Science of the Total Environment 927 (2024) 171515

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Eco-efficiency as a prioritization tool in the reduction of food waste in restaurants

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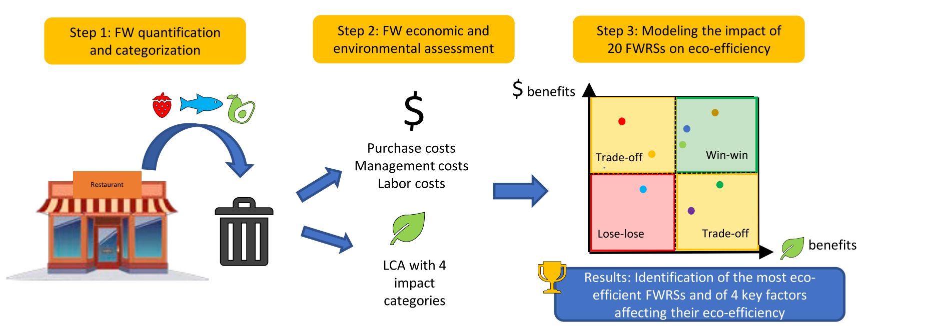
HIGHLIGHTS

- Food waste costs come from food purchasing, then labor and waste management.
- The main contributors to food waste cost are vegetables, meat and sea products.
- The majority of the strategies modeled show environmental and economic benefits.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jacopo Bacenetti

Keywords:
Foodservice (catering) industry
Restaurant
Food waste costs
Food waste environmental impacts
Food waste reduction strategies
Eco-efficiency

ABSTRACT

Striving towards eco-efficiency means creating more value while generating a product or service with a reduced environmental impact. This quest makes it possible to link objectives associated with both the environmental and the economic pillars of sustainable development. Eco-efficiency could therefore be an interesting tool to evaluate the impacts of food waste (FW) and the potential of various food waste reduction strategies (FWRSs). However, the use of eco-efficiency to assess the interest in implementing FWRSs has never been explored in the foodservice sector. This work firstly aims to carry out an in-depth analysis of the costs of the FW generation of an independent restaurant. Secondly, based on these costs data and on some previously documented environmental impact data with a life cycle assessment according to ISO 14045:2012, this work also aims to model and evaluate the performance of FWRSs from a perspective of improving a restaurant eco-efficiency. The impact of each FWRS on the eco-efficiency of the restaurant under study was measured by modeling their economic and environmental net benefits over three implementation periods (one week, one month and six months) and under scenarios of strong and weak adherence. The study identified the most eco-efficient FWRSs to be implemented to reduce FW in the studied restaurant. In addition, key factors affecting eco-efficiency were raised, namely the period following the implementation of FWRSs, the FW reduction rate between FWRSs affecting the same type of FW, the specificity of the FWRSs and their ability to limit the waste of vegetables, meat, sea products and food requiring significant processing time by the cooks. Thus, these elements will guide foodservice managers in adopting FWRSs aimed at reducing FW generated in their restaurant and at improving its eco-efficiency. In

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https://doi.org/10.1016/j.scitotenv.2024.171515
Received 19 August 2023; Received in revised form 13 November 2023; Accepted 4 March 2024
Available online 7 March 2024
0048-9697/

addition, this work proposes a new methodology intended for the scientific community to identify FWRSs that have a strong impact on a restaurant eco-efficiency.

1. Introduction

Food losses and waste (FLW), the food discarded all along the food supply chain (FAO, 2019), are a societal issue as its magnitude and the challenges associated with it constitute an obstacle to achieve a sustainable food system. Indeed, 31 % of the global food production is discarded each year, which represents more than one billion tons of food (FAO, 2019; United Nation Environmental Program, 2021). At the same time, more than 820 million people live in a situation of food insecurity, which highlights inequalities in food access (FAO, 2019). FLW also have a major economic impact as ithey lower the income of all actors involved in the food supply chain, whether through loss of income due to unsold and discarded food, or through higher food prices due to losses along the food chain. The Food and Agriculture Organization of the United Nations (FAO) estimated that the global economic costs of FLW are about USD 1 trillion each year (FAO, 2014). However, the organization claims that this value is underestimated since it does not include the FLW's environmental and social costs. This loss of income subsequently impacts the end consumer by increasing the price of food, thus contributing to the growth of food insecurity (Gooch et al., 2019). The environmental impacts of FLW are related to the loss of the resources used for cultivation (e.g. lands, water, pesticides, fertilizers), transport and food processing (e.g. energy, water, packaging) in addition to the greenhouse gases (GHGs) emitted in the atmosphere during food decomposition (FAO, 2019). It is estimated that if FLW were considered a country, they would be placed as the third GHGs emitting country in the world, with the emission of 3.3 Gt of CO_2 eq. each year (FAO, 2013). It is also estimated that 30 % of the world's agricultural land is used to grow food that will eventually be discarded (FAO, 2013). These data corroborate the conclusion of The Eat-Lancet Commission (2019) report which puts forward the goal of halving FLW in the world to achieve a healthy and sustainable food system. This objective of significant FLW reduction also meets the United Nations Sustainable Development Goal 12.3 (Hanson, 2017). Thus, all actors of the food chain (e.g. producers, retailers, consumers) should take their part to reduce FLW.

Restaurateurs are among the players who must play a role in reducing food waste (FW), the food discarded between the retail and consumption levels (FAO, 2019), as it is omnipresent in the sector. In fact, 26 % of the FW generated from the retail to the consumer comes from the foodservice sector (United Nation Environmental Program, 2021). It is therefore urgent to put in place food waste reduction strategies (FWRSs) in order to reduce its extent. To this end, several studies have been conducted in restaurants and school cafeterias to assess the effectiveness of FWRSs. This was achieved by setting up a single FWRS to measure precisely its impact or by setting up several strategies to measure their overall impact. Kallbekken and Sælen (2013) separately tested reducing buffet plate size and placing a sign at the buffet table encouraging consumers to help themselves several times rather than overloading their plate. This led to a FW reduction of 19.5 % and 20.5 %. Along the same line, Wansink and van Ittersum (2013) pointed out that a 26.5 cm buffet plate generated more than twice as much plate waste as a 21 cm one. For kitchen waste, de Visser-Amundson and Kleijnen (2019) observed a 34 % reduction of this waste type related to the signing by the kitchen staff of a contract stating that they will do their best to prevent FW. Another FWRS investigated by these researchers is the impact of putting up FW posters in the kitchen to educate staff about FW, their role in reducing it and their employer's expectations regarding FW reduction, which led to a 25 % FW reduction. Alcorn et al. (2020) measured the individual impact of providing on-demand burger set-ups and pickles and of reducing portion sizes of salsa and chips. It led to a reduction in wastage of these items from 21 to 71 %. Additionally, in this same study, an employee training session and the preparation of smaller batch sizes were implemented, which led to an overall FW reduction of 36 %. Meier et al. (2021) and Strotmann et al. (2017) have also implemented several FWRSs at the same time in cafeterias. It resulted in a FW reduction of 35 % (Strotmann et al. study) and 1.8 to 17.9 % for different meals Meier et al. (2021). Although these methods for evaluating the effectiveness of FWRSs are highly relevant, they do not inform restaurant owners about the economic and environmental net benefits generated by the implementation of FWRSs. However, these two aspects are of great importance, in order to ensure that it is financially realistic to put them in place and that the final balance sheet of the implemented FWRSs is positive.

To this end, an interesting tool to evaluate the potential of FWRSs in the foodservice sector is the eco-efficiency. According to the definition of the ISO 14045 standard "eco-efficiency is the aspect of sustainability relating the environmental performance of a product system to its product system value". This value component can take various forms such as monetary, aesthetic, nutritional and functional ones (ISO, 2012). Eco-efficiency has been used in a few studies in the food sector related to FW. Among these, Maxime et al. (2006) created eco-efficiency indicators addressing the main environmental issues in the food sector, namely energy consumption, GHG emissions, water use, wastewater generation, organic waste and packaging residues in relation to the volume of manufactured products. This study allowed to derive evaluation tools to help the food industry to adopt cleaner production initiatives that will improve its performance and competitiveness. Laso et al. (2018) used an eco-efficiency index to identify the best production scenarios in the fish canning industry depending on the origin of anchovy species and different waste management alternatives. In the foodservice industry, Strasburg and Jahno (2017) created three eco-efficiency indicators for meal production. These take into account the energy value of the meal in calories, the use of non-food inputs (cleaning products and disposable products) and the environmental impact of the meal (water footprint and FW quantity). Papargyropoulou et al. (2016) and Thamagasorn and Pharino (2019) used eco-efficiency to identify the priority categories of FW to reduce according to the discarded quantity and its costs in a Malaysian hotel restaurant and an airline caterer. As for the relationship between eco-efficiency and the performance of FWRSs in the foodservice sector, it has not been studied to date, to the best of our knowledge. However, Clowes et al. (2019) analyzed the economic benefits resulting from the implementation of FWRSs in 114 restaurants across 12 countries through the use of a cost-benefit ratio. As for the environmental benefits of the FWRSs, Meier et al. (2021) assessed the environmental impacts resulting from FW reduction in canteens in terms of GHG emissions, water and land use. The impact on climate change and biodiversity of the implementation of FWRSs was highlighted by Beretta and Hellweg (2019) who implemented and studied several FWRSs in a restaurant, a primary school, a hospital, a hotel and a business canteen.

Thus, this study explores a methodology that has never been used before to assess the performance of restaurant FWRSs: eco-efficiency. The use of this tool will make it possible to better document the net economic and environmental benefits of the implementation of FWRSs, which is crucial to ensure the financial survival of foodservice establishments and to respect the earth carrying capacity. In addition, this article presents a robust methodology, taking into account waste management and the impacts of the FWRSs' implementation (e.g. additional labor costs, the environmental impact of new equipment), which the majority of studies assessing the environmental impacts or the costs of FWRSs implementation do not perform (Goossens et al., 2019). This article also emphasizes the costs associated with FW, which is vital in the restaurant industry since this sector only benefits from low profit margins (National Restaurant Association, 2021). The aim of this study is, first, to carry out an in-depth analysis of the costs of the FW generation for an independent restaurant then to model the impact of individual FWRSs on a restaurant's eco-efficiency to evaluate the performance of each of them and to identify the most beneficial ones.

2. Material and methods

2.1. Study environment and data acquisition

This article follows a previous study aimed at quantifying the environmental impacts of FW in a restaurant (Lévesque et al., 2023), where the study environment, data acquisition procedure and environmental assessment were extensively detailed.

Briefly, data acquisition was carried out in an independent high-end hotel restaurant in Montreal (Canada). The restaurant received on average 110 consumers a day for breakfast, lunch and dinner meals. Breakfast was served as a buffet formula while lunch and dinner were offered as *à la carte* meals. The data were collected during one week, which corresponds to five full days of restaurant operation. During the data collection, a waste composition analysis was carried out to quantify and categorize the FW generated. Each discarded food was precisely weighed and categorized according to its origin, i.e. preparation (food of inadequate quality, food discarded during preparation or cooking errors), storage (spoiled, moldy or expired food), surplus (remaining food never served to consumers) and plate waste (food served to consumers but not consumed), its avoidance potential (avoidable, potentially avoidable and unavoidable) and the service (buffet or *à la carte*) for which it was intended. This information was recorded in a diary. The definitions used for the different FW avoidance potentials can be found in the supplementary material.

2.2. Eco-efficiency assessment

An eco-efficiency assessment was used to estimate and compare the environmental performance of different FWRSs in relation to their value. It was performed according to ISO 14045 and its specifications.

2.2.1. Goal and scope definition

The goal of the eco-efficiency assessment in this study is, firstly, to assess the initial costs and environmental impacts of FW in an independent restaurant, and then to estimate the environmental and economic benefits that different FWRSs can bring when implementing them. This analysis will allow to compare the impact on the restaurant eco-efficiency of various FWRSs. In addition, it will allow to identify the key elements to consider to guide restaurateurs in choosing FWRSs offering the maximum economic and environmental benefits. The functional unit (FU) of the system under study is the food wasted during one day of restaurant operations. The assessment was carried out under a cradle-to-grave approach (see Fig. 1).

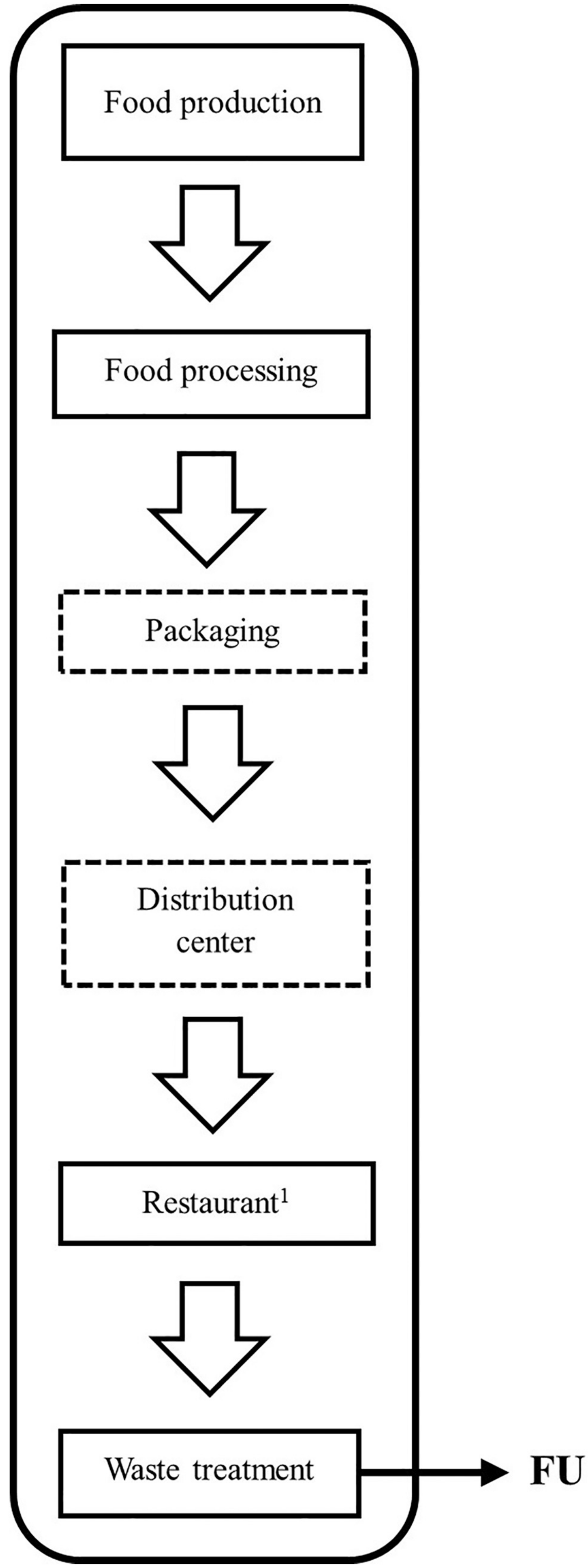

Fig. 1. System boundaries of the study. The dotted squares steps and transport are excluded from the LCA. [1]The food preparation and storage in the restaurant (e.g. cooking, freezing) are not included in the LCA.

2.2.2. Evaluation of costs related to food waste

The value used in this study is the economic one, e.i. the financial costs (in Canadian dollars, CAD) associated with FW itself and with the implementation of FWRSs. Food purchase costs and labor costs especially were calculated based on one day of restaurant operations. The purchase costs of FW were determined by linking the purchase cost of food found in order forms and in the restaurant's billing system to the amount of each food item wasted during data collection. In the case where the discarded item was food previously processed by the cooks, the recipes provided by the chef allowed to assess the quantity of each raw material composing this food. As described by Lee et al. (2013), "Labor costs refer to the back-of-house costs associated with the preparation and cooking of food destined to be wasted". Thus, plate, surplus and preparation waste can have related labor costs as they required working time from the cooks. Storage waste is not related to labor costs, except in the case where discarded foods had been previously processed by the cooks. The first step in estimating these costs was to assess the preparation time related to the food discarded. Two professional cooking teachers were involved to measure in real time or estimate the time needed to peel, cut, set up and prepare a variety of foods. Subsequently, these results were aggregated into different categories to estimate the average time related to the different operations (see Table SM1). These times were then multiplied by the average salary of a cook in the restaurant under study at the time of data collection. The labor costs obtained for the different operations were then linked to each wasted food item and multiplied by its quantity. The waste management costs only include the costs charged to the restaurant by the company collecting FW and are fixed per tonne of waste generated. This cost was therefore multiplied by the quantity of FW generated each day. Finally, it should be noted that the costs of plate waste could not be estimated with precision, except for the costs of waste management. This is explained by the fact that it was not possible to precisely identify the foods composing this waste because it consisted of a mixture of hard-to-identify foods. Thus, purchase costs were calculated using plate waste proportion to total FW, which was then multiplied by the purchase costs of total FW. Labor costs for plate waste could not be estimated since it was not possible to identify the foods composing it.

2.2.3. Evaluation of environmental impacts related to food waste

As mentioned before, a life cycle assessment (LCA) was used to estimate the environmental impacts of FW in a previous study (Lévesque et al., 2023). These data are used in this study to model the environmental impacts of the implementation of FWRSs. Briefly, the LCA was performed according to ISO 14040 and 14044 and their specifications. The transportation and packaging steps were excluded from the analysis due to the lack of information. Open LCA software (version 1.10.3, Green Delta, Berlin) was used to perform the LCA. The environmental impact of FW was calculated using Ecoinvent 3.6 and Agribalyse 3.0.1 databases as well as scientific literature and industrial data. The impact assessment method Impact World + was used. The impact categories of global warming potential (short term) in CO_2 eq. (carbon dioxide equivalent), ecosystem quality in PDF.m^2.yr (Potentially Disappeared Fraction of species in a square meter within a year), human health in DALY (Disability-Adjusted Life Year) and fossil and nuclear energy use in MJ (Megajoule) have been chosen to illustrate the environmental impacts of FW. As for the FWRSs, the environmental impact associated with the purchase of equipment and materials necessary for their implementation was considered and measured according to the same methodology as for FW.

2.2.4. Modeling the performance of food waste reduction strategies

Basically, FW generation can be described as an “inecoefficient” process as it leads to increased costs and environmental impacts for a restaurant. In order to improve a restaurant's eco-efficiency, FWRSs must be implemented in a way that yields economic and environmental benefits compared to an initial state where no FWRS was in place. Thus, FWRSs were identified as appropriate to be implemented based on the categorization of the FW, the analysis of its environmental impacts and costs as well as based on the characteristics of the restaurant. In addition, these FWRSs were presented to the operations manager and the head chef of the restaurant to ensure organizational support for their future implementation. They have been subdivided according to the origin of the FW they could reduce and are described in detail in the Supplementary Material. Each of these FWRSs represents a FW reduction scenario whose economic and environmental benefits are defined in relation to the initial scenario, i.e. when no FWRS is in place. The quantification of the impact of each individual FWRS on restaurant's eco-efficiency was performed with cost-benefits analyses on both an environmental and an economic basis. To this end, the calculation of the net benefits (NB) was used to determine their effectiveness as presented by Eq. (1). The benefits' calculation considers a FW reduction rate (based on FW quantity), which was estimated based on 1) previous studies from the scientific literature that measured the impact of individual FWRSs, and 2) on consultation with the operations manager and the head chef of the restaurant participating to the current study.

In order to consider that the FW reduction rate on a weight basis does not necessarily bring an equivalent reduction in FW costs and environmental impacts, the FW reduction rate was multiplied by 1) the amount of FW related to each food group (vegetables, fruits, dairy products and eggs, seafood, meat, cereal products, legumes and others) for the assessed implementation period (see Section 2.2.5 for more details) and 2) the average costs (see Eq. (2)) or environmental impacts (see Eq. (3)) of each food group per kilo wasted on the basis of the FU (i.e. one day of restaurant operations). The environmental impact of the waste management method was also estimated with a LCA, which is related to the composting process. As FW has been precisely quantified and categorized, it was possible to calculate the FW reduction benefits related to a certain FW category. For example, the FWRS of configuring a meal booking window for breakfast will only affect the surplus produced by the buffet service. Thus, only the costs and environmental impacts associated with this type of FW (buffet surplus) are considered in the calculations of net benefits. Finally, costs and environmental impacts of the FWRSs include the purchase of new equipment (e.g. display, markers, board), the printing of paper or posters (user fees), the hiring of a trainer, staff training time and extra work time for the cooks (wages).

$$NB = FW\ reduction\ benefits - FWRS\ costs\ or\ EI \tag{1}$$

$$\mathrm{EcNB} = \left(\sum\nolimits_{\mathrm{i=food\ group}} \%\mathrm{FW\ reduction} \bullet \mathrm{i\ FW\ quantity} \bullet \left(\frac{\mathrm{i\ FW\ PC} + \mathrm{i\ FW\ LC} + \mathrm{i\ FW\ MC}}{\mathrm{i\ FW\ quantity\ by\ FU}}\right)\right) - \mathrm{FWRS\ costs} \tag{2}$$

$$EnvNB = \left(\sum\nolimits_{i=food\ group} \%FW\ reduction \bullet i\ FW\ quantity \bullet \left(\frac{i\ FW\ EI + i\ FW\ MEI}{i\ FW\ quantity\ by\ FU}\right)\right) - FWRS\ EI \tag{3}$$

where

NB = Net benefits
EI = Environmental impacts
EcNB = Economic net benefits
PC = Purchase costs
LC = Labor costs
MC = Management costs
EnvNB = Environmental net benefits
MEI = Management environmental impact
FU = Functional unit

2.2.5. Sensitivity analysis

Two sensitivity analyzes were performed on each FWRS. The first type of sensitivity analysis concerns the level of adherence to the FWRS. Thus, it was estimated that strong adherence to a FWRS leads to a higher FW reduction rate than weak adherence, which will necessarily lead to greater economic and environmental benefits. This sensitivity analysis provides a more realistic view of the impact of implementing a FWRS on the restaurant eco-efficiency. The second sensitivity analysis aims at assessing the evolution of the FWRSs over time, in particular, to assess the payback times. Thus, the calculations of economic net benefits and environmental net benefits were performed over three periods after their implementation, either in short term (one week), medium term (one month) and long-term (six months). The results for the implementation period corresponding to the FU (i.e. one day of restaurant operation) are not presented since these three implementation periods are more relevant. These were measured by multiplying the results obtained for one day by the corresponding implementation period.

For each adherence level and implementation period, the impact of the FWRSs on the restaurant eco-efficiency was illustrated on a graph as shown in Fig. 2, which leads to six different graphs for each environmental impact category. Note that only eco-efficiency graphs for the climate change impact category are presented in this article. Those related to the other environmental impact categories are accessible in the Supplementary Material. The X axis represents the environmental benefits generated by the implementation of a FWRS and the Y axis its economic benefits. The center point of the graph represents the initial scenario, when no FWRS is in place, meaning that all economic and environmental impacts related to FW are present. The graph is then divided into four sections according to the impact of the FWRSs on the restaurant eco-efficiency (reduction of environmental impacts or environmental benefits and reduction of FW costs or economic benefits). It is desired that the FWRSs end up in the win-win section, which indicates that they bring economic and environmental benefits compared to the initial scenario. On the contrary, FWRSs in the lose-lose section are to be avoided. The two sections in yellow represent a trade-off between economic and environmental benefits.

2.3. Statistical analyses

The FW generated during one day of the restaurant's operations was chosen as the experimental unit, which was repeated five times. Simple comparisons were used as experimental design. The data from different FW origins were subjected to an analysis of variance using SigmaPlot Software (SigmaPlot 12.0). Tukey posthoc test and *t*-test were used at a significance level of $p < 0.05$ to assess significant differences between data.

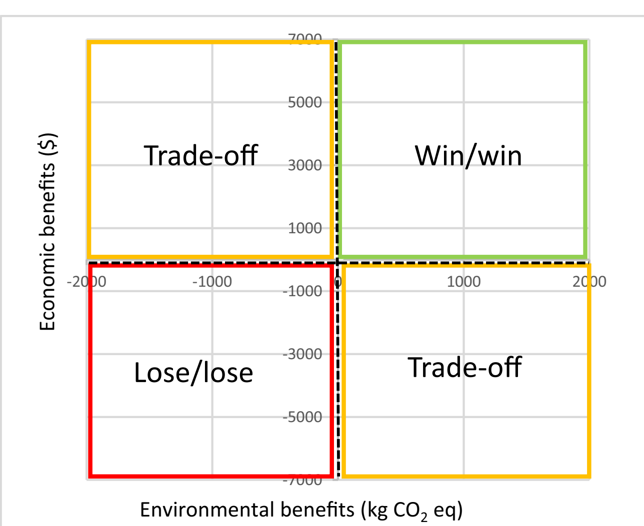

Fig. 2. Graphical illustration of the impact of the food waste reduction strategies on the restaurant eco-efficiency related to its food waste.

Table 1
Food waste quantity, cost and environmental impacts according to its origin per consumer per day.

Origin	Preparation waste	Storage waste	Surplus	Plate waste	Total
Quantity (g/consumer)	52 ± 17^{A}	22 ± 15^{B}	26 ± 12^{B}	31 ± 7^{AB}	131 ± 36
Cost ($/consumer)	0.69 ± 0.21^{A}	0.22 ± 0.19^{B}	0.23 ± 0.12^{B}	0.29 ± 0.06^{B}[a]	1.44 ± 0.32
Climate change (g CO_2 eq./consumer)[b]	124 ± 88^{A}	59 ± 74^{A}	70 ± 56^{A}	101 ± 18^{A}	354 ± 114
Ecosystem quality (PDF.m^2.yr/consumer)[b]	4.6 ± 3.3^{A}	3.3 ± 5.7^{A}	3.0 ± 3.0^{A}	2.7 ± 0.5^{A}	1.4 ± 0.8
Human health (DALY/consumer)[b]	5E-06 ± 3E-06^{A}	6E-07 ± 1.0E-06^{B}	2E-06 ± 1E-06^{B}	1.6E-06 ± 4E-07^{B}	9E-06 ± 4E-06
Fossil and nuclear energy use (MJ/consumer)[b]	1.0 ± 0.3^{A}	0.4 ± 0.5^{A}	0.4 ± 0.4^{A}	0.7 ± 0.1^{A}	2.6 ± 0.8

[a] Plate waste don't include labor costs.
[b] Data extracted from the article of Lévesque et al. (2023).

3. Results and discussion

3.1. Costs and environmental impacts of food waste

During the data collection period in the restaurant, an average of 131 g of FW was generated per consumer. As shown in Table 1, the quantity of preparation waste is significantly greater than the quantity of storage waste ($p = 0.013$) and surplus ($p = 0.037$). When looking at the FW produced in the kitchen and at the consumer level, it is possible to observe that smaller share is generated at consumer level. Indeed, plate waste quantity (consumers) is significantly lower ($p = 0.004$) than global kitchen waste (which includes preparation waste, storage waste and surplus). This therefore indicates that efforts to reduce FW must be focused on FW generated in the kitchen in this restaurant given its importance.

Compared to the restaurants surveyed in other studies, the restaurant studied generates a lower amount of food waste, 131 g per consumer. Indeed, a quantity of 150 to 300 g has generally been obtained in the literature (Dagiliūtė and Musteikytė, 2019; Malefors et al., 2019; MAPRAAT, 2011; McAdams et al., 2019; Silvennoinen et al., 2015) with a few exceptions (Engström and Carlsson-Kanyama, 2004; McAdams et al., 2019). However, it is necessary to consider that these various studies (including the one presented in this paper) do not all use the same definition of FW, which can lead to discrepancies in its quantification.

The average cost of FW per consumer is 1.44 CAD. Just as in the case of the quantification of FW by weight, the costs associated with preparation waste are also significantly higher than for the other types of FW ($p < 0.001$ for storage waste and surplus and $p = 0.005$ for plate waste) (see Table 1). A significant difference ($p < 0.001$) can also be observed between the costs associated with global kitchen waste compared to plate waste. If we focus specifically on the global kitchen waste, purchased food represents the vast majority of its costs (80 %), followed by

Table 2
Example of food waste costs breakdown per kilogram discarded.

Wasted food	Purchase costs	Labor costs	Waste management cost	Total costs
Squash gnocchi	2,53$	22,50$	0,07$	25,10$
Poultry liver foam	5,52$	11,30$	0,07$	16,89$
Trout fillet	26,00$	0,30$	0,07$	26,30$
Fruit salad	3,54$	0,30$	0,07$	3,91$

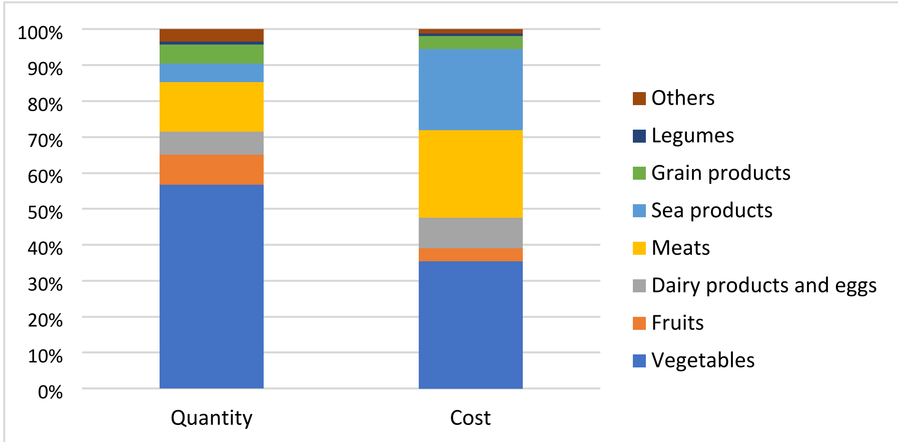

Fig. 3. Relative contributions of food categories on the quantity and cost of the kitchen food waste. Data were measured in kg (quantity) and in Canadian dollars (cost) for a day of restaurant operation and transposed to a 100% scale.

labor costs (14 %) and then waste management costs (6 %). It turns out to be of interest to consider these last two FW costs categories as these represent one-fifth of the total costs. However, these costs are rarely considered in the literature. It should also be considered that the proportion of each of these costs varies greatly depending on the type of FW. To this end, Table 2 presents a breakdown of the costs associated with four wasted foods.

It is first possible to observe that the costs of waste management is identical for the four wasted foods since it is fixed according to weight. In any case, this is the costs category with the lowest impact on total costs by far. Thereafter, the purchase costs vary according to the food constituting the FW. Gnocchi have the lowest purchase costs since they are prepared from cheap foods (squash, potato, flour, eggs). On the contrary, trout is a high quality fish with a high price. The fact that it is received filleted rather than whole also has an impact on the purchase price, since a processed food will be more expensive than its unprocessed (raw) equivalent. Thus, the more a restaurant wastes foods such as meat, seafood and dairy products, the higher the related purchasing costs will be, especially if these foods are processed. As for labor costs, they may be absent in the case where the FW has not undergone any transformation by the cooks (e.g. stored vegetables that have come moldy before being used) or be relatively high as for gnocchi. In the latter case, the large number of preparation steps (peeling and cutting the vegetables, pureeing, mixing the ingredients and forming the gnocchi) requires a lot of work time for the cooks, which leads to high labor costs. On the contrary, cutting large pieces of fruit to make a salad or cleaning and deboning trout fillets are relatively quick operations, hence their low labor costs. The size of the food and the type of cut are also to be considered as they have an impact on the preparation time. As shown in Table SM1, the smaller the food, the more the peeling and cutting operations will require labor time. This will also be the case for a fine cut (e.g. julienne) compared to a coarser cut (e.g. large cubes). Thus, the more wasted food will require preparation steps and the more the operations carried out are meticulous or carried out on small foods, the higher the labor costs will be. Thus, despite the fact that labor costs represent a low proportion of the total costs of the restaurant kitchen FW (14 %), they are still to be closely monitored as they can skyrocket the total costs, as the examples of gnocchi and poultry liver foam show (see Table 2).

A few studies have looked at the overall costs of FW in a foodservice establishment. Cohen et al. (2013) estimated that the average cost of food discarded at dinner by middle school students at a Boston cafeteria was 1.20 USD per child. However, only purchase costs were taken into account in this study. Dias-Ferreira et al. (2015) calculated that for each patient hospitalized in a Portuguese hospital, 3.90 EUR was lost in the form of plate waste. This FW cost was evaluated based on a fixed cost of 4.08 EUR per kg of FW, this figure including FW purchase and management costs. The average cost of FW (including avoidable and unavoidable wastes) for a UK restaurant was evaluated at 0.97 pennies per meal by Lee et al. (2013). Their results indicate that the majority of costs are related to the purchase of food (52 %), followed by labor costs (37 %), energy costs (4 %), waste management costs (3 %) and miscellaneous costs (e.g. administration, water, transport, consumables, 3 %). The differences between these previous results and the cost distribution of the present restaurant under study may be caused by a variety of factors. Among them, Lee et al. (2013) estimated the labor costs by multiplying the salary of the employees by the ratio of the quantity of FW to the quantity of food ordered. However, depending on the origin of FW, it may or may not have required processing time. In addition, it is important to mention that these studies were carried out in different countries where the costs of labor, food and waste management vary.

Subsequently, it was possible to measure the distribution of kitchen FW costs according to the food groups constituting FW (including purchase, labor and waste management costs), as illustrated by Fig. 3. It is possible to observe substantial differences depending on whether FW is calculated based on quantity or costs. One can observe that vegetables represent more than half (57 %) of the amount of FW, but only a third (35 %) of its costs. On the contrary, although the amount of meat and seafood wasted is minimal at 14 % and 5 % respectively, they each represent almost a quarter of the costs (24 % and 23 % respectively). Indeed, these two categories included expensive foods such as lamb, mussels and sea urchins, which has a big impact on purchase costs, as mentioned earlier. It is also possible to observe that vegetables represent more than a third of the total costs of FW, which is explained on one hand by their large quantity discarded, but also the fact that this food category represents 54 % of the labor costs associated with FW. This therefore demonstrates the relevance of using complementary methods to mass quantification and categorization to identify FW hotspots. The cost analysis has thus highlighted that vegetables, meats and sea products waste must be reduced as a priority from an economic point of view. These two last food categories have also been previously identified as hot spots in terms of the environmental impacts of FW (Costello et al., 2016; Lévesque et al., 2023) thus demonstrating that meats and sea products are major hotspots from an eco-efficiency perspective.

Finally, in order to complete this section and to have a global vision of the eco-efficiency associated with the FW of the restaurant under study, the results of an in-depth analysis of the environmental impacts of FW carried out beforehand (Lévesque et al., 2023) is briefly presented.

This analysis has put forward that the FW environmental impacts of the restaurant under the study are 354 g of CO_2 eq., 1,4 PDF.m^2.yr,[1] 9E-06 DALY[2] and 2.6 MJ for one day of restaurant operation. The distribution of these impacts according to the origin of the FW, is presented in Table 1. It indicates that the majority of environmental impacts come from preparation waste for all impact categories. However, these are significantly superior to storage waste ($p = 0.004$), surplus ($p = 0.021$) and plate waste ($p = 0.032$) only in the case of the human health impact category. The absence of a significant difference for the other environmental impact categories could be explained by the substantial standard deviation between the data from day to day data collection. For example, preparation waste represents 22 kg of CO_2 eq. during the first day of data collection while it reaches 241 kg of CO_2 eq. the day after. These variations are attributable to the quantity of FW produced (25 vs. 48 kg), but also to the type of food wasted, whereas nearly five times more meat was wasted on the second day. Finally, as in the case of FW on the basis of its weight and costs, a significant difference can be observed between global kitchen waste and plate waste according to their impacts on climate change ($p = 0.015$), ecosystem quality ($p = 0.005$), human health ($p = 0.005$) and fossil and nuclear energy use ($p = 0.016$).

Some studies have also measured the carbon footprint of FW generated by different foodservice establishments. It reaches 124.5 g of CO_2 eq. in four all-you-care-to-eat Campus Dining Services facilities at the University of Missouri (Costello et al., 2016), 129.2, 284.8 and 280.6 g of CO_2 eq., respectively, in a restaurant buffet, a beer hall restaurant and a luxury restaurant (Beretta and Hellweg, 2019) and 250 to 9380 g of CO_2 eq. following six events that took place in restaurants and hotels in Abu Dhabi (Pirani and Arafat, 2016).

3.2. Selection of food waste reduction strategies

Twenty FWRSs adapted to the context of the restaurant under study were chosen to model the impact of their implementation on the restaurant eco-efficiency. A more detailed description of each FWRS is presented in the Supplementary Material. As shown in Table 3, the FWRSs have been subdivided according to the origin of the FW they affect.

The FWRSs defined to affect "global kitchen waste" have an impact on all FW produced in the kitchen by the cooks (i.e. preparation waste, surplus and storage waste). Some FWRSs affect a certain type of FW more specifically than others according to the hot spots identified from an economic and environmental points of view. For example, although there was surplus related to both *à la carte* and buffet services, these were generated in minimal amounts in à la carte service compared to the buffets (Lévesque et al., 2023). Thus, the FWRSs chosen to limit surplus are only related to the buffet. Another example is that two FWRSs related to plate waste aim to specifically reduce bread and butter since these foods have been discarded in large quantities and are linked to high cost and/or environmental impacts. It is possible to observe in Table 3 that only a few FWRSs adapted to the restaurant under study have been evaluated in previous studies, such as the addition of a sign on the buffet and the signature of a FW reduction contract with the employees. It is worth noting that these FWRSs were mainly focused on plate waste except for de Visser-Amundson and Kleijnen (2019) study, who investigated global kitchen waste FWRSs. The FW reduction rates vary greatly from one FWRS to another and according to the adherence level. For example, it was estimated that the application of awareness posters could be completely ineffective when employees are already surrounded by information on the kitchen walls. On the contrary, it was estimated that storage waste could be reduced by 60 % if the number of choices and items on the menu was significantly reduced based on the

[1] PDF.m^2.yr: Potentially Disappeared Fraction of species in a square meter within a year
[2] DALY: Disability-adjusted life year

Table 3
Food waste reduction rates assessed for the different food waste reduction strategies according to two adherence levels.

Food waste origin	Strategy	Weak adherence	Strong adherence	Reference
Plate waste	Add a sign on the buffet	10 %	42 %	Kallbekken and Sælen (2013)
	Add an awareness memo on the menu	10 %	25 %	Pinto et al. (2018); Whitehair et al. (2013)
	Reduce the size of buffet plates	10 %	20 %	Kallbekken and Sælen (2013); Wansink and van Ittersum (2013)
	Give butter and bread on request	50 %	70 %	Restaurant operations manager and head chef
	Offer smaller amount of butter	35 %	50 %	Restaurant operations manager and head chef
Preparation waste	Carry out a co-creation workshop	15 %	25 % to 35 %[a]	Restaurant operations manager and head chef
	Plan the menu to reuse FW	15 % to 20 %[a]	20 % to 35 %[a]	
Surplus	Ask hotel guests for breakfast	0 %	10 %	Restaurant operations manager and head chef
	Create a breakfast reservation window	10 %	20 %	
	Calculate food consumption tendencies	10 %	30 %	
Storage waste	Improve the food inventory system	5 %	15 %	Restaurant operations manager and head chef
	Set up a soon-to-expire food drop-off place	20 %	40 %	
	Reduce menu choices and items	30 %	60 %	
	Perform a daily observation tour	10 %	25 %	
	Improve food reception	10 %	20 %	
Global kitchen waste	Conduct FW training (all staff)	15 to 20 %[b]	20 to 30 %[2]	Restaurant operations manager and head chef
	Conduct FW training (key staff)	5 to 10 %[b]	15 to 25 %[b]	Restaurant operations manager and head chef
	Add work time to increase FW recovery	20 %	35 %	Restaurant operations manager and head chef
	Put FW awareness posters in the kitchen	0 to 10 %[b]	10 to 25 %[b]	de Visser-Amundson and Kleijnen (2019)
	Sign FW reduction contract	5 %	10 %	de Visser-Amundson and Kleijnen (2019)

[a] Increase in reduction rate over time with FWRS adoption.
[b] Decrease in reduction rate over time with FWRS abandonment and return to routine.

consultation of the restaurant operations manager and head chef. In addition, the FW reduction rate may vary depending on the implementation period in the case of some FWRSs. For example, for menu planning based on FW reuse (e.g.vegetable peelings from one dish can be reused in another dish on the menu such as soup), it was assumed that the FW reduction rate would increase from 20 % in the short term to 35 % in the long term for strong adherence. Indeed, it was estimated that the person in charge of making the menus would become more and more comfortable over time applying this FWRS, which would result in a greater reduction in FW.

3.3. Modeling the impact of food waste reduction strategies on eco-efficiency

3.3.1. Short-term observations

First of all, it is possible to observe that no FWRS had both negative environmental and economic net benefits to end up in the lose-lose section of graphs a and b of Fig. 4, Fig. SM1, Fig. SM2 and Fig.SM3. However, several FWRSs bring economic losses, both in weak and strong adherence levels. This is the case of the co-creation workshop, the improvement of the inventory system and the improvement of the food reception method as they bring losses ranging from 2 to 214 CAD. These FWRSs require monetary investments during their implementation, such as paying employees for training or workshop time, hiring a trainer and purchasing material (pencils, board, tape). A return on investment is therefore not achieved in these cases resulting in low eco-efficiency. Otherwise, all FWRSs bring environmental benefits except in the case of the sign on the buffet for the weak short-term adherence level for the climate change and fossil and nuclear energy use impact categories. The material constituting the signs (plexiglass) has a carbon footprint that is 731 g of CO_2 eq. greater than the impact of the reduction of buffet plate waste. Also, the signs generate a greater energy expenditure (21 MJ) than what is saved by reducing the FW. This is explained by the fact that the plexiglass is polymerized from hydrocarbons, which has a major impact on those two impact categories but less on ecosystem quality and human health. The environmental impacts due to this material could be reduced by using laminated paper, which requires less polymer, or by printing the message to be conveyed to consumers on rigid cardboard.

For the climate change impact category (Fig. 4), it is possible to observe that the global FWRSs (shape of circles) and FWRSs related to preparation waste (shape of a square with an X) bring environmental benefits superior to the majority of FWRSs as they provide a reduction from 15 to 38 kg of CO_2 eq. for low adhesion and from 19 to 66 kg of CO_2 eq. for high adhesion compared to the initial scenario. FWRSs related to plate waste (shape of a square), surplus (shape of a diamond) and storage waste (shape of a triangle) seem for their part to be less effective. This could be explained by the fact that these FWRSs affect a smaller amount of FW, which brings less economic and environmental benefits. In the case of the impact categories of ecosystem quality and human health, variations are observable with the results mentioned above on climate change. It should be noted that these differences are the same for the short, medium and long-term periods.

For the ecosystem quality impact category, FWRSs associated with plate waste (shape of a square) are less beneficial because this FW type consists of a high proportion of dairy products (16 %). As this food category has a smaller impact on the quality of the ecosystem than climate change, the FWRS affecting plate waste prove to be less effective. On the contrary, storage waste FWRSs (shape of a triangle) provide more benefits (see Fig. SM1). In the case of the human health impact category, the FWRS related to storage waste and plate waste seem to bring fewer benefits than in the case of climate change (see Fig. SM2). This can be explained by the fact that approximately half (48 % and 57 %) of the foods making up storage and plate waste are vegetables, this food category having less impact on human health compared to climate change. On the contrary, the two FWRS affecting preparation waste (in the shape of a square with an X) bring greater human health benefits than for the climate change impact category. This is explained by the fact that 91 % of sea products, which is the source of the majority of impacts on human health (Lévesque et al., 2023), are waste associated with preparation. This demonstrates that the foods constituting FW have a strong impact on the effectiveness of a FWRS. Thus, any FWRS that reduces a significant amount of meat and/or sea products is to be preferred as these foods have strong environmental impacts. Other food groups like vegetables should not be ignored as their waste reduction is also beneficial from an economic point of view since they represent approximately one-third of FW costs (see Fig. 3). In addition, foods that have undergone a high degree of processing should also be prioritized in the reduction of FW as they required a significant amount of work time and are therefore linked to high labor costs. The food categories composing FW and the processing time brought to the wasted food thus represent the first of the four factors to be considered to identify FWRSs with a high impact on the restaurant eco-efficiency, as presented in Fig. 5. Finally, it should be noted that no major difference is observable between the fossil and nuclear energy use impact category and the climate change impact category.

In the short-term, the most eco-efficient FWRSs to reduce restaurant FW according to climate change, ecosystem quality and nuclear and fossil energy use impact categories are awareness posters, menu reduction and adding working time to reuse FW. In the case of the human health impact category, the FW reduction contract FWRS is more eco-efficient than the menu reduction, since the environmental benefits of this last FWRS affecting storage waste are reduced as previously discussed. The least eco-efficient FWRSs for all environmental impact categories are the improvement of food reception, the improvement of the inventory system and the co-creation workshop.

3.3.2. Medium-term observations

The one-month time frame seems to be a pivot point for several FWRSs as they all have a positive economic net benefit in the weak and strong adherence level (see graphs c) and d) in Fig. 4, Fig. SM1, Fig. SM2 and Fig. SM3). This fact is due to the achievement of a return on investment. From this point, all FWRSs end up in the win-win section of the graphs. For instance, FWRSs reducing global kitchen waste and preparation waste, such as training of all staff and the co-creation workshop, were situated among the least eco-efficient FWRSs in the short term perspective. They are now situated among the most eco-efficient ones for the strong adherence perspective, as are the awareness posters and the addition of extra working time.

The least eco-efficient FWRSs change greatly from the short-term implementation period. In the latter case, the least impactful FWRSs are those with a negative economic net benefits (the co-creation workshop, the improvement of food reception and the improvement of the inventory system) whereas in the medium term implementation period it is rather ineffective FWRSs which are, in general, related to plate waste, storage waste and surplus (i.e. reducing the size of the plates, affixing a sign on the buffet and ask for breakfast). As a demonstration, those FWRSs bring 9 to 31 times less economic benefits than conducting a FW training for all, and 10 to 43 times less environmental benefits for the climate change impact category. It is also possible to observe that the FWRSs associated with storage waste seem to be more beneficial from an economic point of view than from an environmental one. This could be explained by the fact that storage waste was mainly composed of fruits and vegetables having a medium to high cost but a quite low impact according to all impact environmental categories (Lévesque et al., 2023).

It is also possible to observe that the most and the least impactful FWRSs vary significantly between the two levels of adherence. The addition of working time, the training of key staff and the co-creation workshop bring little economic benefit in a low level of adherence. However, these three FWRSs are among the best at a high level of adherence. This is caused by the labor costs associated with these FWRSs and the difference in the FW reduction rate between the two adherence levels. Indeed, a FW reduction rate that is too low makes it more difficult

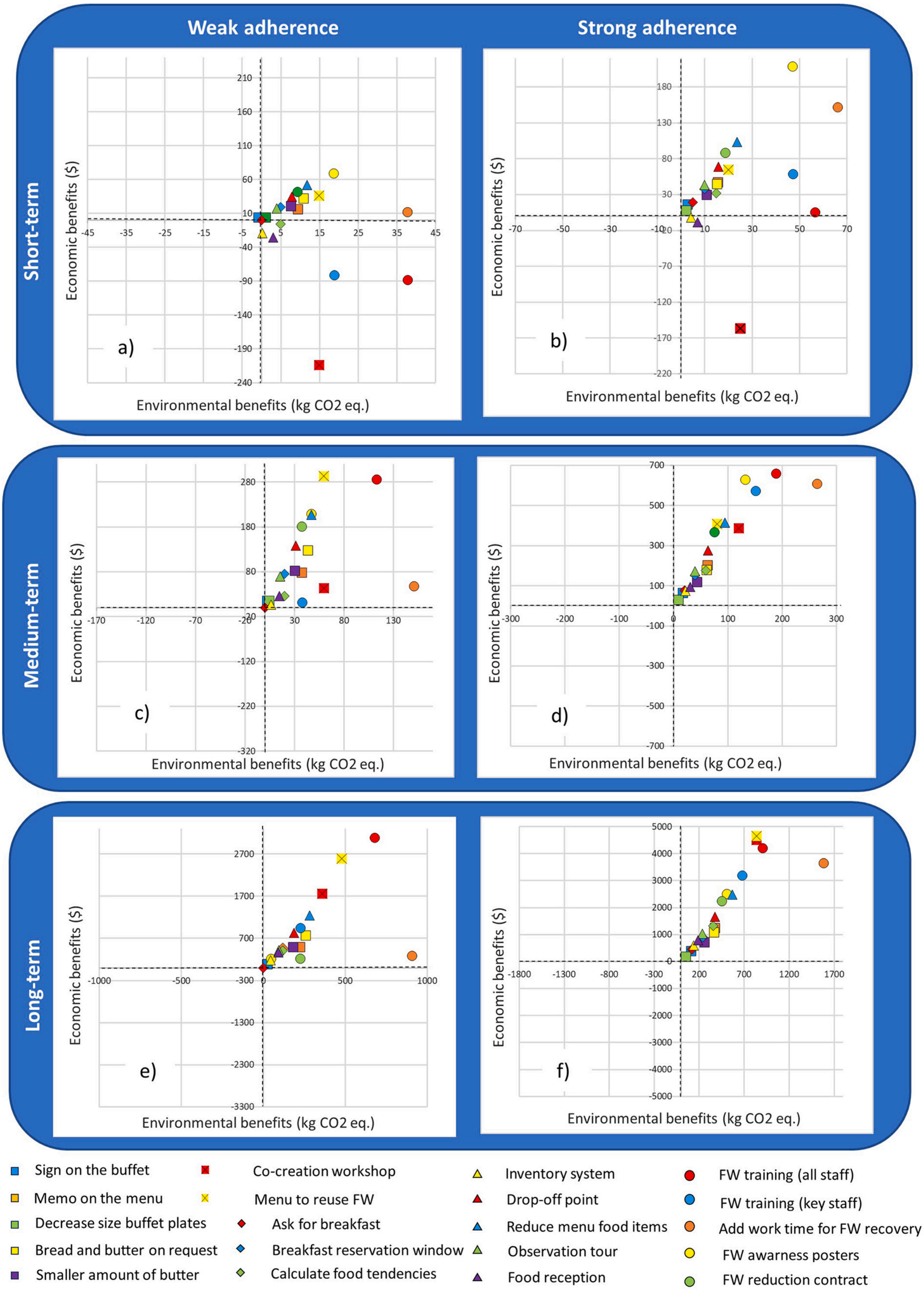

Fig. 4. Eco-efficiency modeling of food waste reduction strategies for the climate change impact category under a scenario of a) weak short-term adherence, b) strong short-term adherence, c) weak medium-term adherence, d) strong medium-term adherence, e) weak long-term adherence and f) strong long-term adherence.

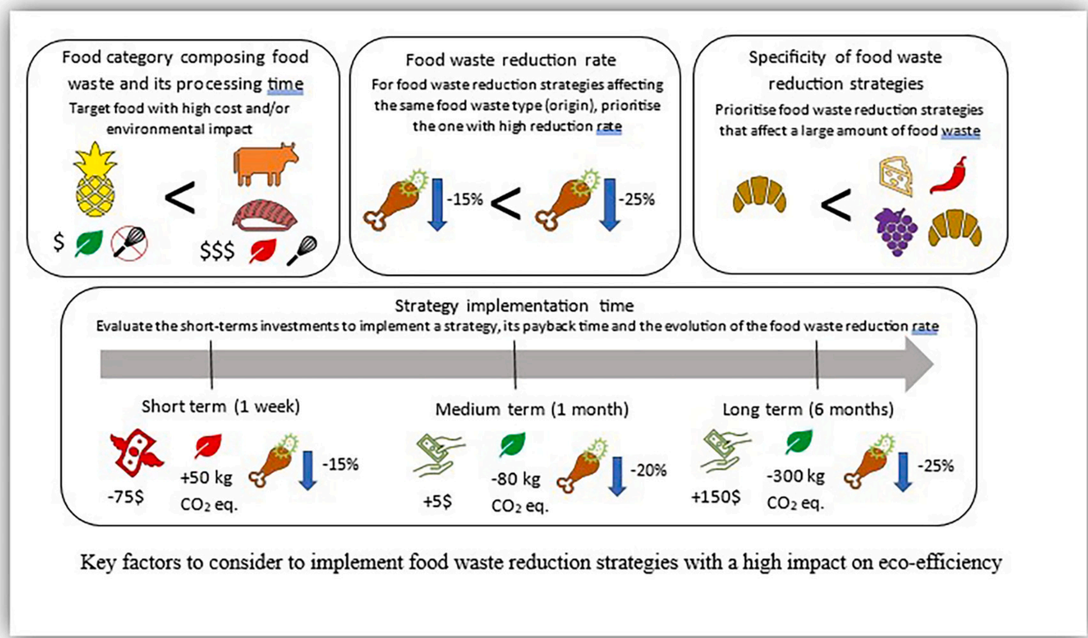

Fig. 5. Key factors to consider to implement food waste reduction strategies with a high impact on eco-efficiency.

to balance the labor costs related to these FWRSs. Thus, it is possible that a FW reduction rate lower than the assessed minimum limits may lead to monetary losses rather than positive economic net benefits in a medium time frame. It should also be considered that, as mentioned in Section 3.2, the more the processing of the foods constituting the FW requires preparation steps, meticulousness from the cooks or is carried out on small foods, the higher the labor costs will be. Thus, choosing simple and rapid processing methods, ideally on large to medium volume foods, is a key to increasing the economic benefits associated with this FWRS.

3.3.3. *Long term observations*

After six months, there is little difference between the estimated most and least impactful FWRSs compared to medium-term estimations (see graphs e) and f) in Fig. 4, Fig. SM1, Fig. SM2 and Fig. SM3). The major difference is the co-creation activity which is among the top three FWRSs. On the contrary, it is possible to observe that the awareness posters, which have proven to be very interesting in the short and medium terms, is no longer one of the most interesting FWRSs due to a projected decrease in its effectiveness over time. This demonstrates the importance of considering the period following the implementation of the FWRSs, from the short to the long term. This element is therefore the second key factor to consider in identifying FWRS with a high impact on the restaurant eco-efficiency (see Fig. 5).

The six months results show that the FWRSs related to preparation waste and those related to global kitchen waste are projected to be the most eco-efficient to reduce restaurant FW in the long-term perspective, since plate waste and surplus FWRSs are projected to be the least eco-efficient ones. Storage FWRSs have a low to medium impact on eco-efficiency. Moreover, within the same type (or origin) of FWRSs, there are sometimes large differences in modeled economic and environmental benefits, as in the case of global kitchen waste FWRSs. For example, the FW reduction contract can bring three times fewer economic and environmental benefits (for the climate change impact category) than the FW training for all for a weak adherence level and two times fewer economic and environmental benefits for a strong adherence level. This, therefore, raises two other key factors to consider, namely the FW reduction rate associated to the FWRSs and their specificity (see Fig. 5). The FW reduction rate is a good indicator for identifying the most eco-efficient FWRSs among those affecting the same type of FW. In general, the higher the FW reduction rate is, the more FW can be reduced by employing a FWRS, which translates into greater economic and environmental benefits. For example, reducing the number of menu items is the most eco-efficient FWRS associated with storage waste as its FW reduction rate (30 % for low adherence and 60 % for high adherence) is higher than the reduction rate of other FWRSs of the same type (5–40 %). Between two FWRSs affecting different types of FW, the specificity of the FWRSs should be considered to assess their impact on the restaurant eco-efficiency. Indeed, although giving bread and butter on demand seems an interesting FWRS due to its high reduction rate (50 to 70 %), this FWRS is very specific as it only aims to reduce wasted bread and butter. The co-creation activity has a much lower reduction rate (15 to 35 %), but due to its low specificity (all types of food discarded during the mise en place), this FWRS turns out to be more interesting as it affects a greater amount of FW.

3.4. *Study limitations*

The results presented above are specific to the restaurant under study as they are strongly related to its characteristics and the context in which it operates. For example, the co-creation workshop is very interesting to implement in a high-end restaurant, because the cooks have excellent cooking skills and are very creative. On the contrary, reducing the size of the buffet plates is less relevant since there is very little plate waste in this type of restaurant. However, this FWRS could be very interesting for a different restaurant type. In addition, the results presented above are a model obtained from various estimated parameters, including the FW reduction rate. Thus, this study does not necessarily draw an accurate portrait of the impact of FWRS on the restaurant eco-efficiency, but rather aims to demonstrate a methodology for evaluating them in an eco-efficiency perspective and identifying those that have the highest application potential. Finally, this study only documented the potential direct effect of FW reduction on eco-efficiency through the implementation of FWRSs. It has not documented the indirect effects of the implementation of FWRSs, such as customer satisfaction with these

FWRSs, which could affect a restaurant's performance. In addition, the extent to which the implementation of these FWRSs will benefit a restaurant's overall eco-efficiency remains unknown.

3.5. Conclusions

This study examined a novel topic: the eco-efficiency of different FWRSs in the foodservice sector to identify those with the greatest potential to achieve beneficial results in both economic and environmental terms. Whereas previous studies have measured the costs of FW incompletely or inaccurately, this study used a rigorous methodology to assess them. These costs reach 1.44 CAD per consumer and come mainly from the purchase of food (80 %) followed by labor (14 %) and waste management (6 %). Despite the fact that labor costs represent a lower proportion of the total costs of the restaurant kitchen FW compared to purchasing costs, they are still to be closely monitored as they can cause the total costs of some FW to skyrocket. Vegetables, meat and sea products contribute to the majority of FW costs, although these last two food categories were generated in small quantities. Subsequently, the impact of FWRSs on the restaurant eco-efficiency was modeled according to three implementation periods and two levels of adherence, which is also a unique element of the methodology used. The results show that the most interesting FWRSs in the long term turn out to be to plan the menu to reuse FW, to conduct a FW training for all staff, to set up a cocreation workshop and to add working time to reuse FW. The less ecoefficient FWRSs for this same implementation period are projected to be to reduce the size of the buffet plate, to add a sign on the buffet and to ask hotel guests if they plan to attend breakfast. A final point to consider is that a FWRS with a low impact on the restaurant eco-efficiency is not necessarily irrelevant. It can be complementary to a high eco-efficiency FWRS if they affect a different type of FW and should therefore still be implemented. Also, this study highlighted four key factors to identify FWRSs that could lead to a high eco-efficiency, namely 1) to promote FWRSs that reduce high amounts of vegetables, meat, sea products and food which require a significant processing time by the cooks, 2) to identify the FW reduction rate of FWRSs affecting the same type of FW, 3) to analyze the specificity related to the FWRSs and 4) to consider the duration of their implementation. These key factors can guide restaurant chefs and managers as well as experts in the field in prioritizing FWRSs according to the potential eco-efficiency benefits of their implementation. The benefit of this project for the scientific community is the conception of a rigorous methodology for measuring eco-efficiency, which can be used in future studies on FW reduction in the foodservice sector.

Despite all this work, it was not possible to model the cumulative effect of these FWRSs. Thus, it would be relevant to implement them in the field and directly measure their total impact on the restaurant eco-efficiency. In addition, it would be relevant to document the indirect effects of implementing these FWRSs on the restaurant's performance and overall eco-efficiency. Additional studies could be carried out on other types of restaurants and foodservice establishments to explore the impact of proposed and new FWRSs on their eco-efficiency.

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.

Acknowledgments

The financial support of the Mitacs Accelerate program with Société des casinos du Québec [grant number IT12400], the Institute of Nutrition and Functional Foods (INAF), the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Fonds québécois de la recherche sur la nature et les technologies (FRQNT) [grant number 301900] is acknowledged. The authors would like to thank the Restaurant Services Manager, Jonathan Lapierre-Réhayem, and the ITHQ teachers, Pascale Beirouti and Olivier Guiriec, for their precious collaboration.

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