Deliverable D4.1 presented the previous tests and, among them, those involving rinsing pear and tomato demonstrate an excessive stress of the UF membranes generating an over-requirement of filter's cleanings and plant (micro-)stops. Within that context, the project team outlined the opportunity to add a self-cleaning filter on top of the purification chain, after the active carbon unit and before the UF's. This plant feedback corrective action is done and the following tests show the technical performance after this improvement.

The key features of the added unit are the following:

- Model: FD2000;
- Material: DUPLEX;
- Nominal efficiency: 90%;
- Min working pressure: 0.5 bar;
- Max working pressure: 10 bar;
- Max suspended solids: 100 mg/l;
- Max inlet particle diameter: 3mm;
- Max working temperature: 60°C;
- Max turbidity: 10 NTU.

According to the purpose of validating the plant against organic contaminated wastewater and matching the availability of the CCDP consortium hosting the plant, three tests are done with the following features:

- Test n.8 (the previous ones are in deliverable D4.1): 0.6% concentration fruit (0.3% rinsing pear 18 °Bx + 0.3% rinsing peach 12°Bx), flow rate of 32,000 l/h.
- Test n.9: 0.3% concentration rinsing tomato 18 °Bx, flow rate of 32,000 l/h.
- Test n.10: 0.1% concentration rinsing orange from juice production, flow rate of 32,000 l/h.

The test campaign is done in early June 2017 and in all tests UF units work in cross-flow mode. In the following tables and figures the key results coming from the before vs. after analsysis of samples of the treated water are proposed.

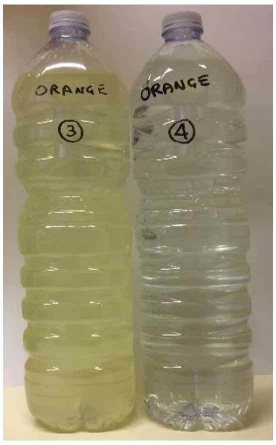
8 – Rinsing pear and peach	
Concentration	0.6% fruit (0.3% pear 18 °Bx + 0.3% peach 12°bx)
Water treated	46 m3
Water recovered	21 m3
Efficiency	46 %
Note	Flow rate 32 m3/h – cross flow – sodium metabisulphite

Parameter	Inlet water	After UF	Outlet water
Total Hardness(CaCo3)(mg/l)	1130	588	26
Oxidability (Kubel) (mg/l O2)	31.1	1.92	394
Conductivity	2450	1345	29.2
pH	6.6	7.0	5.4
Redox potential (mV)	-239	-201	-160
Total Suspended solids(mg/l)	570	25	<5
Turbidity (NTU)	69.2	2.01	<0.4
Total Alkalinity (CaCo3)(mg/l)	639	377	23
BOD5 (O2) (mg/l)	2590	455	1130

9 – Rinsing tomato

Concentration	0.3% tomato 18°bx
Water treated	36 m3
Water recovered	13 m3
Efficiency	36 %
Note	Flow rate 32 m3/h – cross flow – sodium metabisulphite

Parameter	Inlet water	After UF	Outlet water
Total Hardness(CaCo3)(mg/l)	452	812	28
Oxidability (Kubel) (mg/l O2)	111	122	<0.5
Conductivity	1098	1864	26.2
pH	6.2	7.2	5.7
Redox potential (mV)	-266	-229	-131
Total Suspended solids(mg/l)	230	30	<5
Turbidity (NTU)	32.6	10.3	<0.4
Total Alkalinity (CaCo3)(mg/l)	270	584	5.3
BOD5 (O2) (mg/l)	530	240	14



10 – Rinsing orange	
Concentration	0.1% orange juice (12%)
Water treated	12 m3
Water recovered	13 m3
Efficiency	36 %
Note	Flow rate 32 m3/h – cross flow – sodium metabisulphite

Parameter	Inlet water	After UF	Outlet water
Total Hardness(CaCo3)(mg/l)	222	228	10
Oxidability (Kubel) (mg/l O2)	2900	146	<0.5
Conductivity	414	511	24
pH	5.9	6.9	5.5
Redox potential (mV)	-183	-114	-184
Total Suspended solids(mg/l)	83	<5	<5
Turbidity (NTU)	18	2.02	<0.4
Total Alkalinity (CaCo3)(mg/l)	48	119	4.2
BOD5 (O2) (mg/l)	2600	600	12

The following table reports the most relevant lab results of all tests described in deliverables D4.1 and D4.2 together with the benchmarks for bottling water reuse (TG1) and boiler water reuse (TG2).

Lab results vs. bottler requirements (TG1) and steam-boiler requirements (TG2)

Parameter	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*TG1*	*TG2*
Total Hardness (CaCo3) (mg/l)	66	34	2	3.8	<2	<2	4.1	26	28	10	<250	5
Conductivity (µS/cm)	30.7	<20	274	67	20	20	23.3	29.2	26.2	24	-	-
pH	7.8	7.2	10.9	4.1	5.9	5.9	5.5	5.4	5.7	5.5	>4.9	-
Total Suspended solids (mg/l)	0.5	0.5	7.6	2.4	20	20	<5	<5	<5	<5	<500	-
Turbidity (NTU)	<0.4	<0.4	0.4	<0.4	0.6	0.6	<0.4	<0.4	<0.4	<0.4	<0.5	-
Total Alkalinity (CaCo3)(mg/l)	29.1	16.9	84.9	<5	18.7	18.7	35.4	23	5.3	4.2	<85	-

The evidences from this highly representative set of plant tests allow to conclude about the potential to purify wastewater at an output standard fully compatible with the F&B industry. From this viewpoint, the technical performance assessment allows to definitely conclude about the fit of the proposed technical solution to the needs of the F&B industry.

Long-duration test with F&B industrial line wastewater, summary & technical performance assessment

The project team traced continuously the working activities of the pilot plant (and of its subunits in the case of specific tests on some of the functional modules) to collect data over a long period of time, representative of the plant run-time within a mid-size company like CCDP. Fluctiations around the data proposed in this section are always possible depending on the specific installation context.

The overall goal of this phase is to fix REFERENCE INDICES, expressed as intensive parameters, to be scaled depending on the amount of treated wastewater and representative of the performance of the plant.

The collected data are over a period of working time of about 254 days from late June 2016 to late May 2017 with a total of ~4,000 worked hours. This means that in this period the plant does not worked continuously due to the constraints of the CCDP (wastewater lack, mainly) and the necessary activities on the plant to improve it as reported in the previous released deliveries. Such conditions are not far from the operative environment of a F&B company so that the evidences and reference indices obtained here are to be considered realistic, final and representative.

The following table provides the most aggregate data about the plant INPUT conditions.

Parameter	Value	Unit
Total days of working	254	days
Total hours of working	4,064	hours
Overall treated water (input)	62,179,300	liters
from CCDP RO (input)	26,738,100	liters
from CCDP PET line (input)	35,441,200	liters
Average overall flow rate	15,300	liters/hour

As evident from the table, the overall plant flow rate is lower than the nominal plant capacity. This is due to the constraints of CCDP in terms of wastewater availability that depends on the company production plans and the seasonality of some of the productions, e.g. tomato based products.

In the following, separate discussion for each key plant functional module is provided.

ULTRAFILTRATION

Liminting the focus to the UF unit, the following table aggregates the process parameters measured during the reference working time.

Parameter	Value	Unit
Total hours of working	1,940	hours
Average flow rate	32,000	liters/hour
Ultrafiltered water (output)	57,325,728	liters
Drained water (losses)	4,753,988	liters
from production	3,879,982	liters
from backwashes	565,831	liters
from CEB	282,915	liters
from flux	25,260	liters
UF global efficiency	92.3	%
NaClO 15% (BW + CEB)	273	liters
Soda 30% (CEB)	236	liters
HCl 30% (CEB)	157	liters
Power need (production)	11,640	kWh
Power need (BW + CEB)	91	kWh

Globally, over 60,000m^3 of wastewater are treated generating ~57,300m^3 of ultrafiltrated water ready for the RO unit. The overall UF efficiency if of about 92.3%.

Concerning the reference indices related to this stage, they are (on average) the followings, referred to both input and output water flow.

	Input water flow		Output water flow	
	Index	***Unit***	***Index***	***Unit***
Power need	0.1890	Wh/l	0.2046	Wh/l
NaClO 15%	0.0044	ml/l	0.0048	ml/l
Soda 30%	0.0038	ml/l	0.0041	ml/l
HCl 30%	0.0025	ml/l	0.0027	ml/l

REVERSE OSMOSIS

Switching the focus to the RO unit, the following table aggregates the process parameters measured during the reference working time.

Parameter	Value	Unit
Total hours of working	1,433	hours
Average flow rate	40,000	liters/hour
Ultrafiltered water (output)	35,271,247	liters
Drained water	22,054,481	liters
from production	21,497,148	liters
from flux	557,333	liters
RO efficiency	61.5	%
Antiscalant 100%	344	liters

$Na_2S_2O_5$ 25%	688	liters
HCl 30%	7,643	liters
Power need (production)	45,861	kWh
Power need flux	307	kWh

Globally, over 57,200m^3 of wastewater are treated generating ~35,300m^3 of osmotized water ready for the last UV final treatment (no water is lossed in such a last phase of the process). The overall RO efficiency if of about 61.5%.

Concerning the reference indices related to this stage, they are (on average) the followings, referred to both input and output water flow.

	Input		**Output**	
	Index	***Unit***	***Index***	***Unit***
Power need	0.8054	Wh/l	1.3089	Wh/l
Antiscalant 100%	0.0060	ml/l	0.0098	ml/l
$Na_2S_2O_5$ 25%	0.0120	ml/l	0.0195	ml/l
HCl 30%	0.1333	ml/l	0.2167	ml/l

OTHERS

Additional process parameters measured during the reference working time and related to the other functional modules are below.

- Active carbon unit
  - Drained water: 99,483 liters (74,083 liters due to backwashes + 25,400 liters due to cooling)
  - Steam need: 15,240 kg
- UV treatment
  - Power need: 3,251 kWh
- Pumps (water recovery & recirculation)
  - Power need: 9,949 kWh

GENERAL BALANCES

The following table collects the extensive parameters cumulated over the entire working time.

Parameter	**Value**	**Unit**
Overall treated water	62,179,200	liters
Overall recovered water	35,271,247	liters
Overall efficiency	**56.7**	**%**
Antiscalant 100%	344	liters

$Na_2S_2O_5$ 25%	688	liters
HCl 30%	7,800	liters
HClO 15% (BW + CEB)	273	liters
Soda 30% (CEB)	236	liters
Steam	15,240	kg
Power need *(*includes all needs)*	71,099	kWh

In particular, ***the global recovery efficiency of the proposed system, in mass, is close to 57%, matching the expected nominal value.***

Finally, despite all reference indices should refer to the functional module they are associated to, concerning (electric) power, due to its global and massive need through all the plant, a global index is computed, equal to 1.1435 Wh/l of input water corresponding to 2.0158 Wh/l of purified recovered output water.

Environmental performance assessment

The environmental sustainability of the proposed wastewater purification technology is to be assessed through the application of the ISO14040 standard developing the LCA of the plant. Basically, such analysis adopts a *cradle-to-grave* approach computing or estimating the impacts, and saved impacts, on the environment, i.e. air, soil, water, etc., of the system, assumed as the functional unit, through all its lifetime. In particular, the plant manufacturing and assembly are former blocks to analyse, while the working life is the latter key block to study. Typically, the formers are resource intensive because of the need of resources to build and assemble the plant, while the latter is resource saving toward the as-is condition that, in this context, is the open-loop water approach draining the process wastewater.

Within deliverable D4.3 the evidences of the LCA developed by the project team are reported concluding about the environmental sustainability of the plant over its expected lifetime. All detail and reference indices from the environmental perspective are presented in that context and skipped here to avoid duplicates.

Economic performance assessment

The economic performance assessment aims at validating the proposed technology and plant solution against economic metrics expressing the overall long-term sustainability of investing in the proposed plant for wastewater recovery.

According to the standard practice, the present economic analysis starts from the evidences and reference indices presented above in the plant technical validation section and refers to the investments and rising costs (including opportunity costs due to savings) occurring during the plant lifetime. The so-called *standard reference year* (SRY) methodology is adopted together with the *net present value* (NPV) method.

The following table introduces the basic plant working parameters with reference to the SRY, representative of the full use of the pilot plant within the CCDP industrial environment (further representative of a common mid-size F&B industry).

PLANT WORKING PARAMETERS (Std. Ref. year)		
Nominal Plant Capacity	45,000	liters/hour
Overall avg annual utilization factor	0.90	%
Input flow rate	40,500	liters/hour
from "customer" RO	13,500	liters/hour
from filler PET	27,000	liters/hour
Avg annual worked days	320	days/year
Avg worked hours per day	20	hours/day

Starting from the input wastewater flows of the previous table and adopting the reference indices calculated in the previous sections, the annual balance of water, energy, chemicals and auxiliaries is done for the key plant functional modules, i.e. activated carbon filter, UF, RO and UV. Evidences are in the table in the next page where the green cells indicate the aforementioned reference indices.

Given the annual standard water flows and requirements (power and chemicals) the cost & investment analysis is developed adopting a differential approach. The rising costs coming from the installation of the proposed plant are quantified including savings due to the raw water unuse because of wastewater recovery and reuse. In addition, the extra-investment to install the new plant is included. The following table presents a synthesis of this step of the analysis.

COST & INVESTMENT DRIVERS			*Differential annual cash flows*	
Initial extra-investment (turnkey, all included)	355,000	€		
O&M cost (incidence on investment)	0.04	%	14,200	€/year
Cost of raw water (opportunity cost)	*0.00212*	*€/liter*	*-311,340*	*€/year (saving)*
Cost of grid electric power (industry)	0.20	€/kWh	59,279	€/year
Power factor (includes all needs & auxiliaries)	1.1435	Wh/l		
Cost of chemicals				
NaClO 15%	0.2160	€/liter	246	€/year
Soda 30%	0.2660	€/liter	262	€/year
HCl 30%	0.9525	€/liter	30,935	€/year
Antiscalant 100%	4.2000	€/liter	6,018	€/year
$Na_2S_2O_5$ 25%	0.3935	€/liter	1,128	€/year
General & other plant differential annual costs			5,000	€/year
	Contribution margin		**194,106**	**€/year**

Finally, the net contribution margin drives the investment analysis developed adopting the NPV investment assessment methodology considering a time horizon of 15 years. In this context the residual value is assumed to be null to balance the cost of the dismantling activities. The final results are below.

ACTIVATED CARBON FILTER UNIT			*Reference indices*		
Input wastewater flow	172,800,000	liters	Steam index	0.4300	g/l
Drained water (losses)	642,920	liters	Draining index	3.7206	ml/l
Output wastewater flow	172,157,080	liters			
Steam	74,304	kg			

ULTRA-FILTRATION UNIT			*Reference indices*		
Input wastewater flow	258,557,080	liters	Stage efficiency	0.9230	%
Drained water (losses)	19,908,895	liters	Power need	0.1890	Wh/l
Output wastewater flow	238,648,185	liters	NaClO 15%	0.0044	ml/l
Power	48,867	kWh	Soda 30%	0.0038	ml/l
NaClO 15%	1,138	liters	HCl 30%	0.0025	ml/l
Soda 30%	983	liters			
HCl 30%	646	liters			

REVERSE OSMOSIS UNIT			*Reference indices*		
Input flow rate	238,648,185	liters	Stage efficiency	0.6150	%
Drained water (losses)	91,879,551	liters	Power need	0.8054	Wh/l
Output flow rate	146,768,634	liters	Antiscalant 100%	0.0060	ml/l
Power	192,207	kWh	Na2S2O5 25%	0.0120	ml/l
Antiscalant 100%	1,432	liters	HCl 30%	0.1333	ml/l
Na2S2O5 25%	2,864	liters			
HCl 30%	31,812	liters			

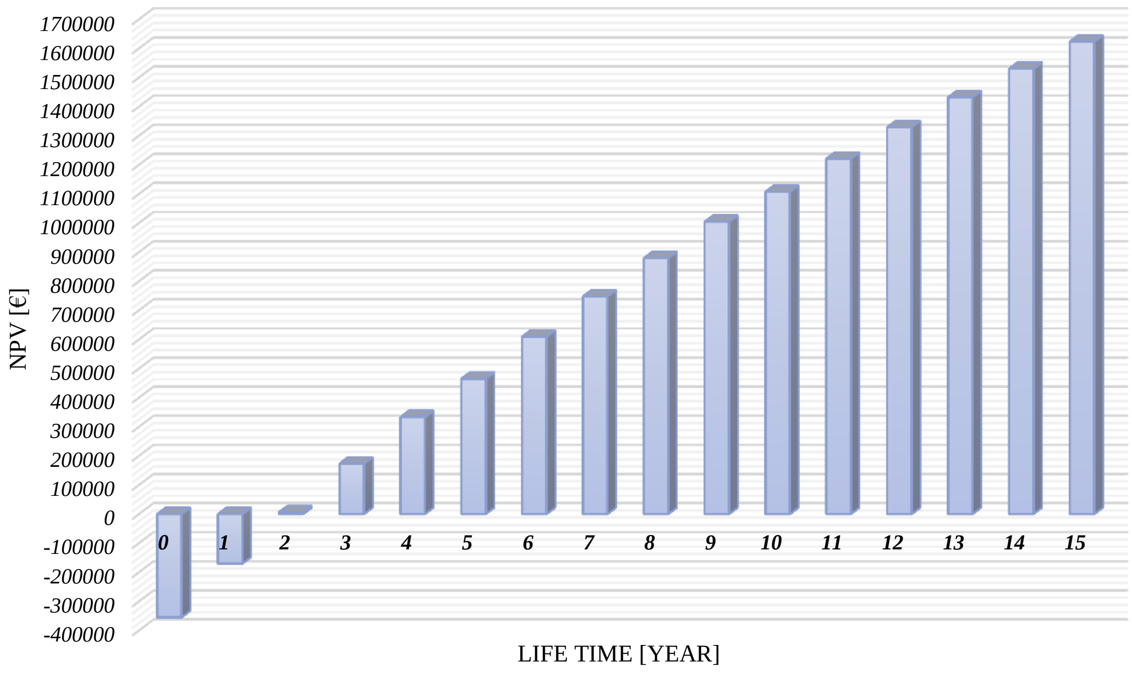
UV UNIT			*Reference indices*		
Input flow rate	146,768,634	liters	Stage efficiency	1.0000	%
Drained water (losses)	-	liters	Power need	0.0922	Wh/l
Output flow rate	146,768,634	liters			
Power	13,528	kWh			

DIFFERENTIAL NET PRESENT VALUE ANALYSIS

Lifetime Year	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Initial investment	355,000										
On-going investments (replacements)						26,000					26,000
Operative contribution margin	0	194,106	194,106	194,106	194,106	194,106	194,106	194,106	194,106	194,106	194,106
WACC	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Discounted cash flow	-355,000	184,863	176,060	167,676	159,692	131,716	144,845	137,948	131,379	125,123	103,203
Net present value	-355,000	-170,137	5,923	173,599	333,291	465,006	609,851	747,799	879,177	1,004,300	1,107,503

Lifetime Year	*11*	*12*	*13*	*14*	*15*
Initial investment					
On-going investments (replacements)					
Operative contribution margin	194,106	194,106	194,106	194,106	194,106
WACC	5%	5%	5%	5%	5%
Discounted cash flow	113,490	108,086	102,939	98,037	93,368
Net present value	1,220,992	1,329,078	1,432,017	1,530,053	1,623,422

Differential NPV analysis



The plant economic assessment highlights its long-term sustainability and value creation for the F&B industrial company with a pay-back period of about 2 years (without accelerated amortization policies) so that the initial investment is adequately remunerated.

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