How is possible to reduce the environmental impact of the use phase of food systems?

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Abstract: The current national and international regulations invite companies to reduce the environmental impact of their industrial processes to reach more sustainable development as asked by the 2030 Agenda signed by the United Nations in 2015. Besides these premises, this work aims to evaluate the environmental performance of a peracetic acid-based aseptic filling machine used to sterilize bottles in food industries. The final goal is to investigate the main hotspot that negatively impacts the environment, proposing then solutions to solve them. The consumptions during the use phase, such as electricity, steam, water, caustic soda, nitric acid, gas nitrogen, compressed air and peracetic acid were collected from an Italian company. A Life Cycle Assessment (LCA) evaluation has been carried out following the ISO 14040 and 14044, using EPD 2018 method to evaluate the impact of the use phase on global warming, acidification, eutrophication, water consumption, ozone layer depletion, abiotic depletion and photochemical oxidation. Results highlights that electricity is the most impactful consumption. Thanks to a sensitivity analysis, different countries (Italy, France, India, USA, Germany, China) where the machine can be sold and electricity can be supplied were evaluated: results demonstrate that the impact of the food machine strongly depends on the electricity country mix. Moreover, the process steam used in the process causes the second main impact, but its recovery allows to reduce up to 10% the global warming and abiotic potentials, 7-9% acidification, photochemical oxidation and ozone layer depletion potentials. The key findings of the work demonstrate that the use of renewable resources and processes designed in a circular economy approach can help to reduce the impact of these food machines on the environment, helping to obtain more sustainable processes.

Keywords: Life Cycle Assessment; bottle; food industry; environmental sustainability; sterilization

I. Introduction

Today, thanks to national and international regulations, people and companies are called to pay attention to their impact on the environment: the adoption of a sustainable lifestyle, sustainable processes and products is almost mandatory (United Nations, 2022). However, in any type of activity, zero impact does not exist: in fact, every activity requires resources, raw materials and energy to provide a service or produce a good, and generate emissions and waste (Koumparou, 2018).

Therefore, the only possible solution is only the reduction of the impact, that could be as large as possible: to reach this goal, the first step is the calculation of the current impact on the environment of process and products during their life. In fact, only after this assessment, that highlight the main hotspot of the process, it will be possible to think about technical solutions to improve the system (ISPRA, 2022).

Each product has a "life": it begins with the design and development of the product, followed by the supply of resources and raw materials essential for its production, then follows the production process itself, and ends with its use by the final consumer and end-of-life activities (collection and sorting, waste disposal, reuse or recycling).

The methodological framework, known by the European Commission, for estimating and evaluating the environmental impacts attributable to the life cycle of a product/process, is the Life Cycle Assessment (LCA) (European Commission, 2022). The LCA is a decision support tool capable of assessing the sustainability of products and supply chains, since it helps to understand their environmental performance (such as the potentials of climate change, reduction of stratospheric ozone, creation of smog, eutrophication and acidification, the depletion of renewable and non-renewable resources), in an objective and technically argued form.

Since 1990, there has been a strong development and harmonization that has led to the development of its international standard: the ISO 14040 series (Larsen, et al., 2022). This has increased the reliability and methodological robustness of the LCA.

An LCA study must therefore be consistent with ISO standards, and is divided in 4 steps: definition of the goal and the Functional Unit (FU) of the study, inventory analysis, impact assessment and interpretation (Pré, 2022). In the food supply chain, LCA is applied to many supply chain steps (Takacs & Borrion, 2020). It has been used in the agriculture systems to quantify their environmental impact, or for example for comparing the traditional and organic cultivation (Coppola, et al., 2022). It has been applied on a food, such as bread (Câmara-Salim, et al., 2020) and on many others crops and products across the world (Alhashim, et al., 2021). Moreover, thanks to LCA is possible to compare different technologies for food processing (Borghesi, et al., 2022), cooking (Favi, et al., 2018) packaging systems (Wohner, et al., 2020) or packaging materials (Stefanini, et al., 2021).

Overall, the food industry results really impactful on the planet (Ritchie & Roser, 2021), also because the great amount of waste generated (Food and Agriculture Organization, 2021), but thanks to LCA studies the main hotspots of the systems can be highlighted and consequently companies should focus on them to find new solutions to improve their processes.

Besides these premises, the present work aims at evaluating a food mechanical equipment from an environmental point of view: the purpose is not only to highlight the main hotspots of the process, but also investigate some changes that could be introduced to obtain some impacts improvements.

The paper is structured as follows: the next chapter describes the methods used to carry out the study and the data collection. Then, the main results of the analysis are presented and discussed with a sensitivity analysis. Finally, the main conclusions of the work are draw.

II. Methods

The work took as a reference a peracetic acid (PAA) aseptic filling block for juices, created by a food machine producer located in Italy (GEA Filling & Packaging, 2022). It uses a single PAA solution to sterilize the environment, bottles and caps. After sterilization, the bottles are rapidly rinsed with sterile water at room temperature, ensuring a total peroxide residue of less than 0.5 ppm in compliance with Food and Drug Administration regulations. Five parameters need to be controlled to achieve effective and reliable sterilization: pressure, temperature, concentration, flow rate and contact time.

To evaluate the food equipment from an environmental point of view, the Life Cycle Assessment (LCA) methodology was used. The study was carried out following the ISO 14040 and 14044 through the SimaPro 9.1.1 software and the database Ecoinvent 3.6. The functional unit is 1000 bottles, as suggested by the Product Category Rule (PCR) "*Machines for filling and packaging of liquid food*" (EPD, 2012). The validation protocol is 6 Log for low acid drinks, while the external bottle sterilization is 5 Log. Every 162h, the start-up cycle occurs. The primary data of consumption during the use phase were collected from the company and involve the production of the bottles and the start-up cycles. Consumptions were modelled on the SimaPro 9.1 software using the Ecoinvent 3.6 database (Table 1).

To refer consumptions to the functional unit, the hourly consumption was divided by the number of bottles produced in one hour and multiplied by 1000 bottles.

TABLE 1
CONSUMPTION DURING THE EQUIPMENT'S PRODUCTION PHASE

Utility	Ecoinvent Dataset	Production phase	Start up cycle
Compressed air	Compressed air, 800 kPa gauge {RER}| compressed air production, 800 kPa gauge, >30kW, average generation	X	X
Treated and city water	Tap water {Europe without Switzerland}| tap water production, conventional treatment	X	X
Tower water	Electricity, medium voltage {IT}| market for		X
Chilled water	Electricity, medium voltage {IT}| market for	X	
Process steam & filtered culinary steam	Steam, in chemical industry {RER}| production	X	X
Gas nitrogen	Nitrogen, liquid {RER}| air separation, cryogenic	X	X
Caustic soda 33%	Sodium hydroxide, without water, in 50% solution state {RER}| chlor-alkali electrolysis, membrane cell + Tap water {Europe without Switzerland}| tap water production, ultrafiltration treatment	X	X
Nitric acid 33%	Nitric acid, without water, in 50% solution state {RER}| nitric acid production, product in 50% solution state | Cut-off, S + Tap water {Europe without Switzerland}| tap water production, ultrafiltration treatment		X
Sterilizing agent (PAA) 15%	Acetic acid, without water, in 98% solution state {GLO}| market for + Hydrogen peroxide, without water, in 50% solution state {RER}| market for hydrogen peroxide, without water, in 50% solution state + Peracetic acid + Wastewater, average {Europe without Switzerland}| market for wastewater, average	X	X
Electrical power	Electricity, medium voltage {IT}| market for	X	X

The complete start-up cycle takes 3 hours and is performed approximately every 162h, except for cleaning with nitric acid, that occurs every 4 weeks. The consumptions are illustrated in Table 1. To find the consumption per functional unit, each was divided by the total productivity of bottles in 162h (or in 4 weeks in the case of nitric acid) and multiplied by 1000 bottles.

Finally, also the emission in air during the use phase were considered: Acetic Acid (AA), Hydrogen Peroxide, Volatile Organic Compounds (VOC), particulates (50% < 10 μm; 50% <2.5 μm).

Once all the collected data during the inventory analysis were entered on SimaPro, their impact was assessed.

The method used is EPD 2018 (Environdec, 2022) as suggested by the PCR. Please note that the impact results presented in the next chapter are estimated for the functional unit, i.e. the production of 1000 bottles.

III. RESULTS

Overall, the numerical results of the production and start up cycle impacts are summarized in Table 2: the environmental impacts of the entire food equipment are mainly due to the first rather than the second phase analysed.

In particular, Figure 1 illustrates in detail the percentage impacts of production: electricity is the main contributor, and this is in line with other LCA studies (Favi, et al., 2018), followed by the process steam. Electricity is responsible for the 50% of the global warming, ozone layer depletion and abiotic depletion potentials, while the process steam is responsible for the 30-40% of the results on all the impact categories.

Instead, the treated water affects about 40% of the impact on water scarcity. VOC and AA emissions only have an impact on photochemical oxidation, while H_2O_2 and particulate emissions have zero impact on all categories.

As regards the start-up cycle of the equipment, Figure 2 illustrates its main impacts: the process steam has an average impact of 21-43% on the categories, except for the water scarcity, where 68% is due to the water treatment, and for the element of abiotic exhaustion, where 56% is due to caustic soda.

TABLE 2
EQUIPMENT'S PRODUCTION PHASE AND START-UP CYCLE IMPACTS

Impact category	Production	Start-up cycle
Acidification [kg SO2 eq]	5.08E-02	6.56E-04
Eutrophication [kg PO4---eq]	1.42E-02	1.82E-04
Global warming [kg CO2 eq]	1.41E+01	1.91E-01
Photochemical oxidation [kg NMVOC]	2.89E-02	3.72E-04
Abiotic depletion, elements [kg Sb eq]	3.02E-05	6.49E-07
Abiotic depletion, fossil fuels [MJ]	1.91E+02	2.62E+00
Water scarcity [m3 eq]	7.24E+00	1.49E-01
Ozone layer depletion [kg CFC-11 eq]	1.88E-06	3.32E-08

IV. DISCUSSION AND SENSITIVITY ANALYSIS

Since the electricity used in the machines resulted impactful, a sensitivity analysis was created to observe how the impact results can change using different electrical energy mix supplied by different countries. The electricity produced in Italy, France, Germany, Europe, China, United States and India have been taken as a reference. In particular, the production consumptions that include electricity are the electrical power, the chilled and tower water. Results demonstrate that India is often the state with the highest impact, followed by China and Germany. France, certainly thanks to nuclear power, resulted the best country according to all impact categories, except for the ozone layer depletion, where it is the worst. Italy, on the other hand, according to global warming, acidification, eutrophication is always the second country with the lowest impact and is the worst according to the water scarcity. Figure 3 shows that the impacts vary not only based on the country where the electricity is produced, but also based on the impact category considered. Similar results can be obtained considering the consumption during the start-up cycles.

Moreover, since customers can decide to recover or not the process steam during the production, the steam recovery scenario was investigated to evaluate the environmental impact. It is assumed that 75% of the condense is recovered, while 5% is dispersed and need to be reintegrated. The process steam in the recovery scenario is then lower, and the energy for the pump recovery was considered. For this evaluation, the European electricity mix was used. The new results demonstrate that the reduction of the impact due to the recovery of process steam would be up to 10% for global warming and abiotic depletion (fossil fuels), 7-9% for acidification, photochemical oxidation and ozone layer depletion (Table 3).

TABLE 3
EQUIPMENT'S PRODUCTION CONSUMPTION WITH AND WITHOUT PROCESS STEAM RECOVERY

Impact category	No steam recovery	Steam recovery
Acidification [kg SO2 eq]	5.08E-02	3.26E-02
Eutrophication [kg PO4---eq]	1.42E-02	1.10E-02
Global warming [kg CO2 eq]	1.41E+01	7.56E+00
Photochemical oxidation [kg NMVOC]	2.89E-02	1.81E-02
Abiotic depletion, elements [kg Sb eq]	3.02E-05	2.69E-05
Abiotic depletion, fossil fuels [MJ]	1.91E+02	9.77E+01
Water scarcity [m3 eq]	7.24E+00	7.19E+00
Ozone layer depletion [kg CFC-11 eq]	1.88E-06	1.08E-06

V. CONCLUSION

The present work aimed at environmentally evaluating a food mechanical equipment to, not only highlight the main hotspot of the process, but also investigate possible solutions to reduce its environmental impact. A case study on a food beverage system was considered and primary data of consumptions and emissions during production and start-up cycle were collected from an equipment producer located in Italy. LCA methodology was used to carry out the study.

Results demonstrate that, to obtain a reduction of the environmental impact of a similar food machine, particular attention should be paid on electrical power and processes steam, since they are more responsible for global warming, acidification, eutrophication, ozone layer depletion and photochemical oxidation potentials, in comparison to other consumptions such as city and tower water, PAA, gas nitrogen, caustic soda, compressed air, or AA, H_20_2, VOC emissions. Moreover, in the start-up cycle, also the caustic soda is impactful on abiotic depletion elements, and the great amount of water is responsible for the 70% potential impact on water scarcity.

However, results strictly depend on the energy country mix: the production environmental impact can change up to 70% depending on where the food equipment is used. Moreover, the possibility of steam recovery in the system allow to a reduction of the impact up to 10%.

Therefore, to enhance the environmental performance of similar food equipment, the use of renewable resources for the electric power can lead to important improvements, as well as the recovery of streams, such as steam, water or chemicals, that allows to optimize the process thanks to a circular economy perspective.

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Appendix A.

Fig. 1 Equipment impacts during production

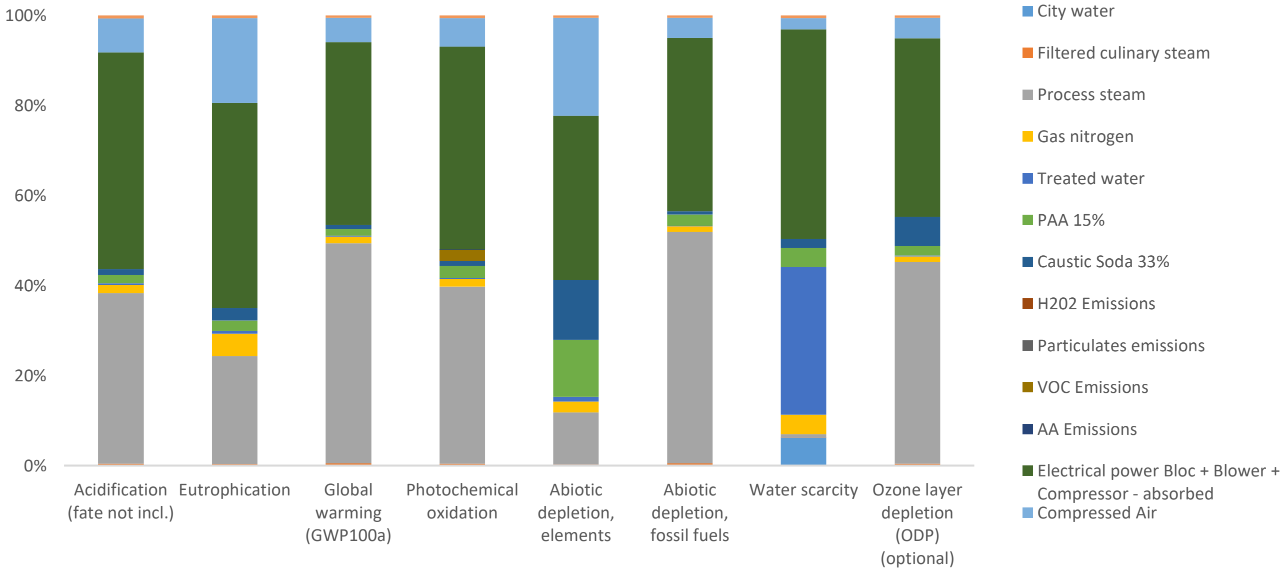

Fig. 2 Equipment impacts during start up cycles

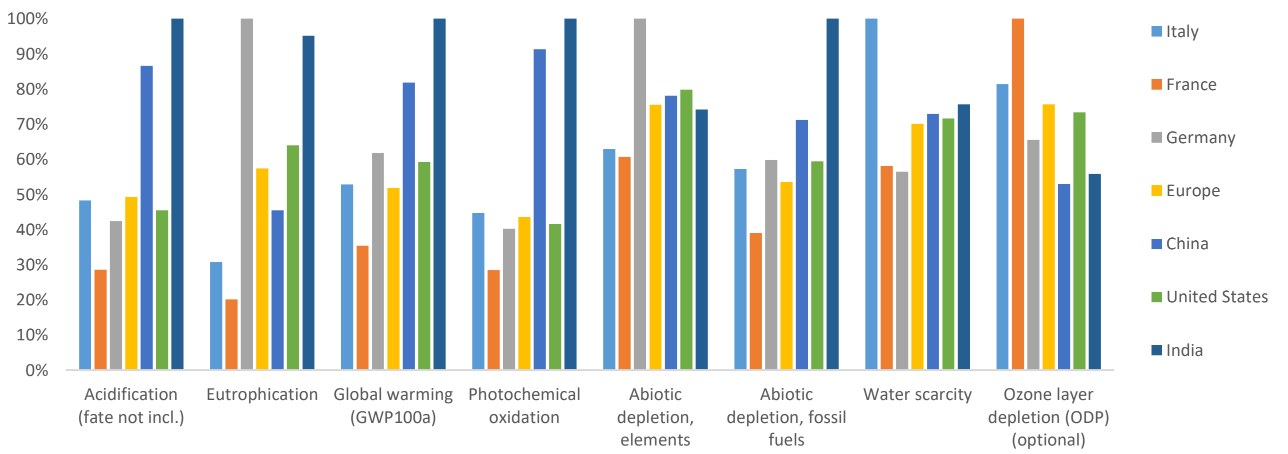

Fig. 3 Sensitivity analysis of different electric country mix