24th International Conference on Production Research (ICPR 2017)
ISBN: 978-1-60595-507-0

ENVIRONMENTAL ASSESSMENT OF AN INNOVATIVE PLANT FOR THE WASTEWATER PURIFICATION IN THE BEVERAGE INDUSTRY

M. Bortolini, L. Botti, M. Gamberi, R. Manzini, C. Mora, A. Regattieri
Department of Industrial Engineering, University of Bologna, Viale Risorgimento 2, Bologna, Italy

Abstract
Nowadays, efforts to reduce the resource depletion and environmental emissions from the anthropic activities, are mandatory for sustainable development pattern. Among the key resources to save, pure water is as important as critic due to its scarcity and its essential role for life and growth. Furthermore, during the last decades, rising attention from institutions and industries is toward solutions for the water intensity decrease and wastewater recovery.
This paper proposes the environmental assessment of an innovative wastewater collection and purification plant tailored to a mid-size beverage industry aiming at locally closing the loop of the water chain, allowing its recirculation and local reuse. After the description of the functional module features, sizes and design, based on a prototype actually working in Italy, the paper follows the ISO 14040 standards to develop an environmental assessment of the industrial system, quantifying the impact rising from the manufacturing and the assembly phases.

Keywords: Wastewater purification, Life Cycle Assessment, Design for the Environment, Water saving, Food and beverage industry.

1. INTRODUCTION

Nowadays the urgency in reduction of emissions and of depletion of resources makes necessary to pay attention to Design for Environment and Eco-design, in order to encourage a sustainable development.
In accordance with the World Commission of Environmental and Development (WCED, 1987), sustainable development is “a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations” [1].
The reduction in the use of raw materials and natural resources, the spread of energy efficient processes and components are necessary from both the economic and the environmental viewpoints. Between the natural resources particular attention need the water, that is known as the ‘blue gold’, the key of life, and its availability is crucial for the equal growth of communities (UN Millennium Development Goal Report, 2011) [2]. Among the key resources to save, pure water is as important as critic due to its scarcity in large geographical areas and its essential role for life, progress and growth. So, during the last decades, rising attention from institutions, industry and the public opinion is toward solutions for the water intensity decrease and wastewater recovery.
Wastewater recovery is a must at the EU level, with the aim to save the environment – water footprint of processes; to comply with the EU regulations; to match high technical/economic target in product/market.

Focusing on the European Union (EU) area, the highest amount of water consumption is from industry.

Furthermore, among all industrial activities, Food & Beverage industry is known as a very water intensive sector (~100.000 liters/hour of raw water generating thousands of litres of wastewater per day).

Within F&B, standard mid-size plants require over 45m3/h of pure water, i.e. reverse osmosis water, to produce common beverages as juices and carbonated soft drinks. Actually, such water is pumped from wells and drained after use (open loop).
This paper proposes the environmental assessment of an innovative wastewater collection and purification plant tailored to a mid-size beverage industry aiming at locally closing the loop of the water chain, allowing its recirculation and local reuse. After a legislative overview about the European and Italian strategies on food and water production (paragraph 2), the authors conduct a literature review on the Life Cycle Assessment analysis in industrial application (paragraph 3). Then a description of the functional module features, sizes and design, based on a prototype actually working in Italy is made (paragraph 4). Following paragraph 5 presents the environmental assessment of the industrial wastewater recovery plant quantifying the key categories of impact and effect on the environment rising from the manufacturing and the assembly phases.

2. LEGISLATIVE OVERVIEW

2.1. The European strategy on food and water production

People ingest water directly or indirectly, as other foods, taking all the substances contained in it and swallowing microbiological contaminants and chemicals. The Council of the European Communities ([3],[4]) control the quality of the water used for human consumption, aiming to guarantee a high level of health protection for the European community. Specifically, the food law applies to food and feed traded both on the internal market and internationally. The food production chain and the food safety issues cover a wide range of critical aspects, from the primary production to the final consumption, going through its transport and distribution. The European Food Safety Authority promotes, applies and controls the procedures in matters of food safety. Specifically, the protection of the human health from the adverse effects of any contamination of water intended for human consumption is one of the main goals of the European strategy for food safety. Furthermore, the comprehension of the scarcity of natural resources and of the vulnerability of biosphere health induced a deep re-thinking of the concept of development, as a process harmonised with the environment, in the interests of present and future generations. In a sustainable growth perspective, the European Parliament ([5]) from the Council Directive 98/83/EC sets the goal to increase efficiency standards for water using products up to the 16% by 2030.

2.2 The Italian approach

The Italian regulations on water production is fragmented. Several national regulations address the water production chain, defining the Italian strategy and responsibilities at national and local levels.

The Presidency of Italian Republic actuates the Council Directive 80/778/EEC [3] with Legislative Decree 2 febbraio 2001, n. 31 [6], regulating the management of the water for human consumption, specifying the water quality control methods, the responsibilities in industry and the control Authority. The Italian legislation prohibits the use of recovered and purified wastewater within F&B and pharmaceutical industries except in the case of a local recover. Specifically, the Minister of Environment and Land Protection has defined the Decree GAB/DEC/ 93/06 on Technical standards for wastewater reuse [7]. In the Art. 3 (eligible use), such decree states that the treated wastewaters can be used for watering, civil use and industrial use. Finally, the Legislative Decree 11 maggio 1999, n. 152 [8] transfers the responsibility of setting rules for water saving, control and reuse to the local regions.

3. LITERATURE REVIEW

Increasing the eco-efficiency of the global economy and decreasing the environmental impact associated with the industrial processes is a crucial goal for the developed countries. Companies are one of the key players in the pursuit of a more sustainable society.

This Section introduces a brief literature review on Life Cycle Engineering (LCE) and Life Cycle Assessment (LCA), showing the importance of LCA in the Eco-Design and some applications of LCA in industry.

Jeswiet defines the “Life Cycle Engineering” (LCE) as “the application of technological and scientific principles to the design and manufacture of products, with the goal of protecting the environment and conserving resources, while encouraging economic progress, keeping in mind the need for sustainability, and at the same time optimising the product life cycle and minimising pollution and waste” [9].

The same author defines LCE as a multitude of topics such as: sustainability, economics, market, economic progress, social concern, environment, protect the environment, minimise pollution/waste, resource conservation, engineering activities, optimisation, eco-design, green design, product life cycle, product/process assessment. Wenzel and Alting [10] and Rosen and Kishawy [11] define three dimensions of levels on eco-efficiency in LCE: product, process and practices. Consequently, Life Cycle Engineering addresses the eco-efficiency by focusing on the design of product and its manufacturing process by using organisational practices.

3.1. LCA and Eco-Design

Eco-Design, or Design for Environment, focuses on the resource preservation, the environmental protection and the human health during the whole product life cycle [12], [13]. Regardless of the restrictions imposed by the regulations and the standards in force, the compliance with the best practices in eco-design may provide competitive leverage in the market, given its sustainability advantages [14]. Bovea and Pérez-Belis have developed an extended taxonomy of Eco-Design tools based on literature contributions concerning the environmental design methodology [15]. Their study includes twenty main Eco-Design methodologies. More than the 50% of such methods are based on the use of LCA for the product environmental profile assessment. The literature on the use of LCA for the Eco-Design shows both potential benefits and the limits of the LCA-based approach [16]. However, today LCA is a standardized methodology and its application is popular in several industries, from agriculture to food packaging. The following Section 3.2 shows some applications of LCA in different industries.

3.2. LCA in industry

LCA is widely adopted in industry. Several researches show the use of LCA for the water treatment industry [17]–[23]. In the last years, the study of the environmental impact assessment of the processes related to the agricultural industry has increased significantly. Such interest is justified by the importance of the food production to the environmental impact generation. Roy et al. have proposed an extended review on LCA studies related to the food production, classifying several contributions on the basis of the food product features [24]. Hospido et al. have analysed milk production in Spain. Their research shows that the feed production phase is a hotspot of milk life cycle [25]. Specifically, the production of silage, representing the 21% by weight of the animal feed, is estimated to be responsible for 29% of global warming and acidification, and 23% of the eutrophication effects of the total milk production process. Accorsi et al. propose an original conceptual framework for the integrated design of a food packaging and distribution network. In such paper, LCA methodology is used to evaluate the carbon footprint associated with the life cycle of packages in a distribution network [26].

Finally, in their study, Cascini et al. have shown a streamlined version of LCA, the Carbon Footprint Assessment, for the analysis of the whole refrigeration system life cycle. Their results demonstrate that the use-phase contributes significantly to the total environmental impact, and that indirect emissions resulting from refrigerating unit electric energy consumption are larger than those associated with refrigerant leakage.

4. THE PLANT

The analysis concerns an innovative plant for water treatment and wastewater recovery and purification in the food & beverage industry. The key aspects of the plant are: water saving, wastewater recycling, solid waste minimisation and recovery. The rated drinkable water production of the plant object of this project is 50’000 l/h all spent in beverage preparation, divided in Non-Carbonated Beverage (NCB) and Carbonate Soft Drinks (CSD). Design and modelling of NCB or CSD water-saving production plant components will be developed considering the main goal of total water consumption minimisation and waste water amount reduction.

The target is a mid-size F&B Italian company producing soft drinks, non-carbonated beverages, juices and vegetable sauces. The annual water intensity is 2.4 billion liters/year actually supplied from five wells and managed in open-loop.

The block diagram of the pilot plant is reported In Figure 1.

The main components of the system are Carbon Filter, Tanks, Prefiltration, Ultrafiltration, Reverse Osmosis, Ultraviolet Treatment, Cleaning in Place (CIP),Pump for water recovery.

The water streams of the plant are:

- Fillers: 3 lines, 30,000 l/h, continuous;
- Osmosis retentate: 15,000 l/h, continuous;
- CIP: 4,000 l/h, discontinuous & highly polluted;
- Cooling towers: 2,000 l/h, continuous;
- Syrup room: 1,000 l/h discontinuous.

4.1. Ultrafiltration (UF) system

“UF is recognized as a low-pressure membrane filtration process; it is usually defined to be limited to membranes with pore diameters from 0.005μm to 0.1μm. When the source water is passing through the filter under a trans-membrane pressure provided by the gravity or a pump, the bacteria and most viruses can be removed, […] the drinking water quality can be satisfied for consumers, and the use of chemicals, capital, and operating cost can be reduced.”[27]

The overall operating conditions and output of the ultrafiltration system are:

- Pressures: 0.03 ÷ 3 bar
- Pore diameter: 0.005 ÷ 0.1 μm
- Withholding molecular amount: 1 ÷ 500 kDalton
- Membrane structure: porous anisotropic structure.

- Typical removed impurities: suspension, colloids, bacteria, dissolved organics (*partially*)
- Unremoved solutes: fine minerals, soluble salts, metal ions
- Flow rate: 40 ÷ 90 l/m^2h (depending on the treated water) Hagen-Poiseuille Carman-Kozeny equations.

4.2. Reverse osmosis system

The ultrafiltration treatment eliminated from our water all suspended solids and most of the microbial contamination, but did not act in any way on the contaminants dissolved in the water to be treated.
To remove the contaminant solutes from the water it is necessary to use a reverse osmosis plant. Reverse osmosis uses a different principle than the purely mechanical ultrafiltration one, in this case osmotic membranes are used that are permeable to water and not to solutes present in it. Applying a higher pressure than the osmotic one to the water to be treated a migration of water is obtained in the opposite direction to the natural one, i.e., from the more concentrated part to the less concentrated one. In this way two waters are obtained, one rich in solutes that will be discarded and one poor in solutes that will be sent to the customer's treated water storage tank. For the osmotic membrane sizing the authors rely on a well-known calculation programme "Rosa" by DOW. The output is 25000 l / h of water having the following characteristics:

- turbidity: < 0.1 NTU
- total suspended solids: < 0.1 mg/l
- total dissolved solids (TDS): 50 mg/l

The selected membranes are the BW30-400 a model specifically designed to work with water having a dissolved solids content of greater than 2000 mg / l, was also considered a flow factor of 0.85 to consider the fouling of the membranes to three years.
The complete scheme of the prototypal wastewater recovery plant is reported in Figure 2.

5. LIFE CYCLE ASSESSMENT

The LCA is a useful tool for the evaluation of the environmental impact associated to a specific product life cycle. Topics and steps of the LCA methodology are regulated by the International Organization for Standardization (ISO). According to the ISO 14040:2006 (E) the complete LCA framework includes four steps: goal and scope definition; inventory analysis; impact assessment; interpretation of results. In this study SimaPro 7.3.3 by Pré Consultants is the software used as support. This LCA considers: raw material extraction processes; manufacturing and assembly of components; transports. Life cycle impact assessment is carried out using three methods: Eco-indicator 99 Hierarchical version (EI99H), ReCiPe H/A and IPCC 2007 Global Warming Potential (GWP). The first one focuses on the evaluation of midpoint indices: damage on human health, measured in "DALY" (Disability Adjusted Life Years); ecosystem quality, quantified in PAF·m2·year (Potentially Affected Fraction); resource preservation, evaluated in "MJ surplus". Therefore, through weighting and normalisation, EI99H elaborates an endpoint index (Pt) that measures the total environmental impact of the analyses object: 1000 Pt corresponds to the average environmental burden introduced by an European citizen in one year. The ReCiPe method comprises two sets of impact categories with associated sets of characterisation factors. Eighteen impact categories are addressed at the midpoint level. At the endpoint level, most of these midpoint impact categories are further converted and aggregated into the following three endpoint categories: damage to human health (HH), measured in "DALY"; damage to ecosystem diversity (ED), measured in Ecosystem species*yr; damage to resource availability (RA), measured in Resources Surplus Cost.

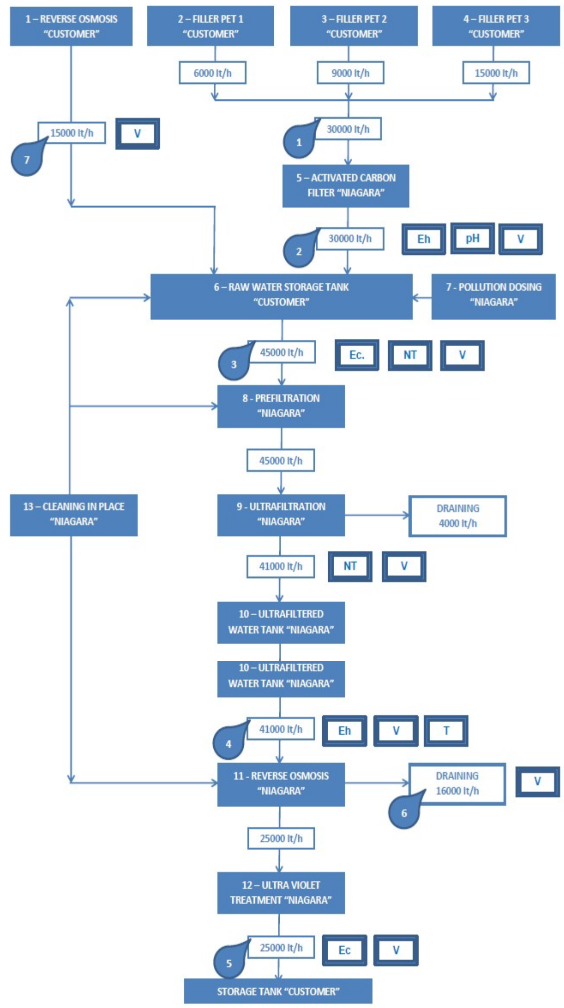

Figure 1. Block diagram of the pilot plant.

Finally Global Warming Potential is defined as "the climatic warming potential of a greenhouse gas relative to that of carbon dioxide and is calculated in terms of the 100-year warming potential of 1 kg of a gas relative to 1 kg of CO2" (Directive 2006/842/EC). The GWP of a gas is measured in mass of equivalent carbon dioxide CO2(eq)).

5.1. Goal and Scope definition

The main objective of this LCA is the environmental impact evaluation of the manufacturing and the assembly phases of the industrial system, with the final aim of identifying the life cycle stages and plant components that, directly and indirectly, introduce the greatest impact on the final results. The characterization of the most relevant contributions is mainly intended to redesigning the plant in a greener perspective.

For the present study, the functional unit is the construction of an innovative plant for water treatment and wastewater recovery and purification in the food & beverage industry. The confines of the system are from "the cradle to the gate of the industry", so the use phase and the disposal at the end of life are not included in this analysis.

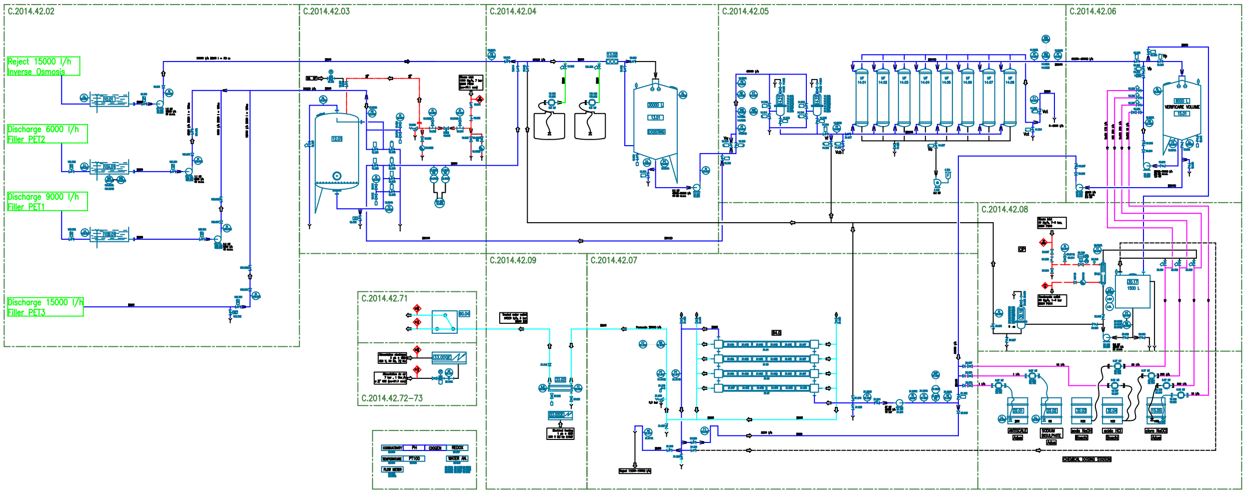

Figure 2. Scheme of the prototypal wastewater recovery plant.

5.2. Inventory Analysis (LCI)

The Inventory analysis considers raw material extraction processes; manufacturing and assembly of components; transports. Process data, material and energy consumption information derive from direct observation or reliable assumptions, while pollutant emission and waste generation values are mined from Ecoinvent databank. In a few cases, in order to limit mismatches between data bank information and actual data on employed materials and processes, some simplifying hypotheses are made.

The plant is subdivided in the following functional parts:

- Cleaning In Place (CIP)
- Carbon Filter
- Pump for water recovery
- Reverse Osmosis
- Tank 8000 l
- Tank 3000 l
- Ultrafiltration
- Ultra Violet Treatment (UV)
- Electrical system

For each of these functional parts, all the constitutive components and materials are considered for the analysis.

The inventory analysis, in this phase, incudes all the constitutive components and materials, with the exception of some elements with low influence on the global impact or of difficult characterisation, such as: the electrical system, the electronic measurement instruments, the gaskets, the heat exchanger, the aspiration spear, the hatchway, the PVC reduction, the electronic components.

Although the complexity of the plant, it is possible to list the main materials of which it is composed: Steel (S), Aluminium (AISI 304L), Polypropylene (PP), Polyamide (PA), Polyester, Polycarbonate, Polyvinylfluoride film (PVDF).

Thanks to the use of databanks, all the processes necessary to extraction and transformation of raw materials are considered in this analysis. All the processes required for manufacturing and assembly of the plant are included in this study. The main processes are: welding (with gas Argon), folding, cold impact extrusion, drawing of pipes, thermoforming, sheet rolling, wire drawing, injection moulding.

The amounts of energy consumption and secondary materials used for manufacturing activities is also taken from the producer.

The transportation phase is considered for all the components and materials: the metal sheet, the valves “Bardiani”, the piping and junctions, the osmosis houses, the uv, the pre-filtration housing, the pre-filtration canisters, the pump bodies come from Europe. The pump motors come from China, the ultrafiltration membrane come from Rimini (Italy), osmosis canister come from USA, the active carbon come from Thailand.

In order to provide for lack of information, average geographical distances between suppliers and manufacturer are considered. Particularly the distances of the European suppliers are calculated as a mean of the distances between the manufacturer, located at Fornovo di Taro (Italy) and Sweden, Germany and Spain. The vehicles considered for the transportations are lorry >16t, fleet average and lorry 3.5-7.5t, EURO4.

5.3. Impact Assessment

Life cycle impact assessment of the plant is carried out using Eco-indicator 99 Hierarchical version (EI99H), ReCiPe H/A and IPCC 2007 and Global Warming Potential (GWP).

Eco-indicator 99 Hierarchical version

Table 1 show the damage assessment of the single functional parts of the plant. In the proposed results life cycle is split in the eight functional parts: Cleaning In Place (CIP), Carbon Filter, Pump for water recovery, Reverse Osmosis, Tank 8000 l, Tank 3000 l, Ultrafiltration, Ultra Violet Treatment (UV). Reverse Osmosis, Ultrafiltration and Carbon Filter are the represents the components with the highest environmental burden. In particular the component that bring the highest damage is Reverse Osmosis, that have the major impact in Ecotoxicity and Climate Change categories; Carbon Filter introduces significant damages in Land Use; Ultrafiltration generates significant damage in Radiation and in Oxone layer.

The same results are visible in Figure 3. Figure 4 reports the same results in the impact categories’ perspective. Considering the Single Point indicator as assessment index, 4321,17 Pt is the environmental impact values due to the production of Reverse Osmosis.

ReCiPe H/A

The results of the impact assessment are confirmed also by the analysis conduct with the ReCiPe H/A method. Reverse Osmosis is the most damaging component and it has the major impact in Climate Change Human Heath and Climate Change Ecosystem; Ultrafiltration generates significant damage in Radiation and in Oxone layer.

Carbon Filter introduces significant damages in Agricultural land occupation and Particulate matter formation. Considering the Single Point indicator as assessment index, 3206,60 Pt is the environmental impact values due to the production of Reverse Osmosis system.

In Figure 6 and 7 are reported the damage assessment respectively of the subgroups of the water recovery plant and on impact categories. ***IPCC 2007 Global Warming Potential***

The same conclusion can be achieved considering the analysis with GWP method. The whole water recovery plant produces 60872 kg CO_2 eq. Also in this method the Reverse Osmosis is the group with the major impact. Particularly the manufacturing of this component produces 32400 kg CO_2 eq that represent the 53,2% of the total kg CO_2 eq. The ultrafiltration group is the second in term of GWP emissions. Table 2 and Figure 7 report the results of the GWP analysis.

Table 1. Damage assessment of the water recovery plant with Eco-indicator 99 method.

Impact Categories	Carbon Filter	CIP	N.4 Pump for Water Recovery	Reverse Osmosis	Tank 30k	Tank 8k	Ultrafiltration	UV	total
Carcinogens	130,76	195,67	157,33	1056,66	363,12	330,07	304,85	0,02	**2538,48**
Resp. organics	0,32	0,04	0,02	0,38	0,03	0,10	0,30	0,00	**1,19**
Resp. inorganics	1181,50	111,34	77,76	1652,64	66,25	196,42	444,33	6,48	**3736,73**
Climate change	35,71	20,81	13,74	311,67	5,01	35,64	163,29	1,53	**587,40**
Radiation	1,16	0,13	0,08	1,51	0,12	0,22	2,89	0,00	**6,10**
Ozone layer	0,01	0,00	0,00	0,03	0,00	0,01	0,05	0,00	**0,11**
Ecotoxicity	51,57	41,63	30,00	467,30	33,73	65,69	52,92	2,21	**745,05**
Acidification/ Eutrophication	33,17	3,24	2,27	50,11	1,74	6,84	20,03	0,19	**117,59**
Land use	157,88	0,89	0,51	7,41	0,87	1,72	7,69	0,00	**176,97**
Minerals	6,62	25,02	18,33	127,36	41,46	38,84	27,13	0,04	**284,80**
Fossil fuels	114,82	46,78	29,07	646,09	19,06	94,83	487,06	2,28	**1439,98**
total	**1713,51**	**445,56**	**329,11**	**4321,17**	**531,39**	**770,35**	**1510,54**	**12,74**	**9634,38**

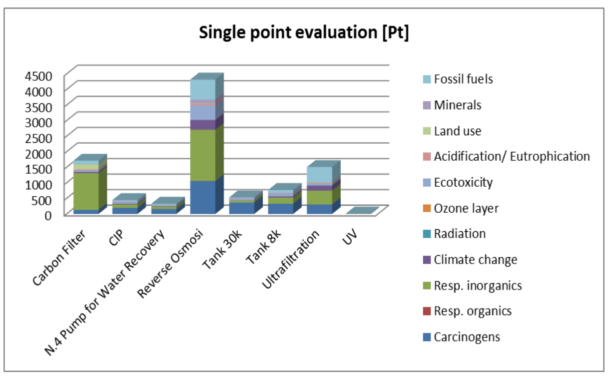

Figure 3. Damage assessment of the subgroups - Eco-indicator 99 method (Single Point).

5.4. Interpretation of Results

In an Eco-design perspective, some elements of the actual prototype design can be modifying in order to obtain minor environmental impact of the plant.

Particularly, since Reverse Osmosis, Ultrafiltration and Carbon Filter are the parts with the greatest impact, the manufacturing and assembly phases of these components are considered in order to find the processes or the sub-components generating the majority of the damage. Figure

9 reported the damage assessment (normalization) of the single component Reverse Osmosis. The major damaging contribution is due to the pressure vessel and pump components. So future change in manufacturing of this component is desirable for a more sustainable design.

Referring to Ultrafiltration the impact assessment of this component is reported in figure 9, where it is evident that the negative impact is mainly due to ultrafiltration membrane.

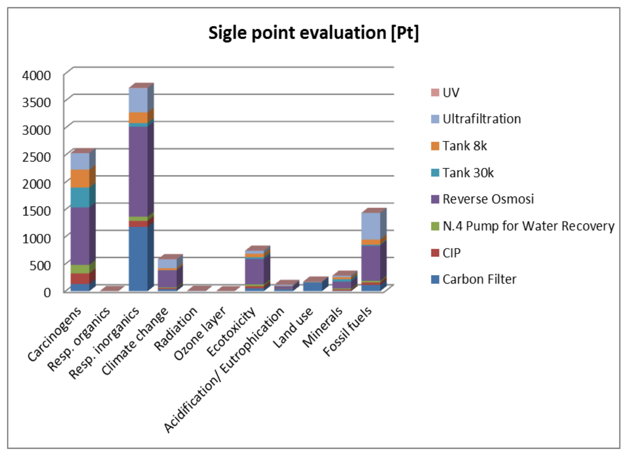

Figure 4. Damage assessment on impact categories - Eco-indicator 99 method (Single Point).

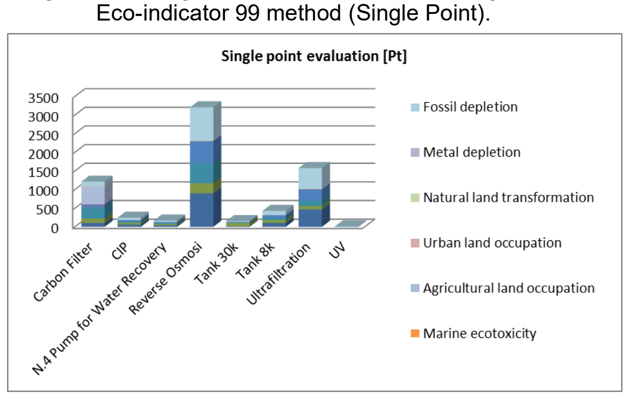

Figure 5. Damage assessment of the subgroups of the water recovery plant with ReCiPe H/A method.

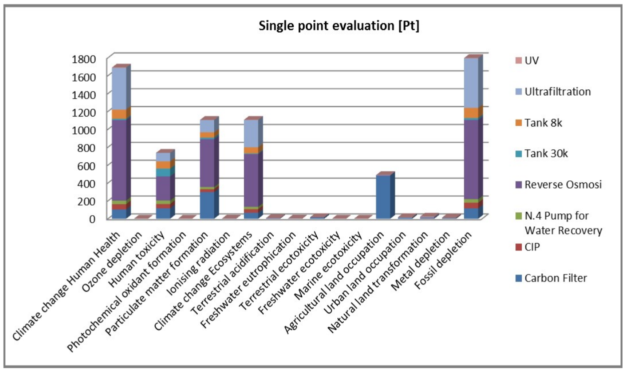

Figure 6. Damage assessment on impact categories of the water recovery plant with ReCiPe H/A method.

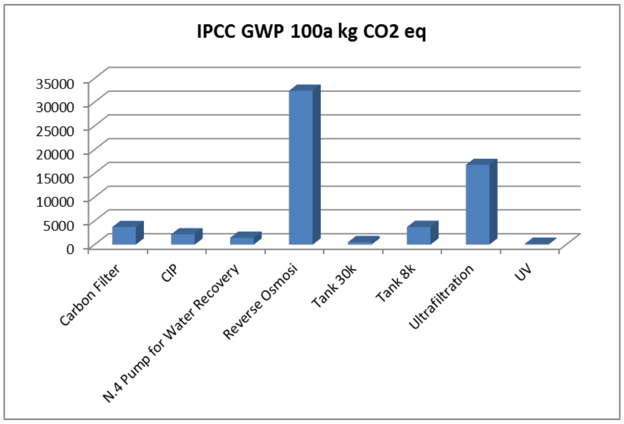

Figure 7. Impact assessment of the subgroup of the water recovery plant with GWP 100a method.

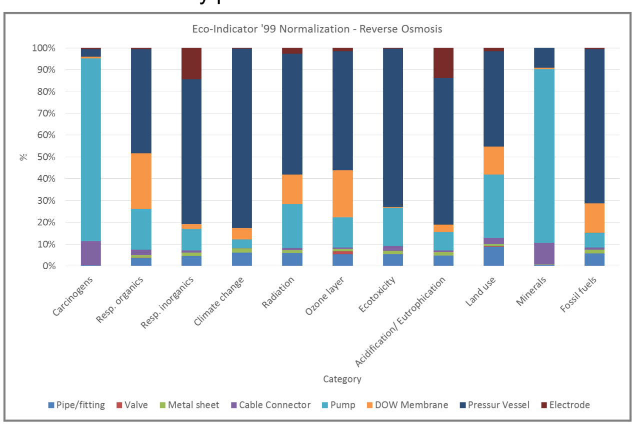

Figure 8. Impact Assessment of Reverse Osmosis in Eco-Indicator 99 method – Normalization.

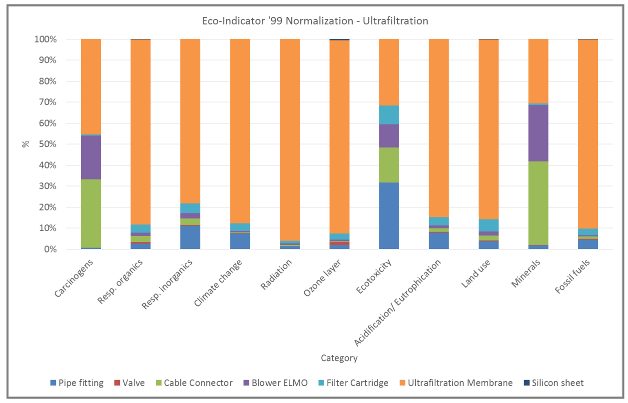

Figure 9. Impact Assessment of Ultrafiltration in Eco-Indicator 99 method – Normalization.

6. CONCLUSIONS

In this paper, an innovative plant for water treatment and wastewater recovery and purification in the food & beverage industry is presented.

After the description of the functional module features, sizes and design, the environmental impact on different damage categories introduced during its life cycle is analysed and estimated through the adoption of LCA methodology.

The analysis concern the evaluation of the environmental impact of the manufacturing and the assembly phases, in an eco-design perspective. So the confines of the system are from “the cradle to the gate of the industry”.

The analysis is conduct according with the International Organization for Standardization (ISO) and with the support of the software SimaPro 7.3.3 by Pré Consultants. Three different methods of evaluation are considered: Eco-indicator 99 Hierarchical version (EI99H), ReCiPe H/A and IPCC 2007 Global Warming Potential (GWP).

The impact assessment analysis demonstrates that the functional subgroup with the major impact is the Reverse Osmosis group, considering all the three methods. Particularly this subgroup is responsible of the 53,2% of the total kg CO_2 eq. emitted, of the 44,85% of damage Pt in Ecoindicator99 and of 45,78% of damage Pt in ReCiPe H/A. The other subgroups mainly damaging are Carbon Filter and the Ultrafiltration groups.

As regards these three subgroups, the phases with major impact are the construction of the ultrafiltration membranes for the Ultrafiltration group, the pump ad the pressure vessel for the reverse osmosis group.

Table 2. Damage assessment of the subgroup of the water recovery plant with GWP 100a method.

Impact Category	Unit	Total	Carbon Filter	CIP	N.4 Pump for Water Recovery	Reverse Osmosis	Tank 30k	Tank 8k	Ultrafiltration	UV
IPCC GWP 100a	kg CO2 eq	60872,6	3696,9	2165,9	1430,2	32400,5	525,84	3711,5	16782,78	158,78

The impact categories of Eco-indicator 99 method, characterised by major damage, are Resp.Inorganics (38,69%) Carcinogens (26,35%) and Fossil Fuels (14,95%). As regards ReCiPe H/A the impact categories mainly interested are Fossil Deplation (25,65%), Climate Change Human Health (24,14%) and Climate change Ecosystem (15,79%).

7. FUTURE DEVELOPMENT

The future development of this study concern the inclusion of the Electrical and Electronical System in the Inventory Analysis. The whole life cycle of the plant have to be included in the analysis, with particular attention to the use phase, in which the water recovery could have a positive effect on the environmental impact for the ground water’s consumption avoided. So a comparison between a traditional system without water recovery and the system with the prototype object of this study is desirable.

Then, in light of the results of the environmental impact of the manufacturing and assembly of the wastewater recovery plant, the authors will propose some changes to the prototype design, in an eco-design perspective, equal performance. Finally these design alternative could be included in a sensitive analysis, with the aim of define the better configuration in an environmental point of view.

8. ACKNOWLEDGMENTS

This work is developed within the CIP Eco-innovation Project No. Eco/13/630314/LESS-WATER BEV.TECH, co-funded by the Eco-innovation Initiative of the European Union, in partnership with A DUE S.p.A. and CVAR Ltd.

REFERENCES

[1] World Commission of Environmental and Development (WCED, 1987),

[2] UN Millennium Development Goal Report, 2011.

[3] Council of the European Communities, 1980, Council Directive 80/778/EEC of 15 July 1980 relating to the quality of water intended for human consumption.

[4] Council of the European Union, 1998, Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

[5] European Parliament, 2002, Regulation (ec) no 178/2002 of the European Parliament and of the council of 28 January 2002.

[6] Presidenza della Repubblica Italiana, 2001, Decreto Legislativo 2 febbraio 2001, n. 31, Attuazione della direttiva 98/83/CE relativa alla qualita' delle acque destinate al consumo umano.

[7] Ministero dell'Ambiente e della Tutela del Territorio, 2006, GAB/DEC/ 93/06 del 2/05/2006.

[8] Presidenza della Repubblica Italiana, 1999, Decreto Legislativo 11 maggio 1999, n. 152.

[9] Jeswiet J., 2003, A definition for Life Cycle Engineering," in 36th International seminar on Manufacturing Systems, 17–20.

[10] Wenzel H., Alting L., 2004, Architecture of Life Cycle," in Global Conference on Sustainable Product Development and Life Cycle Engineering, Sept. 29th - Oct. 1st, 2004.

[11] Rosen M.A., Kishawy H.A., Sustainable Manufacturing and Design: Concepts, Practices and Needs," Sustainability, 2012, 4(12), 154–174.

[12] Fiksel J., 1993, Design for environment: an integrated systems approach," in Proceedings of the 1993 IEEE International Symposium on Electronics and the Environment, 126–131.

[13] Hauschild M.Z., From life cycle assessment to sustainable production: Status and perspectives," CIRP Ann. - Manuf. Technol., 2005, 54(2), 535–554.

[14] Cascini A., Gamberi M., Mora C., Rosano M., Bortolini M., Comparative Carbon Footprint Assessment of commercial walk-in refrigeration systems under different use configurations," J. Clean. Prod., 2016, 112, 3998–4011.

[15] Bovea M.D., Pérez-Belis V., A taxonomy of ecodesign tools for integrating environmental requirements into the product design process," J. Clean. Prod., 2012, 20(1), 61–71.

[16] Keoleian G.A., The application of life cycle assessment to design, J. Clean. Prod., 1993, 1(3–4), 143–149.

[17] Tangsubkul N., Beavis P., Moore S.J., Lundie S., and Waite T.D., Life Cycle Assessment of Water Recycling Technology, Water Resour. Manag., 2005, 19(5), 521–537.

[18] Lundie S., Peters G.M., and Beavis P.C., 2004, Life Cycle Assessment for Sustainable Metropolitan Water Systems Planning.

[19] Raluy R.G., Serra L., Uche J., Valero A., Life Cycle Assessment of Water Production Technologies - Part 2: Reverse Osmosis Desalination versus the Ebro River Water Transfer (9 pp), Int. J. Life Cycle Assess., 2005, 10(5), 346–354.

[20] Vlasopoulos N., Memon F.A., Butler D., and Murphy R., Life cycle assessment of wastewater treatment technologies treating petroleum process waters, Sci. Total Environ., 2006, 367(1), 58–70.

[21] Guest J.S., A New Planning and Design Paradigm to Achieve Sustainable Resource Recovery from Wastewater, Environ. Sci. Technol., 2009, 43(16), 6126–6130.

[22] Zhou J., Chang V. W.-C., and Fane A.G., Environmental life cycle assessment of reverse osmosis desalination: The influence of different life cycle impact assessment methods on the characterization results," Desalination, 2011, 283, 227–236.

[23] Hancock N.T., Black N.D., and Cath T.Y., A comparative life cycle assessment of hybrid osmotic dilution desalination and established seawater desalination and wastewater reclamation processes, Water Res., 2012, 46(4), 1145–1154.

[24] Roy P., Nei D., Orikasa T., Xu Q., Okadome H., Nakamura N., Shiina T., A review of life cycle assessment (LCA) on some food products, Journal of Food Engineering, 2009, 90(1), 1-10, ISSN 0260-8774, https://doi.org/10.1016/j.jfoodeng.2008.06.016.

[25] Hospido A., Moreira M.T., Feijoo G., Simplified life cycle assessment of galician milk production, International Dairy Journal, 2003, 13, 783–796.

[26] Accorsi R., Cascini A., Cholette S., Manzini R. and Mora C., Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study, Int. J. Prod. Econ., 2014, 152, 88–101.

[27] Gao, W., Liang, H., Ma, J., Han, M., Chen, Z., Han, Z., Li, G., Membrane fouling control in ultrafiltration technology for drinking water production: a review. Desalination, 2011, 272, 1-8.

[28] European Parliament And The Council Of The European Union, 2006, Regulation (ec) no 842/2006 of the European Parliament and of the council of 17 May 2006 on certain fluorinated greenhouse gases.