Life cycle assessment of biological and mechanical processes of valorisation of absorbent hygiene products

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In Italy, Absorbent Hygiene Products (AHPs) are about 1.2 Mt, which means 4 % of total solid urban waste. Currently, AHPs are collected with no separated waste and disposed in landfill or incinerated causing emissions of greenhouse gases, consumption of space and economic issues.
AHPs is made up of 88.3 %v/v diaper, 3.9 % v/v bedding, 3.7 % v/v dressings, 1.2 black bags and 0.8 % v/v gloves and 2.1 % v/v other materials contained body fluids from non-infectious humans.
In Italy AHPs are identified with waste code (EER) 150203 and 180104.

In Italy, the End of Waste regulation of 15/05/2019 N62 stated that AHPs are not waste, and they can be recovery and recycled. This regulation assesses the specific criteria in compliance with heterogeneous polyolefin-based plastic, AHPs and cellulose deriving from recovery of waste of absorbent products for person, stop to be classified as waste, allowing, and promoting the concrete development of a Circular Economy.
Rather than general bio-waste, AHPs require more stringent storage and disposal measures, but their non-hazardous nature make them suitable to valorisation.
According to Waste Hierarchy treatment and Circular Economy policy, innovative biological and physical technologies to treat AHPs are studied and implemented.

The aim of the present study is the evaluation of technical feasibility, and the environmental impacts of innovative scenarios concerning the end-of-life treatments of AHPs by carrying out the Life Cycle Assessment (LCA). The environmental impacts are estimated through the Software Sima Pro 9.1.1 and the data base Ecoinvent 3.7. The functional unit (FU) was 1 t of AHPs and from cradle to grave approach was adopted.
The innovative end-of-life analysed treatments concerned one biological and two mechanical processes.
To measure the possible positive effects comparing to the current AHPs management, landfill and incineration processes were considered.
The biological and mechanical treatments were tested at the laboratory and pilot scales, but the following reported data will be referring the chosen FU to develop the Life Cycle Inventory (LCI).
The AHPs were collected from 10 houses of the elderly for a total of 100 kg, the main composition according to (Mundia et al., 2019) was 63.8 %v/v organic body fluids, 17.6 %v/v cellulose, 8.5 %v/v polyacrylate, 4.6 %v/v polypropylene, 2.7 %v/v polyethylene, and 2.8 %v/v other polymers.

The biological process was carried out at the laboratory scale according to (Munidia et al., 2019; Espinosa et al., 2011), employing the fungi *Pleurotus Ostreatus*, able to bio-degrade cellulosic matter.
Pleurotus ostreatus was chosen because its life cycle is short, it is not easily defeated by parasite, it is low cost cultivable, it is able to degrade a large variety of lignocellulosic substrates due to its capacity to secret specific lignocellulosic enzymes. This biological process consisted in AHPs preparation through sterilisation and wash treatments by means of centrifuge and H_2O_2 according to (Elviliana et al.2020) and comminution through a shredder to obtain a homogeneous substrate easily degradable by fungi. The sterilisation and washing treatment of 1 t of AHPs required pump of 2.5 kWh, 0.8 t of H_2O and 0.1 t H_2O_2, whereas the energy need to comminute is 5.1 kWh/t.
The biological treatment consists in three main phases: inoculation, first and second fungi growths. The sterilised and comminuted AHPs is used as cultivation medium for fungi in growth cell. To treat 1 t of AHPs, 533 g of *Pleurotus Ostreatus* seeds was added. The first phase of growth lasted 21 d at 25-29 °C with 70-80 % humidity without light, whereas the second growth lasted 47 d at.22-25 °C with 70-80 % humidity under aerobic conditions and with light. The air conditioning in the growth cell required an energy power of 46 kWh. At the end of the process the amount of collected fungi is equal to 225 kg and the waste to disposed is equal to 0.28 t.
This biological technology achieved a weight and volume reductions respectively equal to 72 and 88 % according to (Munidia et al., 2019; Espinosa et al., 2011), moreover the residual fungi can be exploited as animal food due to their protein contents, whereas the degraded AHP substrate is incinerated.

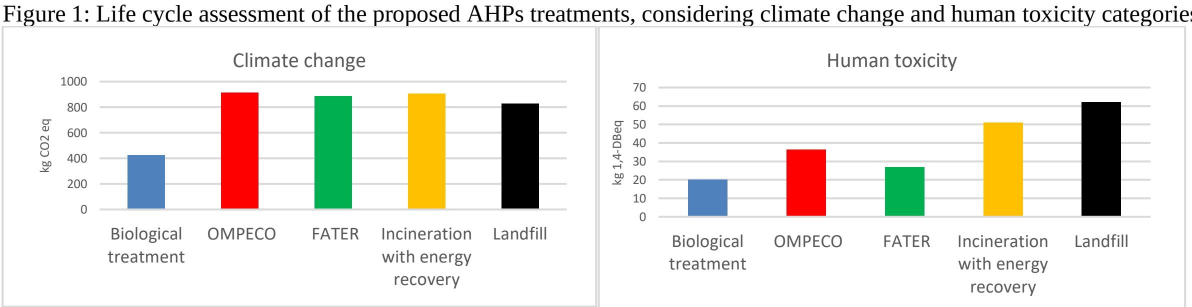
The two mechanical treatments were carried out at pilot scales according to the Ompeco and Fater technologies.

Ompeco S.r.l (Turin, Italy) patented Ompeco technology consisting into Converter of 5 m^3 able to transform 1t of AHP into 370 kg of combustible from waste in 45 min with energy consumption equal to 0.5 KWh/kg AHPs and 5 L of water. Ompeco technology is made up of the following main steps: comminution of AHPs with heat production for the friction up to 100 °C, evaporation and sterilisation with weight reduction and cooling.
The obtained product is a fluff with 63 and 70 % of weight and volume reduction. The final product is disposed in landfill.
Fater technology was developed by Fater S.p.A, SMART (Sustainable Materials And Recycling Technologies) and it consisted into stabilisation and elimination of the organic matter and possible pathogenic compounds of AHPs by means of the autoclave exploiting the pressure steam.
In Fater technology from 1 t of AHPs were separated 150 kg of cellulose and 75 kg of plastics which can be further used as filler for 3D printing. The energy required to separate the cellulose and plastic fractions are respectively 9.19 and 6.5 MJ/t of AHPs.
Incineration and landfill were considered as base line scenarios to compare environmental pros-cons of the innovative technologies proposed. According to AHPs management in Nord-West part of Piedmont, the distances of landfill and incinerator from the collect centre are respectively 16.2 and 16.9 km. For incinerator the energy recovered was 2.38 MJ/t of AHPs burned, since the low heating value of AHPs is 10.36 MJ/t.
The Life Cycle Impact Assessment (LCIA) was done with Recipe Mid-Point (H) 2016 and the following impact categories were considered: Global Worming Potential and Human Toxicity, whereas Cumulative Energy Demand (CED) method was employed to evaluate the energy impact of the proposed AHPs valorisation treatments.

The preliminary results achieved about the environmental evaluations concerning the climate change and human toxicity of all the proposed processes, are depicted in Figure1.
Among all the investigated process, the biological one reached the minor impact, since it required lower energy consumption rather than the others and, furthermore it produced a valuable by product for animal feed, avoiding the impacts due to the production of this product from raw materials (about -375 kg of CO_2 eq).
Landfill was the second low- impact climate change treatment, and the emissions were mainly due to the structure and composition of un-valorised AHPs. The mechanical processes are very energy-intensive, and therefore in Fater technology the impact saved to produce secondary raw material (about -300 kg of CO_2 eq) did not balance the impact of the whole process (about +550 kg of CO_2 eq).
Concerning the human toxicity category, the biological process reached the lowest impact, followed by Fater process because the recovery of cellulose significantly reduced the impact (about -19 kg 1.4-DB eq) and then Ompeco process.

These preliminary results proved that AHPs can be treated with biological and mechanical processes able to reduce the volume and weight of waste and to recover valuable materials, promoting the circular management of waste, according to Sustainable Development and Circular Economy pillars.

Figure 1: Life cycle assessment of the proposed AHPs treatments, considering climate change and human toxicity categories.



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