Proceedings of the 8th International Conference on Environmental Pollution, Treatment and Protection (ICEPTP'23)
Lisbon, Portugal – March 29 – 31, 2023
Paper No. ICEPTP 150
DOI: 10.11159/iceptp23.150

Life Cycle Assessment of a New Device for Hydrocarbon Recovery from Groundwater: E-Hyrec®

Alessandra De Folly D'Auris[1], Francesca Rubertelli[2], Stefano Loda[3], Camilla Lanari[4]
[1] Eni R&D, Environmental and Biological Laboratories, Eni SpA, San Donato Milanese, Italy"Eni S.p.A.
Via F. Maritano 26, 20097, San Donato Milanese (MI), Italy
Alessandra.de.folly.dauris@eni.com;
[2]Eni DE-R&D Process Development, Eni S.p.A
Via Fauser 4, 28100 Novara, Italy
Francesca.Rubertelli@eni.com,
[3]Eni DE-R&D Technical Services for Research
Stefano.Loda@eni.com
[4] Eni Rewind S.p.A.
Piazza Boldrini, 1, 20097 San Donato Milanese (MI), Italy
Camilla.Lanari@enirewind.com

Abstract –The underground effect of the pollution is less visible and obvious, but not negligible. Depending on the amount of product released and the environmental conditions, the substance may percolate from the surface into the soil, reaching eventually the aquifer's water table. In this case, the product removal is more complex and the economic impacts for the company are higher. In our study, LCA analysis has been adopted to compare two devices used for hydrocarbons recovery from contaminated groundwater: e-hyrec®, Eni's in-house developed tool, and skimmer, the reference technology, considering their Production, Operations and End of Life phases. Global Warming Potential as kgCO_2 eq. is considered, and it results less for e-hyrec® than for skimmer.

***Keywords*:** Life Cycle Assessment, Water treatment, LNAPL, Global Warming Potential

1. Introduction

Many methods are used for groundwater remediation in case of supernatant oil contamination (LNAPLs - Light Non Aqueous Phase Liquids), based on different technologies: in situ flushing, soil vapour extraction, bioremediation, pumping systems [1, 2, 3].

The pumping systems are widely employed because of the ease of operation, low costs, no use of chemicals. Among them, the skimmer option is characterized by the application of a floating inlet on the pump, that is positioned at the oil/water interface, limiting the recovery of water to be sent for disposal. In practice, the process of oil removal is not selective because of the limited discrimination capacity between oil and water in case of low LNAPL thickness and because of the narrow float stroke (normally does not exceed 50 cm), useless for wide aquifer oscillations.

The e-hyrec® technology, an Eni trademark and European patented technology [4], is an automatic device able to follow the aquifer movements and it uses a hydrophobic and oleophilic filter capable of recovering only the organic phase [5-6]. E-hyrec® is a highly selective and efficient system: by separating the aqueous phase from the oily one and recovering only the latter, it allows a drastic reduction in the quantities of extracted water to be sent for disposal, thus allowing a very positive impact on the environmental and economic sustainability of remediation.

Even from an energy point of view, e-hyrec® is very sustainable, guaranteeing lower consumption compared to traditional recovery systems, thanks also to the possibility of being completely self-powered by renewable sources (photovoltaic).

The increased awareness of the environmental protection importance and the possible impacts associated with products, both manufactured and consumed, lead to the adoption of Life Cycle Assessment (LCA) studies as an important tool used by industries, governments, and environmental groups to improve processes, support policy and provide a basis for informed decisions. LCA aids the quantification and evaluation of environmental burdens and impacts in close relation with product systems and activities.

In our study, Life Cycle Assessment (LCA) has been adopted to compare e-hyrec® and skimmer, the reference technology, considering their Production, Operations and End of Life (EoL) phases.

2. Materials and methods

2.1 Functional unit and system boundaries

The functional unit (FU, Functional Unit) is a key element in the definition of an LCA study and represents the unit of measurement with which the system has been studied and the inputs and outputs relationship. In this case, the production of one device for the construction and end-of-life (EoL) phase and the quantity of oil recovered in a year (L / year) per device for the operational phase are chosen as FU. All values are then normalized over 15 years, which considers the estimated life for e-hyrec®, 5 years, and the estimated for skimmers, 3 years. In this time window are therefore counted 3 e-hyrec® and 5 skimmers.

The system boundaries are delimited, for the construction phase, from the production of the devices (in the same factory) to their transport to the site of use. For the operational phase, are considered the operations that are carried out from the arrival and start-up of the devices at the site up to the transport and disposal of the liquid phase recovered from the groundwater**.**

For the EoL phase we considered recycling process for aluminium and steel and landfill for all the other components.

2.2 Inventory analysis and construction of floors

The LCI (Life Cycle Inventory) is the most delicate of an LCA study as it is represented by the collection of data that will then be the basis of the study itself. As a result, the quality of the study itself derives from the quality of the data.

For construction phase, for each part, materials and weight are identified and used in the calculation model. E-hyrec® and skimmer are represented respectively in figure 1 and 2, with the indication of the component parts.

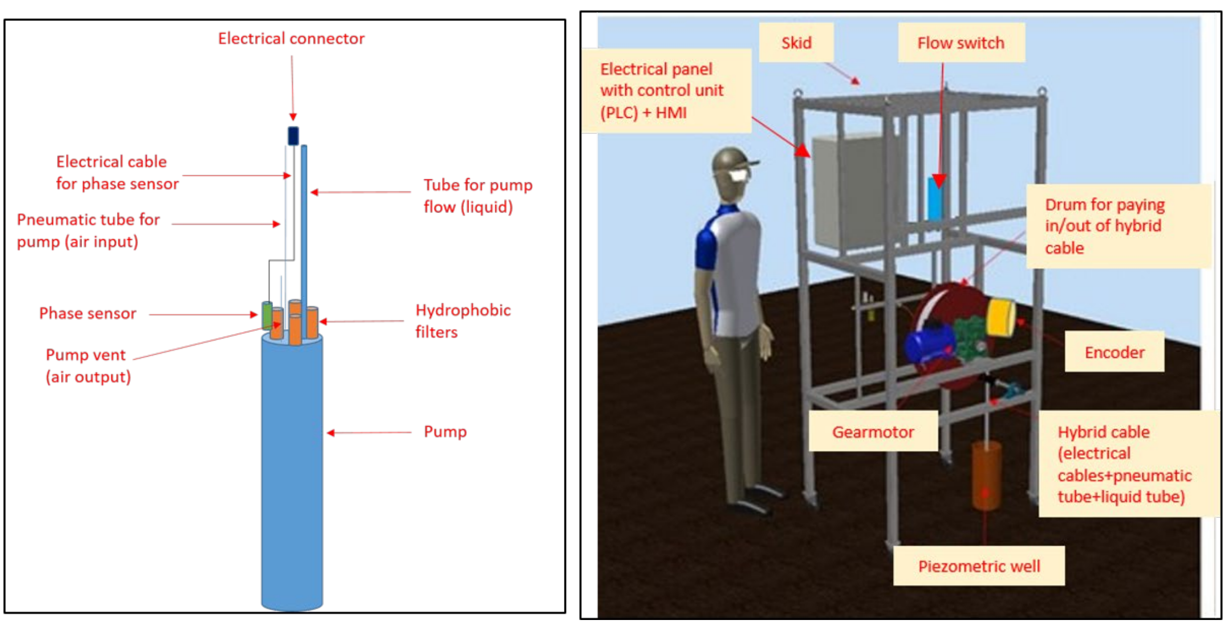


Fig. 1: The e-hyrec® device. On the left: well unit. On the right: surface unit

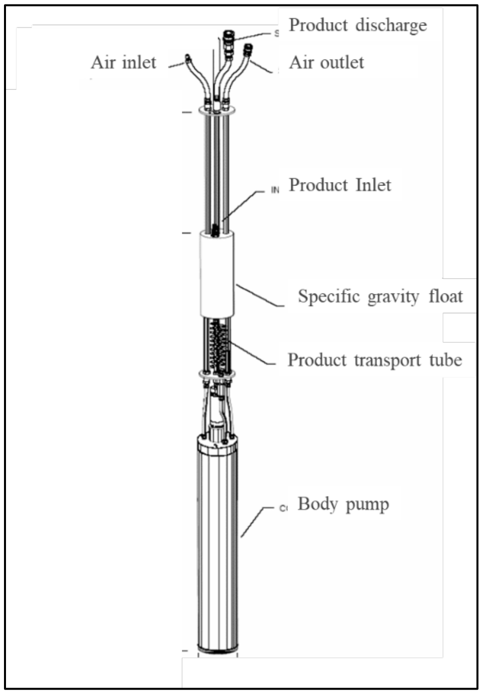


Fig. 2: The skimmer device.

The Operations phase is intended as tool's utilization moment and waste destination; thus, site data were used to make an assessment considering the quantity of LNAPLs extracted in one year of operations as functional unit. Wastewater treatment was associated to water pumped out with oil in skimmer case, considering 50% and 80% water cut.

In presence of a sufficient oil thickness in the aquifer (more than few mm), recognized by the phase sensor, the filter is automatically positioned in the liquid at the air/oil or water/oil interface. Selective permeation of the organic phase occurs, while the aqueous phase is repelled by the filter surface.

When the pump body is full, the extracted liquid is automatically sent to the well surface and collected in a storage tank or in-line collector. When the oil thickness reaches the limit value of few mm, due to removal process, the phase sensor detects the water phase, and the filter is positioned outside the liquid in standby mode. Once a sufficient time interval has elapsed for the permeation of new oil phase in the well, the filter is positioned again in the liquid and the described process is repeated. The signal coming from the phase sensor allows to adjust the position of the filter according to the variation in the aquifer level, therefore the device follows the movement of the water table for wide oscillations both upwards and downwards (up to tens of meters).

Inputs and outputs quantified are that one represented in figure 3, two scenarios are compared.

In blue the boundaries relating to scenario 1 where oil is incinerated, while in orange the boundaries relating to scenario 2 with sending the oil to a cement plant to its use as fuel in clinker production. The applicability of scenario 2 was verified comparing waste chemical analysis with requested characteristic by cement factories [7].

In scenario 1, the contribution of the recovery of electricity (as a credit) deriving from the incineration of oil was included, considering an efficiency of the waste-to-energy plant of 33%.

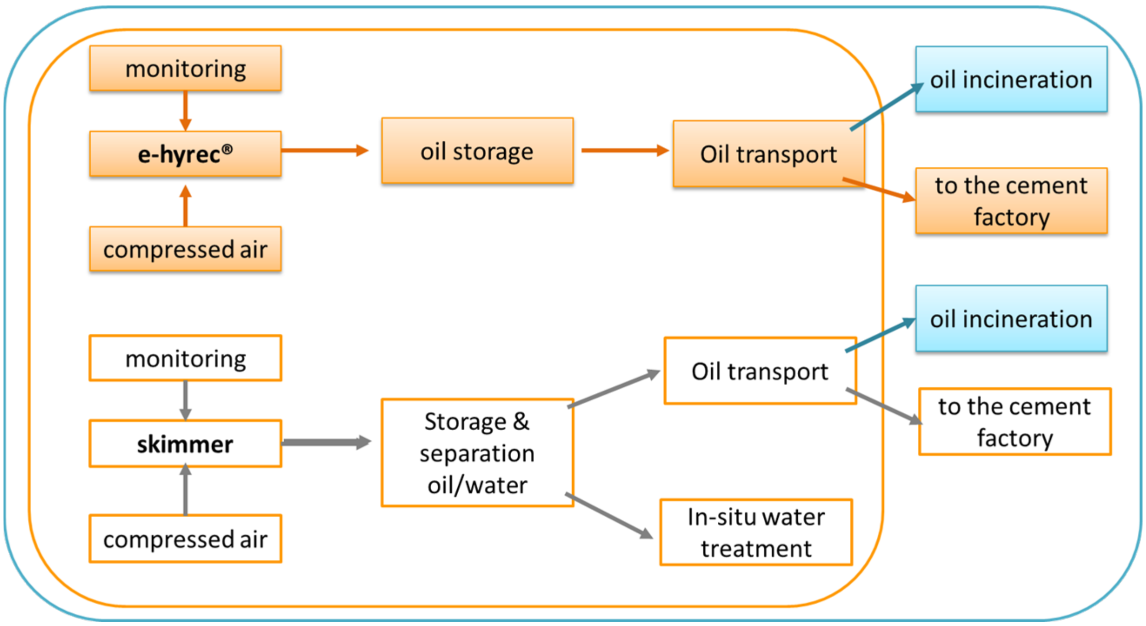


Fig. 3: Scheme and system boundaries of the operational phase

Monitoring was estimated in annual kilometres travelled and were calculated considering a monitoring frequency equal to 2 times a month for e-hyrec® and 6 times a month for skimmers over a distance of 500 meters between the starting point of the maintenance staff and the device. Furthermore, among the inputs, the consumption of electronics, sensors and motor has not been included, as the presence of the photovoltaic panel allows to produce all the electricity necessary for the operation of the device.

2.3 Results expression methodology

The result of the assessment is expressed according to the impact characterization factors indicated by the ReCiPe2016 v1.1 method. Independent method by the Dutch National Institute for Public Health and the Environment (RIVM) and Pré Consultants, is a method that covers a very broad spectrum of environmental impact categories, and, with the 2016 version, it passes from a European to a global approach. It has both midpoint and endpoint characterization factors [8]. The midpoint indicators are expressed by impact categories with the relative "characterization", while to pass to the endpoint indicators, the midpoint indicators, after the characterization phase, require a normalization process to be aggregated into homogeneous damage categories. As impact category Climate Change is reported. Climate Change evaluates the impact of the greenhouse gas complex, that is, all those gases that can retain the infrared radiation emitted by the earth's surface and the atmosphere, thus contributing to the alteration of the earth's climate. ReCiPe uses kgCO_2eq as the unit of measurement.

The methodology used to estimate the environmental impact follows the approach outlined by the ISO standards ISO 14040 [9] and ISO 14044 [10].

3. Results: Impact Value

In figure 4 is represented the detail of e-hyrec® balance for the construction phase: skid made in stainless steel AISI304 photovoltaic panel represent respectively 45% and 34% on the total impact for this phase.

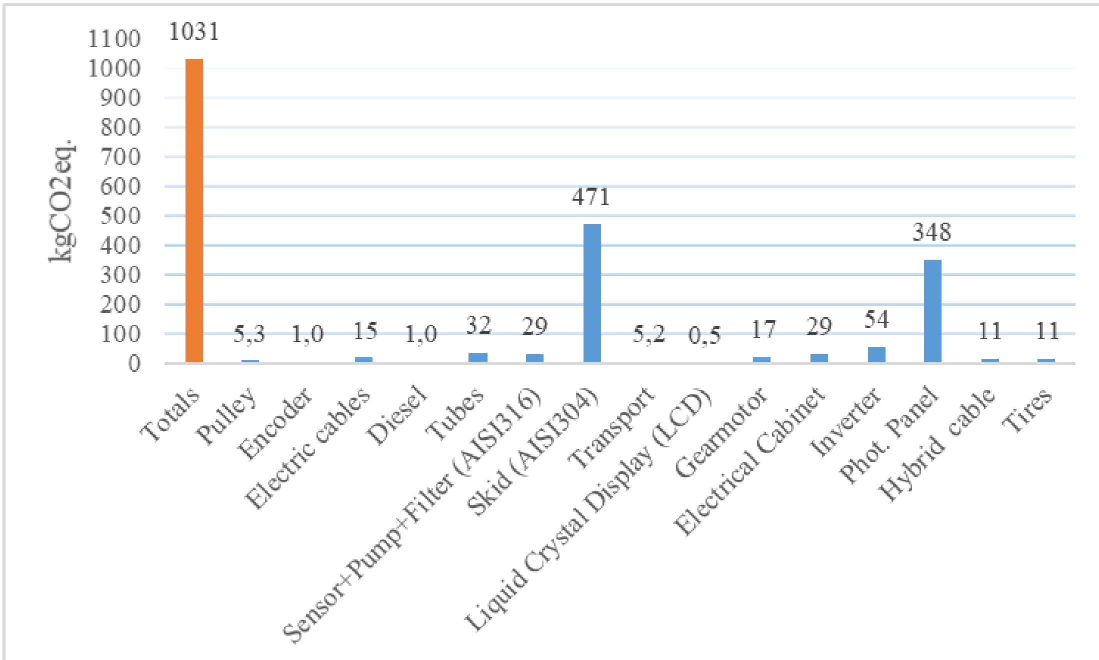
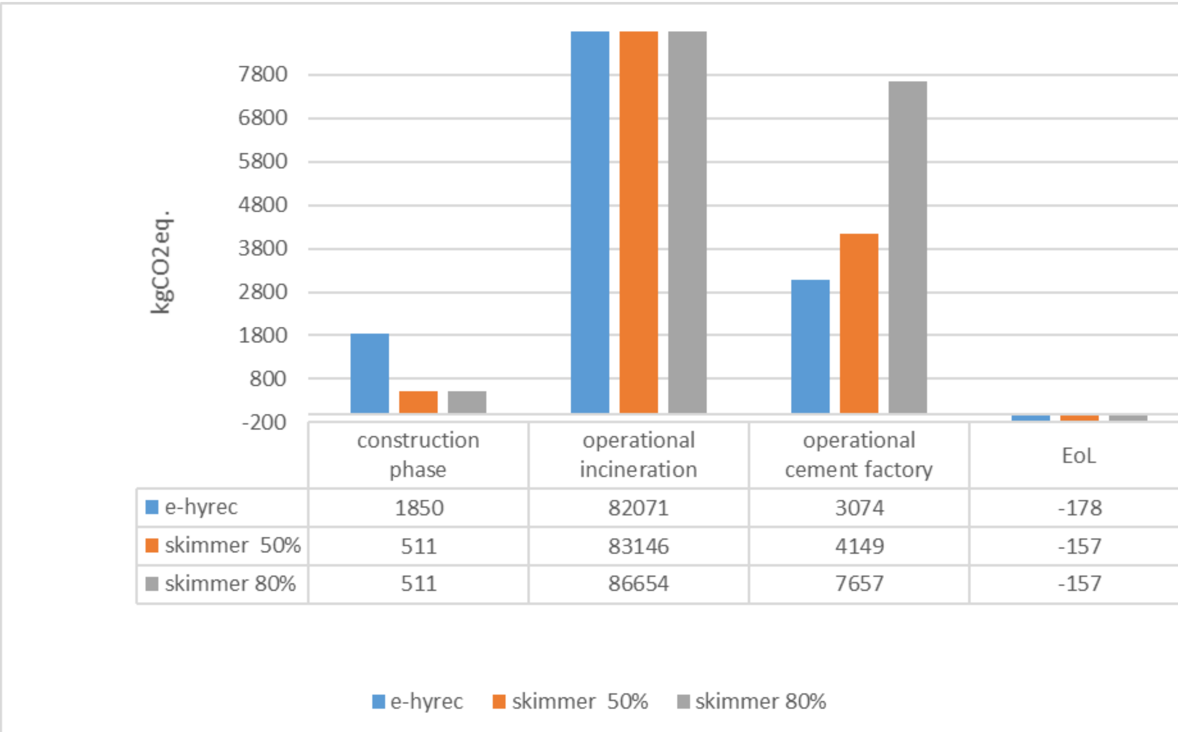


Fig.4: Climate change expressed in $kgCO_2eq.$ for each component part in construction phase (e-hyrec®).

The graph in Figure 5 represents the contributions to climate change of the different phases of the life cycle of the two devices. You can see that for the construction phase the impact of e-hyrec® is greater than that of skimmers, also subtracting the EoL contribution (1819 vs 354 $kgCO_2eq.$). For the operational phase of both scenarios the advantage is in favour of e-hyrec®. This advantage is more appreciable in scenario 2, with sending the oil to the cement factory, this is because incineration represents over 97% of the total and therefore "hides" all the other processes included in the analysis. It should be remembered that in scenario 1 the emissions from incineration (as opposed to those from co-combustion, scenario 2) are included in the analysis and are almost equal.



	construction phase	operational incineration	operational cement factory	EoL
e-hyrec	1850	82071	3074	-178
skimmer 50%	511	83146	4149	-157
skimmer 80%	511	86654	7657	-157

Fig. 5: Complete life cycle: comparison of the values relating to climate change in $kgCO_2eq$. The emissions from incineration (orange bar) are off the scale and the length of the bars is not representative as they are cut.

Figure 6 shows the impact values for all the processes involved in operational phase and compared for the two devices. In all cases there is, as expected, an advantage of e-hyrec® compared to skimmers for all categories. The greatest contribution is given by the consumption of compressed air for activating the pump.

A separate discussion, it applies to transport (lorry and freight barge in the graph), which are the same in all cases, as they refer only to the oil extracted; transports that have an important role on the total impact value.

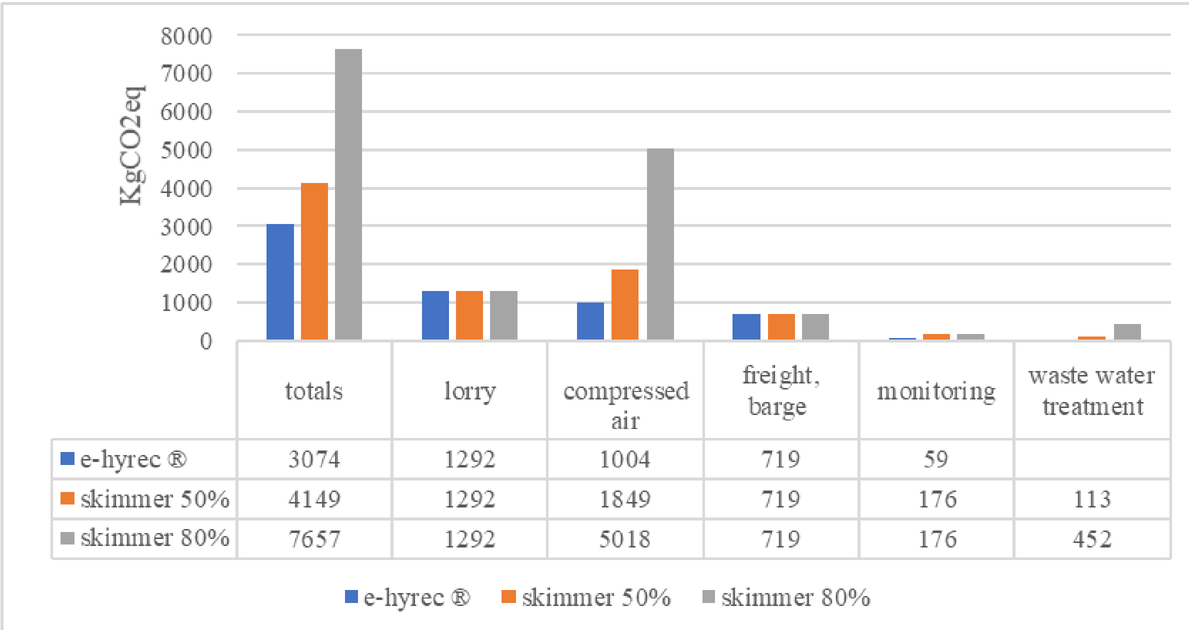


Fig.6: Impact value comparison of single process considered in operational phase, expressed in kgCO2eq. for the three devices (blue e-hyrec®, orange skimmer 50%, grey skimmer 80%)

4. Conclusion

The results, expressed through the indicator Climate Change in $kgCO_2$ eq. and calculated using the ReCiPe2016 method, are related to a complete study includes the construction, operational and end-of-life phases for e-hyrec® an innovative eni's device for LNAPL removal from groundwater. E-hyrec® is an automatic device that uses a hydrophobic and oleophilic filter capable of recovering only the organic phase with high selectivity, by separating the aqueous phase from the oily one and recovering only the latter. This allows a drastic reduction in the quantities of extracted water to be sent for disposal, thus allowing a very positive impact on the environmental and economic sustainability of remediation.

Even from an energy point of view, e-hyrec® is very sustainable, guaranteeing lower consumption compared to skimmer, the traditional recovery systems, thanks also to the possibility of being completely self-powered by renewable sources (photovoltaic).

From the balance of $kgCO_2$eq. of the complete life cycle of the two devices (Fig. 5) for the operational phase, the values relating to the e-hyrec® are lower than those relating to the skimmer for both scenarios; the scenario relating to the incineration of oil involves emissions that represent over 97% of the total. The transfer of the oily waste to a cement factory would therefore entail considerable advantages in terms of environmental sustainability of the process.

References

[1] S. Paria, "Surfactant-Enhanced Remediation of Organic Contaminated Soil and Water", *Adv. in Colloid and Interface Science*, vol. 138, pp. 24-58, 2008.

[2] H. Kim, T. Kim, S. Shin, M.D. Annable, "Measurement of Air and VOC Vapor Fluxes during Gas-Driven Soil Remediation: Bench-Scale Experiments", *Env. Sci & Tech.,* vol. 46, pp. 9533-9540, 2012.

[3] P.K. Gupta., B.K. Yadav "Bioremediation of non-aqueous phase liquids (NAPLS) polluted soil and water resources", *Water Air Soil Pollut.*, vol. 220, pp. 225–239, 2011.

[4] F. Rubertelli, A. Conte, "Process for removing hydrocarbons from a body of water by means of selective permeation, and relative apparatus", EU Patent 2938574B1, September 05, 2018

[5] J. Yuan, X. Liu, O. Akbulut, J. Hu, S.L. Suib, J. Kong, F. Stellacci, "Superwetting nanowire membranes for selective absorption", Nature Nanotechnology, vol. 3, pp. 332-336, 2008.

[6] F. Rubertelli, A. Chiodini, R. Bagatin, L. Carnelli, "A novel hydrophobic material for oil-water separation through selective permeation: the study of key parameters affecting performance", in *Proceedings of the 12th Offshore Mediterranean Conference and Exhibition*, Ravenna Italy, 2015.
[7] G.A. Blengini, M. Fantoni, M. Busto, G. Genon, M.C. Zanetti M., "Participatory approach, acceptability and transparency of waste management LCAs: case studies of Torino and Cuneo" *Waste Management*, vol. 32 n.9, pp. 1712–1721, 2012.
[8] C. Broadbent, "Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy", *Int. J. of Life Cycle Assessment* vol. 21, pp.1658–1665, 2016.
[9] ISO 14040: Environmental Management Life Cycle Assessment_ Principals and Framework; International Organization for Standardization: Geneva, Switzerland, 2006.
[10] ISO 14040-44. Environmental Management: Life Cycle Assessment. Principles and Guidelines, International Organization for Standardization, Geneva 2006.