Assessing the impact of autoclaving versus purchasing new Plastic Flasks in a technological platform

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Executive Summary

This report presents a definition of the goal and scope of the Life Cycle Assessment project performed for the SV-PTPSP core technological platform of EPFL, which evaluates the environmental impacts of using single-use versus reusable plastic flasks. As a Biosafecty Level 1 (BSL1) environment, the platform purchases over 1200 single-use plastic flasks yearly. This practice has raised both environmental and cost concerns, and triggered a request for a Life Cycle assessment.

Single-use flasks, made of materials such as polycarbonate (PC) and high-density polyethylene (HDPE), generate significant waste, while reusable flasks, sterilized through autoclaving, reduce waste but consume huge amount of electricity and water. The study assesses both options from raw material extraction to end-of-life disposal, incorporating EPFL's specific lab context.

In the following sections, the function and functional unit are defined. This functional unit is for the moment restricted to a certain producer's flasks, namely one year of Corning flasks use sufficient to process $25\,\mathrm{L}$ of a certain cell culture medium at EPFL SV-PTPSP in 2024. Then, the process tree, system boundaries, reference flows and key parameters of this study are defined, discussed and calculated, which enables our future comparative analysis between the two scenarios. In the last part, the data used in this work is shown, which is partially provided by the facility, for gate-to-gate processes, based on their internal processes and documentation on the different machines and resources. When the data was not readily available, and for cradle-to-grave unit processes, the different flows have been determined with the best of knowledge, based on the process and situation/location of the facility.

This midterm report sets the foundation for final results and will inform procurement practices, aiding SV-PTPSP and similar laboratories in minimizing environmental footprints.

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Contents

1   Introduction

The escalating global concern over plastic waste and its environmental ramifications has prompted various sectors to reassess their reliance on single-use plastics. Scientific laboratories, which have traditionally depended on disposable plastic equipment for convenience and sterility, are no exception. Laboratories contribute significantly to plastic waste generation, with estimates suggesting that the scientific sector produces millions of tons of plastic waste annually. This reality underscores the urgent need for sustainable practices within research environments.

At EPFL, the SV-PTPSP core technological platform specializes in the production and purification of proteins in mammalian cells, operating within a Biosafety Level 1 (BSL1) environment. A critical component of their operations involves the use of single-use plastic flasks for cell culture experiments made from high-density polyethylene (HDPE) and polycarbonate (PC) materials. Annually, the platform purchases over 1,200 disposable plastic flasks. While these flasks offer convenience and ensure sterility, their single-use nature raises significant environmental and economic concerns.

The environmental issues associated with the extensive use of disposable plastic flasks are multifaceted. Firstly, the production of plastic flasks involves the consumption of non-renewable resources such as petroleum and natural gas. The manufacturing process emits greenhouse gases (GHGs), contributing to global warming and climate change. Secondly, the disposal of plastic flasks after a single use adds to the growing problem of plastic pollution. Plastics can take hundreds of years to degrade, and improper disposal can lead to environmental contamination, affecting wildlife and ecosystems.

One potential solution is the adoption of reusable flasks that can be sterilized through autoclaving. Autoclaving involves using pressurized steam at high temperatures to sterilize equipment, effectively eliminating microorganisms. Reusable flasks made from durable materials, can withstand multiple autoclave cycles before they degrade. By transitioning to reusable flasks, the platform could significantly reduce plastic waste generation and lower long-term costs associated with purchasing disposable equipment.

It is important to note that reusable flasks have a limited lifespan before they degrade. As they undergo repeated autoclaving cycles, their structural integrity and performance can diminish. This degradation can lead to issues such as contamination risks or failure to maintain the required experimental conditions, ultimately affecting the reliability of results. For example, initial attempts at using glass flasks at the SV-PTPSP platform revealed a significant decline in performance after just a few autoclaving cycles, resulting in failed experiments. This highlights the importance of carefully evaluating both the material durability and the practicality of adopting reusable flasks in a research environment.

In addition to the challenges of flask durability, the environmental costs of autoclaving must also be considered to determine whether this approach represents a net improvement in sustainability. The autoclaving process consumes energy and water and may involve the use of detergents and other chemicals for cleaning. These inputs contribute to the overall environmental impact, potentially offsetting the benefits of reducing plastic waste.

These considerations underscore the importance of conducting a thorough Life Cycle Assessment to evaluate the environmental trade-offs between these two approaches. By assessing the complete lifecycle of both single-use and reusable flasks, this study aims to provide data-driven insights to inform sustainable decision-making at the SV-PTPSP platform.

1.1   Objective of the study

In light of these considerations, this study aims to conduct a comprehensive Life Cycle Assessment (LCA) to evaluate the environmental impacts of autoclaving reusable flasks compared to

the continued use of single-use plastic flasks at the SV-PTPSP platform. The assessment will consider the entire life cycle of the flasks, from the production of raw materials to end-of-life disposal, including the use phase involving autoclaving for reusable flasks.

1.2   Overview of similar studies

Some LCA study of the topic or related topics has already been performed. In fact, going over some of the findings helps us to understand the context of our current study and to specifically target questions that remain unanswered. To do so we have identified 4 studies (3 LCA's and one aggregate study on 18 LCA's) that have particular relevance for our own analysis. Namely, these studies focus on the laboratory environment and the life cycle of laboratory equipment.

Firstly, a 2022 LCA study of UCL's Bartlett department by Y. Cai provides useful insights that help motivate our analysis. This study assessed the department's overall emissions from 2018 to 2019, highlighting the main environmental contributors. While it grouped all lab procurements into a single category and did not focus solely on lab equipment, it showed that lab equipment and chemicals are major sources of greenhouse gas emissions, accounting for approximately 24% of the department's total emissions [1]. This finding underscores the importance of examining laboratory-specific impacts, which our study aims to address more directly.

Furthermore, an LCA study commissioned by lab equipment manufacturer Eppendorf and one published as part of Volume 1 of the journal *Advances in Sample Preparation* examine environmental performance of plastic lab containers and of sample preparation techniques respectively. The Eppendorf study finds that raw materials, distribution and end of life (EoL) contribute the most to CO2 emissions outside of the lab. Within the lab, it highlights procurement and EoL management of containers as the biggest levers for improvement. The second study supports these findings, further indicating that while washing reusable containers increases the environmental burden (primarily due to chemical usage), this impact is outweighed by the environmental benefits gained through reuse [2, 3].

Finally, an aggregate study on a total of 18 cradle-to-gate LCA's (5 additional LCA's were used specifically for disposal methods) was published in the *PLOS* journal, analyzing the use of life cycle assessments to guide reduction in the carbon footprint of single-use lab consumables. This paper is particularly relevant to our study as it assesses equipment of the same material (HDPE) within a very similar context. The paper highlights polymer and raw material production as the largest contributors to overall emissions, followed by end-of-life when incineration was the chosen disposal method. Additionally, it concludes that the most significant emission reductions can be achieved through circular supply chains, and identifies disposal choice of the equipment as one of the main levers on impact within the lab [4].

1.3   Gaps addressed by this study

In light of these findings, this study aims to provide further insights into the trade-offs involved specifically in choosing between single-use and multi-use containers of different materials and sizes within the scope of SV-PTPSP's research. It seeks to offer a comparative analysis of these trade-offs across the life cycle of each container type.

Additionally, this study is meant to take EPFL's specific context into account, namely the regulations and processes that dictate work within the SV-PTPSP lab. This means considering the local energy mix, the geographical context as well as the specific equipment and washing infrastructure available to the staff.

2   Project goals

As mentioned, this study specifically addresses the SV-PTPSP lab at EPFL and was commissioned by the lab as part of a broader EPFL initiative to evaluate the environmental impact across its labs and departments. The study aims to optimize the lab's sustainability performance by assessing and comparing the environmental impacts of single-use versus multi-use containers and flasks in lab operations.

The results of this study are intended to inform procurement and usage decisions regarding containers, helping to minimize environmental impact at the SV-PTPSP lab and, more generally, at EPFL. This information could guide the lab's sustainability practices, potentially influencing resource efficiency and waste reduction.

The primary audience for this study is decision-makers within EPFL, including lab managers and sustainability officers. However, it may also benefit other laboratories working under similar conditions, both in terms of scientific focus and geographic context.

As such, if the study finds significant differences between the two approaches (reuse vs. single-use), these findings may be used for comparative assertions disclosed to the public.

3   Function and functional unit

The primary function of the product systems under consideration is to provide sterile flask volume for the production and purification of proteins in mammalian cell cultures at the SV-PTPSP core technological platform of EPFL, Lausanne, in 2024. The flasks are critical to ensuring the sterility and efficiency of cell culture experiments conducted in a Biosafety Level 1 (BSL1) environment.

The product systems being compared are:

Single-use plastic flasks: Made from materials such as polycarbonate (PC) and high-density polyethylene (HDPE), these flasks are designed for one-time use, ensuring sterility but contributing to significant plastic waste.

Reusable flasks: Made from durable materials capable of withstanding autoclaving cycles, these flasks can be sterilized and reused multiple times, reducing plastic waste but requiring energy and water for the autoclaving process.

While both systems serve the same primary function, their environmental impacts differ due to the single-use nature of plastic flasks versus the energy-intensive maintenance of reusable flasks. To ensure meaningful comparison, functional equivalence between the systems has been established by considering scalability and interchangeability across flask sizes and materials.

3.1   Functional Unit

The functional unit for this study is defined as:

> *The use of flasks sufficient to process* **25 L of a certain cell culture medium at EPFL SV-PTPSP in 2024**.

This definition assumes that flasks of the same material are scalable and interchangeable for the experimental process. For example, the same culture volume could be achieved using one 4 L flask or two 2 L flasks. This allows for a direct comparison of systems while accounting for variations in flask size and usage frequency.

Key Assumptions

Scalability: Flasks of different volumes made from the same material can perform equivalent functions by scaling their usage appropriately.

Interchangeability: Experiments requiring a specific flask type can use alternative volumes without compromising functionality.

Material Grouping: Flasks of the same material are grouped for analysis to simplify comparisons across different product systems.

3.2 Limitations

The functional equivalence assumes that all flask sizes of the same material are equally suited to the cell culture process. Any material- or size-specific performance issues, such as sterility or structural integrity, are not explicitly considered in this functional unit but will be addressed in the broader LCA discussion.

4 Description of the product systems

This LCA study evaluates the environmental impacts of using single-use plastic flasks versus reusable flasks with autoclaving for protein production in a BSL1 lab setting at EPFL PTPSP. The functional unit (FU) for this analysis is defined as the "use of flasks sufficient to process 25 liters of cell culture medium in 2024." The process tree and system boundaries for each product system are designed to capture all relevant life cycle stages, from raw material extraction to end-of-life treatment.
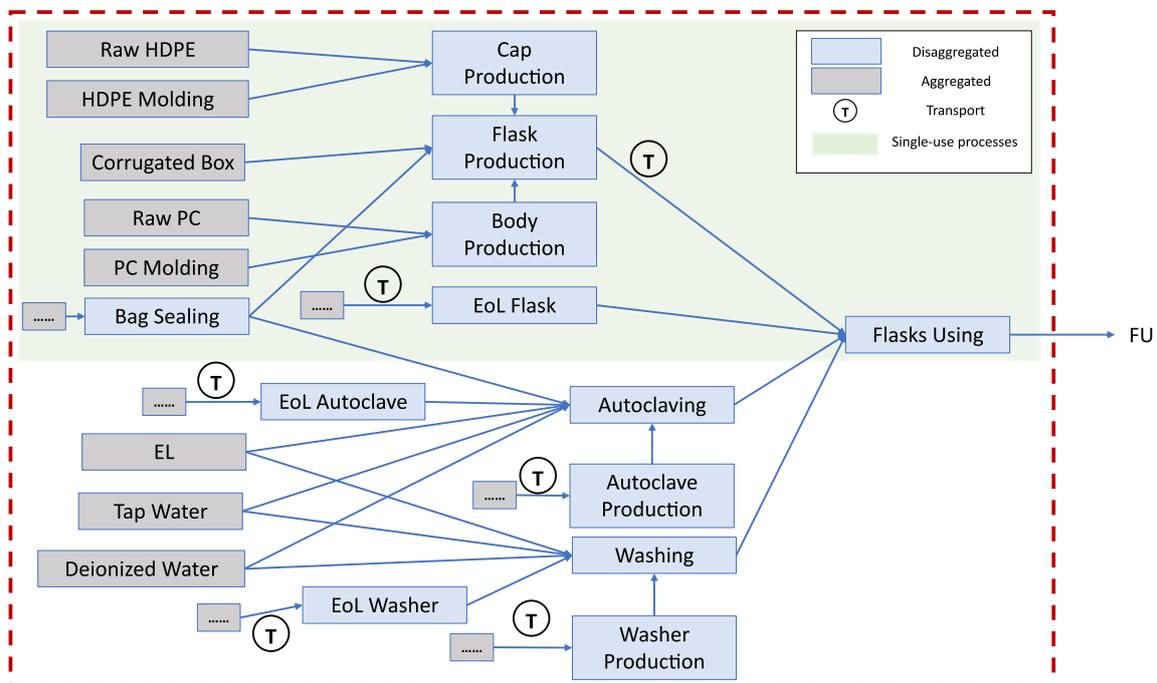

Figure 1: Process tree about the product systems

4.1 Process Tree Overview

The process tree, as shown in figure 1, includes two main product systems:

1. **Single-Use Plastic Flasks**: These flasks are manufactured from high-density polyethylene (HDPE) and polycarbonate (PC) materials. They go through production stages including material extraction, molding, and assembly. Once used in the lab, these flasks are disposed of by incineration with energy recovery.

2. **Reusable Flasks with Autoclaving**: These flasks are sterilized and reused multiple times through autoclaving. This system includes additional processes like washing and autoclaving, which require inputs of electricity, tap water, and deionized water. At the end of their lifecycle, the reusable flasks are also disposed of through incineration with energy recovery.

4.2   System Boundaries and Process Classification

4.2.1   Foreground Processes (Gate-to-Gate)

These processes occur within the lab's operational boundaries and include flask usage, washing, and autoclaving. The impacts of these stages, such as energy and water consumption, are directly controlled by the lab and are thus categorized as gate-to-gate processes.

4.2.2   Background Processes (Cradle-to-Gate)

Background processes include the upstream activities of raw material extraction and flask production. These cradle-to-gate stages are outside the lab's direct control but are essential to the product systems being assessed. Examples include HDPE and PC production, molding, transport, and end-of-life processing.

The system boundary is set as cradle-to-grave to capture the entire lifecycle of both single-use and reusable flasks, ensuring a comprehensive assessment.

4.3   Inclusions and Exclusions

In the life cycle assessment of single-use and multi-use flasks, certain processes and resources are included or excluded to focus on the most impactful stages. Included are the production of flask components (cap and body), plastic packaging bags, and box materials. Plastic bags are used frequently to maintain sterility after each cleaning of reusable flasks, adding significantly to the environmental impact. The box material also contributes to the lifecycle footprint, especially during transportation. Additionally, the resources used for washing and autoclaving reusable flasks, such as water and electricity, are included due to their high consumption across multiple use cycles. Conversely, excluded processes include resources for initial flask assembly, as their impact is minimal compared to other stages, and on-campus maintenance and transportation, which are negligible. Furthermore, the energy and resources involved in manufacturing and maintaining the autoclaving and washing machines are excluded due to lack of specific data and the shared usage of these machines across various lab functions. These inclusions and exclusions ensure that the assessment focuses on the primary environmental impacts associated with each flask system.

4.4   End-of-Life (EoL) Treatment

For the end-of-life (EoL) treatment of flasks, incineration with energy recovery is utilized, allowing the energy generated from burning the flask materials to offset some of the system's energy demands. This approach introduces a boundary expansion in the life cycle assessment (LCA) by considering both waste disposal and the environmental credit from recovered energy.

Rather than feeding energy directly back into the system, the recovered energy offsets the overall energy requirements, slightly reducing the environmental burden associated with energy use. This boundary expansion enables the LCA to capture the dual function of incineration, accurately reflecting the impact of energy recovery at the EoL stage.

5 Reference flows and key parameters

Definition: The Functional Unit (FU) is defined as the number of flasks required to process 25 liters of a specific cell culture medium at EPFL PTPSP in 2024.

For this analysis, we selected the Corning 431144 flask (250 mL), which would require 100 experiments of 250 mL each per FU to process the total volume.

Single-Use Flask Requirement (RF_{single})

$$RF_{single} = \frac{100 \text{ experiments/FU}}{1 \text{ experiment/flask}} = 100 \text{ flasks/FU}$$

Thus, for the single-use scenario, 100 flasks are required per FU.

Multiple-Use Flask Requirement (RF_{multi})

$$RF_{multi} = \frac{100 \text{ experiments/FU}}{10 \text{ experiments/flask}} = 10 \text{ flasks/FU}$$

For the multiple-use scenario, only 10 flasks are required per FU, assuming each flask can be reused for up to 10 experiments.

After defining the function unit, process tree and system boundaries, with data acquired in part 6, the key parameters about flask use and washing facility are calculated and shown in table 1 and table 2 respectively, the calculation processes are listed in appendix A .

Table 1: Reference flows and Key parameters (Flask)

Unit Process	Unit	Key parameters
PP for Cap Production	g/FU	- 830 g per FU for single-use scenario (100 caps per FU) - 83 g per FU for multiple-use scenario (10 caps per FU) - Material: Polypropylene (PP)
PC for Body Production	g/FU	- 4900 g per FU for single-use scenario (100 bodies per FU) - 490 g per FU for multiple-use scenario (10 bodies per FU) - Material: Polycarbonate (PC)
Electricity for Bag Sealing	kWh/FU	- 2.5 kWh per FU for single-use scenario (100 items) - 0.25 kWh per FU for multiple-use scenario (10 items) - Sealing energy requirement
Box Production	kg/FU	- 2.478 kg of cardboard per FU for single-use scenario (2 boxes for 100 flasks) - 0.2478 kg of cardboard per FU for multiple-use scenario (1/5 of a box for 10 flasks)
Bag Production (Paper)	g/FU	- 74.35 g per FU for single-use scenario (100 bags) - 74.35 g per FU for multiple-use scenario (10 bags) - Material: Paper (50% of bag composition)
Bag Production (HDPE)	g/FU	- 74.35 g per FU for single-use scenario (100 bags) - 74.35 g per FU for multiple-use scenario (10 bags) - Material: High-Density Polyethylene (HDPE, 50% of bag)
Distribution	tkm/FU	- 161.43 tkm per FU for single-use scenario (weight: 8.3567 kg per FU) - 44.58 tkm per FU for multiple-use scenario (weight: 2.3075 kg per FU) - Transportation path: 80% by sea/truck (China to Lausanne via Le Havre), 20% by air/truck, final disposal 11.5 km to incineration plant

Table 2: Reference flows and Key parameters (Washer and Autoclave)

Unit Process	Unit	Key parameters
Electricity for Washing	kWh/FU	- 0.9375 kWh per FU (PTPSP allocation) - Washer model: Getinge S8666-7 - 32 flasks per cycle, 0.3125 cycles per FU - Total electricity: 3.125 kWh per FU
Tap Water for Washing	L/FU	- 9.375 L per FU (PTPSP allocation) - 31.25 L per FU total - 32 flasks per cycle, 0.3125 cycles per FU
Deionized Water for Washing	L/FU	- 2.8125 L per FU (PTPSP allocation) - 9.375 L per FU total - 32 flasks per cycle, 0.3125 cycles per FU
Electricity for Autoclaving	kWh/FU	- 0.4285 kWh per FU (PTPSP allocation) - Autoclave model: FOB3 TS - 28 flasks per cycle, 0.3571 cycles per FU - Total electricity: 1.4284 kWh per FU
Tap Water for Autoclaving	L/FU	- 6.9642 L per FU (PTPSP allocation) - 23.214 L per FU total - 28 flasks per cycle, 0.3571 cycles per FU
Deionized Water for Autoclaving	L/FU	- 3.2139 L per FU (PTPSP allocation) - 10.713 L per FU total - 28 flasks per cycle, 0.3571 cycles per FU
Washer Utilization per FU	cycles/FU	- 0.09375 cycles per FU - Contributes approximately 0.00625% of the washer's service life per FU
Autoclave Utilization per FU	cycles/FU	- 0.1071 cycles per FU - Contributes approximately 0.00714% of the autoclave's service life per FU

6 Data sources

6.1 Flask data

This study examines the performances of different flasks when used one or multiple times. The flasks presented below are produced in China, with the exception of the TPP model, that is sourced from Switzerland directly. For given types of flasks, data on unit price, number of annual purchase, number of cleaning before disposal, maximum number of flasks per cleaning cycle in washer's chamber and autoclaving machine's chamber is provided by PTPSP's statistics, shown in table 3.

Table 3: Information about flasks used in PTPSP

Type	Unit Price/CHF	Annual purchase	Nb cleaning	Nb/Washer	Nb/Autoclave
Nest 786111	78.3	30	5~8	12	6
Nest 787011	107.5	20	5~8	4	6
Nest 785111	59.8	6	5~8	16	11
Thompson 931116	125	45	0	4	6
Thompson 931114	48.3	20	0	12	6
Thompson 931113	57.6	25	0	16	16
Corning 430421	6.7	69	10	64	45
Corning 431144	8.32	60	10	32	28
Corning 431145	7.72	30	10	18	18
Corning 431147	17.25	100	10	18	18
TPP 87600	12.5	468	1	64	>100

Parameters of the flasks used in the lab are shown in table 4. The volume in the table corresponds to the nominal volume of each type of flask, raw materials used for manufacturing

the body and cap are from the websites of producers[5, 6, 7, 8]. Data on mass, height and diameter is measured by group members in the lab.

Table 4: Parameters of flasks used in PTPSP

Type	Volume	Body material	m_{body}/g	Cap material	m_{cap}/g	Height/cm	$\varnothing$/cm
Nest 786111	3 L	PC	237.1	HDPE	19	24	17
Nest 787011	5 L	PC	367.1	HDPE	28.9	28	22
Nest 785111	2 L	PC	203.7	HDPE	19	20	15
Thompson 931116	5 L	PC	TBM	PTFE	TBM	N/A	N/A
Thompson 931114	2.8 L	PC	TBM	PTFE	TBM	N/A	N/A
Thompson 931113	1.6 L	PC	TBM	PTFE	TBM	N/A	N/A
Corning 430421	125 mL	PC	26.5	PP	7.7	12	7
Corning 431144	250 mL	PC	49	PP	8.3	14	9
Corning 431145	500 mL	PC	66	PP	9	16	11
Corning 431147	1000 mL	PC	113.1	PP	10.5	19	13
TPP 87600	600 mL	PP	98.5	PE	12.2	17	9

6.2   Washing facility data

Table 5 shows key data on the washer and autoclaving machine from the washing facility on EPFL campus, including average electricity usage, tap water usage, demineralized water usage and expected service life of the two machines. The total weight and effective chamber volume of them can be found in the manufacturers' website [9, 10].

Table 5: Statistics on machines from the washing facility

Model	Washer Getinge S8666-7	Autoclave (sterilizer) FOB3 TS
Average electricity use (kWh/cycle)	10	4
Average tap water use (L/cycle)	100	65
Average demineralized water use (L/cycle)	30	30
Average service life (years)	20	20
Effective chamber volume (L)	316	36

From the similar LCA study on the autoclaving machine [11], the raw materials used for manufacturing the sterilizer FOB3-TS is estimated by down-scaling and shown in table 6 .

Table 6: Raw Materials Usage of the Autoclave Machine (scaled from [11])

S/n	Material types	Mass (kg)
1	Stainless Steel 316	246.9
2	Stainless Steel 304	70.6
3	Aluminum	3.3
4	Glass Wool	3.9
5	PTFE	9.7
6	Copper	0.7
7	Cast Iron	11.1
8	Electronic and control	3.9
Total weight		350

6.3   Other data and assumptions

Bag sealing and packaging

- **Bag**: 50 % paper and 50 % HDPE. Since each flask is re-bagged after each sterilization, need 100 bags per FU. Assuming each re-bag is constructed from the same materials as the original packaging and transported from China to the lab in Switzerland.

- **Electricity for Bag Sealing**: 0.025 kWh per item, estimated based on typical energy requirements for heat sealing [12].

- **Flask Dimensions for Packaging**: 15 cm height and 10 cm diameter — Packaging size is adjusted to fit the flask dimensions and allow for sealing.

- **Cardboard Box for 50 Flasks**: 1.239 kg, estimated based on typical corrugated box size and density.

- **Packaging Material Density**: 700 kg/cm^3, typical corrugated box density.

Transportation Path (Flask)

- **80% by Sea and Truck**: About 80 % of deliveries to Switzerland are shipped by sea from the manufacturing site in China to Le Havre, France. From there, the flasks are transported by truck to Geneva, then to Lausanne (61 km from Geneva). This route covers approximately 21 588.21 km by sea and 742.93 km by truck. Sea freight is chosen for cost-effectiveness and its lower carbon footprint compared to air freight.

- **20% by Air and Truck**: To ensure flexibility and meet urgent demand, around 20 % of shipments are sent by air directly from China to Geneva, covering 7098.78 km by air, then trucked 61 km to Lausanne. Air freight is faster but has a higher environmental impact.

- **Disposal**: After use, flasks are incinerated, with an average transportation distance of 11.5 km from EPFL to the nearest incineration facility.

Cleaning

- **Neglecting Detergent Usage**: Detergent used in the washing process is ignored for this assessment.

- **Daily Operation**: Assume that each machine (washer and autoclave) completes one cycle per workday throughout its 20-year service life.

- **Occupancy Rate Calculation**: Since the chamber cannot be fully optimized due to flask arrangement (flasks placed upside down on nozzles), the effective capacity differs between washing and sterilization processes.

- **Resource Allocation to PTPSP**: 30% of the total resources (electricity, water, etc.) of the cleaning facility are allocated for use by PTPSP, the facility where flask processing is conducted.

6.4   Background processes

The background (cradle-to-grave) unit processes included in this project are shown in table 7, which comes from Ecoinvent databases [13].

Table 7: Cradle-to-grave data from Ecoinvent

Input	Provider
Electricity	market for electricity, low voltage | electricity, low voltage | cutoff, S - CH
Raw HDPE	market for polycarbonate | polycarbonate | cutoff, S - GLO
Moulding HDPE / PC	market for injection moulding | injection moulding | cutoff, S - GLO
Raw PC	market for polyethylene| polyethylene, high density, granulate | cutoff, S - GLO
Corrugated Box	market for corrugated board box | corrugated board box | cutoff, S - RoW
Tap Water	market for tap water | tap water | cutoff, S - CH
Deionized Water	market for water, deionized | water, deionized | cutoff, S - CH
Cast Iron	cast iron production | cast iron | Cutoff, S
Electronic and control	electronics production, for control units | electronics, for control units | Cutoff, S
Glass Wool	glass wool mat production | glass wool mat | Cutoff, S
Aluminum	market for sheet rolling, aluminium | sheet rolling, aluminium | Cutoff, S
Copper	market for sheet rolling, copper | sheet rolling, copper | Cutoff, S
Stainless Steel 304	market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, S
PTFE	market for tetrafluoroethylene | tetrafluoroethylene | Cutoff, S
Waste Water	market for wastewater, average | wastewater, average | Cutoff, S - CH

7   Impact assessment

The four evaluated scenarios and their labels are:

- Single use of a Corning 43144 flask (label S-44, base scenario)

- Multiple use of a Corning 431144 flask (label M-44)

- Single use of a Corning 431145 flask (label S-45)

- Multiple use of a Corning 431145 flask (label M-45)

- Single use of a Nest 785111 flask (label S-N11)

- Multiple use of a Nest 785111 flask (label M-N11)

- Single use of a TPP 87600 flask (label S-T00)

- Multiple use of a TPP 87600 flask (label M-T00)

The aggregated damage level impact categories are evaluated using the IMPACT World+ footprint framework. The results of the impact assessment are presented in Tables 8 and 8. In order to be able to compare the scenarios between one another, an internal normalization for each category has been performed, and the results are graphically displayed in Figure 2. Additionally, the midpoint impact categories for Environmental quality and Human health are also presented in Figures 6 and 8

Table 8: Impact score categories and results according to IMPACT World+ (1/2)

Impact category	S-44	M-44	S-45	M-45	Unit
Carbon footprint	69.30	27.00	44.17	20.80	[kg CO_2 eq.]
Fossil and nuclear energy use	906.81	639.55	570.98	512.14	[MJ deprived]
Remaining Ecosystem quality damage	6.71	4.18	3.76	3.23	[PDF m^2 yr]
Remaining Human health damage	5.36E-05	3.06E-05	3.35E-05	2.41E-05	[DALY]
Water scarcity footprint	19.53	52.12	12.56	43.34	[m^3 world eq.]

Table 9: Impact score categories and results according to IMPACT World+ (2/2)

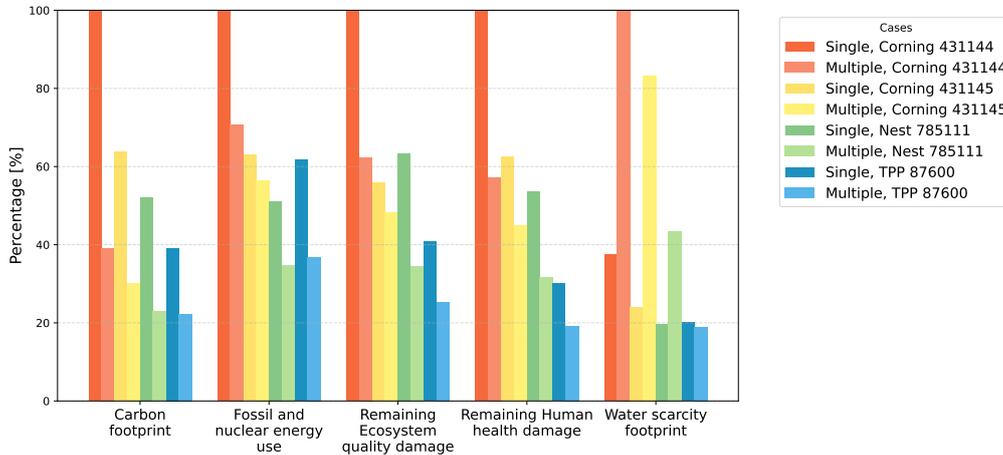|	S-N11	M-N11	S-T00	M-T00	Unit
Carbon footprint	36.11	15.9	27.1	15.36	[kg CO$_2$ eq.]
Fossil and nuclear energy use	463.67	314.94	559.25	331.71	[MJ deprived]
Remaining Ecosystem quality damage	4.25	2.31	2.74	1.7	[PDF m^2 yr]
Remaining Human health damage	2.87E-05	1.70E-05	1.61E-05	1.02E-05	[DALY]
Water scarcity footprint	10.27	22.62	10.46	9.86	[m^3 world eq.]

Figure 2: Normalized impact scores

7.1 Contribution trees

For the different scenarios, the main processes can be divided into 5 categories.

1. Autoclaving process

2. End of Life

3. Assembly and production of the flask

4. Transport

5. Washing

In this section, the results for all the aggregated damage level impact categories are detailed with the contribution of each process and compared with one another.

7.1.1 Carbon footprint

The contribution for each process category are displayed in Figure3.

As expected, reusing the flasks generates a lower carbon footprint. However, using the Corning 431144 flasks multiple times is roughly equivalent to a single use of the TPP 87600 flask type overall (27.0 against 27.1 [kg CO$_2$ eq.]). Among all scenarios, the carbon footprint of transport is minimal, ranging from 0.5 % (Multiple, Corning 431145) to 5.3 % (Single, Nest 78511) of the total impact, and is therefore not seen as a noticeable parameter for potential of improvement.

Another point of notice is the EoL impact for the TPP 87600. The impact is lower than the Corning 431144 but higher compared to other flasks. Furthermore, the EoL represents 38.7 % of its total carbon footprint, the highest fraction among all flasks. Looking at the properties of the different flasks, we can see that this is related to the material density of the TPP 87600
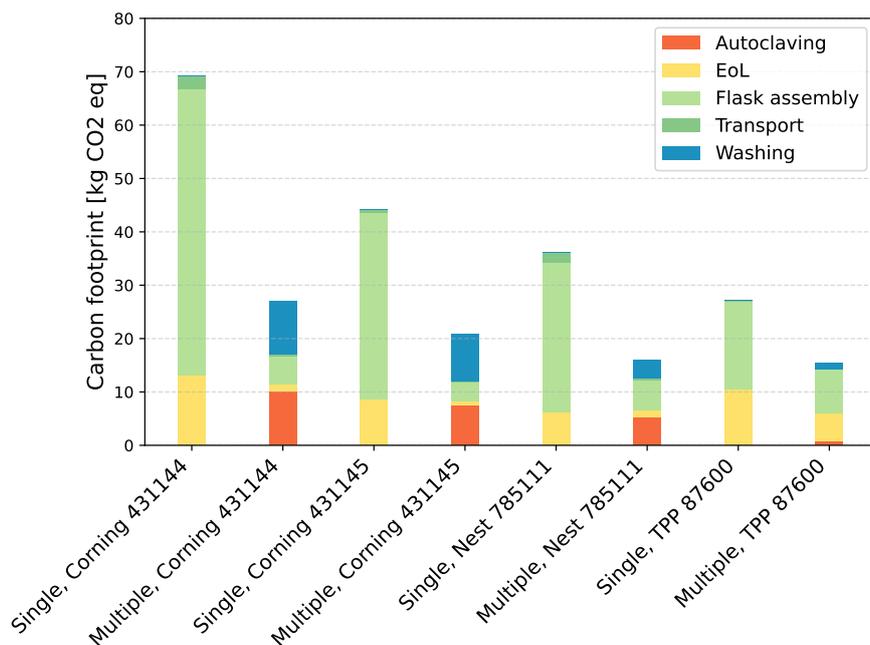
Figure 3: Carbon footprint by process category

(see Table 10). Because it has a higher material density than Corning 431145 and Nest 785111, there will be more material to incinerate for the same volume based on the functional unit.

Also note that because the body material of the TPP flask differs from that of the others (PE instead of PC), its footprint for production and assembly is lower, making it overall better for single use for this damage category. For instance for the Single use Nest 785111 the total results for the "market for polycarbonate — polycarbonate — Cutoff, S" in the body production amount to 20.88 [kg CO_2 eq.], while for the TPP 87600 the "market for polypropylene, granulate — polypropylene, granulate — Cutoff, S" process in the body production is 9.38 [kg CO_2 eq.], less than half of the production impact.

Table 10: Mass volume and densities of the different flasks

Flask	Total mass [g]	Volume [L]	Density [g/L]
Corning 431144	57.3	0.25	229.2
Corning 431145	75	0.5	150
Nest 785111	222.7	2	111.35
TPP 87600	110.7	0.6	184.5

7.1.2 Fossil and nuclear energy use

The contribution for each process category are displayed in Fig. 4.

Upon examination of the results, one can see that the TPP 87600 flask has a surprisingly large impact due to the production and assembly steps. The multiple use case is especially important in this impact category relatively to its role in the other categories. Similarly to its carbon footprint, this is due to the difference in material. For single use, the TPP 87600 has an impact of 337 [MJ deprived], in contrast to the 283.3 of the Nest 78111 flask ("market for polypropylene, granulate — polypropylene, granulate — Cutoff, S" and "market for polycarbonate — polycarbonate — Cutoff, S" processes). This impact catergory is also the only one for which both TPP use cases rank second worse among all options. In fact, multiple use of
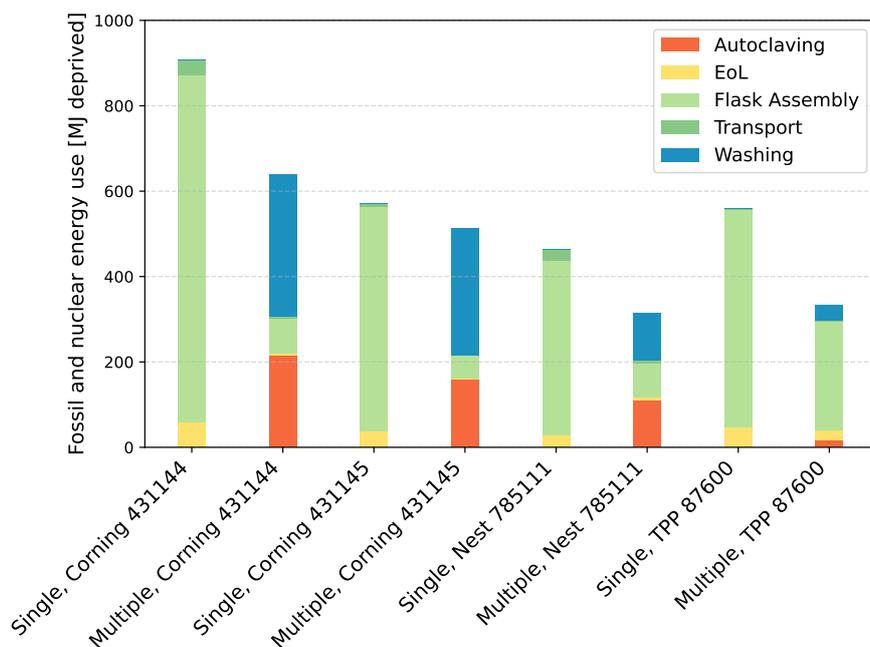
Figure 4: Fossil and nuclear energy use by process category

Corning 431145 and Nest 785111 is better than single use of TPP, with Nest 785111 being the least energy intensive overall.

Despite this, the Single-use TPP 87600 flask still outperforms the multiple use of the Corning 431144 flask. This is because the washing and autoclaving processes require energy outweighing that required for the production of the TPP87600 flask. The impact of changing the energy source, away from fossil and nuclear, will be investigated in the sensitivity analysis section.

7.1.3   Remaining Ecosystem quality damage

The contribution for each process category are displayed in Fig. 5.

Unlike the other impact categories, transport plays a significant role for the remaining ecosystem quality damages. Notably, it represents 13% of the impact contribution of the Corning 431144 flask (single-use), and even 16% of that of the Nest 785111 (single-use). Note that the Swiss-sourced TPP flask is not significantly affected by transport related impacts. Also note that the effect of transport is distributed over each use when using the flask multiple times and is thus negligible for the multiple-use cases of all flasks.

Again, as expected, washing and autoclaving are almost the sole contributors to the impact related to the multiple-use scenarios (except for TPP that is reused only once). This is due to the pollution of the water during the cleaning stages, which is showcased by the relative importance of freshwater ecotoxicity for the multiple-use scenario as described in Fig. 6 (roughly 30% of damage contribution for multiple-use, except TPP which is reused only once).

7.1.4   Remaining Human health damage

The contribution for each process category are displayed in Fig. 7. Furthermore, the relative midpoint impact categories for human health are shown in Fig. 8.

Fig. 8 shows that a lot of the impact on human health for the multiple use of the flasks comes from the water availability, which is in the 30 to 50 % range, depending on the flask. Similarly, for the single use cases, the long term climate change impact plays a significant role, representing almost 50 % of the impact.
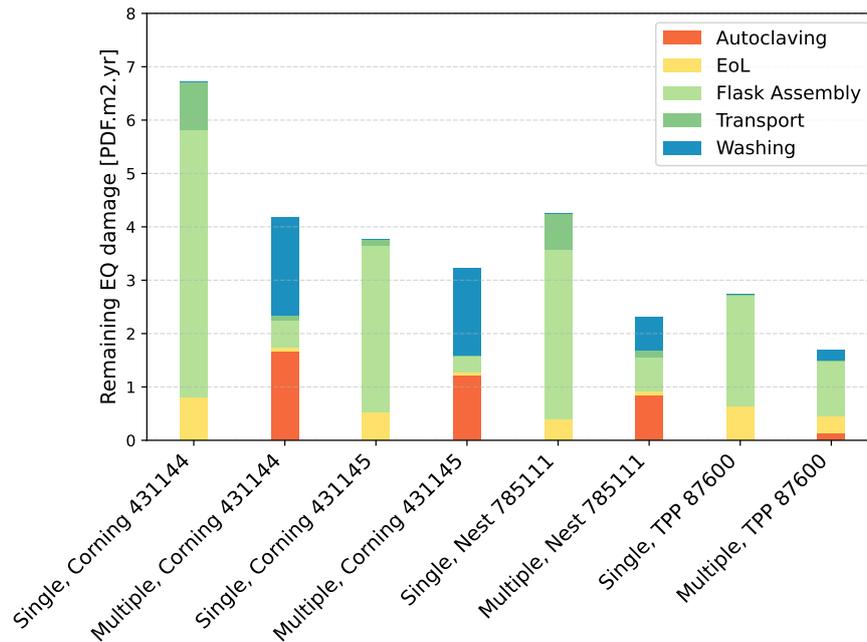
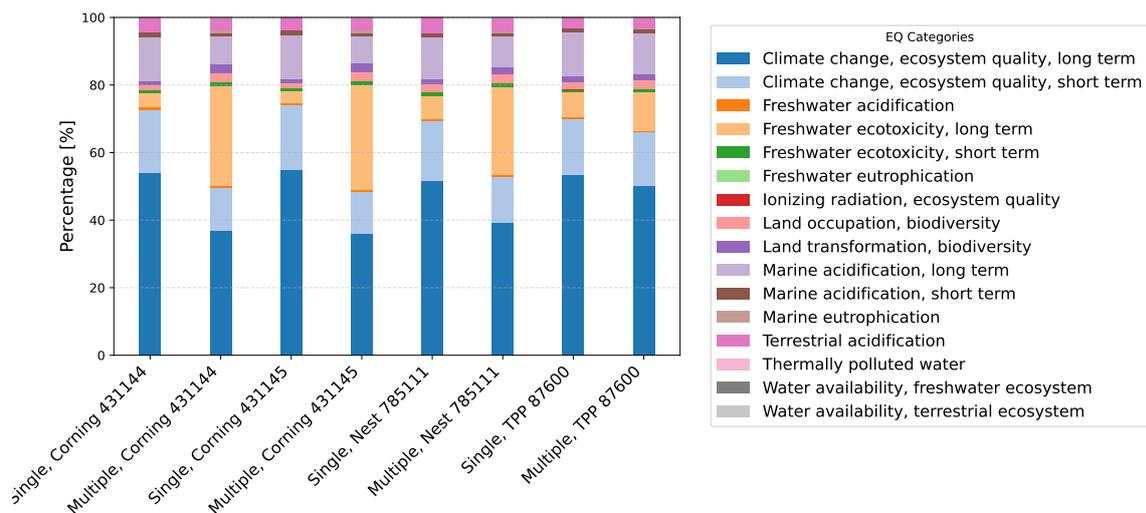Figure 5: Remaining Ecosystem quality damage by process category

Figure 6: LCIA Damage EQ

Similarly to other damage categories (e.g fossil and nuclear energy use), we see that using of the Corning 431144 flask multiple times is only significantly better when compared to the Single use of the same flask. It slightly improves compared to the single use of the Corning 431145, but both single and multiple use of the other flasks outperform it with respect to this indicator.

7.1.5 Water scarcity footprint

The contribution for each process category are displayed in Figure9.

As it could be expected the impact on water scarsity is higher for the product systems that require Autoclaving and washing (e.g. multiple use). In particular, with respect of this damage category, the multiple use of the Corning 431144 and 431145 should be avoided as it impacts are more than twofold compared to the worst-performing single use flask. However, the multiple
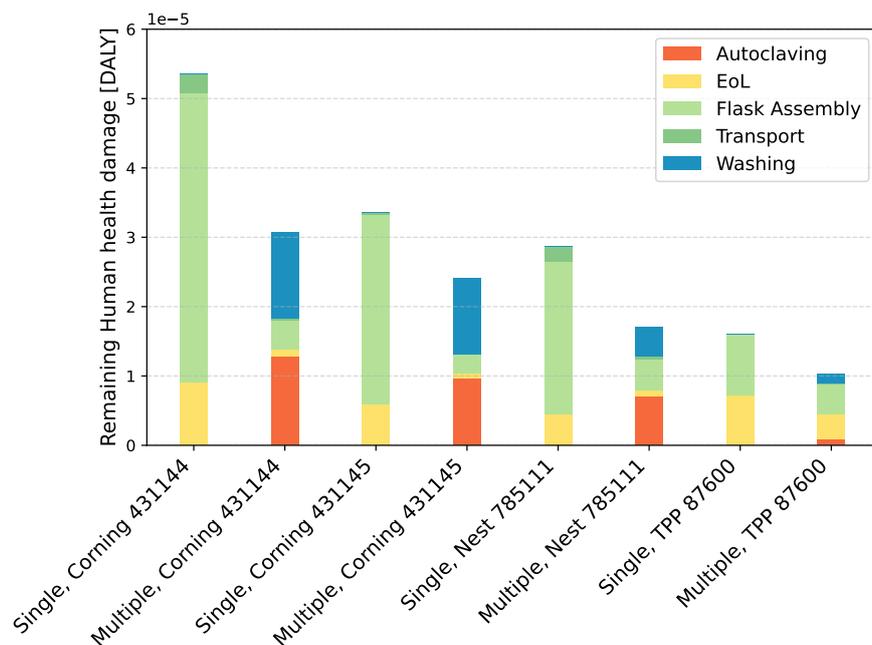
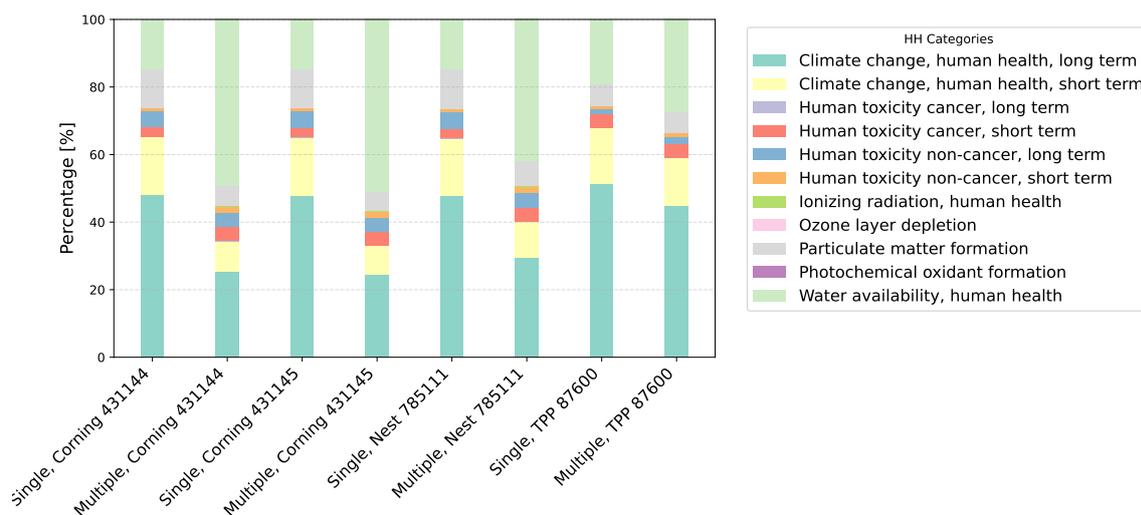Figure 7: Remaining Human health damage by process category

Figure 8: LCIA Damage HH

use of the Nest 78511 is comparable with the single use of the Corning 431144 flask, so it is a viable option, if one considers the other damage impact categories.

Finally, and more interestingly, the multiple use of the TPP 87600 has an impact comparable,and slightly lower, than all the single-use flasks. This goes to show that the improvement (reduction in Assembly and EoL impacts) due to the reusing of the flask is compensated by the increased use of water that is a consequence of the washing and Autoclaving processes. A potential improvement to minimize use of water could be to improve the fill factor of the machine. This path will be explored in the sensitivity analysis
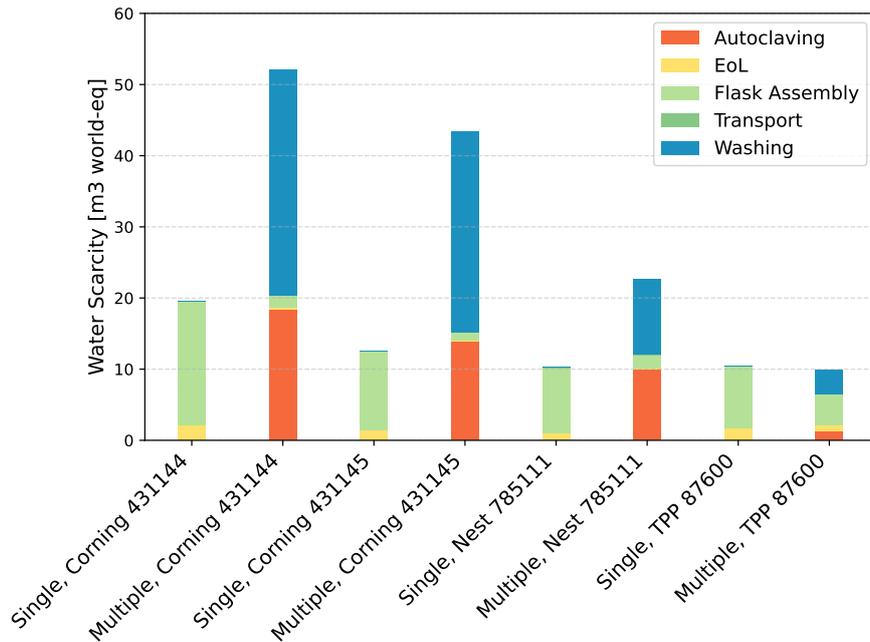
Figure 9: Water scarcity footprint by process category

7.2 Impact contribution analysis of Processes

7.2.1 Carbon footprint

7.2.2 Fossil and nuclear energy use

7.2.3 Remaining Ecosystem quality damage

7.2.4 Remaining Human health damage

7.2.5 Water scarcity footprint

8 Sensitivity Analysis

8.1 Scenario Analyses - PV vs Baseline Scenario

With increasing emphasis on global sustainability goals, laboratories are under growing scrutiny for their environmental performance, particularly regarding energy use. Solar photovoltaic (PV) energy has emerged as a key solution for laboratory sustainability as it provides a low-carbon, renewable alternative to conventional electricity. By integrating PV energy, laboratories can significantly reduce their environmental burden during operations. This study compares a **PV scenario** with a **baseline scenario** to assess potential improvements.

PV electricity generates significantly lower carbon emissions during production compared to traditional grid electricity, particularly in regions reliant on fossil fuels. Replacing grid electricity during cleaning and sterilization processes can effectively reduce the system's carbon footprint. Fossil and nuclear energy consumption, which are major contributors to environmental impacts in the baseline scenario, are also significantly reduced by introducing PV energy. Additionally, PV energy has lower water consumption compared to grid electricity, which relies heavily on water for cooling during power generation. Given that EPFL already operates its own PV power system, the adoption of solar energy is technically feasible and aligns with EPFL's long-term campus sustainability goals.

8.1.1 Scenario Setup

In the baseline scenario, electricity for the cleaning and sterilization stages is sourced from the market grid electricity, represented by the flow *"market for electricity, low voltage."* In the PV scenario, the electricity source is replaced by PV power, using the flow *"electricity production, photovoltaic, 3kWp slanted-roof installation, ribbon-Si, panel, mounted."*

To evaluate the environmental impacts of these scenarios, we applied the **IMPACT World+ method** within the life cycle assessment framework. This method provides a comprehensive evaluation across multiple impact categories, including climate change, fossil and nuclear energy use, ecosystem quality, human health damage, and water scarcity. The analysis specifically focuses on the Corning 431144 Erlenmeyer flask during the cleaning and sterilization stages. This flask serves as the functional unit (FU) for comparing environmental impacts between the baseline and PV scenarios.
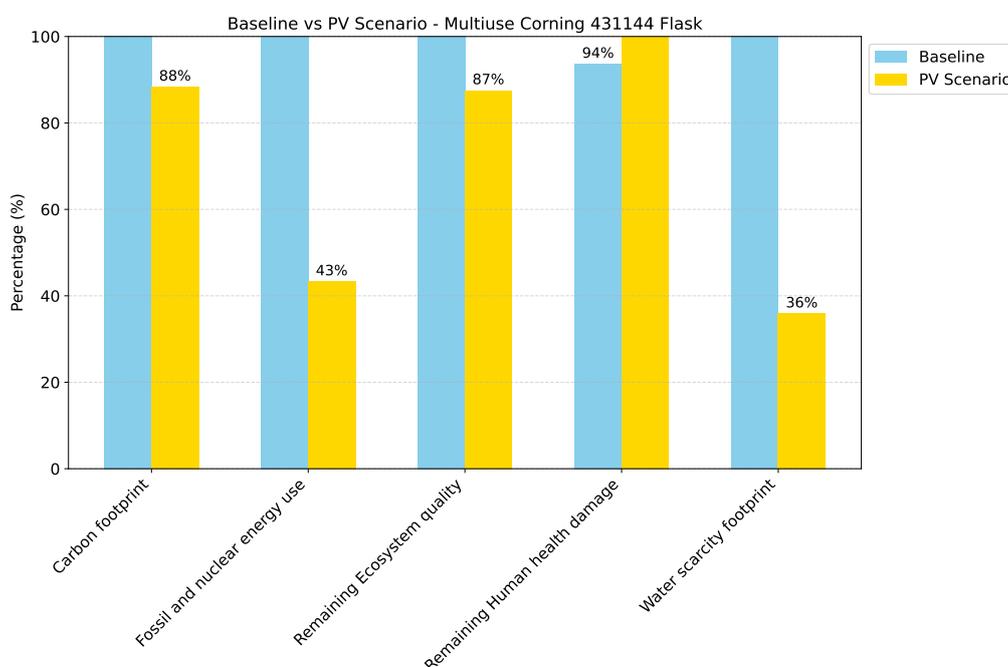
8.1.2 Results Analysis

Figure 10: Comparison of Baseline and PV Scenarios

The carbon footprint in the baseline scenario is **27.00 kg CO$_2$-eq**, while in the PV scenario, it is reduced to **23.84 kg CO$_2$-eq**, a decrease of approximately 12%. The life-cycle carbon emissions of PV electricity are significantly lower than conventional grid electricity.

Fossil and nuclear energy consumption drops from **639.42 MJ deprived** in the baseline scenario to **276.49 MJ deprived** in the PV scenario, a reduction of 57%. The use of PV power effectively reduces dependence on non-renewable energy sources.

For ecosystem quality, the baseline scenario measures **4.18 PDF·m^2·yr**, while the PV scenario reduces this to **3.66 PDF·m^2·yr**, an approximate 13% decrease. This demonstrates that PV energy has a smaller impact on ecosystem damage compared to grid electricity.

Human health damage, expressed in **DALY**, increases slightly from **3.06E-05** in the baseline to **3.27E-05** in the PV scenario, an increase of approximately 7%. This small rise is likely due to the resource extraction and manufacturing processes involved in PV electricity production. However, the overall impact remains minimal and acceptable.

Water scarcity footprint is significantly improved, with the baseline scenario measuring **52.13 m³ world-eq** and the PV scenario reducing this to **18.67 m³ world-eq**, a 64% decrease. PV electricity requires significantly less water compared to conventional grid power, particularly in cooling processes during generation.

The PV scenario demonstrates clear environmental advantages by reducing the carbon footprint, fossil and nuclear energy consumption, and water scarcity impacts. Although human health damage increases slightly, the magnitude of change is minimal and acceptable. With EPFL's existing PV infrastructure, the transition to PV electricity is both technically feasible and aligns with the institution's sustainability strategy. This shift can significantly contribute to reducing the environmental burden of laboratory operations.
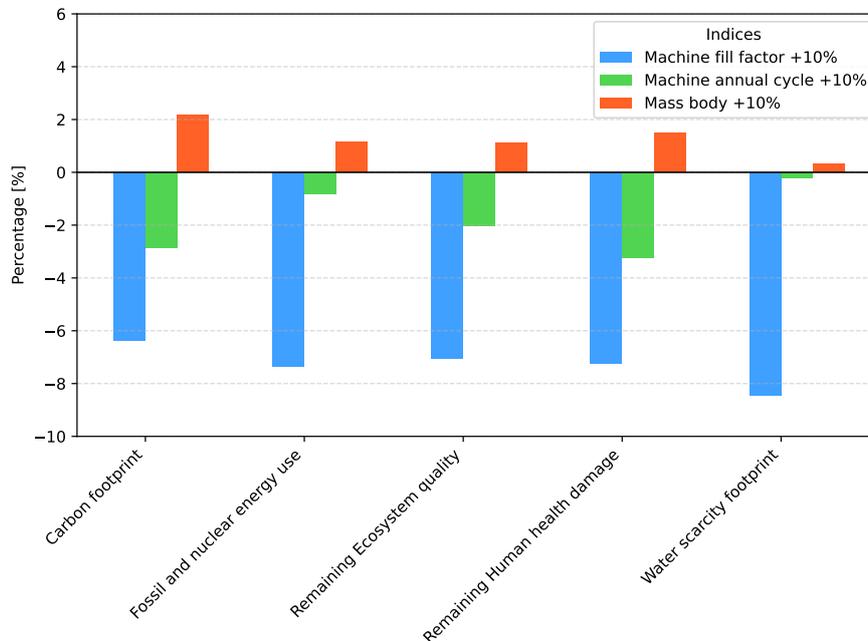

Figure 11: Sensitivity Analysis

9   Uncertainties and limits of the study

9.1   Uncertainties and limitations

9.2   Data quality

10   Recommendations

11   Conclusion

In this report, the goals and scope for the LCA have been defined. The LCA study will serve as a decision making tool for the SV-PTPSP lab regarding the environmental impacts of single

use flasks, compared to reusable ones after autoclaving. For this LCA, the functional unit has been set as the number of flasks required to process 25 liters of a specific cell culture medium at EPFL PTPSP in 2024. The analysis focuses on the Corning 431144 flask (250 mL), requiring 100 experiments to reach the total volume defined by the functional unit. From this basis, the system boundaries and the process trees have been defined, detailing included and excluded processes, End-of-life treatment and other relevant parameters/assumptions. Then, the key parameters and related reference flows for the analysis have been determined.

This intermediate reports also presents the available data sources available and required to perform the complete assessment, providing the foundation for the final report containing the full LCA results.

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A   Appendix: Calculations

A.1   Flask Production Flow Calculations

A.1.1   Single-Use Scenario (100 flasks per FU)

1. **PP for Cap Production**:

$$\text{PP mass for cap production (single-use)} = \left(\frac{100 \text{ caps}}{\text{FU}}\right) \cdot 8.3 \text{ g/cap} = 830 \text{ g/FU}$$

2. **PC for Body Production**:

$$\text{PC mass for body production (single-use)} = \left(\frac{100 \text{ bodies}}{\text{FU}}\right) \cdot 49 \text{ g/body} = 4900 \text{ g/FU}$$

3. **Electricity for Bag Sealing**:

$$\text{Electricity for bag sealing (single-use)} = \left(\frac{100 \text{ items}}{\text{FU}}\right) \cdot 0.025 \text{ kWh/item} = 2.5 \text{ kWh/FU}$$

4. **Box Production** (Calculation of Cardboard Mass for 50 Flasks):

   - **Box Dimensions**: 40 cm (length) x 30 cm (width) x 25 cm (height)

   - **Thickness**: 0.3 cm

   - **Density**: 700 kg/m³

   - **Surface Area**:

$$2 \times (40 \times 30 + 40 \times 25 + 30 \times 25) = 5900 \,\text{cm}^2 = 0.59 \,\text{m}^2$$

   - **Volume**:
$$0.59 \,\text{m}^2 \times 0.003 \,\text{m} = 0.00177 \,\text{m}^3$$

   - **Mass**:
$$0.00177 \,\text{m}^3 \times 700 \,\text{kg/m}^3 = 1.239 \,\text{kg}$$

   - **Mass of Cardboard for Single-Use**:

$$\text{Cardboard box mass (single-use)} = \left(\frac{2 \text{ boxes}}{\text{FU}}\right) \cdot 1.239 \,\text{kg/box} = 2.478 \,\text{kg/FU}$$

5. **Bag Production for Packaging** (Calculation of Packaging Material Density):

   - **Total Bag Mass** (based on measured weight): Assume a total bag mass of 3.77 g for a small bag.

   - **Bag Area**: For a bag with a length of 20 cm and width of 16 cm:

$$\text{Area} = 20 \times 16 = 320 \,\text{cm}^2$$

   - **Density per Unit Area**:

$$\text{Density per unit area} = \frac{\text{Bag Mass}}{\text{Bag Area}} = \frac{3.77 \,\text{g}}{320 \,\text{cm}^2} = 0.011805 \,\text{g/cm}^2$$

- **Total Mass for Packaging per Flask**:

$$126 \, \text{cm}^2 \times 0.011805 \, \text{g/cm}^2 = 1.487 \, \text{g}$$

- **Paper (50%)**:

$$1.487 \, \text{g} \times 0.5 = 0.7435 \, \text{g}$$

- **HDPE (50%)**:

$$1.487 \, \text{g} \times 0.5 = 0.7435 \, \text{g}$$

- **Total Bag Material for 100 Flasks**:
  - **Paper**: $100 \times 0.7435 = 74.35 \, \text{g/FU}$
  - **HDPE**: $100 \times 0.7435 = 74.35 \, \text{g/FU}$

6. **Distribution (Transportation)**:

$$\left[\frac{5.73 \, \text{kg} + 2.478 \, \text{kg (box)} + 0.1487 \, \text{kg (bags)}}{\text{FU}} \cdot \frac{1 \, \text{t}}{1000 \, \text{kg}} \right]$$

$$\cdot \left[0.8 \times (21,588.21 + 681.93 + 61) + 0.2 \times (7,098.78 + 61) + 11.5 \right] \, \text{km}$$

- Calculated Value:

$$0.0083567 \, \text{t/FU} \cdot 19,308.368 \, \text{km} = 161.43 \, \text{tkm/FU}$$

A.1.2 Multiple-Use Scenario (10 flasks per FU)

1. **PP for Cap Production**:

$$\text{PP mass for cap production (multiple-use)} = \left(\frac{10 \text{ caps}}{\text{FU}} \right) \cdot 8.3 \text{ g/cap} = 83 \text{ g/FU}$$

2. **PC for Body Production**:

$$\text{PC mass for body production (multiple-use)} = \left(\frac{10 \text{ bodies}}{\text{FU}} \right) \cdot 49 \text{ g/body} = 490 \text{ g/FU}$$

3. **Electricity for Bag Sealing**:

$$\text{Electricity for bag sealing (multiple-use)} = \left(\frac{10 \text{ items}}{\text{FU}} \right) \cdot 0.025 \text{ kWh/item} = 0.25 \text{ kWh/FU}$$

4. **Box Production**:

$$\text{Cardboard box mass (multiple-use)} = \left(\frac{1}{5} \text{ box/FU} \right) \cdot 1.239 \, \text{kg/box} = 0.2478 \, \text{kg/FU}$$

5. **Bag Production for Packaging**: - Since each flask is re-bagged after each sterilization, we need **100 bags per FU**.
- Total Mass for Packaging per Flask:

$$1.487 \, \text{g}$$

- Paper (50%):

$$0.7435 \, \text{g}$$

- HDPE (50%):

$$0.7435\,\text{g}$$

- **Total Bag Material for 100 Bags**: Assuming each re-bag is constructed from the same materials as the original packaging and transported from China to the lab in Switzerland, the distribution calculation requires modification to account for the transportation of these additional bags.

- **Paper**: $100 \times 0.7435 = 74.35\,\text{g/FU}$

- **HDPE**: $100 \times 0.7435 = 74.35\,\text{g/FU}$

6. **Distribution (Transportation)**: - Calculation:

$$\left[\frac{0.573\,\text{kg} + 0.2478\,\text{kg (box)} + 1.487\,\text{kg (bags)}}{\text{FU}} \cdot \frac{1\,\text{t}}{1000\,\text{kg}} \right]$$

$$\cdot 19{,}308.368\,\text{km} = 44.58\,\text{tkm/FU}$$

A.2   Calculations for Washer and Autoclave Resource Usage

With the new per-cycle capacities for washing and sterilization, the resource allocation for each functional unit (FU) can be recalculated.

A.2.1   Multiple-Use Flask Requirement

- **Functional Unit (FU)**: 10 flasks per FU, with each flask reused 10 times (100 experiments per FU).

- **Washer (32 flasks per cycle)**: Each washing cycle can handle 32 flasks, so 1 cycle can cover 3.2 FUs.

- **Autoclave (28 flasks per cycle)**: Each sterilization cycle can handle 28 flasks, so 1 cycle can cover 2.8 FUs.

Thus, to clean and sterilize 10 flasks per FU:

- Washing cycles required per FU: $\dfrac{10}{32} = 0.3125$ cycles/FU

- Sterilization cycles required per FU: $\dfrac{10}{28} = 0.3571$ cycles/FU

A.2.2   Resource Allocation Per FU

Using the above cycle requirements, we can allocate resources for washing and sterilizing each FU as follows:

1. **Electricity for Washing**:

$$\text{Electricity per FU} = 0.3125\,\text{cycles/FU} \times 10\,\text{kWh/cycle} = 3.125\,\text{kWh/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 3.125\,\text{kWh/FU} \times 0.3 = 0.9375\,\text{kWh/FU}$$

2. **Tap Water for Washing**:

$$\text{Tap Water per FU} = 0.3125 \,\text{cycles/FU} \times 100 \,\text{L/cycle} = 31.25 \,\text{L/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 31.25 \,\text{L/FU} \times 0.3 = 9.375 \,\text{L/FU}$$

3. **Deionized Water for Washing**:

$$\text{Deionized Water per FU} = 0.3125 \,\text{cycles/FU} \times 30 \,\text{L/cycle} = 9.375 \,\text{L/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 9.375 \,\text{L/FU} \times 0.3 = 2.8125 \,\text{L/FU}$$

4. **Electricity for Autoclaving**:

$$\text{Electricity per FU} = 0.3571 \,\text{cycles/FU} \times 4 \,\text{kWh/cycle} = 1.4284 \,\text{kWh/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 1.4284 \,\text{kWh/FU} \times 0.3 = 0.4285 \,\text{kWh/FU}$$

5. **Tap Water for Autoclaving**:

$$\text{Tap Water per FU} = 0.3571 \,\text{cycles/FU} \times 65 \,\text{L/cycle} = 23.214 \,\text{L/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 23.214 \,\text{L/FU} \times 0.3 = 6.9642 \,\text{L/FU}$$

6. **Deionized Water for Autoclaving**:

$$\text{Deionized Water per FU} = 0.3571 \,\text{cycles/FU} \times 30 \,\text{L/cycle} = 10.713 \,\text{L/FU}$$

Allocated to PTPSP:

$$\text{PTPSP Allocation} = 10.713 \,\text{L/FU} \times 0.3 = 3.2139 \,\text{L/FU}$$

A.3 Machine Resource Consumption Per Cleaning and Sterilization Cycle

1. **Machine Service Life**:

- Each machine (washer and autoclave) operates for **20 years**, with an estimated **250 cycles per year**.

- **Total operational cycles over 20 years**:

$$20 \,\text{years} \times 250 \,\text{cycles/year} = 5000 \,\text{cycles}$$

- This is the total cycle capacity for each machine over its service life.

2. **PTPSP Allocation**:

- PTPSP utilizes **30% of the total service life** for both the washer and autoclave.

- Therefore, the effective cycle allocation for PTPSP over 20 years is:

$$5000\,\text{cycles} \times 0.3 = 1500\,\text{cycles}$$

- This means that PTPSP has access to 1500 cycles on each machine over its service life.

3. **Cycle Requirements per FU**:

- For each functional unit (FU) in the multiple-use scenario:

    - **Washer cycles per FU**:

$$\text{Washer cycles per FU} = \frac{10\,\text{flasks/FU}}{32\,\text{flasks/cycle}} = 0.3125\,\text{cycles/FU}$$

    - **Autoclave cycles per FU**:

$$\text{Autoclave cycles per FU} = \frac{10\,\text{flasks/FU}}{28\,\text{flasks/cycle}} = 0.3571\,\text{cycles/FU}$$

4. **PTPSP Utilization per FU**:

- Given PTPSP only uses 30% of each machine's total cycles, we calculate the **PTPSP-specific cycle usage per FU**:

    - **Washer utilization per FU**:

$$\text{Washer utilization per FU} = 0.3125\,\text{cycles/FU} \times 0.3 = 0.09375\,\text{cycles/FU}$$

    - **Autoclave utilization per FU**:

$$\text{Autoclave utilization per FU} = 0.3571\,\text{cycles/FU} \times 0.3 = 0.1071\,\text{cycles/FU}$$

5. **Percentage of Service Life Used per FU**:

- To determine the contribution of each FU to the total service life (in percentage terms), we divide the PTPSP-specific cycle usage per FU by the total PTPSP cycle allocation:

    - **Washer**:

$$\% \text{ of Washer service life per FU} = \frac{0.09375\,\text{cycles/FU}}{1500\,\text{cycles}} \times 100 = 0.00625\%\,\text{life/FU}$$

    - **Autoclave**:

$$\% \text{ of Autoclave service life per FU} = \frac{0.1071\,\text{cycles/FU}}{1500\,\text{cycles}} \times 100 = 0.00714\%\,\text{life/FU}$$