Resources, Conservation & Recycling 161 (2020) 104946

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

No time to waste: assessing the performance of food waste prevention actions

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ARTICLE INFO

Keywords:
Food waste
Food waste evaluation
Food waste prevention
Life cycle assessment

ABSTRACT

As a result of the growing awareness of the need to prevent food waste, several initiatives have been launched in the last few years to reduce food waste generated across the food supply chain. However, the evaluation of food waste prevention interventions is still at an early stage of development and appropriate methods to assess their effectiveness are missing, hampering the identification of best practices amongst existing initiatives and the prioritisation of those that are most promising. To address such needs and provide a common approach to consistently assess the performance of food waste prevention initiatives, the European Commission Joint Research Centre has developed an evaluation framework for food waste prevention actions. The framework supports the EU Platform on Food Losses and Food Waste, which has been established to identify best practices and share knowledge on food waste prevention initiatives. Additionally, a food waste prevention calculator, based on life cycle thinking, has been developed to support such an evaluation by a consistent assessment of the environmental and economic benefits of such initiatives, and the identification of potential trade-offs at early design stages. The main goal of this paper is to present the evaluation framework and the calculator developed, critically discussing how future initiatives should be designed, monitored and reported, to ensure sufficient and relevant data is made available to enable their proper assessment. Crucially, this would enable practitioners and decision makers to evaluate the success of existing initiatives and give priority to the implementation of the best performing ones.

1. Introduction

According to the Food and Agriculture Organization of the United Nations (FAO), about one third of the food produced globally for human consumption is lost or wasted. This represents a loss of resources consumed along the food supply chain (FSC), but also a threat to food security (FAO, 2013). Furthermore, it has a negative economic impact on the income of farmers and on consumers: the cost of food waste at global level in 2007 was estimated around USD 750 billion (FAO, 2013). Due to a rapidly growing world population and a rise in prosperity with consequent changing lifestyles, the demand for food, feed and energy in the next few decades is expected to pose an unprecedented pressure on natural resources. The reduction of food waste is therefore a potential strategy for closing the gap between the supply and demand of food (Foley et al., 2011; Godfray and Garnett, 2014).

To address this issue, several initiatives have been launched globally. The United Nations has adopted a specific target in the Sustainable Development Goals (SDGs) aiming at halving per capita global food waste at retail and consumer levels and reducing food losses along production and supply chains by 2030 (Target 12.3) (United Nations, 2015). The European Commission committed to achieve such a target within its Circular Economy Action Plan (European Commission, 2015 and its recent 2020 update), defining food waste as a priority area. In this context, the European Commission established the EU Platform on Food Losses and Food Waste (FLW), with the aim of supporting all actors in defining measures needed to prevent food waste, sharing best practices and evaluating progress made over time.

The increased interest in the environmental and economic damage caused by food waste (FAO, 2019) has led to a growing political and public consensus on the need to address this challenge (as proven by the inclusion of food waste reduction in the Farm to Fork Strategy for Sustainable food, currently being developed by the European Commission as part of the European Green Deal[1]). As a result, local authorities, businesses, institutions, and organizations have put in place measures and launched campaigns to reduce the food waste generated during the production, processing, distribution and consumption of food in households and food service establishments (Reynolds et al., 2019). Nevertheless, there is a dearth of studies assessing the efficacy of

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1 https://ec.europa.eu/food/farm2fork_en

https://doi.org/10.1016/j.resconrec.2020.104946
Received 19 January 2020; Received in revised form 6 May 2020; Accepted 8 May 2020

such prevention measures, mainly due to a lack of evidence. A few recent reviews have assessed the success of existing food waste prevention measures. One example is the work by Aschemann-Witzel et al. (2017), who analysed the key success factors reported for 26 initiatives to reduce consumer food waste. Their main conclusions were that the collaboration between different stakeholders, correct timing, the involvement of people with the right competencies, the adoption of a positive focus, the suggestion of easy-to-implement solutions, and the large scale of operations are key factors in securing the success of food waste prevention measures. Reynolds et al. (2019) focused on 17 applied interventions that claimed to have achieved a food waste reduction, of which 13 had quantified such reduction. They identified as promising actions that changed the size or type of plates in the hospitality sector, initiatives changing nutritional guidelines in schools, and information campaigns focused on small samples. Additionally, they identified typologies of actions that were supposedly effective (e.g. cooking classes, food sharing apps) for which, however, no or little supporting evidence had been provided. The authors concluded that the potential effectiveness of food waste reduction measures is only being evaluated to a limited extent, calling for the development of longitudinal and larger sample size intervention studies. This would enable to gain a better insight of the potential effect of different actions, consequently supporting evidence-based decisions for the achievement of food waste reduction. Stöckli et al. (2018) conducted a review of consumer food waste interventions and came to a similar conclusion stating that "interventions should be evaluated in a systematic manner, by using a framework that implements standardized definitions and measurement methods, addresses specific behaviours and behavioural change processes, differentiates between combined interventions (i.e., a campaign as a whole) and isolated interventions, and ensures evaluations of long-term effectiveness" (Stöckli et al., 2018, p.460).

Work recently conducted by Goossens et al., (2019), further stressed this knowledge gap. The authors conducted a review of the methods applied in the literature to evaluate food waste prevention measures targeting the food service sector, providing an overview of the extent to which initiatives have been measured to date. They concluded that as relatively few studies reported on the amount of food waste prevented by an intervention, the environmental, economic, and social impacts of food waste prevention interventions are rarely evaluated and their efficiency is only seldom assessed, limiting the scope for comparing interventions, identifying trade-offs, and prioritising actions that have proven successful.

Although academics have only just started posing questions on the efficacy of food waste prevention interventions, the studies cited show an agreement on (i) the need for a common evaluation framework and (ii) the need to develop interventions that foresee the collection and consistent reporting of data before/during/after their implementation, to enable their evaluation according to the framework defined. To address such a need the European Commission Joint Research Centre (EC-JRC) has developed an evaluation framework for food waste prevention actions, in support of the activities of the EU Platform on FLW. To test the framework developed, the EU Platform on FLW asked its members and other relevant stakeholders to provide information on existing food waste prevention actions, through a reporting template developed by the EC-JRC. A total of 91 initiatives were submitted and evaluated (the reader is referred to Caldeira et al. (2019) for more details of this exercise). The first goal of this article is to present the evaluation framework developed and the approach that led to its formulation.

A central part of the evaluation framework developed involved assessing the benefits of implementing a food waste prevention initiative from an environmental and economic perspective. This is a key aspect in the evaluation of food waste prevention interventions as highlighted by previous research. The Champions 12.3, an international coalition of executives from governments, businesses, international organisations, research institutions, farmer groups, and civil society, aiming at accelerating progress towards SDG target 12.3, calculated the benefit-cost ratio of prevention actions implemented at country, city, and business level, showing that there is a strong business case to reduce food waste (Hanson and Mitchell, 2017). The project ReFED evaluated the potential economic benefits that could be achieved thanks to the implementation of a series of food waste prevention measures, to identify which types of measures are more cost effective (ReFED, 2016). Some studies have assessed the environmental benefits of preventing food waste: those are generally measured using Life Cycle Assessment (LCA), a methodology that enables the assessment of the environmental impact associated with all the stages of the life cycle of a product or a service focusing on several impact categories. Most studies limited environmental considerations to impacts on climate change (e.g. Cánovas Creus et al., 2018; European Union Committee House of Lords 2014; Monier et al., 2010). In others, the impact of food waste prevention initiatives was measured in terms of land use and water depletion (FAO, 2013; Hanson and Mitchell, 2017) and in terms of biodiversity impacts (FAO, 2013).

To support the assessment of the environmental and economic benefits of food waste prevention initiatives, a calculator was developed for use by those designing or assessing such initiatives. The purpose of this calculator is to enable the quantification and visualisation of the net economic benefits and net environmental savings (metrics explained in the following sections) resulting from the implementation of a food waste prevention initiative through the adoption of a consistent methodology based on life cycle thinking. The results provided by the calculator can support (i) the assessment of ongoing and concluded actions, (ii) the prioritisation of those actions that are more effective in reducing the impacts related to food waste (e.g. embedded emissions), and (iii) the identification, at early design stages, of trade-offs between environmental/economic benefits and impacts caused/costs incurred. The second goal of this article is to present the methodology followed in the creation of the calculator and to provide an example of its application through a real-life case study.

2. Material and methods

This section presents an overview of the approach followed in the design of an evaluation framework for food waste prevention actions (Section 2.1) and in the development of a calculator to assess the economic and environmental performance of an action (Section 2.2). The calculator developed is freely available online[2]. This article follows the definition of food waste provided in the amendment to Directive 2008/98/EC on Waste (European Commission, 2018).

2.1. Evaluation framework development

The evaluation framework for food waste prevention actions was developed through an iterative process (presented in detail in Caldeira et al., (2019)) and thanks to the contribution of several stakeholders (food waste experts from academia and members of the EU Platform on FLW including Member States representatives, private organizations, NGO's, and food business operators). Initially, the literature was reviewed to identify the relevant criteria to assess the performance of prevention actions. Key studies identified were the EU Better Regulation Toolbox (European Commission, 2017), the European project FUSIONS (FUSIONS, 2016), the projects ReFED and STERFOWA (Obersteiner et al., 2016; ReFED, 2016). Based on the criteria suggested in these studies and those proposed by us, a first draft of the framework was developed and presented in an expert workshop[3] that took place on the 13th of September 2018 at the EC-JRC premises in Ispra (Italy). The resulting discussion led to the refinement of the framework, which was

[2] Available under "Key recommendations for action of the EU Platform on Food Losses and Food Waste", at: https://ec.europa.eu/food/safety/food_waste/eu_actions/eu-platform_en

[3] The list of experts participating in the workshop can be found in the acknowledgments.

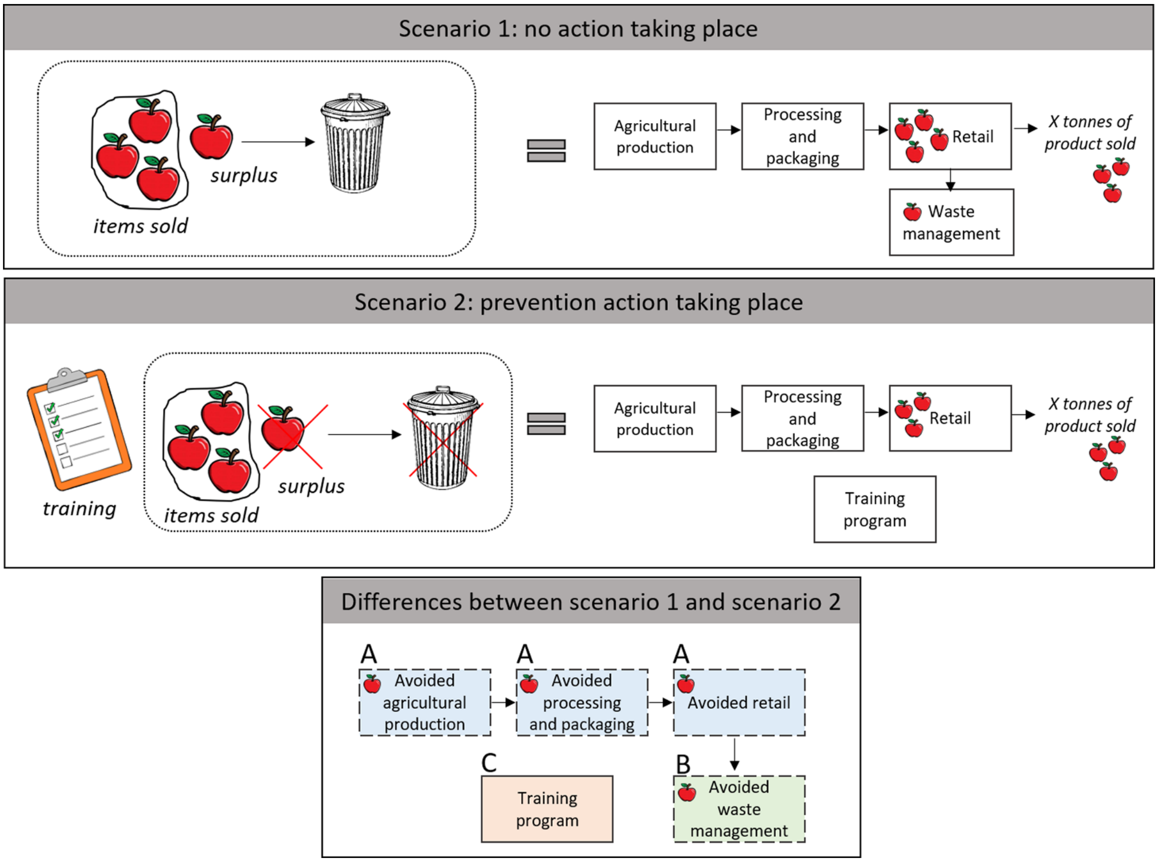

Figure 1. Graphical representation and conceptual framework for the assessment of economic and environmental benefits of food waste prevention actions achieving reduction at source. Blue shaded (component A) and green shaded (component B) boxes are savings (both economic and environmental) obtained by implementing the action while orange shaded boxes (component C) are additional burdens caused by the action.

then presented to the members of the EU Platform on FLW and subsequently refined further. Envisioning the notable diversity of food waste prevention actions, criteria relevant for all types of actions were selected. Hence, the framework was developed to enable the assessment of different types of actions in a consistent way. A reporting template was developed to collect information on food waste prevention actions for their assessment according to the framework developed. A total of 91 actions were collected through the reporting template, and their performance was assessed based on the criteria set in the evaluation framework. These included initiatives focusing on the redistribution of surplus food from manufacturing, retail and food services to people in need, initiatives avoiding at source the generation of food waste by nudging a behavioural change in citizens, and initiatives that enabled preventing food waste by increasing the efficiency of food production processes, e.g. at manufacturing or in commercial kitchens. This process enabled to validate and test the evaluation framework developed. The resulting evaluation framework is presented in Section 3.1.

Additionally, a calculator was developed to support the evaluation of food waste prevention actions for two of the criteria considered in the assessment, the environmental and economic efficiency of an action (i.e. environmental and economic benefits obtained per unit of resources invested); this is presented in detail in the following section.

2.2. Development of the food waste prevention calculator

The food waste prevention calculator is an Excel-based tool built to enable non-experts to assess the net economic benefits and net environmental savings deriving from the implementation of an action. It was developed to support the assessment of the economic and environmental efficiency of an action. Furthermore, it enables the early identification of potential trade-offs (i.e. situations in which the costs – economic or environmental - outweigh the benefits). With this in mind, the calculator was designed to be easy to use, to require readily available input data and provide proxy data to fill potential data gaps (i.e. information not known to the user), and to present the results of the analysis in a comprehensible way.

The user is asked to provide the following inputs to perform the analysis:

- Country where the action takes place
- Type of food waste prevention action
- Stage of the FSC where the food waste is prevented
- Cost of implementing the action
- Resources needed to implement the action (e.g. number of leaflets, kilometres of transport, electricity used)
- Waste treatment that would have been used if the food had been wasted
- Types and quantities of food items saved (choosing from a list of 32 food commodities)
- Economic value of the food items saved

The calculator includes some proxy data to be used when the last three elements of the list are not known (i.e. the waste treatment option, the types of food items saved, and their economic value). Regarding the type of food waste prevention action, the user can choose from a list of five types of actions (redistribution, consumers behaviour change, supply chain efficiency, and food waste prevention governance) following the classification presented in Caldeira et al. (2019). Although this information is not needed to perform the calculation, it is asked for completeness of reporting. Sections 2.2.1 and 2.2.2 present the rationale adopted in performing the economic and environmental assessment, respectively, the data sources, and underlying assumptions taken to fill data gaps.

2.2.1. Economic assessment

The implementation of a food waste prevention action will have some associated costs and in return, if successful in achieving a food waste reduction, will bring some economic benefits related to not wasting food that has an economic value and not having to cover disposal costs. The purpose of this assessment is to evaluate if the savings outweigh the costs, in order to assess the economic feasibility of implementing an initiative.

The assessment is conducted for two different groups of actions: prevention at source and redistribution. The first is a group of actions that enable to avoid the generation of surplus food that might become food waste, while the second is a group of actions that take care of the surplus food already generated and avoid its becoming food waste by redistributing it for human consumption.

The conceptual framework adopted to perform the economic assessment is illustrated in Figure 1 for prevention at source actions and Figure 2 for redistribution actions. For illustrative purposes, the prevention action represented in Figures 1 and 2 is taking place at the retail stage; however, the same rationale would apply to all stages of the supply chain.

In conducting the assessment, three elements are considered:

A *The avoided costs of producing and distributing the food items saved up to the point of the food supply chain where the food waste is avoided (light blue shaded boxes in Figures 1 and 2).*

The embodied cost of food items can be determined based on their market price. This can be provided by the user, or alternatively it is derived by the calculator based on the average market value of 32 food commodities in each European country (when such information was available from the sources consulted) and at three steps of the FSC. To this end, the selling prices of agricultural commodities were used to estimate the value of food items at primary production and processing stages, the selling prices of processed food were used to estimate the value of food items saved at retail stage, and supermarket food prices provided an estimate of the value of food items at consumption stage. Such values (provided in SI file 2) were taken from several statistical sources (e.g. Eurostat); the full list of sources used, by food type and stage of the FSC, is provided in SI file 1, Table S1.

B *The avoided cost of disposing of the food waste (green shaded box in Figures 1 and 2).*

This is estimated by the calculator, based on the waste treatment option selected by the user and the average costs of waste treatment options at EU level, taken from Manfredi and Cristobal (2016). Waste treatment costs were derived considering the cost of waste collection, transport and treatment, existing subsidies and taxes. The calculator also provides an option to select if the user does not know the relevant waste treatment option, in which case a proxy value is used. Proxy values were calculated for each EU country as a weighted average of the cost of different waste treatment options performed considering the average national mix of waste treatment options, which was derived from Eurostat for food items wasted at industrial level and within urban waste collection systems (Eurostat, 2019).

C *The cost of implementation of the action (orange shaded box in Figures 1 and 2).*

This includes the cost of all the activities put in place to implement the action and needs to be provided by the user to perform the calculation.

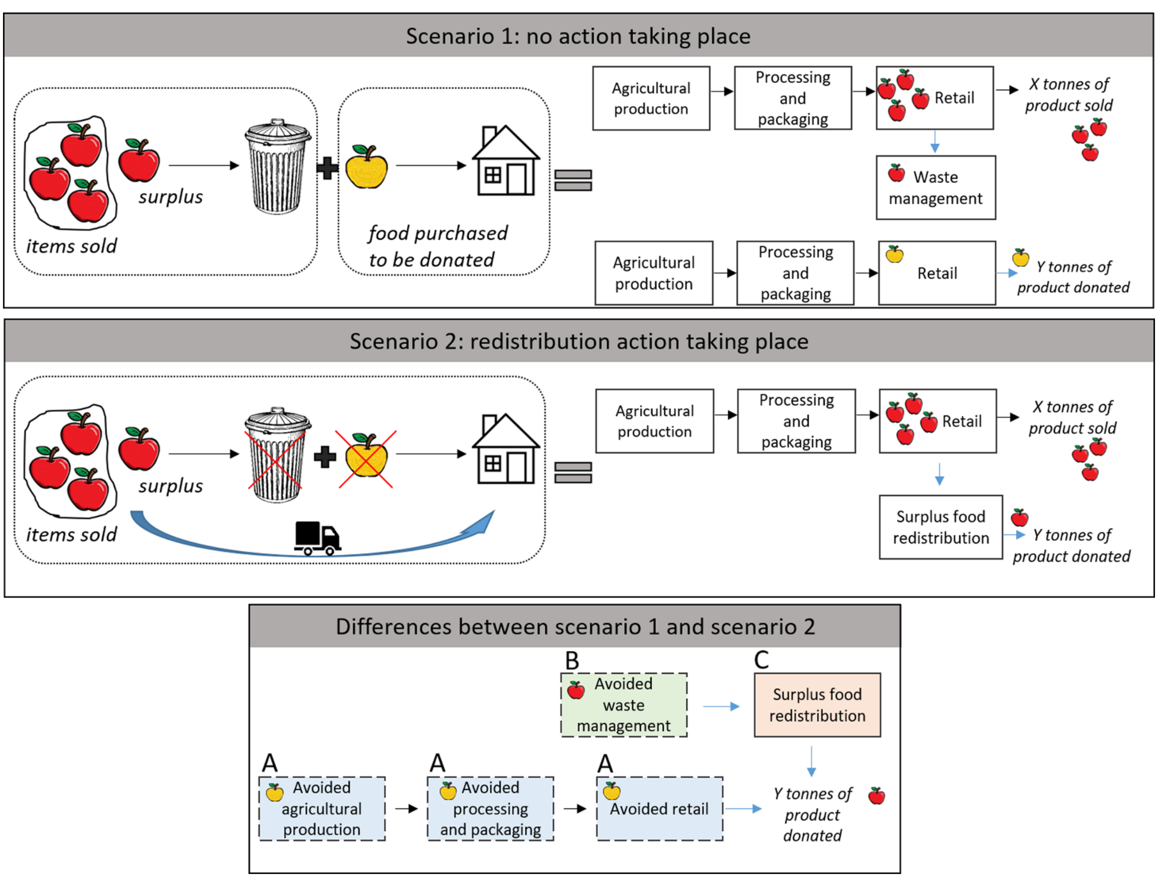

Figure 2. Graphical representation and conceptual framework for the assessment of economic and environmental benefits of actions based on the redistribution of surplus food. Blue shaded (component A) and green shaded (component B) boxes are savings (both economic and environmental) obtained by implementing the action while orange shaded boxes (component C) are additional burdens caused by the action.

All costs and savings refer to the output of the action in a selected period of time (e.g. 500 tonnes of fruit saved from being wasted), defined as the functional unit of the analysis. An overview of the proxy data used and its sources is provided in Table S2.

As an example, Figure 1 compares a 'no-action scenario', in which a certain amount of surplus food is wasted, with a 'prevention action scenario' in which, due to a training activity there is no generation of surplus food, and therefore the food waste was prevented at source. The differences between the two scenarios are that in the second costs linked to the production, distribution and retail operations of the items saved are avoided (element A), costs linked to the waste management operations of the items saved are avoided (element B) and there are some additional costs due to the training activities (element C). Similarly, Figure 2 provides an illustrative example of a comparison between a 'no-action scenario' and a 'redistribution action scenario'. In the first scenario surplus food generated is wasted and, in parallel, similar food items are purchased by a charitable organisation to be donated to families in need. In the second scenario the surplus food items are diverted to a charity to be donated to families in need. This is based on the assumption that in the absence of organisations redistributing surplus food, charitable organisations would need to purchase food to donate it to people in need. The differences between the two scenarios are that in the second, costs linked to the production, distribution and retail operations of the items purchased to be donated are avoided (element A), costs linked to the waste management operations of the items redistributed are avoided (element B), and there are some additional costs due to the redistribution activities (element C).

In both cases, the net economic benefits are calculated by adding together elements A and B and subtracting element C. The main difference between the assessment of these two typologies of actions is that for prevention at source actions element A refers to the cost of producing the food items of the system under study, while for redistribution actions it refers to the cost of producing alternative food items that are hypothetically replaced by the food items saved. It is important to stress that this calculator was not designed to assess food waste valorisation actions. An example of such a calculator can be found at REFRESH (2018).

2.2.2. Environmental assessment

An action successful in achieving a food waste reduction will bring an environmental benefit by avoiding the impacts embedded in the food items saved and the impacts of the waste management operations and might cause some additional environmental impacts due to the energy and material resources used when implementing the action. The environmental assessment is performed by using LCA, following the conceptual framework described in section 2.2.1 and illustrated in Figure 1 and Figure 2 for actions achieving, respectively, prevention at source of food waste and redistribution of surplus food. To this end, the life cycle impacts of the three following components are considered:

A *The avoided impact of producing and distributing the food items saved up to the point of the FSC where the food waste is avoided (light blue shaded box in Figures 1 and 2).*

In the case of actions causing prevention at source of food waste, this element refers to the life cycle impacts of the food items saved, while in the case of redistribution actions it refers to the life cycle impacts of the items replaced by the ones redistributed (following the logic presented in Section 2.2.1). The calculation of this component is based on the amounts and types of food items saved and the stage of the FSC where the food waste is avoided (information provided by the user). The background data used to perform this calculation are the environmental impacts of 32 food commodities, taken from Sinkko et al., 2019, representing the impacts of food consumption of an average European citizen. Environmental impacts were calculated using LCA modelled with SimaPro 8.5 software (Pré-Sustainability, 2018), and encompass six stages of the FSC (agricultural production, processing, packaging, retail, use, and end of life), as presented in Notarnicola et al. (2017), Sinkko et al. (2019) and Crenna et al. (2019). The impact assessment method used is the Environmental Footprint (version 2.0), which recommends a set of sixteen midpoint impact categories (EC-JRC, 2019; European Commission, 2013). The reader is referred to Crenna et al. (2019) for a detailed explanation of the modelling approach and underlying data sources. The calculator also provides an option to select when the user does not know the types of food items saved. In this case, the impacts are calculated as a weighted average of the 32 food items recorded in the calculator considering the average EU food consumption in 2015, as modelled in Sinkko et al. (2019).

B *The avoided impact of the food waste disposal (green shaded box in Figures 1 and 2).*

Environmental impacts of waste treatment operations are calculated for five different waste treatment options (landfill, composting, incineration, anaerobic digestion, and wastewater, including drinks wasted through the sink), as presented in Notarnicola et al. (2017). Additionally, average values of waste treatment impacts were calculated for each European country considering the relative share of each treatment option (both for agricultural, industrial and municipal waste), to be used as proxies when the waste treatment option is not known. It is important to stress that the environmental impacts of waste treatment options are calculated as in Notarnicola et al. (2017), and therefore do not account for differences in the performance of waste treatment plants across EU countries. Environmental impact values of the waste treatment options considered can be found in SI file 2.

C *The impacts caused by the implementation of the action (orange shaded box in Figures 1 and 2).*

This element is estimated considering three proxies: the transport distances, the electricity used, and the amount of paper used (expressed as number of leaflets). Information on the resources used is provided by the user and is then combined with the average impacts associated with: 1 km of transport in a passenger car, 1 kWh of electricity consumed, and the production of 1 A4 of printed paper. Background data were taken from the Ecoinvent 3 database (Wernet et al., 2016). The list of proxies might be expanded in a future version of the tool to enable a more comprehensive assessment of the action impacts (e.g. by including water use, changes in the use of packaging). An overview of the proxy data used in the calculation is provided in Table S2 of SI file 1, and the environmental impact values used are provided in SI file 2.

For both typologies of action, net environmental savings are calculated by adding together elements A and B and subtracting element C.

This last element enables the identification of environmental trade-offs caused by a prevention action, to avoid situations in which the environmental impact caused by its implementation might outweigh the benefits obtained.

2.3. Case study application

For illustrative purposes, one of the 91 initiatives submitted through the EU Platform on FLW and evaluated by the EC-JRC with the evaluation framework presented in this article (exercise described in detail in Caldeira et al. 2019), was selected to demonstrate the application of the assessment framework and the use of the food waste prevention calculator. The initiative selected is the Gothenburg model for reduced food waste, which took place in Gothenburg (Sweden) between 2014 and 2018. The Gothenburg model is a procedure developed by the City of Gothenburg in 2014-2015, providing tips and measures to reduce food waste in the public food sector, that was implemented in approximately 520 public kitchens. The City of Gothenburg trained 40 key employees in all city districts to coordinate the development of the programme and approximately 1200 employees to implement the model as a daily routine. The aim of this initiative was to obtain a 50% reduction of the food waste generated during procurement, storage, preparation, and serving of the meals (i.e. excluding plate waste), by December 2018 against a baseline of January 2017. To track progress towards this target, the public kitchens taking part in the programme were asked to measure daily the food waste generated and register it in a meal planning software system. Furthermore, two surveys were conducted: the first during the training session and the second a few months later, to establish the effectiveness of the training program.

The following data was used to perform the calculation of the economic and environmental performance of this initiative, referring to the years 2017 and 2018:

- The amount of food waste avoided over the two years
- The economic value of the food waste prevented
- The cost of the initiative
- The waste treatment option used
- The resources used to run the initiative

3. Results and discussion

The resulting evaluation framework is presented in Section 3.1, while the food waste prevention calculator is presented in Section 3.2, followed by an example of its application through a case study (Section 3.3). Section 3.4 discusses the potential use of these tools, providing some suggestions for the design, monitoring and reporting of food waste prevention actions to ensure their consistent evaluation.

3.1. Evaluation framework

The evaluation framework developed is based on six criteria: quality of the action design, effectiveness, efficiency, sustainability of the action over time, transferability and scalability and intersectorial cooperation (Figure 3). Two of the criteria selected (effectiveness and efficiency) are quantitative, whereas the remaining four are qualitative.

The first criterion is the **quality of an action design**. This is considered good when actions clearly define their aim, objectives (and related targets), a strategy and implementation plan to achieve them, key performance indicators (KPIs) and a monitoring system to track progress towards the achievement of the targets set. The effectiveness and efficiency (second and third criteria) can be assessed only for those actions clearly setting objectives and targets, and monitoring and reporting their performance through relevant KPIs.

The **effectiveness** of an action is defined as the degree to which it was successful in producing the desired results, as defined by the objectives and related targets set upfront. Targets should ideally be set on reducing the food waste generated against a baseline measured before the start of the action (e.g. to reduce by 50% the total amount of food waste generated in 2020 compared to 2019). However, for some types of actions (e.g. an awareness campaign) it might be challenging to estimate the amount of food waste prevented as a result of the action. In this case other outcomes may by measured instead (e.g. the number of people reporting a change in behaviour as a result of the campaign).

The **efficiency** of an action is defined as the capacity to reach a desired outcome with the least effort. To measure it, all the resources used to implement the action should be accounted for, including the design and investment cost, operational costs, and, if relevant, the economic value of resources made available free of charge (e.g. volunteer hours, donated equipment). These need to be compared with the results of the action, in terms of: food waste prevented, net economic benefits, net environmental savings, social benefits, and outreach impact. For the assessment of an action's efficiency, it is key to measure the amount of food waste prevented, by implementing a monitoring system, as this information is required to assess the net economic benefits and net environmental savings of an action.

Net economic benefits represent the economic savings to society, calculated considering the value of the food saved and the cost of the waste treatment operations, minus the cost of the action implementation. Net environmental savings are measured as the avoided environmental impact (due to the avoided production of the food items and the avoided waste treatment) minus the environmental impact caused by the action's implementation. Both components can be assessed by using the food waste prevention calculator as presented in Section 2.2. Social benefits can be measured in terms of jobs created, meals donated, food insecure people supported or people learning new skills. The outreach impact of an action describes the number of people reached by the initiative, who report either having become more aware of the issue of food waste or having changed behaviour accordingly. When comparing the results of an action with the resources used, to calculate its efficiency, it is key that both elements are referred to the same timeframe.

The **sustainability of an action over time** refers to the potential of an action to be maintained over time and is assessed considering if the following elements are in place: organisational support for the action, the availability of financial and human resources, skills and knowledge, and the existence of a long-term strategic plan.

The **transferability and scalability** of an action are the degree to which actions have been transferred to a different context or have grown since the start, or the degree to which the possibility of transferring the action to a different context or upscaling it was considered in the design phase.

The **intersectorial cooperation** criterion assesses if the action is the result of the cooperation between different sectors of society and if this is the case, what were the specific roles and responsibilities of the different actors involved.

For more information on the application of the evaluation framework the reader is referred to Caldeira et al. (2019), where the evaluation of 42 food waste prevention initiatives according to the framework is presented in factsheets.

3.2. Food waste prevention calculator

Figure 4 illustrates the user interface of the calculator, through which the user can input the data required to perform the analysis and is provided with the results of the economic and environmental assessment both in the form of bar charts and tables. The results of the environmental assessment are provided for each of the 16 impact categories analysed, which can be selected through a drop-down menu (in Figure 4 results are presented for the impact category climate change). Additionally the user can access a user guide explaining how to use the calculator and can print a document that provides an overview of the input data and of the results and that provides a table and plots of the impact values calculated for the full list of impact categories.

3.3. Case study results

The Gothenburg model for reduced food waste presented a good level of technical quality, as it defined a baseline (the average food waste per meal in January 2017), a goal (i.e. to obtain a reduction of 50% of the food waste generated during procurement, storage, preparation and serving of the meals by December 2018 against a baseline of January 2017), and a monitoring system to track progress towards achieving this goal. According to the information provided by the City of Gothenburg, the food waste generated by the public canteens in the city went from 30 grams per serving at the start of the program (January 2017) to 15 grams per serving (at the end of 2018), and therefore the action can be considered effective in achieving this goal.

Based on the variation of the average waste per serving and the number of meals served, a total food waste reduction of 387 tonnes was estimated over the two years analysed (Backlund and Östergren, 2020). In the first two years of the implementation, the economic savings caused by the food waste reduction alone (implying that less food needed to be

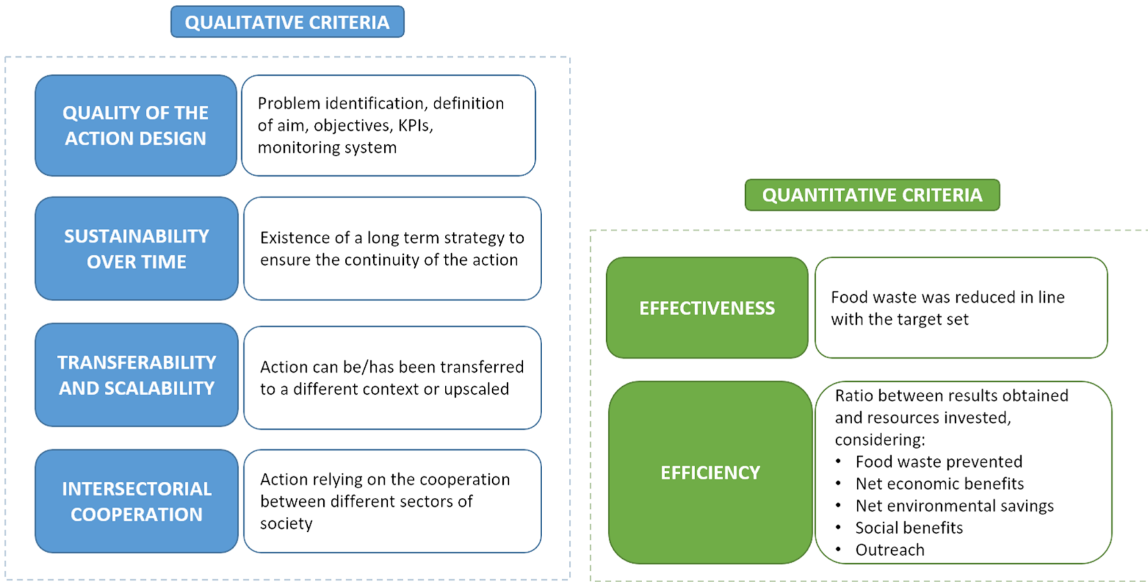

Figure 3. Evaluation framework for food waste prevention actions. Adapted from Caldeira et al. (2019).

purchased by the public kitchens) outweighed the cost of implementation of the action. The cost of the action from the start (2016) up to the end of 2018 was 5.7 million SEK, equal to approximately 555,000 euros. The food waste avoided was roughly worth 11.6 million SEK (considering that the average cost related to the purchase of raw materials per tonne of food prepared was estimated as 30,000 SEK), equal to approximately 1,130,000 euros. If the avoided cost of treating the food waste avoided is considered (estimated as 75,000 euros), the total net economic benefit of implementing the initiative was 650,000 euros. Due to lack of data, the avoided costs relating to cooking the additional food (both due to energy consumption and staff related costs), could not be considered. Including such figures would have resulted in a higher economic benefit. Additionally, if the initiative was successful in changing the operations of the public kitchens permanently, the net economic benefits in the following years would be higher as most of the costs were related to designing the procedure, preparing the training materials and performing the training activities, which would no longer need to be sustained. Nevertheless, it is important to keep in mind that the costs linked to monitoring food waste generation would still need to be sustained to ensure the long-term impact of the initiative.

As no information was available on the detailed breakdown of the food waste avoided by food types, the estimation of the environmental savings linked to the food waste avoided was done considering the average impact of 1 kg of food consumed by a EU citizen (as explained in Section 2.2). As different types of food present significantly different embedded impacts, this is a critical assumption, and, ideally, this information should be known to ensure better quality of the results. The avoided impacts related to the waste treatment process were calculated considering that, had the food been wasted, it would have been treated with anaerobic digestion (Linnerhag, 2019).

Finally, the environmental impact linked to the implementation of the initiative was quantified considering the main materials used in the training programme. These were: information leaflets (2,000 copies made of four A5 sheets), participation awards (1,800 copies made of one A4 sheet), and a hard copy of the Gothenburg model procedure for each kitchen (700 copies, each containing 24 A4 sheets) (Linnerhag, 2020). To enable the calculation of environmental impacts using the calculator, these quantities were converted into their total expressed in A4 equivalent, resulting in 29,880 sheets of A4 sized paper.

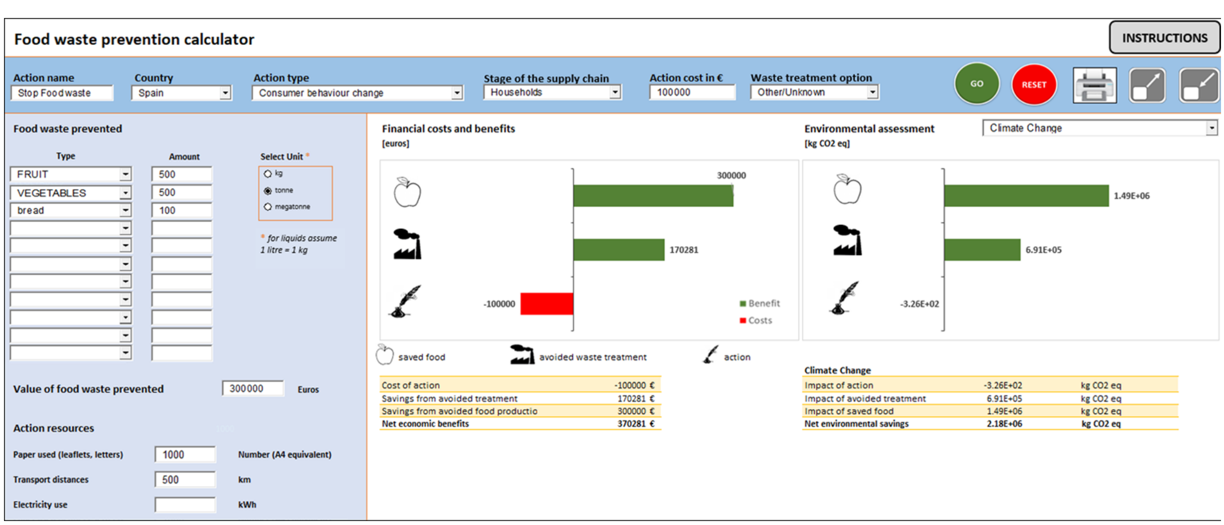

Figure 4. User interface of the food waste prevention calculator for the assessment of net economic benefits and net environmental savings of food waste prevention actions.

Table 1
Overview of the environmental assessment of the food waste prevention initiative "the Gothenburg model for reduced food waste", components A, B and C are described in section 2.2.2.

Impact category	Unit	Impact of saved food (A)	Impact of avoided treatment (B)	Impact of action (C)	Net environmental savings (A+B-C)
Climate Change	kg $CO_{2\ eq}$	1.58E+06	1.78E+05	3.92E+03	1.76E+06
Ozone depletion	kg CFC-11 $_{eq}$	2.19E+00	4.39E-03	2.63E-04	2.19E+00
Human toxicity, non-cancer effects	CTUh	1.24E+00	9.53E-02	6.34E-04	1.33E+00
Human toxicity, cancer effects	CTUh	1.89E-02	2.00E-02	4.69E-05	3.89E-02
Particulate matter	Disease incidence	1.61E-01	7.73E-03	2.83E-04	1.68E-01
Ionizing radiation HH	kBq $U^{235}{}_{eq}$	3.24E+04	3.23E+03	2.12E+02	3.54E+04
Photochemical ozone formation	kg NMVOC $_{eq}$	2.72E+03	4.53E+02	1.15E+01	3.16E+03
Acidification	molc H+ $_{eq}$	2.20E+04	8.60E+02	2.50E+01	2.28E+04
Terrestrial eutrophication	molc N $_{eq}$	9.32E+04	2.47E+03	3.92E+01	9.57E+04
Freshwater eutrophication	kg P $_{eq}$	4.17E+02	2.20E+02	2.33E-01	6.37E+02
Marine eutrophication	kg N $_{eq}$	1.03E+04	1.83E+02	3.75E+00	1.05E+04
Freshwater ecotoxicity	CTUe	7.91E+06	5.38E+06	4.38E+03	1.33E+07
Land use	Pt	1.51E+08	2.51E+06	3.30E+05	1.54E+08
Water scarcity	m3 water $_{eq}$	3.22E+06	1.24E+04	2.09E+03	3.23E+06
ADP Fossil	MJ	9.28E+06	-1.16E+06	6.48E+04	8.05E+06
ADP (ultimate)	kg Sb $_{eq}$	1.54E+00	8.69E-02	8.11E-03	1.62E+00

Table 1 presents an overview of the results of the environmental assessment for the 16 impacts categories considered. It is possible to see that for all the impact categories the environmental benefits outweigh the burden caused by the initiative, in other words, there are no environmental trade-offs linked to the implementation of this initiative.

As the costs of the action were outweighed by the economic savings from the avoided food purchases, the action is considered to be sustainable over time. Additionally, to ensure that the long-term effects of the action are maintained, the material developed during the project will be used by the kitchens in Gothenburg City and food waste will be measured and reported by kitchens and followed up centrally once every six months (Backlund and Östergren, 2020). Regarding the transferability and scalability of this initiative, it was reported that several other municipalities make use of the Gothenburg Model for reduced Food Waste and that this initiative inspired parts of a model launched by the Swedish Food Agency at national level to measure and reduce food waste in municipal restaurants and canteens (Swedish Food Swedish Food Agency, 2020). Finally, although the initiative was mainly conducted within the public food service of the City of Gothenburg, it presented a degree of intersectorial cooperation as it encouraged the cooperation of different city districts towards a common goal of food waste reduction.

3.4. Suggestions for the design, monitoring and reporting of food waste prevention actions

A major outcome of this work was the identification of the necessary elements that need to be in place to enable the assessment of the performance of a food waste prevention action using the evaluation framework and the food waste prevention calculator developed. These elements should be taken into account in the design stage, to ensure that the action planning, implementation, and reporting provide sufficient information, and that the selected KPIs are measured in a consistent way throughout the action development and across similar actions. This would enable to compare different initiatives and ultimately to identify the best performing ones. The high diversity of existing food waste prevention actions has set the need for establishing an evaluation framework flexible enough to be used to assess all types of actions. Nevertheless, when assessing the different criterion, the indicators used should be tailored to the type of action, in particular in the case of the effectiveness and efficiency criteria. To this end, suggestions are provided for the design, monitoring, and reporting of actions and for the selection of promising KPIs to be used to measure effectiveness and efficiency for three main types of actions: initiatives to redistribute surplus food, actions preventing food waste at source by increasing the efficiency of the supply chain and actions preventing food waste at source by influencing the behaviour of consumers.

For redistribution actions, the amount of food redistributed can be easily (and often is) measured, in terms of weight, number of portions, or considering its total economic value. The amount of food redistributed is a good KPI to measure both effectiveness, by setting a target on increasing such an amount against a baseline, and efficiency, e.g. by comparing the total food redistributed in one year with the related costs. As the purpose of redistribution actions is often to support people in need, another promising KPI is the number of food insecure individuals reached (assessing the social impact of the action).

For actions preventing food waste at source by increasing the efficiency of the activities undertaken by food business operators (e.g. farmers, food manufacturers, retailers and food services) it is crucial to select KPIs that are not influenced by changes in production/sales volumes. For instance, at primary production or manufacturing, targets can be set on reducing the food waste generated per unit produced, at retail the food waste generated per unit sold and at food services the average food waste per meal served. Similarly, when assessing the efficiency of this type of actions, the total amount of food waste prevented should be estimated taking into account that the level of production varies from year to year (a detailed example of how to calculate this is provided in Annex 7 of Caldeira et al. (2019)).

In the case of actions that achieve prevention at source by influencing the behaviour of consumers, it might be more challenging to assess the amount of food waste avoided due to the intervention, although whenever possible priority should be given to this type of assessment. A good KPI is the amount of food waste generated in one year by a household (for initiatives targeting food waste generated at home) or the amount of plate waste generated per meal (for initiatives targeting food waste generated in food services). The REFRESH project recently published a reported providing guidance specifically for the evaluation of household food waste prevention (Quested, 2019). When the food waste prevented cannot be quantified, effectiveness can be measured by tracking through time KPIs such as 'the share of the targeted population aware of the campaign' or reporting a change in behaviour as a result of the campaign.

It is suggested that relevant KPIs are selected in the design stage, and are measured before the start of the initiative, enabling to set a baseline. The monitoring of KPIs should then take place during the action development and after it is concluded, to assess whether the targets set were achieved, to evaluate the action's efficiency and its long-term impact. Only a transparent and comprehensive reporting of the performance of prevention initiatives, and their assessment according to a unique evaluation procedure, can ensure that future evaluations exercises will shed a light on which typologies of actions are more successful and should be replicated in a new context. It is to respond to such a need that the evaluation framework suggested in this article was conceived.

The exercise conducted by EC-JRC on the collection and analysis of food waste prevention initiatives clearly showed how the outcomes of current initiatives are rarely monitored and reported systematically through relevant KPIs to enable a full assessment of their performance according to the evaluation framework suggested. The most critical criterion to assess was the actions' effectiveness, as in few cases a food waste prevention target had been set upfront, a measurement of the baseline situation had been conducted and a monitoring approach put in place to track the generation of food waste. The assessment of the action's efficiency was also critical as often the cost of the action was provided without taking into account the economic value of resources made available free of charge (e.g. volunteer hours, donated equipment); in other cases it was critical to extrapolate the costs of the initiative from a company's operational costs (when the activities were conducted by members of staff as part of their daily operations), furthermore costs and economic benefits provided were not always referred to the same timeframe, and the total food waste prevented was often not quantified.

The development and testing of the evaluation framework led to the identification of the most common challenges encountered in the evaluation of food waste prevention initiatives. These include the ability to single out the effect of an action in cases where several initiatives are conducted in parallel (e.g. in a national food waste prevention programme) and all together contribute to a reduction in food waste generation, and also to distinguish between the effect of a specific initiative and other contextual factors (e.g. economic recession) on the reduction in the observed levels of food waste, also reported by Goossens and colleagues (2019). Another crucial challenge is how to take into account the contribution of volunteers in the assessment of the efficiency of an action (in particular for redistribution actions which often rely on volunteer work). If on one hand volunteers do not represent an economic burden in the implementation of an initiative (as opposed to hired staff), their involvement in terms of time and human resources should beyond doubt be taken into account when assessing the efficiency of an action. An initial suggestion is to monetise these resources by considering the total hours worked by volunteers and the gross minimum hourly wage in the country where the initiative is taking place, but this approach could be refined. An additional challenge is to quantify the amount of food waste prevented by food business operators independently from variations in production/sales volumes. If an initiative is evaluated without taking into account this element (by simply comparing the food waste generated in one year against the baseline year), and then the evaluation is repeated including such considerations (e.g. by comparing the food waste per unit of production generated in the two years), the results might be significantly different (even showing opposite trends) if the production volumes have changed significantly between the two years considered.

Two elements for further consideration were identified when testing the evaluation framework. The first is that such evaluation might not capture situations in which an initiative might reduce food waste at the stage of the FSC where it takes place by shifting its generation to another level of the FSC (e.g. in the case of initiatives encouraging restaurant guests to take their leftovers home, which might then still be wasted at household level). The second, more broadly related to food waste prevention, is the occurrence of possible rebound effects: situations in which the avoidance of food waste in households causes an increase in the disposable income that could be potentially spent on other products or services, which might have higher environmental impact (Salemdeeb et al., 2017). Care should be taken in the design phase of the action to avoid as much as possible such unintended consequences. For instance, initiatives encouraging restaurant guests to take home their leftovers could be combined with the resizing of portions, to avoid at source the generation of leftovers. In order to limit rebound effects, an awareness campaign to reduce household food waste could encourage citizens to purchase less but better quality and/or certified (e.g. fair trade) food.

4. Conclusions

Scientific research on the effectiveness of food waste prevention initiatives is in its early stages, and existing studies have identified the need to evaluate consistently such actions to reach sound conclusions and prioritise efforts. This work paves the way in this direction, by suggesting a common approach to consistently assess the performance of a broad range of food waste prevention initiatives, and by identifying the data needed to support such assessment.

This was achieved by developing an evaluation framework assessing the performance of food waste prevention actions, and a calculator, supporting the quantification of the economic and environmental benefits of implementing such initiatives, as part of the evaluation procedure. The calculator, built on the principle of life cycle thinking, ensures that different actions are assessed in a consistent manner, and, if used in early design stages, can help identifying potential trade-offs. To the best knowledge of the authors, this is the first time that a concrete method has been proposed to compare environmental benefits and burdens caused by food waste prevention. We believe this aspect to be of particular interest to the scientific community as it represents a potential application of life cycle assessment little explored thus far.

A key outcome of this work is the identification of the necessary elements that need to be in place to enable the evaluation of a food waste prevention action. These include a quantification of the food waste generated through time (before, during and after the end of the initiative), which, when relevant, should be assessed taking into account variations in production/sales volumes, and a comprehensive assessment of the economic, material and human resources used (including those made available free of charge). Suggestions are provided on which key performance indicators are better suited to monitor different types of food waste prevention initiatives and track their progress against a baseline situation.

The outcome of this exercise served as a starting point for the development of recommendations for action by public and private stakeholders in food waste prevention, published by the EU Platform on FLW in December 2019. Recommendations were defined for each stage of the food supply chain. Additionally, a set of 'cross-cutting' recommendations, common across various stages of the food value chain and often involving multiple actors, were defined (EU Platform on Food Losses and Food Waste (FLW), 2019). It is expected that, based on this joint effort, future food waste prevention initiatives will be designed, monitored and reported in such a way to enable practitioners and decision makers to evaluate their success, identify trade-offs, compare similar initiatives and prioritise promising actions, ultimately contributing to the achievement of SDG target 12.3.

CRediT authorship contribution statement

Valeria De Laurentiis: Writing - original draft, Writing - review & editing, Formal analysis, Investigation, Visualization. **Carla Caldeira:** Formal analysis, Methodology, Writing - review & editing. **Serenella Sala:** Conceptualization, Methodology, Validation, Writing - review & editing.

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.

Acknowledgments

This publication is part of a project on the assessment of food waste prevention actions financially supported by the Directorate-General for the Health and Food Safety of the European Commission in the context of the Administrative Arrangement “Prevent Food Waste – Support to the European Platform on Food Losses and Food Waste” (contract n° 2018 SI2.776026). The authors of this article would like to thank Hilke Bos-Brouwers (Wageningen UR, NL), Richard Swannell (WRAP, UK), Alba Cánovas (Espigoladors, ES), Hector Barco Cobalea (Universidad de Deusto, ES), Fabio De Menna (University of Bologna, IT), and Morvarid Bagherzadeh (OECD) for their participation in the expert workshop, and the valuable comments they provided on the food waste prevention actions evaluation framework, Christina Linnerhag (Gothenburg City Council, SE) for her availability and support in providing information for the case study analysis, and Karin Östergren (RISE Research Institutes of Sweden, SE) for providing insights on the case study analysis.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.104946.

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