

LOWINFOOD

**Multi-actor design of low-waste food value chains
through the demonstration of innovative solutions
to reduce food loss and waste**

GA No. 101000439

D1.8 Evaluation of the environmental impacts of innovations

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Summary

The LOWINFOOD project aims to co-design low-waste value chains in the food sector by demonstrating a portfolio of innovations that reduce food loss and waste (FLW) by prevention (e.g., prevention of surplus food at source), reuse (e.g., through food redistribution, food donation) and reprocessing (e.g., reprocessing of surplus food for human consumption). This deliverable (D1.8) entails the results of the environmental evaluation for all innovations including the data inventory and interpretation of results. It complements the results of the efficacy of innovations presented in D1.6 and socio-economic impact evaluation presented in D1.7.

The assessment employs Life Cycle Assessment (LCA) as a standardized method to evaluate the environmental impacts of the innovations across all stages of the supply chain, from raw material acquisition to waste management (cradle-to-grave). The approach of the EU Joint Research Centre (Caldeira et al., 2019) is applied to assess food waste prevention and redistribution actions. The environmental impact categories recommended in the EU Environmental Footprint (EF) method are used. Inventory data for the assessment is gathered from direct quantification, expert consultations, qualitative information from test users, and observations. The situation at baseline is compared with the situation at demonstration of the innovation.

The environmental impacts that can be attributed to food surplus and waste are significant, primarily linked to impacts from food production. Optimized redistribution and waste prevention can enhance supply chain efficiency, leading to reduced emissions and costs. The LOWINFOOD innovations indicate substantial potential for emission and cost savings by minimizing food surplus and waste. Particularly with animal-based and citrus products hotspots for prevention are identified. Global Warming Potential is the leading environmental impact. Future research should ensure consistent data quality and granularity, expand sample sizes, and include the production of electronic devices to better assess Human Toxicity and Resource depletion in environmental impact evaluations.

Introduction to the deliverable

LOWINFOOD is a project committed to co-design, together with actors of the food chain, low-waste value chains by supporting the demonstration of a portfolio of innovations in a set of value chains particularly concerned by food loss and waste (fruits & vegetables, bakery products and fish), as well as in at-home and out-of-home consumption. Each of these value chains corresponds to a single Work Package (WP) of the project. The innovations are selected among promising solutions that have already been developed and tested by some partners of the consortium, with the aim to provide the necessary demonstration and upscale to allow market replication.

The LOWINFOOD consortium comprises 28 entities, located in 13 different countries, and ranging from universities and research institutes to start-ups, foundations, associations, and companies working in the food sector. During the 52 months of the project, the partners are committed to complete 30 tasks and to deliver 60 outputs (deliverables).

WP1 is focused on the evaluation of the efficacy, the economic and social impacts as well as the environmental impacts of the innovations, based on the results achieved and data gathered in WP2 to 5 about their ability to reduce FLW. This deliverable (D1.8) entails the evaluation of the environmental impacts by describing the evaluation method applied for all innovations as well as the data inventory, results and interpretation for each innovation. This deliverable (D) is complementary with D1.6 “FLW evaluation of innovations” and D1.7 “Socio-economic evaluation of innovations”, building on the work presented in D1.1 “Methodological framework” and D1.2 “Environmental data collection protocol”. It ends with a discussion and conclusion section, which will be further examined in the concluding deliverable of WP1 (D1.9). As all LOWINFOOD partners have contributed to the elaboration of this evaluation a detailed credit authorship statement is added in the last chapter.

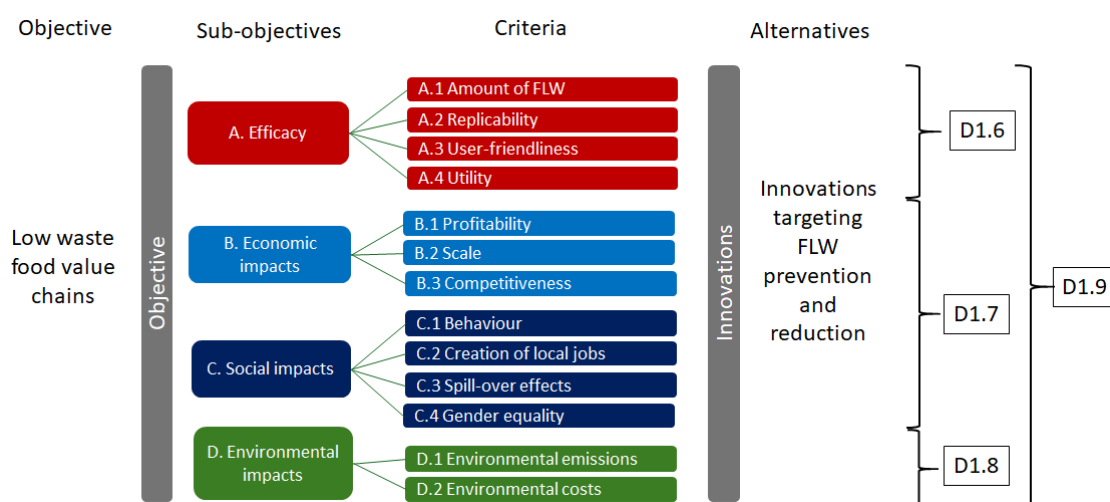


Figure 1: Target hierarchy of the evaluation of LOWINFOOD's innovations and dedicated deliverables presenting the results, the present report D1.8 covers D (green) sub-objectives

1 Innovations in LOWINFOOD

LOWINFOOD's innovations aim to reduce food waste by prevention (e.g., prevention of surplus food at source), reuse (e.g., through food redistribution, food donation) and reprocessing (e.g., reprocessing of surplus food for human consumption), and are therefore situated in the upper half of the waste hierarchy.

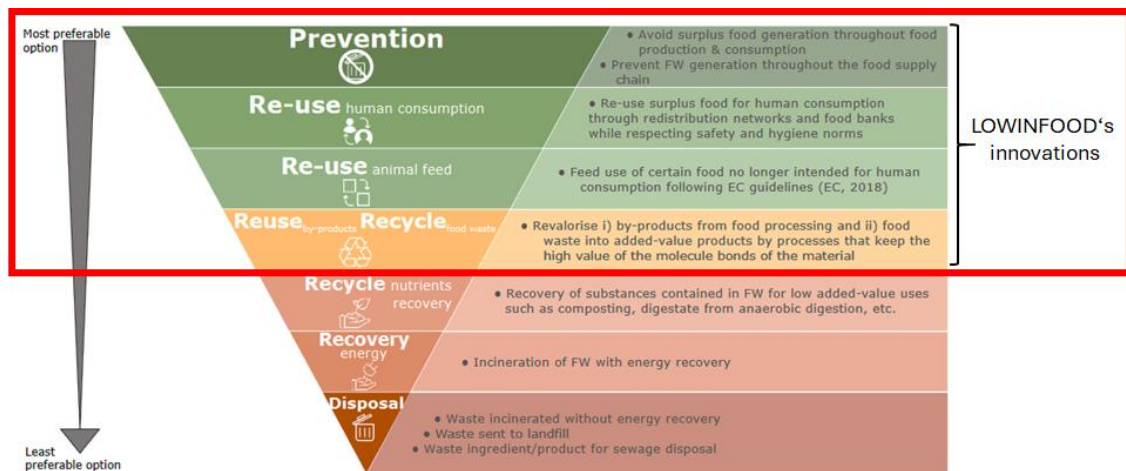


Figure 2: Hierarchy for prioritisation of food surplus, by-products and food waste (FW) prevention (European Commission, 2020) and corresponding LOWINFOOD innovations

Two scenarios are compared:

- BASELINE “no action scenario”, the system without the innovation/before the innovation was introduced.
- DEMONSTRATION “Prevention/Redistribution action scenario”, the system when the innovation was introduced.

1.1 Overview of innovations

Table 1 shows an overview of all innovations addressed in LOWINFOOD including their short name and countries, where the innovation was demonstrated.

Table 1: Overview of LOWINFOOD's demonstration of innovations and its status of implementation

WP	Task (T) No.*	Geographical scope	Innovation - Short name
WP2	T 2.1	RO	RER Software for F&V
WP2	T 2.2	AT	UNV Cooperation system for F&V
WP2	T 2.3	DE	Leroma B2B digital marketplace for F&V
WP2	T 2.4	IT	Forecasting software to reduce waste of F&V products
WP3	T 3.1	SE, FI, IT	Supplier-retailer agreements
WP3	T 3.2	SE, FI, IT	Stakeholder dialogue in the bread value chain
WP3	T 3.3	DE	FoodTracks Software for bakeries
WP4	T 4.1	DE, UK	Stakeholder dialogue in the fish value chain
WP4	T 4.2	DE, UK	Leroma B2B digital marketplace for fish
WP5	T 5.1	DE, CH, GR	KITRO Innovative food waste solution
WP5	T 5.2	DE, SE	MITAKUS Forecasting software for restaurants
WP5	T 5.3	DE, SE, AT	MATOMATIC Plate Waste Tracker
WP5	T 5.4	SE, AT	SLU/AIE Holistic educational approach
WP5	T 5.5	FI, AT, GR	CozZo Mobile App
WP5	T 5.6	IT	REGUSTO Mobile App

*AT = Austria, CH = Switzerland, DE = Germany, FI = Finland, GR = Greece, IT = Italy, RO = Romania, SE = Sweden.

**B.... Baseline measured; D... Demonstration measured; S... Baseline and/or demonstration was simulated[SP5] [NK6]

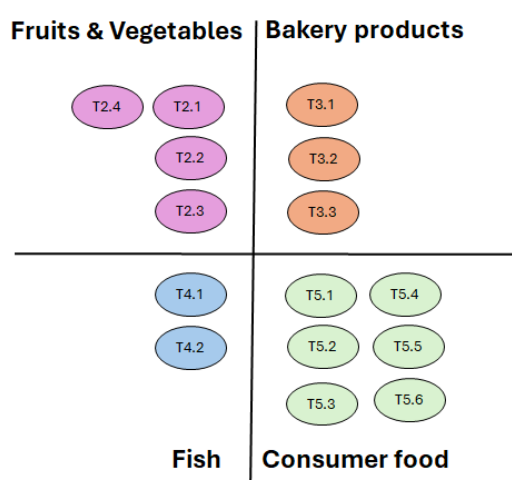
1.2 Innovation types and groups

For a better understanding of the functionalities and for the interpretation of results a grouping of LOWINFOOD's innovations is of relevance. LOWINFOOD's innovations can be grouped by the following categories:

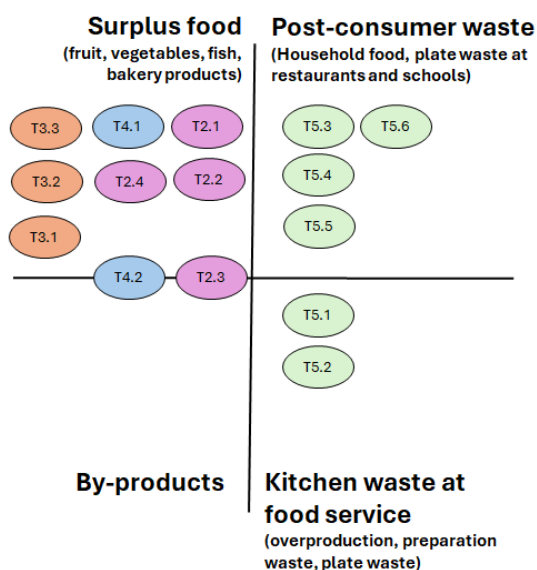
- A. Type of food (fruit & vegetables, bakery products, fish, consumer food)

- B. Type of food waste (surplus food, post-consumer waste, food by-products, kitchen waste at food service),
- C. Design of action (organisational, managerial, technological that is forecasting related, technological that is behaviour related),
- D. Type of action (according to Caldeira et al. (2019): food redistribution, consumer behaviour change, supply chain efficiency, food waste prevention governance)

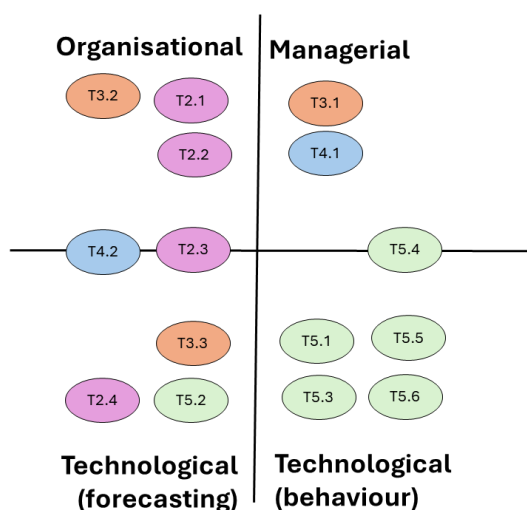
A) Grouping by type of food commodity



B) Grouping by type of food waste



C) Grouping by design of action



D) Grouping by type of action

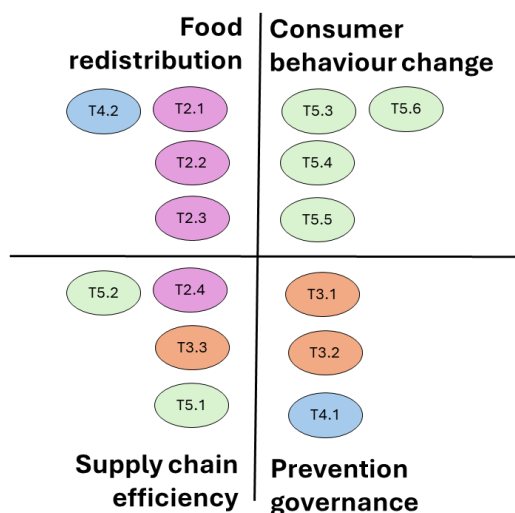


Figure 3 Grouping of LOWINFOOD's innovations by A) type of food commodity, B) type of food waste, C) design of action and D) type of action

1.3 Food loss and waste (FLW) definition and types

LOWINFOOD uses the term ‘food loss and waste’ (FLW), which refers to “any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)” (Östergren et al., 2014). This term reflects the EU definition of ‘food waste’ but also the definitions by the FAO of ‘food losses’ and ‘food waste’ (FAO, 2021).

LOWINFOOD’s innovations cover specific parts of FLW, whereby the general focus is on the avoidable part that is by definition of Quested and Johnson (2009) “food and drink thrown away that was, at some point prior to disposal, edible (e.g., slice of bread, apples, meat).” or by definition of Lebersorger and Schneider (2011) “which are still unrestrictedly edible at the time of their disposal or which would have been edible if used in time”. However, also unavoidable FLW can be covered in some innovations that is “waste arising from food or drink preparation that is not, and has not been, edible in normal circumstances (e.g., meat bones, egg shells, pineapple skin, tea bags)” (Quested & Johnson, 2009).

In the description of LOWINFOOD’s innovations a further classification of FLW is necessary:

Table 2: Type of food waste handled in LOWINFOOD’s innovations

FLW type	Description	Innovations and LOWINFOOD tasks
Surplus food	is arising in food production and distribution chain for a variety of reasons and is by definition of European Commission (2017) “consisting of finished food products (including fresh meat, fruit and vegetables), partly formulated products or food ingredients”. “Foods which do not meet manufacturer and/or customer specifications (e.g., variations in product colour, size, shape, etc.) as well as production and labelling errors can generate surplus in the agricultural and manufacturing sectors for instance. Difficulties in managing supply and demand can lead to over-ordering and/or cancelled orders.”	Surplus fruits & vegetables: T 2.1, T 2.2, T 2.3, T 2.4) Surplus bread: T 3.1, T 3.2, T 3.3 Surplus fish: T 4.1, T 4.2
Kitchen waste	is typically arising in restaurants and food service as well as households, but also in retail and other distribution sectors. Kitchen waste covers waste from overproduction, preparation waste and serving as well as plate waste. According to the waste code included in the European list of waste for types of waste which typically includes food waste, this fraction is	T 5.1, T 5.2

FLW type	Description	Innovations and LOWINFOOD tasks
	covered in “20 01 08 - biodegradable kitchen and canteen waste”.	
Plate waste	this includes food that is served but not eaten. It is a sub-category of kitchen and canteen waste. Generally, food waste in restaurants and canteens can be categorized by its receiving point (e.g., storage, preparation, dishwasher sieve, serving and plate) (C. Caldeira, Sara, & Serenella, 2017 ^[f1]).	T 5.1, T 5.3, T 5.4, T 5.6
By-products	are defined as circular flows of food removed from the FSC to be used to produce other products such as animal feed or biomaterials (Carla Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019). Although by-products are according to the EU definition not included in food waste, it is often classed and reported as waste in industrial context (Corrado et al., 2019).	T 2.3, T 4.1, T 4.2
Food waste at household (or post-consumer food waste)	this includes food damaged due to lack of cooling/storage facilities; food not eaten e.g., due to excess, elapsed expiration date, low consumer appeal, and plate waste; and inedible food waste (fruit kernels, bones, etc.)	T 5.5
Food losses	pre-harvest losses, i.e., losses that occur before the raw material is ready for harvest or slaughter, such as weather-related damage to crops (which is accounted for as agricultural waste) [SS2] [NK3]	T 4.1, T 4.2 T 2.2

2 Evaluation method

The production of food demands a lot of resources and energy which results in the release of emissions, especially of greenhouse gas (GHG) emissions in the form of methane and nitrous oxide from livestock farming and the use of fertilizers. Emissions are in vain when the food is not eaten but wasted instead. It becomes apparent, reducing FLW can decrease emissions and thus preserve our environment. Scherhauser et al. (2018) estimated the environmental impacts from FLW throughout the food supply chain including FLW management. They concluded that 186 million tonnes of CO₂-equivalents (CO₂e) can be related to food wastage in the European Union, that accounts for 5% of the overall European Global Warming Impact (2019: 3610 Mt CO₂e). Emissions at food production are the determining factors for the overall environmental impacts of food (Bernstad Saraiva Schott and Cánovas, 2015). Improved tailoring of food systems is thus essential for FLW prevention, efficient use of food as a resource, and consequent global warming mitigation. The EU is committed to achieving the global Sustainable Development Goal (SDG) Target 12.3 to halve per capita FLW at the retail and consumer level by 2030, and reduce food losses along the food production and supply chains. LOWINFOOD will support reaching this goal by demonstrating the efficacy of low-waste food supply chain (FSC). By also quantifying potential environmental benefits of low-waste food supply chains, LOWINFOOD will also indicate achievements towards GHG emission reduction targets.

2.1 Environmental impacts

Method

The environmental impacts are calculated by means of Life Cycle Assessment (LCA). LCA is a systematic methodology used to assess the environmental impacts of products and product systems, caused by the use of resources and the release of emissions along all stages of the supply chain, from raw material acquisition to the waste management at end of life (cradle-to-grave). LCA is a tool to identify hotspots along supply chains, unveiling trade-offs among life cycle stages or environmental impact categories (Caldeira et al., 2019). The application of the method is standardised in ISO14040 (2006a), ISO14044 (2006b), as well as in the ILCD handbooks of the European Commission (2010) and the Product Environmental Footprint (PEF) recommended by European Commission (2021).

Impact categories

The environmental impact categories chosen for the assessment include the ones from the environmental footprint (EF) method (Table 3).

Table 3: Environmental impact categories chosen for the assessment of LOWINFOOD's innovations

Environmental category	Unit	Acronym
Global Warming Potential (IPCC, 100a)	kg CO ₂ eq	GWP
Ozone depletion	kg CFC11 eq	ODP
Human toxicity, non-cancer effects	CTUh	HTOX_NC
Human toxicity, cancer effects	CTUh	HTOX_C
Particulate matter	Disease incidences	PM
Ionizing radiation HH	kBq U235 eq	IR
Photochemical ozone formation	kg NMVOC eq	POF
Acidification	molc H ⁺ eq	AC
Terrestrial eutrophication	molc N eq	TEU
Freshwater eutrophication	kg P eq	FEU
Marine eutrophication	kg N eq	MEU
Freshwater ecotoxicity	CTUe	ECOTOX
Land use	Pt	LU
Water scarcity	m ³ water eq	WU
Abiotic depletion potential, fossil/Fossil Resource Depletion	MJ	FRD
Abiotic depletion potential, ultimate/Mineral Resource Depletion	kg Sb eq	MRD

The Life Cycle Impact Assessment (LCIA) results are presented for each innovation and each country for the following aspects:

Absolute results representing the absolute impacts of the baseline and the demonstration phase of every innovation to explore hotspots and to detect improvement potential for the following indicators:

- Global Warming Potential (GWP) of the baseline and the demonstration scenario: GWP is one out of 16 environmental indicators recommended by the European Commission. As it is the most prominent, it was decided to show its results separately.
- Product Environmental Footprint score (PEF score) of the baseline and the demonstration scenario: The PEF score indicator evaluates the net environmental saving based on the 16 environmental indicators (Table 3), calculated according to the European "PEF" (Product Environmental Footprint) methodology (European Commission, 2021).
- Environmental category contribution analysis for the baseline and/or the demonstration scenario: The contribution of different steps of the supply chain to the total results of the scenario for specific impact categories are expressed in percent.

Relative results, representing the difference in impacts between baseline and demonstration relative to one kg of food prevented from being wasted for the following indicators:

- Global Warming Potential (GWP) of the prevention and/or redistribution action of the innovation
- Normalised and weighted environmental impacts according to EF 3.1 latest update July 2022

The net emissions of the scenario are the sum of the positive and the negative environmental impact results. If the net emissions are negative, the scenario has an overall positive effect on the environment (environmental benefits). On the other hand, if the net emissions are positive, the scenario has an overall negative effect on the environment (environmental burden).

If the PEF score is negative but some environmental indicators do not achieve an environmental benefit, the environmental impact of the indicators achieving a positive environmental impact outweighs the impact of the indicators achieving a negative impact. Indicators achieving a negative impact will be listed. If the score is positive, the action has an overall negative impact on the environment and thus results in environmental burdens.

The life cycle interpretation concludes the findings of the inventory analysis and the impact assessment in relation to the defined goal and scope.

System boundaries

Both the system boundaries for the baseline and the demonstration system include the entire food production value chain in context to the innovation. The stage of the supply chain where the FLW is avoided is relevant to consider up-stream emissions in the environmental assessment. The supply chain encompasses five stages of the food supply chain: primary production (PP), food processing (FP), wholesale, retail and distribution (RD), food service (FS), consumer (C). They are illustrated in the system diagrams for each innovation (see chapter 3).

It should also be noted that the waste management of the innovations entails composting and anaerobic digestion as traditional recycling options and incineration as well as landfill as disposal options. However, it also covers food that is valorised (e.g., reworking to other products) or redistributed (reused for human consumption or animal feed) which is by definition not food waste according to the EU definition of food waste. The demonstration of the innovation also affects the amount of food that is reused (e.g., a forecasting software reduces the amount of surplus food, thus also reducing the amount of food available for redistribution in return). Thus, the amount of food that is reused for human consumption (donation or valorisation) or for animal feeding is also considered in both scenarios, in the baseline as well as in the demonstration.

Type of data and allocation rules

LOWINFOOD's innovations can be grouped into two types of actions (see also Figure 3 D): food prevention at source (e.g., supply chain efficiency and consumer behaviour change), and food redistribution (e.g., valorisation of food by-products, donations to charities). For both groups of actions, the net environmental savings associated with an action are calculated considering the following elements based on Caldeira et al. (2019):

- A. Type A data 'Food supply chain': the environmental impacts linked to producing the food no longer purchased,
- B. Type B data 'Reuse, recycling and disposal options': the environmental impacts linked to the food surplus and food waste treatment operations, and
- C. Type C data 'Innovation action': the environmental impacts caused by implementing the action.

The first two components represent a saving, while the last is a burden; therefore, the algebraic sum of the three components provides the overall net environmental impacts. Background data is taken from suitable LCI databases (e.g., Ecoinvent 3.8; Agribalyse 3.1, Sphera). An overview of the proxy data used is provided in Table 4.

Table 4: Type of process data (variables) collected for each LOWINFOOD innovation and data sources of the corresponding emission factors

Component	Process data collected within LOWINFOOD (so-called proxy data)	Inventory data to model background system
Type A data 'Food supply chain'	Composition of the food surplus or waste Stage of the food supply chain	Agribalyse v3.1 (ADEME, 2023)
Type B data 'Food surplus and food waste treatment'	Reuse, recycling and disposal options	Ecoinvent v3.8 (Wernet et al., 2016) Sphera
Type C data 'Innovation action'	Transport Packaging Other activities (e.g., storage, unpacking) Use of computer devices Energy (e.g., electricity)	Ecoinvent v3.8 (Wernet et al., 2016) Sphera (Sphera Solutions GmbH, 2011)

Type A data covers food products diverted from being wasted and is assumed to replace food production elsewhere ("substituted product"). This assumption is not necessarily based on evidence. In fact, the extent to which preventing FLW affects food production is not known. Nevertheless, such a phenomenon is expected to take place in the long term (Caldeira et al., 2019). The type and amount of food that is replaced is defined for each innovation based on the kind of food (e.g., food category) that is diverted from being wasted

and/or redistributed, as well as the location in the value chain where the innovation takes place.

The calculation of the embedded impacts in food products is based on the types and amounts of food products reported and the stage of the supply chain where the FLW is avoided. Agribalyse 3.1 is used for the calculation of the impacts of food products, presenting emission factors for the EF impact categories as well as for different steps of the supply chain.

Type B data covers FLW management practices such as recycling and disposal as well as reuse practices such as redistribution (donation) or animal feeding. Environmental impacts related to these practices are taken from the Ecoinvent 3.8 and Sphera databases and then adapted to the respective national conditions (e.g., national electricity mix) as well as to material conditions (e.g., food waste has low calorific value). The principles of consequential modelling (decision tree of the ILCD handbook) are applied for solving multifunctional processes at End-of-Life (EoL). It was assumed that with the innovation an additional demand for electricity and heat might be necessary (e.g., when food waste is not digested but prevented or redistributed instead). The EoL can be reasonably expected to have no large-scale consequences in terms of additionally installed or reduced capacity of electricity and heat in the background system. Consequently, to consider relevant effects of the reduced food waste input for anaerobic digestion, short-term marginal consequences were considered: for electricity “the market consumption mix” and for heat “Thermal energy from natural gas” as the most cost-competitive system for gas from anaerobic digestion.

Impact factors for anaerobic digestion were calculated based on the Circularity Footprint Formula (European Commission, 2021) which takes into account the emissions of the anaerobic digestion process as well as the resulting substitution of primary electricity and thermal heat production (combined heat and power engine). For this, credits for the substituted primary electricity production were assigned based on the respective national electricity mix. The impact factors for this were taken from the Sphera database. Each country has a different electricity mix with different shares of electricity production from for example natural gas, wind power or geothermal energy. Thus, countries with more impact-intensive electricity production receive higher credits for substituting their electricity production. Biogas from anaerobic digestion of food waste is also assumed to replace heat from natural gas. For this, impact factors for the EU market mix were used (also from the Sphera database).

The emissions associated with the production of substituted products (e.g., in case of redistribution or animal feeding) are subtracted from the total emissions based on equivalent units. For this, it was considered that the food redistributed replaces the production of an equivalent food mix by 30%. This is due to the assumption that the redistributed food is to some extent consumed instead of purchasing primary food products, to some extent wasted and to some extent eaten in addition to purchasing primary food products without any substitution (similar to Eriksson and Spångberg (2017)). Similarly,

feeding the food to animals was assumed to replace the production of an equivalent feed mix for feeding purposes by 30%. Assumptions concerning the EoL are listed in Table 5.

Table 5: Assumptions and allocation rules considered for system expansion (reuse, recycling and disposal options)

Options		Process name, allocation rules and taken assumptions
REUSE	Redistribution	incl. donations (at food production, processing, retail and distribution), redistribution at restaurants (doggy bag), redistribution at households (to family, friends, neighbours). Replaces the production of an equivalent food mix by 30% Thus, the negative weighted emission factors for the HH food waste mix were used as a credit
	Valorisation	e.g., reworking to other products (at bakeries)
	Animal feeding	Replaces the production of an equivalent food mix intended for animal feed by 30% Thus, the negative weighted emission factors for the HH food waste mix were used as a credit
RECYCLING	Composting plant	Emission factors from Sphera 'Enclosed composting including compost application and credits'
	Anaerobic digestion	Emission factors from Ecoinvent 3.8 'CH: treatment of biowaste by anaerobic digestion ecoinvent 3.8' with the following adaptations: Emission factors were calculated based on the Circular Footprint Formular (European Commission, 2021) using Sphera data and process-specific data from Lampert et al. (2011) and Jungbluth et al. 2007. Negative weighted emissions factors for the production of electricity (the respective national electricity mix was applied) as well as for the production of heat (natural gas was applied) were used to assign credits.
	Separate collection of biodegradable waste	Food waste disposed of through separate collection of biodegradable waste was assumed to be composted and/or anaerobically digested. The ratio of food waste being treated through composting and/or anaerobic digestion were taken from country-level Eurostat data.
DISPOSAL	Incineration	Emission factors from Sphera for 'Municipal waste in waste incineration plant' were used with the following adaptations: Credits from electricity and heat were excluded due to the consideration that food waste is too wet to burn. Credits from metal extraction from the slag were excluded due to the consideration that food waste does not contain metals.
	Landfill	Emission factors from Sphera for 'Biodegradable waste on landfill' were used
	Municipal solid waste mix	Country level data from Eurostat was used to estimate the share of anaerobic digestion, composting, incineration and landfill used for mixed municipal solid waste. Emission factors from Ecoinvent 3.8. following the adaptations described above.

Type C data covers all activities related to the innovation action. The environmental impacts are estimated considering the following proxies: transport, storage or other additional treatment options, packaging, use of computer devices. As many of the innovations include software programs or apps, the use of computer devices is expected to be a prominent point

regarding the innovation action activities. The influence on the total environmental performance is not at all clear, but looking at the impacts of computer production (e.g., mining of precious but also critical metals) but also its usage (e.g., electricity demand) the relevance might not be negligible. For this reason, data proxies on the use of computer devices are asked for:

- Type and location of server
- Server capacity
- Type of device used for the innovation qn
- Duration of using the device

This information is provided by the user, and is then combined with the average impacts associated with 1 kg of food surplus and food waste as the reference flow. Background data is taken from suitable LCI databases (e.g., Sphera, Ecoinvent 3.8). Sources and assumptions for each of the data are listed in chapter 4 in the respective sub-chapter 'Life Cycle Inventory (LCI)'.

2.2 Environmental (external) costs

The environmental damage or benefits are further evaluated economically by combining environmental assessment of food waste prevention actions with monetary valuation. Valuation methods generate monetized estimations of social and biophysical impacts (externalities) for which no market exists, making them comparable to other economic costs (Pizzol et al., 2015; Timonen et al., 2017). A multitude of valuation approaches exist that draw on different methods for the determination of external costs. In this study, the total environmental costs are calculated on the basis of the impact categories ('midpoints') as given in the Environmental Footprint (EF) method recommended by the European Commission (2021) in combination with monetisation values of the approach by Trinomics (Smith et al., 2020).

The study of Smith et al. (2020) shows monetization values for all environmental impact categories recommended in the EF method, except for terrestrial eutrophication. Values were adjusted to the year 2023 with the inflation rate (Eurostat's Harmonised index of consumer prices) and are shown in Table 6. There is no robust enough value for terrestrial eutrophication, therefore this category is not valued in the work of Smith et al. (2020) and also not considered here.

Table 6: Monetization values for the calculation of environmental costs based on data of Smith et al. (2020) adjusted to the price level of 2023 by Münch (2024)

Environmental category	Unit	2018	2023
Global Warming Potential	€/ kg CO ₂ eq	1.03E-01	1.25E-01
Ozone depletion	€/ kg CFC11 eq	3.14E+01	3.83E+01
Human toxicity, non-cancer effects	€/ CTUh	1.63E+05	1.99E+05
Human toxicity, cancer effects	€/ CTUh	9.03E+05	1.10E+06
Particulate matter	€/ Disease incidences	7.84E+05	9.57E+05
Ionizing radiation HH	€/ kBq U235 eq	1.20E-03	1.46E-03
Photochemical ozone formation	€/ kg NMVOC eq	1.19E+00	1.45E+00
Acidification	€/ molc H ⁺ eq	3.44E-01	4.20E-01
Terrestrial eutrophication	€/ molc N eq	-	-
Freshwater eutrophication	€/ kg P eq	1.92E+00	2.34E+00
Marine eutrophication	€/ kg N eq	3.21E+00	3.92E+00
Freshwater ecotoxicity	€/ CTUe	3.82E-05	4.66E-05
Land use	€/ Pt	1.75E-04	2.14E-04
Water scarcity	€/ m ³ water eq	4.99E-03	6.09E-03
Abiotic depletion potential, fossil	€/ MJ	1.30E-03	1.59E-03
Abiotic depletion potential, ultimate	€/ kg Sb eq	1.64E+00	2.00E+00

3 Evaluation results

3.1 Overview of innovations used for the assessment

The evaluation results for the environmental impacts are shown for each individual LOWINFOOD innovation for which the efficacy of the demonstration was successfully quantified (see D1.6 'FLW evaluation of innovations').

Table 7: Overview of the innovations considered in the environmental impact evaluation

WP	Task (T) No.*	Geographical scope	Innovation - Short name	Environmental Evaluation
WP2	T 2.1	RO	RER Software for F&V	No
WP2	T 2.2	AT	UNV Cooperation system for F&V	Yes
WP2	T 2.3	DE	Leroma B2B digital marketplace for F&V	No
WP2	T 2.4	IT	Forecasting software to reduce waste of F&V products	Yes
WP3	T 3.1	SE, FI, IT	Supplier-retailer agreements	Yes*
WP3	T 3.2	SE, FI, IT	Stakeholder dialogue in the bread value chain	Yes
WP3	T 3.3	DE	FoodTracks Software for bakeries	Yes
WP4	T 4.1	DE, UK	Stakeholder dialogue in the fish value chain	No
WP4	T 4.2	DE, UK	Leroma B2B digital marketplace for fish	No
WP5	T 5.1	DE, CH, GR	KITRO Innovative food waste solution	Yes
WP5	T 5.2	DE, SE	MITAKUS Forecasting software for restaurants	Yes*
WP5	T 5.3	DE, SE, AT	MATOMATIC Plate Waste Tracker	Yes
WP5	T 5.4	SE, AT	SLU/AIE Holistic educational approach	Yes
WP5	T 5.5	FI, AT, GR	CozZo Mobile App	Yes
WP5	T 5.6	IT	REGUSTO Mobile App	Yes

*... simulated demonstration

For most of the LOWINFOOD innovations the environmental impact assessment was realised. For Task 3.1 and Task 5.2 the impact assessment was conducted based on the baseline data and demonstration scenarios that were simulated (simulated demonstration).

The demonstration of the innovation T 2.1 RER software could not be fully realised in the course of the project. Primary data was collected, but not to an extent that would allow a reasonable environmental evaluation.

The demonstration of the innovation T23 'Leroma B2B digital marketplace for F&V' could not be successfully realised in the course of the project, since fresh fruit and vegetables are not suitable for the digital marketplace. The same as for the innovation T42 'Leroma B2B digital marketplace for fish' since no company from the seafood sector, neither in Scotland nor in Germany, registered on the platform and exchanged seafood products. For this reason, no environmental evaluation could be carried out.

The social innovation T4.1 'Stakeholder dialogue in the fish value chain' consisted in a dialogue among stakeholders of the whole seafood (i.e., fish and shellfish) supply chain aimed at identifying waste generation hotspots, exploring reduction strategies, and finding opportunities for enhancing the value of surplus materials and by-products through exchanges between stakeholders. The dialogue took place in Scotland and Germany, with Scotland being a major seafood producer, and Germany a leading import and consumption market. As such, no proper "demonstration" was foreseen and no impact was expected in the course of the project. Primary (baseline) data was collected from five stakeholders (all processors), but not to an extent that would allow a reasonable evaluation. Indeed, the sample is small and diverse, raising issues in terms of confidentiality, representativeness, and comparability. Potential environmental benefits include: the avoided emissions associated to by-catch, if this was reduced (including direct emission from fishing vessels); the avoided emission associated to food products that would be replaced with surpluses and by-products currently underutilised; reduced emissions from transport of seafood material if local clusters of producers and users were to be created, shortening geographical distances. In turn, the creation of new exchange flows could lead to new emissions from transport.

Every chapter starts with the description of the goal and scope of the individual innovation, the type of data and collection method used for the evaluation (Life Cycle Inventory), the presentation of the absolute results of the environmental impacts of the baseline and the demonstration as well as the relative results per kg food surplus and food waste that is prevented (Life Cycle Impact Assessment). Results are then interpreted and reviewed.

3.2 Environmental impacts of FW governance innovations

T3.1 'Supplier-retailer agreements'

Goal and scope

This innovation (T3.1) consists of innovating supplier-retailer agreements to avoid waste of bakery products. The demonstration was conducted in Sweden, Italy and Finland. However, only the outcomes of the Swedish demonstration were considered for modelling the

potential food waste reduction for two different scenarios: food waste prevention and food redistribution. The food waste reduction at the demonstration is based on expert knowledge that was collected during stakeholder dialogues in Sweden. For further details, it is referred to Deliverable 3.4 and to the scientific publication of Bartek et al. (2024).

The supplier-retailer interface is a key hotspot of food waste in the bakery sector. This is partly due to the business model including take back agreements (TBA) that apply a reversed logistic to the bread value chain. The reversed logistics is logical in terms of efficient source separated waste management, but it restricts the incentives and possibilities for retailers to take waste reducing actions. As a consequence, it leads to overproduction and inefficient logistics. The bread waste is physically generated in the supermarket, but since it is owned by the bakery the supermarket has limited mandate and interest to take actions to reduce the waste. The objective of Task 3.1 is to demonstrate the efficiency of new business models for bread supply without the misplaced incentive structure imposed by the take back agreement, in order to reduce bread waste in the supplier retailer interface.

The functional unit of the system is **1 kg of prevented bread surplus or waste in bakeries**. The reference flow at baseline is the amount of food waste at the bakery sector in Sweden with TBA, collected from secondary literature (see Bartek et al., 2024). The demonstration scenarios were aligned to the scenarios built during the stakeholder dialogues in Sweden simulating situations with and without TBA. The reduction potentials were taken from Bartek et al. (2024). Scenarios of the type of food waste prevention (sharing data, optimised shelves, retail ownership, co-logistics, loss rates) as well as of the type of food redistribution (food donation) were aggregated for showing the environmental impacts of two demonstration scenarios:

Table 8: Reference flows of the baseline and the demonstration scenario of T3.1 in Sweden

Country	Type of food waste	Average amount of food surplus or waste at BASELINE (n)	Average amount of food surplus or waste at DEMONSTRATION "Prevention action" (n-x _p)	Average amount of food surplus or waste at DEMONSTRATION "Redistribution action" (n)
Sweden	Surplus bread	44,588 tons per year	32,245 tons per year	44,588 tons per year*

*Note, that it is assumed that the same amount of surplus bread as in the baseline is produced, but that the amount that is redistributed increased (see lower part of Figure 4).

The system boundaries for both the baseline and the demonstration system are shown in Figure 4. Both the system boundaries for the baseline and the demonstration system include production of raw materials, processing of raw materials to bread, distribution and retail (selling the bakery products and the bakery stores). Surplus bread at bakeries is managed through redistribution, valorisation to food products or feeding to animals. For this, credits

are assigned for substituting primary food production. In the demonstration system, the supplier-retailer agreements are introduced at processing, distribution and retail in order to reduce the production of surplus bread or to increase the amount that is redistributed.

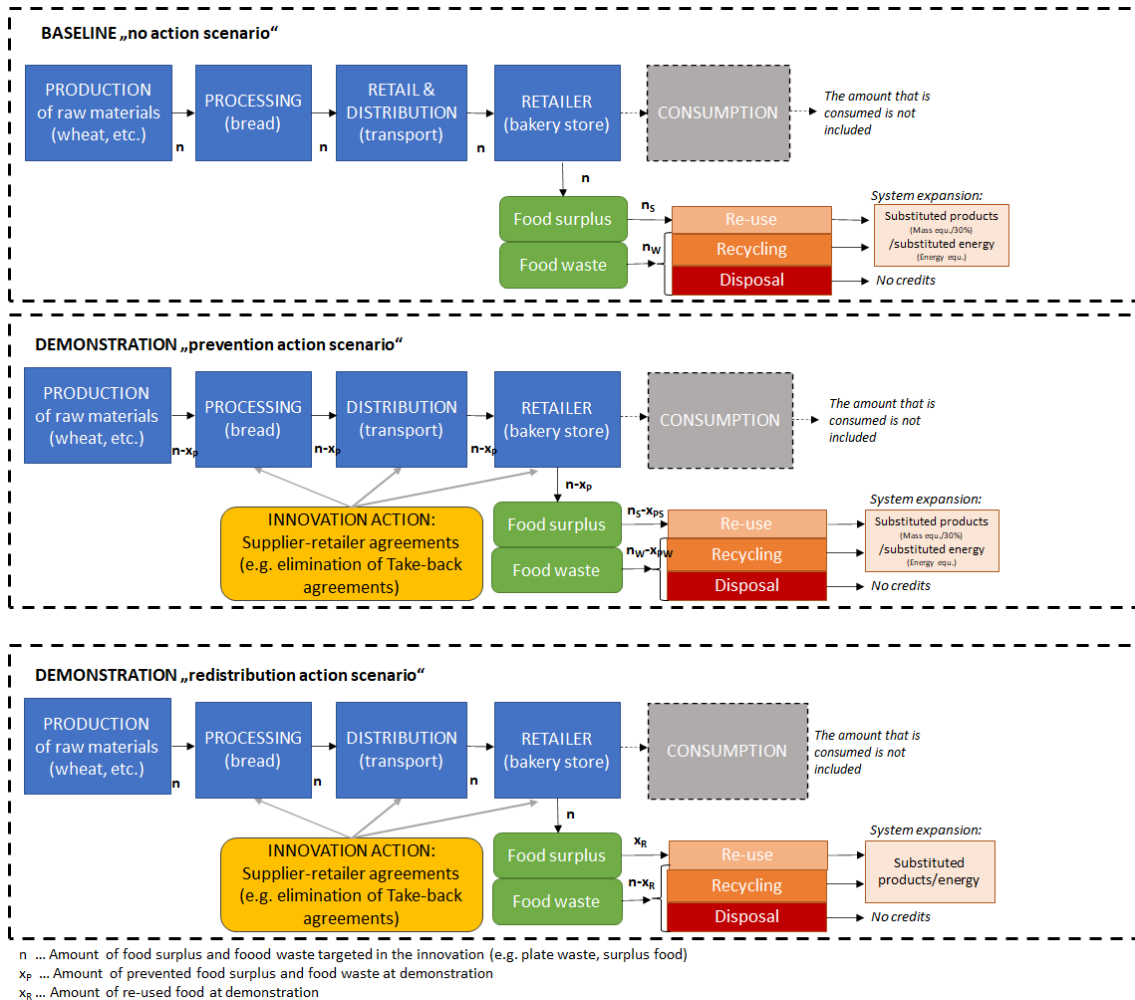


Figure 4: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T3.1

Life cycle inventory (LCI)

Table 9 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 9: Type of process data and collection method used for Task 3.1

Component	Process data collected within LOWINFOOD (so-called proxy data)	T3.1	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Secondary literature Secondary literature
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Expert consultation
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

Data on the amount and composition of food waste was collected through literature research in Task 3.1. They are provided in Bartek et al. (2024). Table 10 shows the food waste related LCI data.

Table 10: Type A data: Food surplus or waste quantities for T 3.1 in Sweden

Food surplus or waste data	Sweden		
	Baseline	Demonstration "Prevention action"	Demonstration "Redistribution action"
Bakery food surplus per bakery and year [tons]	44,588.00	32,245.38	44,588.00
Number of participating bakeries [no]	Entire bakery sector in Sweden		

The composition of the bakery food waste was determined through literature research in Task 3.1.

Table 11 shows the composition of the bakery food waste. Emission factors were calculated for each individual type of food (e.g., soft bread, hard bread, convenience) with Agribalyse data.

Table 11: Type A data: Breadsurplus or waste composition for T3.1 in Sweden

Breadsurplus or waste composition	Sweden	
	Baseline	Demonstration (both food waste prevention and redistribution)
soft bread, savoury, pre-packed ¹	43%	43%
soft bread, sweet, pre-packed ²	30%	30%
hard bread, savoury, pre-packed ³	5%	5%
hard bread, sweet, pre-packed ⁴	10%	10%
bake-off, savoury ⁵	6%	6%
bake-off, sweet ⁶	2%	2%
convenience, savoury ⁷	2%	2%
convenience, sweet ⁸	2%	2%

The majority of bakery products (87%) are packaged in plastic bags. For this, a mass of 0.006 kg per bag was assumed, based on weighing the packaging of exemplary bakery products by BOKU. Ecoinvent emission factors for LLDPE (Linear Low Density Polyethylene) were used to calculate environmental impacts associated with packaging. The total amount of packaging per bakery and year is shown in Table 12.

Table 12: Type A data: Product packaging for T3.1 in Sweden

Packaging input	Sweden		
	Baseline	Demonstration (food waste prevention)	Demonstration (food waste redistribution)
Material of packaging	LLDPE	LLDPE	LLDPE
Total mass of packaging [kg]	232.75	168.32	232.75

The life cycle inventory for the end-of-life treatment of bakery food waste is presented in Table 13. This data was collected through literature research and stakeholder consultation in T 3.1 in Sweden. The emissions of substituted primary production (e.g., in case of redistribution or animal feeding) are subtracted from the total emissions based on equivalent units. For this, it was assumed that this replaced the production of an equivalent food mix by 30%. The waste management option “other” entails selling leftover products at a lower price and is calculated the same way as redistribution. In the course of valorisation,

¹ e.g., brioche, sandwich bread, toast bread

² e.g., sponge cake, soft waffles

³ e.g., crispbread, baguette, full grain bread

⁴ e.g., fruit tart, macarons, wafer biscuits

⁵ average of savoury soft bread, hard bread and convenience products

⁶ average of sweet soft bread, hard bread and convenience products

⁷ e.g., sandwiches

⁸ e.g., croissants, muffins, doughnuts

bread waste is used for ethanol production. For this, an ethanol yield of 0.35 kg ethanol per kg bread waste was assumed (Ebrahimi et al., 2008). Credits for the avoided rye production for producing ethanol were assigned.

Table 13: Type B data: Reuse, recycling and disposal options for T3.1 in Sweden

Options	Sweden		
	Baseline	Demonstration (food waste prevention)	Demonstration (food waste redistribution)
Redistribution	0.20%	0.20%	20.38%
Reworking	0.00%	0.00%	0.00%
Valorisation to food products	22.17%	22.17%	17.69%
Animal feeding	16.77%	16.77%	13.38%
Composting	0.00%	0.00%	0.00%
Anaerobic digestion	29.14%	29.14%	23.25%
Incineration	30.18%	30.18%	24.08%
Municipal waste treatment	0.00%	0.00%	0.00%
Other (selling at reduced price)	1.53%	1.53%	1.22%

Innovation action impacts are only assigned for the demonstration scenario for food waste redistribution as an additional transport step is applied here. The bread surplus is redistributed and thus transported by truck to the point of donation. For this, a transport distance of 0.14 km per kg redistributed food was assumed based on food bank transportation data (Rienstra, 2021).

Table 14: Type C data: Innovation action related life cycle inventory data for T3.1 in Sweden

Transport inputs	Sweden		
	Baseline	Demonstration (food waste prevention)	Demonstration (food waste redistribution)
Transport vehicle	No additional transport	No additional transport	Truck
Transport distance per kg redistributed food [km/kg]			0.14
Freight [kg]			9,016.26
Total transport distance [tkm]			1,672.51

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The innovation resulted in a GWP of 98,000 tons CO₂e for the baseline scenario, 70,000 tons CO₂e for the food waste prevention demonstration scenario and 98,000 kg CO₂e for the food waste donation demonstration scenario. In all three scenarios, the majority of GWP is associated with food production. This is shown in Figure 5. The net emissions in the food waste donation scenario are on the same level as in the baseline. This is due to the additional transport that is foreseen for donated food compared to the baseline that outweigh the additional benefits of donation. Waste management reduces total GWP results. The reason for this is that credits were assigned for avoided primary food production resulting from the discarded food being fed to animals, donated or the valorisation to ethanol. The transport impacts associated with the innovation action contribute 0.2% to the food waste donation demonstration scenario.

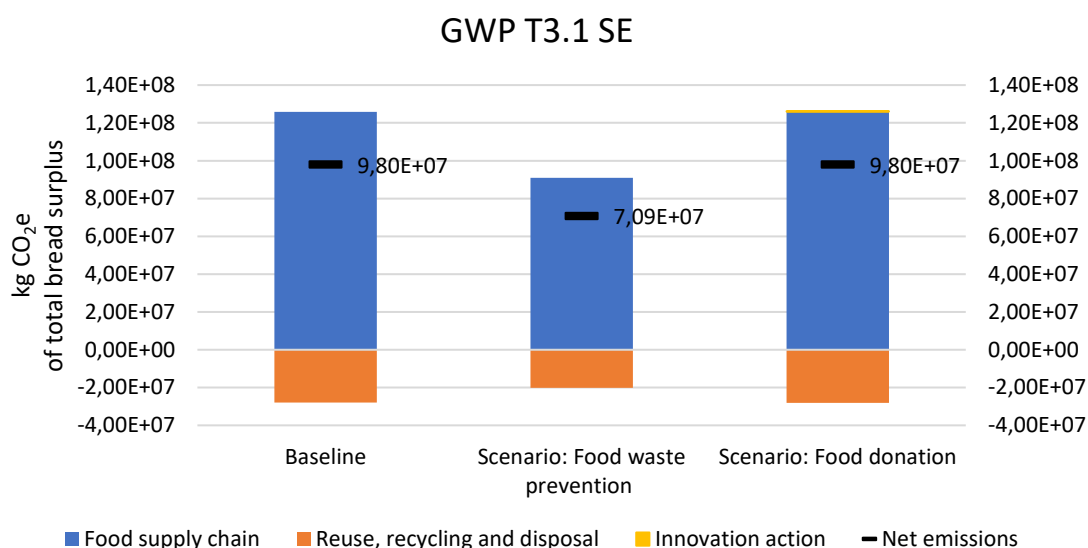


Figure 5: Global warming potential for the baseline and demonstration scenario for the innovation T3.1 in Sweden

Figure 6 shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 13,300, the food waste prevention demonstration results equal 9,619 and the food waste redistribution demonstration PEF score equals 12,679. As shown in Figure 6, the PEF score result can largely be attributed to food production.

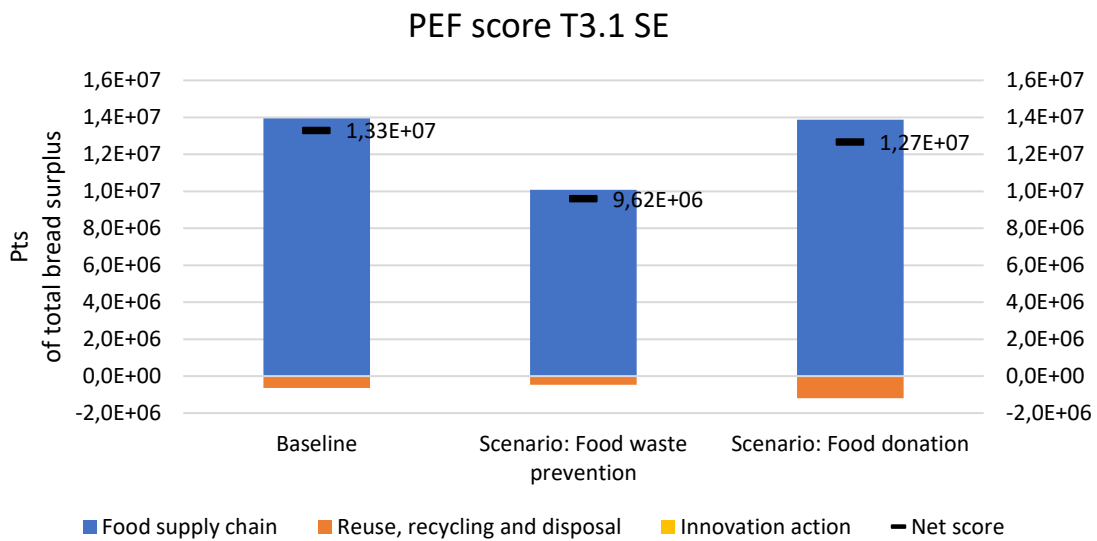


Figure 6: PEF score for the baseline and demonstration scenario for the innovation T3.1 in Sweden

Figure 7 shows the GWP contribution of waste management. Waste management reduces total GWP impacts. This is caused by the credits assigned for avoided primary food production. Using bread waste for ethanol production replaces primary rye production. When donating the leftover bakery products, animal feeding or selling leftover products for a reduced price (other), the demand for primary food or feed production is reduced and thus credits are assigned. Credits are also assigned for anaerobic digestion, as this substitutes primary energy production. These credits outweigh the impacts of incineration.

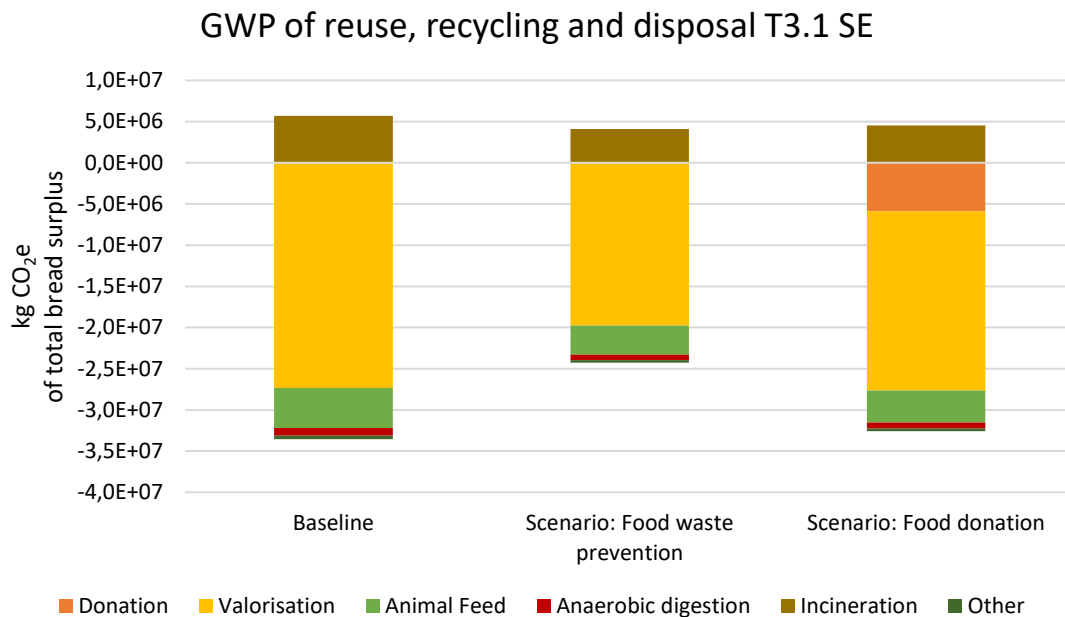


Figure 7: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline scenario for the innovation T3.1 in Sweden

In the food waste prevention demonstration scenario, all EF impact category results decreased (global warming potential: -28%, ozone depletion: -28%, human toxicity non-cancer effects: -28%, human toxicity cancer effects: -28%, particulate matter: -28%, ionising radiation HH: -28%, photochemical ozone formation: -28%, acidification: -28%, terrestrial eutrophication: -28%, freshwater eutrophication: -28%, marine eutrophication: -28%, freshwater ecotoxicity: -28%, land use: -28%, water scarcity: -28%, fossil resource depletion: -28%, abiotic resource depletion: -28%).

As shown in Figure 8, food production is the main contributor to environmental impacts for most impact categories. Waste management reduces most impact category results, except for human toxicity (non-cancer), freshwater eutrophication and water use. This is the same for the baseline and both demonstration scenarios.

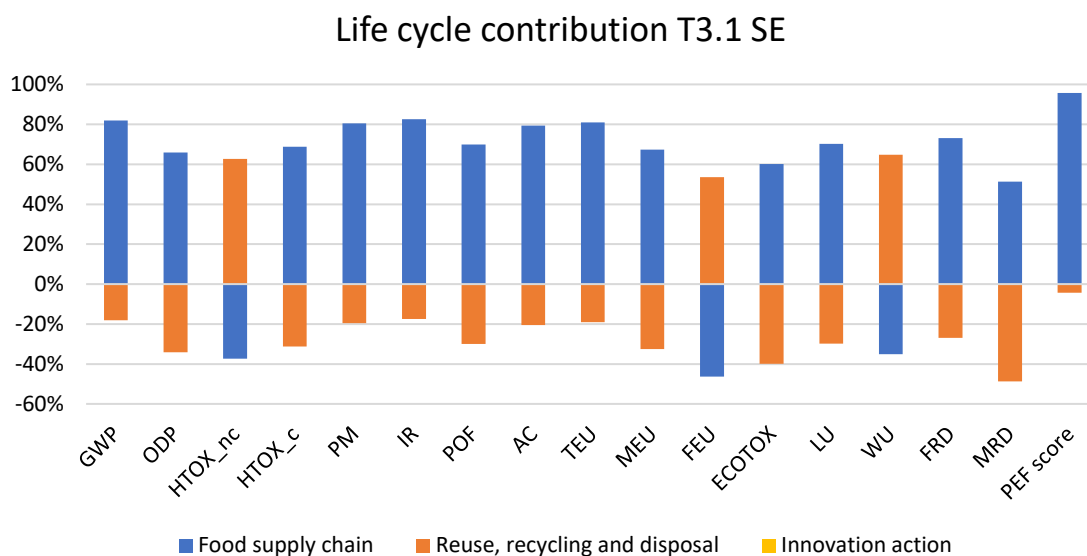


Figure 8: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T3.1 in Sweden for the demonstration scenario

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

With food waste prevention, this innovation prevented 12,343 tons of food waste. This resulted in emissions savings of 27,000 tons CO₂e. As shown in Figure 9, the total GWP of 1 kg prevented food waste equals -2.20 kg CO₂e. The majority of GWP savings results from avoided food production.

Food waste redistribution increased total GWP results, as less food was used for ethanol production and more food was donated. The credits for the substituted primary rye production are greater than the credits for avoided primary food production. Thus, less valorisation to ethanol leads to an increase in GWP. The amount of food waste in this scenario remained unchanged compared to the baseline food waste amount, but the food donated increased from 91 tons to 9,100 tons.

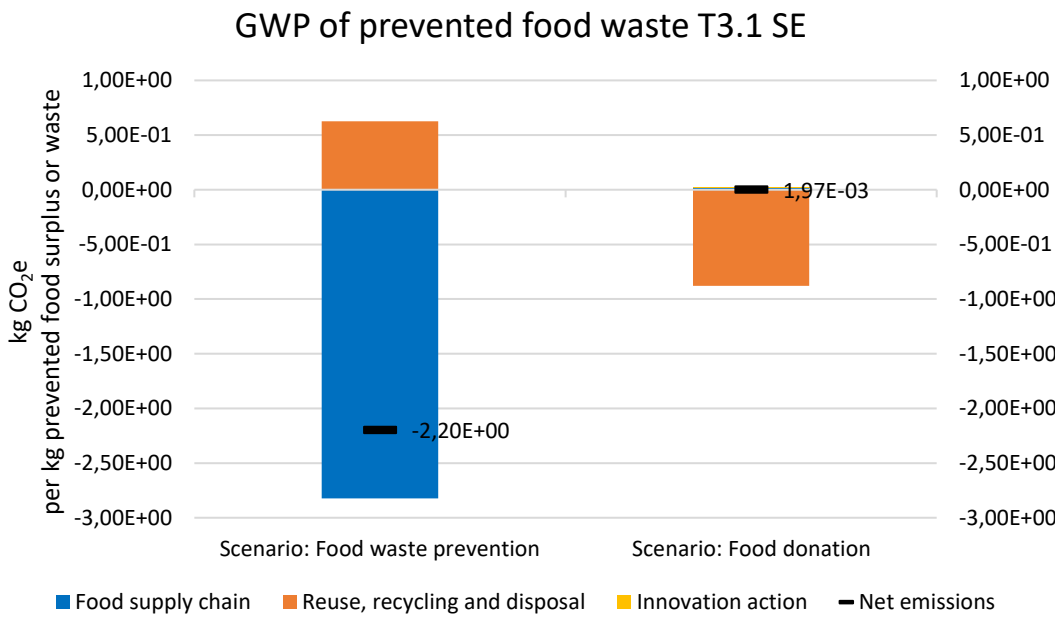


Figure 9: Global warming potential results for 1 kg of prevented food waste for the innovation T3.1 in Sweden

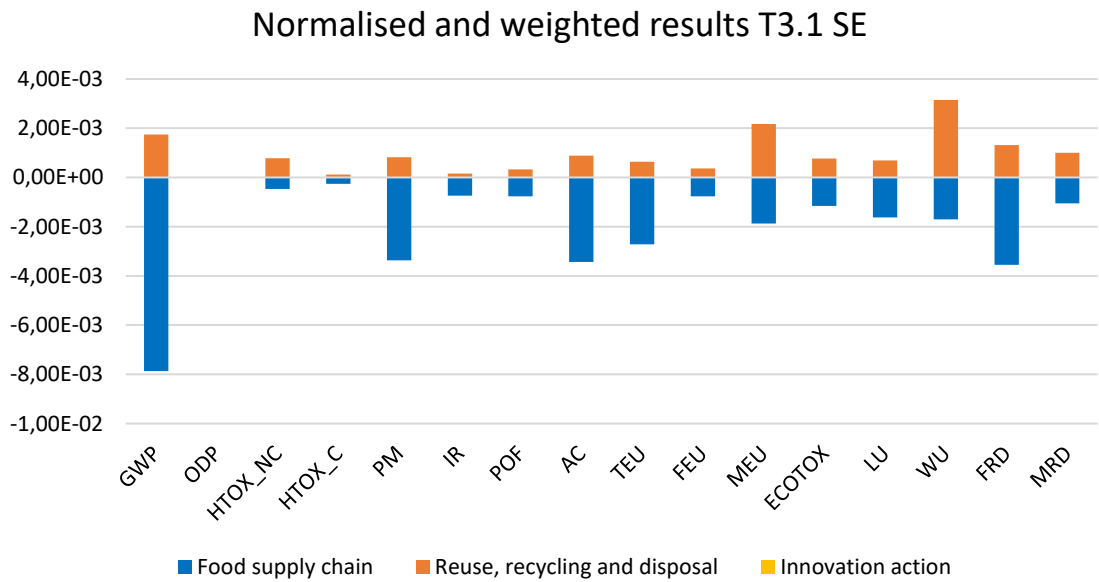


Figure 10: Normalised and weighted results for 1 kg of prevented food waste for the innovation T3.1 in Sweden (Scenario: Food waste prevention)

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs resulted in 5,920,000 EUR that can be saved by bread surplus prevention in the bakery sector in Sweden (see Table 15).

Table 15: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T3.1 (Scenario: Food waste prevention)

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		12,343 kg per year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.20E+00	-2.75E-01	-2.71E+07	-3.39E+06
ODP	kg CFC11 eq	-6.78E-08	-2.60E-06	-8.37E-01	-3.21E+01
HTOX_NC	CTUh	2.21E-08	4.40E-03	2.73E-01	5.43E+04
HTOX_C	CTUh	-1.15E-09	-1.27E-03	-1.42E-02	-1.56E+04
PM	Disease incidences	-1.70E-07	-1.62E-01	-2.09E+00	-2.00E+06
IR	kBq U235 eq	-4.96E-01	-7.24E-04	-6.12E+06	-8.94E+03
POF	kg NMVOC eq	-3.71E-03	-5.38E-03	-4.58E+04	-6.65E+04
AC	molc H ⁺ eq	-2.28E-02	-9.58E-03	-2.82E+05	-1.18E+05
TEU	molc N eq	-9.87E-02		-1.22E+06	
FEU	kg P eq	-2.27E-04	-5.30E-04	-2.80E+03	-6.54E+03
MEU	kg N eq	1.93E-03	7.55E-03	2.38E+04	9.32E+04
ECOTOX	CTUe	-1.15E+01	-5.36E-04	-1.42E+08	-6.62E+03
LU	Pt	-9.64E+01	-2.06E-02	-1.19E+09	-2.55E+05
WU	m ³ water eq	1.94E+00	1.18E-02	2.39E+07	1.46E+05
FRD	MJ	-1.75E+01	-2.78E-02	-2.16E+08	-3.43E+05
MRD	kg Sb eq	-4.46E-07	-8.91E-07	-5.50E+00	-1.10E+01
Environmental costs			-4.80E-01		-5.92E+06

Interpretation and review

The simulated scenarios for the bakery sector in Sweden made a direct comparison of food waste prevention and food redistribution possible. Results showed that food waste

prevention leads to higher environmental savings compared to food redistribution. This result is based on the assumption that food that can be prevented at source doesn't need to be produced and food that is redistributed, needs to be produced, redistributed and is to a certain extent (was assumed by 30% in this stud) also wasted in the end. This is due to the assumption that the redistributed food is to some extent consumed instead of purchasing primary food products, to some extent wasted and to some extent eaten in addition to purchasing primary food products without any substitution.

The advantage of this simulated innovation is that the extent of the entire bakery sector is highlighted. If bread waste prevention actions can be implemented in the bakery sector in Sweden, environmental impacts can potentially be reduced by 27,100 tons CO₂e and costs by 5.92 Mio EUR. If surplus bread redistribution actions can be implemented in the bakery sector in Sweden, environmental impacts can potentially be reduced by 24 tons CO₂e and costs by 1.09 Mio EUR.

T3.2 'Stakeholder dialogue in the bread value chain'

Goal and Scope

This innovation (T3.2) is a stakeholder dialogue to develop guidelines against FLW in the bread value chain in Italy, Finland, and Sweden. This innovation to reduce FLW in bakeries and their branches was tested, however, in Italy, and therefore, the environmental impact assessment was conducted only for Italy.

Lack of communication, inefficient organisation, unfair commercial practices, imbalance of the bargaining power and logistics issues affect the quantity of bread wasted at retail stores and/or at the bakeries. Depending on the size of the bakery, setting an efficient and fruitful interaction with retailers is a challenge especially for small bakeries. Coordination among bakeries would improve their bargaining power as well as the spread of efficient and business-relevant practices to avoid the waste of bread. Furthermore, establishing collaboration with retailers would facilitate mutual benefits from reducing bread waste.

The functional unit of the system is **1 kg of prevented food surplus or waste in bakeries**. The reference flow is the amount of surplus bread measured at the baseline and demonstration stage:

Table 16: Reference flows of the baseline and the demonstration scenario of T3.2 in Italy

Country	Type of food waste	Average amount of food surplus or waste at BASELINE (n)	Average amount of food surplus or waste at DEMONSTRATION (n-x _p)
Italy	Surplus bread	4.88 kg per bakery and day	7.48 kg per bakery and day

The system boundaries for both the baseline and the demonstration system are shown in Figure 11. Both the system boundaries for the baseline and the demonstration system

include production of raw materials, processing of raw materials to bread, distribution and retail (selling the bakery products and the bakery stores). Surplus bread is managed at the investigated bakeries in Italy through redistribution, valorisation to food products or feeding to animals. For this, credits are assigned for substituting primary food production. In the demonstration system, the stakeholder dialogue is introduced at production, processing, distribution and retail in order to prevent food waste.

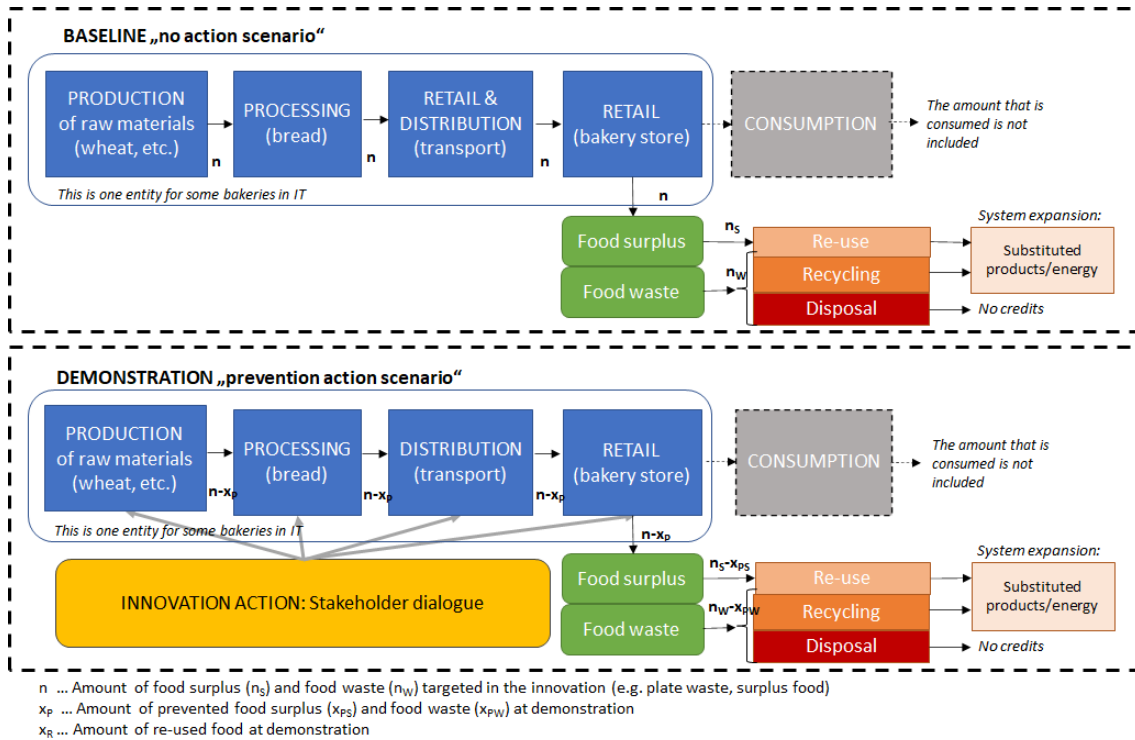


Figure 11: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T3.2

Life cycle inventory (LCI)

Table 17 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 17: Type of process data and collection method used for Task 3.2 in Italy

Component	Process data collected within LOWINFOOD (so-called proxy data)	T3.2	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• • • •	Diary by bakery staff Diary by bakery staff Questionnaire Questionnaire
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Questionnaire
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - -	- - - - -

Data on the amount and composition of surplus bread was collected through diaries that were compiled daily from the bakery staff in Task 3.2 in Italy. Table 18 shows the quantities and number of participating bakeries.

Table 18: Type A data: Food surplus or waste quantities for Task 3.2 in Italy

Food surplus or waste data	Italy	
	Baseline	Demonstration
Average surplus bread per bakery and day[kg]	4.88	7.48
Number of participating bakeries [no.]	14	14

The composition of the surplus bread was determined through diaries that were compiled daily from the bakery staff in Task 3.2 in Italy. Table 19 shows the composition of the surplus bread per bakery and day. Emission factors were calculated for each individual type of bread (e.g., common bread, focaccia bread, bread rolls) with Agribalyse data.

Table 19: Type A data: Food surplus or waste composition for Task 3.2 in Italy

Food surplus or waste composition	Italy	
	Baseline	Demonstration
Common bread	70%	64%
Focaccia bread	14%	23%
Bread rolls	16%	13%

As shown in

Table 20, the bread is packaged in paper bags. The bakery products are transported to the stores in vans fuelled with diesel.

Table 20: Type A data: Packaging and transport for Task 3.2 in Italy

Input	Italy	
	Baseline	Demonstration
Paper bag [kg]	0.17	0.29
Transport vehicle	Diesel van	Diesel van
Transport distance [km/bakery]	35.81	35.81

The life cycle inventory for the management pathways for surplus bread is presented in Table 21. The composition of the reuse, recycling and disposal pathways is calculated based on the information given in the interviews (by questionnaires) conducted in Task 3.2. at baseline. The same composition was assumed for the demonstration. The emissions of substituted primary production (e.g., in case of redistribution or animal feeding) are subtracted from the total emissions based on equivalent units. For this, it was assumed that this replaced the production of an equivalent food mix by 30%. The waste management option “other” entails giving leftover bread to employees instead of disposing of it. Thus, it is calculated the same way as redistribution. Municipal waste treatment consists of the Italian waste treatment mix for processing and retail waste (24% anaerobic digestion, 71% composting, 6% incineration). For reworking the bakery products to bread crumbs, emission factors from Agribalyse and Ecoinvent were used and the loss of water content of the bread (Jourden et al., 2016) was considered as well.

Table 21: Type B data: Reuse, recycling and disposal options for Task 3.2 in Italy

Options	Italy	
	Baseline	Demonstration
Redistribution	18%	the same composition as for the baseline was assumed
Reworking	33%	
Valorisation to food products	0%	
Animal feeding	25%	
Composting	0%	
Anaerobic digestion	0%	
Municipal waste treatment	15%	
Other	9%	

There are no impacts associated with innovation action.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The innovation resulted in a GWP of 16.3 kg CO₂e for the baseline scenario and 17.7 kg CO₂e for the demonstration scenario. In both scenarios, the majority of GWP is associated with food production. Waste management reduces total GWP results. The reason for this is that credits were assigned for avoided primary food production resulting from the discarded food being fed to animals or the reworking to different food products. Since there are no

inputs associated with the innovation action, there are no environmental impacts caused by the innovation action stage. During the stakeholder dialogue, environmental impacts increased by 1.4 kg CO₂e/bakery and day. This equals an increase by 9%, which is caused by external factors that influenced the cost of raw materials in 2022 (the beginning of Ukrainian conflict) that affected the cost of energy and flour. Furthermore, in the same year COVID-19 restrictions were still in place and the quantity produced by bakeries was lower compared with 2023.

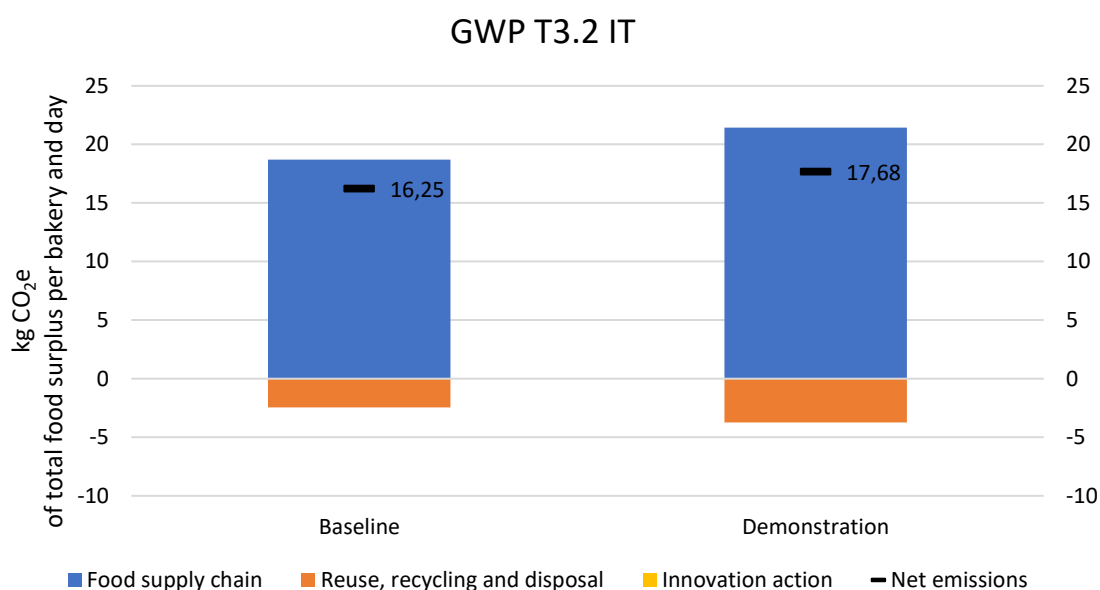


Figure 12: Global warming potential for the baseline and demonstration scenario for the innovation T3.2 in Italy

Figure 13 shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 0.19 and the demonstration PEF score equals 0.28. This equals an increase by 53%. As shown in Figure 13, the PEF score result can largely be attributed to food production.

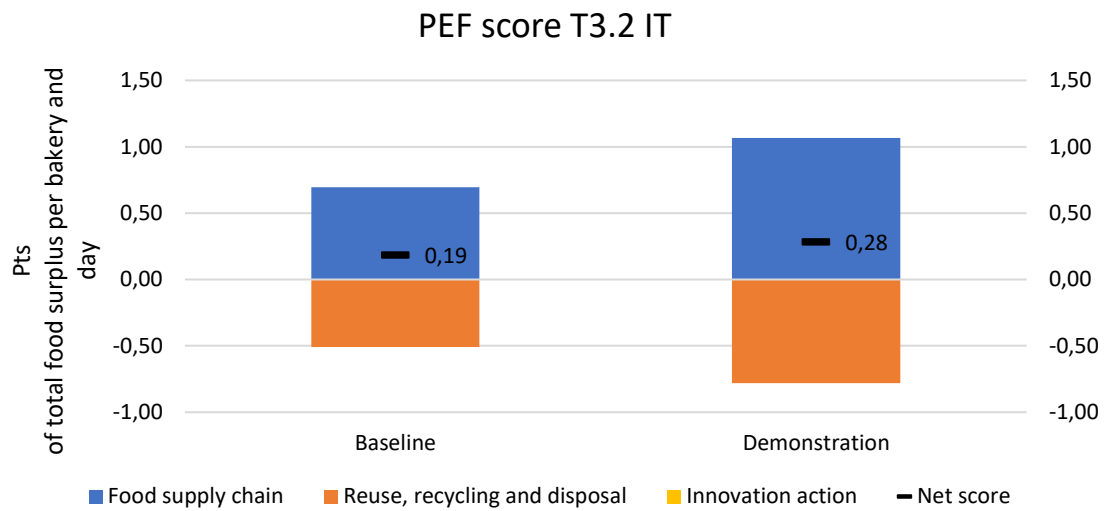


Figure 13: PEF score for the baseline and demonstration scenario for the innovation T3.2 in Italy

Waste management reduces total GWP impacts. This is caused by the credits assigned for avoided primary food production when donating, reworking or feeding the bread waste to animals. Municipal waste management also reduces GWP impacts. The reason for this is that 24% of the food waste disposed of through municipal waste management is anaerobically digested, which substitutes primary energy production. Furthermore, surplus bread is also donated (18%), reworked to bread crumbs (33%) or fed to animals (25%). For this, credits are assigned, which reduces overall GWP impact assessment results.

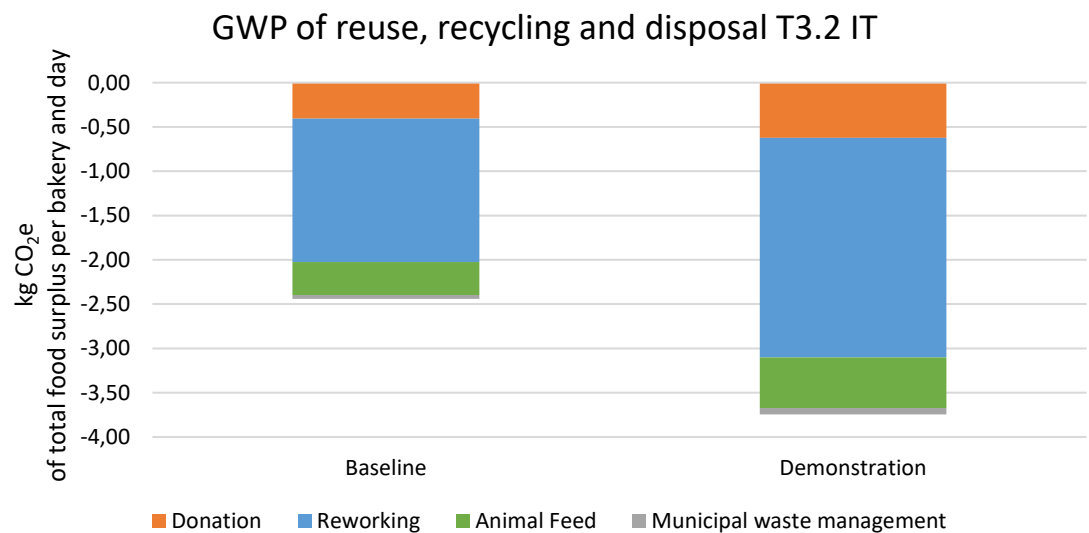


Figure 14: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline scenario for the innovation T3.2 in Italy

During the demonstration stage of the stakeholder dialogue, all EF impact category results increased (global warming potential: +9%, ozone depletion: +4%, human toxicity non-cancer effects: +15%, human toxicity cancer effects: +10%, particulate matter: +16%, ionising radiation HH: +22%, photochemical ozone formation: +7%, acidification: +19%, terrestrial eutrophication: +24%, freshwater eutrophication: +26%, marine eutrophication: +30%, freshwater ecotoxicity: +18%, land use: +42%, water scarcity: +46%, fossil resource depletion: +7%, abiotic resource depletion: +5%).

As shown in Figure 15, food production is the main contributor to environmental impacts for all impact categories. Waste management reduces most impact category results except for human toxicity (non-cancer), marine eutrophication and water scarcity.

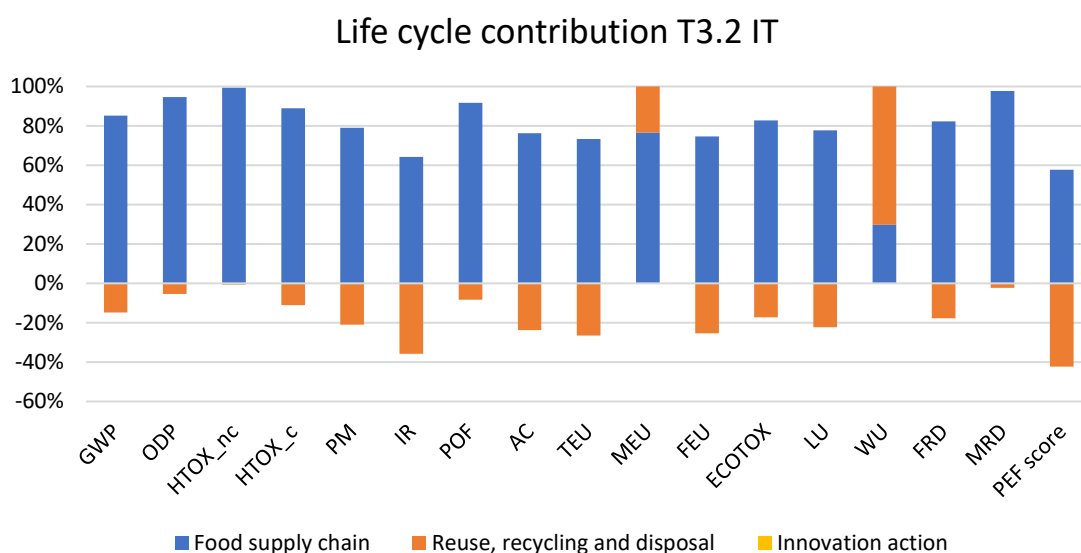


Figure 15: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T3.2 in Italy for the demonstration scenario

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

During the stakeholder dialogue demonstration stage bread surplus increased by 2.6 kg per bakery and day. This resulted in an increased GWP of 1.4 kg CO₂e.

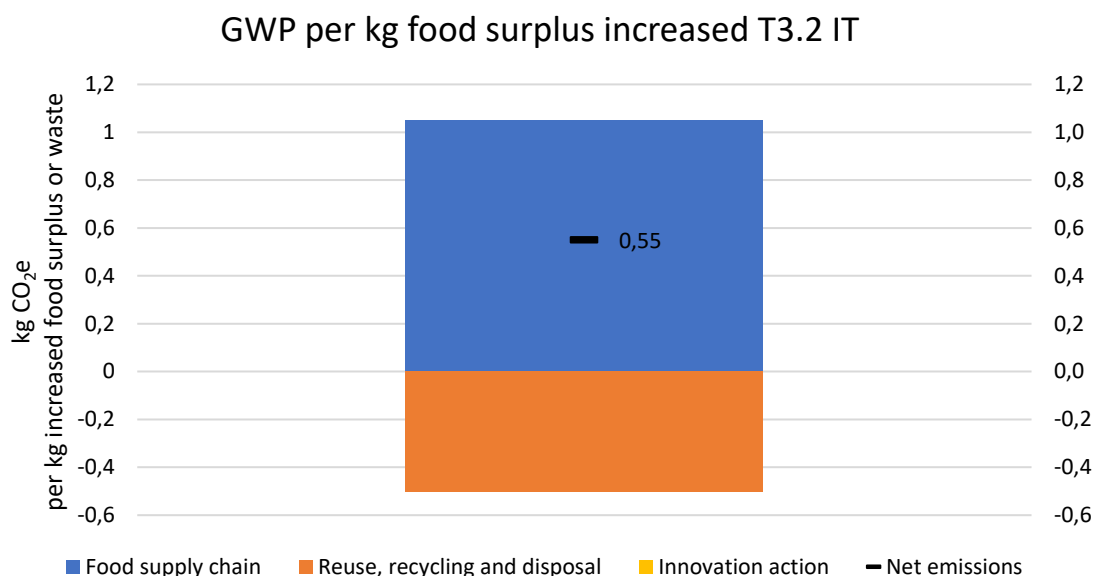


Figure 16: Global warming potential results for 1 kg of food waste for the innovation T3.2 in Italy

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs that can be saved by the demonstration of T5.5 resulted in 682 EUR per day for in total 14 bakeries in Italy (see Table 22).

Table 22: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T3.2

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		36 kg per day (14 bakeries)	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	5.51E-01	6.89E-02	2.01E+01	2.51E+00
ODP	kg CFC11 eq	3.83E-08	1.47E-06	1.39E-06	5.34E-05
HTOX_NC	CTUh	1.62E-08	3.22E-03	5.89E-07	1.17E-01
HTOX_C	CTUh	7.44E-10	8.18E-04	2.71E-08	2.98E-02
PM	Disease incidences	5.20E-08	4.98E-02	1.89E-06	1.81E+00
IR	kBq U235 eq	1.50E-01	2.20E-04	5.48E+00	7.99E-03

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
POF	kg NMVOC eq	1.80E-03	2.62E-03	6.57E-02	9.52E-02
AC	molc H ⁺ eq	7.45E-03	3.13E-03	2.71E-01	1.14E-01
TEU	molc N eq	3.09E-02		1.13E+00	
FEU	kg P eq	4.11E-04	9.61E-04	1.50E-02	3.50E-02
MEU	kg N eq	4.31E-03	1.69E-02	1.57E-01	6.16E-01
ECOTOX	CTUe	9.64E+00	4.49E-04	3.51E+02	1.63E-02
LU	Pt	6.79E+01	1.45E-02	2.47E+03	5.29E-01
WU	m ³ water eq	2.55E+00	1.55E-02	9.29E+01	5.66E-01
FRD	MJ	6.51E+00	1.04E-02	2.37E+02	3.77E-01
MRD	kg Sb eq	3.76E-06	7.52E-06	1.37E-04	2.74E-04
Environmental costs			1.87E-01		6.82E+00

Interpretation and review

Overall bread surplus increased from baseline to demonstration. Therefore, the environmental impacts increased as well. Credits (negative values) at demonstration are though higher than at baseline. This is due to the higher amount of surplus that goes to redistribution (donation) or reworking.

The impacts of reuse, recycling and disposal have a bigger contribution looking at the PEF score than the GWP. This is due to the high share of reuse (18% for donation, 33% for reworking) that is modelled by considering avoided production of bread.

3.3 Environmental impacts of consumer behavioural change innovations

T5.3 and T5.4 'MATOMATIC Plate Waste Tracker' and 'Educational approach'

Goal and Scope

The MATOMATIC plate waste tracker (T5.3) is a technical innovation to increase students' awareness about food waste in school canteens. The plate waste tracker was tested in Austria, Germany and Sweden. Holistic educational concepts (T5.4) were tested in Austria and Sweden to reduce food waste at schools. The MATOMATIC plate waste tracker includes a smart scale giving primary school students feedback on how much plate waste they generate. This scale informs students about the amount of plate waste generated by them. It also allows the students to provide feedback to the canteen staff on why they wasted food in order to not just nudge the students to waste less, but also inform the staff of what could be improved according to the students.

The functional unit of the system is **1 kg of prevented school canteen plate waste**. The reference flow is the amount of food waste measured at the baseline and at demonstration stage:

Table 23: Reference flows of the baseline and the demonstration scenario of T5.3

Country	Average amount of food waste at BASELINE (n)	Average amount of food waste at DEMONSTRATION (n-x _p)
Austria	148.80 g per student and day	53.90 g per student and day
Germany	38.90 g per student and day	24.80 g per student and day
Sweden	23.40 g per student and day	17.50 g per student and day

The system boundaries for both the baseline and the demonstration system are shown in Figure 17. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing of the food items, as well as their distribution and retail. Finally, the food gets prepared (e.g., cooked) by the school canteen staff and then consumed by the students. Plate waste is then disposed of. In the demonstration system, the MATOMATIC plate waste tracker is introduced at the consumption stage, in order to prevent plate waste at the school canteen. Additionally, the plate waste tracker also indirectly impacts the food preparation stage (cooking at the school canteen), as students can give feedback on what can be changed by the canteen staff to reduce food waste. In Austria, the application of the plate waste tracker (T5.3) is combined with educational meals (T5.4). In Germany, only the plate waste tracker is used in T5.3 and in Sweden the plate waste tracker (T5.3) as well as the educational approach (T5.4).

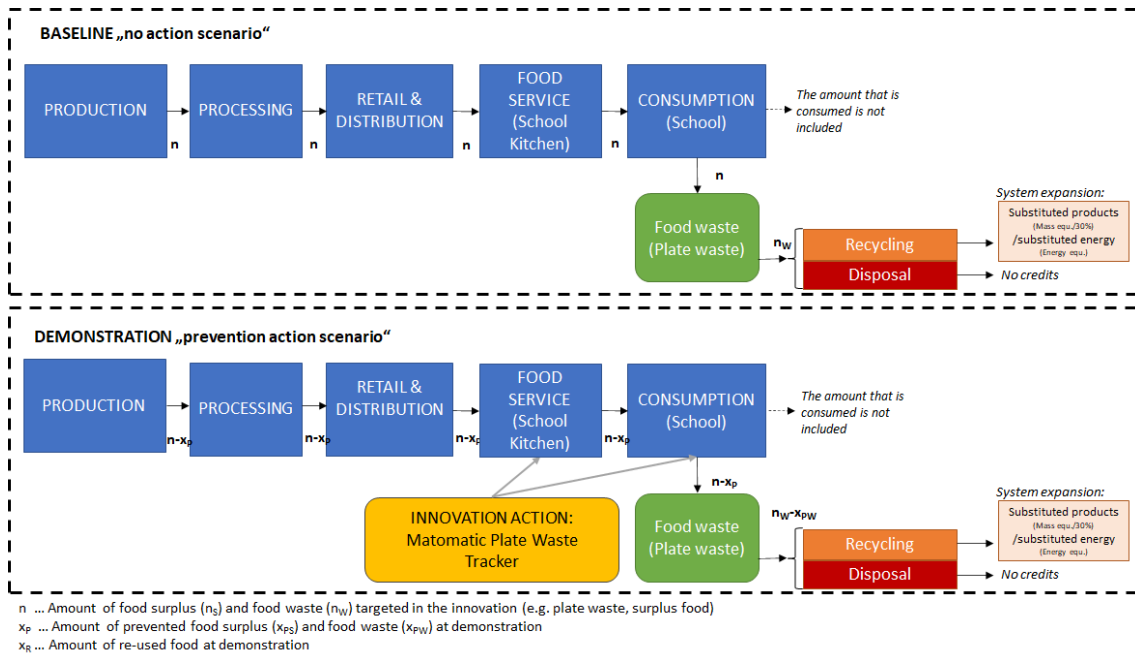


Figure 17: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.3

School meals are not only intended to fulfil a nutritional need, they also represent a learning opportunity. In educational meals, teachers eat together with the students, teaching them and acting as role models. In some European countries, there are guidelines on how meals can be used to teach a sustainable lifestyle. However, these guidelines are often not compulsory, and teachers generally do not receive any formal training on how to conduct educational meals. As a result, educational meals can take different forms depending on where they are conducted and by whom. A best practice guideline for educational meals is not yet established. Neither are indications on how to talk to students about the environmental issues related to food. Different teaching materials on food waste which are intended to be used at schools already exist, but they are not specifically intended to be used during meals. This provides an opportunity to adapt already existing learning material to be suitable for educational meals and thereafter train and support teachers to use these materials to apply food waste reducing educational meals. By doing so, awareness of the issue of food waste can be raised and the quantity of food wasted during school meals by students can be reduced. The same applies to kitchen staff, who are usually not trained about the need to reduce food waste, although already established educational concepts (e.g., the Smart KITCHEN Workshops) are available to show how meals can be prepared with efficient and creative use of the ingredients and demonstrate how food waste can be avoided. Different educational concepts can be integrated in order to create a holistic approach to reach, inspire and motivate different professions involved in meal service across different countries and sectors.

The functional unit of the system is **1 kg of prevented school canteen plate waste**. The reference flow is the amount of food waste measured at the baseline and at demonstration stage:

Table 24: Reference flows of the baseline and the demonstration scenario of T5.4

Country	Average amount of food waste at BASELINE (n)	Average amount of food waste at DEMONSTRATION (n-x _p)
Austria	49.00 g per student and day	54.50 g per student and day
Sweden	22.20 g per student and day	22.00 g per student and day

The system boundaries for both the baseline and the demonstration system are shown in Figure 18. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing of the food items, as well as their distribution and retail. Finally, the food gets prepared (e.g., cooked) by the school canteen staff and then consumed by the students. Plate waste is then disposed of. In the demonstration system, the educational meals are introduced at the consumption stage, in order to prevent plate waste at the school canteen. In Sweden, T5.4 combines the application of the plate waste tracker and educational meals. In Austria, only the educational meals are applied in T5.4.

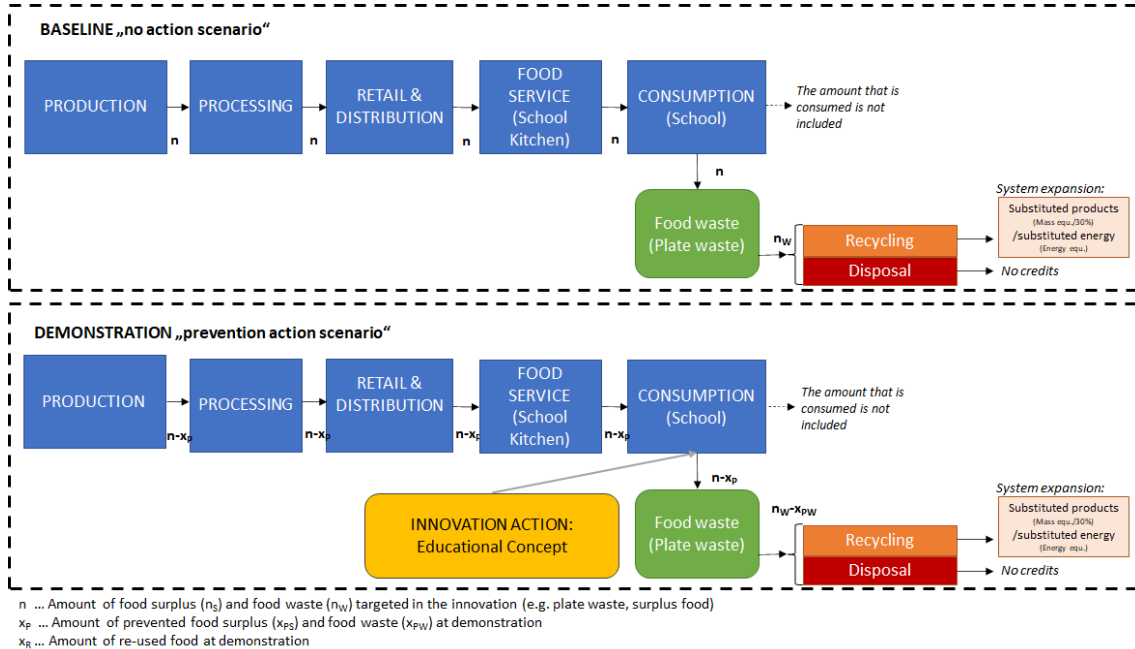


Figure 18: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.4

Life cycle inventory (LCI)

Table 25 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 25: Type of process data and collection method used for Task 5.3 and 5.4

Component	Process data collected within LOWINFOOD (so-called proxy data)	T5.3/ T5.4	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records/interviews (SE) Direct quantification (AT)
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	National statistics and interviews
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

In Austria, baseline and demonstration data had to be collected, since there was no established system to create records of food waste quantities at Austrian schools. The data was gathered by weighing leftover food on plates, and kitchen waste as separate categories, to check for possible shifts in food waste occurrence. The number of guests was reported by the schools for each day according to the registered pupils in their management systems.

In Germany, food waste quantities were collected at baseline and at demonstration. At baseline quantities were collected by weighing with electronic scales, paper-based documentation of the results and subsequent transfer to MS Excel. Weighing and documentation were carried out either by the instructed kitchen staff or by the scientists themselves, transfer to MS Excel was completed by the scientists. At demonstration quantities were recorded via the Plate Waste Tracker. It was assumed that the composition of the plate waste would be proportionally the same as the food that was served. Therefore, an average composition was assumed here, in line with the recommendations of the German Nutrition Society for school meals (Deutsche Gesellschaft für Ernährung e.V, 2023).

In Sweden, records from schools (Malefors et al., 2022) were used to extract food waste quantities, more specifically food waste and serving waste, for the baseline. The food waste data was recorded as part of a daily routine where the bags of waste were put on a scale at the end of the meal serving. The daily waste quantities were documented continuously. To supplement the mass of the waste fractions, the number of plates was calculated when passing the dishwasher to get an estimate of the number of guests served. The numbers

were then inserted in the meal planning software to be used for follow up purposes, and later the data was exported to be used in this study. In order to use a consistent methodology throughout the entire study, this method was used through both the baseline and demonstration phases. Additionally, interviews were conducted with the schools to collect information on the type of food waste, waste management operations and the efforts at innovation action. The life cycle inventory data for the MATOMATIC plate waste tracker (T5.3) for both baseline and demonstration are shown in Table 26 and the life cycle inventory data for the educational meals (T5.4) are shown in

Table 27.

Table 26: Type A data: Food surplus or waste related life cycle inventory data for the operation of the MATOMATIC plate waste tracker (T5.3)

Food waste data	Austria		Germany		Sweden	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Total canteen plate waste [kg]	336.79	294.40	306.70	273.67	10,794.71	3,409.81
Total number of guests/ students served	5,124	5,453	8,643	10,791	513,357	172,727
Average plate waste per guest and serving [g]	148.80	53.90	38.90	24.80	23.80	17.50

Table 27: Type A data: Food surplus or waste related life cycle inventory data for the educational meals (T5.4)

Food waste data	Austria		Sweden	
	Baseline	Demonstration (EM)	Baseline (PWT)	Demonstration (PWT + EM)
Total canteen plate waste [kg]	373.69	440.11	3,325.36	1,073.76
Total number of guests/ students served	5,366	4,976	146,990	51,137
Average plate waste per guest and serving [g]	49.00	54.50	22.10	21.90

The composition of the Swedish plate waste was estimated based on a study on the composition of food waste at school canteens (Halvarsson, 2023). The composition of the plate waste in Austrian schools was taken from BOKU internal investigations at Viennese Schools (Obersteiner and Luck, 2024).

Emission factors were calculated for each individual food group from the study (e.g., vegetables, pasta, bread) with Agribalyse data. Then, these food group emission factors were

aggregated to a single emission factor for 1 kg school canteen food waste, based on their percentage share of the total canteen food waste.

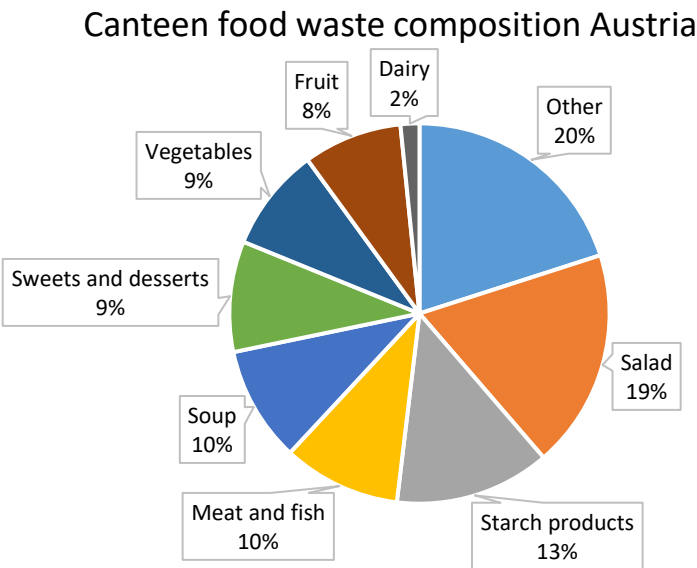


Figure 19: Composition of the school canteen food waste for T5.3 in Austria (own calculation based on data collected in Obersteiner and Luck (2024))

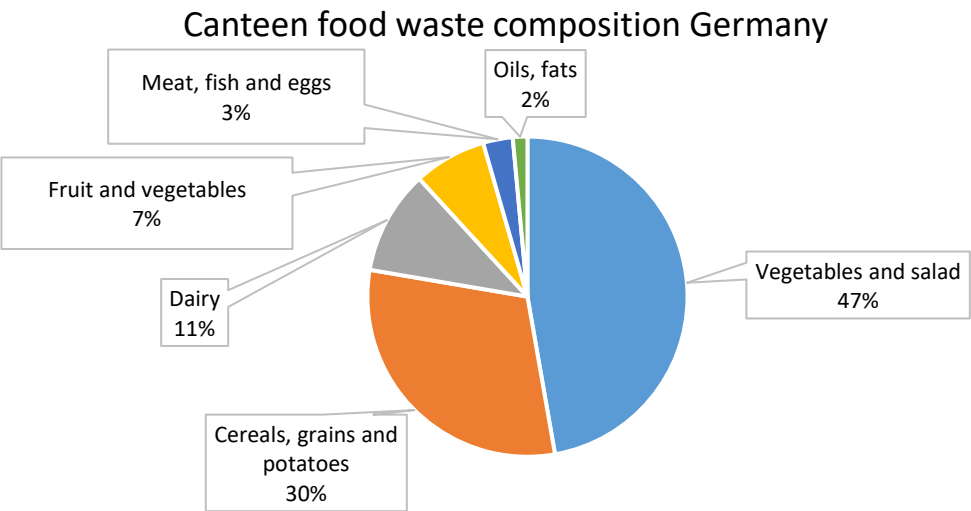


Figure 20: Composition of the school canteen food waste for T5.3 in Germany based on Deutsche Gesellschaft für Ernährung e.V (2023)

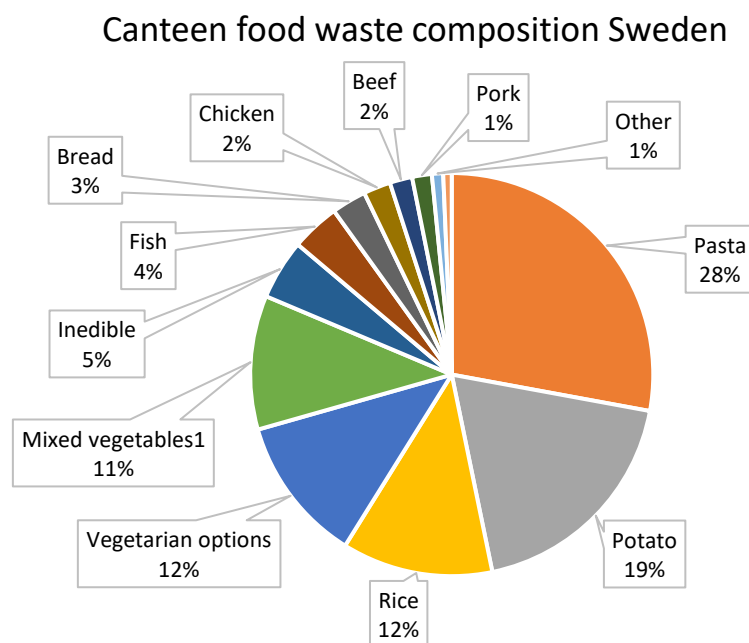


Figure 21: Composition of the school canteen food waste for T5.3 and T5.4 in Sweden based on Halvarsson (2023)

In all three participating countries, the schools dispose of their food waste through a separate collection of kitchen waste. In Austria, organic waste which is collected separately and is treated through composting and anaerobic digestion. About two thirds are treated through composting and one third is treated through anaerobic digestion (BMK, 2023). This is also the case in Germany, with 47% being composted and 53% being treated through anaerobic digestion (Umweltbundesamt, 2023). In Sweden, the entire plate waste is treated through anaerobic digestion according to the school survey (see Table 28).

Table 28: Type B data: Reuse, recycling and disposal options for Task 5.3 and 5.4 for both the baseline and demonstration scenario

Options	Austria (T5.3 and T5.4)	Germany (T5.3)	Sweden (T5.3 and T5.4)
Redistribution	0%	0%	0%
Animal feeding	0%	0%	0%
Composting	64%	47%	0%
Anaerobic digestion	36%	53%	100%
Municipal waste treatment (incinerated)	0%	0%	0%
Municipal waste treatment (landfill)	0%	0%	0%

The electricity consumption of the plate waste tracker scale and the server hosting the app was taken into account. For this, the national electricity mix of either Austria, Germany or

Sweden (plate waste tracker use at schools) and Finland (servers hosting the corresponding app) were used. The electricity and data consumption of the plate waste tracker was provided by MATOMATIC. The electricity consumption of the app server was calculated using scientific literature (Seppälä and Mattila, 2013). The life cycle inventory associated with the plate waste tracker is shown in Table 29.

Table 29: Type C data: Innovation action related life cycle inventory data for the operation of the MATOMATIC plate waste tracker (T5.3)

Innovation action data	Austria	Germany	Sweden
Plate waste tracker use			
Electricity consumption of the plate waste tracker per day [kWh/d]	0.27	0.27	0.27
Total days when a plate waste tracker was used (all schools together) [no.]	79	77	666
Energy consumption for network connection (Seppälä and Mattila, 2013) [kWh/MB]	2.28E-04	2.28E-04	2.28E-04
National electricity mix	AT	DE	SE
Electricity consumption of the plate waste tracker per day [kWh/guest]	4.25E-03	2.10E-03	1.03E-03
App server			
Data consumption per month [MB/month]	350	350	350
Duration of demonstration phase [no of months]	28	28	28
Electricity consumption server (Seppälä and Mattila, 2013) [kWh/MB]	1.75E-03	1.75E-03	1.75E-03
Data consumption per guest over total project duration [MB/guest]	1.80	0.91	0.06
National electricity mix	FI	FI	FI
Total server electricity consumption per guest [kWh/guest]	3.15E-03	1.59-03	9.93E-05

For the innovation action impacts, only electricity consumption of the plate waste tracker and app server were considered. The impacts associated with the production of smartphones, network infrastructure and app server infrastructure are not included in this calculation.

As the educational meals (T5.4) do not result in any consumption of electricity or materials, no innovation action-related inputs were considered for this innovation. In Sweden, T5.4 combined the application of the MATOMATIC plate waste tracker and educational meals. Thus, the plate waste tracker electricity impacts were considered for T5.4 in Sweden.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

In Austria, the MATOMATIC plate waste tracker resulted in a GWP of 0.70 kg CO₂e for the baseline scenario (plate waste per student and day without any intervention) and 0.26 kg CO₂e for the demonstration scenario (plate waste per student and day when the plate waste tracker and educational meal are used) (see Figure 22). In both scenarios, the majority of GWP is associated with food production. Waste management reduces the total GWP results by 2% in both scenarios. The reason for this is that credits were assigned for substituted primary electricity and thermal energy production as a result of anaerobic digestion. Innovation action impacts (plate waste tracker and server electricity consumption) contribute 0.63% to the demonstration GWP results. In Austria, the MATOMATIC plate waste tracker (in combination with educational meals) resulted in a 63% decrease of plate waste per student and day. As a result, the food waste-related GWP per student and day decreased by 64%.

During the educational meal demonstration stage (no combination with the plate waste tracker) the plate waste increased from 49 g per student and day to 54.50 g per student and day (+11%). Thus, the plate waste-related GWP increased from 0.23 kg CO₂e to 0.26 kg CO₂e per student and day. Again, the majority of GWP results is associated with food production. Waste management reduces GWP results due to the credits assigned for anaerobic digestion. Innovation action has no environmental impact.

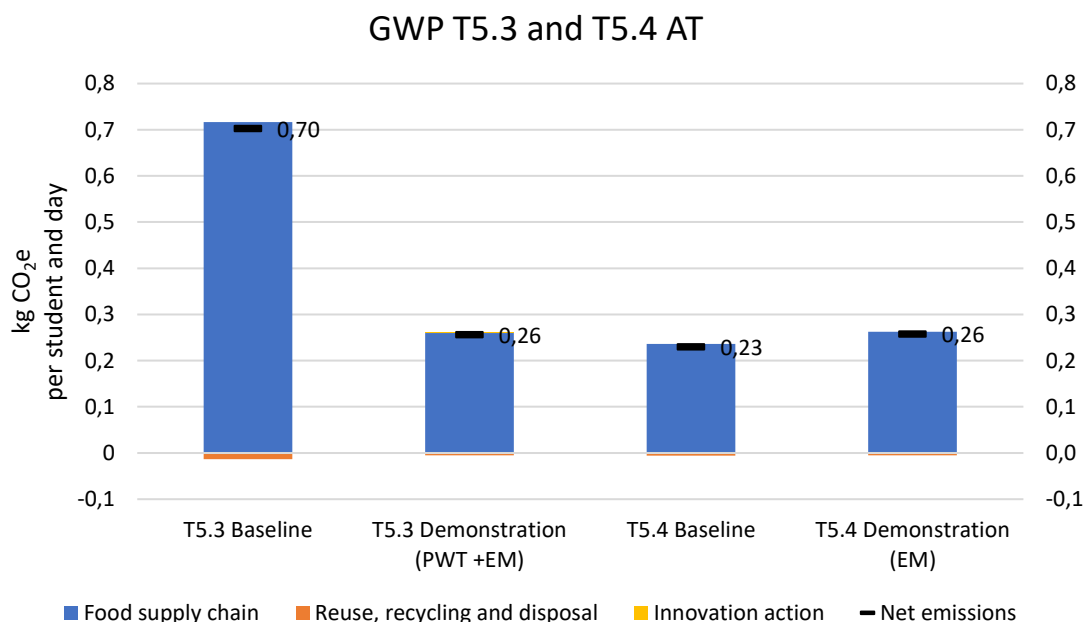


Figure 22: Global warming potential for the baseline and demonstration scenario for the innovation T5.3 and T5.4 tested in Austria

In Germany, the MATOMATIC plate waste tracker (T5.3) resulted in a GWP of 0.08 kg CO₂e for the baseline scenario (plate waste per student and day) and 0.06 kg CO₂e for the demonstration scenario (plate waste per student and day while the plate waste tracker is used) (see Figure 23 below). In both scenarios, the majority of GWP results from food production. Waste management reduces total impacts in both the baseline (-13.2%) and demonstration scenario (-12.9%). This is caused by the credits assigned for the substituted primary electricity production based on the national electricity mix and for the substituted thermal energy production from natural gas (anaerobic digestion). Impacts resulting from the innovation action are responsible for 2.2% of total impacts in the demonstration scenario. The MATOMATIC plate waste tracker resulted in a 36% decrease of school canteen plate waste. As a result, the GWP per student and day decreased by 35%.

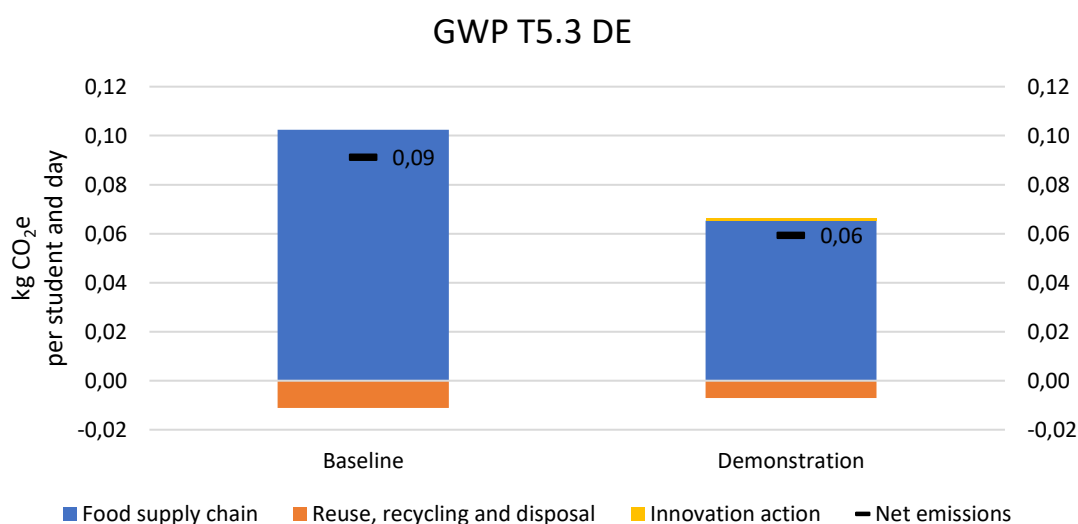


Figure 23: Global warming potential for the baseline and demonstration scenario for the innovation T5.3 tested in Germany

As shown in Figure 24, in Sweden the MATOMATIC plate waste tracker (T5.3) resulted in a GWP of 0.08 kg CO₂e for the baseline scenario (plate waste per student and day) and 0.06 kg CO₂e for the demonstration scenario (plate waste per student and day when the plate waste tracker is used). In both scenarios, the majority of GWP results are caused by food production. Waste management impacts reduce the total GWP results by 2%. This results from the credits assigned for anaerobic digestion substituting primary electricity and heat production. Innovation action contributes 0.13% to the demonstration GWP impacts. During the use of the MATOMATIC plate waste tracker, plate waste per student decreased by 26%, which reduced the plate waste GWP by 26% as well.

For the educational meals (T5.4), the baseline GWP results are 0.0713 kg CO₂e for the baseline scenario (only the plate waste tracker is used) and 0.0706 kg CO₂e (the plate waste tracker is used in combination with educational meals). Again, the majority of GWP impacts are caused by food production and waste management reduces the total GWP results by 2%

in both the baseline and demonstration scenario. The plate waste tracker used in both scenarios is responsible for 0.05% of the total GWP impacts. During the implementation of the educational meals, plate waste per student was reduced by 1%. The plate waste GWP reduced in the same proportion.

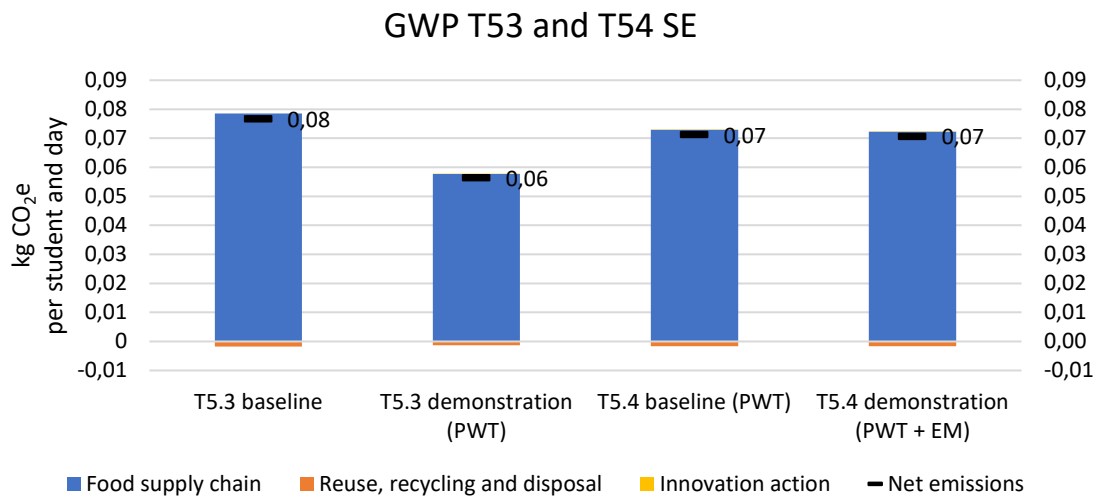


Figure 24: Global warming potential for the baseline and demonstration scenario for the innovation T5.3 and T5.4 tested in Sweden

The following figures show the PEF score results for the baseline and demonstration scenario. In Austria, the baseline PEF score for T5.3 equals 0.08 and the demonstration PEF score equals 0.03. Through the use of the MATOMATIC plate waste tracker (in combination with educational meals), PEF score results were reduced by 64%. The PEF score result can be entirely attributed to food production. The PEF score results for T5.4 (only educational meals) increased by 11% from 0.028 to 0.031. This is caused by the increased amount of plate waste.

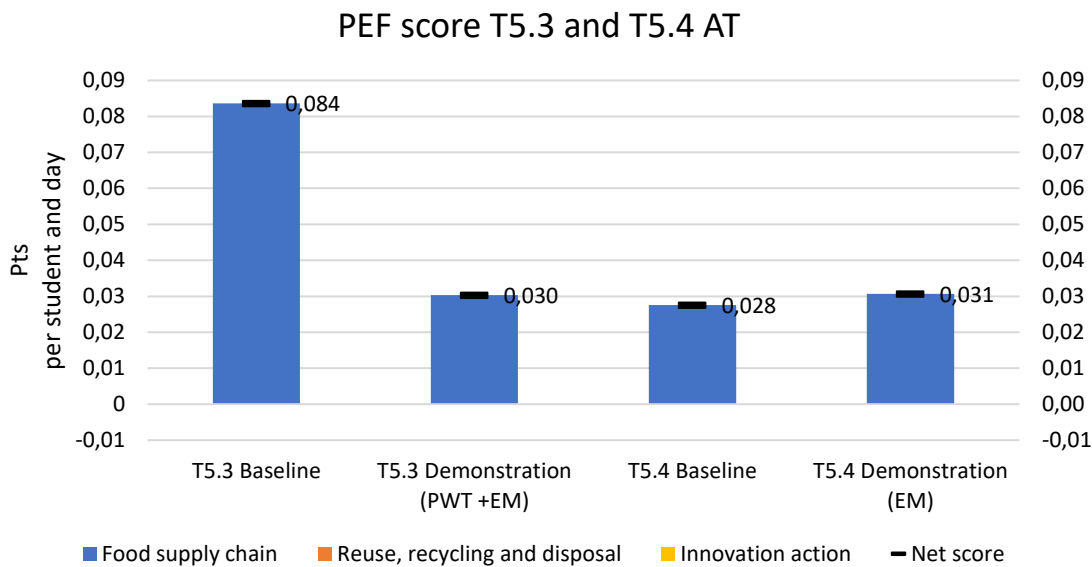


Figure 25: PEF score for the baseline and demonstration scenario for the innovations T5.3 and T5.4 tested in Austria

In Germany, the baseline PEF score for T5.3 equals 0.015 and the demonstration PEF score equals 0.009 (see Figure 26). The majority of PEF score impacts are associated with food production. Through the use of the MATOMATIC plate waste tracker, PEF score results were reduced by 36%.

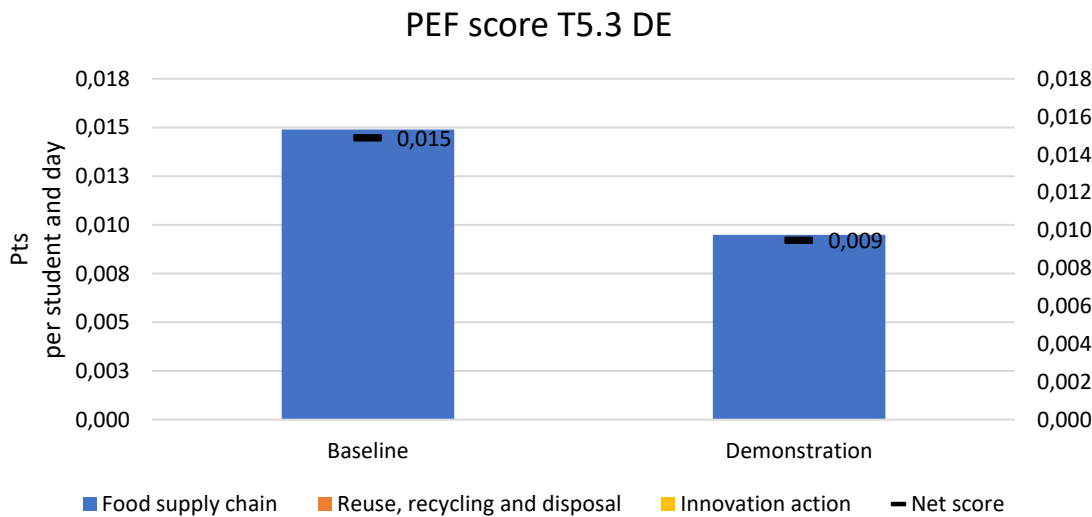


Figure 26: PEF score for the baseline and demonstration scenario for the innovation T5.3 tested in Germany

In Sweden, the PEF score results for T5.3 equals 0.011 for the baseline and 0.008 for the demonstration scenario. This is shown in Figure 27. Through the use of the MATOMATIC plate waste tracker, PEF score results were reduced by 26% for T5.3. The vast majority of PEF score impacts are caused by food production. For the educational meals (T5.4), the baseline PEF score is 0.0101 and the demonstration PEF score is 0.0100. This equals a reduction by 1%. Again, food production is responsible for the impacts.

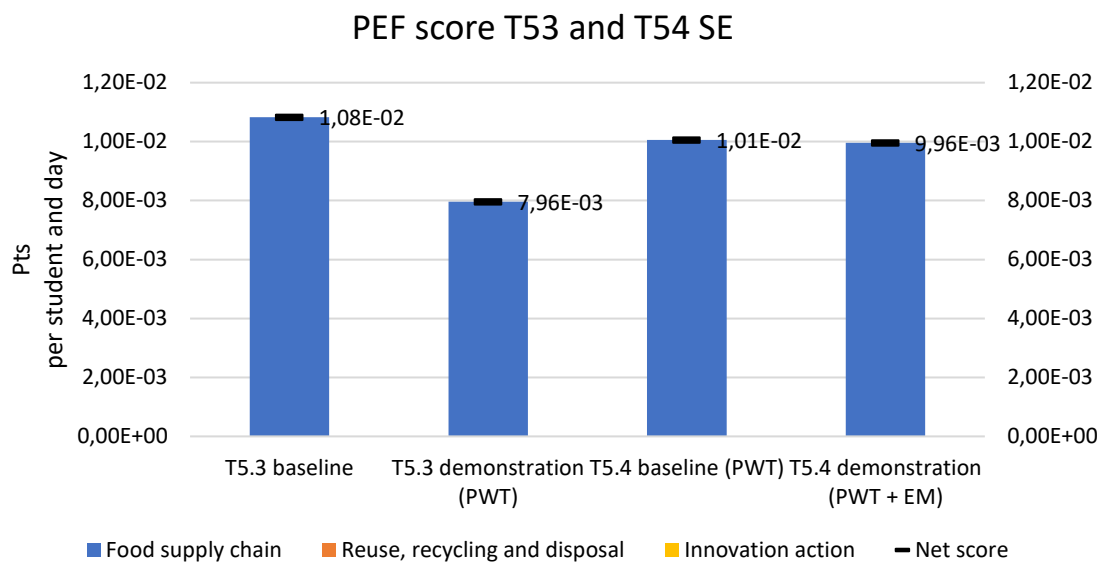


Figure 27: PEF score for the baseline and demonstration scenario for the innovation T5.3 tested in Sweden

As shown in Figure 28, for both T5.3 and T5.4 in Austria the waste management GWP for anaerobic digestion is negative. This is caused by the negative impacts of anaerobic digestion outweighing the impacts of composting. Anaerobic impacts are negative because the credits assigned for substituted primary electricity and thermal heat production outweighing the environmental impacts resulting from the anaerobic digestion process itself. For composting, credits are assigned as well. However, these credits do not exceed the environmental impacts resulting from the composting process and thus composting impacts result in positive values and therefore an environmental burden.

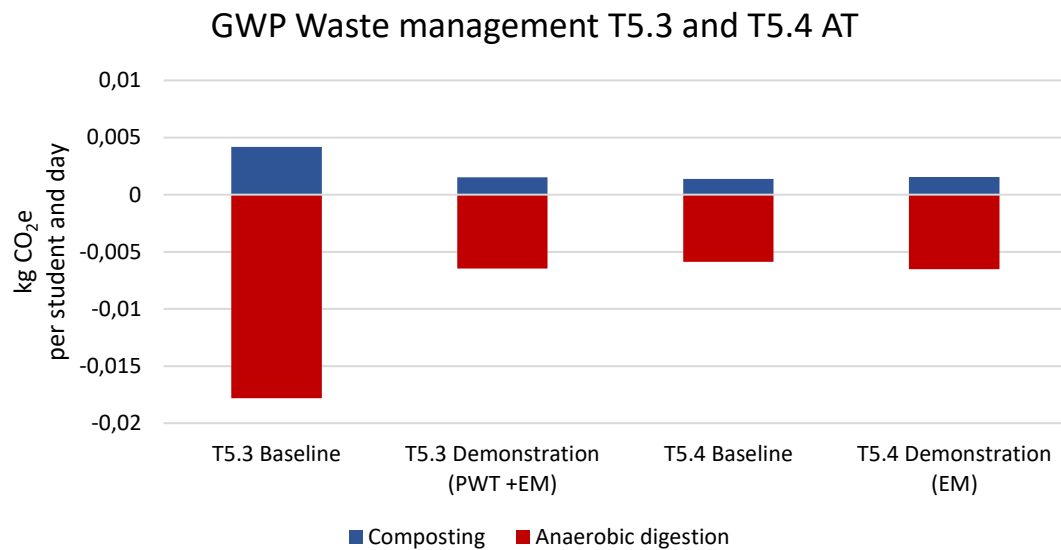


Figure 28: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovations T5.3 and T5.4 tested in Austria

As shown in Figure 29, anaerobic digestion reduces total waste management related GWP results. This is caused by the negative impacts of anaerobic digestion outweighing the impacts of composting. Anaerobic impacts are negative because the credits assigned for substituted primary electricity and thermal heat production outweighing the environmental impacts resulting from the anaerobic digestion process itself. For composting, credits are assigned as well. However, these credits do not exceed the environmental impacts resulting from the composting process and thus composting impacts result in positive values and therefore an environmental burden.

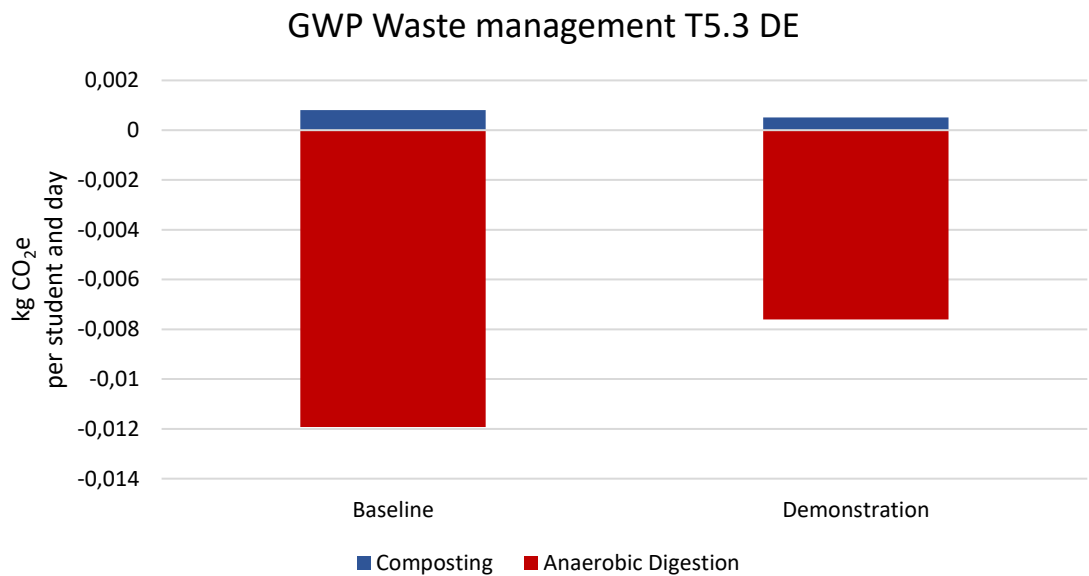


Figure 29: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.3 tested in Germany

As shown in Figure 30, all of the plate waste in Sweden is treated through anaerobic digestion (for T5.3 and T5.4). As a result of the credits assigned for substituted energy production, the total waste management GWP is negative.

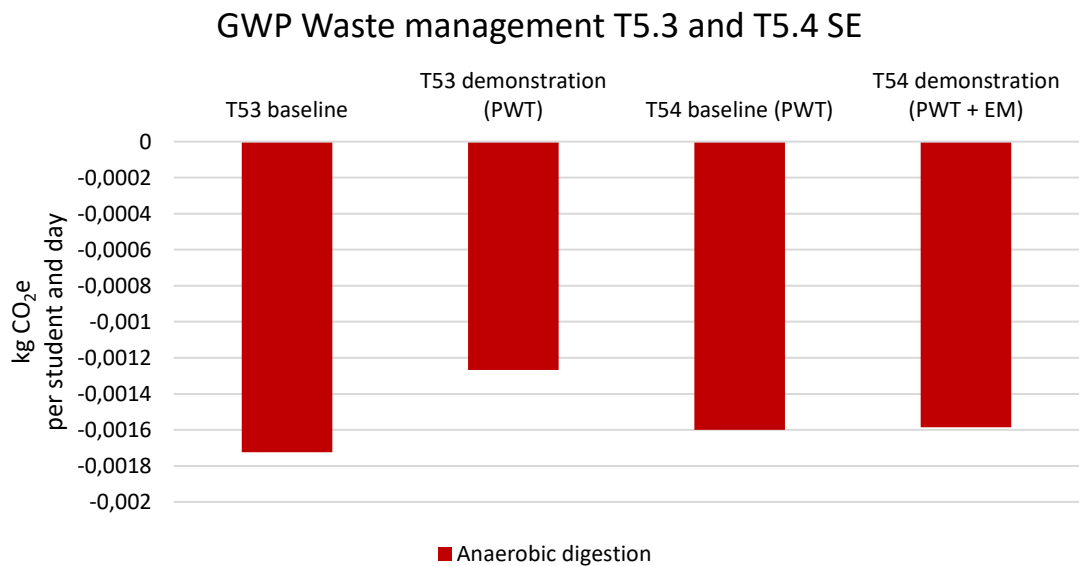


Figure 30: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.3 and T5.4 tested in Sweden

In Austria, the use of the MATOMATIC plate waste tracker (T5.3, in combination with educational meals) resulted in an impact reduction across all EF impact categories (global warming potential: -64%, ozone depletion: -64%, human toxicity non-cancer effects: -64%, human toxicity cancer effects: -64%, particulate matter: -64%, ionising radiation HH: -63%, photochemical ozone formation: -64%, acidification: -64%, terrestrial eutrophication: -64%, freshwater eutrophication: -64%, marine eutrophication: -64%, freshwater ecotoxicity: -64%, land use: -64%, water scarcity: -64%, fossil resource depletion: -63%, abiotic resource depletion: -64%). For T5.4, all impact category results increased by 11% as a result of the increase in plate waste amounts.

As shown in Figure 31, food production is the major contributor to environmental impacts for all impact categories for both T5.3 and T5.4. With the exception of ozone depletion, human toxicity (non-cancer), marine eutrophication, freshwater ecotoxicity, water use and abiotic resource depletion, waste management reduces impact assessment results for all categories for both T5.3 and T5.4. This results from the credits assigned for anaerobic digestion. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

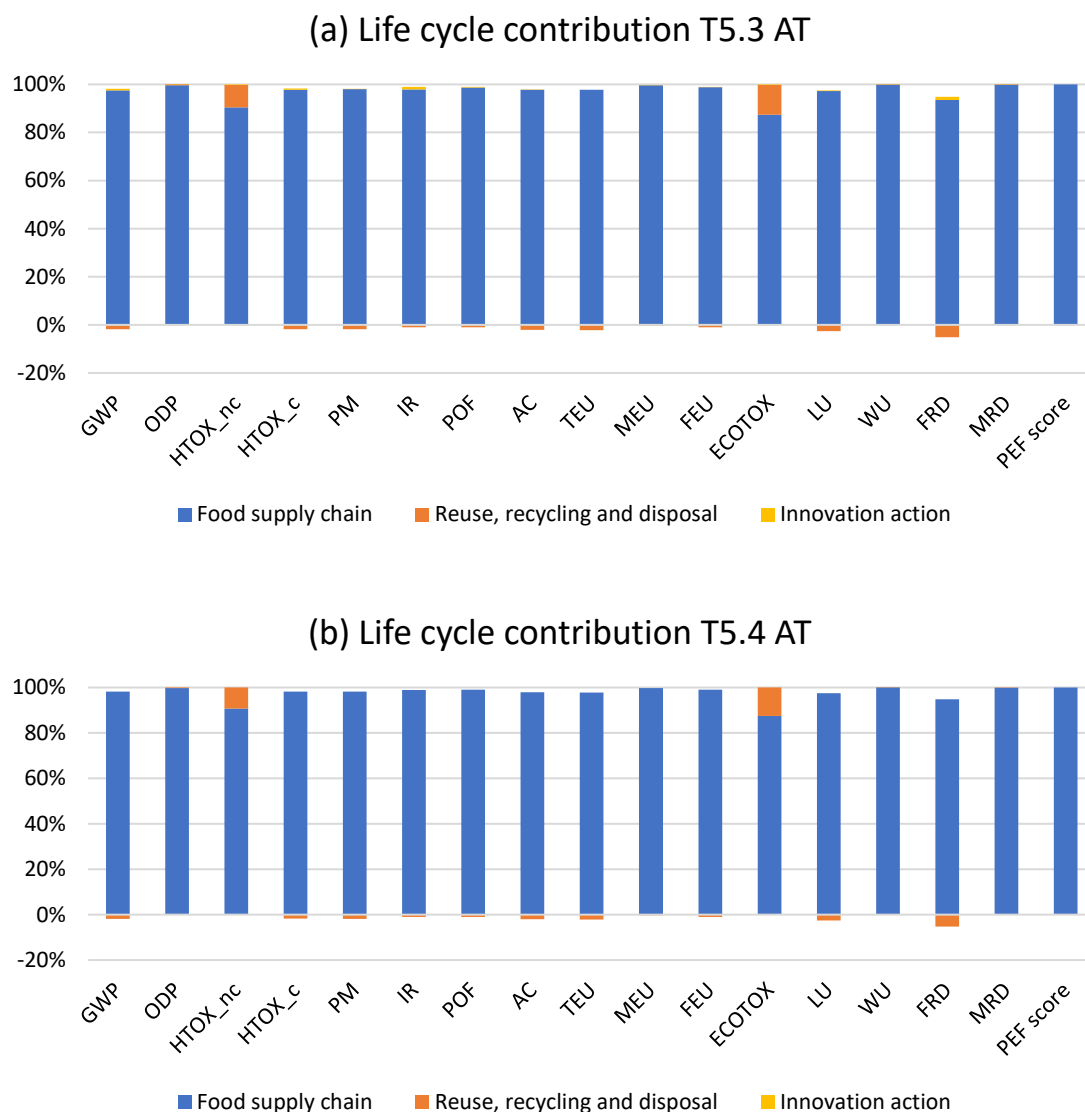


Figure 31: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovations T5.3 (a) and T5.4 (b) in Austria

In Germany, the use of the MATOMATIC plate waste tracker resulted in an impact reduction across all EF impact categories (global warming potential: -35%, ozone depletion: -36%, human toxicity non-cancer effects: -36%, human toxicity cancer effects: -36%, particulate matter: -36%, ionising radiation HH: -35%, photochemical ozone formation: -36%, acidification: -36%, terrestrial eutrophication: -36%, freshwater eutrophication: -36%, marine eutrophication: -36%, freshwater ecotoxicity: -36%, land use: -36%, water scarcity: -36%, fossil resource depletion: -36%, abiotic resource depletion: -36%).

As shown in Figure 32, the majority of environmental impacts for T5.3 in Germany result from food production. With the exception of ozone depletion, human toxicity (non-cancer)

and abiotic resource depletion, waste management has negative impact assessment results in all categories. This results from the credits assigned for anaerobic digestion. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

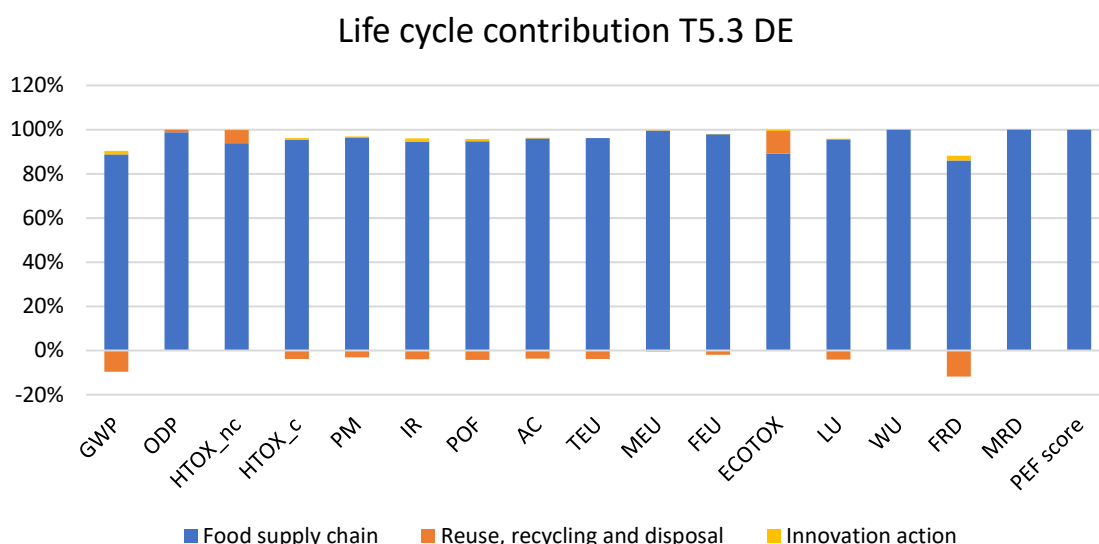


Figure 32: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.3 in Germany

In Sweden, the use of the MATOMATIC plate waste tracker (T5.3) resulted in an impact reduction across all EF impact categories (global warming potential: -26%, ozone depletion: -26%, human toxicity non-cancer effects: -26%, human toxicity cancer effects: -26%, particulate matter: -26%, ionising radiation HH: -26%, photochemical ozone formation: -26%, acidification: -26%, terrestrial eutrophication: -26%, freshwater eutrophication: -26%, marine eutrophication: -26%, freshwater ecotoxicity: -26%, water use: -26%, land use: -26%, fossil resource depletion: -26%, abiotic resource depletion: -26%). The implementation of educational meals (T5.4, in combination with the plate waste tracker) reduced all impact category results by 1%.

As shown in Figure 33, food production is the major contributor to environmental impacts for all impact categories for both T5.3 and 5.4 in Sweden. With the exception of ozone depletion, marine eutrophication, land use and abiotic resource depletion, waste management reduces impact assessment results for all categories. This results from the credits assigned for anaerobic digestion of the food waste. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

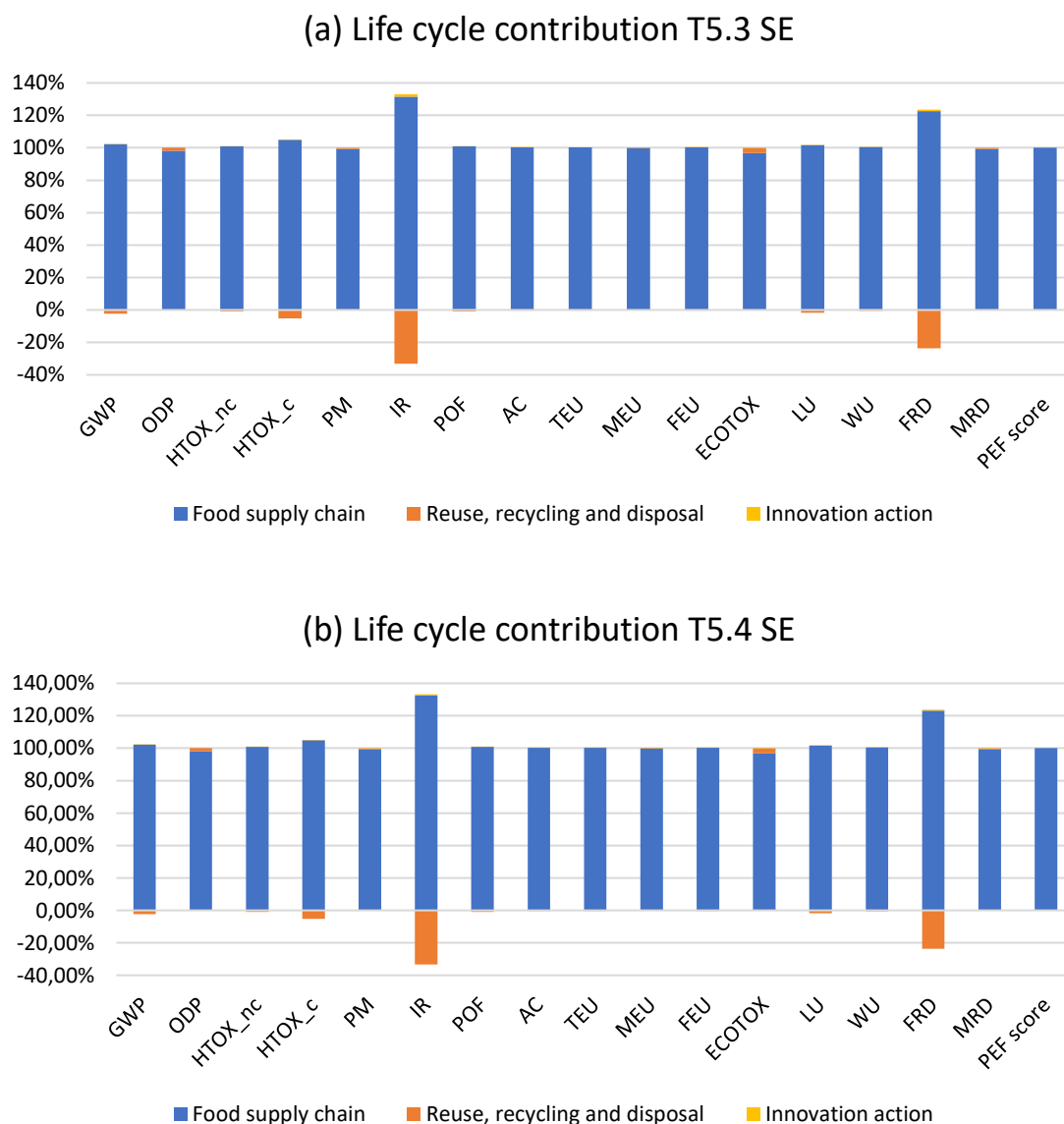


Figure 33: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovations T5.3 (a) and T5.4 (b) in Sweden

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

In Austria, the plate waste tracker (T5.3) in combination with educational meals can save up to 94.90 g of school canteen plate waste per student and day. This prevents emissions of 0.45 kg CO₂e per student and day on average. With a prevention potential of 63%, an environmental saving of up to 2.23 kg CO₂e per student and school week could be achieved. The total GWP result of 1 kg prevented HH food waste equals -4.71 kg CO₂e, which is shown in Figure 34. The majority of the GWP savings results from avoided food production.

During the demonstration phase for the educational meals, plate waste increased by 5.5 g or 11%. So, no food was prevented from being wasted. Consequently, the GWP per kg avoided food waste is not displayed in this case.

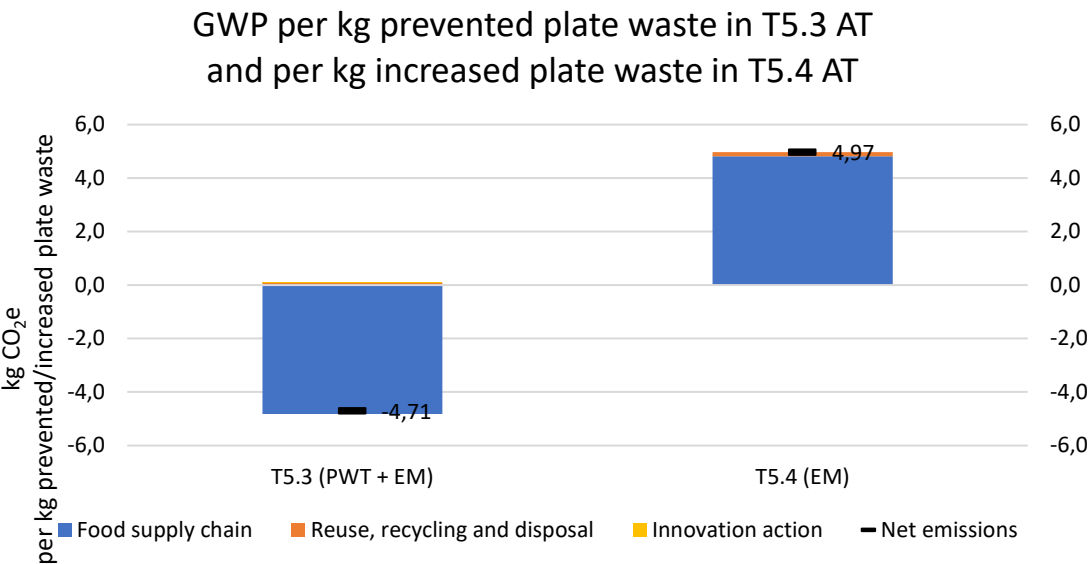


Figure 34: Global warming potential results for 1 kg of prevented school canteen plate waste for the innovation T5.3 and T5.4 tested in Austria. Note that for T5.4 no food waste was prevented.

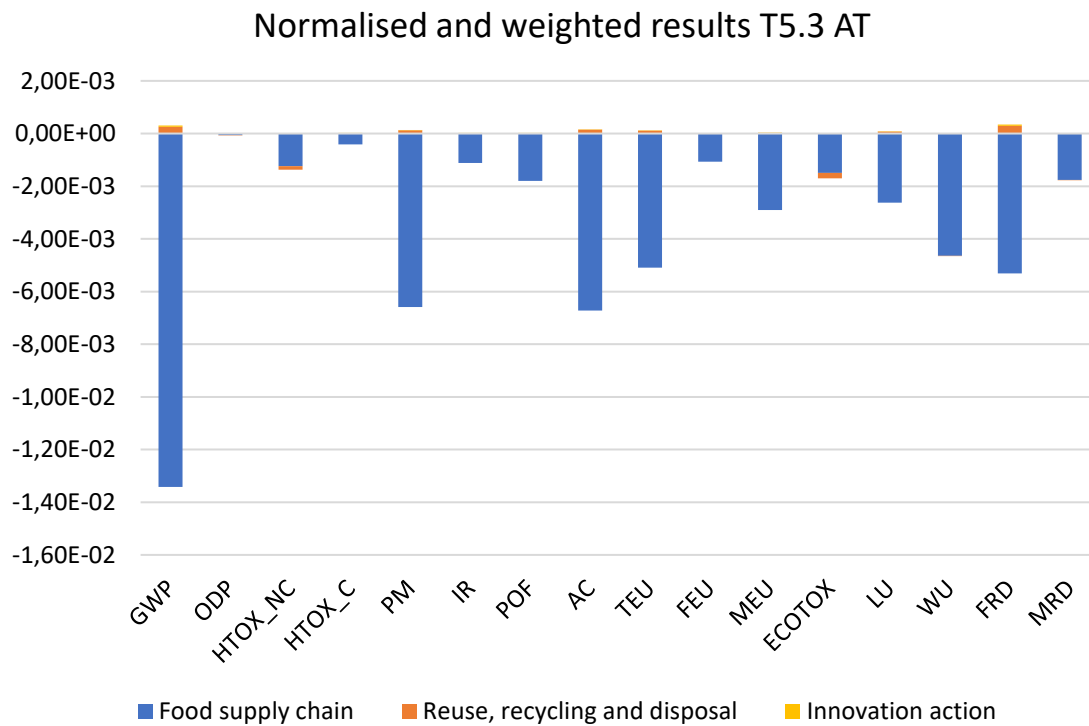


Figure 35: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.3 in Austria

In Germany, the plate waste tracker (T5.3) can prevent up to 14.10 g of school canteen plate waste per student and day. This prevents emissions 0.03 kg CO₂e per student and day on average. With a prevention potential of 36%, an environmental saving of up to 0.15 kg CO₂e per student and school week could be achieved. The total GWP result of 1 kg prevented HH food waste equals -2 kg CO₂e, which is shown in Figure 36. The majority of the GWP savings result from avoided food production.

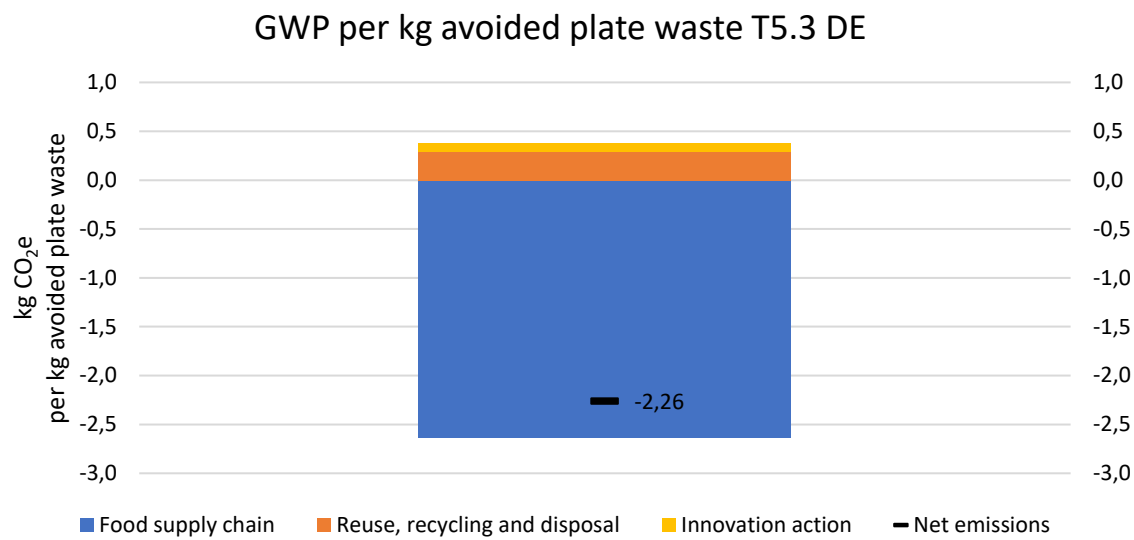


Figure 36: Global warming potential results for 1 kg of prevented school canteen plate waste for the innovation T5.3 tested in Germany

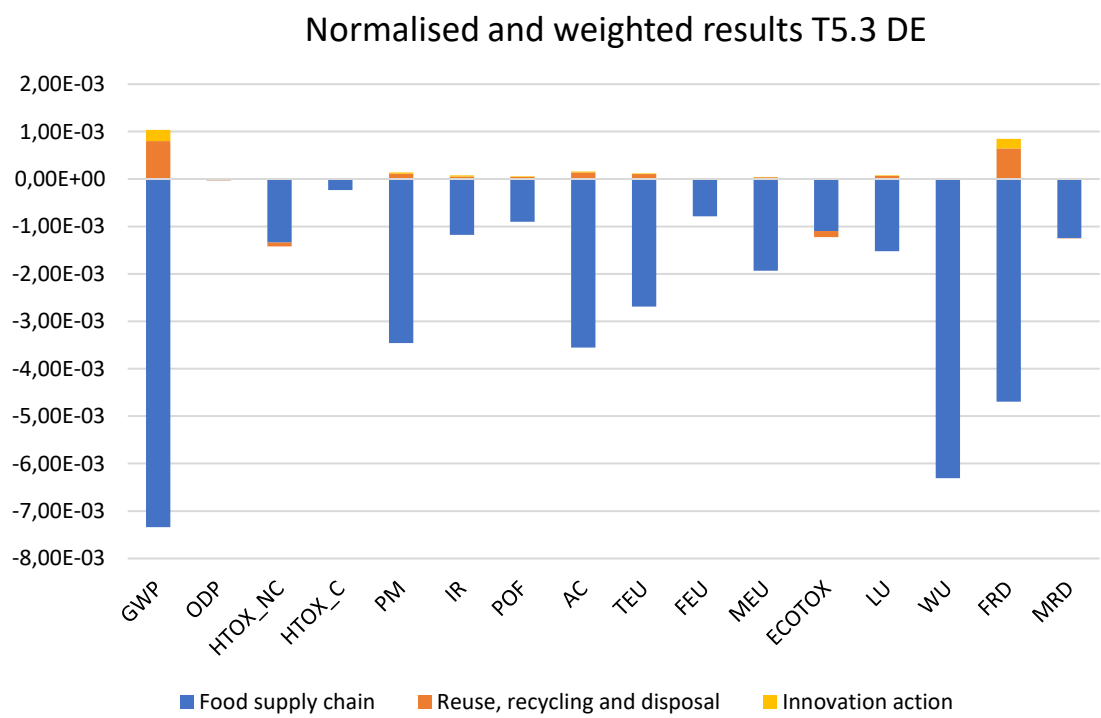


Figure 37: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.3 in Germany

In Sweden, the plate waste tracker (T5.3) can save 6.30 g of school canteen plate waste per student and day. This prevents emissions of 0.02 kg CO₂e per student and day on average. With a prevention potential of 26%, an environmental saving of up to 0.10 kg CO₂e per student and school week could be achieved. The total GWP result of 1 kg prevented school canteen plate waste equals -3.2 kg CO₂e, which is shown in Figure 38. The majority of the GWP savings results from avoided food production.

Furthermore, the educational meals (T5.4, in combination with the plate waste tracker) reduced the plate waste per student and day by 0.2 g or 1%. This resulted in avoided emissions of 6.5E-04 kg CO₂e per student and day, which equals emissions savings of 0.003 kg CO₂e per student and school week. The prevented emissions for 1 kg of avoided school canteen plate waste equal -3.2 kg CO₂e. As shown in Figure 38, the majority of avoided emissions results from food production.

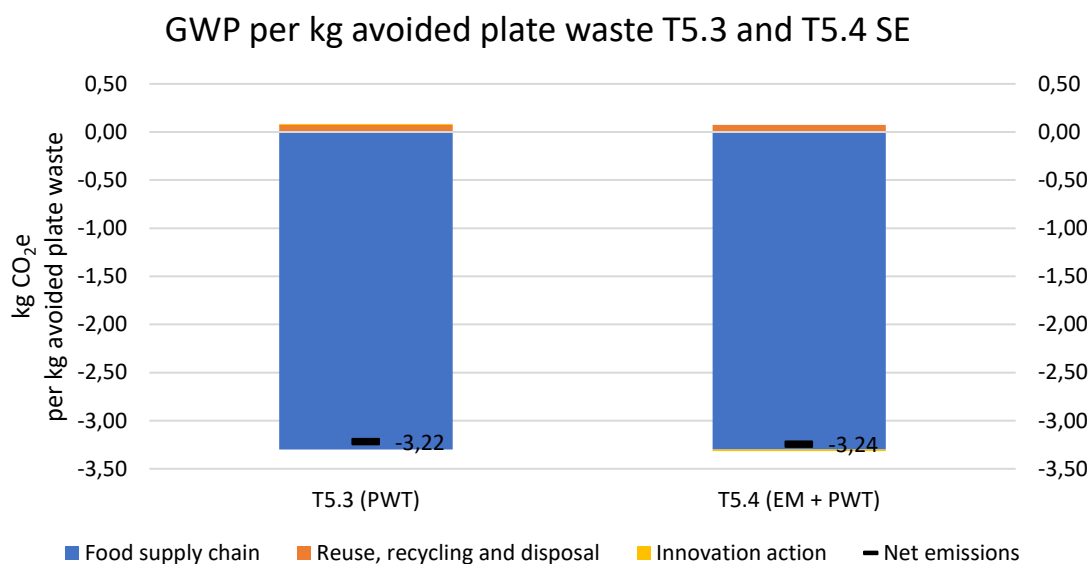


Figure 38: Global warming potential results for 1 kg of prevented school canteen plate waste for the innovations T5.3 and T5.4 tested in Sweden

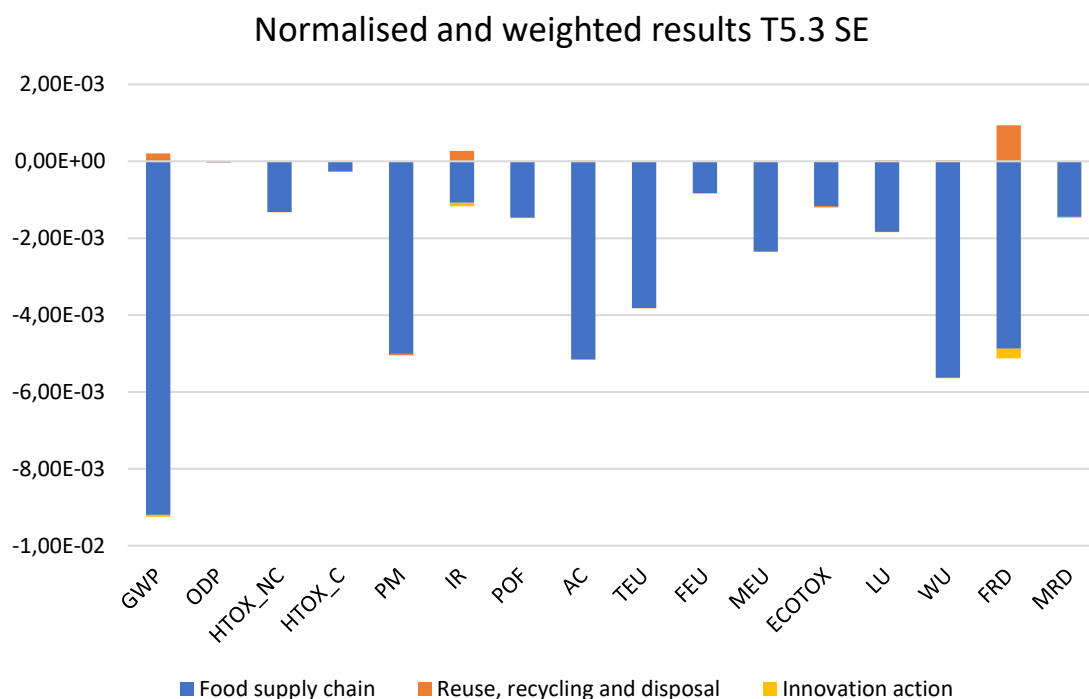


Figure 39: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.3 in Sweden

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The relative external environmental costs result in 1.3 EUR, 0.72 and 0.89 EUR in Austria, Germany and Sweden respectively per kg of food surplus that can be saved in schools by using the plate waste tracker (T5.3).

Table 30: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.3 in Austria

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		17.56 kg per student and year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-4.71E+00	-5.88E-01	-8.26E+01	-1.03E+01
ODP	kg CFC11 eq	-5.18E-07	-1.98E-05	-9.09E-06	-3.48E-04

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
HTOX_NC	CTUh	-9.55E-08	-1.90E-02	-1.68E-06	-3.34E-01
HTOX_C	CTUh	-3.26E-09	-3.59E-03	-5.72E-08	-6.30E-02
PM	Disease incidences	-4.29E-07	-4.10E-01	-7.53E-06	-7.21E+00
IR	kBq U235 eq	-9.21E-01	-1.34E-03	-1.62E+01	-2.36E-02
POF	kg NMVOC eq	-1.52E-02	-2.21E-02	-2.67E-01	-3.87E-01
AC	molc H ⁺ eq	-5.89E-02	-2.47E-02	-1.03E+00	-4.34E-01
TEU	molc N eq	-2.37E-01		-4.16E+00	
FEU	kg P eq	-6.09E-04	-1.43E-03	-1.07E-02	-2.50E-02
MEU	kg N eq	-1.89E-02	-7.42E-02	-3.33E-01	-1.30E+00
ECOTOX	CTUe	-5.02E+01	-2.34E-03	-8.81E+02	-4.10E-02
LU	Pt	-2.64E+02	-5.64E-02	-4.63E+03	-9.90E-01
WU	m ³ water eq	-6.25E+00	-3.81E-02	-1.10E+02	-6.69E-01
FRD	MJ	-3.89E+01	-6.18E-02	-6.82E+02	-1.08E+00
MRD	kg Sb eq	-1.48E-05	-2.96E-05	-2.60E-04	-5.20E-04
Environmental costs			-1.30E+00		-2.29E+01

Table 31: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.3 in Germany

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		2.66 kg per student and year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.26E+00	-2.82E-01	-6.01E+00	-7.51E-01
ODP	kg CFC11 eq	-1.92E-07	-7.35E-06	-5.10E-07	-1.95E-05
HTOX_NC	CTUh	-9.91E-08	-1.97E-02	-2.63E-07	-5.24E-02
HTOX_C	CTUh	-1.78E-09	-1.96E-03	-4.73E-09	-5.20E-03
PM	Disease incidences	-2.21E-07	-2.11E-01	-5.86E-07	-5.61E-01
IR	kBq U235 eq	-9.25E-01	-1.35E-03	-2.46E+00	-3.59E-03
POF	kg NMVOC eq	-7.19E-03	-1.04E-02	-1.91E-02	-2.77E-02
AC	molc H ⁺ eq	-3.04E-02	-1.28E-02	-8.08E-02	-3.40E-02
TEU	molc N eq	-1.22E-01		-3.25E-01	
FEU	kg P eq	-4.47E-04	-1.05E-03	-1.19E-03	-2.78E-03
MEU	kg N eq	-1.25E-02	-4.88E-02	-3.31E-02	-1.30E-01
ECOTOX	CTUe	-3.58E+01	-1.67E-03	-9.53E+01	-4.44E-03
LU	Pt	-1.49E+02	-3.19E-02	-3.97E+02	-8.49E-02
WU	m ³ water eq	-8.49E+00	-5.17E-02	-2.26E+01	-1.37E-01
FRD	MJ	-3.01E+01	-4.78E-02	-8.00E+01	-1.27E-01
MRD	kg Sb eq	-1.05E-05	-2.10E-05	-2.78E-05	-5.57E-05
Environmental costs			-7.23E-01		-1.92E+00

Table 32: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.3 in Sweden

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		1.12 kg	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.70E+00	-3.37E-01	-3.02E+00	-3.78E-01
ODP	kg CFC11 eq	-2.48E-07	-9.51E-06	-2.79E-07	-1.07E-05
HTOX_NC	CTUh	-8.88E-08	-1.77E-02	-9.96E-08	-1.98E-02
HTOX_C	CTUh	-2.05E-09	-2.25E-03	-2.30E-09	-2.53E-03
PM	Disease incidences	-3.17E-07	-3.04E-01	-3.56E-07	-3.41E-01
IR	kBq U235 eq	-7.68E-01	-1.12E-03	-8.62E-01	-1.26E-03
POF	kg NMVOC eq	-1.17E-02	-1.70E-02	-1.31E-02	-1.90E-02
AC	molc H ⁺ eq	-4.41E-02	-1.85E-02	-4.94E-02	-2.08E-02
TEU	molc N eq	-1.79E-01		-2.00E-01	
FEU	kg P eq	-4.78E-04	-1.12E-03	-5.35E-04	-1.25E-03
MEU	kg N eq	-1.52E-02	-5.97E-02	-1.71E-02	-6.70E-02
ECOTOX	CTUe	-3.26E+01	-1.52E-03	-3.65E+01	-1.70E-03
LU	Pt	-1.88E+02	-4.03E-02	-2.11E+02	-4.52E-02
WU	m ³ water eq	-7.50E+00	-4.57E-02	-8.41E+00	-5.12E-02
FRD	MJ	-2.58E+01	-4.10E-02	-2.89E+01	-4.59E-02
MRD	kg Sb eq	-1.23E-05	-2.46E-05	-1.38E-05	-2.75E-05
Environmental costs			-8.87E-01		-9.94E-01

Table 33: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.4 in Sweden

		Food waste prevented per kg		Total food waste prevented per student and year	
Amount of food waste prevention		1 kg		0.04 kg	
Environmental category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.72E+00	-3.41E-01	-3.06E+00	-3.82E-01
ODP	kg CFC11 eq	-2.48E-07	-9.51E-06	-2.79E-07	-1.07E-05
HTOX_NC	CTUh	-8.92E-08	-1.77E-02	-1.00E-07	-1.99E-02
HTOX_C	CTUh	-2.10E-09	-2.31E-03	-2.36E-09	-2.60E-03
PM	Disease incidences	-3.18E-07	-3.05E-01	-3.57E-07	-3.42E-01
IR	kBq U235 eq	-8.77E-01	-1.28E-03	-9.84E-01	-1.44E-03
POF	kg NMVOC eq	-1.18E-02	-1.71E-02	-1.32E-02	-1.92E-02
AC	molc H ⁺ eq	-4.42E-02	-1.85E-02	-4.95E-02	-2.08E-02
TEU	molc N eq	-1.79E-01		-2.01E-01	
FEU	kg P eq	-4.78E-04	-1.12E-03	-5.36E-04	-1.25E-03
MEU	kg N eq	-1.53E-02	-5.98E-02	-1.71E-02	-6.71E-02
ECOTOX	CTUe	-3.27E+01	-1.52E-03	-3.67E+01	-1.71E-03
LU	Pt	-1.90E+02	-4.06E-02	-2.13E+02	-4.56E-02
WU	m ³ water eq	-7.52E+00	-4.58E-02	-8.43E+00	-5.13E-02
FRD	MJ	-2.86E+01	-4.54E-02	-3.20E+01	-5.09E-02
MRD	kg Sb eq	-1.23E-05	-2.46E-05	-1.38E-05	-2.76E-05
Environmental costs			-8.97E-01		-1.01E+00

Interpretation and review

The analysis clearly shows the potential to decrease food waste and resulting environmental burdens through behavioural interventions such as the plate waste tracker and educational interventions. While national differences in school canteens definitely play a role in the way food waste is handled and its occurrence, the results show that the presented interventions can be successfully applied to multiple settings.

Further, the varying degrees of success observed with educational meals highlight the need for context-specific adaptations of behavioural interventions. This suggests that while the

plate waste tracker is universally beneficial, educational programs might require more customization to effectively engage students and teachers to reduce waste in different cultural or operational environments.

Environmental impacts per kg of food waste is depending on the food mix that was considered in the different countries. The emission factor of the mixed plate waste is the highest in Austria (4.8 kg CO₂e), followed by Sweden (3.3 kg CO₂e) and then by Germany (2.2 kg CO₂e). As the composition does not change between baseline and demonstration, this emission factor corresponds to the environmental impacts per kg of food waste. A clear shortcoming is that data on the food waste composition at the observed schools was lacking. The food waste composition was assumed based on the food that was usually served in schools in the respective countries, not the food that was actually wasted. It is therefore recommended to include the composition of the food waste in future studies.

Impacts from the innovation action of the Plate Waste Tracker are the highest in Austria. This is due to the fact that the PWT was used by more pupils in Germany and Sweden compared to Austria. So, the respective electricity consumption per pupil was also the highest in Austria.

T5.5 'CozZo Mobile App'

Goal and Scope

This innovation (T5.5) is a mobile application for consumers that contributes to reducing household food waste. It was tested in Austria, Finland and Greece.

The mobile app named CozZo combines a digital shopping planner with automated food and home supplies catalogues. It offers more features than a regular pantry list and utilises artificial intelligence. Unlike similar retailer-branded applications, CozZo is not dependent on choice of store. During grocery shopping, all food is added to the user's "home catalogue" with calculated expiry dates and reminders. This reduces user's product management efforts with suggestions and auto-update algorithms based on predictive self-learning technology and helps users to buy products in the right quantity, to know which products are close to their expiry date and to see their actual food waste level.

The functional unit of the system is **1 kg of prevented food surplus or waste in households (HH)**. The reference flow is the amount of food waste measured at the baseline and at demonstration stage:

Table 34: Reference flows of the baseline and the demonstration scenario of T5.5

Country	Average amount of food surplus or waste at BASELINE (n)	Average amount of food surplus or waste at DEMONSTRATION (n-x _p)
Austria	1.00 kg per HH and week	0.42 kg per HH and week
Finland	1.37 kg per HH and week	0.79 kg per HH and week
Greece	0.70 kg per HH and week	0.61 kg per HH and week

The system boundaries for both the baseline and the demonstration system are shown in Figure 40. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing of the food items, as well as their distribution and retail. Finally, the food gets prepared (e.g., cooked) by the consumers/the HHs. The food is then redistributed or disposed of through the municipal waste management system. For this, credits are assigned for substituting either primary food production or primary energy production (for details see chapter 2). In the demonstration system, the CozZo mobile app is introduced at the consumption stage, in order to prevent HH food waste.

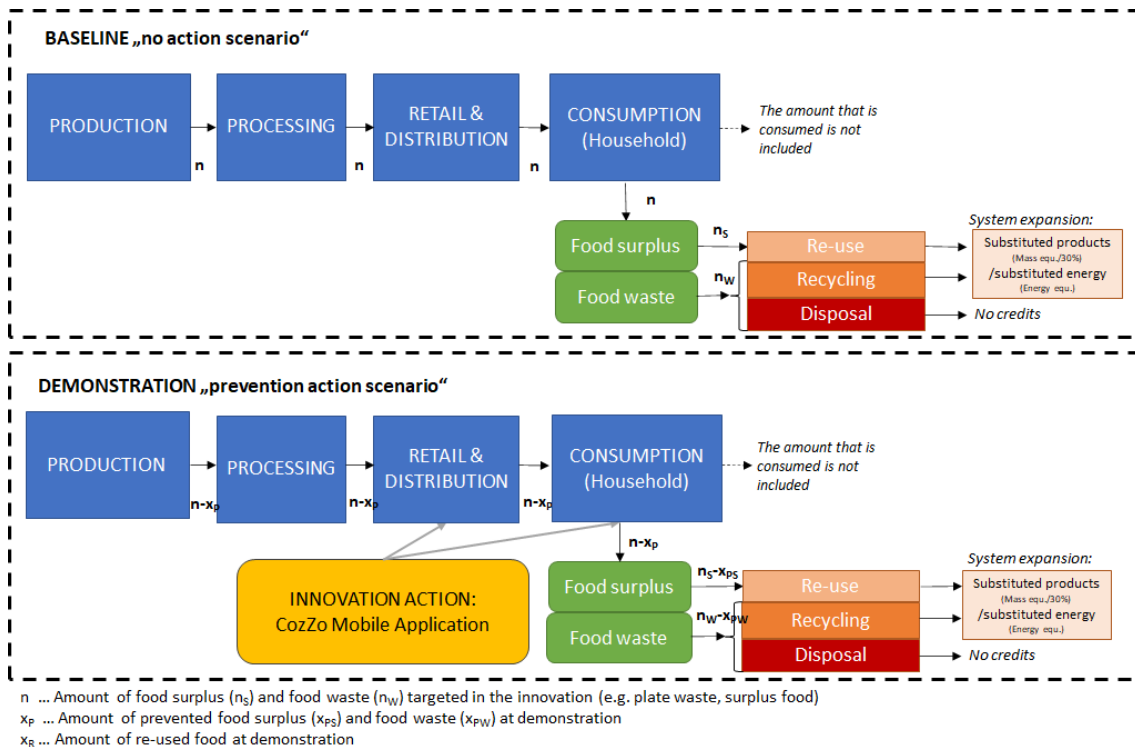


Figure 40: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.5

Life cycle inventory (LCI)

Table 35 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 35: Type of process data and collection method used for Task 5.5

Component	Process data collected within LOWINFOOD (so-called proxy data)	T5.5	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Direct quantification Direct quantification
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Interviews
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Interviews and expert consultation

Data on the amount and composition of food waste was collected through two sorting analyses. The first sorting analysis was conducted before the CozZo mobile app was introduced to the participating HHs. Then, the HHs used the CozZo mobile app over a period of three to six weeks. After this, the second sorting analysis of the HH food waste was conducted. Additionally, qualitative surveys were conducted. Through the first survey, the waste management options the HHs used for the food waste were queried. The second survey established the average time of daily app use for each HH during the demonstration phase.

Table 36: Type A data: Food surplus or waste related life cycle inventory data for Task 5.5

Food waste data	Austria		Finland		Greece	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Total HH food waste per week [kg/week]	18.97	7.88	24.74	14.28	10.53	9.07
Total number of participating HHs	19	19	18	18	15	15
Average HH food waste [g]	998.10	414.60	1,374.33	793.56	701.80	604.60
Min HH food waste [g]	114.00	0.00	33.00	11.00	55.00	67.00
Max HH food waste [g]	3,047.50	1,749.30	7,121.00	3,684.00	1,556.00	1,064.00
Median HH food waste [g]	699.00	303.00	858.00	441.00	705.00	703.00

The composition of the HH food waste was determined through two sorting analyses (one before and one after the demonstration phase). Emission factors were calculated for each individual food group (e.g., fruits, vegetables, bread, meat) with Agribalyse data. Then, these food group emission factors were aggregated to a single emission factor for 1 kg HH food waste, based on their percentual share in total HH food waste.

Table 37: Type A data: Food surplus or waste composition for Task 5.5

HH food waste composition	Austria		Finland		Greece	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Storage losses ⁹	14%	0%	0%	2%	1%	6%
Fruits	9%	21%	9%	10%	20%	21%
Vegetables	14%	25%	24%	19%	15%	22%
Legumes	0%	3%	1%	2%	5%	1%
Bread and Pastry	17%	8%	10%	13%	11%	5%
Other desserts/sweets	3%	3%	1%	1%	4%	1%
Meat and meat products	1%	12%	8%	9%	6%	5%
Fish	0%	2%	2%	0%	0%	0%
Dairy products	7%	10%	7%	17%	22%	11%
Eggs	4%	5%	1%	0%	1%	1%
Side dishes ¹⁰	3%	0%	10%	9%	7%	15%
Snacks	1%	0%	2%	3%	4%	2%
Soups	0%	0%	1%	1%	0%	0%
Beverages	16%	3%	21%	9%	0%	4%
Other ¹¹	12%	8%	2%	5%	5%	6%

The participating HHs were surveyed on their food disposal practices (e.g., feeding to animals, separate waste collection of organic waste, municipal solid waste collection). Redistribution in the context of households means that food is handed over to family and friends. This is very common in Greek households. Based on this information and the respective waste quantities of each HH, the EoL treatment of the HH food waste was calculated. The results are shown in Table 38.

⁹ average composition of all the other categories

¹⁰ e.g., rice, pasta potatoes

¹¹ e.g., soup

Table 38: Type B data: Reuse, recycling and disposal options for Task 5.5

Options	Austria		Finland		Greece	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Redistribution	12%	<i>the same as for the baseline are assumed</i>	6%	<i>the same as for the baseline are assumed</i>	20%	<i>the same as for the baseline are assumed</i>
Feeding to pets (or wild animals)	2%		12%		13%	
Composting	29%		10%		0%	
Home composting	4%		13%		0%	
Anaerobic digestion	10%		31%		0%	
Municipal waste treatment (incinerated)	42%		28%		0%	
Municipal waste treatment (landfill)	0%		0%		67%	
Other disposal (sewer/toilet)	1%		0%		0%	

The app use-related electricity consumption of the smartphone and the server hosting the app were taken into account. The smartphone electricity consumption was calculated based on the average yearly energy consumption of a smartphone (Seppälä and Mattila, 2013; Yu et al., 2010; Zink et al., 2014) under the assumption that 90% of the energy is used during active use only (Ardito et al., 2013) and the share of active use time during a smartphone's life is roughly 15% as smartphone energy consumption is substantially higher during active use than during stand-by (Wang et al., 2016). The average number of app accesses per HH and week were calculated based on how often the participating HHs used the app per week. Based on the duration (in minutes) of each app use, the average duration of the app use per HH and week was determined as well. The respective national electricity mix of Austria, Finland or Greece was used for this.

For the smartphone and server emissions, the corresponding national electricity mix (the smartphones were used and charged in the respective countries Austria, Finland and Greece) and USA (server hosting the corresponding app) were used in combination with their respective electricity demand per reference unit. The electricity consumption of the app server was calculated using scientific literature (Seppälä and Mattila, 2013).

Table 39: Type C data: Innovation action related life cycle inventory data for Task 5.5 (Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Austria	Finland	Greece
App-related smartphone use			
Smartphone electricity consumption per hour [kWh/h]	8.86E-03		
Average duration of app use per week [min/week]	14.58	32.11	43.00
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.28E-04		
National electricity mix	AT	FI	GR
Average app use-related smartphone electricity consumption per HH and week [kWh/HH*week]	3.48E-03	9.59E-03	7.60E-03
App server			
Data consumption per app access (provided by CozZo) [MB/access]	5.5		
Average number of app accesses per HH and week [no/HH*week]	1.06	3.86	8.73
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03		
National electricity mix	USA		
Average server electricity consumption per HH and week [kWh/HH*week]	0.01	0.04	0.09

For the innovation action impacts, only electricity consumption of smartphones, network infrastructure and app server were considered. The impacts associated with the production of smartphones, network infrastructure and app server infrastructure are not included in this calculation.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The GWP resulted in 3.28 kg CO₂e for the baseline scenario (HH food waste of one week without any intervention) and 2.13 kg CO₂e for the demonstration scenario (HH food waste of one week while the CozZo mobile app is used) in Austria (see Figure 41). In both scenarios, the majority of GWP is associated with food production. Waste management contributes very little to the total GWP results (baseline: 2.10%, demonstration: 0.04%). The reason for this is that credits were assigned for avoided primary food production from redistributing or feeding food to pets and for avoided electricity and thermal energy production as a result of anaerobic digestion. Innovation action impacts (smartphone and app server electricity consumption) contribute 0.39% to the demonstration GWP results. The CozZo mobile app

resulted in a 60% decrease of HH food waste. As a result, the food waste-related GWP per HH and week decreased by 35% (1.15kg CO₂e).

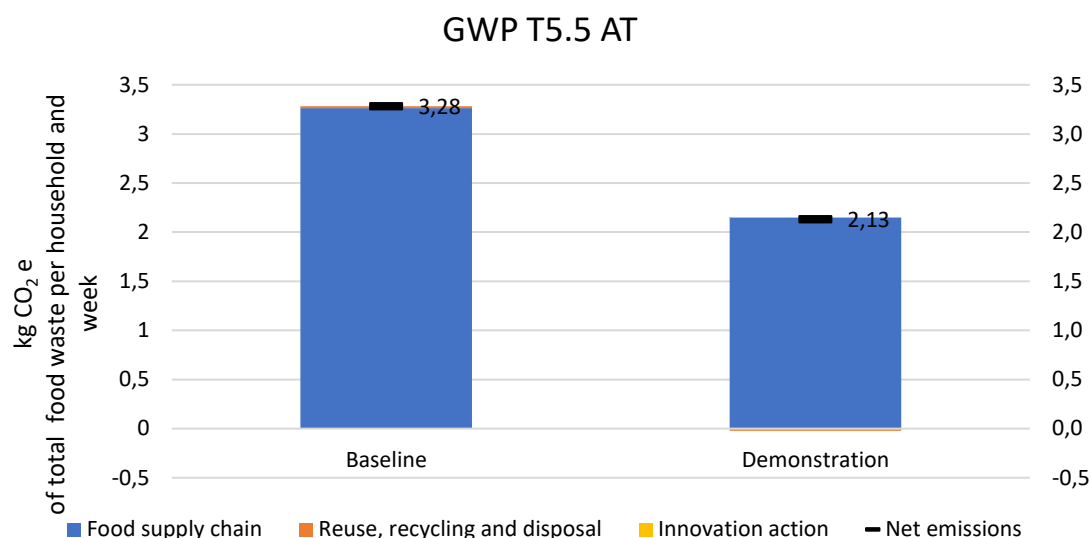


Figure 41: Global warming potential for the baseline and demonstration scenario for the innovation T5.5 tested in Austria

The observation in Finland resulted in a GWP of 4.38 kg CO₂e for the baseline scenario (HH food waste of one week without any intervention) and equals 2.72 kg CO₂e for the demonstration scenario (HH food waste of one week while the CozZo mobile app is used) (see Figure 42). In both scenarios, the majority of GWP results from food production. Waste management reduces total impacts by 3% in both the baseline and demonstration scenario. This caused by the credits assigned for the substituted primary food production (donation and animal feed) and for the substituted primary electricity production based on the national electricity mix and for the substituted thermal energy production from natural gas (anaerobic digestion). Impacts resulting from the innovation action are responsible for 0.7% of total GWP impacts in the demonstration scenario. The CozZo mobile app resulted in a 42% decrease of HH food waste. As a result, the GWP per HH and week decreased by 38% (1.7 kg CO₂e).

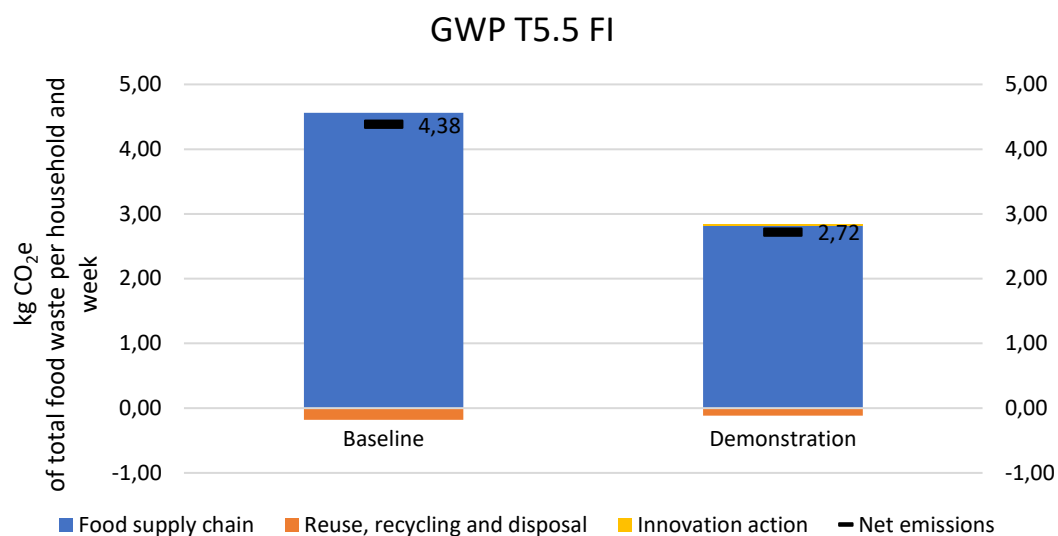


Figure 42: Global warming potential for the baseline and demonstration scenario for the innovation T5.5 tested in Finland

As shown in Figure 43, the GWP resulted in 2.30 kg CO₂e for the baseline scenario (HH food waste of one week without any intervention) and equals 1.85 kg CO₂e for the demonstration scenario (HH food waste of one week while the CozZo mobile app is used) in Greece. In both scenarios, the majority of GWP is associated with food production (baseline: 97%, demonstration: 94%). Waste management is responsible for 3% of the GWP in the baseline scenario and for 4% of the GWP in the demonstration scenario. Innovation action impacts (smartphone and app server electricity consumption) contributes 2% to the demonstration GWP results. The CozZo mobile app resulted in a 14% decrease of HH food waste. As a result, the GWP per HH and week decreased by 20% (0.45 kg CO₂e).

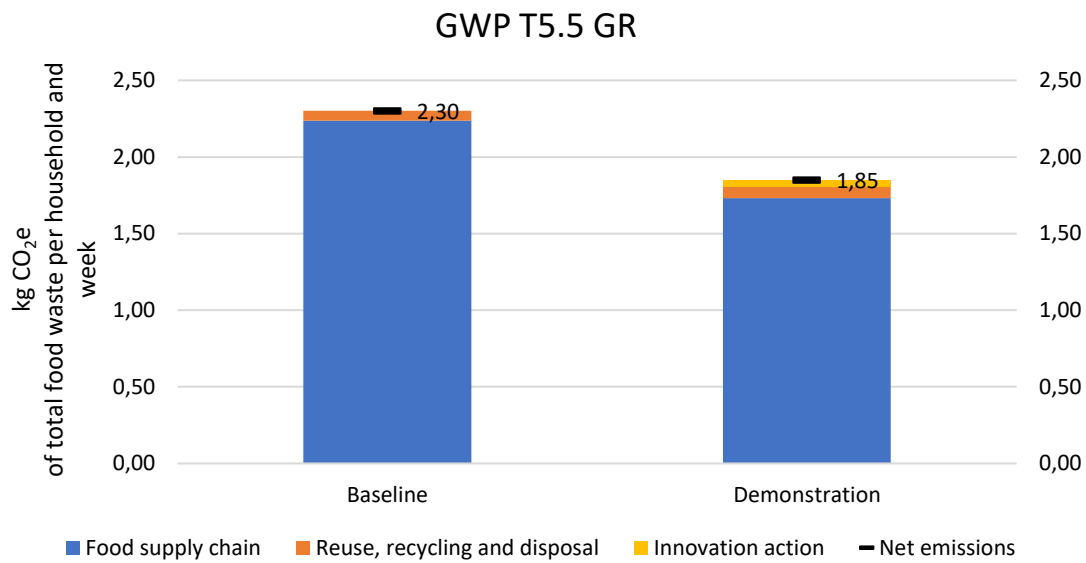


Figure 43: Global warming potential for the baseline and demonstration scenario for the innovation T5.5 tested in Greece

In Austria, the baseline PEF score equals 0.39 points and the demonstration PEF score equals 0.26 points. This is shown in Figure 44. Through the use of the CozZo mobile app, PEF score results were reduced by 34% (0.13 points). The PEF score result can largely be attributed to food production. Waste management reduces PEF score results in both scenarios. This is caused by the credits for the avoided food production from food donation, animal feed and anaerobic digestion outweighing the PEF score contribution of composting and municipal waste management.

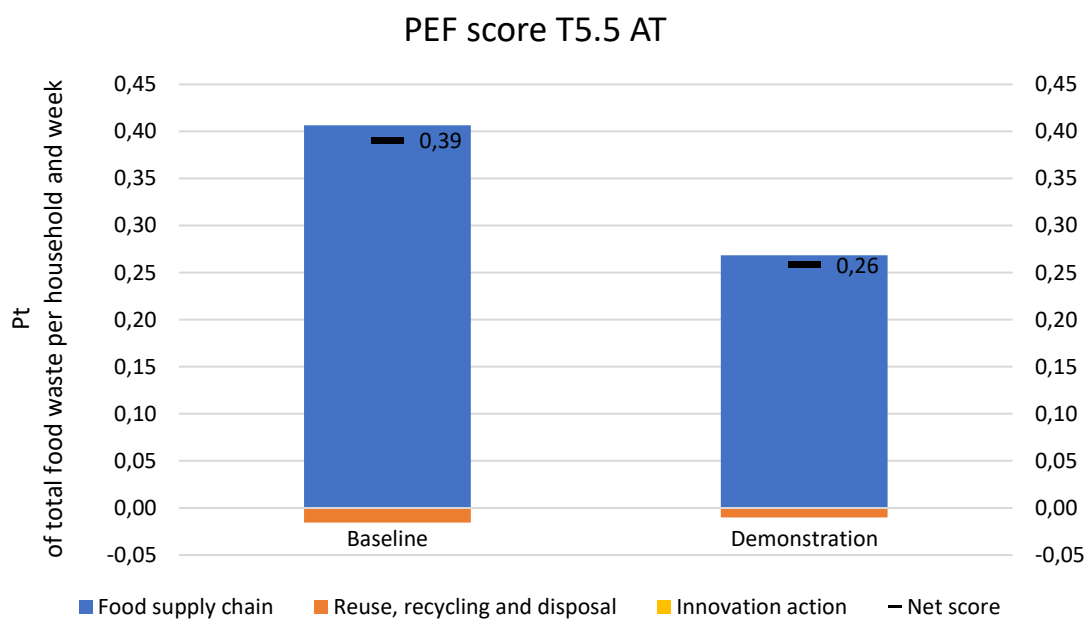


Figure 44: PEF score for the baseline and demonstration scenario for the innovation T5.5 tested in Austria

In Finland, the baseline PEF score equals 0.54 and the demonstration PEF score equals 0.32. The majority of PEF score impacts are associated with food production. Waste management reduces PEF score impacts by 5.1% in the baseline scenario and by 5.6% in the demonstration scenario. Again, this results from credits assigned for substituting primary food production and primary energy generation. Innovation action does not contribute to the PEF score impacts in either scenario. Through the use of the CozZo mobile app, PEF score results were reduced by 41%.

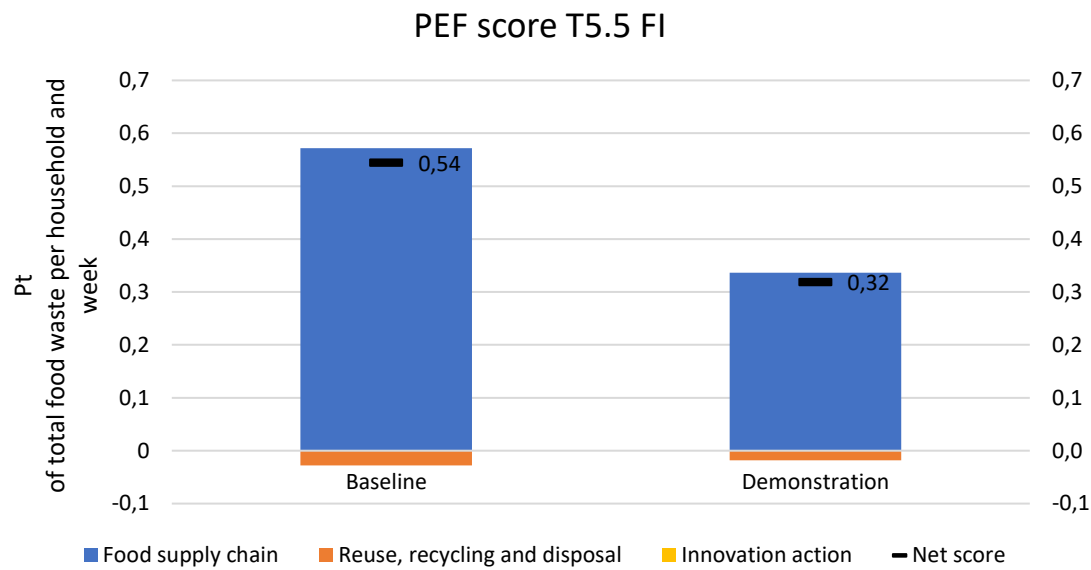


Figure 45: PEF score for the baseline and demonstration scenario for the innovation T5.5 tested in Finland

In Greece the baseline PEF score equals 0.25 points and the demonstration PEF score equals 0.21 points. This is shown in Figure 46. Through the use of the CozZo mobile app, PEF score results were reduced by 18% (-0.04 points). The PEF score result can be entirely attributed to food production. Waste management reduces PEF score results in both scenarios. This is caused by the credits for the avoided food production from food donation and animal feed outweighing the PEF score contribution of municipal waste management.

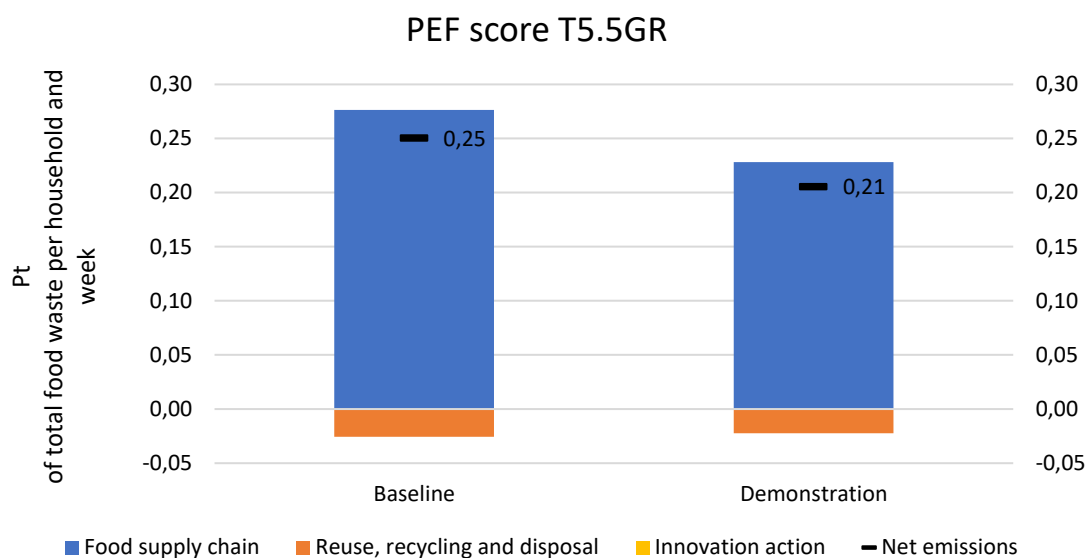


Figure 46: PEF score for the baseline and demonstration scenario for the innovation T5.5 tested in Greece

As shown in Figure 47, the majority of the waste management related GWP for Austria, both for the baseline as well as the demonstration scenario, is caused by municipal waste treatment, composting (both at a composting plant and home composting) and other waste treatment (disposing of food waste through the toilet/waste water treatment). Donation, feeding to pets and anaerobic digestion produce negative GWP results, thus reducing the total GWP results. The reason for this is that credits are assigned for substituting primary food production (donation and animal feed) and for substituted primary electricity or thermal energy production (anaerobic digestion). It was assumed that the food redistributed by the HH or fed to animals replaces the production of an equivalent food mix by 30%.

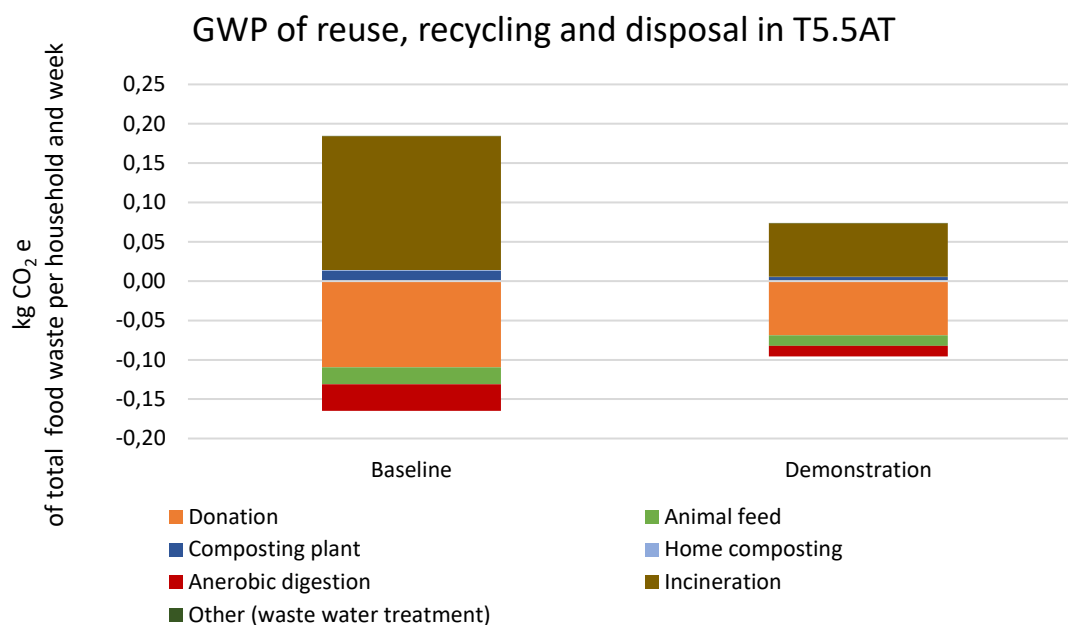


Figure 47: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.5 tested in Austria

As shown in Figure 48, the majority of the waste management related GWP in Finland, both for the baseline as well as the demonstration scenario is caused by municipal waste management. Composting has little contribution to the total GWP in both scenarios. Food donation, feeding food waste to animals and anaerobic digestion reduce total waste management related GWP. The reason for this is that credits are assigned for substituting primary food production (donation and feeding to animals) and for substituted production of electricity and thermal energy (anaerobic digestion). It was assumed that the food redistributed by the HH or fed to animals replaces the production of an equivalent food mix by 30%. The credits for avoided electricity production were assigned based on the Finnish national electricity mix and the credits for avoided thermal energy production are based on the European mix for generating thermal energy from natural gas.

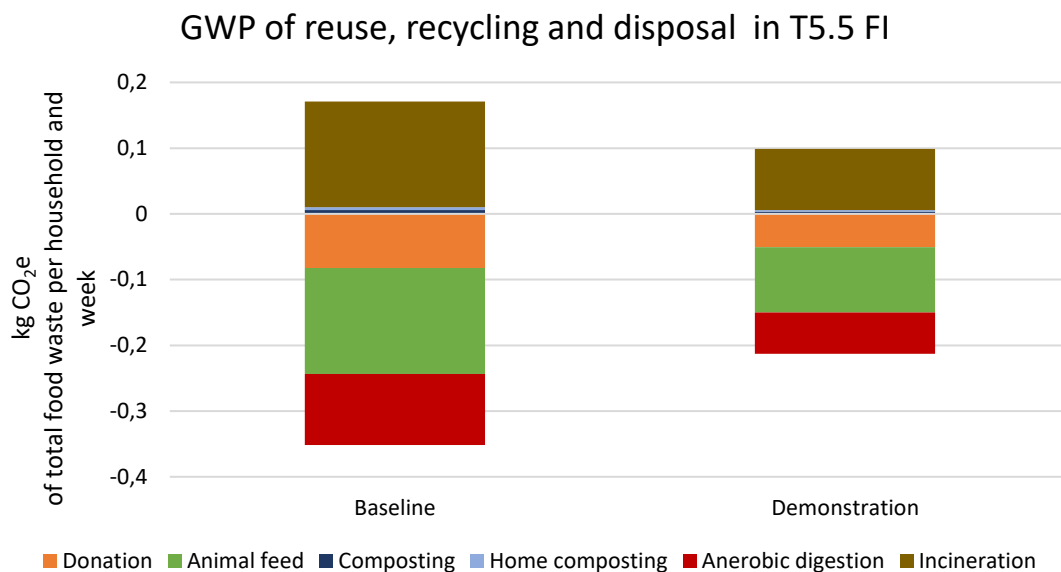


Figure 48: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.5 tested in Finland

As shown in Figure 49, the majority of the waste management related GWP in Greece, both for the baseline as well as the demonstration scenario, is caused by municipal waste treatment. This is likely because 67% of HH food waste is disposed of through municipal waste management, and thus (in the case of Greece) being landfilled. Food donation and animal feed reduce waste management related GWP. The reason for this is the credits assigned for substituting primary food production. It was assumed that the food redistributed by the HH or fed to animals replaces the production of an equivalent food mix by 30%.

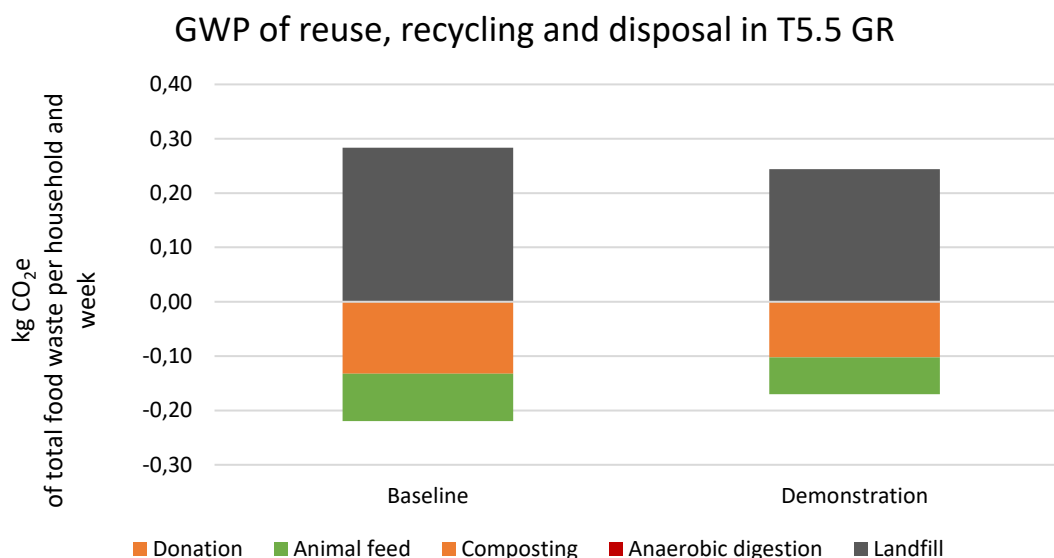


Figure 49: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.5 tested in Greece

In Austria, the use of the CozZo mobile app resulted in an impact reduction across all EF impact categories (global warming potential: -43%, ozone depletion: -34%, human toxicity non-cancer effects: -53%, human toxicity cancer effects: -52%, particulate matter: -35%, ionising radiation HH: -49%, photochemical ozone formation: -51%, acidification: -33%, terrestrial eutrophication: -30%, freshwater eutrophication: -51%, marine eutrophication: -46%, freshwater ecotoxicity: -51%, land use: -31%, water scarcity: -41%, fossil resource depletion: -51%, abiotic resource depletion: -56%).

As shown in Figure 50, food production is the major contributor to environmental impacts for all impact categories. With the exception of global warming potential, human toxicity (non-cancer), photochemical ozone formation, marine eutrophication and freshwater ecotoxicity, waste management reduces impact assessment results for all categories. This results from the credits assigned for avoided food production when food is donated/redistributed or fed to animals and credits assigned for anaerobic digestion. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

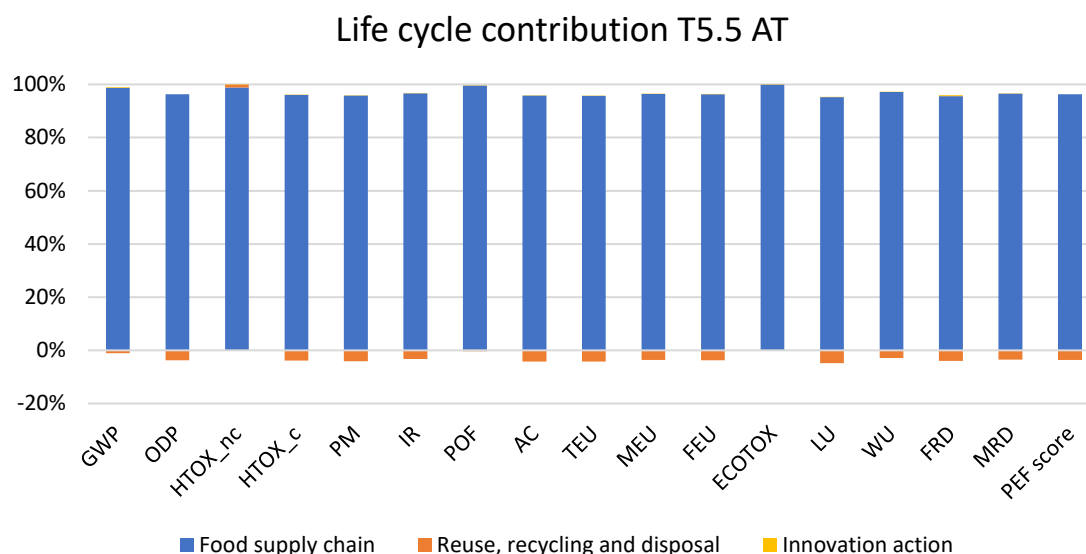


Figure 50: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.5 in Austria

In Finland, the use of the CozZo mobile app resulted in an impact reduction across all EF impact categories (global warming potential: -38%, ozone depletion: -45%, human toxicity non-cancer effects: -43%, human toxicity cancer effects: -46%, particulate matter: -41%, ionising radiation HH: -40%, photochemical ozone formation: -52%, acidification: -40%, terrestrial eutrophication: -38%, freshwater eutrophication: -46%, marine eutrophication: -39%, freshwater ecotoxicity: -45%, land use: -31%, water scarcity: -43%, fossil resource depletion: -45%, abiotic resource depletion: -50%).

As shown in Figure 51, the majority of environmental impacts result from food production. With the exception of photochemical ozone formation, waste management has negative impact assessment results in all categories. This results from the credits assigned for avoided food production when food is donated/redistributed or fed to animals and from the credits assigned for anaerobic digestion. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

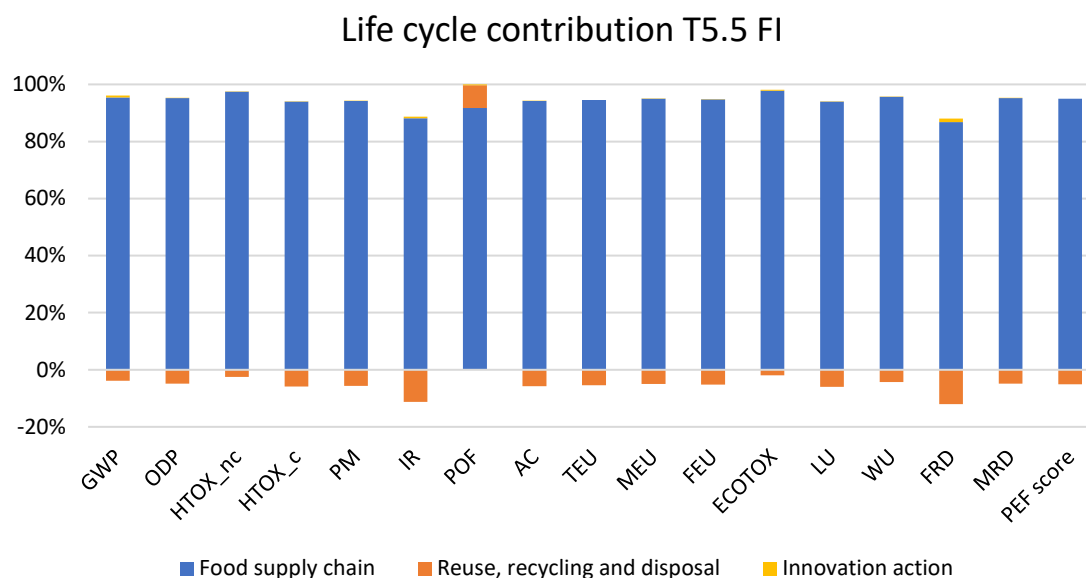


Figure 51: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.5 in Finland

In Greece, the use of the CozZo mobile app resulted in an impact reduction across all EF impact categories (global warming potential: -20%, ozone depletion: -6%, human toxicity non-cancer effects: -10%, human toxicity cancer effects: -15%, particulate matter: -20%, ionising radiation HH: -10%, photochemical ozone formation: -11%, acidification: -21%, terrestrial eutrophication: -23%, freshwater eutrophication: -17%, marine eutrophication: -26%, freshwater ecotoxicity: -14%, land use: -27%, fossil resource depletion: -7%, abiotic resource depletion: -10%), with the exception of water scarcity, which increased by 7%. The reason for this is that there is an increase in waste from water-intensive food groups (storage loss, vegetables, side dishes) in the demonstration scenario compared to the baseline scenario.

As shown in Figure 52, food production is the major contributor to environmental impacts for all impact categories. With the exception of global warming potential, waste management reduces impact assessment results for all categories. This results from the credits assigned for avoided food production when food is donated/redistributed or fed to animals. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

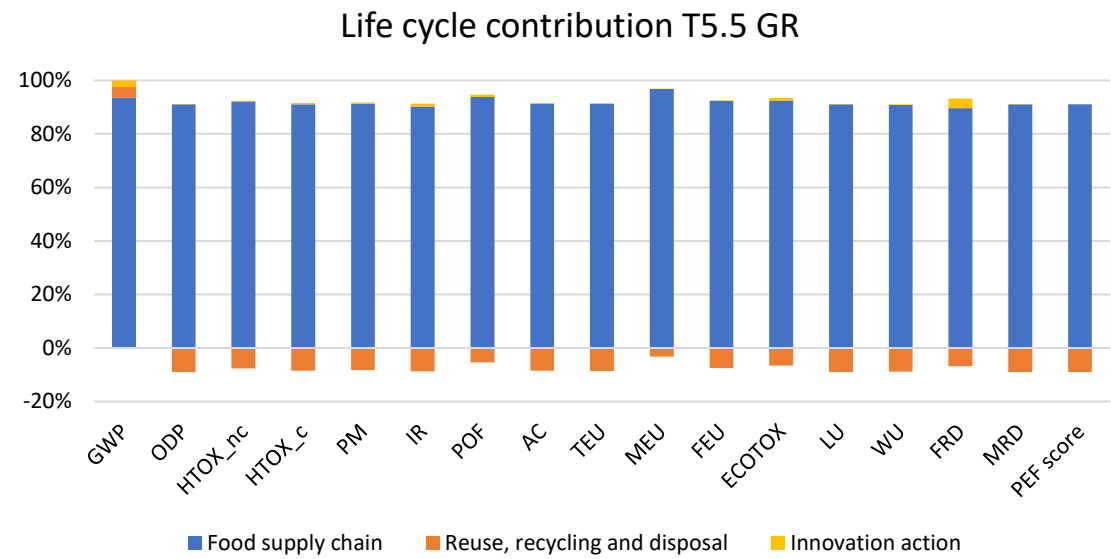


Figure 52: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.5 in Greece

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

In Austria, this innovation can save up to 0.6 kg of HH food waste per week. This prevents emissions of 1.1 kg CO₂e per HH and week on average. With a prevention potential of 35%, an environmental saving of up to 60 kg CO₂e per HH and year can be achieved. The total GWP result of 1 kg prevented HH food waste equals -1.91 kg CO₂e, which is shown in Figure 53. The majority of the GWP savings results from avoided food production.

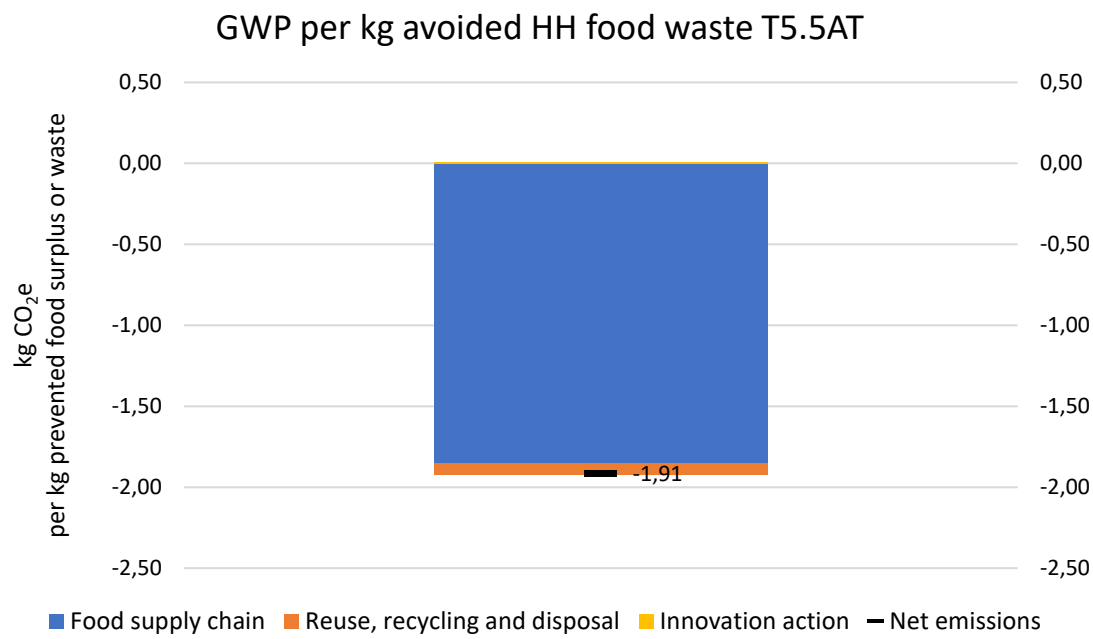


Figure 53: Global warming potential results for 1 kg of prevented HH food waste for the innovation T5.5 tested in Austria

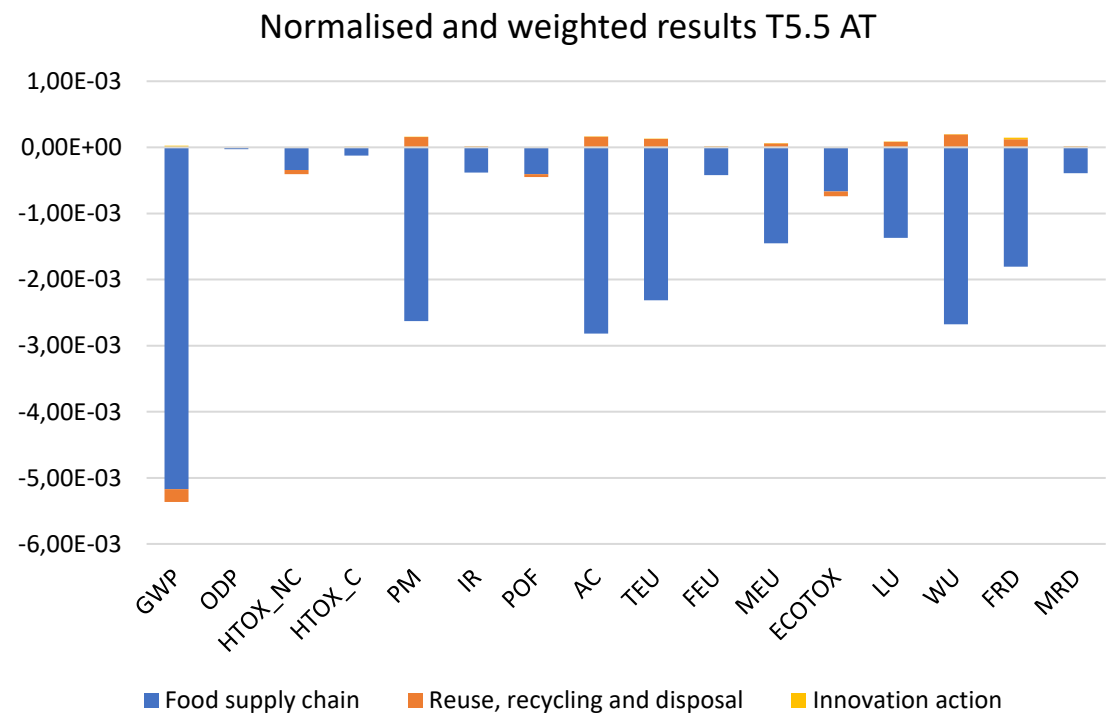


Figure 54: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.5 in Austria

In Finland, this innovation can prevent up to 0.58 kg of HH food waste per week. This prevents emissions of 1.7 kg CO₂e per HH and week on average. With a prevention potential of 38%, an environmental saving of up to 86.4 kg CO₂e per HH and year can be achieved. The total GWP result of 1 kg prevented HH food waste equals -2.86 kg CO₂e, which is shown in Figure 55. The majority of the GWP savings results from avoided food production.

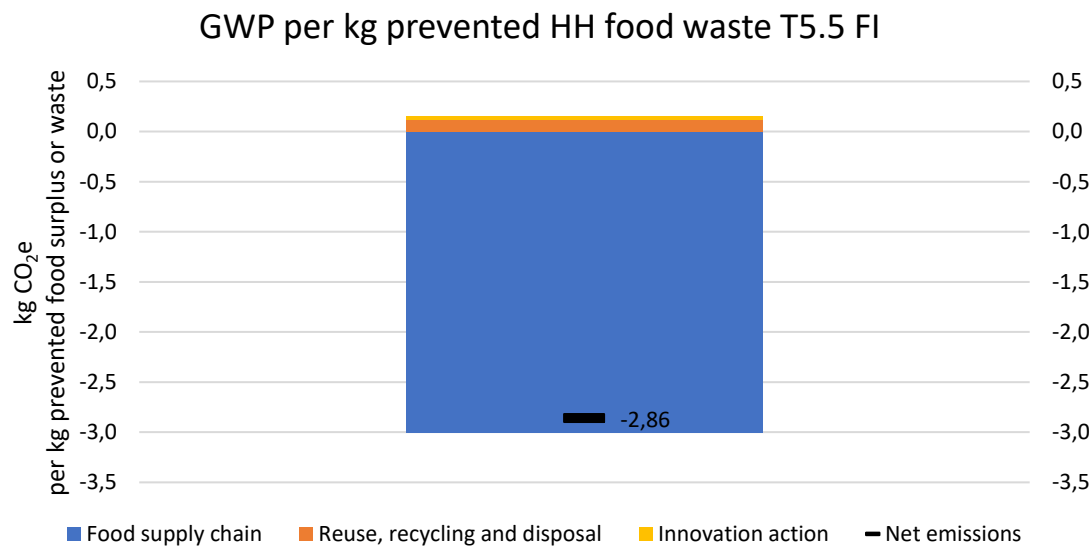


Figure 55: Global warming potential results for 1 kg of prevented HH food waste for the innovation T5.5 tested in Finland

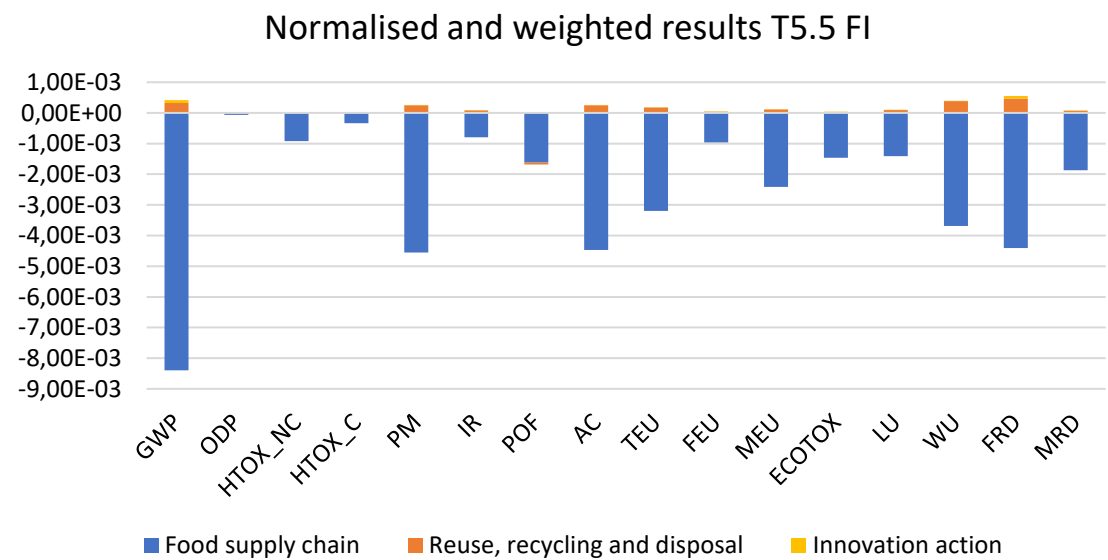


Figure 56: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.5 in Finland

In Greece, this innovation can save up to 0.097 kg of food waste at HH per week. This prevents emissions of 0.45 kg CO₂e per HH on average. With a prevention potential of 19%, an environmental saving of up to 23.41 kg CO₂e per HH and year can be achieved. The total GWP result of 1 kg prevented HH food waste equals -4.63 kg CO₂e, which is shown in Figure 57. The majority of the GWP savings results from avoided food production.

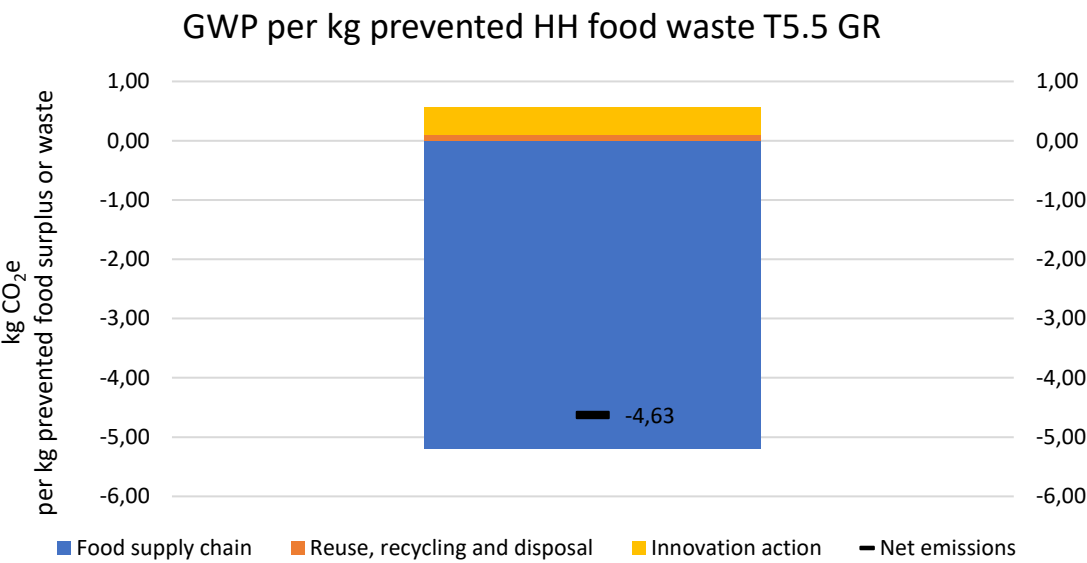


Figure 57: Global warming potential results for 1 kg of prevented HH food waste for the innovation T5.5 tested in Greece

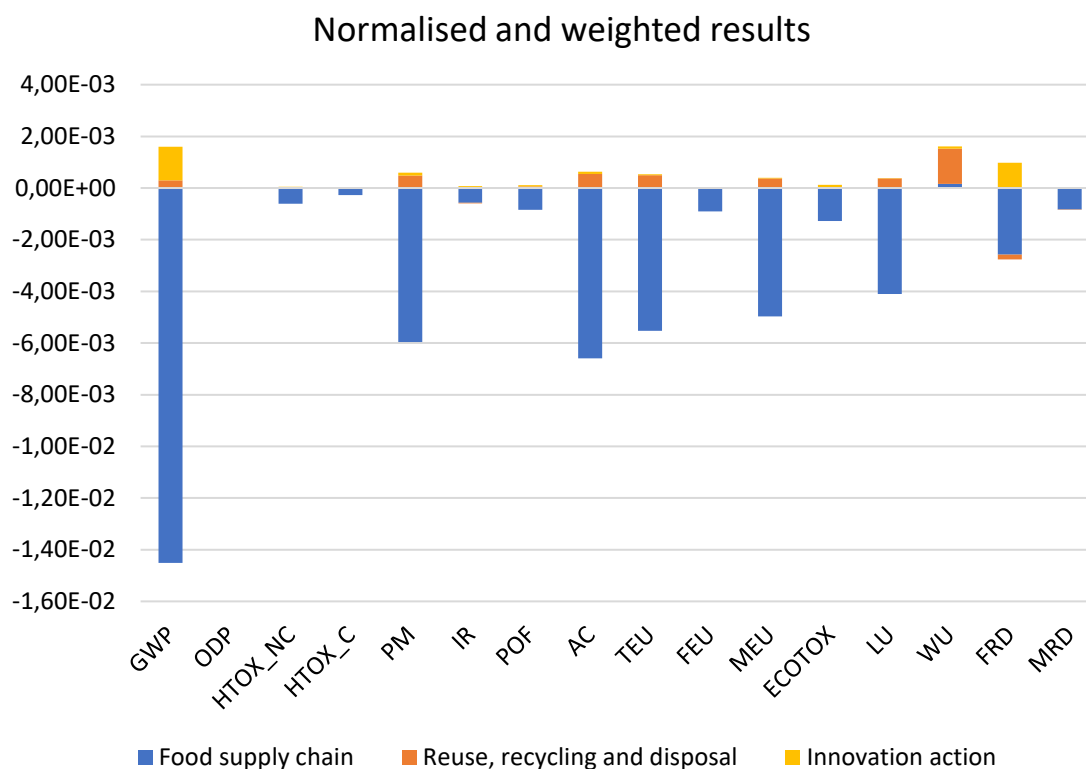


Figure 58: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.5 in Greece

Of all three countries where the CozZo app was tested (Austria, Finland and Greece), the HH food waste-related emission reduction potential is the highest in Greece. The majority of the GWP savings result from avoided food production. This is caused by the food waste composition for the Greek HHs, especially by the share of meat (6% of HH food waste) and dairy products (22% of HH food waste).

In comparison to the other countries where the CozZo app was tested, innovation action resulted in higher impacts with the Greek HHs. This is caused by the longer duration of app use by the Greek HHs (on average 43 min per week compared to 14 min per week in Austria and 32 min per week in Finland). Additionally, the emission factors for the respective national electricity mix used to calculate smartphone energy consumption differ from each other. The Greek electricity mix is more emission-intensive than the Austrian and Finnish electricity mix.

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs that can be saved by the demonstration of T5.5 resulted in 278 EUR in Austria, 465 EUR in Finland and 98 EUR in Greece (see Table 40, Table 41 and Table 42).

Table 40: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.5 of Austria

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		593 kg per year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-1.76E+00	-2.20E-01	-1.04E+03	-1.30E+02
ODP	kg CFC11 eq	-2.51E-07	-9.60E-06	-1.49E-04	-5.69E-03
HTOX_NC	CTUh	-4.53E-08	-9.01E-03	-2.69E-05	-5.35E+00
HTOX_C	CTUh	-1.67E-09	-1.83E-03	-9.90E-07	-1.09E+00
PM	Disease incidences	-1.22E-07	-1.16E-01	-7.22E-05	-6.91E+01
IR	kBq U235 eq	-5.02E-01	-7.33E-04	-2.98E+02	-4.35E-01
POF	kg NMVOC eq	-7.20E-03	-1.04E-02	-4.27E+00	-6.19E+00
AC	molc H ⁺ eq	-1.51E-02	-6.35E-03	-8.97E+00	-3.77E+00
TEU	molc N eq	-5.56E-02		-3.30E+01	
FEU	kg P eq	-3.40E-04	-7.95E-04	-2.01E-01	-4.71E-01
MEU	kg N eq	-9.55E-03	-3.74E-02	-5.66E+00	-2.22E+01
ECOTOX	CTUe	-3.06E+01	-1.43E-03	-1.82E+04	-8.47E-01
LU	Pt	-6.78E+01	-1.45E-02	-4.02E+04	-8.61E+00
WU	m ³ water eq	-2.39E+00	-1.46E-02	-1.42E+03	-8.64E+00
FRD	MJ	-2.25E+01	-3.57E-02	-1.33E+04	-2.12E+01
MRD	kg Sb eq	-1.02E-05	-2.04E-05	-6.05E-03	-1.21E-02

	Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Environmental costs		-4.69E-01		-2.78E+02

Table 41: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.5 of Finland

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		544 kg per year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.90E+00	-3.62E-01	-1.57E+03	-1.97E+02
ODP	kg CFC11 eq	-5.18E-07	-1.98E-05	-2.81E-04	-1.08E-02
HTOX_NC	CTUh	-6.29E-08	-1.25E-02	-3.42E-05	-6.80E+00
HTOX_C	CTUh	-2.58E-09	-2.83E-03	-1.40E-06	-1.54E+00
PM	Disease incidences	-2.85E-07	-2.73E-01	-1.55E-04	-1.48E+02
IR	kBq U235 eq	-5.89E-01	-8.60E-04	-3.20E+02	-4.67E-01
POF	kg NMVOC eq	-1.44E-02	-2.08E-02	-7.81E+00	-1.13E+01
AC	molc H ⁺ eq	-3.77E-02	-1.59E-02	-2.05E+01	-8.62E+00
TEU	molc N eq	-1.43E-01		-7.79E+01	
FEU	kg P eq	-5.34E-04	-1.25E-03	-2.90E-01	-6.79E-01
MEU	kg N eq	-1.52E-02	-5.95E-02	-8.25E+00	-3.23E+01
ECOTOX	CTUe	-4.23E+01	-1.97E-03	-2.30E+04	-1.07E+00
LU	Pt	-1.37E+02	-2.92E-02	-7.43E+04	-1.59E+01
WU	m ³ water eq	-4.41E+00	-2.69E-02	-2.40E+03	-1.46E+01

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
FRD	MJ	-3.02E+01	-4.81E-02	-1.64E+04	-2.61E+01
MRD	kg Sb eq	-1.52E-05	-3.04E-05	-8.27E-03	-1.65E-02
Environmental costs			-8.55E-01		-4.65E+02

Table 42: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.5 of Greece

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		76 kg per year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-4.63E+00	-5.79E-01	-3.51E+02	-4.39E+01
ODP	kg CFC11 eq	-2.86E-07	-1.09E-05	-2.17E-05	-8.30E-04
HTOX_NC	CTUh	-3.87E-08	-7.70E-03	-2.93E-06	-5.84E-01
HTOX_C	CTUh	-2.04E-09	-2.24E-03	-1.54E-07	-1.70E-01
PM	Disease incidences	-3.56E-07	-3.41E-01	-2.70E-05	-2.58E+01
IR	kBq U235 eq	-4.46E-01	-6.50E-04	-3.38E+01	-4.93E-02
POF	kg NMVOC eq	-6.21E-03	-9.00E-03	-4.71E-01	-6.82E-01
AC	molc H ⁺ eq	-5.35E-02	-2.25E-02	-4.05E+00	-1.70E+00
TEU	molc N eq	-2.38E-01		-1.80E+01	
FEU	kg P eq	-5.12E-04	-1.20E-03	-3.88E-02	-9.08E-02
MEU	kg N eq	-3.02E-02	-1.18E-01	-2.29E+00	-8.97E+00
ECOTOX	CTUe	-3.44E+01	-1.60E-03	-2.61E+03	-1.22E-01
LU	Pt	-3.84E+02	-8.21E-02	-2.91E+04	-6.22E+00

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
WU	m ³ water eq	2.17E+00	1.32E-02	1.65E+02	1.00E+00
FRD	MJ	-1.40E+01	-2.22E-02	-1.06E+03	-1.68E+00
MRD	kg Sb eq	-7.10E-06	-1.42E-05	-5.38E-04	-1.08E-03
Environmental costs			-1.17E+00		-8.90E+01

Interpretation and review

The demonstration of the CozZo App had the advantage that it was tested in three different countries and with the same approach. The environmental performance of the three countries differs a lot. Calculated GHG savings per household and week between baseline and demonstration resulted in -1.92 kg CO₂e in Austria, 2.86 kg CO₂e in Finland and 4.63 kg CO₂e in Greece. This is depending on the different food waste composition and on the different reuse, recycling and disposal options applied in all three countries, whereas first has a larger effect on the overall results than latter. In Greece the share of dairy products halved from demonstration to baseline, whereas in Austria the share of dairy products and also meat increased.

The treatment of food waste led to negative environmental impacts in all three countries (the credits are higher than the impacts), with the exception of Greece in the case of the GWP. This is due to the high proportion of landfilling in Greece. However, if we look at other impact categories, landfilling plays a subordinate role compared to the credits from animal feed. This is based on the assumption that food waste fed to animals can replace other feedstuffs. This rather optimistic assumption should be analysed in more detail in future studies, as it has an impact on the environmental performance of waste management.

The contribution of the impacts related to waste management and the innovation action (smartphone use) is low compared to the impacts of the food supply chain. However, when comparing countries, it can be seen that the contribution of the innovation action is higher in Greece than in Finland and Austria. This is due to the fact that the average amount of food that could be saved from being wasted was lower and the average duration of app use was higher in Greece than in Finland and Austria.

T5.6 'REGUSTO Mobile App'

Goal and Scope

This innovation (T5.6) is a mobile application selling restaurants' surplus food to customers and tracking the delivered products up to the customer. The app is called REGUSTO and was tested in Italy.

REGUSTO is a mobile application that allows consumers to buy meals from restaurants at a reduced price and thus helps prevent food waste at the same time. Restaurants use REGUSTO to sell fresh meals prepared in surplus. REGUSTO enables its users (consumers) to find the closest offers, thanks to geo-location and proximity marketing. Once the food has been selected, the quantities and the time to collect them from the restaurant are decided. At the time of collection, the purchased meals are stored in the REGUSTO Bag, which is a convenient and ecological box that innovates the concept of take-out and "doggy" bags. REGUSTO is the first in Italy to introduce the innovative concept of "dynamic pricing" to promote food redistribution and thus reduce food waste: It offers restaurants the opportunity to sell their food with variable and timed discounts. This task aims at using this application to improve the mission of avoiding food waste at restaurants as well as at home by tracking the surplus food from restaurants that was sold via the REGUSTO app and surplus food from customer plates at restaurants that are brought home through the REGUSTO Bag (doggy-bag) and eaten or wasted at home.

The functional unit of the system is **1 kg of prevented food surplus or waste restaurants**. Two types of food surplus or waste were addressed within this innovation: "Kitchen food waste"; the reduction is caused by the surplus redistribution via the REGUSTO App as well as "Plate waste"; the reduction is caused by the use of REGUSTO doggy bag, as customers take their food surplus from restaurants to home. The reference flow is the amount of food waste measured at the baseline and at demonstration stage.

Table 43: Reference flows of the baseline and the demonstration scenario of T5.5

Country	Type of food waste	Average amount of food surplus or waste at BASELINE (n)	Average amount of food waste surplus or waste at DEMONSTRATION (n)
Italy	Kitchen food waste	282.00 kg rest.*month	282.00 kg per rest.*month (x_R) ... 26 kg per rest.*month is redistributed ($n-x_R$) ... 256.00 kg per rest.*month
	Plate waste	210.60 kg rest.*month	210.60 kg per rest.*month, whereby: (x_R) . 50.60 kg per rest.*month is redistributed ($n-x_R$)...160.00 kg per rest.*month

The system boundaries for both the baseline and the demonstration system are shown in Figure 59. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing of the food items, as well as their distribution and retail. Finally, the food gets prepared by the restaurants. The food is then consumed by the customers and food waste is disposed of. For this, credits are assigned for substituting either primary food production (for animal feed) or primary energy production (for details see chapter 2). In the demonstration system, the REGUSTO mobile app and the REGUSTO doggy-bag are introduced at the restaurant stage, in order to redistribute food surplus.

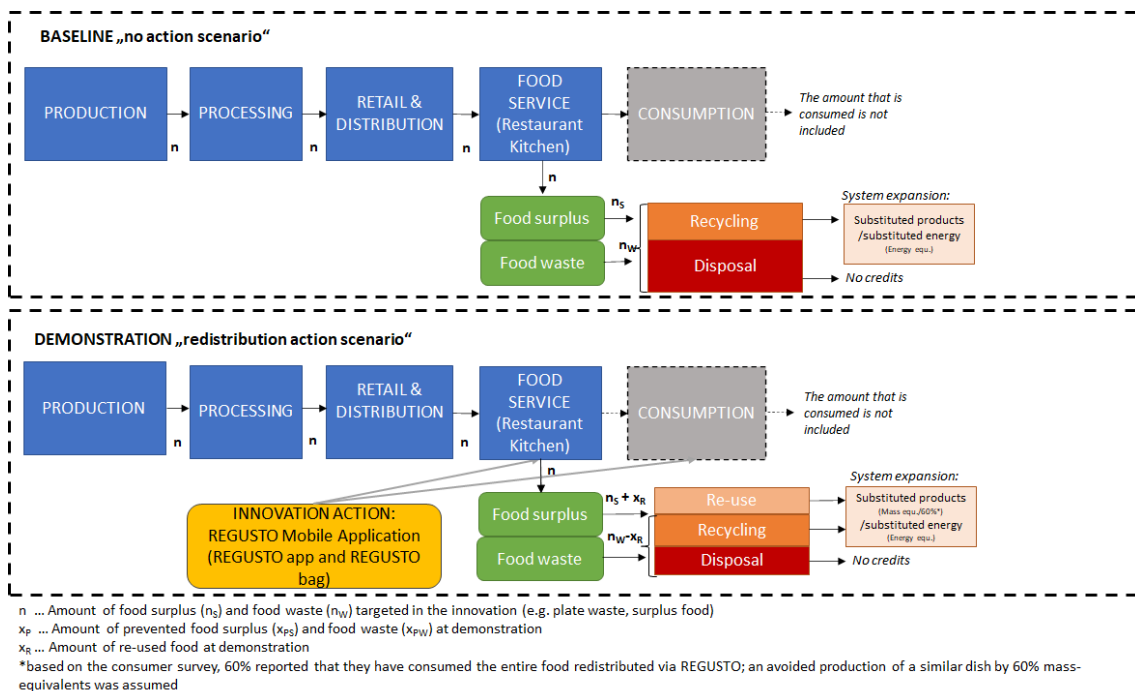


Figure 59: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.5

Life cycle inventory (LCI)

Table 44 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 2.1.

Table 44: Type of process data and collection method used for Task 5.6 in Italy

Component	Process data collected within LOWINFOOD (so-called proxy data)	T5.6	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Survey
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

Data on the amount and composition of food waste was collected through company records. Table 45 shows the food waste related LCI data.

Table 45: Type A data: Food waste related life cycle inventory data for Task 5.6 in Italy

Food waste data	Italy	
	Baseline	Demonstration
Total amount of kitchen food waste [kg]	1,410.00	1,280.00
Total amount of plate waste [kg]	1,018.00	798.00
Number of participating restaurants [no]	5.00	5.00
Average amount of kitchen food waste per restaurant and month [kg/rest.*month]	282.00	256.00
Average amount of plate waste per restaurant and month [kg/rest.*month]	210.60	159.60
Average amount of total food waste per restaurant and month [kg/rest.*month]	485.60	415.60

The composition of the food waste was estimated with supporting information about the type of dishes served at participating restaurants, whereby the different types of dishes were equally weighted (e.g., if a restaurant serves both meat and vegetable dishes, it was weighted 50/50). Table 46 shows the composition of the kitchen waste and plate waste per restaurant

and month. Emission factors were calculated for each individual type of food (e.g., meat dishes, vegetable dishes, pizzeria dishes) with Agribalyse data.

Table 46: Type A data: Food surplus or waste composition for Task 5.6 in Italy

Food waste composition	Italy	
	Baseline	Demonstration
Kitchen waste per restaurant and month		
Meat dishes ¹²	18%	17%
Vegetable dishes ¹³	21%	23%
Seafood dishes ¹⁴	22%	23%
Pizzeria dishes	23%	21%
Cafeteria dishes ¹⁵	16%	16%
Plate waste per restaurant and month		
Meat dishes	34%	33%
Vegetable dishes	17%	19%
Seafood dishes	14%	16%
Pizzeria dishes	28%	25%
Cafeteria dishes	8%	7%

The life cycle inventory for the end-of-life treatment of the kitchen and plate waste is presented in Table 47. This data was collected through surveys at restaurants and customers. Restaurants noted whether the food surplus or waste are disposed of via “organic waste” stream (allocated to anaerobic digestion and composting with a ratio of 25:75), “unsorted waste” stream (allocated to incineration and landfill with a ratio of 19:81) or even “animal feeding”. Animal feeding is an option that is according to European law only limitedly possible. The EU banned the use of animal protein in animal feed (Regulation EC 999/2001) and also the use of kitchen left-overs and catering waste for feed (Regulation EC 1069/20019), giving priority to hygiene regulations ensuring food safety. According to Regulation (EC) No. 1069/2009, food waste streams, where contamination with animal products can be excluded, are still permitted as animal feed (e.g., bread waste). As a disaggregation of the share of food surplus or waste that can be legally fed to animals was not possible, this option was excluded from the environmental impact assessment and integrated in the option for unsorted waste instead.

Table 47: Type B data: Reuse, recycling and disposal options for Task 5.6 in Italy

Options	Italy	
	Baseline	Demonstration
Redistribution	0%	15.6%
Feeding to pets	-	-

¹² e.g., beef stew, bolognese-style pasta, chicken curry, chili con carne, ratatouille

¹³ e.g., falafel, cheese soufflé, eggplant gratin, vegetable risotto, stuffed vegetables

¹⁴ e.g., fish skewers, paella, osso buco

¹⁵ e.g., sandwiches, burgers, wraps

Composting	34.1%	31.6%
Anaerobic digestion	11.4%	10.5%
Municipal waste treatment	54.5%	42.2%

Table 48 shows the inventory data related to the REGUSTO app. In total, 580 orders for a length of the demonstration period of 15 month were processed via the app, which equals an average of 7.73 orders per restaurant and month. According to REGUSTO, one order consumed 0.25 MB of data. The average time spent on one order is 5.4 minutes or 0.09 hours. This information was taken from the survey results. Half of the participating restaurants operated REGUSTO on a smartphone, while 20% used a tablet and 30% used a computer. The electricity consumption associated with the network connection and app server was taken from Seppälä and Mattila (2013). The smartphone electricity consumption, both for the use at the restaurants and by the customers, was calculated on the average yearly energy consumption of a smartphone (Seppälä and Mattila, 2013; Yu et al., 2010; Zink et al., 2014) under the assumption that 90% of the energy is used during active use only (Ardito et al., 2013) and the share of active use time during a smartphone's life is roughly 15% (Wang et al., 2016). The tablet electricity consumption was calculated based on energy consumption data for tablets currently available in retail. The electricity consumption for the computer and the router were taken from Almeida et al. (2011). For the server electricity consumption, Sphera impact factors for the German electricity mix were used. For the smartphone, computer, tablet and router electricity consumption, Sphera impact factors for the Italian electricity mix were used.

*Table 48: Type C data: Innovation action related life cycle inventory data for Task 5.6 in Italy
(Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)*

Innovation action data	Italy
App-related smartphone use at the restaurant	
Average number of app accesses/orders per restaurant and month	7.73
Average duration of app use per order [h]	0.09
Smartphone electricity consumption per hour [kWh]	8.9E-03
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.00E-04
Data consumption per order (data provided by Regusto) [MB]	0.25
National electricity mix	IT
Share of restaurants operating REGUSTO on a smartphone	50%
Average app use-related smartphone electricity consumption (including network connection) [kWh]	3.20E-03
App related tablet use at the restaurant	
Average number of app accesses/orders per restaurant and month	7.73
Average duration of app use per order [h]	0.09
Tablet electricity consumption per hour [kWh]	0.03
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.00E-04

Innovation action data	Italy
Data consumption per order [MB]	0.25
National electricity mix	IT
Share of restaurants operating REGUSTO on a tablet	20%
Average app use-related tablet electricity consumption (including network connection) [kWh]	4.72E-03
App related computer use at the restaurant	
Average number of app accesses/orders per restaurant and month	7.73
Average duration of app use per order [h]	0.09
Computer electricity consumption per hour [kWh] (Almeida et al., 2011)	6.40E-03
Router electricity consumption per hour [kWh] (Almeida et al., 2011)	8.00E-03
National electricity mix	IT
Share of restaurants operating REGUSTO on a computer	30%
App related electricity consumption of computer and router [kWh]	2.92E-03
App related smartphone consumption by the customers	
Average number of app accesses/orders per restaurant and month	7.73
Average duration of app use per order [h]	0.09
Smartphone electricity consumption per hour [kWh]	8.9E-03
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.00E-04
Data consumption per order [MB]	0.25
National electricity mix	IT
Average app use-related customer smartphone electricity consumption (including network connection) [kWh]	6.41E-03
App server	
Data consumption per app access (provided by REGUSTO) [MB]	0.25
Average number of app accesses/orders per restaurant and month	7.73
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03
National electricity mix	DE
Average server electricity consumption per restaurant and month [kWh]	0.03

As shown in Table 49, the REGUSTO box used as packaging is made of cellulose pulp. The mass was assumed to be 0.02 kg per packaging unit, based on a similar packaging box weighed by BOKU. With an average amount of orders/packaging units of 7.73, the total mass of packaging boxes used per restaurant and month is 0.17 kg. Ecoinvent impact factors for a folding boxboard carton (RER: market for folding boxboard carton) were used.

Table 49: Type C data: Innovation action related life cycle inventory data for the packaging/REGUSTO box (Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Italy
Packaging material	Cellulose pulp
Average number of orders/packaging units used per restaurant and month [nr]	7.73
Mass per packaging unit [kg/piece]	0.02

Total mass of packaging used per restaurant and month [kg/rest.*month]	0.17
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Data on the means of transportation used by the customers to pick up the surplus food from the restaurants was collected through the survey. The majority of customers picked up the food by car (66%) and 12% took the public bus. Only 1% used a bike and 21% walked on foot. An average transportation distance from the customer's location to the restaurant of 4.4 km (2.2 km for each direction based on Allen et al. (2021)) was assumed. For transportation by car and by public bus, respective impact factors from the Ecoinvent database were used. Transport by bike or on foot were assumed to not have any environmental impacts.

Table 50: Type C data: Innovation action related life cycle inventory data for the consumer transport associated with the purchase of surplus food via REGUSTO (Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Italy	
	Average number of transportation trips per restaurant and month [no]	Total transportation distance [km]
Transport by passenger car	5.12	22.53
Transport by public bus	0.93	4.11
Transport by bike	0.04	0.18
Transport on foot	1.64	7.22

Life cycle impact assessment (LCIA) of the baseline scenario

The absolute results per restaurant and month showed a GWP of 2,780 kg CO₂e for the baseline scenario and 2,520 kg CO₂e for the demonstration scenario (surplus food is sold to customers). In both scenarios, the majority of GWP is associated with food production (99.7% of baseline GWP, 98.5% of demonstration GWP). Waste management contributes very little to the total GWP results in the baseline scenario (0.26%). The reason for this is that credits were assigned for substituted electricity and thermal energy production as a result of anaerobic digestion. Waste management is responsible for 1.15% of the total demonstration scenario GWP results. Innovation action (app use and consumer transport to pick up the ordered food) contributes 0.34% to the demonstration GWP results. REGUSTO prevents a total of 266 kg CO₂e per restaurant and month, which equals prevented emissions of 3,194 kg CO₂e per restaurant and year. This equals a GWP reduction of 10% compared to the baseline scenario.

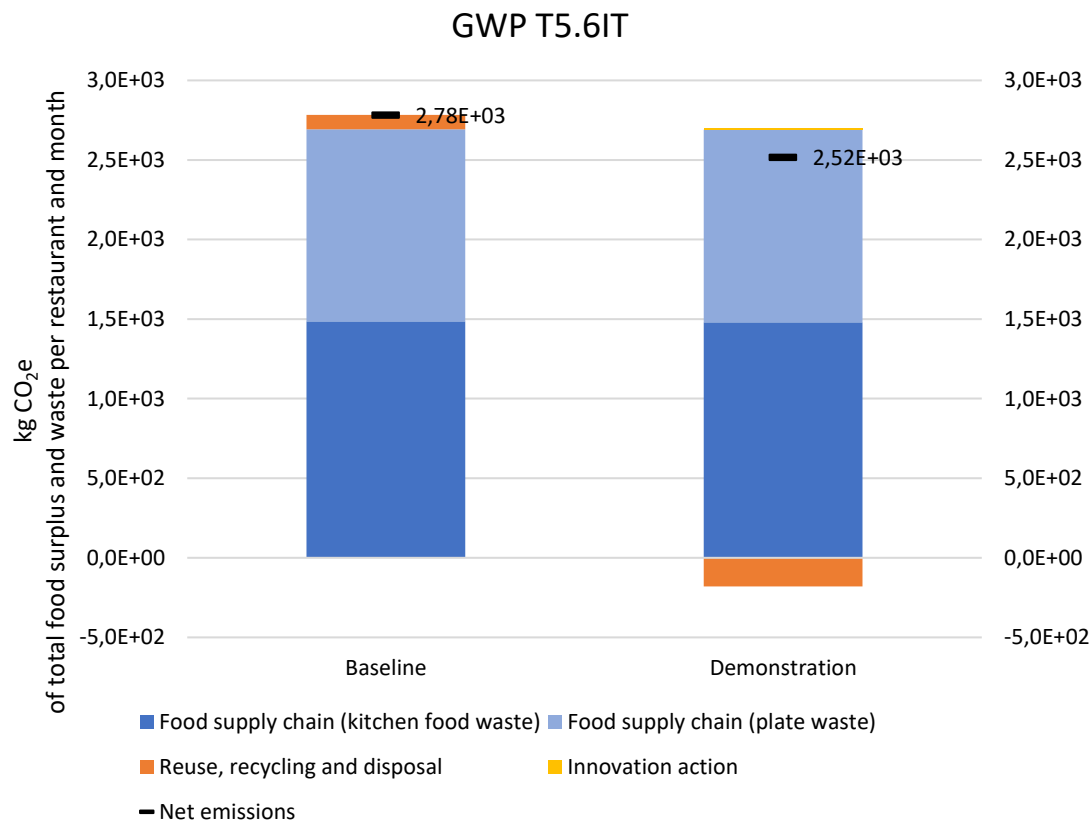


Figure 60: Global warming potential for the baseline and demonstration scenario for the innovation T5.6 in Italy

Figure 61 shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 34.3 points and the demonstration PEF score equals 31.2 points. Through the REGUSTO app, PEF score results were reduced by 9%. As shown in Figure 61, the PEF score result can largely be attributed to food production.

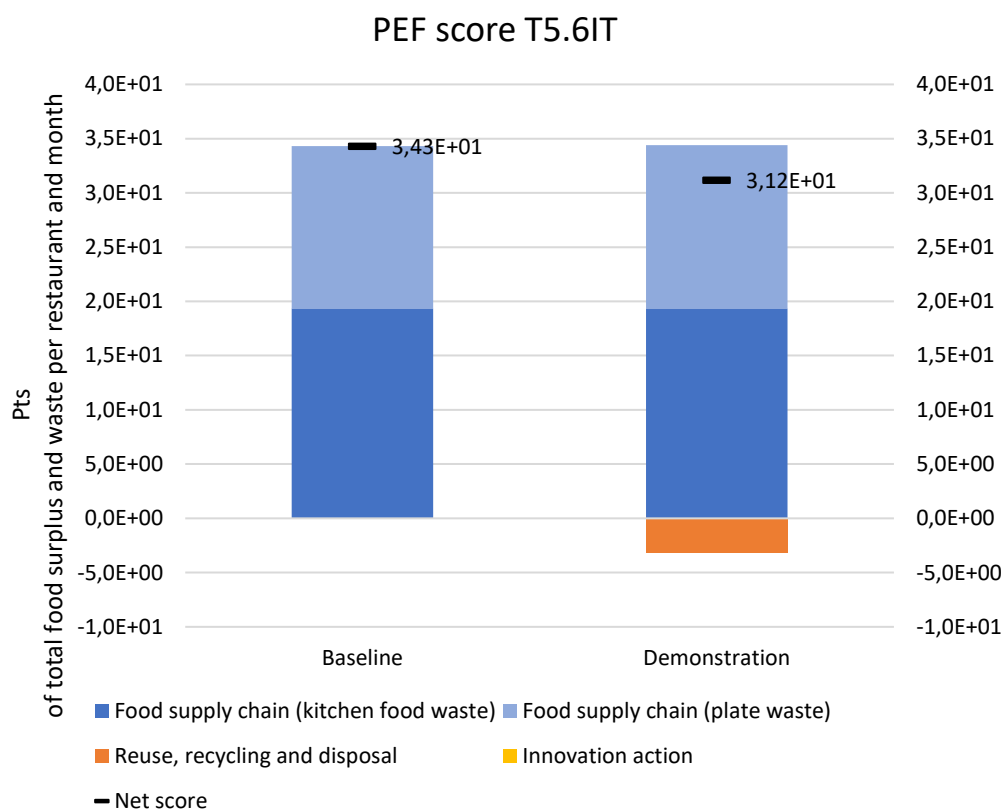


Figure 61: PEF score for the baseline and demonstration scenario for the innovation T5.6 in Italy

The REGUSTO app resulted in an impact reduction for all EF impact categories (global warming potential: -14%, ozone depletion: -11%, human toxicity non-cancer effects: -12%, human toxicity cancer effects: -13%, particulate matter: -13%, ionising radiation HH: -14%, photochemical ozone formation: -10%, acidification: -13%, terrestrial eutrophication: -14%, freshwater eutrophication: -13%, marine eutrophication: -13%, freshwater ecotoxicity: -12%, land use: -15%, water scarcity: -15%, fossil resource depletion: -12%, abiotic resource depletion: -12%).

As shown in Figure 62, food production is the main contributor to environmental impacts for all impact categories. The waste management contribution to the overall impacts is negative. This results from the credits assigned for avoided food production due to redistribution of food. Innovation action contributes very little to the total impacts.

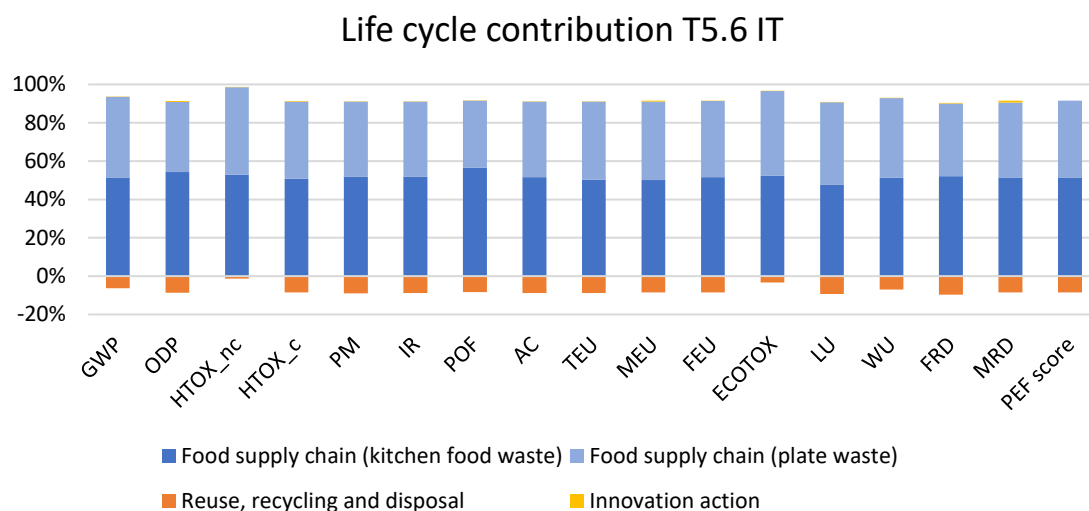


Figure 62: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T5.6 in Italy for the demonstration scenario

Life cycle impact assessment (LCIA) of the demonstration scenario

This innovation redistributed 77.00 kg of food waste per restaurant and month. This resulted in a prevented GWP of 266.13 kg CO₂e. As shown in Figure 63, the total GWP of 1 kg prevented food waste equals -3.46 kg CO₂e. The majority of GWP savings results from the avoided food production when redistributing food.

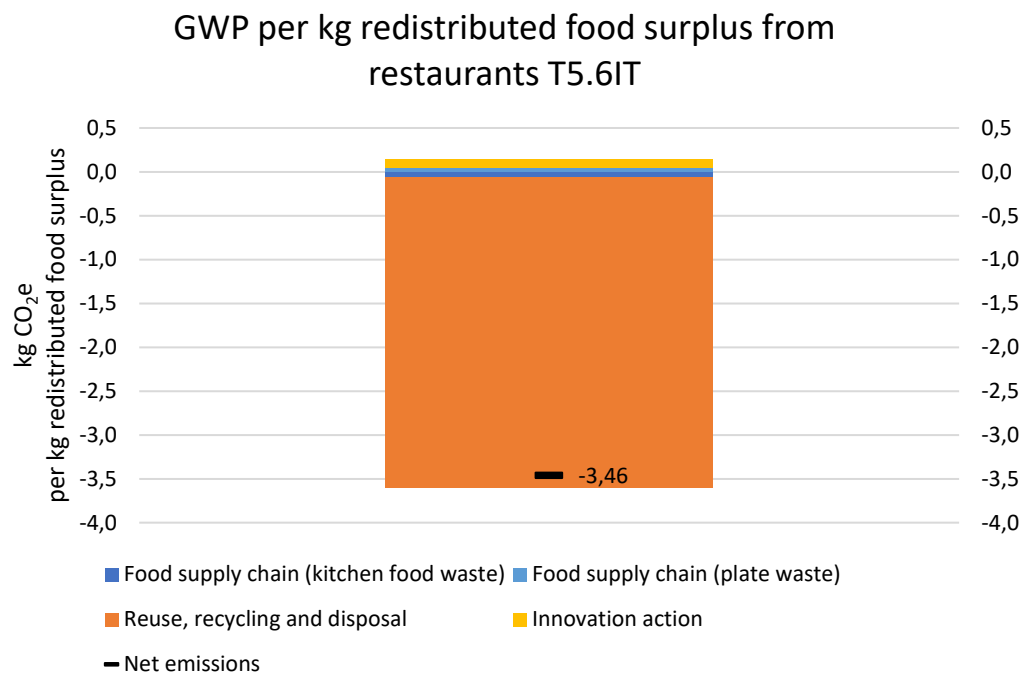


Figure 63: Global warming potential results for 1 kg of prevented food waste for the innovation T5.6 in Italy

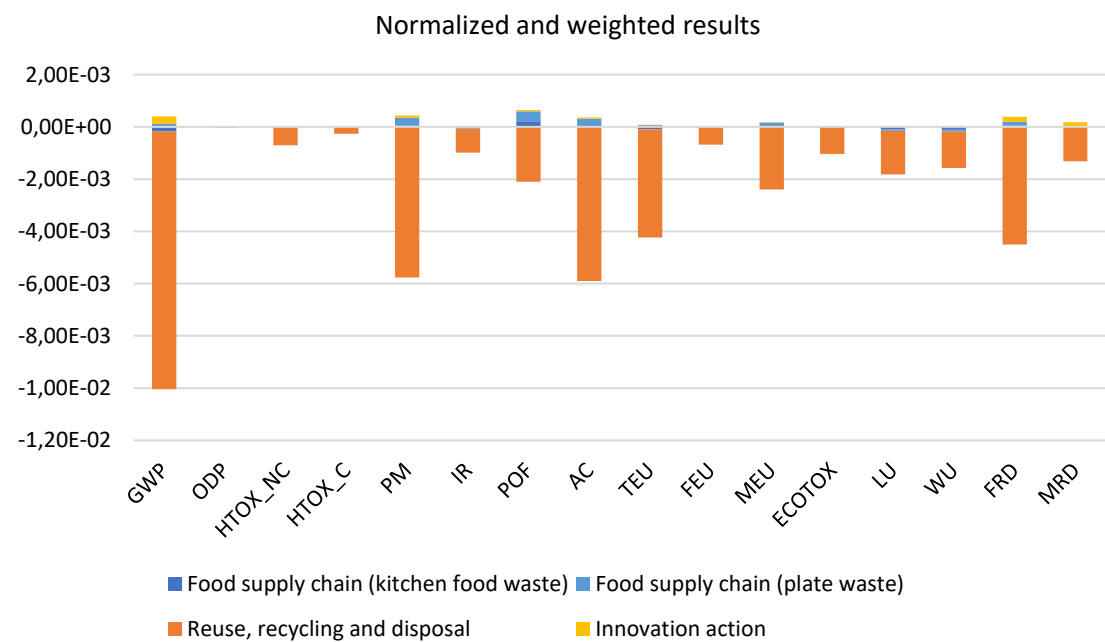


Figure 64: Normalised and weighted results for 1 kg of redistributed food waste for the innovation T5.6 in Italy

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs that can be saved by the demonstration of T5.6 resulted in 4,560 EUR (see

Table 51).

Table 51: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.5 of Austria

		Results per kg of redistributed food surplus		Results per total redistributed food surplus	
Reference flow		1 kg		4620 kg, 5 restaurants per year	
Environmental impact category		Env. emissions [Unit of the category]	Env. costs [EUR]	Env. emissions [Unit of the category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-3.46E+00	-4.32E-01	-1.60E+04	-2.00E+03
ODP	kg CFC11 eq	-2.42E-07	-9.26E-06	-1.12E-03	-4.28E-02
HTOX_NC	CTUh	-4.82E-08	-9.59E-03	-2.23E-04	-4.43E+01
HTOX_C	CTUh	-1.96E-09	-2.15E-03	-9.05E-06	-9.95E+00
PM	Disease incidences	-3.54E-07	-3.39E-01	-1.64E-03	-1.57E+03
IR	kBq U235 eq	-8.26E-01	-1.21E-03	-3.82E+03	-5.57E+00
POF	kg NMVOC eq	-1.25E-02	-1.81E-02	-5.77E+01	-8.37E+01
AC	molc H ⁺ eq	-4.97E-02	-2.09E-02	-2.29E+02	-9.63E+01
TEU	molc N eq	-1.98E-01		-9.15E+02	
FEU	kg P eq	-3.76E-04	-8.81E-04	-1.74E+00	-4.07E+00
MEU	kg N eq	-1.47E-02	-5.75E-02	-6.78E+01	-2.66E+02
ECOTOX	CTUe	-3.00E+01	-1.40E-03	-1.38E+05	-6.45E+00
LU	Pt	-1.87E+02	-4.00E-02	-8.64E+05	-1.85E+02
WU	m ³ water eq	-2.11E+00	-1.29E-02	-9.76E+03	-5.94E+01
FRD	MJ	-3.21E+01	-5.11E-02	-1.48E+05	-2.36E+02
MRD	kg Sb eq	-9.66E-06	-1.93E-05	-4.46E-02	-8.93E-02
Environmental costs			-9.87E-01		-4.56E+03

Interpretation and review

The innovation of REGUSTO mobile app is a combination of surplus food reduction (in terms of cooked but not served meals, so called 'kitchen food waste') and plate waste reduction (in terms of served but not eaten meals, so called 'plate waste'). In both situations food is saved from being wasted by redistribution. Consumers can buy surplus meals from restaurants via the REGUSTO mobile app but can also take home their meals, if they cannot finish it at restaurant, via the REGUSTO bag.

This innovation was initially allocated to the actions of consumer behaviour change as it clearly influences the consumer behaviour. However, looking at the technical side of the action, it is about redistributing food. Food is taken by consumer to eat at home. The demonstration showed that in total 77 kg of food was saved from being wasted. The GWP of the participating restaurants could be reduced by 10% and the PEF by 9% compared to the baseline. Impacts of the innovation action that include additional consumer transport for taking the food to home as well as the use of the smartphone for using the app are neglectable. The majority of the impacts is coming from the food supply chain. Relative results show a GWP reduction potential of 3.46 kg CO₂e per kg of food that can be redistributed, which is the impact category with the highest contribution.

3.4 Environmental impacts of supply chain efficiency innovations

T2.4 'Forecasting software to reduce waste of F&V products'

Goal and scope

The goal of this evaluation is to assess the environmental impacts of innovations for food waste prevention and reduction. This innovation (T2.4) entails a software based on artificial intelligence to improve the accuracy of sales forecasting at retail stores and was tested in Italy.

Task 2.4 aims to demonstrate the efficacy of a newly developed machine learning sales forecasting technology in the operational environment of supermarkets. Historical data of each store was used to train an algorithm based on machine learning and to find trends.

The functional unit of the system is **1 kg of prevented food waste in retail**. The reference flow is the amount of food waste measured at the baseline and demonstration stage.

Table 52: Reference flows of the baseline and the demonstration scenario of T24

Country	Type of food waste	Average amount of food surplus or waste at BASELINE (n)	Average amount of food surplus or waste at DEMONSTRATION (n-x _p)
Italy	Duration of measuring period	2 months	2 months
	Retail fruit and vegetable food surplus or waste	5,680.40 kg per store (total food surplus)	9,202.00 kg per store (total food surplus)
		1,420.10 kg per store and month	2,300.50 kg per store and month

The system boundaries for both the baseline and the demonstration system are shown in the Figure 65. Both the system boundaries for the baseline and the demonstration system include production, processing, distribution and retail of **fruits and vegetables**. Surplus fruits and vegetables are disposed of through donation or recycling. For this, credits are assigned for substituting primary food production. In the demonstration system, the supplier-retailer agreements are introduced at processing, distribution and retail in order to prevent food waste.

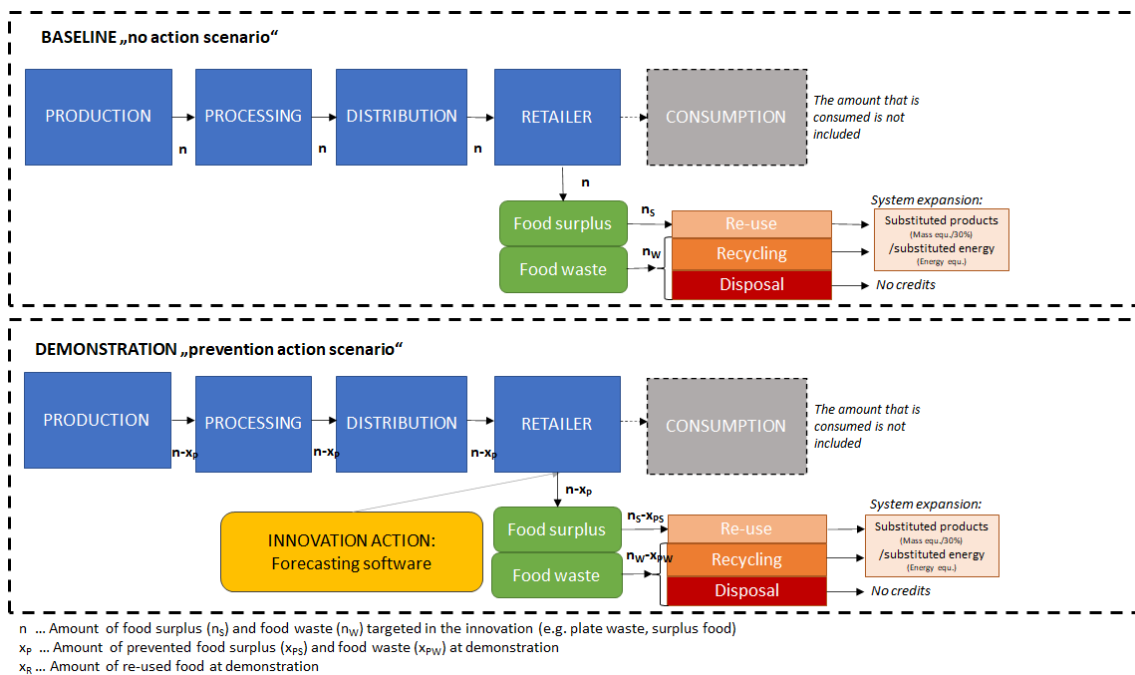


Figure 65: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T2.4

Life cycle inventory (LCI)

Table 53 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 53: Type of process data and collection method used for Task 2.4 in Italy

Component	Process data collected within LOWINFOOD (so-called proxy data)	T2.4	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Expert consultation
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

Data on the amount and composition of F&V waste was collected through company records of two supermarket stores for two months in Italy. Quantities are presented in Table 54.

Table 54: Type A data: Food surplus or waste quantities for Task 2.4 in Italy

Food surplus or waste data	Italy	
	Baseline	Demonstration
Total retail F&V waste [kg]	5,680.40	9,202.00
Participating stores [no]	2	2
Measuring period [months]	2	2
Average food waste per store and month [kg]	1,420.10	2,300.50

The composition of the food waste was determined through records of the supermarket stores. Emission factors were calculated for each individual food group (e.g., apples, artichokes, asparagus, etc.) with Agribalyse data.

Table 55: Type A data: Food surplus or waste composition for Task 2.4 in Italy

Retail F&V surplus or waste composition	Italy	
	Baseline	Demonstration
Apples	3.1%	2.4%
Artichokes	7.0%	1.2%
Asparagus	0.4%	0.3%
Bananas	3.9%	40.0%
Beans	0.4%	1.5%
Cabbage	9.1%	4.5%
Carrots	1.3%	1.6%
Cauliflower	3.3%	1.7%
Chicory	1.5%	1.5%
Cucumber	1.1%	0.5%
Eggplant	3.0%	3.5%
Fennel	10.7%	2.3%
Garlic	0.0%	0.0%
Kiwis	0.4%	0.0%
Lemons	6.0%	2.1%
Mandarins	0.5%	2.0%
Melon	2.4%	2.7%
Nectarines	1.1%	1.7%
Onions	0.0%	0.0%
Oranges	7.0%	6.8%
Pears	1.3%	3.1%
Pineapples	0.9%	0.5%
Potatoes	0.3%	0.5%
Rocket	0.2%	0.3%
Salad/lettuce	17.1%	4.7%
Strawberries	6.5%	0.1%
Tomatoes	4.8%	6.1%
Turnip greens	0.0%	0.8%
Zucchini	6.6%	7.4%

In the municipalities where supermarket stores are located, food waste is disposed of as organic fraction of the municipal waste, collected by municipal services and sent to composting as well as combined aerobic-anaerobic plants. It was therefore assumed that 50% are composted and 50% are anaerobically digested (see

Table 56) for both in the baseline and demonstration phase.

Table 56: Type B data: Reuse, recycling and disposal options for Task 2.4 in Italy

Options	Italy	
	Baseline	Demonstration
Redistribution	0%	0%
Animal feeding	0%	0%
Composting	50%	50%
Home composting	0%	0%
Anaerobic digestion	50%	50%
Municipal waste treatment (incinerated)	0%	0%
Municipal waste treatment (landfill)	0%	0%
Other disposal (sewer/toilet)	0%	0%

The electricity consumption associated with the software server was taken from Seppälä and Mattila (2013). The electricity consumption for the computer and router were taken from Almeida et al. (2011). For the server electricity consumption, Ecoinvent impact factors for the German electricity mix were used. For the computer and router electricity consumption, Ecoinvent impact factors for the Italian electricity mix were used. The data consumption and daily duration of computer use were estimated by the responsible authors at BOKU.

Table 57: Type C data: Innovation action related life cycle inventory data for Task 2.4 in Italy
(Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Italy
Computer and router use	
Duration of use per day [h]	0.88
Duration of use per month [h]	22.75
Computer energy consumption per hour (Almeida et al., 2011) [kWh]	6.40E-03
Router energy consumption per hour (Almeida et al., 2011) [kWh]	8.00E-03
National electricity mix	IT
Electricity consumption per store and month [kWh]	0.33
Server	
Data consumption per day [MB]	16
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03
National electricity mix	DE
Average server electricity consumption per guest and day [kWh]	0.03

For the innovation action impacts, only electricity consumption of smartphones, network infrastructure and app server were considered. The impacts associated with the production of smartphones, network infrastructure and app server infrastructure are not included in this calculation.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The innovation resulted in a GWP of 1,040 kg CO₂e for the baseline scenario and 1,172 kg CO₂e for the demonstration scenario. In both scenarios, the majority of GWP is associated with food production. Waste management reduces total GWP results (baseline: -32% demonstration: -45%). The reason for this is that credits were assigned for substituted primary energy production as a result of anaerobic digestion. The innovation action contribution to the total GWP results is negligible. Due to the increase in food waste, GWP increases by 13%.

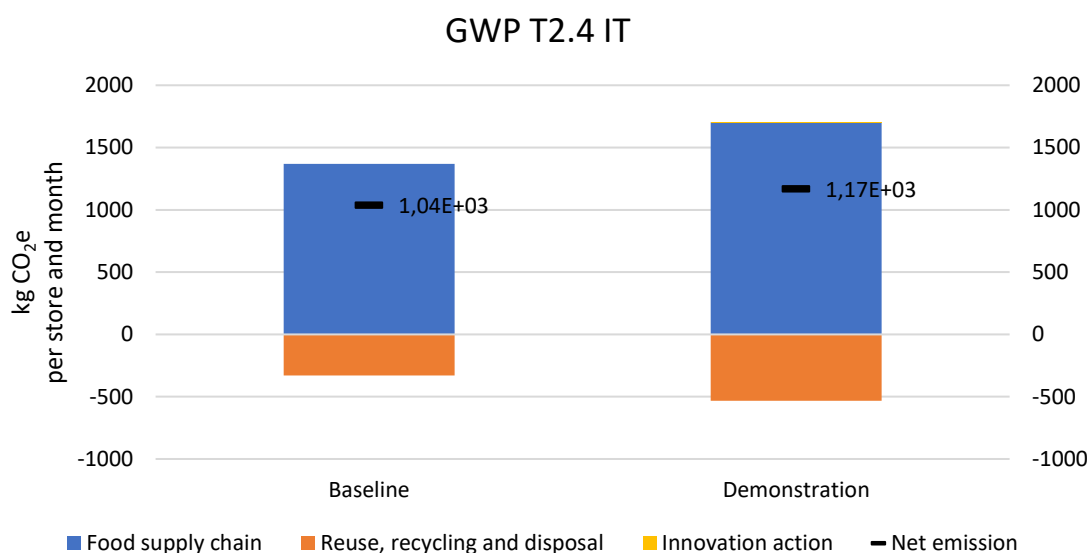


Figure 66: Global warming potential for the baseline and demonstration scenario for the innovation T2.4 in Italy

Figure 67 shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 182 and the demonstration PEF score equals 260. This equals an increase by 43%. As shown in Figure 67, the PEF score result can mostly be attributed to food production.

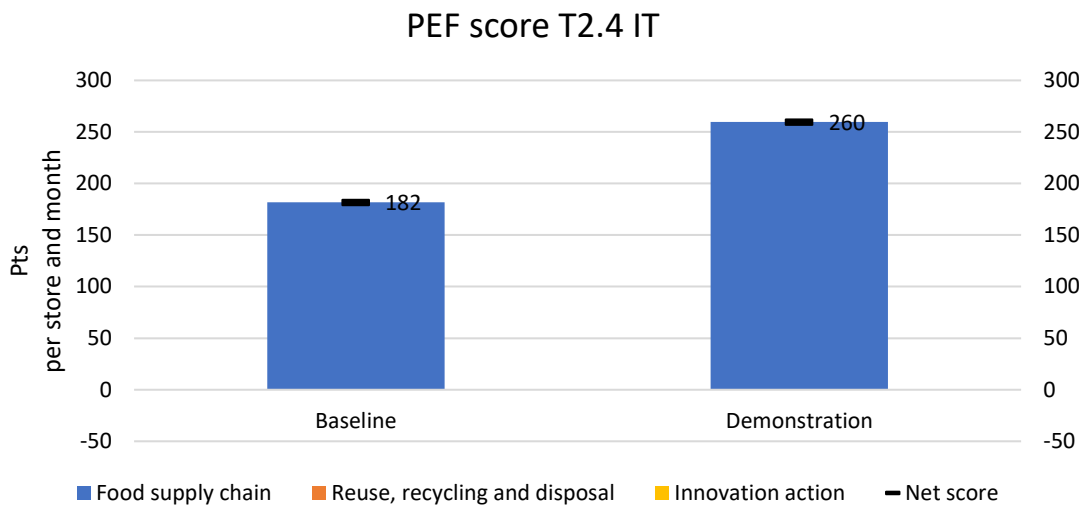


Figure 67: PEF score for the baseline and demonstration scenario for the innovation T2.4 in Italy

Waste management reduces GWP results in both scenarios. Credits are assigned for substituted primary energy production as a result of anaerobic digestion of food waste. These credits outweigh the GWP impacts of composting (impacts from the composting process - credits for compost application) and thus reduce the total GWP.

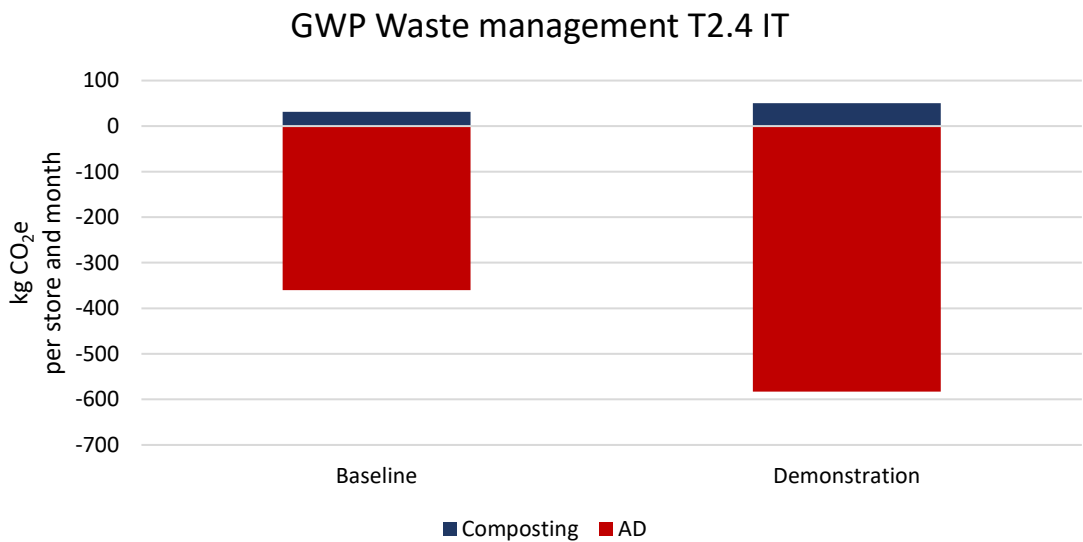


Figure 68: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline scenario for the innovation T2.4 in Italy

During the demonstration stage, most EF impact category results increased (global warming potential: +13%, ozone depletion: +40%, human toxicity non-cancer effects: +11%, human toxicity cancer effects: +23%, particulate matter: +37%, photochemical ozone formation:

+47%, acidification: +56%, terrestrial eutrophication: +43%, freshwater eutrophication: +25%, marine eutrophication: +10%, freshwater ecotoxicity: +28%, land use: +11%, water scarcity: +87%, fossil resource depletion: +9%, abiotic resource depletion: +28%). Ionising radiation results decreased by 2%.

As shown in Figure 69, food production is the main contributor to environmental impacts for all impact categories. Waste management reduces most impact category results except for ozone depletion potential, human toxicity (non-cancer), freshwater ecotoxicity and abiotic resource depletion.

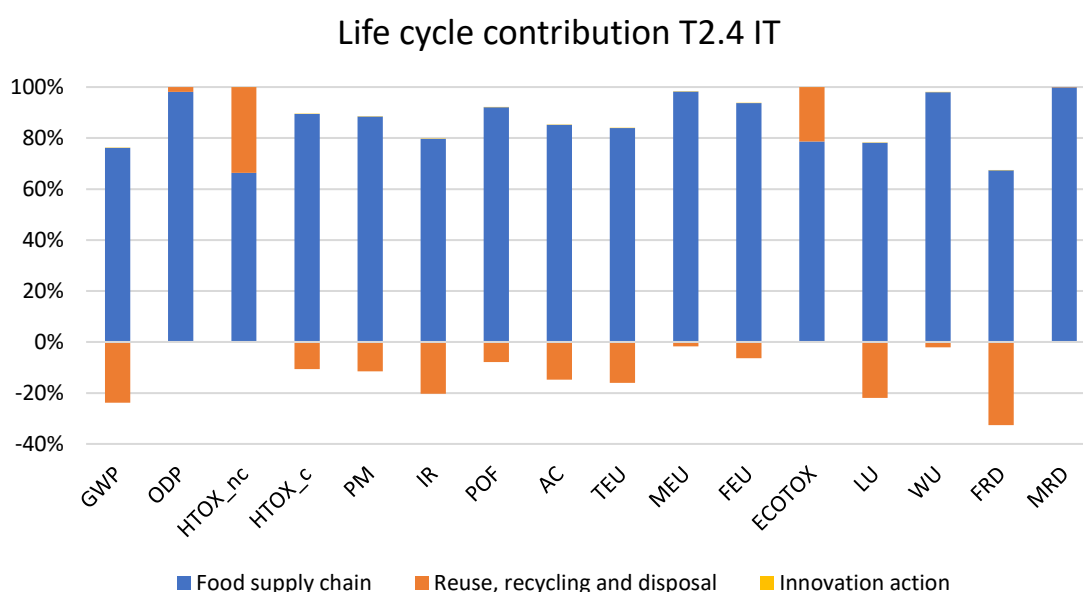


Figure 69: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T2.4 in Italy for the demonstration scenario

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

As retail fruit and vegetable waste increased by 880 kg per store and month, GWP increased by 132 kg CO₂e. As shown in Figure 70, the total GWP of 1 kg food waste equals 0.15 kg CO₂e. Food production is the main contributor to the GWP impacts.

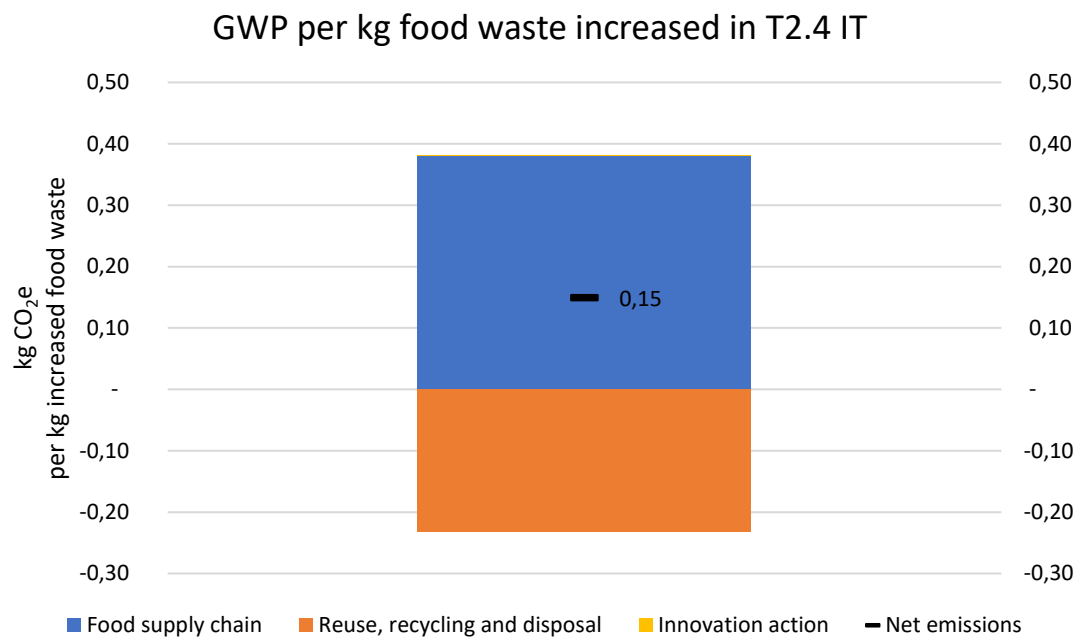


Figure 70: Global warming potential results for 1 kg of prevented F & V waste for the innovation T2.4 in Italy

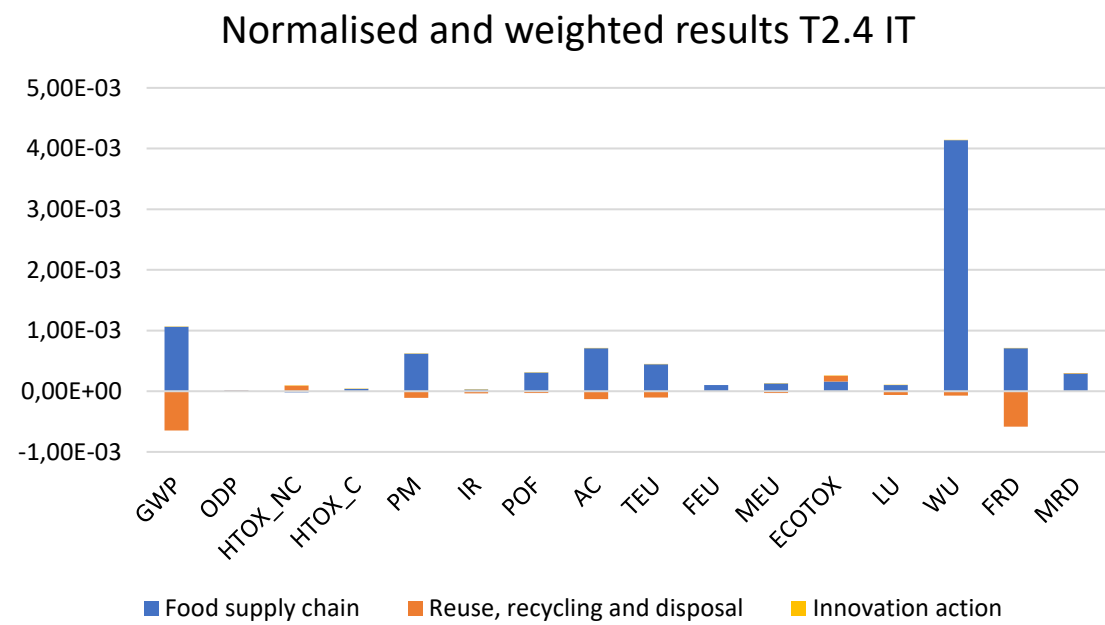


Figure 71: Normalised and weighted results for 1 kg of increased food waste for the innovation T2.4 in Italy

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs resulted in 2,050 EUR per year that can be saved by the demonstration of T2.4 in Italy (see Table 58).

Table 58: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T2.4

		Results per kg of food surplus or waste		Results per total increased food surplus or waste	
Reference flow		1 kg		21,130 kg per year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	1.50E-01	1.87E-02	3.16E+03	3.95E+02
ODP	kg CFC11 eq	8.64E-08	3.31E-06	1.83E-03	6.99E-02
HTOX_NC	CTUh	4.95E-09	9.85E-04	1.05E-04	2.08E+01
HTOX_C	CTUh	2.31E-10	2.54E-04	4.87E-06	5.36E+00
PM	Disease incidences	3.38E-08	3.24E-02	7.14E-04	6.84E+02
IR	kBq U235 eq	-3.38E-03	-4.94E-06	-7.15E+01	-1.04E-01
POF	kg NMVOC eq	2.38E-03	3.45E-03	5.03E+01	7.30E+01
AC	molc H ⁺ eq	5.18E-03	2.18E-03	1.10E+02	4.60E+01
TEU	molc N eq	1.63E-02		3.44E+02	
FEU	kg P eq	5.55E-05	1.30E-04	1.17E+00	2.74E+00
MEU	kg N eq	6.51E-04	2.55E-03	1.38E+01	5.39E+01
ECOTOX	CTUe	7.50E+00	3.49E-04	1.58E+05	7.38E+00
LU	Pt	4.25E+00	9.09E-04	8.97E+04	1.92E+01
WU	m ³ water eq	5.48E+00	3.34E-02	1.16E+05	7.05E+02
FRD	MJ	9.98E-01	1.59E-03	2.11E+04	3.35E+01
MRD	kg Sb eq	2.47E-06	4.95E-06	5.23E-02	1.05E-01
Environmental costs			9.68E-02		2.05E+03

Interpretation and review

A food waste reduction could unfortunately not be observed during demonstration of the innovation. Therefore, also the environmental impacts increased from baseline to demonstration. The advantage of this innovation with respect to the environmental

evaluation was that detailed information on the food waste composition was available, which helps to identify hotspots.

It is noticeable that the indicator water use is dominating the environmental impact categories. This is due to certain food products, such as nectarines, lemons, mandarines, kiwis, that consume 4 to 5 times more water compared to an apple, for example. As a conclusion, if the prevention of citrus fruit can be targeted in future innovations, the environmental impacts can be reduced considerably.

T3.3 'FoodTracks Software for bakeries'

Goal and Scope

This innovation (T3.3) is a technological innovation focused on forecasting to reduce oversupply of bakery sales stores. It is called FoodTracks and was tested in Germany.

FoodTracks offers bakeries (production sites and their sales stores) a demand planning software that provides exclusive insights regarding their sales and all factors influencing the performance of shipping the right quantities of quickly perishable products to stores. This software is based on data from the enterprise resource planning system and cash register, that are combined with external factors – in real-time and for each of the subsidiaries individually. A crucial aspect of a forecasting software's success is its user acceptance. Hence, not only the quality of the data accessed by the software but also the user itself and the organisational context where it is applied need to be regarded when further developing the innovation. FoodTracks works on developing an organisation-specific software solution, that integrates the available data and the situational factors of a bakery (processes, number and organisation of subsidiaries, etc.) in order to deliver the best recommendations for each individual bakery. The Academy of the German Bakery Trade, ADB-Nord, contributed to assessing the utility and user-friendliness of this software, as well as to identify supporting and inhibiting factors for its implementation in the bakery sector. This was accomplished by surveying potential users and by participating in focus group discussions. A training concept for apprentices and professionals was also delivered to reduce food waste in the bakery sector (Strotmann et al., 2024).

The functional unit of the system is **1 kg of prevented food surplus or waste in bakeries**. The reference flow is the amount of food waste measured at the baseline and at demonstration stage:

Table 59: Reference flows of the baseline and the demonstration scenario of T3.3

Country	Type of food waste	Average amount of food surplus or waste at BASELINE (n)	Average amount of food surplus or waste at DEMONSTRATION (n-x _P)
Germany	Surplus bakery products	26.2 kg per store * day	19.1 kg per store * day

The system boundaries for both the baseline and the demonstration system are shown in Figure 72. Both the system boundaries for the baseline and the demonstration system include production of raw materials, processing of raw materials to bakery products, distribution and retail (selling the bakery products in the bakery stores). Bakery food waste is disposed of through redistribution, valorisation to food products, reworking or feeding to animals. For this, credits are assigned for substituting primary food production. In the demonstration system, the FoodTracks innovation is introduced at the distribution and retail stage, in order to prevent food waste already by reducing the production volume at the processing stage.

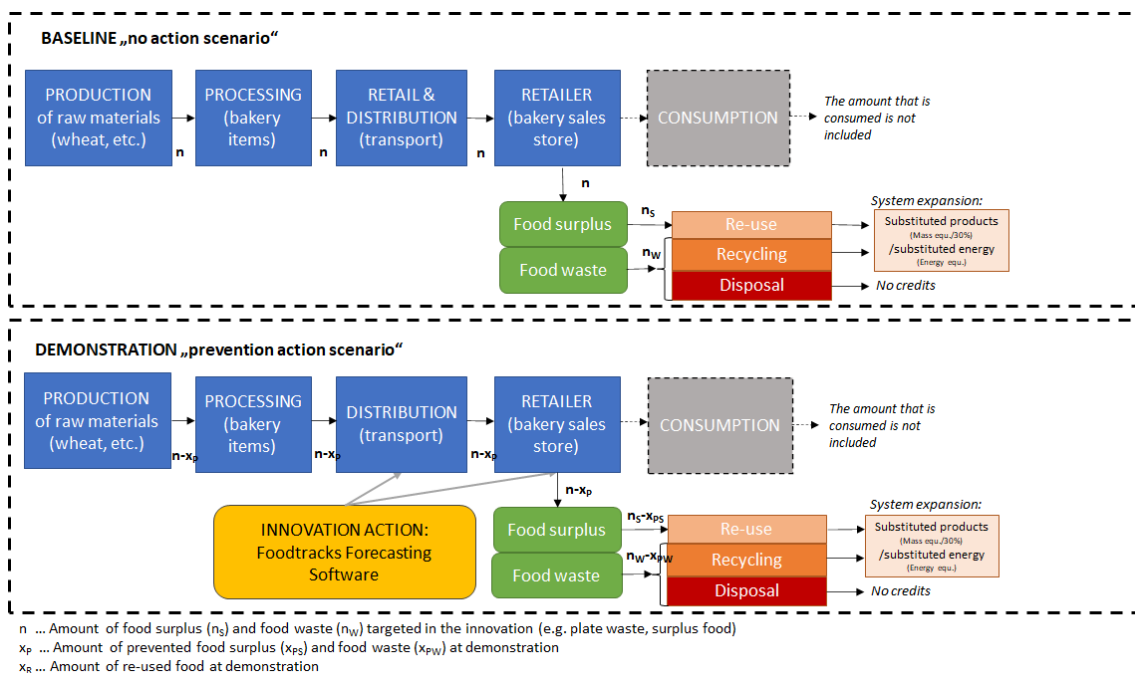


Figure 72: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T3.3

Life cycle inventory (LCI)

Table 60 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 60: Type of process data and collection method used for Task 3.3 in Germany

Component	Process data collected within LOWINFOOD (so-called proxy data)	T3.3	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records/literature Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Questionnaire
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

Data on the amount and composition of food waste was collected through company records (pieces of bakery products sold, produced, depreciated and returned). Mass per item were provided by the bakeries and taken from the literature (Wahrburg and Egert, 2015). Table 61 shows the food waste related LCI data.

Table 61: Type A data: Food surplus or waste quantities for Task 3.3. in Germany

Food surplus or waste data	Germany	
	Baseline	Demonstration
Average bakery food waste per day and store [kg]	26.2	19.1
Number of participating stores [no.]	38	41
Total days measured	1029	1207

The composition of the bakery food waste was determined through company records. Table 62 shows the composition of the bakery food waste per bakery and day. Emission factors were calculated for each individual type of bakery item (e.g., bread, rolls, pastry) with Agribalyse data.

Table 62: Type A data: Food surplus or waste composition for Task 3.3 in Germany

Food surplus or waste composition	Germany	
	Baseline	Demonstration
Bread	45%	44%
Rolls	31%	39%
Pastry	8%	10%
Cake	15%	6%
Snacks	1%	1%

The life cycle inventory for the end-of-life treatment of bakery food waste is presented in Table 63. The composition of the reuse, recycling and disposal pathways is based on the information from bakeries that was collected via questionnaires in Task 3.3. Due to the lack of information based on mass, the number of answers was used instead to estimate the share of each option.

Table 63: Type B data: Reuse, recycling and disposal options for Task 3.3 in Germany

Options	Germany	
	Baseline	Demonstration
Redistribution	25%	25%
Reworking	13%	13%
Valorisation to food products	25%	25%
Animal feeding	38%	38%
Composting	0%	0%
Anaerobic digestion	0%	0%
Municipal waste treatment	0%	0%

Table 64 shows the inventory data related to the FoodTracks innovation. In most cases, a computer was used to operate FoodTracks (94%), but tablets (5%) or smartphones (1%) were used as well. The electricity consumption associated with the network connection and app server was taken from Seppälä and Mattila (2013). The smartphone electricity consumption was calculated on the average yearly energy consumption of a smartphone (Seppälä and Mattila, 2013; Yu et al., 2010; Zink et al., 2014) under the assumption that 90% of the energy is used during active use only (Ardito et al., 2013) and the share of active use time during a smartphone's life is roughly 15% (Wang et al., 2016). The tablet electricity consumption was calculated based on energy consumption data of tablets currently available in retail. The electricity consumption for the computer and router were taken from Almeida et al. (2011). For the server electricity consumption, Ecoinvent impact factors for the German electricity mix were used. For the smartphone, computer, tablet and router electricity consumption, Ecoinvent impact factors for the German electricity mix were used.

Table 64: Type C data: Innovation action related life cycle inventory data for Task 3.3 in Germany
(Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Variables
Tablet use for FoodTracks	
Share of tablet users for FoodTracks	5%
Average daily usage time of tablets for FoodTracks [h]	0.01
Tablet electricity consumption per hour [kWh]	0.03
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.00E-04
Data consumption per day [MB]	1.05
National electricity mix	DE
Average app use-related tablet electricity consumption (including network connection) [kWh]	3.44E-03
Computer and router use for FoodTracks	
Share of computer users for FoodTracks	94%
Average daily usage time of computer and router for FoodTracks [h]	1.88
Computer electricity consumption per hour [kWh] (Almeida et al., 2011)	6.40E-03
Router electricity consumption per hour [kWh] (Almeida et al., 2011)	8.00E-03
National electricity mix	DE
App related electricity consumption of computer and router [kWh]	0.11
Smartphone use for FoodTracks	
Share of smartphone users for FoodTracks	1%
Average daily usage time of smartphone for FoodTracks [h]	0.02
Smartphone electricity consumption per hour [kWh]	8.90E-03
Energy consumption for network connection (Seppälä and Mattila 2013) [kWh/MB]	2.00E-04
Data consumption per day [MB]	1.05
National electricity mix	DE
Average app use-related customer smartphone electricity consumption (including network connection) [kWh]	1.80E-04
Server	
Data consumption per bakery and day [MB]	1.05
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03
National electricity mix	DE
Average server electricity consumption per bakery and day [kWh]	1.84E-03

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

GWP at baseline was 24.1 kg CO₂e and at demonstration 15.6 kg CO₂e per bakery sales store and day. In both scenarios, the majority of GWP is associated with food production. Waste management reduces total GWP results. The reason for this is that credits were assigned for avoided primary food production resulting from the discarded food being fed to animals, redistributed or reworked to different food products. Innovation action contributes

0.00012% to the demonstration GWP results. FoodTracks prevents a total of 8.5 kg CO₂e per bakery sales store and day. This equals a GWP reduction of 35% compared to the baseline scenario.

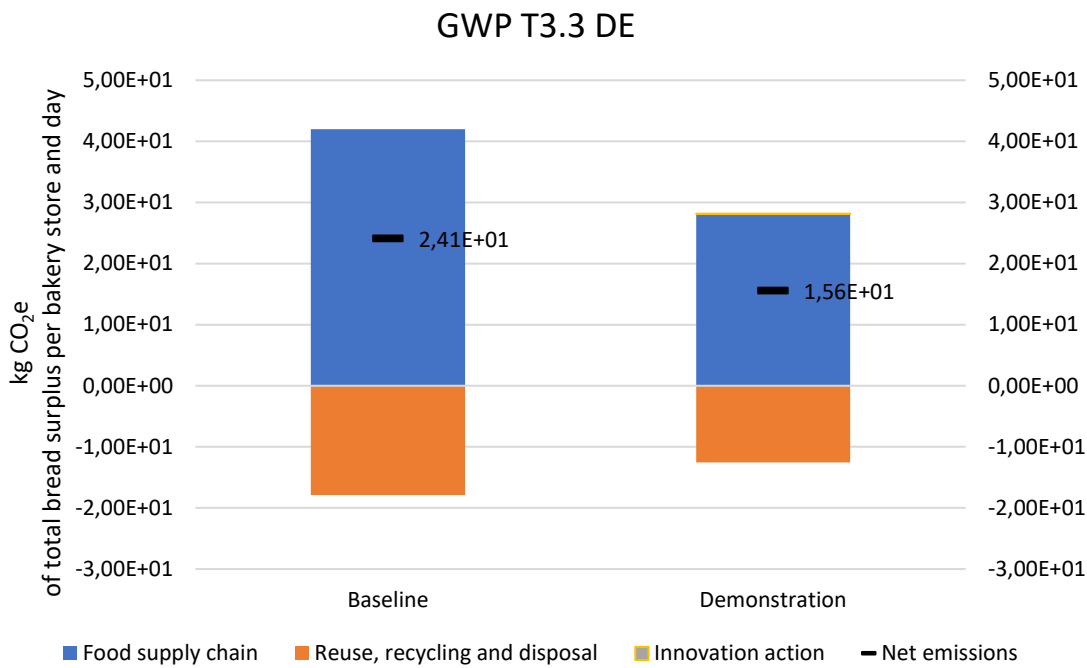


Figure 73: Global warming potential for the baseline and demonstration scenario for the innovation T3.3 in Germany

The following figure shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 2.75 points and the demonstration PEF score equals 1.79 points. Through FoodTracks, PEF score results were reduced by 35%. As shown in Figure 74, the PEF score result can largely be attributed to food production.

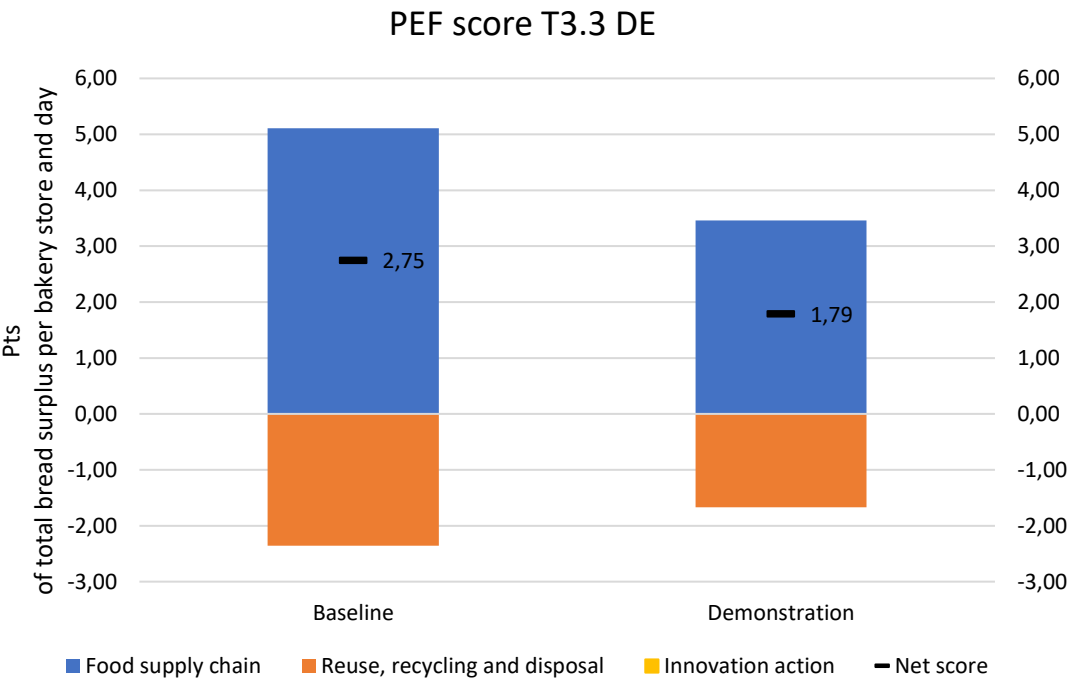


Figure 74: PEF score for the baseline and demonstration scenario for the innovation T3.3 in Germany

Reuse, recycling and disposal show negative results. This is caused by the credits assigned for food donation (redistribution), reworking and valorisation, which are reuse options for human consumption as well as animal feed (substituted primary food production), a reuse option for animal consumption as shown in Figure 75.

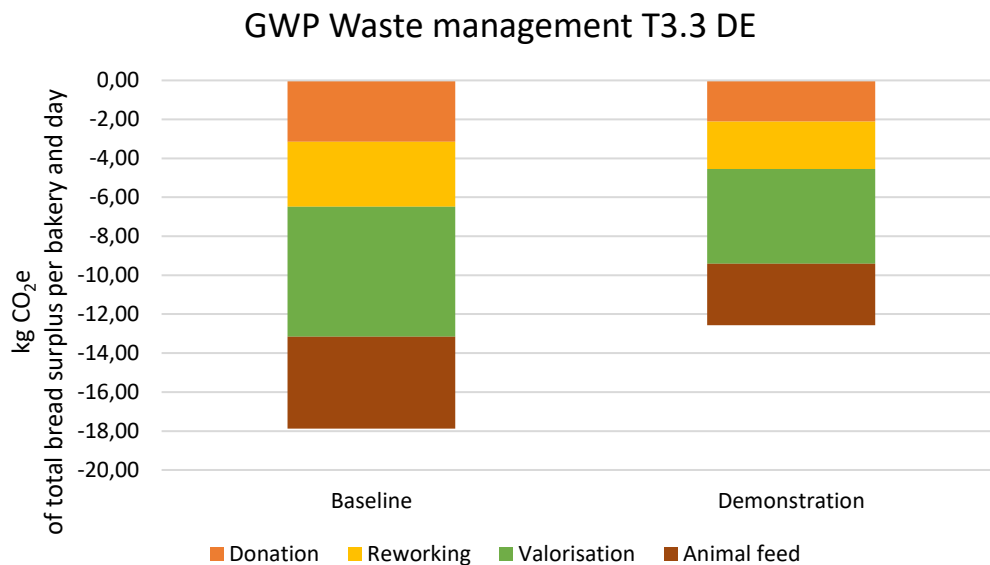


Figure 75: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline scenario for the innovation T3.3 in Germany

FoodTracks resulted in an impact reduction for most EF impact categories (global warming potential: -33%, ozone depletion: -36%, human toxicity non-cancer effects: -39%, human toxicity cancer effects: -39%, particulate matter: -40%, ionizing radiation HH: -34%, photochemical ozone formation: -39%, acidification: -40%, terrestrial eutrophication: -40%, freshwater eutrophication: -37%, marine eutrophication: -37%, freshwater ecotoxicity: -43%, land use: -39%, water scarcity: -48%, fossil resource depletion: -35%, abiotic resource depletion: -38%).

As shown in Figure 76, food production is the main contributor to environmental impacts for all impact categories. As a result of the credits assigned for donation, reworking, valorisation and animal feed, these options reduce total environmental impact results in all impact categories. Innovation action contributes very little to the total environmental impacts.

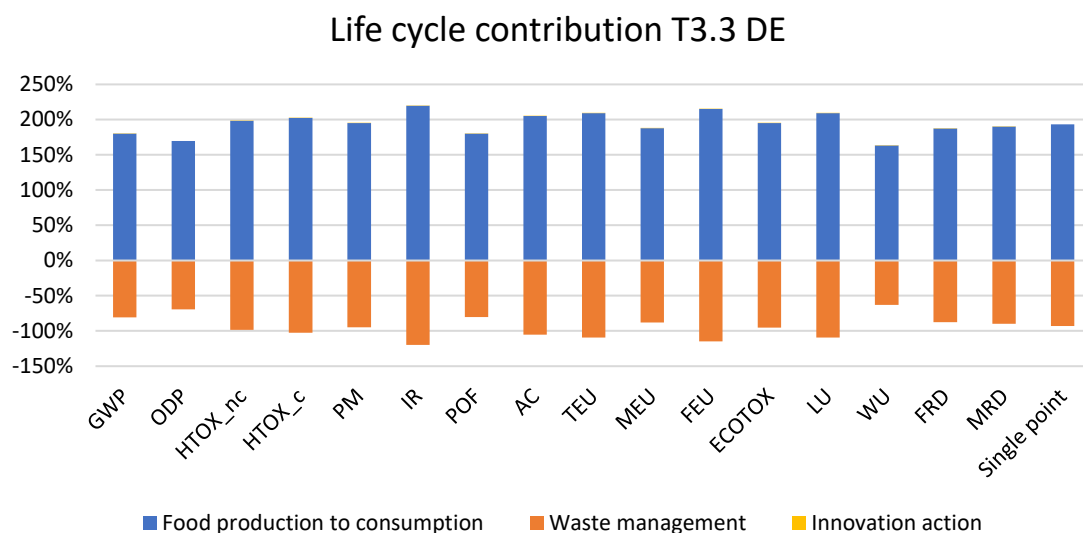


Figure 76: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T3.3 in Germany for the demonstration scenario

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

This innovation prevented 7.10 kg of food waste per bakery sales store and day. This resulted in a prevented GWP of 8.5 kg CO₂e. As shown in Figure 77, the total GWP of 1 kg prevented food waste equals -1.2 kg CO₂e. The majority of GWP savings results from the avoided food production.

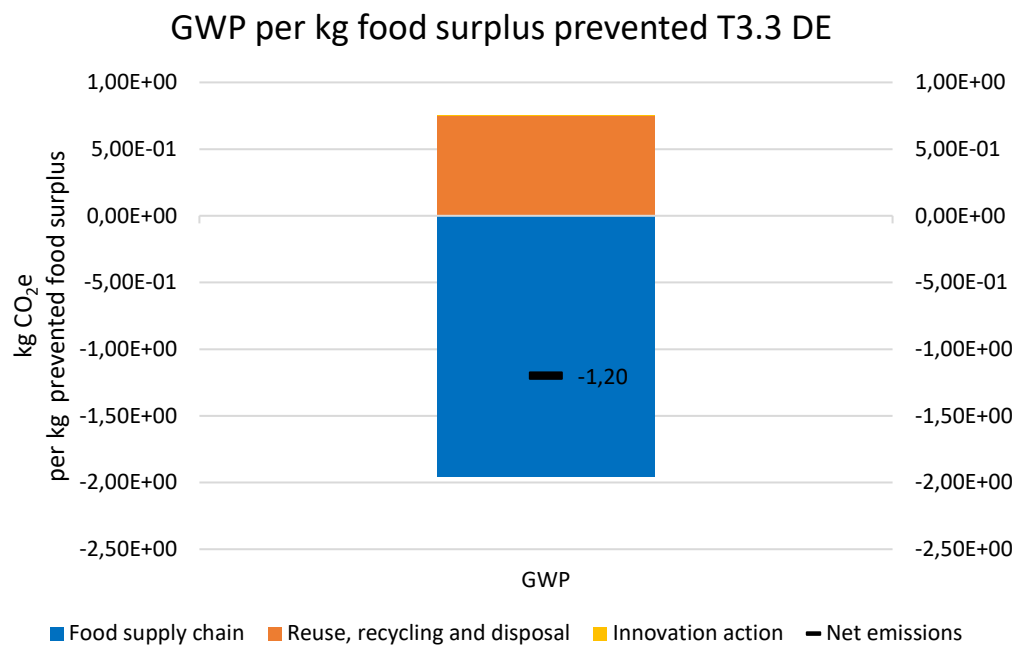


Figure 77: Global warming potential results for 1 kg of prevented food waste for the innovation T3.3 in Germany

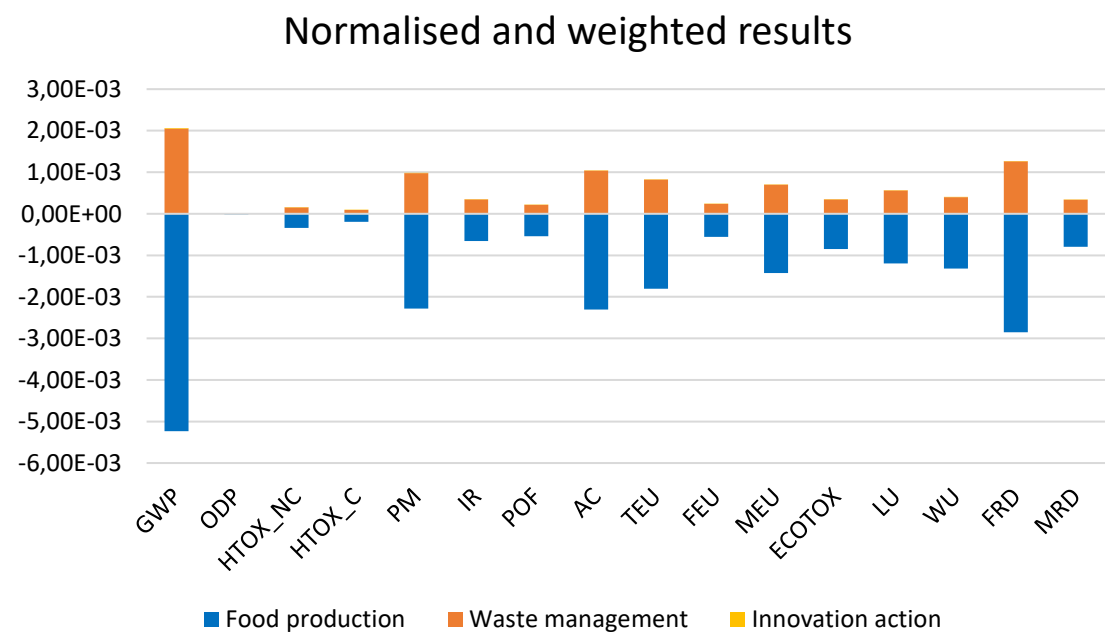


Figure 78: Normalised and weighted results for 1 kg of prevented food waste for the innovation T3.3 in Germany

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The total external environmental costs that can be saved by the demonstration of T5.5 resulted in 815 EUR per bakery sales store and year (see Table 65).

Table 65: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T3.3

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		2592 kg per store and year	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-1.20E+00	-1.50E-01	-3.10E+03	-3.88E+02
ODP	kg CFC11 eq	-6.99E-08	-2.68E-06	-1.81E-04	-6.94E-03
HTOX_NC	CTUh	-1.40E-08	-2.79E-03	-3.64E-05	-7.24E+00
HTOX_C	CTUh	-9.06E-10	-9.97E-04	-2.35E-06	-2.58E+00
PM	Disease incidences	-9.14E-08	-8.75E-02	-2.37E-04	-2.27E+02
IR	kBq U235 eq	-2.64E-01	-3.85E-04	-6.84E+02	-9.99E-01
POF	kg NMVOC eq	-2.91E-03	-4.22E-03	-7.55E+00	-1.09E+01
AC	molc H ⁺ eq	-1.20E-02	-5.04E-03	-3.11E+01	-1.31E+01
TEU	molc N eq	-4.94E-02		-1.28E+02	
FEU	kg P eq	-1.89E-04	-4.42E-04	-4.90E-01	-1.15E+00
MEU	kg N eq	-4.99E-03	-1.96E-02	-1.29E+01	-5.07E+01
ECOTOX	CTUe	-1.58E+01	-7.36E-04	-4.09E+04	-1.91E+00
LU	Pt	-6.84E+01	-1.46E-02	-1.77E+05	-3.79E+01
WU	m ³ water eq	-1.35E+00	-8.23E-03	-3.50E+03	-2.13E+01
FRD	MJ	-1.27E+01	-2.01E-02	-3.28E+04	-5.22E+01
MRD	kg Sb eq	-3.96E-06	-7.92E-06	-1.03E-02	-2.05E-02
Environmental costs			-3.14E-01		-8.15E+02

Interpretation and review

The demonstration of the innovation T3.3 showed that around 7 kg of bread surplus per bakery sales store and day can be reduced due to the use of the Foodtracks software. This

corresponds to a reduction of environmental impacts of 8.5 kg CO₂e or 1.2 kg CO₂e per kg prevented bread surplus.

The special feature of this innovation is that many reuse activities were already documented at baseline. Activities such as donation, reworking and valorisation of surplus bread but also animal feeding result in relatively high credits (negative values) at baseline. Credits at demonstration are diminished due to the fact that less surplus is produced. Yet, also the impacts from food production are reduced at demonstration due to surplus prevention.

T5.1 'KITRO Innovative food waste solution

Goal and Scope

This innovation (T5.1) consists of automated food waste quantification in food service using artificial intelligence. It was tested in Germany, Greece and Switzerland.

KITRO provides restaurants, canteens and hotels with a fully automated food waste management solution. By combining image processing and deep learning technologies with a hardware solution, relevant information on the food being thrown away is captured and analysed. Food services receive detailed insights into their food waste via an online dashboard, empowering them to make informed decisions and optimise work practices leading to a reduction in food waste, food cost and their negative environmental impact. KITRO's goal is to change the way that food waste is handled and bring back the value of food, so it is appreciated and not wasted. The hardware consists of a scale with a camera attached on top to record the kitchen waste bins, where serving losses and plate waste are discarded. Through image recognition, the kind and quantity of food that is wasted is recorded.

The functional unit of the system is **1 kg of prevented food waste in the hotel, restaurant or canteen**. The reference flow is the amount of food waste measured at the baseline and at demonstration stage.

Table 66: Reference flows of the baseline and the demonstration scenario of T5.1

Country	Average amount of food waste at BASELINE (n)	Average amount of food waste at DEMONSTRATION (n-x _p)
Germany	158.50 g per guest and day	89.00 g per guest and day
Greece	102.00 g per guest and day	49.50 g per guest and day
Switzerland	128.00 g per guest and day	142.00 g per guest and day

The system boundaries for both the baseline and the demonstration system are shown in Figure 79. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing

of the food items, as well as their distribution and retail. Finally, the food gets prepared (e.g., cooked) by the hotel kitchen staff and then consumed by the hotel guests. Food waste is then disposed. In the demonstration system, the KITRO device is introduced at the consumption stage, in order to collect data on food waste. The return data is analysed and used by the kitchen staff to reduce food waste in the kitchen.

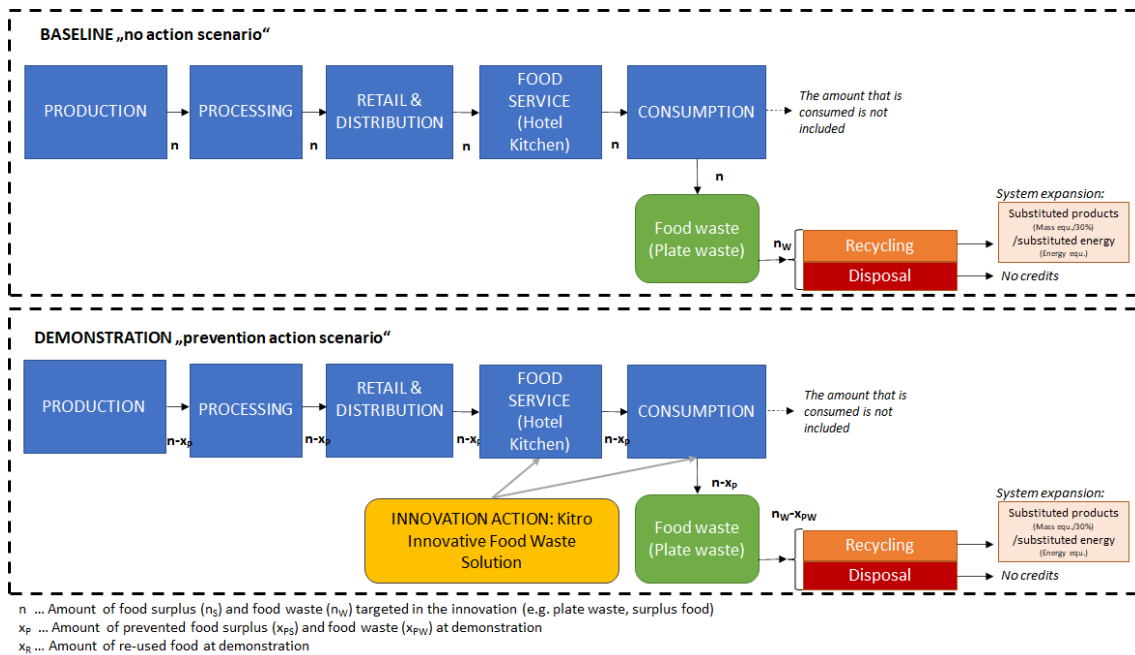


Figure 79: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.1

Life cycle inventory (LCI)

Table 67 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 2.1.

Table 67: Type of process data and collection method used for Task 5.1 in Germany, Greece and Switzerland

Component	Process data collected within LOWINFOOD (so-called proxy data)	T 5.1	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Eurostat
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - - •	- - - - Expert consultation

Data on the amount and composition of food waste was gathered through company records of KITRO in Task 5.1.

Table 68: Type A data: Food surplus or waste related life cycle inventory data for T5.1 in Germany, Greece and Switzerland

Food surplus or waste data	Germany		Greece		Switzerland	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Total food waste [kg]	741	4,413	1,041	9,166	789	12,589
Total number of guests	6,739	52,616	13,628	186,996	6,519	92,342
Average food waste per guest [g]	159	89	102	50	128	142

The composition of the hotel food waste was determined through company records provided by KITRO in T5.1. Emission factors were calculated for each individual food group (e.g., fruits, vegetables, bread, meat) with Agribalyse data. The food surplus composition is listed in Table 69.

Table 69: Type A data: Food surplus or waste composition for T5.1 in Germany, Greece and Switzerland

Hotel food surplus or waste composition	Germany		Greece		Switzerland	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Animal by-product ¹⁶	0.32%	0.08%	0.25%	0.09%	2.02%	1.07%
Animal scrap ¹⁷	2.63%	2.95%	2.98%	5.17%	0.05%	1.43%
Confectionery ¹⁸	1.66%	2.47%	5.19%	8.07%	15.13%	11.32%
Dairy	0.31%	0.59%	1.84%	1.43%	4.65%	3.09%
Dish ¹⁹	3.94%	5.13%	4.10%	8.59%	2.99%	4.82%
Fruit	6.51%	4.34%	19.93%	5.84%	5.21%	2.96%
Herb	1.88%	0.21%	1.42%	0.09%	1.86%	1.03%
Meat	0.77%	1.33%	0.39%	4.76%	1.26%	1.93%
Menu ²⁰	26.06%	6.79%	22.83%	1.85%	23.56%	9.44%
Other ²¹	11.50%	39.73%	1.85%	46.91%	18.57%	39.63%
Pasta	4.39%	3.74%	3.83%	2.76%	0.98%	0.98%
Protein ²²	0.84%	1.07%	0.68%	0.06%	2.59%	0.65%
Seafood	0.00%	0.20%	0.00%	0.41%	0.00%	0.47%
Seed	2.52%	2.07%	2.72%	2.26%	3.13%	4.57%
Starch	0.12%	0.05%	0.25%	0.02%	0.32%	0.10%
Vegetable	36.55%	29.26%	31.74%	11.67%	17.68%	16.52%

The waste treatment for the food waste was calculated based on the treatment operations for municipal solid waste stated in European Statistics (Eurostat, 2020). As there was no data

¹⁶ e.g., egg products

¹⁷ same composition as meat category

¹⁸ e.g., milk rolls, croissants, muffins, candy

¹⁹ e.g., burgers, curry, lasagna, sushi

²⁰ e.g., pizza, quinoa, risotto

²¹ e.g., nuts, coffee grains, sauces

²² average composition of meat and seafood category

available for food waste treatment in Switzerland, data for Germany was used as an approximation.

Table 70: Type B data: Reuse, recycling and disposal options for T5.1 in Germany, Greece and Switzerland

Options	Germany		Greece		Switzerland	
	Baseline	Demonstration	Baseline	Demonstration	Baseline	Demonstration
Redistribution	-	the same as for the baseline are assumed	-	the same as for the baseline are assumed	-	the same as for the baseline in Germany are assumed
Animal feeding	-		-		-	
Composting	21.4%		0%		21.4%	
Home composting	-		-		-	
Anaerobic digestion	7.1%		0%		7.1%	
Municipal waste treatment (incineration)	71.2%		0%		71.2%	
Municipal waste treatment (landfill)	0.3%		100%		0.3%	
Other disposal (sewer/toilet)	-		-		-	

KITRO's tech devices consist of a scale and a camera. The parameters used to calculate the energy consumption per guest and day are listed in Table 71. Information on the energy consumption of the device, duration of use per day and data consumption was provided by KITRO. For this, the national electricity mix for the respective country was used. For the server emissions, the German electricity mix was used based on the server location. The electricity consumption of the app server was calculated using scientific literature (Seppälä and Mattila, 2013).

Table 71: Type C data: Innovation action related life cycle inventory data for T5.1 in Germany, Greece and Switzerland (Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)

Innovation action data	Germany	Greece	Switzerland
KITRO tech device			
Duration of use per day [h]	2.5		
Energy consumption per day [kWh]	1,75E-02		
Average number of guests per day [nr]	261.00	604.19	300.79
National electricity mix	DE	GR	CH
Electricity consumption per guest and day [kWh]	6.71E-05	2.90E-05	5.82E-05
Server			
Data consumption per day [MB]	52		
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03		
National electricity mix	DE		
Average server electricity consumption per guest and day [kWh]	3.49E-04	1.51E-04	3.03E-04

For the innovation action impacts, only electricity consumption of smartphones, network infrastructure and app server were considered. The impacts associated with the production of smartphones, network infrastructure and app server infrastructure are not included in this calculation.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario

In Germany, the GWP resulted in 0.59 kg CO₂e of food waste per guest and day for the baseline scenario and 0.35 kg CO₂e per guest and day for the demonstration scenario (see Figure 80). In both scenarios, the majority of GWP is associated with food production. Waste management contributes very little to the total GWP (baseline: 4%, demonstration: 7%). Innovation action impacts (KITRO devices and server electricity consumption) contribute 0.06% to the demonstration GWP results. KITRO resulted in a 44% decrease of food waste. As a result, the food waste-related GWP per guest and day decreased by 40%.

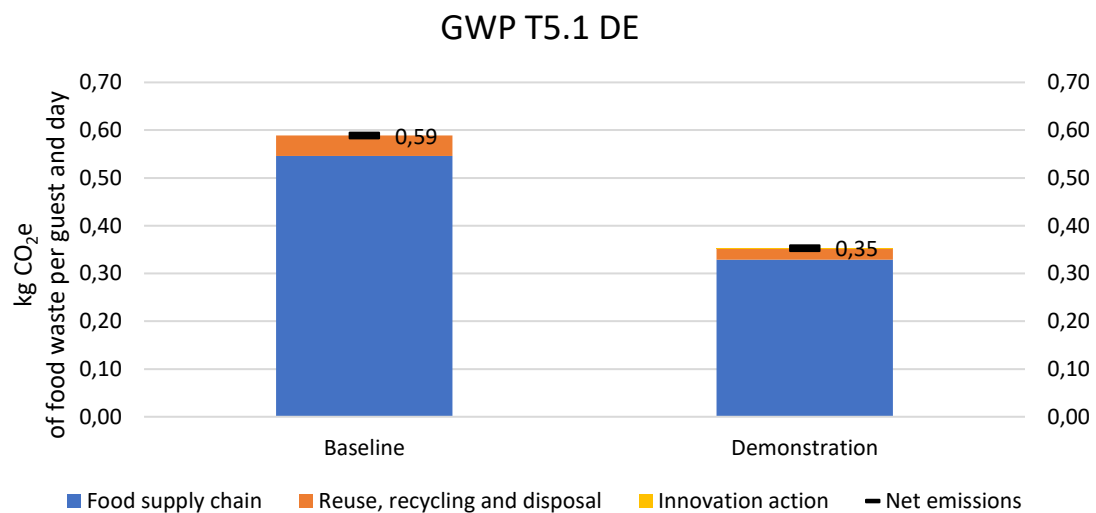


Figure 80: Global warming potential for the baseline and demonstration scenario for the innovation T5.1 tested in Germany

In Greece the GWP resulted in 0.41 kg CO₂e of food waste per guest and day for the baseline scenario and equals 0.26 kg CO₂e per guest and day for the demonstration scenario (see Figure 81 below). In both scenarios, the majority of GWP results from food production (baseline: 85%, demonstration: 89%). Waste management contributes 15% (baseline) and 11% (demonstration) to the total GWP impacts. Impacts resulting from the innovation action are responsible for 0.03% of total impacts in the demonstration scenario. KITRO resulted in a 51 mass-% decrease of food waste. As a result, the GWP per guest and day decreased by 36%.

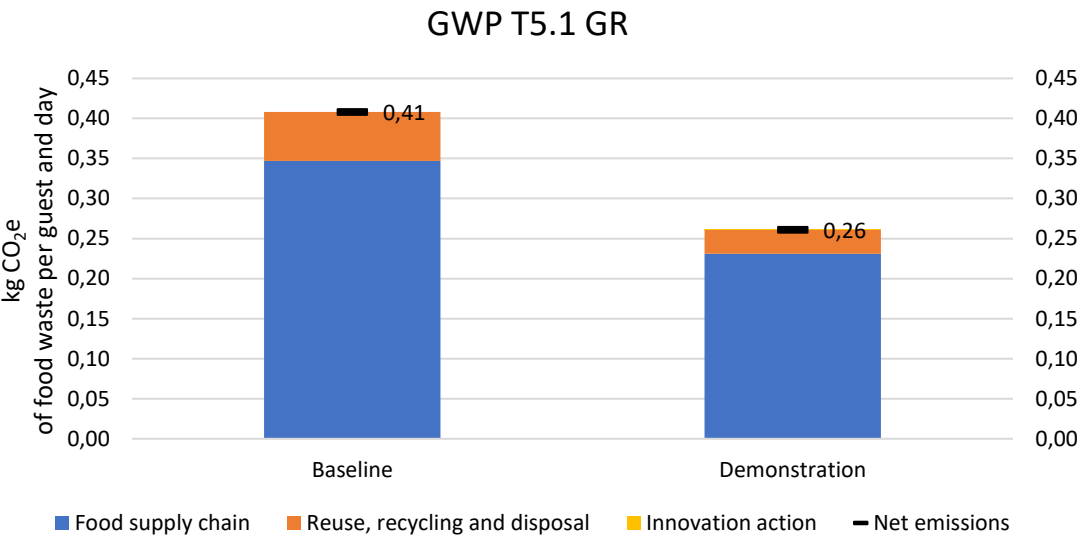


Figure 81: Global warming potential for the baseline and demonstration scenario for the innovation T5.1 tested in Greece

In Switzerland, the GWP resulted in 0.57 kg CO₂e of food waste per guest and day for the baseline scenario and 0.62 kg CO₂e per guest and day for the demonstration scenario. In both scenarios, the majority of GWP is associated with food production. Waste management contributes very little to the total GWP (baseline: 6%, demonstration: 6%). Innovation action impacts (KITRO devices and server electricity consumption) contribute 0.02% to the demonstration GWP results. KITRO resulted in a 11% increase in food waste and thus in a 9% increase in GWP results.

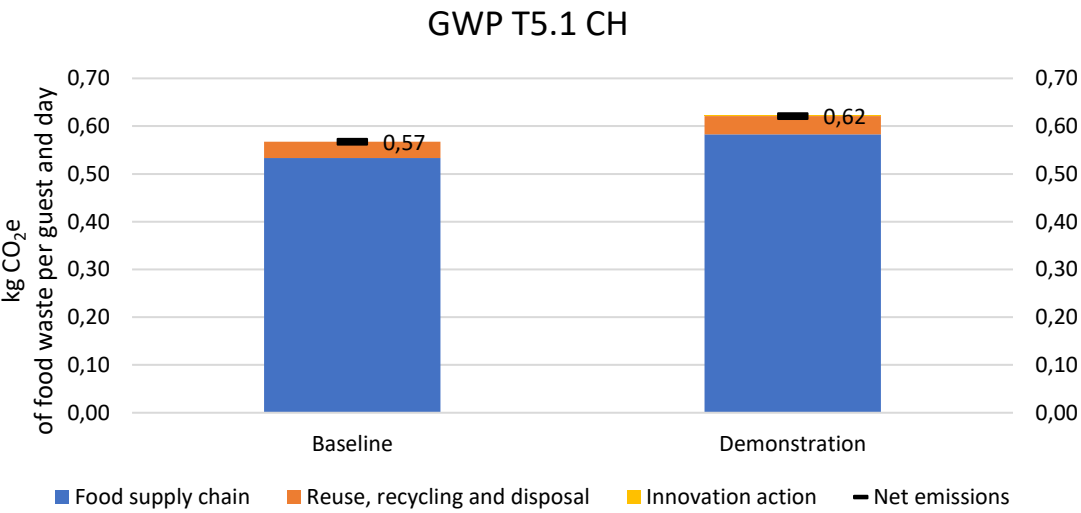


Figure 82: Global warming potential for the baseline and demonstration scenario for the innovation T5.1 tested in Switzerland

In Germany, the baseline PEF score equals 0.07 points and the demonstration PEF score equals 0.05 points. Through the use of KITRO, PEF score results were reduced by 33%. The PEF score result can largely be attributed to food production.

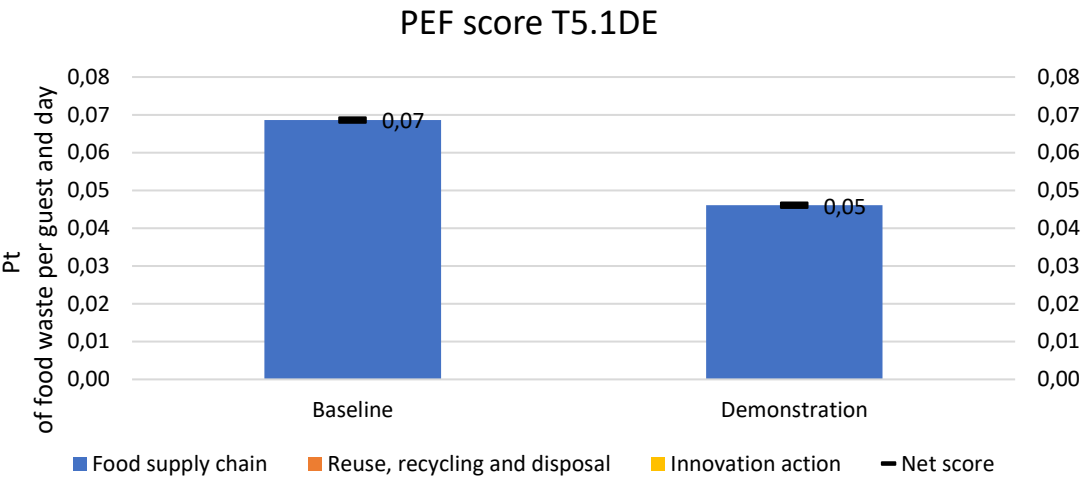


Figure 83: PEF score for the baseline and demonstration scenario for the innovation T5.1 tested in Germany

In Greece, the baseline PEF score equals 0.05 points and the demonstration PEF score equals 0.03 points. The entire PEF score impacts are associated with food production. Innovation action does not contribute to the PEF score impacts in either scenario. Through the use of KITRO, PEF score results were reduced by 30%.

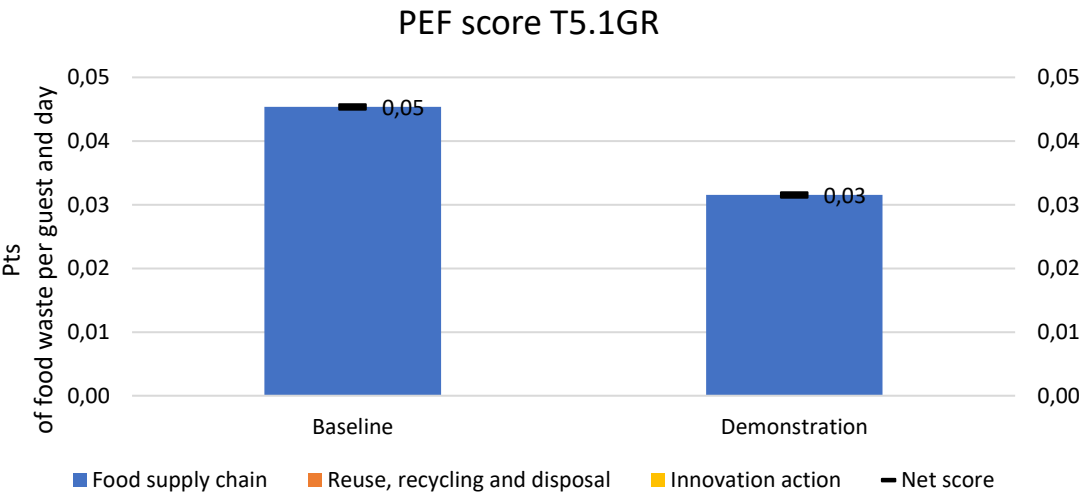


Figure 84: PEF score for the baseline and demonstration scenario for the innovation T5.1 tested in Greece

In Switzerland, the baseline PEF score equals 0.07 points and the demonstration PEF score equals 0.09 points. The PEF score result can largely be attributed to food production. However, as a consequence of the increase in food waste, PEF score results increased by 17%.

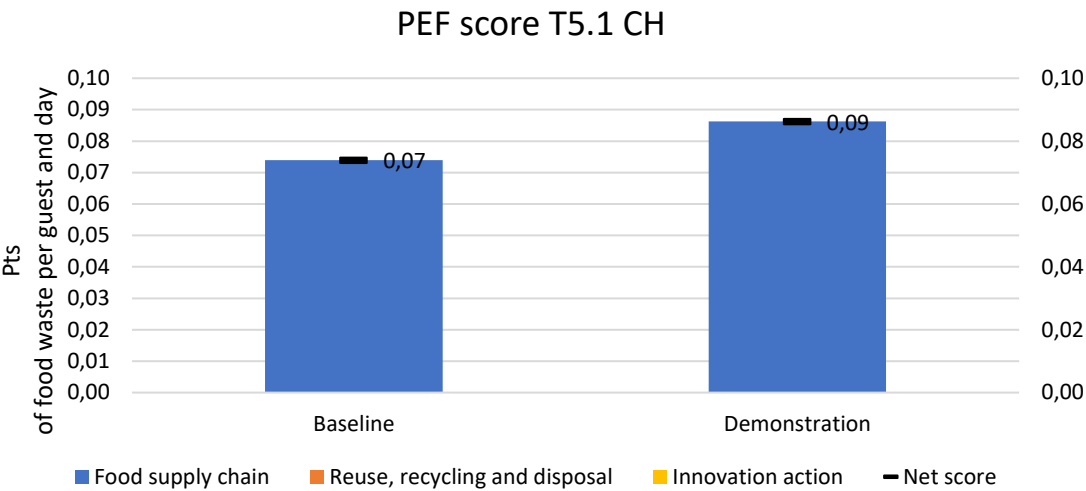


Figure 85: PEF score for the baseline and demonstration scenario for the innovation T5.1 tested in Switzerland

As shown in Figure 86, the majority of waste management GWP for Germany is caused by waste incineration. Anaerobic digestion reduces total waste management GWP. This is caused by the credits assigned for avoided primary energy production.

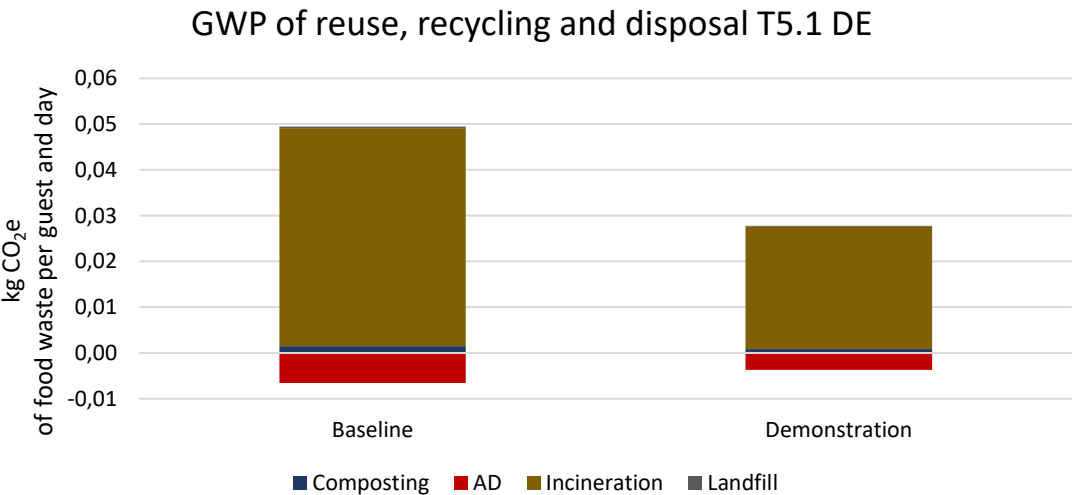


Figure 86: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.1 tested in Germany

As shown in Figure 87, the entire waste management-related GWP is caused by landfilling the food waste. Through this innovation, the waste management GWP was reduced by 51%, as food waste reduction results in less food waste being landfilled.

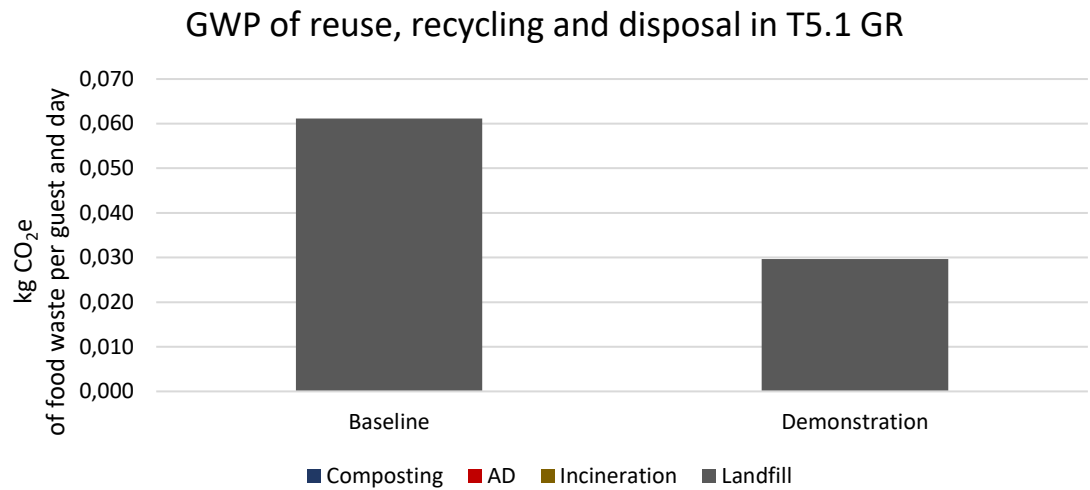


Figure 87: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.1 tested in Greece

As shown in Figure 88, the majority of waste management GWP for Switzerland is caused by waste incineration. Anaerobic digestion reduces total waste management GWP. This is caused by the credits assigned for avoided primary energy production.

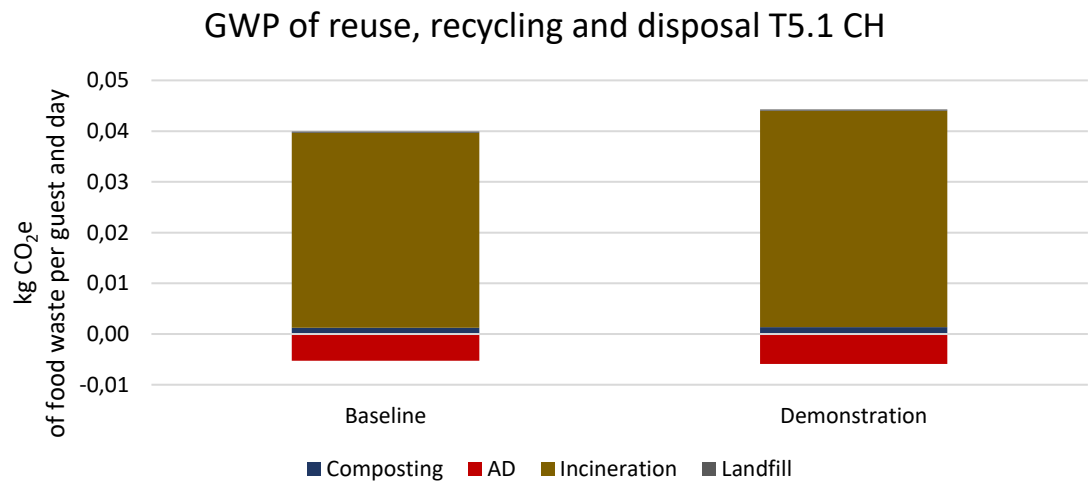


Figure 88: Contribution of the different waste treatment options to the overall waste management GWP impacts for the baseline and demonstration scenario for the innovation T5.1 tested in Switzerland

In Germany, the use of KITRO resulted in an impact reduction across most EF impact categories (global warming potential: -64%, ozone depletion: -100%, human toxicity non-cancer effects: -98%, human toxicity cancer effects: -100%, particulate matter: -100%, ionising radiation: -18%, photochemical ozone formation: -100%, terrestrial eutrophication: -55%, freshwater eutrophication: -100%, marine eutrophication: -18%, land use: -61%, water scarcity: -100%, fossil resource depletion: -47%, abiotic resource depletion: -100%). Acidification increased by 6% and freshwater ecotoxicity increased by 21%.

As shown in Figure 89, food production is the major contributor to environmental impacts for all impact categories. Waste management contributes up to 7% to environmental impacts, depending on the impact category. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

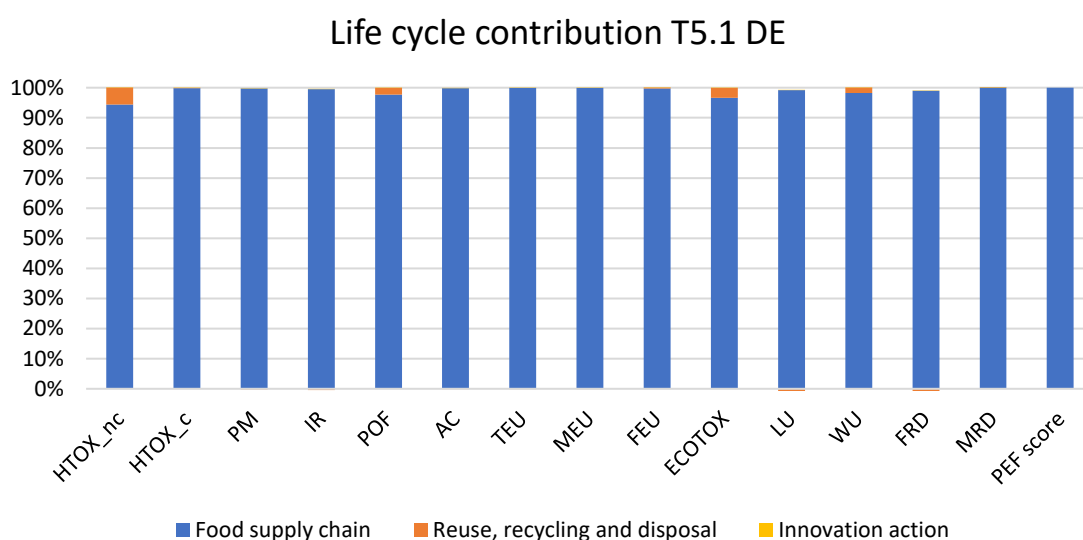


Figure 89: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.1 in Germany

In Greece, the use of KITRO resulted in an impact reduction across almost all EF impact categories (global warming potential: -36%, ozone depletion: -55%, human toxicity non-cancer effects: -15%, human toxicity cancer effects: -14%, particulate matter: -25%, ionising radiation HH: -51%, photochemical ozone formation: -36%, acidification: -25% terrestrial eutrophication: -23%, freshwater eutrophication: -36%, marine eutrophication: -26%, freshwater ecotoxicity: -12%, land use: -28%, water scarcity: -40%, fossil resource depletion: -45%, abiotic resource depletion: -22%).

As shown in Figure 90, the majority of environmental impacts result from food production. The contribution of the different life cycle stages to the total impact of the impact categories is the same in the baseline scenario. Innovation action has a negligible contribution to the total impacts across all impact categories for the demonstration scenario.

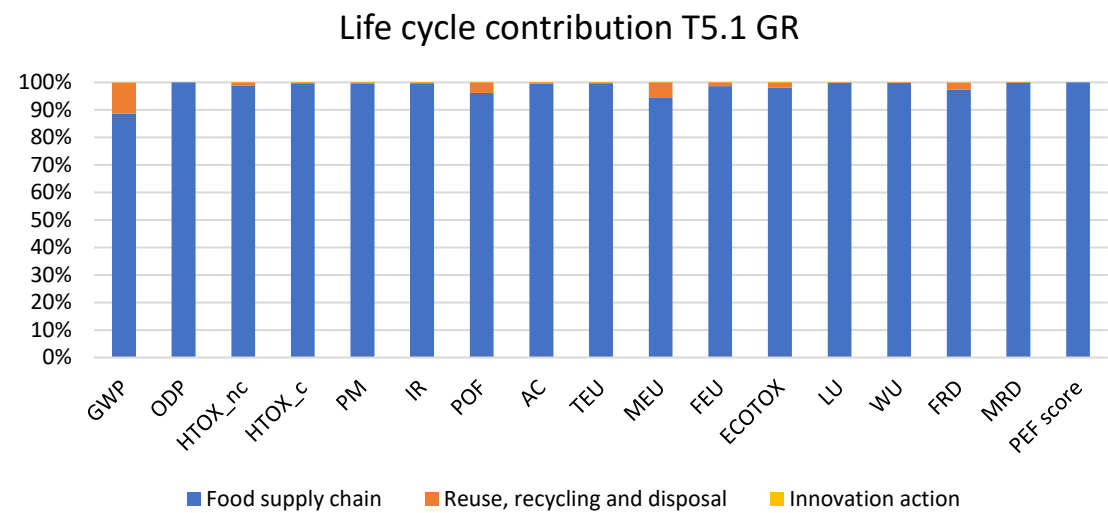


Figure 90: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.1 in Greece

In Switzerland, the use of KITRO increased impacts across all EF impact categories (global warming potential: +9%, ozone depletion: +23%, human toxicity non-cancer effects: +25%, human toxicity cancer effects: +27%, particulate matter: +17%, ionising radiation HH: +7%, photochemical ozone formation: +12%, acidification: +16%, terrestrial eutrophication: +18%, freshwater eutrophication: +16%, marine eutrophication: +18%, freshwater ecotoxicity: +28%, land use: +17%, water scarcity: +31%, fossil resource depletion: +11%, abiotic resource depletion: +26%).

As shown in Figure 91, food production is the major contributor to environmental impacts for all impact categories. Waste management and innovation action contribute little to the total impacts across all impact categories for the demonstration scenario.

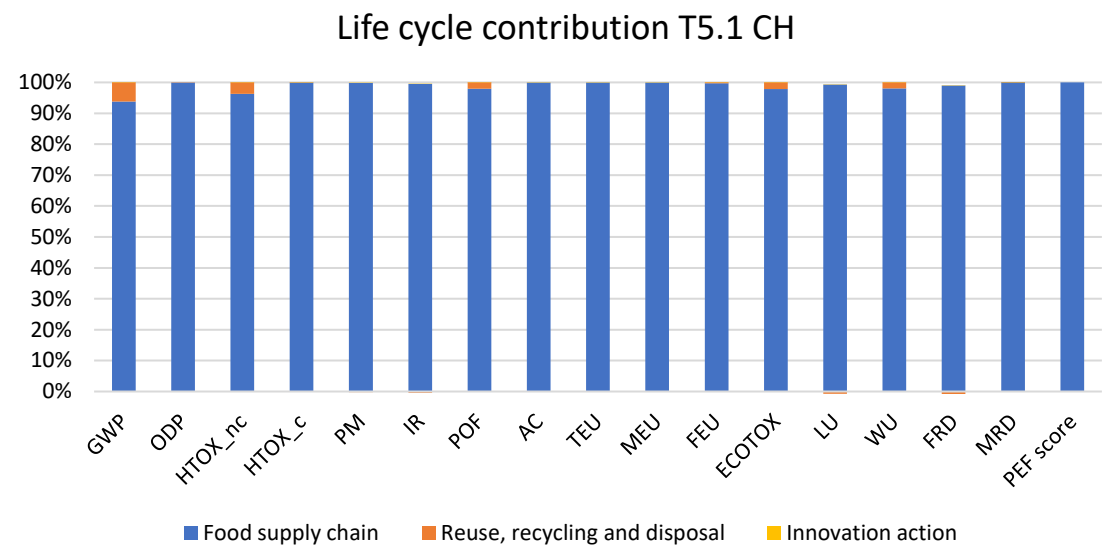


Figure 91: Contribution of the individual life cycle stages (food production, waste management and innovation action) to the total LCIA results for the innovation T5.1 in Switzerland

Life cycle impact assessment (LCIA) of food waste prevention

In Germany, this innovation can save 0.07 kg of food waste per guest and day. This prevents 0.24 kg CO₂e per guest and day. The total GWP result of 1 kg prevented food waste equals - 3.40 kg CO₂e, which is shown in Figure 92. The majority of the GWP savings results from avoided food production.

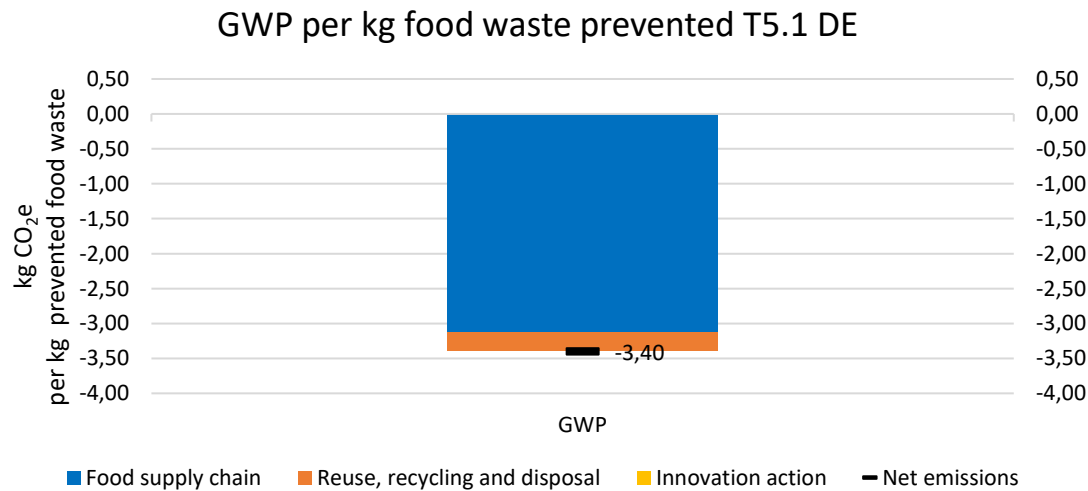


Figure 92: Global warming potential results for 1 kg of prevented HH food waste for the innovation T5.1 tested in Germany

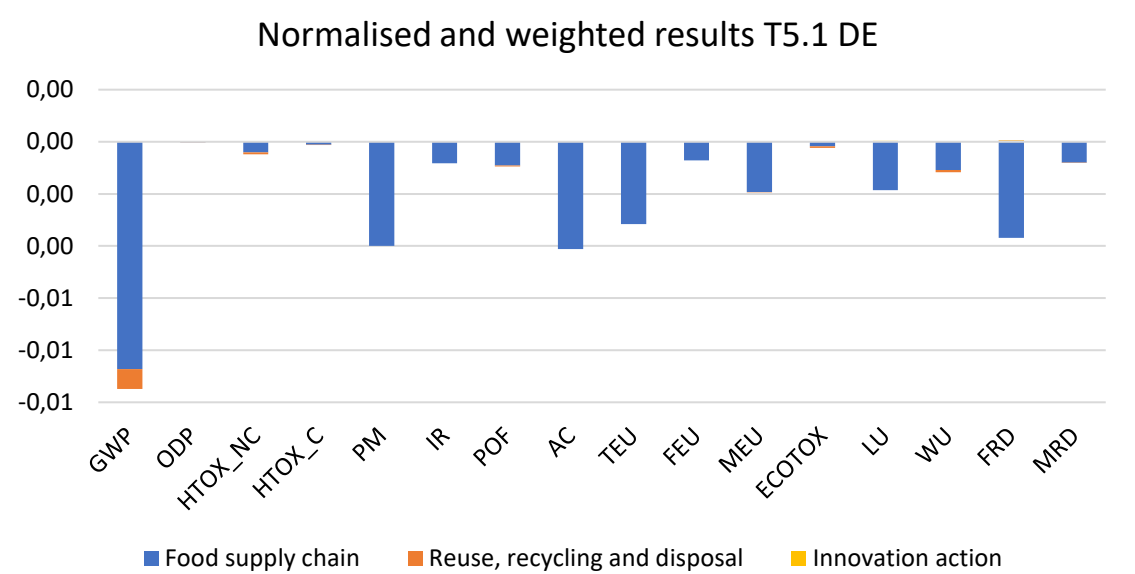


Figure 93: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.1 in Germany

In Greece, this innovation prevented 0.05 kg of food waste per guest and day. This prevents emissions of 0.15 kg CO₂e per guest and day on average. The total GWP result of 1 kg prevented HH food waste equals -2.8 kg CO₂e, which is shown in Figure 94. The majority of the GWP savings results from avoided food production.

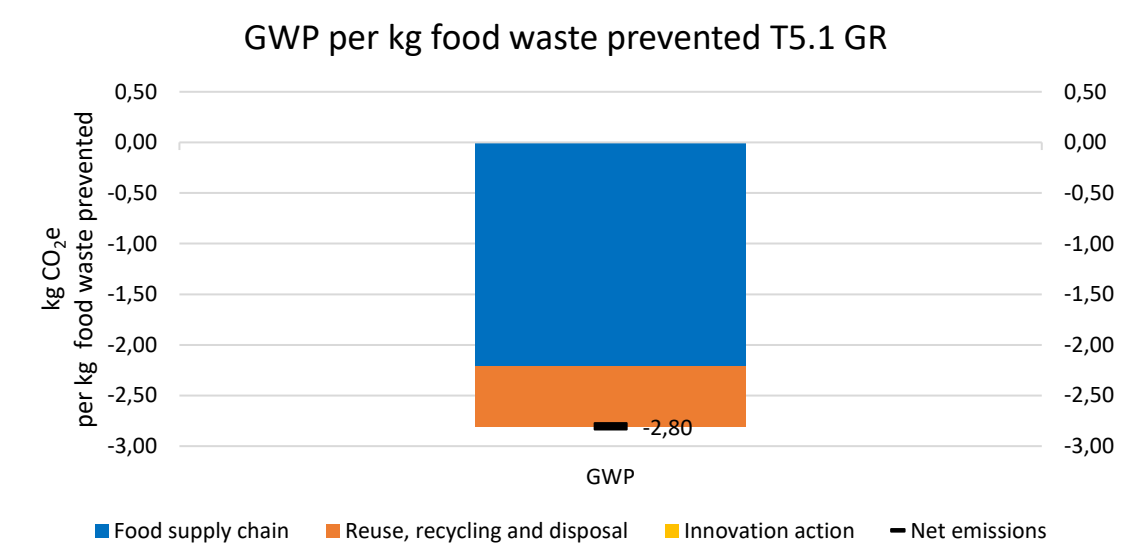


Figure 94: Global warming potential results for 1 kg of prevented food waste for the innovation T5.1 tested in Greece

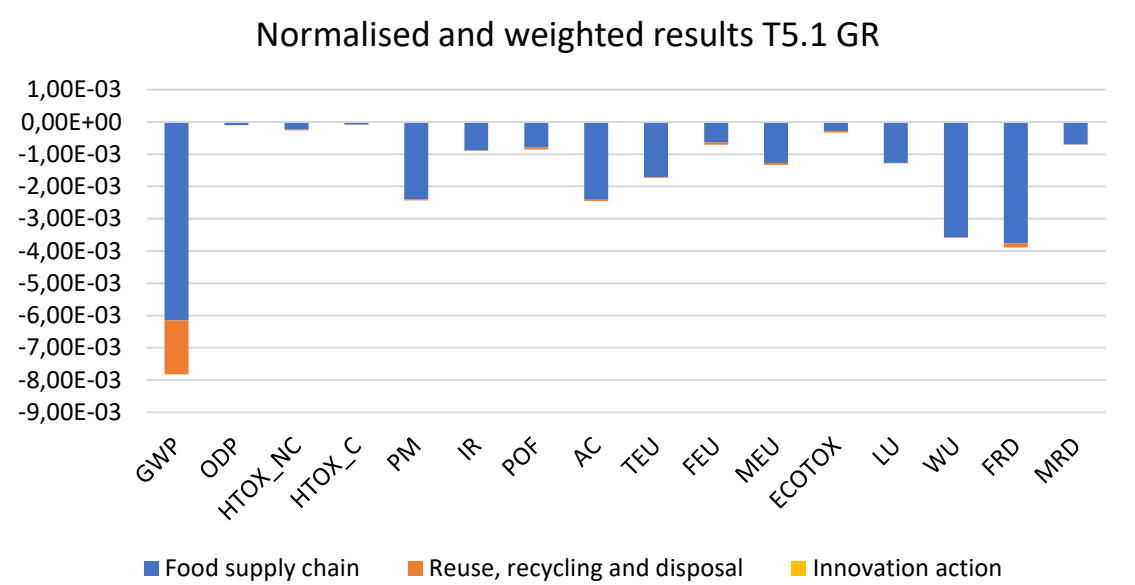


Figure 95: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.1 in Greece

During the demonstration phase in Switzerland food waste per guest and day increased by 0.014 kg or 11%. As a result, GWP per guest and day increased by 0.05 kg CO₂e. The total GWP result of 1 kg food waste increase equals +3.8 kg CO₂e, which is shown in Figure 96.

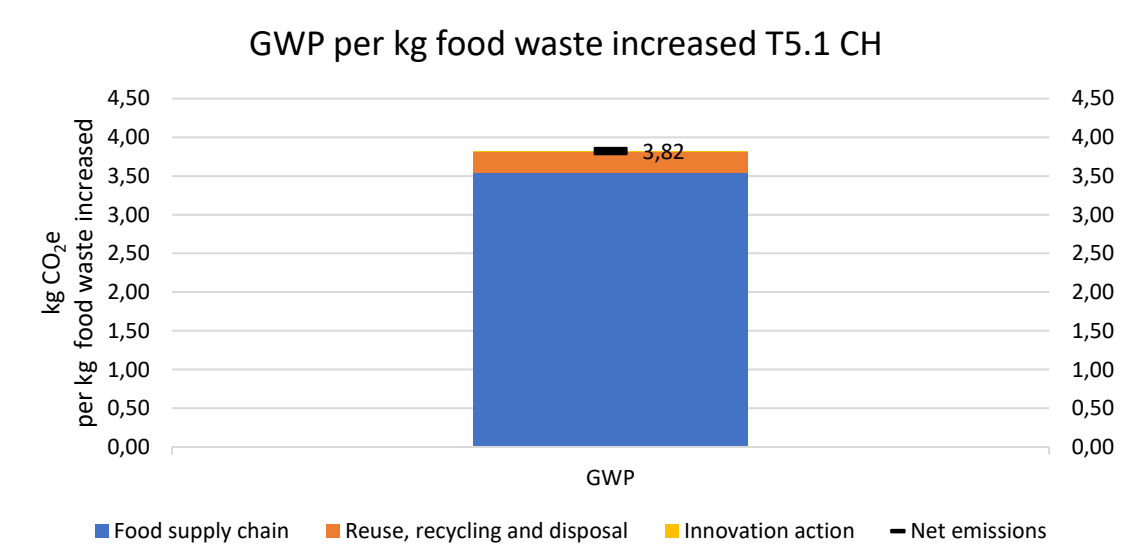


Figure 96: Global warming potential results for 1 kg of increased food waste for the innovation T5.1 tested in Switzerland

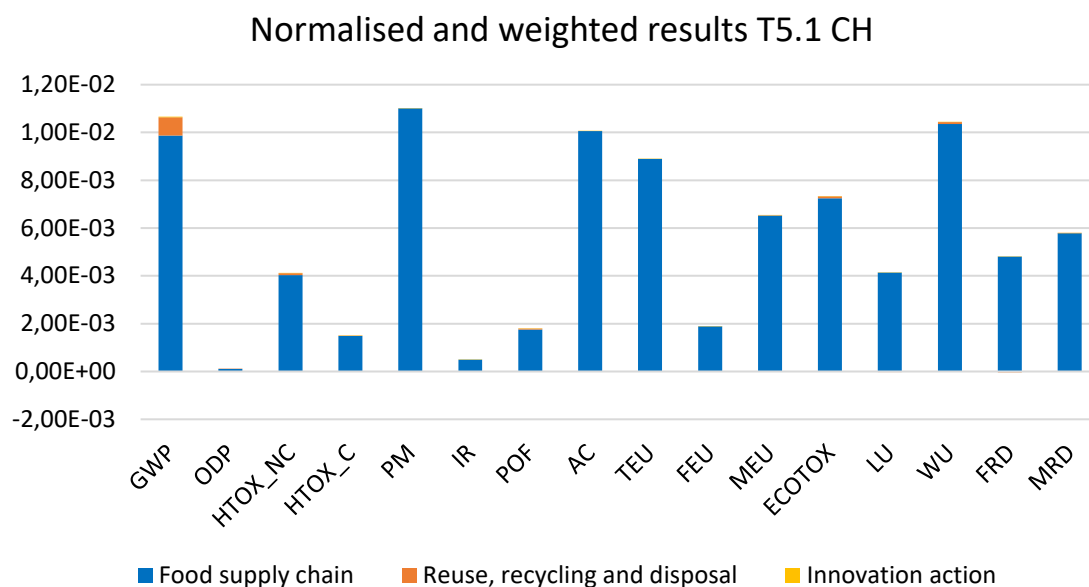


Figure 97: Normalised and weighted results for 1 kg of increased food waste for the innovation T5.1 in Switzerland

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 3.2). The relative external environmental costs resulted in 0.86 EUR, and 0.67 EUR in Germany and Greece respectively that can be saved due to food waste prevention (see Table 72, Table 73). In Switzerland it leads to costs of 1.73 EUR per kg food waste (Table 74).

Table 72: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.1 in Germany

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		16 kg for 234 guests per day	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-3.40E+00	-4.25E-01	-5.52E+01	-6.90E+00
ODP	kg CFC11 eq	-2.13E-07	-8.16E-06	-3.46E-06	-1.33E-04
HTOX_NC	CTUh	-3.39E-08	-6.74E-03	-5.51E-07	-1.10E-01
HTOX_C	CTUh	-9.20E-10	-1.01E-03	-1.49E-08	-1.64E-02
PM	Disease incidences	-2.65E-07	-2.53E-01	-4.30E-06	-4.12E+00
IR	kBq U235 eq	-6.89E-01	-1.01E-03	-1.12E+01	-1.63E-02
POF	kg NMVOC eq	-8.06E-03	-1.17E-02	-1.31E-01	-1.90E-01
AC	molc H ⁺ eq	-3.68E-02	-1.55E-02	-5.99E-01	-2.51E-01
TEU	molc N eq	-1.50E-01		-2.44E+00	
FEU	kg P eq	-4.11E-04	-9.63E-04	-6.69E-03	-1.56E-02
MEU	kg N eq	-1.28E-02	-5.01E-02	-2.08E-01	-8.15E-01
ECOTOX	CTUe	-7.08E+00	-3.30E-04	-1.15E+02	-5.36E-03
LU	Pt	-1.90E+02	-4.06E-02	-3.09E+03	-6.60E-01
WU	m ³ water eq	-1.57E+00	-9.58E-03	-2.56E+01	-1.56E-01
FRD	MJ	-2.84E+01	-4.52E-02	-4.62E+02	-7.34E-01
MRD	kg Sb eq	-6.72E-06	-1.34E-05	-1.09E-04	-2.18E-04
Environmental costs			-8.61E-01		-1.40E+01

Table 73: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.1 in Greece

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		32 kg for 604 guests per day	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-2.80E+00	-3.51E-01	-8.89E+01	-1.11E+01
ODP	kg CFC11 eq	-8.17E-07	-3.13E-05	-2.59E-05	-9.92E-04
HTOX_NC	CTUh	-1.82E-08	-3.62E-03	-5.76E-07	-1.15E-01
HTOX_C	CTUh	-6.86E-10	-7.54E-04	-2.17E-08	-2.39E-02
PM	Disease incidences	-1.62E-07	-1.55E-01	-5.14E-06	-4.91E+00
IR	kBq U235 eq	-7.44E-01	-1.09E-03	-2.36E+01	-3.45E-02
POF	kg NMVOC eq	-7.30E-03	-1.06E-02	-2.31E-01	-3.36E-01
AC	molc H ⁺ eq	-2.19E-02	-9.22E-03	-6.96E-01	-2.92E-01
TEU	molc N eq	-8.29E-02		-2.63E+00	
FEU	kg P eq	-4.06E-04	-9.51E-04	-1.29E-02	-3.02E-02
MEU	kg N eq	-8.77E-03	-3.44E-02	-2.78E-01	-1.09E+00
ECOTOX	CTUe	-9.65E+00	-4.50E-04	-3.06E+02	-1.43E-02
LU	Pt	-1.32E+02	-2.82E-02	-4.17E+03	-8.93E-01
WU	m ³ water eq	-4.83E+00	-2.94E-02	-1.53E+02	-9.34E-01
FRD	MJ	-3.04E+01	-4.83E-02	-9.63E+02	-1.53E+00
MRD	kg Sb eq	-5.89E-06	-1.18E-05	-1.87E-04	-3.74E-04
Environmental costs			-6.72E-01		-2.13E+01

Table 74: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.1 in Switzerland

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		4 kg for 301 guests and day	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	3.82E+00	4.78E-01	1.61E+01	2.01E+00
ODP	kg CFC11 eq	9.03E-07	3.46E-05	3.80E-06	1.46E-04
HTOX_NC	CTUh	2.88E-07	5.73E-02	1.21E-06	2.41E-01
HTOX_C	CTUh	1.21E-08	1.33E-02	5.09E-08	5.60E-02
PM	Disease incidences	7.31E-07	6.99E-01	3.08E-06	2.95E+00
IR	kBq U235 eq	4.21E-01	6.14E-04	1.77E+00	2.59E-03
POF	kg NMVOC eq	1.53E-02	2.23E-02	6.46E-02	9.37E-02
AC	molc H ⁺ eq	9.02E-02	3.79E-02	3.80E-01	1.59E-01
TEU	molc N eq	4.24E-01		1.78E+00	
FEU	kg P eq	1.08E-03	2.53E-03	4.55E-03	1.07E-02
MEU	kg N eq	4.32E-02	1.69E-01	1.82E-01	7.12E-01
ECOTOX	CTUe	2.16E+02	1.01E-02	9.11E+02	4.24E-02
LU	Pt	4.25E+02	9.10E-02	1.79E+03	3.83E-01
WU	m ³ water eq	1.41E+01	8.57E-02	5.92E+01	3.61E-01
FRD	MJ	3.73E+01	5.94E-02	1.57E+02	2.50E-01
MRD	kg Sb eq	4.88E-05	9.75E-05	2.05E-04	4.11E-04
Environmental costs			1.73E+00		7.27E+00

Interpretation and review

The demonstration of the KITRO innovative food waste solution had the advantage that it was tested in three different countries and with the same approach. Food waste decreased from the baseline to the demonstration in Germany and Greece, but not in Switzerland. The environmental performance of the demonstration compared to the baseline therefore leads to environmental burdens in the case of Switzerland and environmental benefits in the case of Germany and Greece.

The global warming potential per kg of food waste was 3.40 kg CO₂e in Germany, 3.82 kg CO₂e in Switzerland and 2.80 kg CO₂e in Greece, which is relatively high. This is due to the composition of food waste, which largely consists of menu dishes with an unspecified mixture of food products. The proportion of animals in these categories may be overestimated and should be analysed in more detail in future studies.

The environmental impact is largely caused by the food supply chain. The more food that can be saved from being wasted, the more environmental emissions can be avoided. The contribution of innovation measures and reuse, recycling and disposal options plays only a limited role.

T5.2 'MITAKUS Forecasting software for restaurants'

Goal and Scope

This innovation (T5.2) consists of a forecasting software (MITAKUS) for restaurants providing accurate demand forecasts allowing to reduce preparation of surplus food. It was tested in Germany.

MITAKUS aims to reduce food waste in the food service sector by providing restaurants with a web-based software that generates accurate demand forecasts and menu recommendations with the help of an artificial intelligence algorithm. This algorithm takes into account internal (historical data on sales) and external factors, such as the weather, holidays, vacations, events and dietary restrictions and preferences of the consumers. MITAKUS web-based software platform supports chefs, production and purchasing managers, and operations personnel during production planning based on customer preferences and volume, while accurately predicting ingredient requirements. This is particularly important for commercial kitchens and restaurants that increasingly use fresh and perishable ingredients. The forecasts provided by the MITAKUS software is expected to reduce overpreparation and overstocking, thus preventing the waste of raw and prepared food and making restaurants more profitable and sustainable. The demonstration of the software had shortcomings because of insufficient forecasting accuracy. Canteens did not fully adopt the innovation but kept using their own planning tools. That is why the demonstration was simulated to detect potential environmental benefits.

The functional unit of the system is **1 kg of prevented food surplus at restaurants**. The reference flow is the amount of food surplus, that is the amount of overproduction, and the amount of food waste, that includes preparation waste, serving waste and plate waste, measured at the baseline. For the simulation of the demonstration two scenarios were used: "Best case scenario" with a reduction potential of overproduced food (surplus food) by 10% and the "Medium scenario" with a reduction potential of overproduced food by 8%:

Table 75: Reference flows of the baseline and the demonstration scenario of T5.2

Country	Food surplus or waste at BASELINE (n)	Food surplus or waste at simulated demonstration (-10%) ($n-x_{ps}$)	Food surplus or waste at simulated demonstration (-8%) ($n-x_{ps}$)
Total food overproduction [kg]	4,784	4,306	4,401
Total other food waste (preparation waste, serving waste, plate waste) [kg]	3,341	3,341	3,341

The system boundaries for both the baseline and the demonstration system are shown in Figure 98. Both the system boundaries for the baseline and the demonstration system include the entire food production value chain. This entails the production and processing of the food items, as well as their distribution and retail. Finally, the food gets prepared (e.g., cooked) by the restaurant kitchen staff and then consumed by the guests. Food waste is then disposed of. Food surplus (overproduction of food) was used on the next day by the canteens involved in the LOWINFOOD demonstration. This surplus food was cooled or frozen before use. In the demonstration system, the MITAKUS forecasting software is introduced at the production stage, in order to prevent overproduction of food. Thus, the amount of surplus food can potentially be decreased ($n-x_{ps}$). The amount of food waste stays the same in this case (n_w).

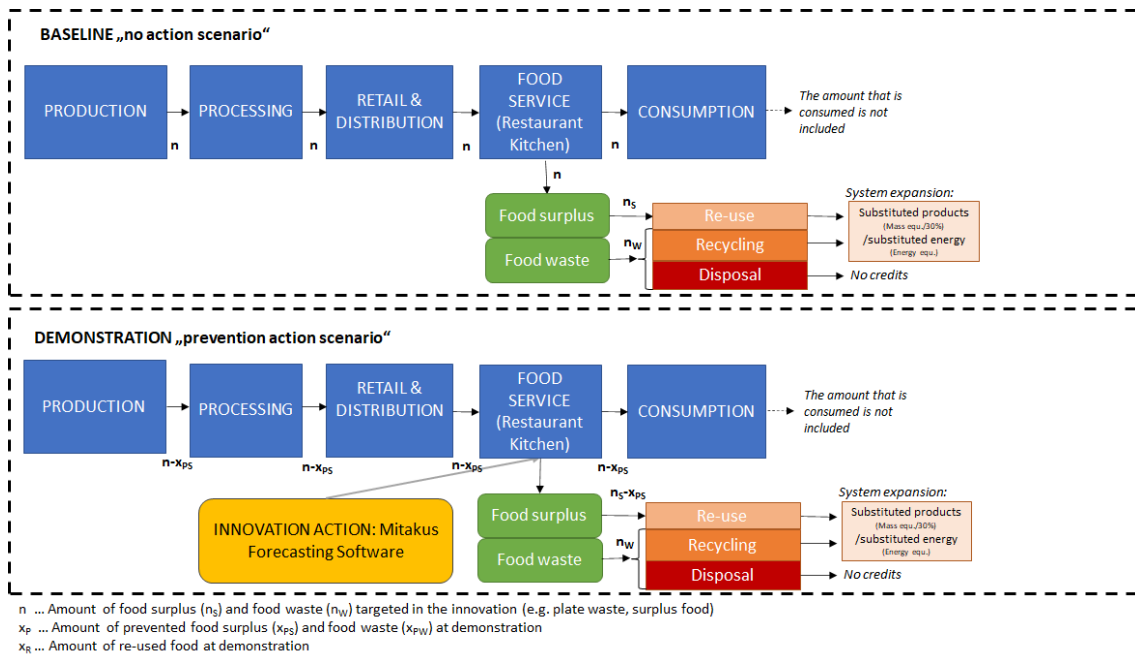


Figure 98: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T5.2

Life cycle inventory (LCI)

Table 76 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 76: Type of process data and collection method used for Task 5.2 in Germany

Component	Process data collected within LOWINFOOD (so-called proxy data)	T 5.2	Collection method
Type A data 'Food life cycle'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Questionnaire
Type C data 'Innovation action'	Transport Consumer Travel Packaging Other activities (e.g., storage) Use of computer devices	- - - • •	- - - Expert consultation Expert consultation

Data on the amount and composition of food waste was collected through company records of MITAKUS in Task 5.2. Table 77 shows the food waste quantities. The food waste composition is listed in Table 78. For the two demonstration scenarios, a decrease in overproduction by 8% and 10% was assumed.

Table 77: Type A data: Food surplus or waste quantities for Task 5.2 in Germany

Food surplus or waste data	Germany		
	Baseline	Simulated demonstration (-10%)	Simulated demonstration (-8%)
Total food overproduction [kg]	4,784	4,306	4,401
Total other food waste (preparation waste, serving waste, plate waste) [kg]	3,341	3,341	3,341
Total number of servings [no]	36,673.50	36,673.50	36,673.50
Number of participating restaurants [no]	2	2	2
Measuring days [no]	23	23	23
Average number of servings per restaurant and day [no]	797	797	797

The food waste composition is based on the menu plans provided by the restaurants. According to the restaurants, these menu plans are based on the recommendations of the German Nutrition Society and consist of 92 meals, of which 18% were vegetarian, 28% were

vegan, 8% contained fish and 46% contained meat (56% chicken, 25% beef, 19% pork). Emission factors were calculated for each individual food group (e.g., fish dish, vegetarian dish, pork dish) with Agribalyse data. Then, these food group emission factors were aggregated to a single emission factor for 1 kg restaurant food waste, based on their percentual share in total restaurant food waste.

Table 78: Type A data: Food surplus or waste composition for T5.2 in Germany

Restaurant food surplus or waste composition	Germany
Vegetarian dish ²³	18%
Vegan dish ²⁴	28%
Fish dish ²⁵	8%
Chicken dish ²⁶	26%
Pork dish ²⁷	9%
Beef dish ²⁸	12%

According to the participating restaurants, all restaurant food waste in Germany is disposed of through anaerobic digestion. The food that is overproduced is not wasted but reused (stored in cooling units and used another day). The electricity consumption for the storage of the reused food in cooling units was considered (electricity consumption of 400 kWh/m³*year, 10m³ cooling unit assumed).

Table 79: Type B data: Reuse, recycling and disposal options for T5.2 in Germany

Options	Baseline	Sim. Dem. -10%	Sim. Dem. -8%
Redistribution	47.1%	45.0%	45.5%
Animal feeding	0%	0%	0%
Composting	0%	0%	0%
Anaerobic digestion	52.9%	55.0%	54.5%
Municipal waste treatment (incinerated)	0%	0%	0%
Municipal waste treatment (landfill)	0%	0%	0%

The software use-related electricity consumption of the computer, the router and the server hosting the software were taken into account. The electricity consumption of the computer and the router were taken from Almeida et al. (2011). For this, the German national electricity mix was used. The electricity consumption of the server was calculated with data from scientific literature (Seppälä and Mattila, 2013). Again, the German national electricity mix was used for this.

²³ e.g., grilled vegetables, veggie lasagna, vegetable fritters

²⁴ e.g., soy-based patty, cereal patty, soybean and wheat-based nuggets

²⁵ e.g., fish skewers, fish in sauce, fish and shrimp gratin

²⁶ e.g., chicken curry, Basque style chicken, chicken tagine, chicken with rice or couscous

²⁷ e.g., carbonara-style pasta, sausage stew, pork belly

²⁸ e.g., beef stew, lasagna, meat balls in tomato sauce, bolognese-style pasta

*Table 80: Type C data: Innovation action related life cycle inventory data for T5.2 in Germany
(Note: only the demonstration scenario is shown, in the baseline there was no app usage, so no innovation action related impacts)*

Innovation action data	Germany
Computer and router use	
Computer electricity consumption per hour (Almeida et al., 2011) [kWh]	6.40E-03
Router electricity consumption per hour (Almeida et al., 2011) [kWh]	8.00E-03
Average duration of computer use per restaurant and day [h]	0.88
National electricity mix	DE
Innovation-related electricity consumption per serving [kWh]	7.90E-03
Server	
Data consumption per day [MB]	1.05
Electricity consumption server (Seppälä and Mattila 2013) [kWh/MB]	1.75E-03
National electricity mix	DE
Average server electricity consumption per serving [kWh]	1.15E-06

For the innovation action impacts, only electricity consumption of computer, router and the server hosting the software application were considered. The impacts associated with the production of the computer, router, network infrastructure and server infrastructure are not included in this calculation.

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The absolute results for all participating restaurants showed a GWP of 35,000 kg CO₂e for the baseline scenario, 32,900 kg CO₂e for the simulated demonstration with a 10% reduction of overproduction and 33,300 kg CO₂e for the simulated demonstration with 8% reduction of overproduction. In all scenarios, the majority of GWP is associated with food. Waste management reduces total GWP results. The reason for this is that credits were assigned for avoided electricity and thermal energy production as a result of anaerobic digestion. Innovation action (software use) contributes very little (0.001%) to the demonstration GWP results. If overproduction is reduced by 10%, MITAKUS prevents a total of 2,150 kg CO₂e. This equals a GWP reduction of 6% compared to the baseline scenario. A reduction in overproduction by 8% prevents GWP emissions of 1,720 kg CO₂e, which equals a reduction of 5% compared to the baseline scenario.

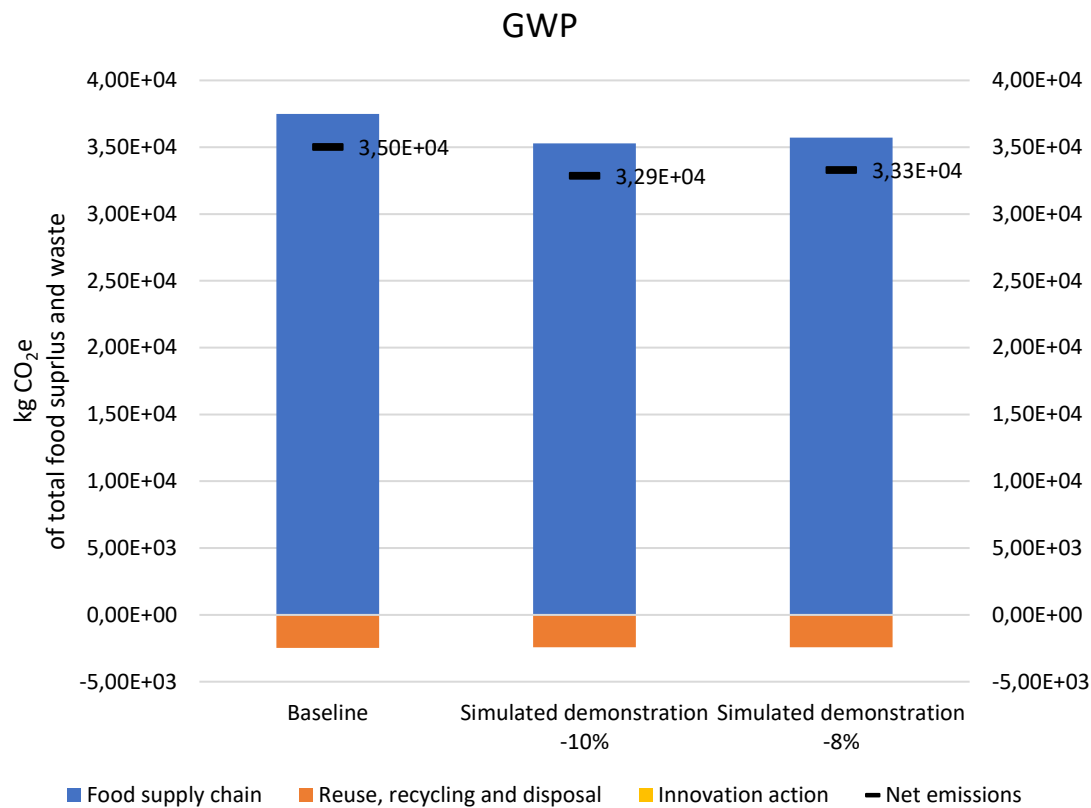


Figure 99: Global warming potential for the baseline and demonstration scenario for the innovation T5.2 in Germany

Figure 100 shows the PEF score results for the baseline and demonstration scenarios. The baseline PEF score equals 4,870 pts and the demonstration PEF score equals 4,580 pts for a 10% reduction and 4,640 pts for a 8% reduction of overproduction. Through MITAKUS, PEF score results were reduced by 6% and 5%, respectively. As shown in Figure 100, the PEF score result can be attributed to the food supply chain.

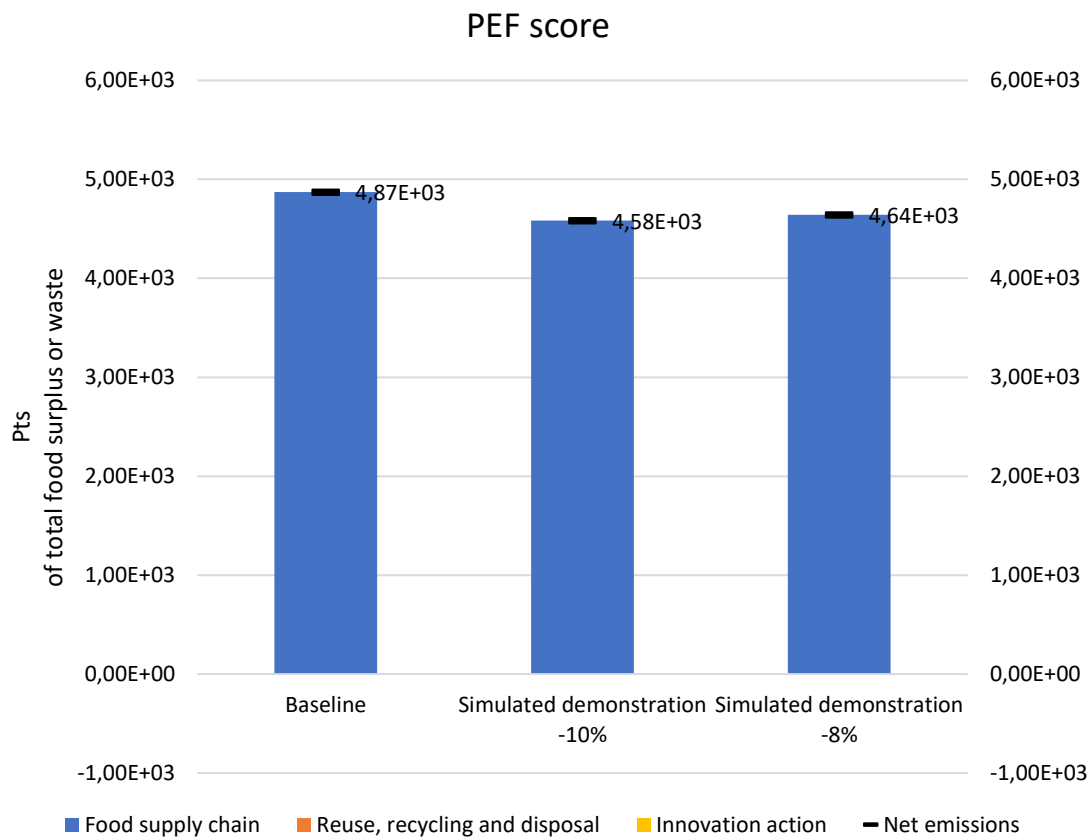


Figure 100: PEF score per serving for the baseline and demonstration scenario for the innovation T5.2 in Germany

MITAKUS resulted in an impact reduction for all EF impact categories. When overproduction is reduced by 10%, all EF impact category results decreased by 6%. A 8% reduction of overproduction leads to a 5% decrease of all EF impact category results.

As shown in Figure 101, food production is the main contributor to environmental impacts for all impact categories. Food production is the main contributor across all EF impact categories. Waste management reduces environmental impacts. This is caused by the credits assigned for avoided electricity and thermal energy production as a result of anaerobic digestion. The contribution of the additional cooled step for the reused food surplus has neglectable impacts. Also, innovation action contributes very little to the total impacts.

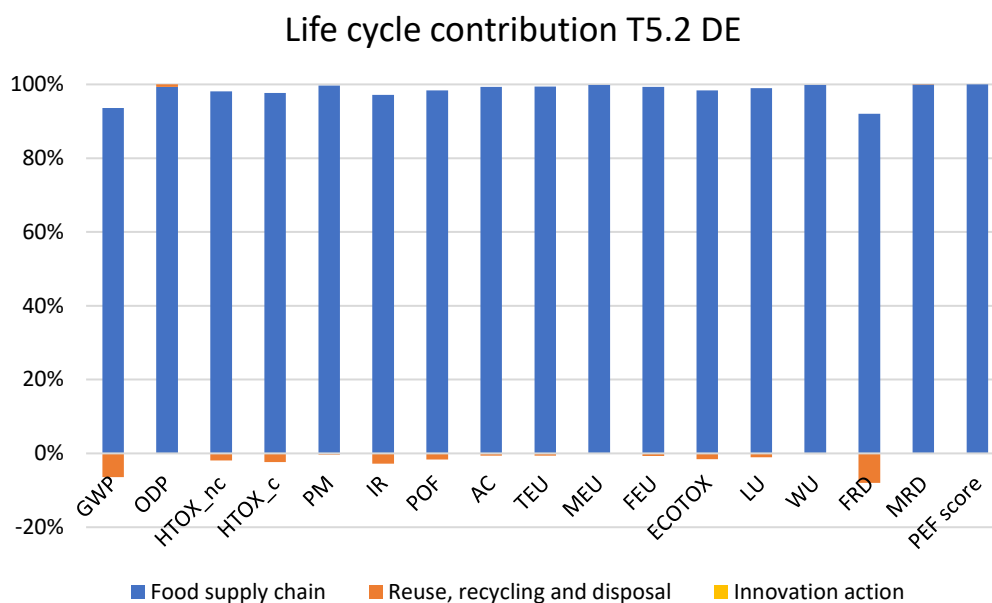


Figure 101: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T5.2 in Germany for the demonstration scenario

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

When overproduction of food is reduced by 10%, 478 kg food surplus is prevented. This resulted in emissions savings of 2,154 kg CO₂e. The majority of GWP savings results from avoided food production. When overproduction of food is reduced by 8%, 383 kg food surplus is prevented. This equals a prevented GWP impact of 1,723 kg CO₂e. As shown in Figure 102, the total GWP of 1 kg prevented food surplus equals in both simulated demonstrations -4.50 kg CO₂e.

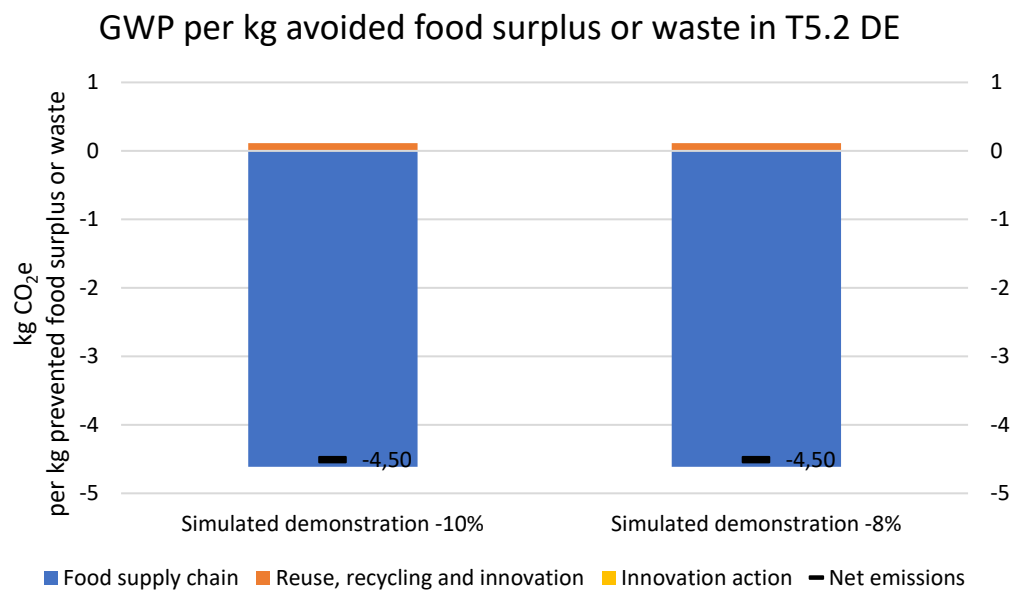


Figure 102: Global warming potential results for 1 kg of prevented food waste for the innovation T5.2 in Germany

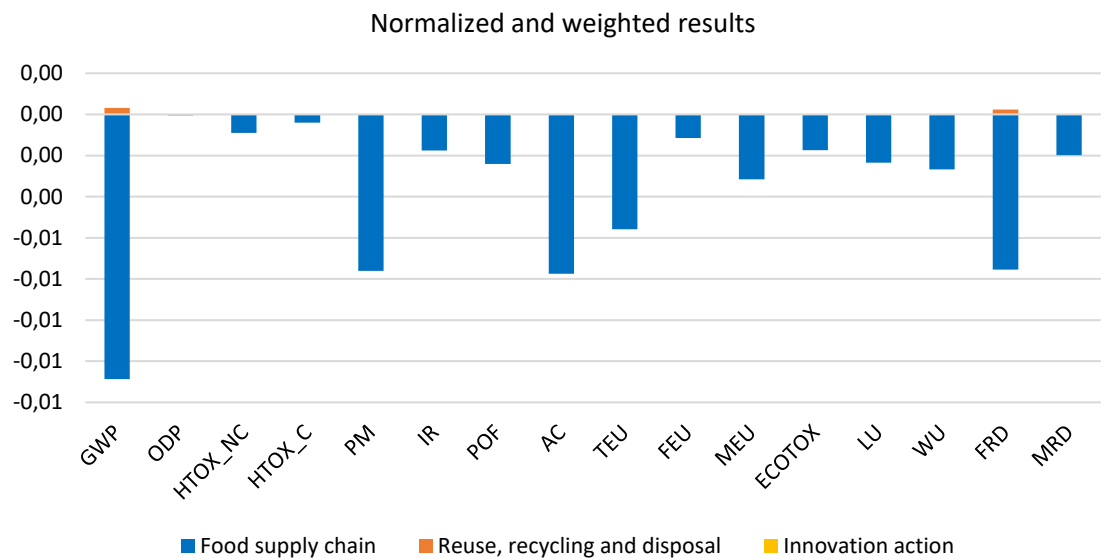


Figure 103: Normalised and weighted results for 1 kg of prevented food waste for the innovation T5.2 in Germany

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 2.2). The total external environmental costs that can be saved by the simulated demonstration (-10% scenario) of T5.1 resulted in 657 EUR.

Table 81: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T5.1 in Germany

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		4,876 kg (2 restaurants, 23 days of observation)	
Environmental impact category		Env. emissions [Unit of the impact category]	Env. costs [EUR]	Env. emissions [Unit of the impact category]	Env. costs [EUR]
GWP	kg CO ₂ eq	-4.50E+00	-5.63E-01	-2.15E+03	-2.69E+02
ODP	kg CFC11 eq	-3.88E-07	-1.49E-05	-1.86E-04	-7.12E-03
HTOX_NC	CTUh	-6.28E-08	-1.25E-02	-3.01E-05	-5.98E+00
HTOX_C	CTUh	-3.25E-09	-3.58E-03	-1.56E-06	-1.71E+00
PM	Disease incidences	-5.05E-07	-4.83E-01	-2.42E-04	-2.31E+02
IR	kBq U235 eq	-1.46E+00	-2.13E-03	-6.99E+02	-1.02E+00
POF	kg NMVOC eq	-2.05E-02	-2.97E-02	-9.81E+00	-1.42E+01
AC	molc H ⁺ eq	-6.93E-02	-2.91E-02	-3.32E+01	-1.39E+01
TEU	molc N eq	-2.66E-01		-1.27E+02	
FEU	kg P eq	-6.61E-04	-1.55E-03	-3.16E-01	-7.40E-01
MEU	kg N eq	-2.08E-02	-8.16E-02	-9.96E+00	-3.90E+01
ECOTOX	CTUe	-5.12E+01	-2.39E-03	-2.45E+04	-1.14E+00
LU	Pt	-2.42E+02	-5.18E-02	-1.16E+05	-2.48E+01

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
WU	m ³ water eq	-3.61E+00	-2.20E-02	-1.73E+03	-1.05E+01
FRD	MJ	-5.71E+01	-9.08E-02	-2.73E+04	-4.35E+01
MRD	kg Sb eq	-1.67E-05	-3.33E-05	-7.97E-03	-1.59E-02
Environmental costs			-1.37E+00		-6.57E+02

Interpretation and review

MITAKUS forecasting software targets the reduction of food surplus at restaurants. In the demonstration, the forecasting software could have been improved. However, the restaurants testing the software unfortunately didn't fully implement the software. So, the reduction of food surplus could not be quantified in the demonstration within LOWINFOOD. Instead, the demonstration and its effects was simulated.

The environmental evaluation with simulated demonstration scenarios revealed that about 6 to 5% of the emissions could be reduced when using MITAKUS software for cutting down the overproduced food. As only the share of overproduced food is targeted and not the other food waste fractions (preparation residues, etc.), the emission reduction potential has not the same extent as the reduction potential by mass. The emission reduction potential per kg food surplus that can be prevented is though high as the dishes contain to a high extent animal based food (54% of the dishes contain fish, chicken, beef or pork). This leads to about -4.5 kg CO₂e per kg of food surplus that can be prevented.

3.5 Environmental impacts of food redistribution innovations

T2.2 'UNV Cooperation system for F&V'

Goal and Scope

This innovation (T2.2) is a cooperation system called Unverschwendet (UNV) between farmers, processing industry and wholesalers to find alternative marketing channels for agricultural products in Austria by redistributing products and largely also by reprocessing products to find buyers. These products are thus made available for human consumption instead of ending up as food waste.

The aim of this task is to promote the use of surplus F&V and to bridge the gap between different actors in the food supply chain in production and processing on an economic and professional scale. UNV acts as an intermediary body to distribute surplus food from farmers to actors in the food production, by creating a continuously optimised and sustainable network. The majority of the redistributed food is sold by UNV B2B (between actors in the food supply chain of production and processing); a lesser extent is sold by UNV B2C, e.g., by UNV jams or chutneys.

The functional unit of the system is **1 kg of prevented food surplus or waste at agriculture, processing and wholesale**. The reference flow is the total amount of food products redistributed and thus prevented from ending up as food waste over the duration of the demonstration phase (2022-2023). The same amount that was redistributed in the demonstration (n_s) was wasted in the baseline (n_w):

Table 82: Reference flows of the baseline and the demonstration scenario of T2.2 (Note that the reference flow of baseline and demonstration is based on the methodological framework of the environmental assessment)

Country	Total amount of food surplus or waste at BASELINE (n_w)	Total amount of food surplus or waste at DEMONSTRATION (n_s)
Austria	685,078 kg	685,078 kg

The system boundaries for both the baseline and the demonstration system are shown in Figure 104. Both the system boundaries for the baseline and the demonstration system include the food supply chain from production to wholesale. The baseline system entails the primary production of F&V, their processing, distribution and retail, consumption and the EoL treatment of the surplus products ending up as food waste at the harvest/agricultural stage. In the demonstration system, these surplus products are redistributed, processed, distributed and sold in retail and then consumed. These surplus products replace equivalent products from the baseline system, e.g., fresh fruit for consumption is being substituted by surplus fruit, fruit jam is made from surplus fruit, etc. Since the surplus food is avoided food

waste, they enter the system without any burdens and no EoL treatment of agriculture food waste is considered.

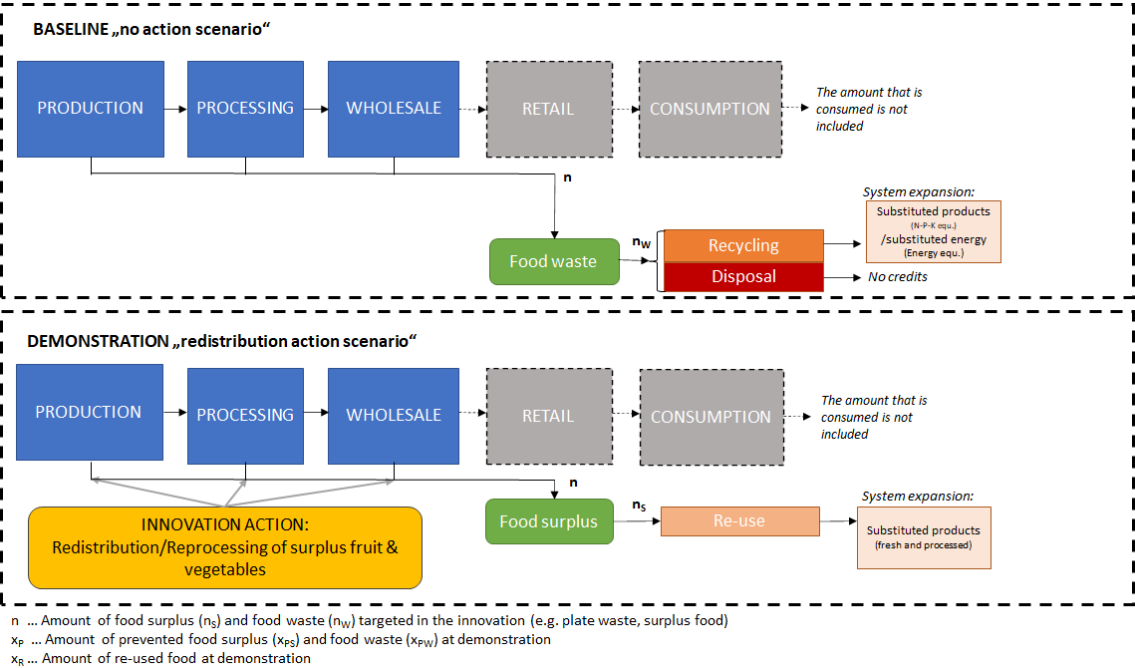


Figure 104: System boundaries of the baseline and demonstration systems considered for the evaluation of the innovation T2.2

Life cycle inventory (LCI)

Table 83 shows the process data and variables used for the environmental assessment of the innovation. For the applied approach and the considered emission factors, it is referred to chapter 3.1.

Table 83: Type of process data and collection method used for Task 2.2

Component	Process data collected within LOWINFOOD (so-called proxy data)	T2.2	Collection method
Type A data 'Food supply chain'	Food surplus or waste quantities Food surplus or waste composition	• •	Company records Company records
Type B data Food surplus or waste treatment'	Reuse, recycling and disposal options	•	Expert consultation
Type C data 'Innovation action'	Transport Packaging Other activities (e.g., processing) Use of computer devices	• • • -	Expert consultation Company records Company records -

Data on the amount and composition of food that is redistributed was calculated based on company records that have been provided by UNV. Additionally, qualitative surveys were conducted to collect information from organisations selling surplus food to UNV. Data gaps were filled by consulting the owner of UNV who is experienced in the field of the redistribution of surplus food (expert consultation).

The demonstration phase of the innovation UNV was defined for the period February 2022 to January 2024. Records of these two years were provided by the company and revealed that in total 685 tonnes were redistributed in this time frame. In the year 2023 alone, it was 343 tonnes. As the focus in LOWINFOOD was on the redistribution of fruit and vegetables, surplus quantities in the form of chocolate flakes and biscuit crumbs were excluded. Table 84 shows the total amounts that were used for the assessment. The same amount that was redistributed in the demonstration was wasted in the baseline:

Table 84: Type A data: Food surplus or waste quantities for Task 2.2 in Austria

Food surplus or waste data	Austria	
	Baseline	Demonstration
Total food surplus or waste [kg]	685,078	685,078
Duration of demonstration phase [years]		2
Total food surplus or waste per year [kg/year]		342,539

The composition of food that is redistributed was determined through company records provided for the two years. Emission factors were calculated for each individual food group (e.g., fruits, vegetables, other) with Agribalyse data.

Table 85: Type A data: Food surplus or waste composition

Food surplus or waste composition	Austria	
	Baseline	Demonstration
Fruit	55%	55%
Vegetables	36%	36%
Other ²⁹	9%	9%

Food that is redistributed in the demonstration phase, is wasted in the baseline (see Table 86). It is assumed that composting and anaerobic digestion are common options for food waste generated at agricultural production, processing and wholesale. A small part from agricultural production is also plugged-in to the field. As there are no records on the amount that is plugged-in on the field, only the registered options such as composting and anaerobic digestion are considered.

Table 86: Type B data: Reuse, recycling and disposal options for Task 2.2 in Austria

Options	Austria	
	Baseline	Demonstration
Redistribution	0%	100%
Animal feeding	0%	0%
Composting	75%	0%
Anaerobic digestion	25%	0%
Municipal waste treatment (incineration)	0%	0%
Municipal waste treatment (landfill)	0%	0%

For the innovation action we had to consider the additional processing step as most of the products are not redistributed directly, but processed according to customer needs as well as the additional transport between surplus food providers and Vienna where the processing takes place. Most of the food bought by UNV is processed before it is distributed to customers; to frozen products, to juice, to puree, to frozen puree, to aseptic shelf-stable puree and kind, to processed and canned products. Only 5 % of the surplus food bought by UNV during the demonstration phase was directly redistributed without processing.

Most of the food distributed comes from the greater Vienna area (Lower Austria, Burgenland, Styria). A smaller proportion comes from EU countries (Germany, Hungary, Poland, Spain, Bulgaria) or RoW countries (Serbia, Türkiye). Average transport distances were assumed based on GoogleMaps data. Most of the goods are transported in normal lorries. A small share (8%) is transported frozen in deep-freeze lorries.

²⁹ pulses, lentil, popped maize, fennel, caraway

Table 87: Type C data: Innovation action related life cycle inventory data for the Unverschwendet cooperation system

Innovation action data	Austria
Processing:	
to F & V, pre-treated	34%
to F & V, frozen	7%
to F & V juice	13%
to F & V puree, fresh	1%
to F & V puree, frozen	1%
to F & V puree, aseptic shelf-stable (jam, chutney)	4%
to F, compote	12%
to V, processed/canned	23%
F & V directly redistributed without processing	5%
Transport:	
Transport by lorry (frozen) [tkm]	10,856
Transport by lorry (standard) [tkm]	125,263

Life cycle impact assessment (LCIA) of the baseline and demonstration scenario (absolute results)

The innovation resulted in a GWP of 96,534 kg CO₂e for the baseline scenario (surplus food products are disposed of as food waste) and 14,342 kg CO₂e for the demonstration scenario (surplus food products are redistributed and substitute primary food production). In both scenarios, the majority of GWP is associated with food production. Waste management reduces the total GWP in the baseline scenario. The reason for this is that credits were assigned for replaced electricity and thermal energy production as a result of anaerobic digestion. At demonstration only redistribution of surplus food is considered, which considers credits for the avoided purchase of similar products. Impacts of the innovation action (transportation for the redistribution of the surplus food products and processing) adds to the impacts of producing the food (food supply chain impacts) in the demonstration GWP results. Redistributing the surplus food products prevents a total of 82 tons CO₂e over the course of two years (difference between demonstration and baseline). This equals a GWP reduction of 85% compared to the baseline scenario.

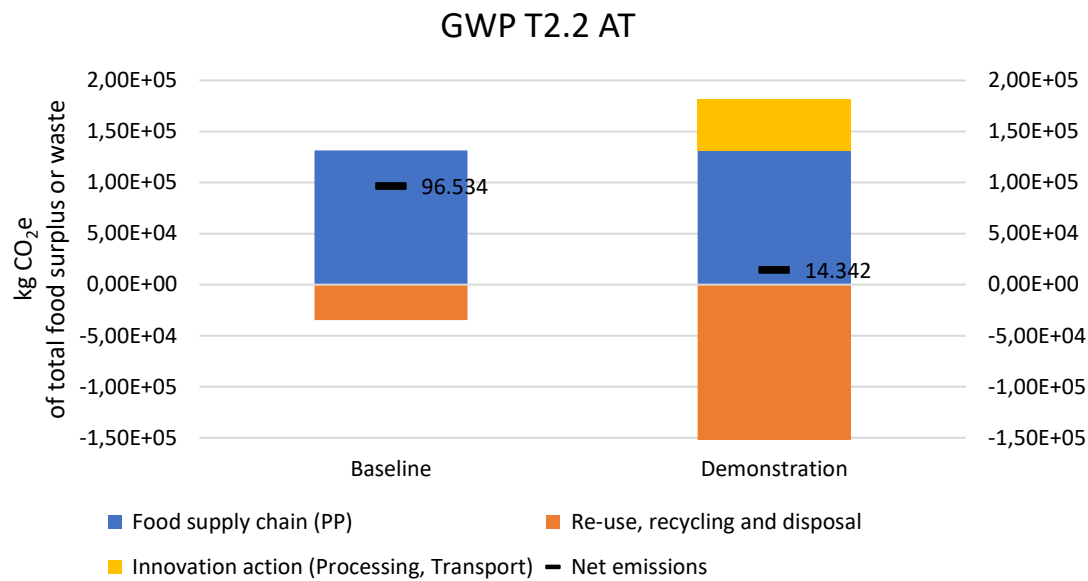


Figure 105: Global warming potential for the baseline and demonstration scenario for the innovation T2.2 in Austria

Figure 106 shows the PEF score results for the baseline and demonstration scenario. The baseline PEF score equals 7 million points and the demonstration PEF score is nearly zero. This is due to the fact that the impacts of agricultural production are higher weighted as impacts from the processing stage (more details are shown in the contribution analysis below).

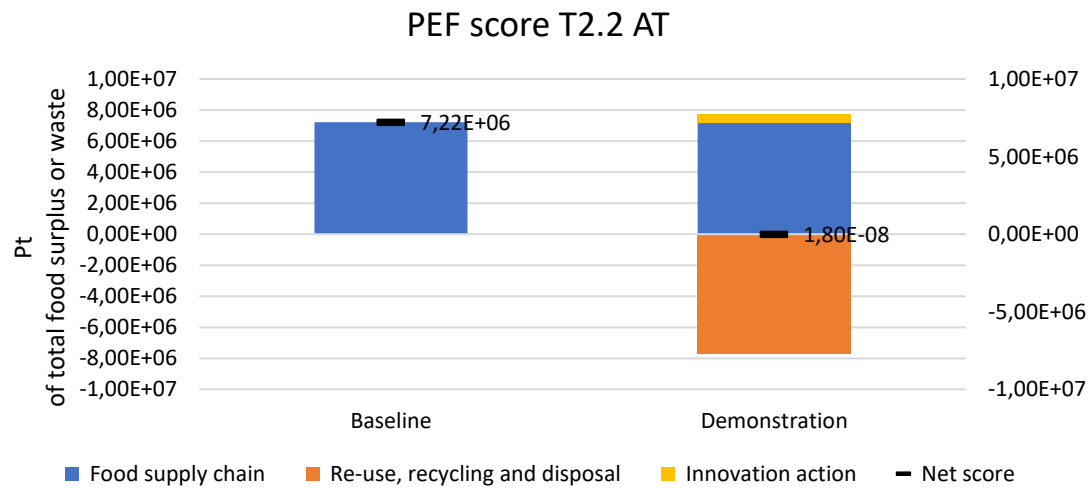


Figure 106: PEF score for the baseline and demonstration scenario for the innovation T2.2 in Austria

The UNV innovation resulted in an impact reduction across all EF impact categories (global warming potential: -85%, ozone depletion: -98%, human toxicity non-cancer effects: -99%, human toxicity cancer effects: -99%, particulate matter: -91%, ionising radiation HH: -99%, photochemical ozone formation: -85%, acidification: -91%, terrestrial eutrophication: -89%, freshwater eutrophication: -100%, marine eutrophication: -95%, freshwater ecotoxicity: -99%, land use: -100%, water scarcity: -100%, fossil resource depletion: -61%, abiotic resource depletion: -100%).

As shown in Figure 107 food production is the main contributor to environmental impacts for global warming potential, ozone depletion potential, human toxicity (cancer), acidification, eutrophication (terrestrial, marine and freshwater), land use, water scarcity, fossil resource depletion and PEF score results in the baseline and demonstration scenario. Waste management is responsible for the majority of human toxicity (non-cancer) and freshwater ecotoxicity impacts. The waste management contribution to acidification, eutrophication (terrestrial, marine and freshwater), land use and fossil resource depletion is negative in the baseline scenario.

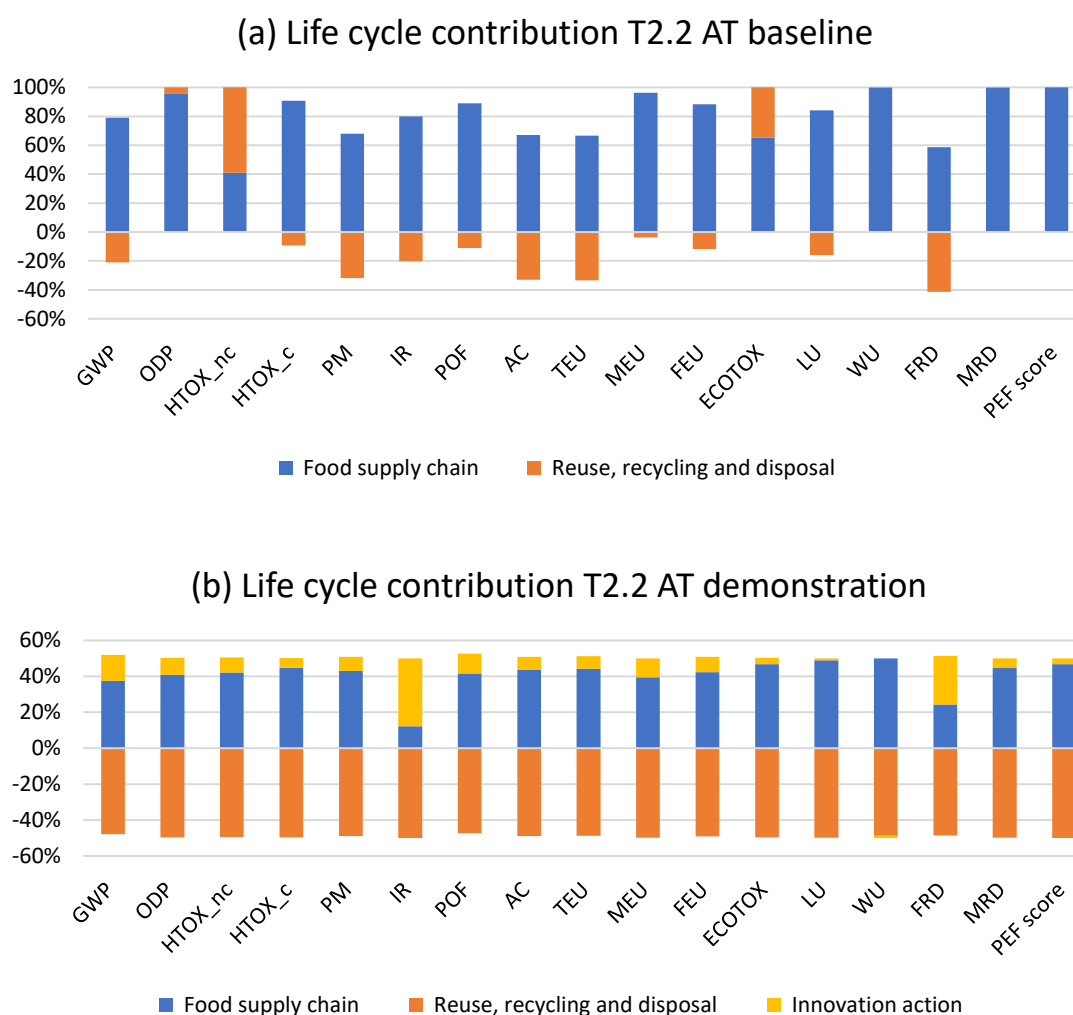


Figure 107: Contribution of the individual life cycle stages (food production, waste management, consumer transport and innovation action) to the total LCIA results for the innovation T2.2 in Austria for the baseline (a) and demonstration scenario (b)

Life cycle impact assessment (LCIA) of food waste prevention (relative results)

This innovation prevented 685 tons of food waste over the course of two years. This prevented a total of 82 tons CO₂e. The total GWP result of 1 kg prevented food waste equals -0.12 kg CO₂e, which is shown in Figure 108. The majority of the GWP savings shown in Figure 108 results from replaced primary food production when redistributing food (indicated by the orange bar) that are higher than the additional efforts for transport and processing (indicated by the yellow bar).

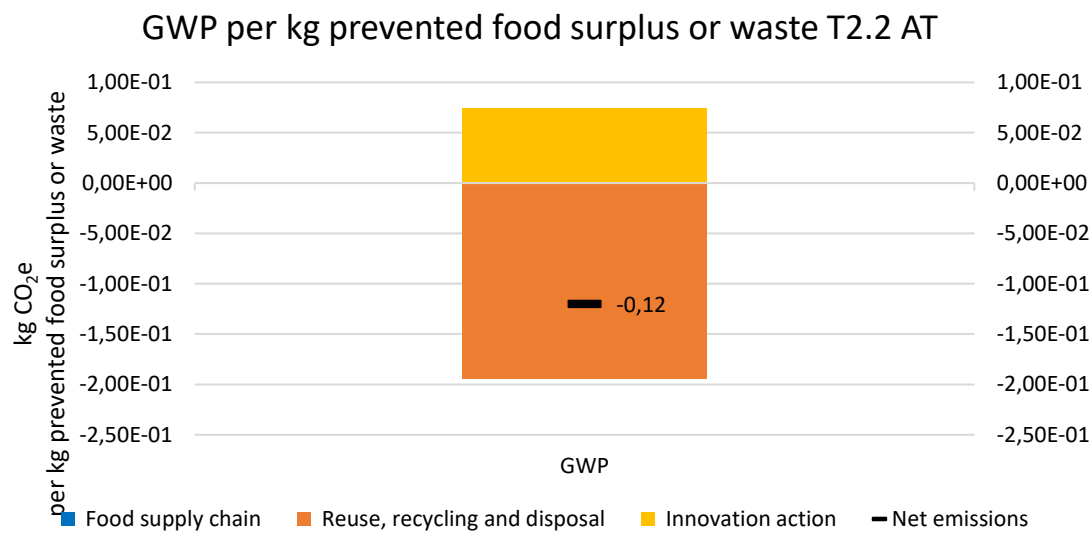


Figure 108: Global warming potential results for 1 kg of prevented food waste for the innovation T2.2 in Austria

The normalised and weighted results of the environmental impacts show the magnitude of each impact category. In this comparison, shown in Figure 109, the reduced water scarcity has the largest effect, followed by the global warming potential. Benefits can be largely attributed to the avoided food production by reusing the surplus food (reuse option), whereas burdens can be attributed to the efforts at innovation (processing and transport) and the corresponding electricity and heat that is consequently not produced in biogas plants.

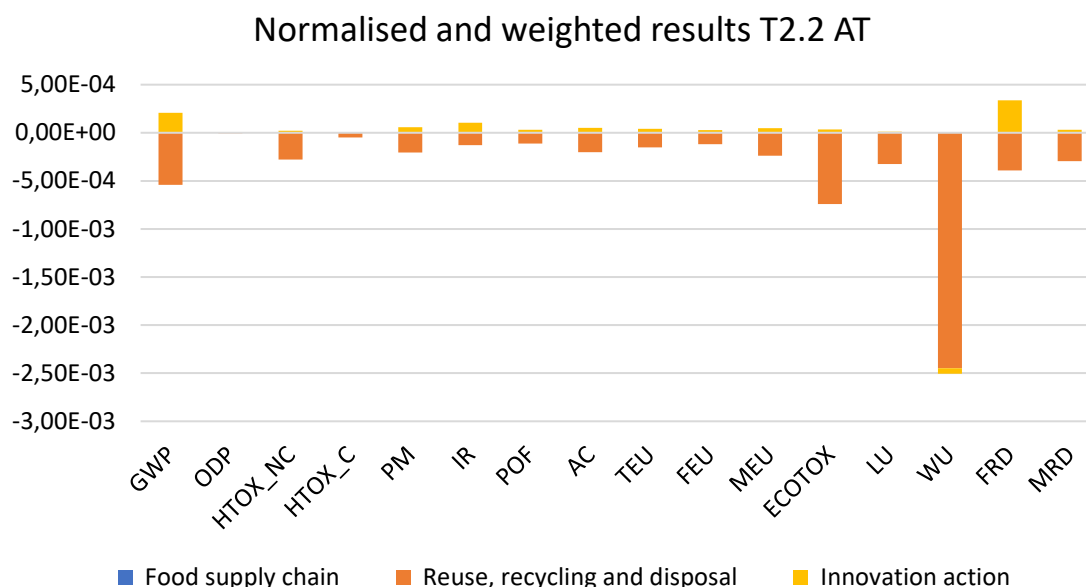


Figure 109: Normalised and weighted results for 1 kg of prevented food waste for the innovation T2.2 in Austria

External environmental costs

The total external environmental costs are calculated based on the results per impact category (see chapter 2.2). The total external environmental costs resulted in 44,000 EUR that can be saved by the innovation T2.2 (see Table 88).

Table 88: Results of the environmental emissions and costs of food waste prevention (positive values represent burdens, negative values represent savings) for T2.2

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
Reference flow		1 kg		356,370.32 kg per year	
Environmental impact category		Env. emissions [Unit of the category]	Env. costs [EUR]	Env. emissions [Unit of the category]	Env. costs [EUR]
GWP	kg CO ₂ e	-1.20E-01	-1.50E-02	-8.22E+04	-1.03E+04
ODP	kg CFC11e	-2.64E-08	-1.01E-06	-1.81E-02	-6.93E-01
HTOX_NC	CTUh	-1.80E-08	-3.59E-03	-1.24E-02	-2.46E+03
HTOX_C	CTUh	-3.60E-10	-3.96E-04	-2.47E-04	-2.71E+02
PM	Disease incidences	-9.81E-09	-9.39E-03	-6.72E-03	-6.43E+03

		Results per kg of prevented food surplus or waste		Results per total prevented food surplus or waste	
IR	kBq U235e	-2.10E-02	-3.07E-05	-1.44E+04	-2.10E+01
POF	kg NMVOCe	-7.11E-04	-1.03E-03	-4.87E+02	-7.07E+02
AC	molc H ⁺ e	-1.33E-03	-5.57E-04	-9.08E+02	-3.81E+02
TEU	molc N e	-5.36E-03		-3.67E+03	
FEU	kg P e	-5.32E-05	-1.24E-04	-3.64E+01	-8.53E+01
MEU	kg N e	-1.27E-03	-4.96E-03	-8.68E+02	-3.40E+03
ECOTOX	CTUe	-2.08E+01	-9.71E-04	-1.43E+07	-6.65E+02
LU	Pt	-3.25E+01	-6.95E-03	-2.23E+07	-4.76E+03
WU	m ³ water e	-3.37E+00	-2.06E-02	-2.31E+06	-1.41E+04
FRD	MJ	-4.25E-01	-6.76E-04	-2.91E+05	-4.63E+02
MRD	kg Sb e	-2.22E-06	-4.45E-06	-1.52E+00	-3.05E+00
Environmental costs			-6.42E-02		-4.40E+04

Interpretation and review

The special feature of the UNV innovation is that surplus food is redistributed by processing it into food in a state that is in demand by customers or also into long lasting products. This increases the chance of finding satisfied buyers and therefore the amount of surplus food that is redistributed and not wasted. About 95% of the surplus food purchased by UNV during the demonstration period of LOWINFOOD (2 years) was processed before being resold to customers. With regard to the environmental impact assessment, this additional processing must be taken into account, including the additional transport.

The environmental impact assessment of the innovation showed that the benefits of avoided food waste (in this case through redistribution for human consumption) offset the additional processing and transport costs. As the impact of processing and transport is largely due to the use of fossil fuels, the indicators related to the use of fossil fuels are more affected than other indicators. This is the reason why GWP and FRD still show positive net emissions (burdens) in the demonstration, while WU and LU are almost equal in the demonstration (burdens outweigh benefits), which can be seen in the PEF value. Compared to the baseline situation, where no redistribution takes place and food is wasted instead, the benefits for the indicators related to fossil fuels are lower than for the indicators related to agricultural needs (water, land).

4 Discussion

Results of each innovation are summarized in Table 89. The indicators Global Warming Potential (GWP) and Product Environmental Footprint (PEF) score, as well as the external environmental costs (EEC) are shown as examples. As a mass-based approach was used, the environmental performance corresponds to the food waste quantities. This means, that innovations that documented an increase of food surplus or waste from baseline to demonstration (4 out of 18 investigated cases) also result in an increase of impacts and costs (positive values represent environmental and cost burdens), whereas innovations that documented a decrease in food surplus or waste from baseline to demonstration (14 out of 18 investigated cases) resulted in a reduction of environmental impacts and costs (negative values stand for environmental impact reductions and cost savings).

The presented results can only be compared to a limited extent. Relative results describe the magnitude of environmental impacts and costs per kg prevented or redistributed food surplus or waste respectively per kg increased food surplus or waste. However, the magnitude is depending on certain factors: (1) the stage of the supply chain where food waste occurs (the more steps, e.g., production, transport, cooking, the more emissions are accounted for), (2) the food waste composition (e.g. the more animal-based products, the more environmental impacts), (3) the food waste management (the lower in the food waste hierarchy e.g. landfill as the least beneficial option, the more environmental impacts) and (4) the innovation action itself (the more inputs like energy, transport, etc. are necessary for the implementation of the action, the more environmental impacts). If a baseline scenario containing components with high emission factors (e.g., food waste occurs at a late stage of the supply chain, animal-based food products, food waste disposal through landfilling) is replaced by the demonstration scenario, the benefits are higher compared to a baseline containing components with low emission factors (e.g., plant-based food products, redistribution of surplus food).

In addition to relative results, absolute results are presented as well to show the magnitude of the demonstration of innovations in LOWINFOOD. It is highly depending on the sample size (e.g., number of users, number of participating restaurants, etc.) and can therefore only be used for communication purposes regarding the individual innovations within LOWINFOOD.

Table 89: Relative results – Global Warming Potential (GWP), Product Environmental Footprint (PEF) score and External Environmental Costs (EEC) per kg food waste that was reduced or increased from baseline to demonstration (negative values represent a saving, positive values a burden)

Task (T) No.*	Innovation - Short name	Geo graph-ical scope	GWP in kg CO ₂ e	PEF score in points	EEC in EUR
Prevention governance					
T 3.1	Supplier-retailer agreements	SE	-2.20	-0.30	-0.48
T 3.2	Stakeholder dialogue in the bread value chain	IT	0.55	0.04	0.19
Consumer behavioural change					
T 5.3	MATOMATIC Plate Waste Tracker	DE	-2.26	-0.38	-0.72
		SE	-2.70	-0.45	-0.89
		AT	-4.71	-0.56	-1.30
T 5.4	SLU/AIE Holistic educational approach	SE	-2.72	-0.45	-0.90
		AT	4.72	0.56	1.31
T 5.5	CozZo Mobile App	AT	-1.91	-0.22	-0.47
		FI	-2.86	-0.39	-0.86
		GR	-4.63	-0.46	-1.17
T 5.6	REGUSTO Mobile App	IT	-3.46	-131.96	-0.99
Supply chain efficiency					
T 2.4	Forecasting software to reduce waste of F&V products	IT	0.15	0.09	0.10
T 3.3	FoodTracks Software for bakeries	DE	-1.31	-0.15	-0.34
T 5.1	KITRO Innovative food waste solution	DE	-3.40	-0.33	-0.86
	KITRO Innovative food waste solution	CH	3.82	0.88	1.73
	KITRO Innovative food waste solution	GR	-2.80	-0.26	-0.67
T 5.2	MITAKUS Forecasting software for restaurants	DE	-4.50	-0.60	-1.37
Food redistribution					
T 2.2	UNV Cooperation system for F&V	AT	-0.12	-0.08	-0.06

The scenarios of all innovations have in common that the impacts associated with the food supply chain are dominating the overall impacts. Impacts from reuse, recycling and disposal options have a neglectable role. Furthermore, impacts resulting from the innovation action, such as the use of smartphones, computers and tablets or additional processing, transport or storage steps also have a small contribution to total impacts. However, the production of servers, computers, smartphones and other electric and electronic devices was not included in the assessment due to lack of data. Therefore, the impact of the innovation action might be underestimated. Impacts of the production of electronic devices and their influence on overall impacts of prevention actions is therefore recommended to address in future studies. Their influence on categories such as Human Toxicity and Resource depletion needs to be investigated. Looking at the difference between baseline and demonstration scenario only, the effect of avoided food production due to food waste prevention actions or the increased food surplus redistribution due to food redistribution actions are dominating.

The different level of granularity and source of data is both a shortcoming and an opportunity regarding the interpretation of the environmental assessment results. On the one hand, the disaggregated level of data in case of food waste composition and options of reuse, recycling and disposal revealed impact hotspots for each innovation. On the other hand, the individuality of the scenarios results in respective but not in average environmental impact results. The small sample size and short test periods for the innovations are shortcomings, but were necessary to find the balance between a robust but feasible and affordable method for the quantification of environmental impacts and costs. However, hotspots of stages and aspects of the food supply chain that influence the results could be revealed and recommendations for improvements identified.

Additionally, the different level of data quality is another shortcoming and needs to be considered when interpreting the results. Some data points are based on expert consultation (e.g. the data consumption volume of apps), some on qualitative information from test users and some on number of observations (e.g. the reuse, recycling and disposal options) which is not mass equivalent. The server energy consumption could not be directly measured and was thus derived from scientific literature. The calculated server energy consumption may deviate from the actual server energy consumption. This is the compromise between robust but feasible methods of data generation and filling data gaps. Sensitivity analysis can help to identify uncertainties and is recommended for future studies.

Furthermore, the comparison of baseline and demonstration also faces shortcomings as data could not be collected at the same level of detail and quality in both scenarios. For example, reuse, recycling and disposal options were in some cases only collected at baseline or only at demonstration. The same shares were assumed for the comparing scenario. The difference is not considered relevant when it comes to certain actions, which do not directly target the waste management options (e.g., T5.5 CozZo application in households). However, if actions target reuse of food surplus, etc., the shares are relevant.

The environmental impact of the saved food was calculated based on datasets which might not be representative for the actually saved food. In some cases, the food waste composition was aligned to the food that was produced and not wasted. Due to lack of data this simplification had to be considered. Also, in some cases the food waste composition was only quantified at baseline or demonstration. The same composition was assumed for the comparing scenario. However, results showed that a change in the food waste composition clearly influences the impacts. For example, if the share of meat or citrus fruits could be reduced at demonstration, environmental savings were higher compared to innovations where more food waste per mass was reduced.

The type and method of data collection is of high importance. It makes a difference, if customers or test users are asked open questions (e.g., Where do you dispose of your food waste?) or if answer options are given. In the latter case it is also crucial, if all answer options are given in all innovations at all comparing alternatives. Unclearities were revealed in relation to "animal feeding" or "pet feeding" as well as "redistribution/donation" or "redistribution to

friends and family". Most of the unclarities could be solved with several feedback loops with task leaders that were in direct contact with test users or innovators.

Moreover, the extent of stakeholder involvement had a crucial influence on the data collection quality. The stakeholder involvement turned out to be lower than initially expected and led to a lower amount of primary data. This had to be compensated by a reliance on qualitative information and secondary sources, which leads to higher uncertainties of results.

Another important limitation of the study that is also highlighted in the deliverables of the other evaluation dimensions (efficacy and socio-economic impact evaluation) is that food waste reduction or increase at demonstration cannot fully be attributed to the innovation. Other extrinsic and intrinsic factors may have influenced the food waste amounts. The results of the environmental impact assessment are directly linked to this issue.

The study primarily focuses on short- to medium-term impacts, leaving the long-term sustainability of e.g. behavioural changes unexamined. Further, the study's scope is confined to specific areas of the food sector, further research would be needed to determine the applicability of these interventions in other institutional settings or sectors.

5 Conclusion

The impact of food waste is mainly caused by emissions associated with food production. If food can be prevented from being wasted or if food can be redistributed instead of being wasted, the food supply chain is more efficient and thus saves emissions and costs. The additional costs of implementing the innovation measures do not outweigh these benefits.

The environmental assessment of the LOWINFOOD innovations has shown that there is a high potential for emission and cost savings if excess food waste can be avoided or redistributed. The further downstream in the supply chain and the more animal-based food can be saved from being wasted, the more environmental impacts can be prevented and costs can be saved.

The environmental impact category with the highest contribution to normalised and weighted results based on the EU's Environmental Footprint method is Global Warming Potential (GWP). This is followed by Water Use (WU), which is especially important when using agricultural products as well as Particulate Matter (PM), Acidification Potential (AC) and Fossil Resource Depletion (FRD).

For future studies it is recommended to use the same level of data granularity and quality for the comparing scenarios, to increase the sample size and testing period for generating average values instead of respective values as well as to include the production of electric and electronic devices in technological innovations.

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7. Credit authorship contribution statement

Table 90: Credit authorship contribution statement of D1.8

Name	Organisation	Conceptualization ¹	Methodology ²	Software ³	Investigation/data collection ⁷	Resources ⁷	Data curation ⁸	Writing – original draft ⁹	Writing – review & editing ¹⁰	Other
Büttner, S.	ADB				T3.3					
Rothe, M.	ADB				T3.3					
Kaltenbrunner, K.	AIE	ALL	ALL		T5.3 T5.4					
Orth, D.	AIE	ALL	ALL		T5.3 T5.4			T5.3 T5.4	ALL	
Pladerer, C.	AIE	ALL	ALL							
Canaj, E.	ARE				T21					
Contrino, L.	ARE				T21					
	BLU				T5.1					
Brunnhuber, N.	BOKU	ALL	ALL			ALL	ALL	ALL	ALL	ALL ¹¹
Gollnow, S.	BOKU	ALL	ALL			ALL				
Ladurner, T.	BOKU				T5.5		T5.5			
Münch, S.	BOKU		ALL			ALL				
Obersteiner, G.	BOKU		ALL						ALL	
Scherhauer, S.	BOKU	ALL	ALL		T2.2 T5.5	ALL	ALL	ALL	ALL	ALL ¹¹ ALL ¹²
Schmied, E.	BOKU				T2.2					
Dimitrov, I.	COZ			T5.5		T5.5				
	CNA				T3.1 T3.2					
Lakar, O.	ELH									
Olazar, E.	ELH									
Urruzola, M.	ELH									
Pfaff, T.	FT				T3.3					
Abeliotis, K.	HUA	ALL	ALL		T5.1 T5.5					
Chroni, C.	HUA				T5.1 T5.5		T5.1 T5.5			
Lasaridi, K.	HUA				T5.1 T5.5					
Baur, V.	ISUN									
Engelmann, T.	ISUN				T42					
Gerwin, P.	ISUN				T5.1 T5.2 T5.3	T5.1 T5.2 T5.3				
Strotmann, C.	ISUN				T2.3 T3.3 T4.1 T4.2 T5.1 T5.2 T5.3	T2.3 T3.3 T4.1 T4.2 T5.1 T5.2 T5.3			T3.3 T5.1 T5.2 T5.3	
Mzek, T.	JHI				T4.1	T4.1				

					T4.2	T4.2				
Koseoglu, N.	JHI				T4.1 T4.2	T4.1 T4.2				
Piras, S.	JHI				T4.1 T4.2	T4.1 T4.2		T4.1 T4.2		
Hofmann, A.	KITRO				T5.1				T5.1	
Billinger, M.	LER			T2.3 T4.2	T2.3 T4.2					
Casalino, F.	LER			T2.3 T4.2	T2.3 T4.1 T4.2					
Giordano, C.	LUKE				T2.1	T2.1				
Malefors, C.	MATO			T5.3 T5.4	T5.3 T5.4					
Wolkow, R.	MITA			T5.2	T5.2					
Bruschini, P.	PICO				T2.4					
Valeri, C.	PICO				T2.4					
Rellini, P.	REG				T5.6					
Pinhgini, R.	RER				T21					
Ziosi, C.	RER				T21					
Bartek, L.	SLU				T3.1 T3.2	T3.1 T3.2				
Eriksson, M.	SLU	ALL	ALL		T2.4 T3.1 T3.2 T5.2 T5.3 T5.4	T2.4 T3.1 T3.2 T5.2 T5.3 T5.4			ALL	
Sjölund, A.	SLU									
Sundin, N.	SLU				T5.3 T5.4	T5.3 T5.4				
Mesiranta, N.	TAU				T3.2 T5.5	T3.2 T5.5	T5.5		T5.5	
Närvänen, E.	TAU				T3.2 T5.5	T3.2 T5.5				
Sutinen, U.-M.	TAU				T3.2 T5.5	T3.2 T5.5				
Mattila, M.	TAU				T3.2	T3.2				
	THA				T5.1					
Falascani, L.	UNIBO				T21					
Blasi, E.	UNITU S				T2.4 T3.2	T2.4 T3.2				
Cicatiello, C.	UNITU S				T2.4 T3.1 T3.2	T2.4 T3.1 T3.2				ALL ¹³
Yu, M.	UNITU S				T5.6	T5.6			T5.6	
Nasso, M.	UNITU S				T2.4 T3.2	T2.4 T3.2				
Pietrangeli, R.	UNITU S				T2.4 T43	T2.4 T3.2				
Secondi, L.	UNITU S				T5.6	T5.6			T5.6	
Diesenreiter, C.	UNV				T2.2	T2.2			T2.2	
Nygardh, S.	UPP				T5.3 T5.4					

Terms and definitions (according to the Contributor Roles Taxonomy of Elsevier):

¹Conceptualization: Ideas; formulation or evolution of overarching research goals and aims

²Methodology: Development or design of methodology; creation of models

³Software: Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components

⁴Validation: Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs

⁵Formal analysis: Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data

⁶Investigation: Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection

⁷Resources: Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools

⁸Data Curation: Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse

⁹Writing - Original Draft: Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation)

¹⁰Writing - Review & Editing: Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or postpublication stages

¹¹Visualization: Preparation, creation and/or presentation of the published work, specifically visualization/ data presentation

¹²Supervision: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team

¹³Project administration: Management and coordination responsibility for the research activity planning and execution

(Funding acquisition: Acquisition of the financial support for the project leading to this publication) excluded from the table

