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Comparative life cycle assessment of reusable and single use take-away lunch boxes used in student restaurants

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ABSTRACT

Student restaurants at Chalmers University have adopted take-away lunch boxes as a convenient dining option for students with disposable single-use containers being the norm. However, there is a growing interest in more sustainable, reusable alternatives. This study conducted a comparative Life Cycle Assessment (LCA) to assess the potential environmental and economic impacts of using reusable lunch boxes in comparison to disposable ones, considering 18 environmental impact categories. The functional unit chosen for evaluation was the provision of takeaway lunches to Chalmers students over the course of a year. The findings revealed that reusable boxes with 20 uses outperformed their disposable counterparts in many environmental impacts, reducing the climate change impact by 59%. However, water and energy consumption were higher for the reusable option by 99% and 62% respectively, primarily due to the cleaning process. From an economic perspective, reusable boxes proved to be 3.3% more costly than disposable ones. In conclusion, this study highlights the benefits of reusable solutions, showing reductions in various environmental footprints but presenting slightly higher economic footprints over 20 uses. However, as the number of uses increases, the advantages also increase, leading to recommendations for better management of the lunch boxes to maximize their reusable potential.

1. Introduction

Student restaurants at Chalmers University provide a wide array of dining options, serving students, faculty, and visitors alike (Chalmers Konferens, 2023). While dine-in experiences were once the norm, the fast-paced nature of modern life, filled with time constraints, busy schedules, online meetings, lunch seminars, and the allure of convenience, has prompted a shift toward take-away solutions (Dorn and Stöckli, 2018; van der Horst et al., 2011). Consequently, disposable take-away lunch boxes have become commonplace. However, an increasingly prevalent trend in student restaurants is the exploration of reusable alternatives, driven by sustainability standards that advocate for the adoption of environmentally friendly products, in line with sustainable development goals (Aarnio and Hämäläinen, 2008; MacKerron and Hoover, 2015; Mason et al., 2004).

In the year 2023, a significant transformation occurred at Chalmers as new reusable lunch boxes were introduced, effectively replacing single-use plastic containers for take-away food. Chalmers University, home to a thriving community of over 10,000 students, benefits from the active stewardship of its student union, which oversees the management of most on-campus restaurants (Chalmers Studentkår, 2023a; *Chalmers University of Technology*, 2023). These operations fall under the purview of “Chalmers Konferens & Restauranger,” a company within the “Chalmers Studentkårs Företagsgrupp" corporate group, wholly owned by the Chalmers Student Union (*Chalmers Studentkår*, 2023a). Their presence extends across Chalmers campus Johanneberg, Lindholmen Science Park, and Universeum, where they oversee a diverse array of restaurants, café, and service units, including two conference centers. The profits generated are reinvested into student welfare, enhancing their daily lives through access to affordable, wholesome meals, an extensive range of services, and a multitude of on-campus activities.

The lunch boxes in student restaurants carry a substantial responsibility for overall student union global greenhouse gas emissions and contribute significantly to plastic waste, largely attributable to non-reusability of these lunch boxes (Aarnio and Hämäläinen, 2008). The handling and disposal of food containers also entail environmental consequences (Marsh and Bugusu, 2007). Therefore, ensuring the sustainability of these lunch boxes becomes paramount in mitigating the environmental impact associated with student restaurants (Gallego-Schmid et al., 2019).

This initiative at Chalmers has historical roots and aligns seamlessly with Gothenburg’s overarching promotion of circular economy

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principles, placing a strong emphasis on reuse and recycling to foster sustainability in all facets of life (Circular Gothenburg, 2021; Rask, 2022). The concept of substituting disposable plastic containers with reusable alternatives for take-away meals emerged in this context (Göteborg and Co, 2023; The Mayor.eu, 2023). Initially, it underwent testing and pilot runs from 2019 to 2021 at Lindholmen, supported by private restaurant proprietors and the City of Gothenburg (Chalmers Studentkår, 2023b). Demonstrating practicality and effectiveness, it naturally gained traction among Chalmers students. Subsequently, the idea made its way to the Student Union Council, the governing body responsible for student-related affairs and restaurant management, leading to its implementation in 2023 (Union council - Chalmers Studentkår, 2023).

Given this backdrop, it becomes essential to comprehensively evaluate the life cycle environmental impacts of both disposable and reusable take-away lunch boxes, commonly employed in student restaurants. Life Cycle Assessment (LCA), following ISO standards 14040/44, offers a holistic methodology to quantify the potential environmental impacts of a product or service throughout its lifecycle (ISO, 2006a, 2006b). While LCA has seen extensive use in evaluating environmental impacts across various sectors, its application in restaurant contexts has been somewhat limited. Nonetheless, it has been identified as the most suitable tool for assessing the environmental implications of plastic reuse and recycling (Kousemaker et al., 2021).

While several LCA studies in restaurant settings have compared single-use materials to equivalent reusable options, with reusable choices typically demonstrating superior environmental performance, the focus has largely centered on food packaging materials (Accorsi et al., 2022; Fetner and Miller, 2021; Gallego-Schmid et al., 2019; Potting and van der Harst, 2015; Woods and Bakshi, 2014). Custom packs, containing numerous disposables take-away lunch boxes, have been a prevalent choice in student restaurants, but they lack reusability. Existing research suggests that reusable alternatives can significantly diminish environmental impacts compared to the conventional practice of using disposable single-use lunch boxes, with variations influenced by energy considerations.

This pioneering study stands as one of the comprehensive LCA endeavor to compare Sweden's reusable and disposable take-away lunch boxes in student restaurants. Its specific focus lies on lunch boxes predominantly utilized by students. The research unfolds in collaboration with student restaurants managed by Chalmers Student Union, as well as providers and manufacturers of reusable boxes. The core objectives encompass an evaluation of the potential environmental and economic impact of reusable take-away lunch boxes in contrast to their disposable single-use counterparts, which remain the prevailing choice in student restaurants at Chalmers, Sweden. Additionally, the study seeks to identify key contributors and critical environmental impacts while conducting sensitivity analysis encompassing varying energy considerations, end of life management, and diverse usage frequencies of reusable boxes.

2. Methods

LCA serves as a valuable tool for comprehensively evaluating the environmental impact of products and services. It enables the quantification of environmental consequences over the entire life cycle of a product or service, drawing on specific data obtained from clients, suppliers, and users. This data encompasses aspects such as consumption patterns, materials, energy usage, emissions, and waste generation. The LCA process adheres to established standards, with ISO 14040 and ISO 14044 providing a robust framework for LCA methodology (ISO, 2006a, 2006b). In line with these norms, this study follows the four key stages of LCA. Sections 2.1, 2.3, and 2.4 delve into the initial three stages, encompassing goal and scope definition, life cycle inventory, and life cycle impact assessment. Furthermore, Section 3 delves into the fourth stage of LCA, which involves interpreting the results.

2.1. Scope of the study and associated system boundaries

This study delves into the evaluation of two distinct take-away lunch box systems: reusable and single-use. Take-away lunch boxes are containers made from various materials like paper, plastic, metal, or hybrid compositions. The choice of these lunch boxes within Student restaurants primarily hinges on considerations of cost-effectiveness, sustainability, and user-friendliness. The systems under examination encompass the provision of daily take-away lunch boxes, be they reusable or disposable, and are considered equally in terms of service delivery. Both systems are currently operational within Student restaurants.

To facilitate a comprehensive comparison, this study establishes a functional unit (FU) focusing on providing takeaway lunches to students over the span of one year. This reference accounts for 200 working days, with an average of 610 takeaway orders daily, a total of 122,000 orders throughout the year. This approach enables a thorough assessment of the environmental impacts associated with these lunch box systems in the specified context. The reference flow represents the number of take-away lunch boxes required to fulfill the FU description, based on the actual lifespan of each lunch box.

A critical aspect involves determining the effective number of uses for reusable boxes, considering both structural durability and aesthetic appeal. Structural integrity is imperative to prevent breakage over time. Simultaneously, the box must maintain a visually appealing condition, as distinguishing between new and old boxes can be challenging, particularly for non-student customers. This study, based on expert opinion, considered that a box can withstand 20 uses. However, the sensitivity analysis also considered 200 uses based on student feedback. Nonetheless, the reusable box could potentially withstand up to 800 uses, depending on its structural strength and appearance. Regarding return rates, communication with restaurant management indicates an anticipated return rate of 95% annually among students. It is worth noting that this study considered a minimal rate of box breakage, accounting for within 5% of boxes not returned, which may include damaged or broken units. Also, in terms of the capacity of the reusable boxes to serve food throughout the year, restaurant owners are confident that the reusable boxes can meet this need. The reusable boxes have a volume of 1050 ml, which is the same as the single-use lunch boxes (17.5*12*5 cm) used in the past. Although the daily quantity of meals may vary throughout the year, the capacity of the reusable boxes can accommodate these changes. This ensures that there will be no need to switch to larger reusable boxes during any month of the year due to variations in the size of meals that the restaurant serves.

In the reusable system, 6421 take-away lunch boxes are needed, considering an average of 20 uses and a 95% return rate per year. In contrast, the disposable system necessitates 122,000 single-use take-away lunch boxes, with the assumption that each takeaway requires a new disposable box. This assumption aligns with interviews and personal communication conducted with restaurant operators, management teams, producers, and students. According to this feedback, students tend to consider disposable single-use lunch boxes strictly as single-use items, often discarding them even if they could be reused for other purposes. Also, in this study, the reusable boxes' return time is not considered because the useable life of the boxes depends on the number of uses, not on a fixed time period. This simply means that a box may not be returned within a reasonable time and may not be used 20 times in a year, but it does not mean it cannot be used next year. On average, a box is used 20 times, which means a box can be used over several years until it completes 20 uses on average. Some boxes may be used less and some more. However, with time, the material may degrade, and if the reusable box is less used and remains in storage, it may not have the structural integrity to be used for 20 uses. But since the boxes are made of materials with a long design life, the limitations on the number of uses of the boxes in different years are considered minimal.

Another assumption in this study is that the boxes, once bought, cannot be reused by the user for personal purposes because they are non-airtight and less suitable for multiple uses. Therefore, it is expected that users will return the reusable boxes rather than repurpose them for personal use. This means a box can be used 20 times, but if a user buys the box and does not return it, using it for personal use is expected to be limited. Additionally, there is an informal guideline from the restaurant owners advising against using the boxes for personal use. It is assumed that the average number of uses for a reusable box is only for restaurant food, not for personal use by the user. While such cases may happen, they are assumed to be limited and are not considered in this study.

In interviews with decision-makers, the operational system of the reusable option emerges. The reusable lunch boxes feature two distinct user categories: students, defined as members of the Student Union, and non-students, including guest faculty and others no longer affiliated with the Student Union. Students with a Student Union membership pay a fee and receive a card that facilitates payments for their lunches and other activities. This card allows them to purchase takeaway lunches along with a reusable lunch box, incurring a 1 kr deposit for the box. Upon returning the box, they receive a tag for future lunch purchases with the reusable lunch box at no extra charge. The deadline for box return is set at the end of the academic year, with failure to comply resulting in an 80 kr fee. Non-students are required to pay an additional 80 kr for the box, and these boxes are not subject to return.

The delineation of system boundaries serves to identify all relevant activities, life cycle stages, processes, and flows considered within LCA assessment. These boundaries align with the study's overarching goal and are organized into different life cycle stages, as shown in Fig. 1. The first stage encompasses raw materials and production, accounting for all energy and materials essential for take-away lunch box manufacturing and assembly, alongside associated emissions. The subsequent stage focuses on transport to Student restaurants, encompassing the logistics involved in moving the lunch boxes from the production site to their destination within the student restaurants. Notably, the use phase is exclusively considered for the reusable lunch boxes, incorporating evaluations of energy and material consumption and emissions during the cleaning process. Lastly, the end-of-life phase entails the transportation and waste treatment of the take-away lunch boxes once they reach the end of their operational life, ensuring an assessment of the complete product life cycle.

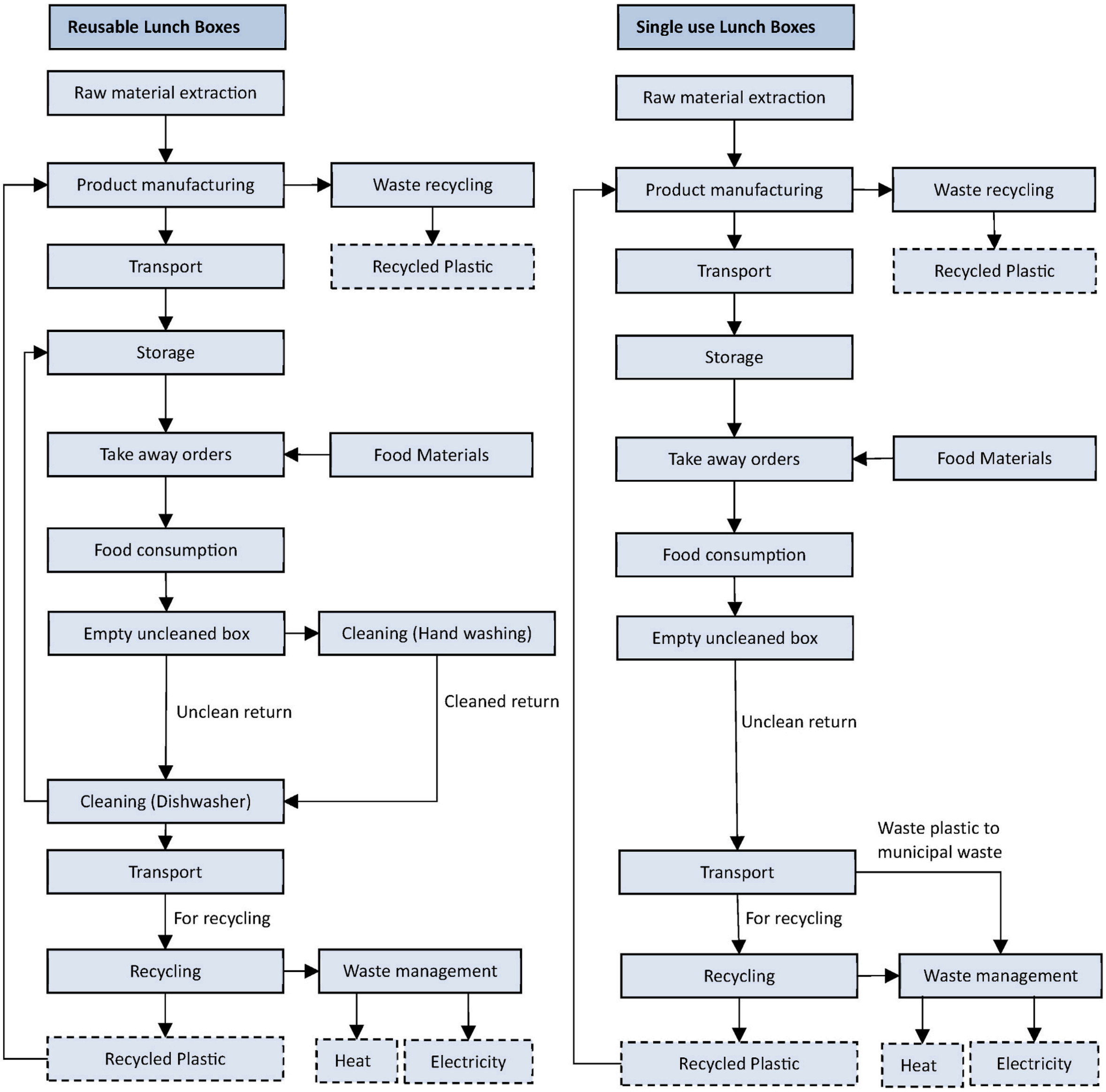

Fig. 1. Flow chart of reusable and single-use take-away lunch boxes systems.

2.2. Data collection

This study sourced data from a variety of channels. Primary data concerning reusable take-away lunch boxes were diligently gathered from student restaurants, their suppliers, and users. In contrast, primary data for disposable single-use take-away lunch boxes were largely derived from existing information within the restaurants and literature. Additionally, data validity was ensured through cross-referencing with available literature, product specifications, and empirical observations, including measurements like weight. For supplementary data, the internationally recognized Ecoinvent (v3.9) life cycle database was used, that is acceptable and reliable within the global scientific community. This research centers on the context of Student restaurants at Chalmers University in Sweden, with both reusable and disposable single-use take-away lunch boxes presumed to be manufactured in Malmö, Sweden. The cleaning processes integral to the reusable system are situated at Chalmers, Sweden. Data specific to the reusable system is based on the year 2023, while the disposable system draws upon data spanning 2021 to 2022. While the outcomes of this study are directly applicable to the use of take-away lunch boxes in Sweden, they can be extrapolated to other European nations by tailoring country-specific data, particularly with regard to variables like electricity and water use.

2.3. Life cycle inventory

Table 1 provides a comprehensive overview of the primary inventory data, structured per functional unit (FU), and includes data concerning both reusable and disposable single-use take-away lunch boxes throughout their entire life cycle. To calculate material and energy consumption, these values are multiplied by the reference flows associated with 122,000 takeaway orders, offering a precise assessment of resource utilization.

Diving into the life cycle stages, the raw material extraction and production phase details are as follows: the reusable boxes, offered as an eco-friendly alternative to single-use containers, are supplied by a Swedish company renowned for its sustainable practices. These boxes are designed, comprising one bowl and one lid, both dishwasher and microwave safe. Constructed from shatterproof, scratch-resistant bioplastic, they guarantee durability. This material exhibits a unique composition, comprising 15% biobased material sourced from sugarcane and certified European wood fiber waste, with the remaining 85% being oil-based Polypropylene. Each reusable box weighs approximately 0.226 kg and is considered to be manufactured in Malmö, Sweden, before being transported to Gothenburg. In contrast, the single-use boxes are assumed to be composed entirely of Polypropylene, featuring a similar configuration of one bowl and one lid, but with a significantly lower weight of 25 g each. For simplicity, it is considered that both reusable and single-use boxes undergo production in Sweden and are transported accordingly.

The use phase solely applies to the reusable system, introducing an additional cleaning step outlined in Fig. 2. The responsibility for this cleaning process falls on the restaurant, which utilizes a dishwasher in conjunction with traditional plates. This process entails water consumption, detergent usage, electricity consumption, and necessitates additional human resources. The cleaning procedure commences with the collection of lunch boxes, which are then segregated and placed on racks. Each rack can accommodate up to 10 boxes, encompassing both the box and its lid. Following this, the boxes undergo two critical phases. First, a pre-rinse phase is executed using the "Prerinse Mach. Curv. R-L Metos WD PRM90″ machine (Metos, 2023a). During this stage, water is internally heated for effective rinsing. Subsequently, the boxes proceed to the main cleaning phase employing the "Dishwasher Metos WD 211E L-R 400V3Ñ" machine (Metos, 2023b). This process incorporates internally heated water and "MASKINDISK KONC MILJÖ" detergent, available in 3 kg packets (Tingstad, 2023a). Finally, the boxes are dried utilizing another chemical, "TORKMEDEL PREMIUM MILJÖ," which is supplied in 10-L packets (Tingstad, 2023b). The inputs for this process include cold tap water, electricity for heating and pumping water, detergent for cleaning, and chemicals for drying. Wastewater generated in this process is treated by the municipal wastewater treatment system. The system has the capacity to clean up to 150 racks per hour, translating to 1500 boxes per hour. However, it is important to note that time is allocated for arranging the boxes on the racks. The entire process is estimated to take approximately 6.5 h per day to clean 610 boxes.

Furthermore, let's delve into the behavior of students utilizing reusable boxes. Given that the price differential between dining within the restaurant and opting for takeout is no longer a motivating factor, logistical considerations come to the forefront. Typically, when a student selects takeaway, they do not consume their meal within the restaurant premises. If they choose to carry the reusable box, it is common for them not to return it immediately. It is plausible that, while on their way home, a student might visit the restaurant to return the box and receive a tag enabling them to purchase another lunch with a reusable box at no additional cost. However, whether the return transpires on the same day or at a later point, it is vital to recognize that the box's lid is not airtight. Consequently, the box cannot be stored in a backpack without being cleaned. This cleaning might not entail a full wash but could involve a simple rinse to remove food residue, ensuring it does not affect other items within the bag. Therefore, it is reasonable to assume that students often clean the box before returning it. Nonetheless, according to restaurant policy, all returned boxes, irrespective of whether they have been cleaned by the students, are subjected to further cleaning by the restaurant. This occasionally results in double cleaning of the boxes. In this analysis, it is assumed that approximately 50% of the boxes undergo double cleaning, initially by the student and subsequently by the restaurant when they are returned. When students engage in the cleaning process, they typically use tap water in conjunction with detergent. Conversely, the restaurant adheres to the cleaning process described in this study.

Lastly, a critical aspect concerns the end-of-life of both reusable and single-use boxes. In the case of single-use boxes, they are commonly disposed of in the regular waste stream, which amalgamates various types of waste. In an ideal scenario, collecting them for plastic recycling could be a preferable option. However, this study operates on the assumption that 50% of the single-use boxes find their way into the regular waste stream, eventually undergoing incineration to generate heat and electricity, aligning with standard Swedish waste management practices (Finnveden et al., 2007; Holmgren and Henning, 2004; Ljunggren Söderman, 2003). The remaining 50% are assumed to be earmarked for recycling, with the recycling process taking place within Sweden. For reusable boxes, a distinct procedure applied in which these boxes are collected by the restaurant and subsequently returned to the company. Then, the collected reusable boxes undergo recycling to produce recyclable plastic. For this analysis, it is assumed that transportation takes place between Gothenburg and Malmö, where the company's recycling facilities are believed to be situated. As for the reusable boxes that go unreturned, they are presumed to undergo a recycling process similar to that of single use take way lunch boxes.

2.4. Life cycle impact assessment

Various recommended life cycle impact assessment methods were employed to comprehensively evaluate the environmental impacts, as outlined in Table 2 (European Commission, 2023; IPCC, 2023). This study encompassed a total of 18 distinct indicators, each selected to give a holistic comparative analysis encompassing diverse impacts. Notably, the choice of indicators was designed to offer a well-rounded assessment of various dimensions. Among these, special significance was attributed to the energy and water use indicator, given its intrinsic link to the cleaning process associated with reusable boxes, thereby accentuating its pivotal role in the analysis.

Table 1
Life cycle inventory data for reusable and single-use take-away lunch boxes systems.

Data	Unit	Value	Reusable lunch boxes system per year			Single-use lunch boxes system per year		
			Value per box	Value per FU	Source/Comment	Value per box	Value per FU	Source/Comment
General data								
Take away orders per day (2023)	–	610	610	610	Chalmers Studentkårs Företagsgrupp	610	610	Chalmers Studentkårs Företagsgrupp
Total student teaching days in a year	days	200	200	200	Teaching days average	200	200	Teaching days average
Total take-away orders per year	FU	122000	122000	122000	Calculations	122000	122000	Calculations
Box return rate in a year	%	–	–	95	Chalmers restaurants	0	0	Chalmers restaurants
Take away lunch box total mass	kg	–	0.226	1451.2	Lunch boxes supplier	0.025	3050	Chalmers restaurants
Number of uses per box	–	–	20	20	Chalmers restaurants	1	1	Chalmers restaurants
Raw materials								
Total production losses	%	–	3.8	3.8	Industry average	3.8	3.8	Industry average
Raw materials – total mass	kg	–	0.235	1506.6	Lunch boxes supplier	0.026	3166.6	Chalmers restaurants
Composition - biobased	%	–	15	15	From Sugarcane	–	–	
Composition – polypropylene	%	–	85	85	Lunch boxes supplier	100	100	Chalmers restaurants
Transport to Chalmers, Sweden								
Transport - road, lorry	km	–	408	408	Assuming 50% empty return	408	408	Assuming 50% empty return
Use								
Double cleaning (Dishwasher and handwashing)	%	–	50	50	Chalmers students	–	–	
Cleaning by dishwasher								
Dishwasher rack capacity (Boxes per rack)	–	10			Chalmers restaurants	–	–	
Machine capacity	racks/h	150			Chalmers restaurants	–	–	
Total employee time needed per day	hours	6.5	0.0107	6.5	Chalmers restaurants	–	–	
Rinsing machine energy required – electricity	kWh	0.75	0.01	61	Chalmers restaurants	–	–	
Cold water consumption	l/rack	0.9	1.8	10980	Chalmers restaurants	–	–	
Dishwasher energy required – electricity	kWh	39.4	0.525	3204.5	Chalmers restaurants	–	–	
Cold water consumption	l/rack	1.8	3.6	21960	Chalmers restaurants	–	–	
Drying chemical use	kg/l	0.001	0.0036	21.96	Chalmers restaurants	–	–	
Detergent use	kg/l	0.002	0.0072	43.92	Chalmers restaurants	–	–	
Cleaning by hand washing								
Total cold water used	l	1	10	61000	Chalmers students	–	–	
Total detergent used	kg	0.002	0.02	122	Chalmers students	–	–	
Energy required for heating 1 L of water – electricity	kWh	0.017	0.1745	1064.3	Calculations	–	–	
Wastewater	L		15.4	93940	Calculations	–	–	
Transport to waste management, Sweden								
Transport - road, lorry	km		408	408	Assuming 50% empty return	408	408	Assuming 50% empty return
End-of-life								
Waste management of product (Recycling)	%		100	100	Chalmers restaurants	50	50	Chalmers restaurants
Waste management of product (Recycling)	kg		0.226	1378.6	Calculations	0.0125	1525	Calculations
Waste management of product (incineration)	%		–	–		50	50	Chalmers restaurants
Waste management of product (incineration)	kg		–	–		0.0125	1525	Calculations
Waste management of production losses (incineration)	kg		0.00864	55.46	Calculations	0.00096	116.6	Calculations
Waste management of non-return boxes (incineration)	kg		–	72.56	Calculations	–	–	
Economic data								
Take away lunch box cost (including transportation cost)	Kr/box	–	42	269684	Chalmers restaurants	3	366000	Chalmers restaurants
Employee cost (at Chalmers restaurants)	Kr/day	988	32.4	197600	Chalmers restaurants	–	–	

(*continued on next page*)

Table 1 (*continued*)

Data	Unit	Value	Reusable lunch boxes system per year			Single-use lunch boxes system per year		
			Value per box	Value per FU	Source/Comment	Value per box	Value per FU	Source/Comment
Lunch boxes return benefit from manufacturers	Kr/box	–	21	128100	Chalmers restaurants	–	–	
Electricity cost	Kr/kWh	1.5	1.06	6495	Chalmers restaurants	–	–	
Water cost	Kr/l	0.04	0.62	3758	Chalmers restaurants	–	–	
Wastewater treatment cost	Kr/l	0.04	0.62	3758	Chalmers restaurants	–	–	
Detergent cost	Kr/kg	473.3	3.81	23229	Chalmers restaurants	–	–	
Drying chemical cost	Kr/l	77.5	0.28	1702	Chalmers restaurants	–	–	

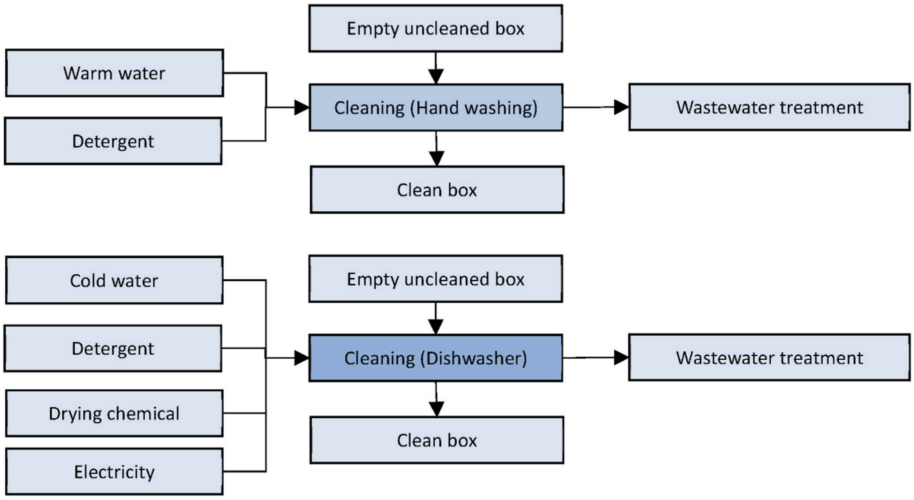

Fig. 2. Cleaning process of reusable take-away lunch boxes by dishwasher and by hand washing.

2.5. *Sensitivity analysis*

This study considered sensitivity analysis to investigate the robustness of the results concerning environmental impacts. The primary focus of these sensitivity analysis revolved around:

i) **The number of uses per reusable box over its design life**: The initial assumption considered a box's reliable use for up to 20 times, based on expert opinion. However, this study also considered 200 uses based on student feedback. Hence, the sensitivity analysis examined the environmental implications of 200 uses per reusable box, along with determining the break-even point concerning the number of uses required for climate change impact to favor the reusable system over the disposable one.

ii) **Energy source mix used for cleaning the reusable boxes**: This study assumed that the cleaning process occurred within Chalmers, Sweden, utilizing the local Swedish electricity mix. However, to gauge the adaptability of the system in various global contexts, a spectrum of electricity mixes was considered. These encompassed scenarios involving European and global electricity mixes, shedding light on the potential impact variations stemming from diverse energy sources.

iii) **End-of-Life Management of Single-Use boxes**: The third sensitivity analysis delved into the end-of-life management strategies for single-use boxes to gauge their influence on the overall environmental impacts in Sweden. This covered two distinct scenarios: the first scenario with 100% recycling, representing the best case for end-of-life management in Sweden. Conversely, the second scenario considered 100% incineration as the worst-case scenario, aiming to highlight the differences in environmental impacts between these two end-of-life treatment options.

iv) **End-of-Life Management of reusable boxes**: The fourth sensitivity analysis investigated the end-of-life management strategies for reusable boxes, assessing their impact on overall environmental impacts. Based on discussions with restaurant owners, it is assumed that the reusable boxes will be collected and recycled by the supplier, either for the same applications or different ones. However, concerns were raised about the potential degradation in plastic quality due to recycling and the complexity of recycling due to the mixed material composition of the boxes, which may require specialized recycling facilities. In this study, it is assumed that the reusable boxes will be recycled, and the recycled plastic will substitute virgin material. Using the avoided burden approach with system expansion, recycled plastic is considered an alternative to virgin material (polypropylene, granulate), with a 100% replacement credit assumed. This sensitivity analysis also considers the worst-case scenario for end-of-life management of the reusable boxes, which is incineration. This approach aims to highlight the environmental impacts associated with different end-of-life treatment options.

2.6. *Economic analysis*

This section provides an economic analysis of the reusable and single-use takeaway lunch box systems within the context of Chalmers Restaurant. Costs that fall outside the purview of Chalmers Restaurant or are not directly associated with the restaurant are excluded from this study. The economic lifespan of the takeaway lunch box system involves three primary stakeholders: (1) Manufacturers/Suppliers, (2) Restaurant Owners, and (3) Waste Management Facilities.

For single-use lunch boxes, the economic analysis is relatively straightforward. Suppliers sell the boxes to restaurant owners at a cost of

Table 2
Selected life cycle impact categories.

Impact categories	Indicators	Unit	LCIA Method
Climate change	Global warming potential (GWP100)	kg CO2-Eq	IPCC 2021
Ecotoxicity: freshwater	Comparative toxic unit for ecosystems (CTUe)	CTUe	EF v3.1
Eutrophication: freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P-Eq	EF v3.1
Eutrophication: marine	Fraction of nutrients reaching marine end compartment (N)	kg N-Eq	EF v3.1
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 world eq. Deprived	EF v3.1
Energy resources: non-renewable	Energy content (HHV)	MJ Eq	Cumulative Energy Demand (CED)
Energy resources: renewable	Energy content (HHV)	MJ Eq	Cumulative Energy Demand (CED)
Material resources: metals/minerals	Abiotic depletion potential (ADP): elements (ultimate reserves)	kg Sb-Eq	EF v3.1
Eutrophication: terrestrial	Accumulated exceedance (AE)	mol N-Eq	EF v3.1
Climate change: biogenic	Global warming potential (GWP100)	kg CO2-Eq	EF v3.1
Acidification	Accumulated exceedance (AE)	mol H+-Eq	EF v3.1
Photochemical oxidant formation: human health	Tropospheric ozone concentration increase	kg NMVOC-Eq	EF v3.1
Ionising radiation: human health	Human exposure efficiency relative to u235	kBq U235-Eq	EF v3.1
Particulate matter formation	Impact on human health	Disease incidence	EF v3.1
Human toxicity: carcinogenic	Comparative toxic unit for human (CTUh)	CTUh	EF v3.1
Human toxicity: non-carcinogenic	Comparative toxic unit for human (CTUh)	CTUh	EF v3.1
Ozone depletion	Ozone depletion potential (ODP)	kg CFC-11-Eq	EF v3.1
Land use	Soil quality index	Dimensionless	EF v3.1

IPCC, 2023: Intergovernmental Panel on Climate Change impact assessment method of 2021, EF v3.1: Environmental Footprint reference package 3.1.

3 kr per box, inclusive of transportation expenses. These boxes are then provided to customers by the restaurants along with their food, with the box cost factored in. After use, the boxes are collected by waste management facilities and processed based on whether they were collected as mixed or separated waste. The costs associated with waste management are considered external to the restaurant's scope and are thus not included in this study. It is important to note that although these costs are not directly associated with the restaurant, they are still incurred, and any reduction in the use of single-use boxes can lead to decreased waste, resulting in potential cost savings in waste management. However, quantifying the specific cost reduction and the contribution of single-use boxes to total waste is complex and therefore not included in this analysis.

The introduction of the reusable lunch box system introduces an additional layer of complexity, involving an additional step and associated service costs related to the cleaning of returned boxes before their reuse. Here's how this system operates: Suppliers can sell the boxes to restaurant owners at a minimum cost of 42 kr per box, covering transportation expenses. Restaurants provide these boxes to customers along with their food, with a deposit of 1 kr for the box, which will be refunded upon the box's return. After use, the box is returned to the restaurant, where it undergoes cleaning and is made ready for reuse. However, it is assumed that 50% of the boxes will also be cleaned by the students themselves, leading to double cleaning efforts. The cleaning process entails additional costs, including employee wages in the restaurants, amounting to approximately 6.5 h per day at a cost of 152 kr per hour. This process also incurs expenses for water, electricity, detergent, drying chemicals, and wastewater treatment. After several uses, the boxes are returned to the supplier, who can offer a maximum discount of 21 kr per box on new ones, including transportation costs. The cost associated with managing reusable boxes that are not returned, accounting for about 5% of the total boxes used per year, falls outside the restaurant's scope and is therefore not included in this study. It is noteworthy that while the cost of cleaning the boxes by students is included, the cost of the machinery used in the restaurant for cleaning is omitted from the analysis, as it is considered relatively low when assessed per functional unit.

It is also important to mention that this economic analysis does not encompass costs related to box management, storage, and data management associated with the digital traceability of students using the lunch boxes, returning them, and their subsequent usage. Additionally, data protection costs are not included in this assessment.

3. Results and discussion

In this section, this study delves into the outcomes of the life cycle impact assessment for both reusable and single-use take-away lunch box systems. Comparative results are summarized in Table 3, offering a clear snapshot of the environmental impacts. Furthermore, it offers a detailed breakdown of these results, shedding light on the specific contributions of each life cycle stage in Table 3. Subsequently, this study shifts its focus to an economic assessment, followed by a sensitivity analysis. As this study aims to envision the future landscape, it also discusses a potential future scenario and outlines the prospects for a follow-up study.

3.1. Comparative results with contribution analysis

In contrast to single-use take-away lunch boxes, the reusable take-away lunch box system demonstrates a lower environmental impact across many indicators as shown in Table 3. However, it is essential to note that the reusable system exhibits higher impacts in terms of freshwater ecotoxicity, water and renewable energy use, metals/minerals material resources, ionising radiation, and land use. The heightened water and renewable energy use is attributable to the cleaning processes, which naturally require water and electricity. The breakdown of the results between the different life cycle stages and break-even uses of reusable take-away lunch boxes are presented for each indicator in Table 3.

For reusable boxes, the raw materials extraction and production phase is the major contributor to all impact categories when only 20 uses are considered. However, as the number of uses increases, this phase contribution decreases. Another significant contributor is the use phase, which includes cleaning the reusable take-away lunch boxes through a combination of dishwasher and handwashing. This phase is independent of the number of uses of the reusable boxes and remains the same. It contributes substantially to environmental impacts across all assessed categories, representing an average of 51% of the overall impact across all indicators and 29% of the impact specifically related to climate change. This significant contribution is due to the considerable amounts of electricity, water, detergent, and drying chemicals utilized during this phase. It is important to emphasize that the use phase only influences the impacts of the reusable system, as it was not applicable to the disposable single-use take-away lunch boxes.

Turning to the disposable single-use take-away lunch boxes, the raw

Table 3

Comparative LCA results of reusable and single-use take-away lunch boxes systems per functional unit.

Impact categories	Unit	Reusable lunch boxes	Raw materials and production phase (%)	Transport (%)	Use phase (%)	End-of-life phase (%)	Single-use lunch boxes	Raw materials and production phase (%)	Transport (%)	Use phase (%)	End-of-life phase (%)	Decrease in impact (%)	Break-even uses
Climate change	kg CO2-Eq	3100 (100)	3994 (129)	270 (9)	894 (29)	−2058 (−66)	7603 (100)	9051 (119)	291 (4)	0 (0)	−1738 (−23)	59	6.6
Ecotoxicity: freshwater	CTUe	24760 (100)	6875 (28)	1911 (8)	15400 (62)	574 (2)	20824 (100)	15288 (73)	2059 (10)	0 (0)	3477 (17)	−19	35
Eutrophication: freshwater	kg P-Eq	1.3 (100)	1 (77)	0.02 (1)	0.5 (35)	−0.2 (−13)	2.1 (100)	2.3 (107)	0.02 (1)	0 (0)	−0.2 (−8)	37	10.6
Eutrophication: marine	kg N-Eq	5.1 (100)	2.7 (52)	0.1 (3)	3.4 (65)	−1 (−20)	5.3 (100)	6.1 (115)	0.2 (3)	0 (0)	−1 (−18)	3	18.1
Water use	m3 world eq. Deprived	7253 (100)	1875 (26)	18 (0)	5920 (82)	−561 (−8)	3637 (100)	4287 (118)	20 (1)	0 (0)	−670 (−18)	−99	[a]
Energy resources: non-renewable	MJ Eq	81295 (100)	143207 (176)	4072 (5)	38109 (47)	−104093 (−128)	218296 (100)	338147 (155)	4389 (2)	0 (0)	−124239 (−57)	63	4.8
Energy resources: renewable	MJ Eq	23046 (100)	6781 (29)	66 (0)	15429 (67)	770 (3)	14218 (100)	14743 (104)	72 (1)	0 (0)	−597 (−4)	−62	[a]
Material resources: metals/minerals	kg Sb-Eq	3.5E-02 (100)	1.5E-02 (43)	8.9E-04 (3)	2.5E-02 (72)	−6.0E-03 (−17)	2.7E-02 (100)	3.5E-02 (129)	9.6E-04 (4)	0 (0)	−8.9E-03 (−33)	−28	98
Eutrophication: terrestrial	mol N-Eq	28.5 (100)	26.1 (92)	1.4 (5)	13.4 (47)	−12.5 (−44)	49.3 (100)	60.7 (123)	1.5 (3)	0 (0)	−12.9 (−26)	42	8.4
Climate change: biogenic	kg CO2-Eq	14.5 (100)	8.1 (56)	0.1 (1)	5.2 (36)	1.2 (8)	29.2 (100)	18.3 (63)	0.1 (0)	0 (0)	10.8 (37)	50	7.9
Acidification	mol H + -Eq	14.3 (100)	14.3 (100)	0.6 (4)	6.6 (46)	−7.2 (−51)	25.7 (100)	33.2 (129)	0.6 (2)	0 (0)	−8.1 (−32)	45	8.1
Photochemical oxidant formation: human health	kg NMVOC-Eq	9.8 (100)	12.2 (124)	0.9 (9)	3.7 (38)	−7 (−71)	21.9 (100)	28.6 (130)	0.9 (4)	0 (0)	−7.6 (−35)	55	6.8
Ionising radiation: human health	kBq U235-Eq	3097 (100)	1174 (38)	6 (0)	1936 (62)	−18 (−1)	2263 (100)	2514 (111)	7 (0)	0 (0)	−258 (−11)	−37	71
Particulate matter formation	Disease incidence	1.4E-04 (100)	1.3E-04 (91)	1.7E-05 (12)	7.0E-05 (51)	−7.5E-05 (−55)	2.3E-04 (100)	3.0E-04 (128)	1.8E-05 (8)	0 (0)	−8.3E-05 (−36)	41	8.3
Human toxicity: carcinogenic	CTUh	3.0E-06 (100)	1.5E-06 (50)	1.2E-07 (4)	1.3E-06 (45)	4.1E-08 (1)	3.7E-06 (100)	3.4E-06 (91)	1.3E-07 (3)	0 (0)	1.9E-07 (5)	19	14
Human toxicity: non-carcinogenic	CTUh	5.6E-05 (100)	2.4E-05 (43)	2.5E-06 (5)	3.3E-05 (60)	−4.4E-06 (−8)	5.8E-05 (100)	5.5E-05 (96)	2.7E-06 (5)	0 (0)	−2.7E-07 (0)	3	18.4
Ozone depletion	kg CFC-11-Eq	1.7E-04 (100)	8.3E-05 (48)	5.9E-06 (3)	5.8E-05 (34)	2.5E-05 (15)	2.0E-04 (100)	1.8E-04 (90)	6.3E-06 (3)	0 (0)	1.4E-05 (7)	14	16.2
Land use	Dimensionless	32027 (100)	12537 (39)	1954 (6)	15354 (48)	2182 (7)	31215 (100)	27068 (87)	2106 (7)	0 (0)	2041 (7)	−3	21.1

Note 1.

[a] Water use and Energy resources: renewable impacts mainly depend on the cleaning of the reusable boxes not on number of uses.

materials and production phase takes the lead in terms of impact contribution. This prominence is due to the absence of reuse, resulting in a higher consumption of single-use take-away lunch boxes per functional unit, thus driving greater material consumption. Additionally, as assumed that the plastic for these boxes is produced within Europe using an electricity mix that has a more substantial environmental impact compared to the Swedish electricity mix, this exacerbates the impacts from the raw materials and production phase.

However, the impact stemming from raw materials diminishes with the reusable option across all impact categories by a factor of more than two. This reduction is attributed to the reuse factor; while the total plastic required per reusable box is approximately nine times that of a single-use box, factoring in reuse calculations, the total plastic required per functional unit for single-use boxes is two times greater than that of reusable boxes. Therefore, the number of uses emerges as a dominant factor influencing the total plastic required in the raw materials and production phase. This results in a stark contrast, with 6421 reusable boxes needed annually to fulfill takeaway orders in comparison to a staggering 122,000 single-use boxes. Consequently, fewer reusable boxes translate to reduced transport requirements, thus avoiding impact per transport compared to the disposable option. However, it is noteworthy that the transport phase contributes roughly the same in both the reusable and single-use box scenarios. In the reusable scenario, boxes are first transported from the supplier to the restaurants and then transported back for recycling. In contrast, in the single-use box scenario, there is only one trip from the supplier to the restaurants, after which the boxes go to local waste management.

Finally, in terms of the end-of-life phase, the disposable system yields negative impact values across different categories. This is primarily due to the waste plastic being either recycled or collected and used in the Swedish waste management system, predominantly through incineration. This process generates valuable by-products, including recycled plastic, as well as heat and electricity from incineration. The study assumes an avoided burden approach, considering these by-products as an alternative to plastic granulate, along with Swedish heat and electricity, respectively. In contrast, the reusable case results in less waste production and predominantly has predefined recycling, leading to high material recovery and benefits from the end-of-life management of reusable boxes.

The end-of-life management phase also introduces uncertainties, particularly related to the avoided burden approach used for by-products. This study applied the avoided burden approach with system expansion, where useful by-products are used as alternatives to the products they replace. This assumption is based on discussions with restaurant owners and relies on the reliability of waste management practices within the restaurants and suppliers, along with Swedish waste management standards. However, this approach is associated with numerous uncertainties that need to be considered when analyzing results and applying them more broadly. These uncertainties are related to defining which waste management practices will be employed, from recycling to incineration. Sensitivity analysis was performed considering the best case as recycling and the worst case as incineration. In recycling, there is uncertainty regarding the quality of the material, exacerbated by the fact that reusable boxes are made of mixed materials, potentially requiring specialized recycling processes. Additionally, there is uncertainty regarding whether the recycled material will be used in the same application or a different one, given that recycled plastic often is of lower quality and may contain higher levels of contamination, impacting its reusability. It is assumed in this study that recycled plastic will replace virgin polypropylene granulate at a European level, with a 100% replacement credit based on discussions with restaurant owners. However, this introduces a limitation in this study as the study does not account for variations in the quality of recycled plastic. The assumption that recycled material will directly replace virgin material, potentially in lower-quality applications but maintaining the same quantity, simplifies the analysis but may not fully reflect real-world recycling dynamics. Considering different qualities of recycled plastic in future studies, along with diverse allocation methods and sensitivity analysis, could provide a more comprehensive understanding of the impacts and benefits of recycling.

The second consideration is incineration, which leads to by-products such as heat and electricity. The study assumes that the incineration of waste polypropylene and the heat and electricity generated are used to replace Swedish heat and electricity. Given the low environmental footprint of Swedish electricity compared to European and global standards, this results in a lower credit in incineration compared to recycling, which replaces European plastic. These assumptions scope the study and contribute to uncertainties as reflected in the sensitivity analysis. Decision-makers must consider the location of the application and the by-products replacing which virgin materials to minimize uncertainty. Changes in location or the alternative product that the by-product substitutes can alter the environmental footprint, along with changing the allocation method from the avoided burden to alternative allocation methods such as cutoff or circular recycling formulas.

Overall, with the given assumptions the impacts of the lunch boxes are reduced in the reusable case, primarily due to diminished raw material requirements and high material recovery in the end of life. However, certain indicators such as water depletion and renewable energy use register an increase in impacts due to the cleaning process, which consumes energy, chemicals, and water.

To understand the potential impact of this study's results on a broader scale, it is crucial to consider the student populations across different regions. In Sweden, there were 490,470 students enrolled in tertiary education in 2021, and in the European Union's 27 countries, the number reached 18,529,195 (EU, E. U., 2024). Assuming the underlying data and assumptions remain consistent with the study conducted at Chalmers University, which has 10,595 students in 2022 requiring 122,000 takeaway boxes per year and achieving a carbon footprint reduction of 4504 kg CO2 eq., one can extrapolate these findings (Chalmers University, 2024). For all students in Sweden, the total annual carbon footprint reduction could amount to 209 tons of CO2 eq. In the European Union, the extrapolated savings could reach 7877 tons of CO2 eq. annually. These figures highlight the significant potential for reducing carbon emissions through the adoption of similar practices across tertiary education institutions in Sweden and the EU.

3.2. Economic assessment

Table 4 offers an overview of the principal cost drivers shaping the economics of both reusable and single-use takeaway lunch box systems within the restaurant's operational scope. While the cost structure for single-use lunch boxes is fundamentally anchored in the cost of the boxes themselves, reusable boxes involve a multifaceted array of contributors to the overall cost, with the most prominent being box cost, and then employee cost linked to the cleaning process, ranking as the second-largest cost component. This analysis hinges on an assumed set

Table 4

Comparative results of economic assessment of reusable and single use take away lunch boxes per functional unit.

S. No.	Cost distribution	Unit	Reusable lunch boxes	Single-use lunch boxes
1	Box cost	Kr	269684 (71.3%)	366000 (100%)
2	Employee cost	Kr	197600 (52.3%)	0
3	Electricity cost	Kr	6495 (1.7%)	0
4	Water cost	Kr	3758 (1%)	0
5	Wastewater treatment cost	Kr	3758 (1%)	0
6	Detergent cost	Kr	23229 (6.1%)	0
7	Drying chemical cost	Kr	1702 (0.5%)	0
8	Return benefit	Kr	−128100 (−33.9%)	0
Total cost		Kr	378125 (100%)	366000 (100%)

number of uses at 20; any variation in the number of uses would consequently alter the cost structure for reusable boxes, which also includes the return cost—an essentially negative cost associated with the reusable system. To attain a break-even point where the cost matches that of single-use boxes, each reusable box must be used a minimum of 22 times on average.

However, within the framework of the reusable system, the costs associated with these contributors exhibit a degree of variability, introducing uncertainty. For instance, employee costs are currently estimated as 152 kr per hour, excluding social benefits, but these could potentially escalate in the future, thereby leading to increased costs for the reusable system. This same variability extends to costs associated with water, electricity, wastewater treatment, as well as expenses related to detergents and drying chemicals. As such, forecasting the precise contours of the cost analysis in the future becomes a challenging endeavor due to the fluid nature of these variable cost factors.

3.3. Sensitivity analysis results

In this study, a sensitivity analysis was performed to assess the robustness of the results, as presented in Table 5 and Fig. 3. The first sensitivity analysis focused on the lifecycle usage of reusable boxes, evaluating a scenario where each box is used 200 times. The analysis revealed that for the 200-use scenario, the environmental impacts across all categories decrease significantly in all impact categories, with a decrease range of 17–64%. This reduction is due to the decreased demand for materials, which in turn reduces the impact of raw materials and the production phase, as well as transportation, because the number of boxes required decreased from 6421 to 642. This study also explores the reusable system's performance if the number of uses decreases to 5 uses as the worst-case scenario. The analysis revealed that for the 5-use scenario, the environmental impacts increase significantly across all categories, with an increase range of 55–200%. This increase is due to the increased demand for materials, which in turn raises the impact of raw materials and the production phase, as well as transportation, because the number of boxes required increased from 6421 to 25,684. This indicates that the environmental impact of reusable boxes is dependent on their use frequency, highlighting the importance of maximizing the number of uses to reduce their overall environmental impact. However, the cleaning process shows minimal sensitivity to changes in usage frequency. In terms of economic assessment, for 20 uses as the baseline, the reusable system is 3.3% more costly compared to single-use takeaway lunch box systems. However, for 200 uses, it is 31.5% less costly. In contrast, for 5 uses, it is 119% more costly, more than twice the cost of the single-use takeaway lunch box systems.

A particularly noteworthy result from this analysis was the calculated break-even number of uses required to equalize the climate change impact between reusable and disposable systems, which stood at 6.6. In other words, for reusable lunch boxes to match the environmental impact of single-use boxes concerning climate change, they must be used

Table 5
Comparative LCA results of reusable and single-use take-away lunch boxes systems per functional unit along with results for different sensitivity scenarios.

Impact categories	Unit	Reusable lunch boxes (5 uses)	Reusable lunch boxes (20 uses) (Baseline)	Reusable lunch boxes (200 uses)	Reusable lunch boxes (100% incineration)	Reusable lunch boxes (European mix)	Reusable lunch boxes (Global mix)	Single-use lunch boxes (Baseline)	Single-use lunch boxes (100% recycling)	Single-use lunch boxes (100% incineration)
Climate change	kg CO2-Eq	9717	3100	1115	5567	4451	6073	7603	4729	10478
Ecotoxicity: freshwater	CTUe	52838	24760	16336	26109	26506	30281	20824	18302	23346
Eutrophication: freshwater	kg P-Eq	4.0	1.3	0.6	1.5	2.6	2.7	2.1	1.9	2.3
Eutrophication: marine	kg N-Eq	10.5	5.1	3.5	6.2	6.2	7.9	5.3	4	6.6
Water use	m3 world eq. Deprived	11252	7253	6054	7755	7208	7144	3637	3072	4202
Energy resources: non-renewable	MJ Eq	210852	81295	42428	174272	91918	99020	218296	113251	323341
Energy resources: renewable	MJ Eq	45897	23046	16190	20790	19138	17011	14218	16678	11758
Material resources: metals/ minerals	kg Sb-Eq	6.38E-02	3.50E-02	2.60E-02	3.80E-02	3.60E-02	3.50E-02	2.70E-02	2.30E-02	3.10E-02
Eutrophication: terrestrial	mol N-Eq	73.7	28.5	14.9	41.1	38.0	56.5	49.3	34.6	64.1
Climate change: biogenic	kg CO2-Eq	42.7	14.5	6.1	23.0	19.6	17.9	29.2	19.8	38.5
Acidification	mol H + -Eq	37.2	14.3	7.4	21.1	21.1	28.7	25.7	17.9	33.5
Photochemical oxidant formation: human health	kg NMVOC-Eq	28.2	9.8	4.4	16.5	13.1	18.3	21.9	14.1	29.7
Ionising radiation: human health	kBq U235-Eq	6582	3097	2052	2873	2202	1672	2263	2508	2019
Particulate matter formation	Disease incidence	3.39E-04	1.40E-04	7.70E-05	2.00E-04	1.50E-04	2.60E-04	2.30E-04	1.50E-04	3.20E-04
Human toxicity: carcinogenic	CTUh	7.95E-06	3.00E-06	1.50E-06	3.00E-06	3.30E-06	3.50E-06	3.70E-06	3.60E-06	3.80E-06
Human toxicity: non-carcinogenic	CTUh	1.22E-04	5.60E-05	3.60E-05	6.30E-05	6.70E-05	7.90E-05	5.80E-05	4.80E-05	6.80E-05
Ozone depletion	kg CFC-11-Eq	5.14E-04	1.70E-04	6.90E-05	1.30E-04	2.00E-04	1.90E-04	2.00E-04	2.40E-04	1.60E-04
Land use	Dimensionless	82045	32027	17021	28518	32048	32362	31215	34043	28386

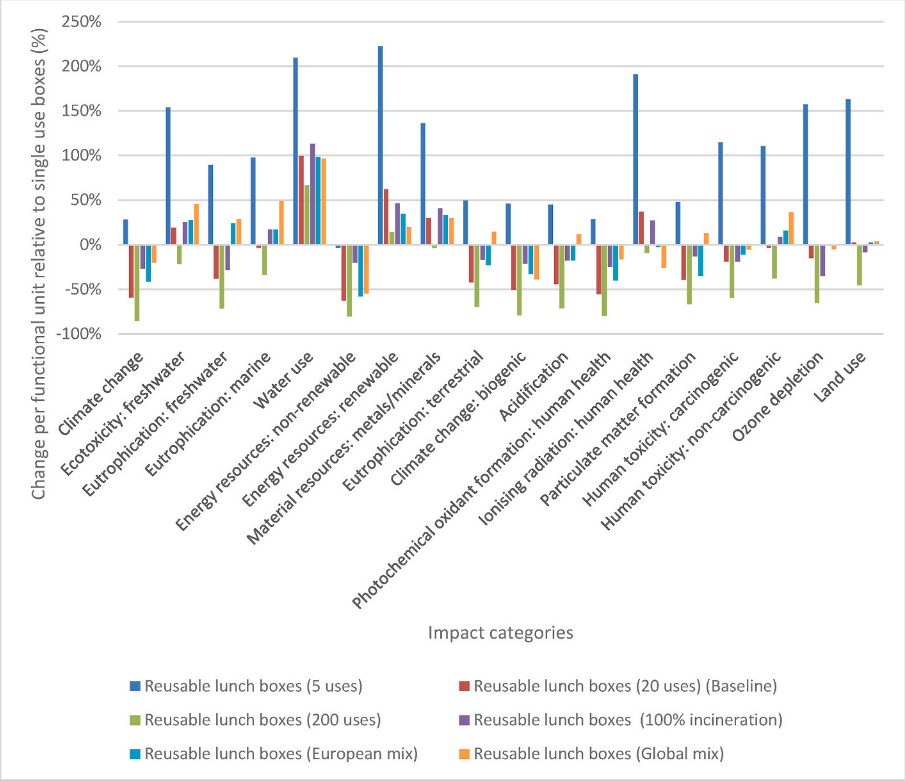

Fig. 3. Percentage change in environmental impact across sensitivity scenarios: Comparing reusable box usage frequencies and electricity mixes used for cleaning, relative to single-use boxes, along with different end-of-life management strategies.

at least seven times in restaurants before being recycled. If they are not utilized more than six times before being recycled, the environmental benefits in terms of climate change would be negligible.

The second sensitivity analysis delved into the energy source mix used for cleaning the reusable boxes. While the cleaning process was primarily carried out using the Swedish electricity mix in the study, this analysis sought to investigate the performance of the system under different energy mixes, including European and global options. The European electricity mix introduced a climate change impact increase of 44%, causing the impact for reusable boxes to surge from 3099.8 kg CO2 eq. to 4451.1 kg CO2 eq. The global electricity mix yielded a more pronounced impact increase, increasing by 96%, from 3099.8 kg CO2 eq. to 6073.2 kg CO2 eq. This significant rise underscored the critical role of the energy source mix in determining the environmental impact of the cleaning process, with more carbon-intensive energy mixes exacerbating the system's climate change footprint.

To calculate the break-even number of uses required to equalize the climate change impact between reusable and disposable systems, based on the energy source mix, this study find that the numbers stand at 6.6 for the Swedish electricity mix, 8.3 for the European electricity mix, and 11.9 for the global electricity mix. In simpler terms, to ensure that reusable lunch boxes have a lower or equivalent environmental impact as single-use boxes in terms of climate change, they must be used a minimum number of times. Specifically, in Sweden, reusable lunch boxes need to be used at least seven times, in Europe more than eight times, and on a global average, at least twelve times before being recycled. If they are not utilized to these extents before recycling, they will not confer any environmental benefits in the context of climate change.

The third sensitivity analysis focused on the end-of-life management of single-use boxes, exploring two scenarios: one with 100% recycling as the best case and the other with 100% incineration as the worst case. Landfilling was not considered the worst-case scenario because it is not a practice in Sweden, although it could be relevant if the analysis were applied to locations outside of Sweden. The findings showed that across most impact categories, the environmental impacts decrease with recycling and increase with incineration. Specifically, with 100% recycling, there was a 38% decrease in the climate change impact, reducing the impact for single-use boxes from 7603.4 kg CO2 eq. to 4728.6 kg CO2 eq. Conversely, 100% incineration led to a significant impact increase of 38%, raising the figure from 7603.4 kg CO2 eq. to 10478.2 kg CO2 eq. This considerable increase highlights the crucial role of end-of-life management in determining a system's environmental impact, with inadequate recycling exacerbating the climate change impact.

The fourth sensitivity analysis examined the end-of-life management of reusable boxes, specifically focusing on a scenario involving 100% incineration as the worst case. The findings indicated that incineration significantly increases environmental impacts across most categories. Notably, 100% incineration resulted in a substantial 79.6% increase in climate change impact, elevating the impact from 3099.8 kg CO2 eq. to 5567.2 kg CO2 eq. This considerable rise underscores the pivotal role of end-of-life management in shaping a system's environmental footprint, with insufficient recycling exacerbating the effects on climate change.

3.4. *Future scenario, follow up study and limitations*

In the context of takeaway orders at Chalmers student restaurants, a notable shift occurred between 2022 and the year 2023. In 2022, an average of approximately 1100 takeaway orders were placed daily. However, in 2023, this figure decreased to 610 orders per day. The primary reason for this decline can be attributed to revised pricing strategies for takeaway meals. The price gap between takeaway and dine-in options was substantially narrower in the year 2023, rendering takeout less attractive, especially when users have time to eat meals within the restaurant premises.

A discussion with restaurant management revealed that this pricing adjustment was a deliberate strategy aimed at fostering in-house dining experiences. The overarching objective was to curtail waste generated by takeaway packaging. While the responsibility for waste management within municipal bins fell outside the jurisdiction of the student union's financial purview, it is essential to acknowledge that all waste management activities within student union buildings incurred associated costs.

It is worth noting that the reduction in takeaway boxes, to the tune of 490 per day, each weighing 25 g, contributed to a daily reduction of approximately 12.25 kg in solid waste. However, this calculation excludes the consideration of small plastic containers for salads, wooden cutlery, and paper bags used to package food items. These elements introduce interest into the comparison between dining in and ordering takeout, which might warrant further examination in a follow-up study comparing dine-in with take away system. Nevertheless, the strategic intent of the decision-makers was evidently aligned with sustainability goals aimed at mitigating takeaway-related waste.

This strategy of reusable take-away boxes, however, comes with certain limitations. First, payment restrictions pose challenges. Student restaurants mandate payment through cards, disallowing physical currency. Cards can either be standard payment cards or student union cards with preloaded funds. Using a regular payment card necessitates an additional charge for lunch boxes, as the system cannot easily track box returns. Conversely, student union cards require a minimal 1 kr deposit, not for the box itself but for security. This system proves cumbersome, particularly for individuals without student union cards, who must purchase boxes for every transaction or bring their own for packaging, incurring additional expenses and inconvenience.

The second challenge pertains to box reusability. The boxes, being non-airtight, are less suitable for multiple uses. Unlike conventional lunch boxes, they may not effectively preserve food freshness, potentially impeding sustainability goals. This issue is more pronounced among non-student users who purchase boxes but are dissuaded from reusing them due to inadequate food preservation. Additionally, data management poses a challenge, as each transaction records purchaser information and frequency of purchases. Addressing this concern is vital for data security and user information handling.

In terms of scope of the study limitations, this analysis primarily focuses on the takeaway box used for the main meal item, with other components of the takeaway meal remaining unchanged, including the small plastic box for salads, wooden cutlery, and paper bag for packaging. Initially, there was also a paper cup for cold drinks, but this has since been replaced with separate cold beverage containers, requiring the purchase of a cold drink can.

4. Conclusions

Compared to single-use boxes, reusable boxes exhibit a lower environmental impact across many analyzed indicators. Notably, the reusable system reduces climate change impact by a remarkable 59% in comparison to the disposable alternative. This significant reduction primarily stems from the decreased number of reusable boxes required per functional unit, thanks to the extended lifespan of 20 uses, with a breakeven point of 6.6 average uses for climate change impact. This results in a reduced demand for raw materials. However, it is crucial to recognize that the environmental benefits of the reusable solution could be moderated by its water stress impact and energy consumption during the cleaning process. Fortunately, in the context of Sweden, where ample water resources and renewable energy sources are readily available, water and energy are not limiting factors. Furthermore, the relatively less carbon-intensive Swedish electricity mix contributes to a diminished electricity impact. Nevertheless, if the electricity mix shifts to a European or global profile, the impact surges by 44% and 96%, respectively, in comparison to the reference scenario for the reusable option with the break-even number of uses needed for reusable options to match the climate change impact of disposable systems as 8.3 uses for the European electricity mix, and 11.9 uses for the global electricity mix.

In terms of economic assessment, the reusable system proves to be 3.3% more costly than the single-use system per functional unit. This cost disadvantage primarily arises from the number of boxes needed for 20 uses considered in this analysis. To achieve a break-even point where the cost equals that of single-use boxes, each reusable box needs to be used at least 22 times on average. However, it is important to note that the reusable system encompasses variable costs, including employee hourly wages, water, electricity, wastewater treatment expenses, detergent, and drying chemical costs. Predicting the final cost analysis for the future is a challenging task due to these variable cost factors, implying that cost analysis may fluctuate in the future. With reusable option, as the number of uses increases, the advantages also increase, leading to recommendations for better management of the lunch boxes to maximize their reusable potential as much as possible.

Data availability statement

All data generated during this study are included in this published article.

Disclosure statement

During the preparation of this work the author(s) used ChatGPT 3.5 in order to improve grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Rahul Aggarwal: Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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